Reflector Performance Study in Ultra-long Cycle Fast Reactor

Taewoo Tak, Chidong Kong, Jiwon Choe, Deokjung Lee*
Ulsan National Institute of Science and Technology, UNIST-gil 50, Ulsan, 689-798, Korea
Corresponding author: deokjung@unist.ac.kr

1. Introduction

Two designs of sodium-cooled fast reactor were presented: UCFR-1000 and UCFR-100 that adopt breed-and-burn strategy [1-3]. These two UCFR models have been studied from the neutronics point of view and it shows that 60-year operation without refueling is feasible. Once the core ignites by the Low Enriched Uranium (LEU) loaded in the lower part of the fuel, it breeds the active core and it moves upward along the axial direction through the blanket loaded in the upper part of the fuel. There are reflector assemblies outside the fuel region, surrounding the fuel assemblies and axial reflector is located at the bottom of the core to control the neutron leakage fraction which is an important factor in fast reactor system. HT-9 was used as a reflector material as well as a structure material.

In this study, alternative reflector materials were proposed and their reflection performance was tested and studied focused on its physics. ODS-MA957 and SiC were chosen from iron based alloy and ceramic respectively. The two materials were tested and compared with HT-9 in UCFR-1000 as a radial and an axial reflector and it was evaluated from the neutronics point of view with comparing the core life and the coolant void reactivity. The calculation and evaluation were performed by McCARD Monte Carlo code [4].

2. Core Configuration of UCFR-1000

Table I: Core Design Parameter

Parameters	Value
Thermal power (MWth / MWe)	2600 / 1000
Cycle length (effective full power years)	60 (Once through)
Initial heavy metal loading (t)	237
Core volume (kL)	42.4
Equivalent core diameter (m)	6.4
Fuel pin overall length (cm)	340
Active core height (cm)	240
Average specific power density (MW/t)	10.9
Average volumetric power density (W/cc)	61.3
Average linear power (W/cm)	158.7
Fuel form	U-10Zr
Fuel density (g/cc)	15.98
Uranium enrichment of bottom-driver/upper-blanket (%)	11.9 / NU
Average coolant velocity (m/s)	2.8
Average discharge burnup (GWD/t / %)	239.4 / 25.2

Key parameters of UCFR-1000 are presented in Table I. The design power is 2600 MWth and the thermal efficiency is assumed to be 38.5 %. Fig. 1 and Fig. 2 show the radial and axial layout of UCFR-1000 respectively. UCFR-1000 has 750 fuel assemblies and 324 reflector assemblies in outer region as a radial reflector. In addition, there is an axial reflector region at the bottom of the core to control axial neutron leakage at the Beginning of Cycle (BOC) while the venting region is on the top for adopting fission gas vented fuel concept.

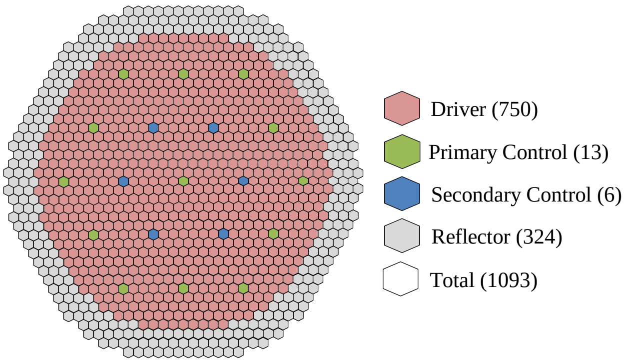

Fig. 1. Radial configuration of UCFR-1000.

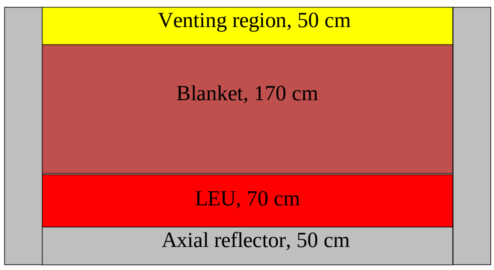

Fig. 2. Axial configuration of UCFR-1000.

The effect of each material as a reflector was tested by replacing the reflector pins with ODS-MA957 and SiC instead of HT-9 while the structure material remains same as HT-9.

3. Results and Analysis

Fig. 3 shows the multiplication factors over the 60-year operation and the depletion calculation was performed under the assumption of All Rod Out (ARO) condition. The values remain over criticality through the whole cycle length in every test case and they show same tendency except the BOC state of SiC case. The axial reflector at the bottom region has an effect on the k-effective at BOC but radial reflector has little effect on the k-effective or the core life because the radial leakage is not dominant.

Table II summarizes the neutron leakage corresponding to reflection condition at each state. The leakage at BOC is the largest due to its large neutron flux, while the leakage at MOC is the smallest for the active core stays in the middle of the core and axial leakage disappears. The sodium void calculation was performed with voiding sodium which is located upper than the active core at each state. The leakage increases as the sodium is voided and the scattering by sodium decreases.

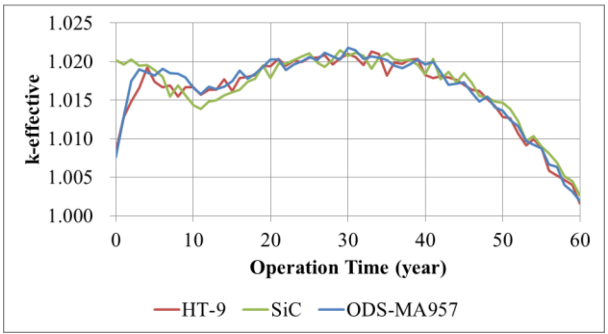

Fig. 3. K-effective vs. time.

Table II: Neutron Leakage from Core (%)

		BOC	MOC	EOC
Reflector void		15.9	5.0	8.4
Reflector used	HT-9	3.9	1.7	4.1
	ODS-MA957	4.6	2.0	4.4
	SiC	5.4	2.2	4.7
Sodium void	HT-9	5.6	1.8	4.6
	ODS-MA957	6.5	2.0	4.4
	SiC	6.9	2.2	4.7

Table III: Core Parameter Corresponding Reflector Material

		BOC	MOC	EOC
Reactivity gain (pcm)	HT-9	7065	492	928
	ODS-MA957	6971	870	829
	SiC	8230	505	916
Effective neutron fraction (pcm)	HT-9	711	356	351
	ODS-MA957	723	366	343
	SiC	704	365	349
Prompt neutron lifetime (10^{-7} sec)	HT-9	8.9	6.4	7.2
	ODS-MA957	11.3	7.3	8.1
	SiC	31.7	13.7	15.0
Sodium void worth ($)	HT-9	0.5	2.0	1.1
	ODS-MA957	0.6	-0.2	-0.1
	SiC	0.4	0	0

Table III shows several core parameters with respect to the reflector materials. The reactivity gain and the delayed neutron fraction show same tendency in all case while the prompt neutron life time and sodium void worth are different. This is due to the softer energy spectrum of ODS-MA957 and SiC cases which have longer prompt neutron life time and more negative sodium void effect. Fig. 4 shows the energy spectrum of each case at EOC.

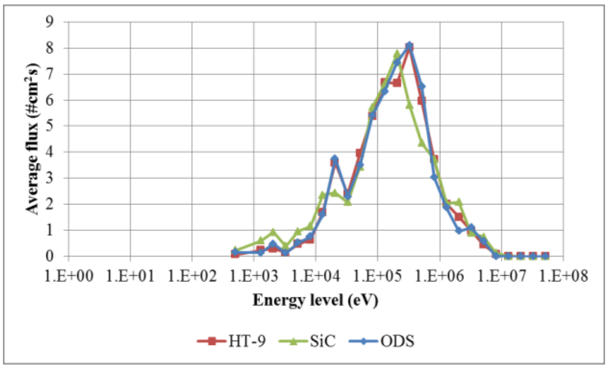

Fig. 4. Neutron energy spectrum at EOC.

4. Conclusions

The reflector materials for UCFR-1000 have been investigated in the aspect of neutronics. The reflection effect shows different performance corresponding to reflector material used. Also, the neutron energy spectrum is affected by changing materials which causes spectrum softening but it is not enough to influence the core life. With more reflector material candidates such as lead-based liquid metal, reflection performance and core parameter study will be investigated for next step.

ACKNOWLEDGMENTS

This work was supported by National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP).

REFERENCES

[1] T. Tak, D. Lee, and T. K. Kim, Design of Ultralong-cycle Fast Reactor Employing Breed-and-burn Strategy, Nuclear Technology, Vol.183, pp. 427-435, 2013.

[2] T. Tak, and D. Lee, Design of Ultra-long Cycle Fast Reactor with PWR Spent Fuel, Transactions of the Korean Nuclear Society Spring Meeting, May 17-18, 2012, Jeju, Korea.

[3] T. Tak, H. Lee, S. Choi, and D. Lee, Design of Small-size Ultra-long Cycle Fast Reactor with PWR Spent Fuel, Proceedings of ICAPP 2013, April 14-18, 2013, Jeju Island, Korea.

[4] H. J. Shim, B. S. Han, J. S. Jung, H. J. Park, and C. H. Kim, McCARD: Monte Carlo Code for Advanced Reactor Design and Analysis, Nuclear Engineering and Technology, Vol.44, No.2, pp. 161-176, 2012.