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A Study for Verifying Dynamic Characteristics of UCFR-1000 by Testing a Fuel Assembly

Taewoo Tak, Deokjung Lee*
Ulsan National Institute of Science and Technology, UNIST-gil 50, Eonyang-eup, Ulju-gun, Ulsan, 689-798, Korea
**Corresponding author: deokjung@unist.ac.kr*

1. Introduction

Authors presented two preliminary core designs of large-size Ultra-long Cycle Fast Reactors with the power rating of 1000 MWe (UCFR-1000s); one with natural uranium (NU) as fertile material in the blanket at PHYSOR 2012 [1] and another with PWR spent fuel as fertile material in the blanket region at KNS 2012 spring meeting [2]. The two UCFR designs showed that the operation of reactors for 60 years without refueling was feasible in the neutronics point of view. Though this core concept has similar core like CANDLE [3] and AFR-100 [4], the coefficients analysis results were different with them. To verify the result, it needs its own analysis more in detail by testing some factors expected to affect the result. In this paper, a pin and an assembly of UCFR-1000 were analyzed.

2. Methods and Results

In this section, model design parameters and their calculation results are described. Homogenized models of a pin and an assembly were also tested in every coefficient calculation. The sodium void worth, isothermal temperature coefficient (ITC) and fuel temperature coefficient (FTC) of each case were evaluated. Model design and calculations were performed by McCARD Monte Carlo code [5].

2.1 Fuel Pin and Assembly Design

Each condition of a pin or an assembly was designed as same as that of UCFR-1000 core and the design parameters are presented in the Table I.

With the values in the table I, following the three figures show the shape of each pin or assembly and homogenizing was performed within those area. In the figure 1 and 2, the green, yellow, and gray regions present a metallic fuel pin, sodium coolant, and duct structure each. The yellow region outside in the figure 2 is also the sodium coolant region between duct structures. Figure 3 shows the axial geometry of the pin and the assembly. Homogenized model of each pin and assembly is also separated in four parts as shown.

Table I: Pin and Assembly Design Parameters

Parameters	Value
Assembly data	
-Number of pins	91
-Assembly pitch, cm	16.5
-Inter-assembly gap, cm	0.30
-Duct thickness, cm	0.30
Pin data	
-Pin material and type	U-10Zr
-Bond material	Na
-Active core height, cm	360
-Smeared density, % TD	74.5
-Cladding material	HT-9
-Clad outer diameter, cm	1.49
-Pin pitch-to-diameter ratio	1.075
-Cladding thickness, cm	0.050
-Bond thickness, cm	0.095
Volume fraction at fabrication, %	
-Fuel or Absorber	43.7
-Bond	14.9
-Structure	15.7
-Coolant	25.7

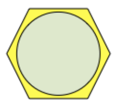

Fig. 1. Pin Geometry of UCFR-1000

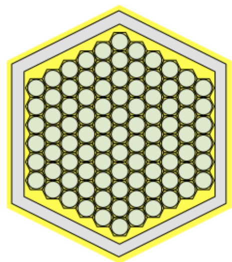

Fig. 2. Assembly Geometry of UCFR-1000

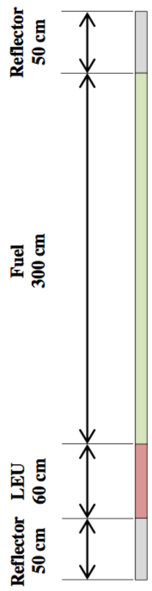

Fig. 3. Axial Pin geometry of UCFR-1000

2.2 Results for Each Coefficient

Total sixteen cases with different condition were tested including criteria cases. A, B, C, and D in the Table II-V are represent Pin, homogenized Pin, Assembly, and homogenized Assembly.

Table II: Calculation Result for Criteria

	A	B	C	D
Keff	1.09606	1.09631	1.04649	1.04586
Standard dev. (pcm)	5	4	2	4
Leakage (w/o)	2.97	2.74	3.41	2.99
Delayed neutron fraction	0.00706	0.00706	0.00707	0.00705
Prompt lifetime (sec)	6.74E-07	6.57E-07	7.92E-07	7.59E-07

Table III: Calculation Result for Sodium Void Worth

	A	B	C	D
Keff	1.10261	1.10463	1.05140	1.05434
Standard dev. (pcm)	5	5	2	4
Leakage (w/o)	4.24	3.59	5.19	4.00
Delayed neutron fraction	0.00706	0.00707	0.00708	0.00707
Prompt lifetime (sec)	5.86E-07	6.08E-07	6.66E-07	7.03E-07
Difference (pcm)	655	832	491	848
Worth ($)	0.93	1.18	0.69	1.20

Table IV: Calculation Result for Fuel Temperature Coefficient

	A	B	C	D
Keff	1.09632	1.09656	1.04682	1.04623
Standard dev. (pcm)	4	5	2	4
Leakage (w/o)	2.97	2.74	3.41	2.99
Delayed neutron fraction	0.00706	0.00705	0.00706	0.00705
Prompt lifetime (sec)	6.74E-07	6.58E-07	7.93E-07	7.59E-07
Difference (pcm)	-26	-25	-33	-37
Coefficient (₡/K)	-0.04	-0.04	-0.05	-0.05

Table V: Calculation Result for Isothermal Temperature Coefficient

	A	B	C	D
Keff	1.09608	1.09643	1.04678	1.04596
Standard dev. (pcm)	5	5	2	4
Leakage (w/o)	2.95	2.72	3.38	2.97
Delayed neutron fraction	0.00706	0.00706	0.00706	0.00706
Prompt lifetime (sec)	6.79E-07	6.62E-07	7.99E-07	7.63E-07
Difference (pcm)	-2	-12	-29	-10
Coefficient (₡/K)	0.00	-0.02	-0.04	-0.01

As comparing Keff and other parameters simply, it is found that the main factors which have dominant effect on reactivity in UCFR-1000 are leakage and spectrum hardening. But there are several noticeable results in common. First, all of the coefficients have very small values. The reason for this is that fuel volume fraction of UCFR-1000 is so high that the lattice is tight and the spectrum is hardened. Second, homogenizing effect increases multiplication factor of the pin but decreases that of the assembly. It is known that homogenizing effect increases multiplication factor about 500pcm in core analysis. Another homogenizing effect is decreasing the leakage and prompt neutron life time. At last, sodium void effect increases the leakage and decreases prompt neutron life time. There are some exceptional results that the effect of homogenizing with sodium void is little different from the other cases.

It is necessary to test spectrum effect and sodium absorption effect for verifying the effect of the two main factors.

3. Conclusions

For analyzing the dynamic characteristics of UCFR-1000, designing and calculating of a pin and an assembly of UCFR-1000 were performed. All the processes were performed with their homogenized model and sodium void worth, FTC, and ITC were analyzed.

The main reactivity factors of UCFR-1000 are leakage and spectrum hardening. But there are some superposition results. It needs to check the sodium absorption effect or test with varying fuel volume fraction and comparing spectrum to verify the results.

REFERENCES

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