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Design Assessment and Transient Simulation of an Integral Reactor, REX-10, using TAPINS code

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1. Introduction

REX-10 is a small-sized integral-type SMR which has a rated thermal output of 10 MW to provide small-scale electricity generation and district heating. Its reactor assemblies are equipped with the thorium-fueled core, the helical-coil steam generator, and the steam-gas pressurizer inside a reactor pressure vessel. The design features of REX-10 are presented in this paper. A thermal-hydraulic system code named TAPINS, which are developed by Seoul National University, is applied to confirm the design decisions and evaluate transient behaviors of REX-10. In this study, the steady-state analysis of REX-10 and the transient simulation on the reactivity insertion event are carried out. To validate the capability of the TAPINS, the calculation results are compared to the prediction results of the TASS/SMR code. General agreements are obtained from comparison results.

2. Description of REX-10

The aim of developing REX-10 is to achieve a more stable, efficient, area-independent system operation and energy production. REX-10 is designed to generate the rated output of 10 MW at a low pressure of 2.0 MPa compared to conventional reactors. It is an integral-type small PWR; housed in the reactor pressure vessel are a thorium-fueled core, a built-in steam-gas pressurizer, a once-through steam generator and so on. Its coolant flow is driven by natural circulation without a reactor coolant pump. The major design parameters of REX-10 are listed in Table I.

The height of the cylindrical reactor vessel is 5.715 m. Placed at the bottom of the reactor vessel are the 9×9 heterogeneous Th/UO2 fuel assemblies that are used to achieve an ultra-long fuel cycle of up to 20 years on the basis of the Seed-Blanket Unit (SBU) design. The long riser region above the core provides sufficient head for the free convection of fluid.

The gaseous mixture volume in the upper part of the reactor above the coolant level is referred to as the built-in steam-gas pressurizer. The once-through steam generator of REX-10 consists of helical tubes wrapped around the entire annulus between the core barrel and the reactor pressure vessel. The containment of REX-10 is filled with water and buried underground. As a representative safety system equipped in REX-10, the passive residual heat removal system (PRHRS) removes the decay heat in the event of reactor shutdown.

Table I: Main Design Parameters of REX-10

Parameters	**Design value**
General information	
Reactor type	Integral PWR
Reactor power (MW)	10
Service years (yr.)	20
Reactor coolant system	
Cooling mode	Natural circulation
Operating pressure (MPa)	2.0
Core inlet / outlet Temp. (^oC)	165.0 / 200.0
Mass flow rate (kg/s)	64.9
Fuel and reactor core	
Fuel type	9×9 Square FA
Fuel material	Heterogeneous Th/UO_2
No. of fuel assembly	37
No. of fuel rods (/FA)	72
Effective height (m)	0.8
Steam generator	
Type	Helical coil HX
Feedwater mass flow (kg/s)	4.47
Feedwater temperature(^oC)	120.0
Steam temperature (^oC)	142.0 (sat. steam)
Steam pressure (MPa)	0.4
Reactor Vessel and Pressurizer	
Vessel outer diameter (m)	2.272
Core barrel diameter (m)	1.607
Vessel height (m)	4.588+1.127 (PRZ)
Non-condensable gas in PRZ	Nitrogen

3. Calculation Results

3.1 Thermal-hydraulic Analysis Codes

In Seoul National University, a system analysis code named TAPINS (Thermal-hydraulic Analysis Program for INtegral reactor System) was developed on the basis of one-dimensional momentum integral model. It is an easy-to-use and fast-running system code for integral reactors. The TAPINS consists of mathematical models for the reactor coolant system, the core, the helical coil steam generator, and the built-in steam-gas pressurizer. The TAPINS is basically validated by comparing with the experimental data of natural circulation tests in the RTF (REX-10 Test Facility) [1].

As a comparison code, the TASS/SMR is also used for the steady-state and transient analyses of REX-10. It is developed by KAERI for safety evaluation and design identification of the advanced integral reactor based on five conservation equations for the mixtures [2].

3.2 Steady-state analysis of REX-10

The assessment of the design decisions of REX-10 is performed through the steady-state analysis using the TAPINS. The resultant steady-state output parameters are listed in Table II with those predicted by the TASS/SMR. Most of the system parameters predicted by the TAPIR conform to the design specification very well. Moreover, other steady-state output parameters show good agreement with the predictions of the TASS/SMR.

One exception is noted for the minimum departure from nucleate boiling ratio (MDNBR). While the CHF is calculated by the Bowring correlation in the TAPIR, the TASS/SMR selects the maximum value between CHFs calculated by W-3 and Macbeth correlation, which do not cover the pressure range of REX-10.

Table II: Steady-state analysis result of REX-10

Parameters	Design	TASS	TAPIR
Pressurizer pressure (MPa)	2.0	2.0	2.0
Coolant flow rate (kg/s)	64.9	65.6	64.2
Core inlet temperature (℃)	165.0	167.1	163.5
Core exit temperature (℃)	200.0	201.6	198.8
Average fuel temperature (℃)	-	290.2	294.4
Minimum DNBR	-	16.9	24.6
Steam quality at the exit		1.0	0.9996
Total DP in tube (bar)		0.59	0.64

3.3 Reactivity Insertion Accident

A hypothetical reactivity insertion event is simulated by the TAPIR and the TASS/SMR. This reactivity-induced accident may be caused by the uncontrolled withdrawal of control rods. Analyzed in this section is a mild reactivity transient when the external reactivity of 0.1 $ is inserted to the core in a stepwise way. The simulation results for the reactivity insertion event are plotted in Figs. 1 - 3.

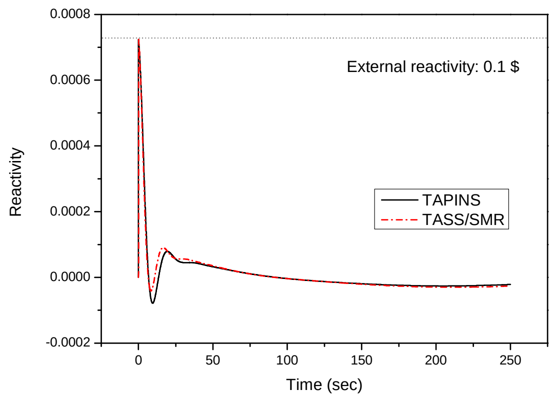

Fig. 1. Variation of the total reactivity

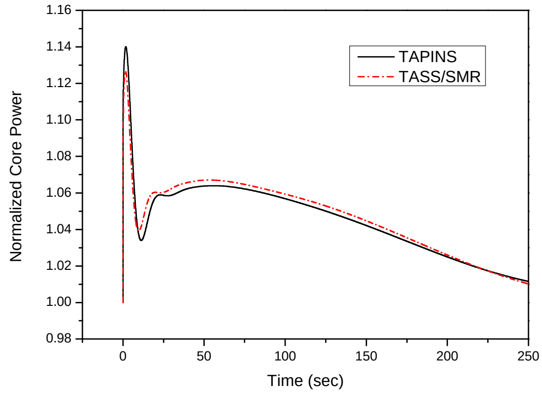

Fig. 2. Transient normalized core power

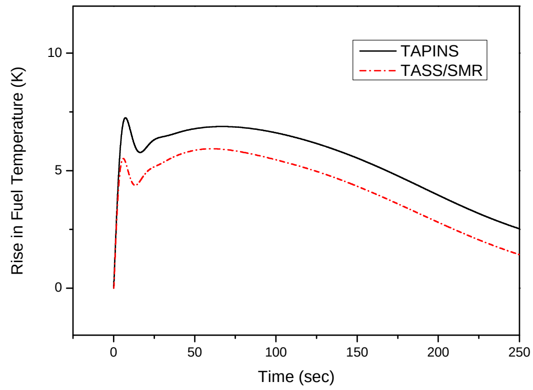

Fig. 3. Transient rise in average fuel temperature

As shown in the results, the power level rises promptly at the instant of reactivity insertion, but total amount of reactivity is rapidly approaches to null by the negative feedback effect arising from the increase in the fuel and moderator temperature. Then the core power is gradually reduced. From the results, it is confirmed that the core can returns to the critical state by the negative feedback effect of fuel and moderator without the occurrence of excessive temperature when the external reactivity of 0.1 $ is inserted to the core of REX-10. In addition, general agreements are obtained between the results of the TAPINS and the TASS/SMR.

4. Conclusions

The steady-state condition and the reactivity insertion accident are analyzed with the TAPINS and the TASS/SMR. It is revealed that most of the predicted system parameters conform to the design specification very well, and good agreements are obtained between the results of two codes on the reactivity insertion event.

REFERENCES

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[2] Y. J. Chung et al., Development and assessment of system analysis code, TASS/SMR for integral reactor, SMART, Nuclear Engineering and Design, Vol. 244, p. 52, 2012