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The Analysis of the MTC Effect for Controlling Secondary Reactivity Based on Coolant Temperature for Soluble Boron-free SMR Core

Yu Yeon Cho [a], Seong Ho Park [a], Junggyu Lee [a], Hwansoo Kim [a], Na Yeon Seo [a]
[a]KEPCO Nuclear Fuel, 242, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon 34057, Republic of Korea
[*]Corresponding author: yycho@knfc.co.kr

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1. Introduction

Recently, Innovative-Small Modular Reactor (i-SMR) has been developed in Korea, which considers soluble boron-free operation as one of its top requirements. The soluble boron free core largely contributes to system simplification by allowing the removal of associated systems and components and the system simplification leads the improvement of the economy and system reliability [1].

In the conventional NPPs, the reactivity control is accomplished through solid burnable absorbers, control rods, and soluble boron in the reactor coolant. However, the soluble boron-free core requires increased dependence on control rods and burnable poisons. Also, relying strongly on moveable control rods can distort the axial power profile negatively and also elevate the risk of having rod-associated accidents [2].

The i-SMR will introduce the primary coolant temperature control as a secondary reactivity control method. Due to the soluble boron-free core, a substantially large negative moderator temperature coefficient (MTC) can lead to large reactivity feedback.

At the previous study, the feasibility of secondary reactivity control using the primary coolant temperature change for daily load follow in the i-SMR was proposed [3]. Due to the strongly negative MTC, the reactivity variation as power change is regulated without movement of the control rods.

It is more possible to compensate for the excess reactivity caused by power defect and xenon burnouts with more negative MTC. In this work, we designed different lengths of the axial blanket to analyze the effect of MTC on secondary reactivity control during the load-follow operation (100-50-100%) for BOC of the initial core cycle (1st cycle).

2. Methods and Results

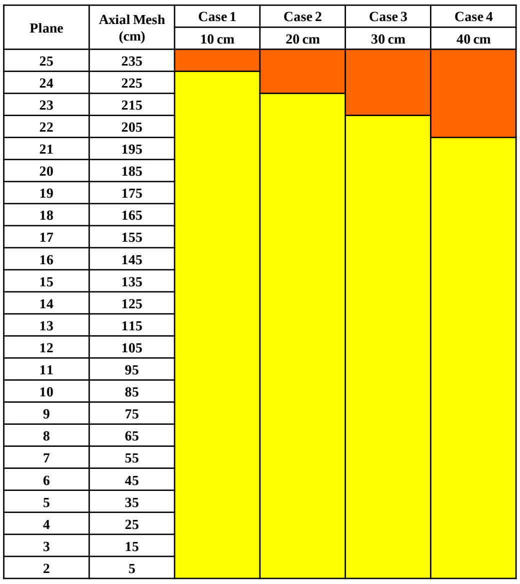
2.1 Computational Methods

Assembly burnup calculations for two group cross section generation were calculated by KARMA (Kernel Analyzer by Ray-tracing Method for fuel Assembly) [4, 5] which is a two-dimensional multi-group lattice transport code using 190 group and 47 group cross section library based on ENDF/B-VI.8. This code uses the subgroup method for resonance self-shielding effect and MOC (Method of Characteristics) as the transport solution method.

ASTRA (Advanced Static and Transient Reactor Analyzer) code was used for three-dimensional core calculation [6]. This code is a 3D core depletion code and developed by KEPCO NF (KEPCO Nuclear Fuel) as a nuclear design code for the core design of pressurized water reactors (PWRs) based on the reactor physics technologies. It adopts a Semi-Analytic Nodal Method (SANM) formulated with the Coarse-Mesh Finite Difference method (CMFD) as the neutronics solver for the reactor core analysis [7, 8].

2.2 Core design and performance analysis

The i-SMR design is for a thermal power of 520 MW. The core has 69 assemblies with 17 x 17 lattice. The active core height is 240 cm divided into 24 axial meshes. The axial blanket is located in upper region with 2.2 w/o uranium enrichment and the length is 20 cm in the reference model (Case 2). In this study, we additionally considered 10 cm (Case 1), 30 cm (Case 3) and 40 cm (Case 4) to analyze the sensitivity of MTC effect. Fig. 1 shows the axial assembly configurations for each core model.



Plane	Axial Mesh (cm)	Case 1 10 cm	Case 2 20 cm	Case 3 30 cm	Case 4 40 cm
25	235	🟧	🟧	🟧	🟧
24	225	🟨	🟧	🟧	🟧
23	215	🟨	🟨	🟧	🟧
22	205	🟨	🟨	🟨	🟧
21	195	🟨	🟨	🟨	🟨
20	185	🟨	🟨	🟨	🟨
19	175	🟨	🟨	🟨	🟨
18	165	🟨	🟨	🟨	🟨
17	155	🟨	🟨	🟨	🟨
16	145	🟨	🟨	🟨	🟨
15	135	🟨	🟨	🟨	🟨
14	125	🟨	🟨	🟨	🟨
13	115	🟨	🟨	🟨	🟨
12	105	🟨	🟨	🟨	🟨
11	95	🟨	🟨	🟨	🟨
10	85	🟨	🟨	🟨	🟨
9	75	🟨	🟨	🟨	🟨
8	65	🟨	🟨	🟨	🟨
7	55	🟨	🟨	🟨	🟨
6	45	🟨	🟨	🟨	🟨
5	35	🟨	🟨	🟨	🟨
4	25	🟨	🟨	🟨	🟨
3	15	🟨	🟨	🟨	🟨
2	5	🟨	🟨	🟨	🟨

Fig. 1. Axial assembly configurations

Fig. 2 shows Isothermal Temperature Coefficient (ITC) versus power change for BOC of 1st cycle. ITC was calculated with power variations in 20% increments. The Case 4 has most negative ITC of -68.63 pcm/℃ and the Case 1 has least negative ITC of -64.85 pcm/℃ at 100% power, respectively.

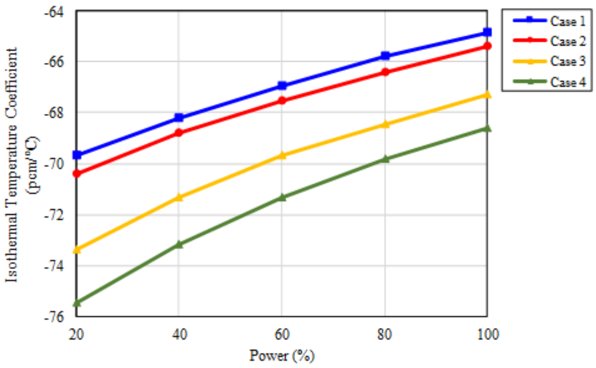


Fig. 2. Comparison of the ITC versus power

2.3 Daily Load follow Operation

We considered the following power control strategy of the daily load follow operation: The core power decreased from 100% to 50% over 2 hours, held at 50% for 4 hours then returned to 100% over 2 hours and held for 16 hours.

Fig. 3 shows that the changes of the inlet temperature and average temperature as the load follow operation for the Case 1. T_in_control in Fig. 3 refers to the calculated inlet temperature required to maintain reactivity without the movement of control rods. The maximum change with the reference temperature and the controlled temperature is ±3.6℃, which is required for daily load follow operation.

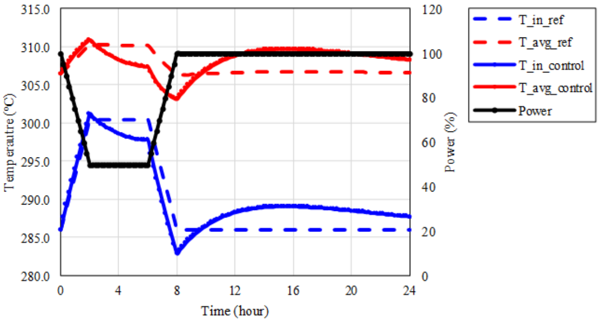


Fig. 3. Temperature change during load follow (Case 1)

Fig. 4 shows that the changes of the inlet temperature and average temperature as the load follow operation for the Case 2. The temperature change of ±3.3℃ is required for daily load follow operation.

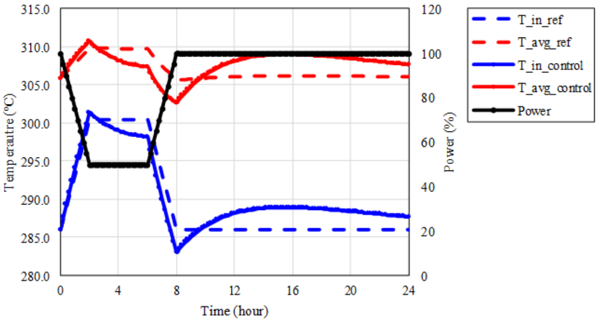


Fig. 4. Temperature change during load follow (Case 2)

Fig. 5 shows that the changes of the inlet temperature and average temperature as the load follow operation for the Case 3. The temperature change of ±2.6℃ is required for daily load follow operation.

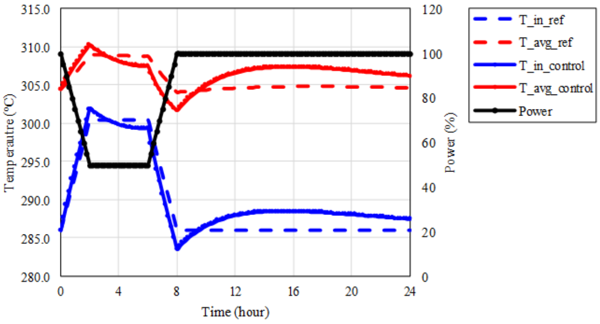


Fig. 5. Temperature change during load follow (Case 3)

Fig. 6 shows that the changes of the inlet temperature and average temperature as the load follow operation for the Case 4. The temperature change of ±2.5℃ is required for daily load follow operation. Table I summarizes the ITC at 100% power and the temperature change for daily load follow operation with different axial blanket length.

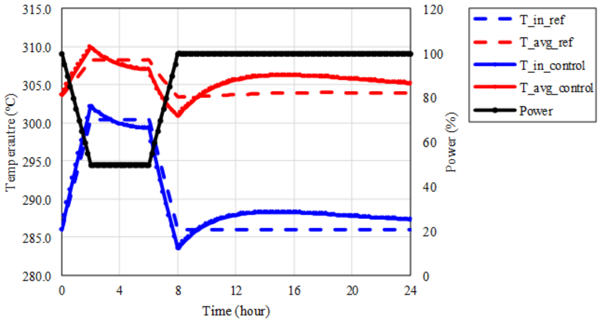


Fig. 6. Temperature change during load follow (Case 4)

Table I. ITC and temperature change for load follow operation

	Case 1	***Case 2***	***Case 3***	***Case 4***
Axial blanket length [cm]	10	20	30	40
ITC [pcm/°C]	-64.85	-65.38	-67.28	-68.63
Temperature change [℃]	±3.6	±3.3	±2.6	±2.5

3. Conclusions

The effect of MTC on the reactivity control was analyzed by changing the axial blanket length for BOC of 1st cycle on the i-SMR core. From the analysis, the large size of the axial blanket makes more negative MTC and the more negative MTC reduces the temperature range during the load follow operation.

The core designed with 40 cm of the axial blanket length has -68.63 pcm/°C of MTC and ±2.5°C of the moderator temperature change during 100-50-100% power, 2-4-2-16 hours daily load follow operation.

In the future work, the study will proceed to develop a more strongly negative MTC to minimize the required temperature change on the RCS temperature control.

Acknowledgement

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