A Study on RVCS Performance with 3D Thermal Hydraulics Analyses

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1. Introduction

As the development of small modular reactors and Generation IV reactors progresses, the shape of the reactor is also changed. One of these, a pool-type reactor, reactor core, reactor coolant pump, and heat exchanger include in a reactor vessel. A prototype gen-IV sodium cooled fast reactor (PGSFR) is one of pool-type reactors. Any safety system which uses water can be used at PGSFR. A reactor vault cooling system (RVCS) can enhance the safety of the reactor by removing the decay heat through the natural convection of the air in the system [1]. Lee et al. used MARS-LMR to analyze the process of DBA and DEC progression in the PGSFR, and MATRA-LMR-FB to analyze local defects [2]. Choi, Jeong, and An used MARS-LMS to analyze the progress of the severe accidents depending on the presence or absence of RVCS [3]. In this paper, when RVCS is analyzed at 3-dimensional geometry, the performance of this component is analyzed to determine whether it is an effective safety system for accident scenarios.

2. PGSFR model description

In this study, TRACE was used to analyze the performance of RVCS. PGSFR was modeled for analysis. Fig.1 shows the nodalization of PGSFR. The reactor pool component is modeled at 17 axial levels, 7 radial rings, and 10 azimuthal sectors. In this reactor, a reactor core, four intermediate heat exchangers (IHX), two primary heat transfer system (PHTS) pumps, and four decay heat exchangers (DHX) include in the reactor vessel. PGSFR generates 392.2 MW_t heat at the normal operating condition. Hot pool and cold pool are separated by redan. Table I summarizes the design parameters for PGSFR and the normal operating conditions of the model [4].

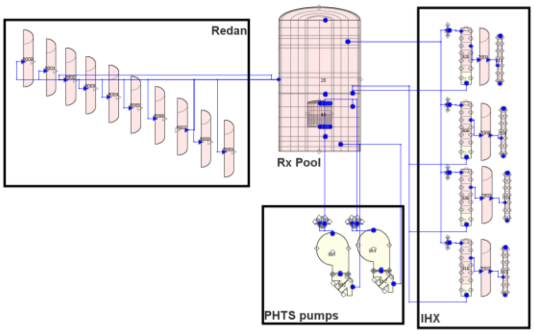

Fig. 1. TRACE nodalization for PGSFR model

Table I. Comparison of the PGSFR design parameter and normal operating conditions of TRACE model [1]

Parameter	Design value	TRACE normal operating conditions
Thermal power [MW_t]	392.2	392.2
Coolant flow rate [kg/s]	1,989	1,932
Core inlet temperature [℃]	390	412
Core outlet temperature [℃]	545	572

3. Transient analyses without RVCS

In this study, to evaluate the performance of RVCS, an unprotected loss of heat sink (ULOHS) is considered. The ULOHS scenario reduces the heat removal rate of the intermediate heat transfer system by stop of all IHXs. This reduction of heat removal rate increases cold pool temperature and core average temperature. The increase of cold pool temperature causes positive reactivity due to the expansion of the reactor vessel. The increase of core temperature inserts negative reactivity due to fuel expansion, doppler effect, and reduction of sodium density. This reactivity reduces the core power, and it becomes similar to decay heat level after approximately 1 h as shown in Fig. 2. Fig. 3 shows the coolant temperature at the core inlet and outlet during the ULOHS scenario without the RVCS. As the core power reduces, the difference of coolant temperature between core inlet and outlet is decreased. However, the decay heat is accumulated in the reactor and the coolant temperature is increased. At approximately 19.4 h, the sodium is boiled.

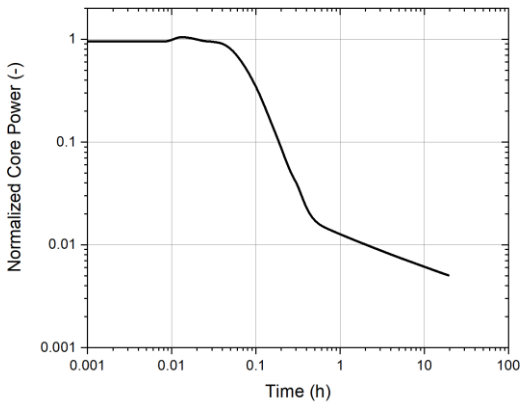

Fig. 2. Normalized core power under ULOHS scenario without RVCS.

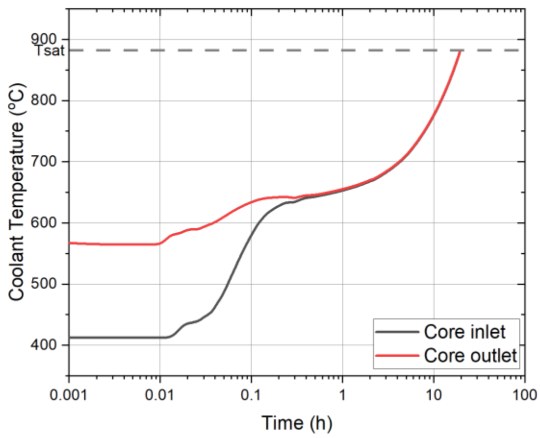

Fig. 3. Coolant temperature under ULOHS scenario without RVCS.

4. Transient analyses with RVCS

RVCS is modeled for heat removal through the reactor vessel on the outer wall of the reactor pool. The heat loss of the RVCS is 0.5 MW_t at the normal operating condition. Fig. 4 shows the reactor core normalized power during ULOHS with RVCS operation. The positive reactivity by reactor vessel expansion becomes smaller as RVCS cooling the reactor vessel. Therefore, the power is decreased faster when the RVCS is operated. The core power becomes similar to the decay heat level at approximately 0.5 h. Fig. 5 shows the reactor coolant temperature at the core during the ULOHS scenario with RVCS operation. The difference of coolant temperature is decreased by reduction of the core power, the same as without RVCS. However, average coolant temperature is increased slower than without RVCS due to the difference in the behavior of the core power and heat loss of the RVCS. Furthermore, the sodium is not boiled until 1 day.

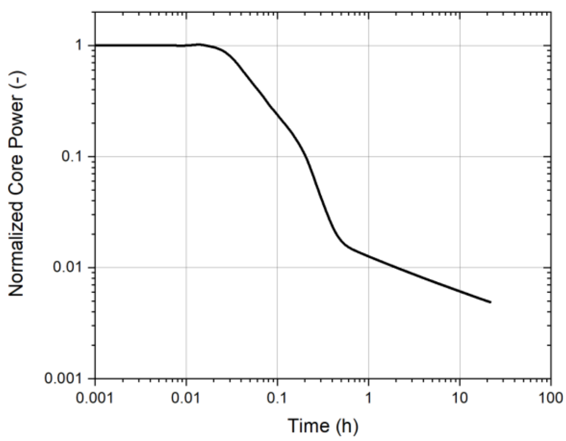

Fig. 4. Normalized core power under ULOHS scenario with RVCS.

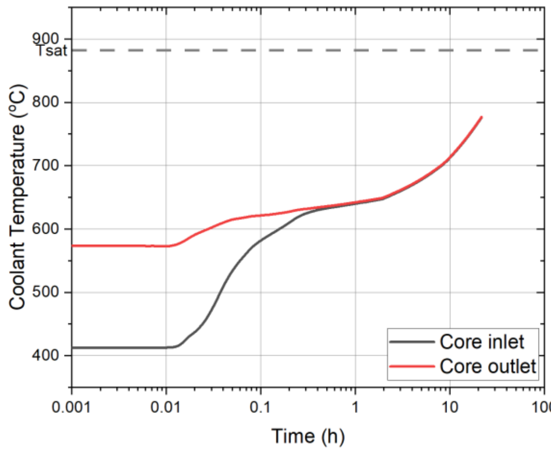

Fig. 5. Coolant temperature under ULOHS scenario with RVCS.

5. Conclusion

The performance of RVCS was analyzed at 3-dimensional geometry. For the ULOHS scenario, with or without RVCS, the reactor core power could be reduced to the decay heat level in less than an hour. RVCS reduced the reactor vessel temperature and decrease the positive reactivity of reactor vessel expansion. Therefore, the operation of RVCS could avoid the evaporation of sodium.

Acknowledgments

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