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Design of Ultra-long Cycle Fast Reactor with PWR Spent Fuel

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1. Introduction

The concept of Ultra-long Cycle Fast Reactor (UCFR) has been investigated as a mean to improve fuel utilization and solve the nuclear proliferation issues since 1950s. Especially, handling spent fuel is an urgent problem in Korea today. The CANDLE design is one of thoroughly studied UCFRs. Its active core moves along the axial direction as the core burns and eventually the core reaches an equilibrium state [1]. But there are some pending issues in designing UCFR such as high neutron flux, high coolant flow speed, and high temperature. Advanced materials for shielding, cladding, and structure also have been developed for these high-value conditions [2]. In this research, HT-9 and sodium were used for structure and coolant each. Authors presented the UCFR-1000 design using U-10Zr metallic fuel [3] and this paper presents UCFR-1000 design with PWR spent fuel. Core design and performance evaluation were performed with McCARD Monte Carlo code [4].

2. Core Design of UCFR-1000

Key parameters for UCFR-1000 with spent fuel (SF-10Zr) are presented in Table I. The thermal efficiency was assumed to be 38.5%. 12.3% enriched LEU is loaded in the lower fuel region as a driver for igniting the reactor at beginning of cycle. The PWR spent fuel blanket is loaded on upper fuel region for breeding.

Table I: Core design parameters

Parameters	Values
Thermal power, MWth / MWe	2600 / 1000
Cycle Length, effective full power years	60 (Once through)
Initial heavy metal loading, t	206
Specific power density, MW/t	12.6
Volumetric power density, W/cm^3	81.0
Fuel form	SF-10Zr
Fuel density, g/cm^3	15.2
Uranium enrichment (bottom-driver/upper-blanket), w/o	12.3(bottom) / Spent fuel(top)
Active core height, cm	360
Fuel pin overall length, cm	460

Whole core shape and each assembly are hexagonal as Fig. 1 shows. There are total 19 control assemblies: 13 primary control assemblies and 6 secondary control assemblies. The number of control assemblies was determined based on the evaluation of the control rod worth and shutdown margin. The control material in the primary control assemblies is natural boron and the control material in the secondary control assembly is 90% enriched boron.

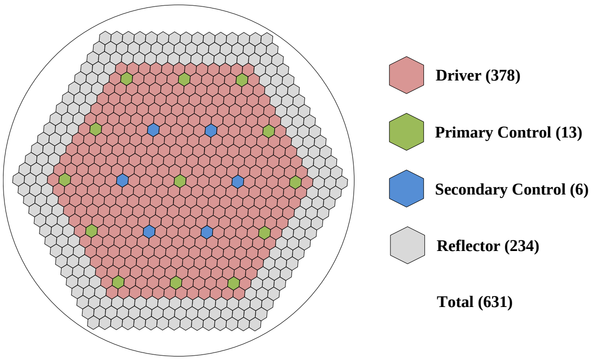

Fig. 1. Core layout of UCFR-1000

Table II shows the PWR spent fuel composition which is used for the design of UCFR in this paper. This data is based on some conditions that it is from a PWR with the discharge burnup of 50 GWD/MTU and the cooling time of 10 years [5].

Table II: Composition of LWR spent fuel

Element or Isotope	wt.%	Element or Isotope	wt.%
Ge	0.00009	Tb	0.0003
Rb	0.1	Dy	0.00016
Sr	0.06	Ho	1.4E-5
Zr	0.51	Er	3.1E-6
Nb	5.5E-7	U-234	1.95E-3
Mo	0.33	U-235	9.72E-1
Tc	0.105	U-236	5.89E-1
Ru	0.296	U-238	9.40E+1
Rh	0.06	Np-237	5.76E-2
Pd	0.176	Pu-238	1.94E-2
Ag	0.0093	Pu-239	5.22E-1
In	0.00038	Pu-240	2.47E-1
Sn	0.011	Pu-241	8.38E-2
Sb	0.0023	Pu-242	6.27E-2
Ba	0.247	Pu-244	1.83E-6
La	0.168	Am-241	5.82E-2
Ce	0.322	Am-242m	1.34E-2
Pr	0.153	Am-243	1.35E-4
Nd	0.555	Cm-242	2.62E-7

3. Performance Evaluation of UCFR-1000

Performance evaluation of UCFR-1000 with different fuel is presented in this chapter. The discharge burnup of one with SF-10Zr is 276 GWd/t (29.1%). Fig. 2 shows the multiplication factors of UCFR-1000 behavior over the depletion during 60 years. The depletion calculation in this figure assumed ARO condition.

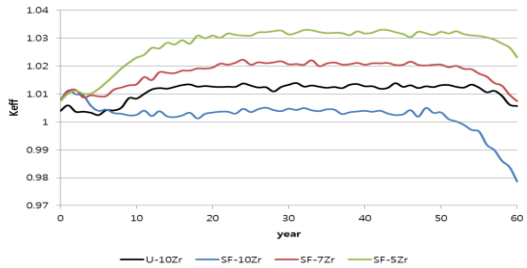

Fig. 2. Depletion performance of UCFR-1000

It is noted that the cores can maintain criticality for 60 years except for SF-10Zr core. Once the values reach equilibrium state after 15 years, value gaps are less than 500pcm in every case. The core reactivity behavior in the initial 15 years could be controlled by varying LEU enrichment and/or its axial size. And core life could be adjusted as loading different amount of fissile material.

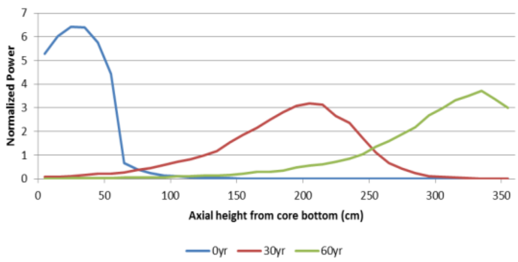

Fig. 3. Normalized axial power distribution of SF-10Zr core

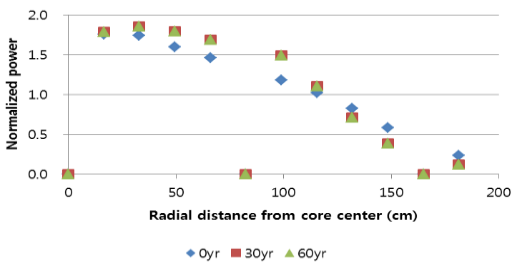

Fig. 4. Normalized radial power distribution of SF-10Zr core

Figs. 3 and 4 show normalized power distribution for beginning of cycle (BOC), middle of cycle (MOC), and end of cycle (EOC) during 60 year operation for the core with SF-10Zr model. Axial mesh size of 10cm was used for axial graph and an assembly row was used for radial graph. An active mesh or an active assembly row was selected for each cycle. Three zero power points in Fig. 4 are control rod position. As shown in the Fig. 3, the active core region is moving from the bottom to the top of the core as the core burns and its average speed of axial movement is measured to be 5.6cm/year. For Fig. 4, since there is only one fuel type in the core, it turns out that power distribution is center-peaked. And because there are a lot of leakage neutrons in general fast reactors, power flattening effect for outer region is weak even though radial reflector is used.

Table III summarizes core characteristics of UCFR-1000 with SF-10Zr. The delayed neutron fraction at BOC is 700 pcm and its value decreases as the core burns and TRU builds up. The total rod worth is 8.80$ and the peak fluence is over the current experience with HT-9 cladding.

Table III: Summary of kinetics parameters

Parameter	Value
Delayed neutron fraction (BOC/MOC/EOC), pcm	700 / 361 / 343
Total rod worth (BOC), $	8.80
Peak fluence, 10^{24} neutrons/cm^2	2.66

4. Conclusion

The design of UCFR-1000 with PWR spent fuel has been developed to achieve the goal of 60 year full power operation without refueling. The reactor power is 2600 MWth / 1000 MWe and the thermal efficiency is 38.5%. The active core height is 3.6m tall and the core diameter is ~5m including reflectors. The core depletion calculation using MC code, McCARD, confirms that 60 years of operation without refueling is feasible.

For the core with SF-10Zr model, the active core region travels along the axial direction at the speed of 5.6cm/year and the core discharge burnup is 276 GWd/t.

ACKNOWLEDGMENTS

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