Spectrum Effect on the Coolant Void Effect in KALIMER-600 Core

Pham Nhu Viet HA*, Jaewoon YOO, and Sang-Ji KIM
Fast Reactor Development Division, Korea Atomic Energy Research Institute
1045 Daedeok-daero, Yuseong-gu, Daejeon 305-353, KOREA
**Corresponding author: phamha@kaeri.re.kr*

1. Introduction

Up to now, the Korea Atomic Energy Research Institute has been developing an advanced fast reactor concept, KALIMER-600 [1], which is the liquid metal sodium cooled fast reactor with an electricity output of 600MWe, uses U-TRU-15%Zr metal fuel, and serves as a prototype demonstration reactor for a future commercial liquid metal fast reactor.

Sodium void reactivity effect (SVRE) is of primary importance in the safety design and analysis of sodium cooled fast reactors and therefore requires being properly assessed [2]. In this study, we perform the first-order perturbation theory calculations for various sodium void scenarios in KALIMER-600 using two different sets of neutron microscopic cross-sections at unperturbed and perturbed states, ISOTXS and ISOTXP, respectively. The purpose is to evaluate the spectrum effect on the prediction of the SVRE in KALIMER-600.

2. Methods and Results

Sodium void scenarios in the inner core, outer core, and whole core at both the beginning and end of equilibrium cycle (BOEC and EOEC) of KALIMER-600 were analyzed using the perturbation theory code PERT-K [3]. The neutron microscopic cross-section sets, ISOTXS and ISOTXP, are used for this analysis. The resulting net reactivity effect and its specific reactivity components are expected to help understand the spectrum effect on the SVRE in KALIMER-600.

2.1 Calculation Method

The reference KALIMER-600 TRU burner core configuration is shown in Fig. 1 with the use of a single-enrichment fuel to facilitate fuel fabrication processes and to reduce the power swing from the BOEC to the EOEC. The triangular-Z geometry of the core is applied in the calculation.

The first-order perturbation theory calculations were conducted using PERT-K so as to analyze the SVRE in KALIMER-600 in comparison with the generally used method that compares the criticality factors from direct flux computations for unperturbed and perturbed cores using the diffusion code DIF3D [4]. The neutron cross-sections for 150 neutron energy groups were collapsed into those for 25 groups using the TRANSX code to generate the effective microscopic cross-section sets ISOTXS and ISOTXP. Accordingly, the impact of the change in microscopic cross-sections resulting from the loss of sodium coolant on the prediction of the SVRE in KALIMER-600 core can be revealed.

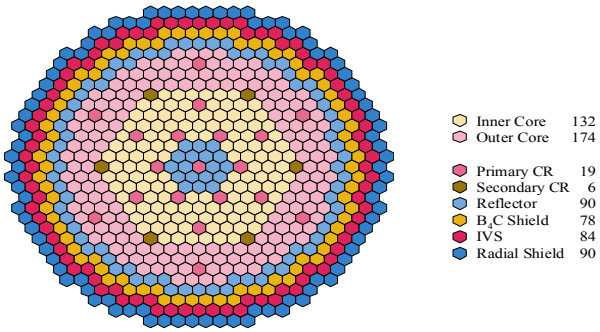

Fig. 1. KALIMER-600 core configuration

2.2 Results and Discussion

The comparative results between PERT-K and DIF3D in predicting the SVRE in KALIMER-600 as sodium void appears in the inner core, outer core, and whole core are presented in Table I. Concerning the DIF3D results, it can be seen that the first-order perturbation theory results with ISOTXP better predict the SVRE at the order of ~200pcm at BOEC and of ~400pcm at EOEC than those with ISOTXS.

Table I: Comparison of SVRE in KALIMER-600 between DIF3D and PERT-K

KALIMER-600		DIF3D	PERT-K			
			ISOTXS		ISOTXP	
Fuel cycle	Void location	ρ_{DIF3D}	ρ	Diff.	ρ	Diff.
		pcm				
BOEC	inner core	1467	1033	-434	1294	-173
	outer core	711	331	-380	555	-156
	whole core	1960	1246	-714	1482	-478
EOEC	inner core	1784	1159	-625	1591	-193
	outer core	1019	387	-632	849	-170
	whole core	2315	1546	-769	1996	-319

Tables II and III show the specific sodium void reactivity components calculated by PERT-K with the use of ISOTXS and ISOTXP. For the calculation with ISOTXS, the reactivity component from the fission

source was canceled in all cases because of the same microscopic fission cross-sections used for unperturbed and perturbed cores. However, the other components including scattering, absorption, and leakage terms were found as contributors to the SVRE due to a change in sodium densities. In contrast, all the components with the use of ISOTXP were found competing to contribute to the SVRE in KALIMER-600 core. That is because of the actual change in effective microscopic cross-sections along with a change in sodium densities.

Table II: Sodium void reactivity components calculated by PERT-K with the use of ISOTXS

KALIMER-600		**PERT-K with ISOTXS**			
Fuel cycle	Void location	ρ_{fiss}	ρ_{scat}	ρ_{abso}	ρ_{leak}
		pcm			
BOEC	inner core	0	1769	49	-784
	outer core	0	1655	50	-1373
	whole core	0	3938	114	-2806
EOEC	inner core	0	1952	53	-846
	outer core	0	1687	49	-1349
	whole core	0	3639	102	-2195

Table III: Sodium void reactivity components calculated by PERT-K with the use of ISOTXP

KALIMER-600		**PERT-K with ISOTXP**			
Fuel cycle	Void location	ρ_{fiss}	ρ_{scat}	ρ_{abso}	ρ_{leak}
		pcm			
BOEC	inner core	33	1800	328	-866
	outer core	39	1690	319	-1493
	whole core	73	4044	429	-3064
EOEC	inner core	37	1953	530	-929
	outer core	37	1672	522	-1382
	whole core	77	3714	613	-2408

In addition, a marked difference shown in Table IV for the absorption and leakage reactivity components with the use of ISOTXS and ISOTXP indicates that the neutron capture and leakage probabilities varied considerably as sodium void appears in the core.

Table IV: Comparison of sodium void reactivity components calculated by PERT-K with the use of ISOTXS and ISOTXP

KALIMER-600		$\Delta\rho = \rho_{ISOTXP} - \rho_{ISOTXS}$			
Fuel cycle	Void location	$\Delta\rho_{fiss}$	$\Delta\rho_{scat}$	$\Delta\rho_{abso}$	$\Delta\rho_{leak}$
		pcm			
BOEC	inner core	33	31	279	-82
	outer core	39	35	269	-120
	whole core	73	106	315	-258
EOEC	inner core	37	1	477	-83
	outer core	37	-15	473	-33
	whole core	77	75	511	-213

3. Conclusions

The SVRE in KALIMER-600 core was analyzed using two different sets of neutron cross-sections at unperturbed and perturbed states. The results show that the change in effective microscopic cross-sections due to the loss of sodium coolant significantly affected the accuracy of the SVRE prediction of the order of ~200pcm at BOEC and ~400pcm at EOEC. Thus, this study clarified quantitatively the spectrum effect on the SVRE, which could be helpful to the safety design of KALIMER-600 core.

Acknowledgement

This work was supported by the Long-term Nuclear R&D Program of the Ministry of Education, Science and Technology (MEST) in Korea.

REFERENCES

[1] D. Hahn et al., Conceptual design of the sodium-cooled fast reactor KALIMER-600, Nuclear Engineering and Technology, Vol.39, No.3, pp.193-206, 2007.
[2] K. Sun et al., Void reactivity decomposition for the sodium-cooled fast reactor in equilibrium fuel cycle, Annals of Nuclear Energy, Vol.38, No.7, pp.1645-1657, 2011.
[3] J. W. Jang et al., Development of a perturbation theory module for triangular-z geometry, Proceedings of '07 KNS Spring Meeting, Korean Nuclear Society, 2007.
[4] K. L. Derstine, DIF3D: A code to solve one-, two- and three-dimensional finite-difference diffusion theory problems, ANL-82-64, Argonne National Laboratory, 1984.