Analyses of Transient Scenarios of Prototype Gen-IV Sodium Cooled Fast Reactor

Gi Hyeon Choi [a], Dong-Wook Jerng [a*]
a School of Energy Systems Engineering, Chung-Ang University, 84, Heukseok-ro, Dongjak-gu, Seoul, Republic of Korea
**Corresponding author: dwjerng@cau.ac.kr*

1. Introduction

Prototype Gen-IV Sodium Cooled Fast Reactor (PGSFR) is a pool-type reactor that includes components like pumps, heat exchangers, a core, etc. at a reactor vessel. The residual heat is removed by a decay heat removal system (DHRS) and a reactor vault cooling system (RVCS) at a decay heat exchanger and the reactor vessel wall, respectively [1]. RVCS absorbs the heat using the natural convection of air. An air separator which is positioned between a containment vessel and a concrete separates a riser and a downcomer. The decay heat flows from the containment vessel into the air at the riser, and the air flows upward by the buoyance force. The air at the downcomer makes a downward flow to inject the cold air into the riser. The decay heat flows as not only a convective heat transfer process but also a radiative heat transfer process at RVCS [2]. Furthermore, natural convection is performed not only at RVCS but also in the cold pool of the reactor. Therefore, a verification of the heat removal performance for RVCS is necessary. In this study, the integrity of the reactor is analyzed when any residual heat removal system except RVCS is not worked.

2. model description

In this paper, TRACE was used to analyze the transient of PGSFR and RVCS combined model. Fig. 1 shows the nodalization for PGSFR-RVCS model. The reactor pool was modeled to express the circulation in the reactor pool by a 3-dimensional component called the 'Vessel component'. The flow area of a redan that separates the cold pool and the hot pool was set to 0 to prevent the coolants in the two pools from mixing. Table I compares the PGSFR design parameter and the normal operating condition of TRACE model [3].

The decay heat removal from the reactor to air at air flow path through reactor vessel and containment vessel as shown in Fig. 2. When the heat flow from the reactor vessel into the containment vessel, the heat was transferred as only the radiative heat. However, when the heat flow from the containment vessel into the air, the heat was transferred as radiative heat and convection heat. Therefore, the air was heated at parallel asymmetric heated walls which were the containment wall and the air separator. K. M. Kim et al. suggested the heat transfer coefficient in this case as shown in Eqs. (1)-(4) [2].

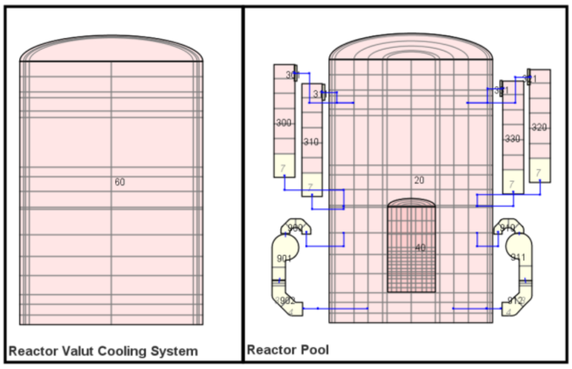

Fig. 1. TRACE nodalization for PGSFR-RVCS model

Table I. Comparison of the PGSFR design parameter and TRACE model steady state condition [3]

		Design Parameter	TRACE model steady state condition
Thermal power [MW_t]		392.2	392.2
PHTS	coolant mass flow rate [kg/s]	1989	1932.27
	cold pool temperature [°C]	390	412.19
	hot pool temperature [°C]	545	572.48
IHTS	coolant mass flow rate [kg/s]	374.325*4	374.325*4
	IHX inlet temperature [°C]	323	323.00
	IHX outlet temperature [°C]	528	527.78

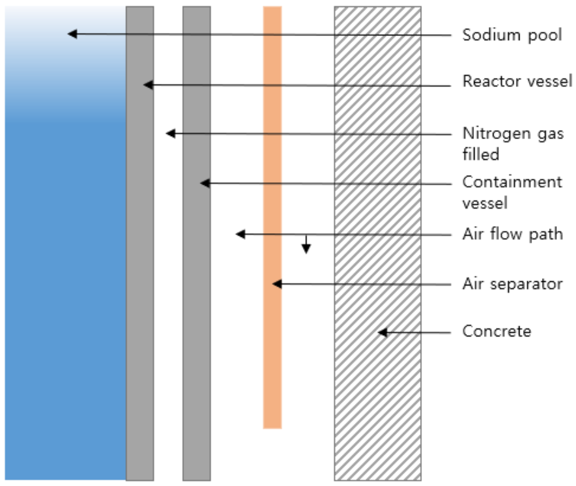

Fig. 2. The schematic diagram of the reactor vault cooling system

$$Bo = Gr/(\mathrm{Re}^{3.425} \times \mathrm{Pr}^{0.5}) \quad (1)$$

$$Nu_f = \frac{(f/2)(Re - 1000)Pr}{1 + 12.7(f/2)^{1/2}(Pr^{2/3} - 1)} \quad (2)$$

$$\frac{Nu}{Nu_f} = \left\{ \left| 1 - 170000 \times Bo \times \left(\frac{Nu}{Nu_f} \right)^{-1.8} \right| \right\}^{0.6} \quad (3)$$

$$h_{RVCS} = \frac{Nu \times k}{D_h} \quad (4)$$

3. Transient analyses

Unprotected loss of heat sink (ULOHS) and unprotected loss of flow (ULOF) were selected as transient scenarios. For both scenarios, reactor shut-down did not occur and any residual heat removal system except RVCS was not considered.

3.1. Unprotected loss of heat sink (ULOHS)

This scenario began with a stop of the intermediate heat transfer system (IHTS). The reduction of the heat removal rate of IHTS induced an increase in the cold pool temperature. This induced increase in fuel and reactor vessel temperature. The increase in fuel temperature made negative reactivity and the increase in reactor vessel temperature made positive reactivity. The negative reactivity was bigger than the positive reactivity, so the reactor core power was decreased as shown in Fig. 3. Due to the decrease of the core power, a difference in temperature between the core inlet and outlet was decreased as shown in Fig. 4. The coolant temperature increased until 31 h. Since 31 h, the RVCS heat removal rate was bigger than reactor core power, so coolant temperature became decreased.

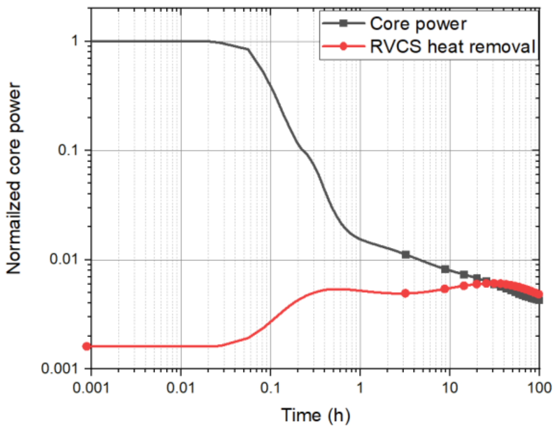

Fig. 3. Normalized power behavior under ULOHS scenario

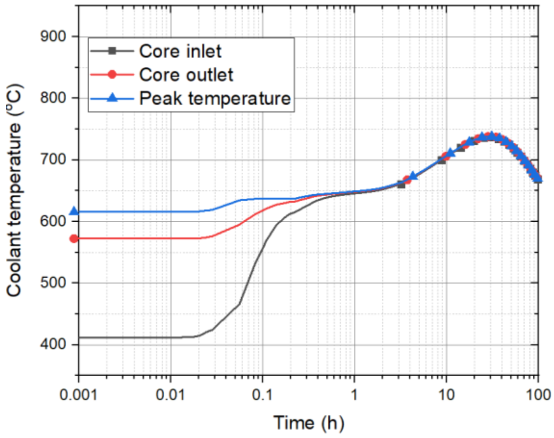

Fig. 4. Coolant temperature behavior under ULOHS scenario

3.2. Unprotected loss of flow (ULOF)

This scenario began with a stop of primary heat transfer system (PHTS) pumps and IHTS was tripped. The decrease of flow at PHTS induced an increase in fuel temperature, rapidly. It made negative reactivity and core power was decreased as shown in Fig.5. After 0.01 h, fuel temperature decreased and negative reactivity also decreased. Since 0.3 h coolant temperature increased as shown in Fig. 6 due to residual heat until 41 h. Since 41 h, the RVCS heat removal rate outtopped the core power, so the coolant temperature decreased.

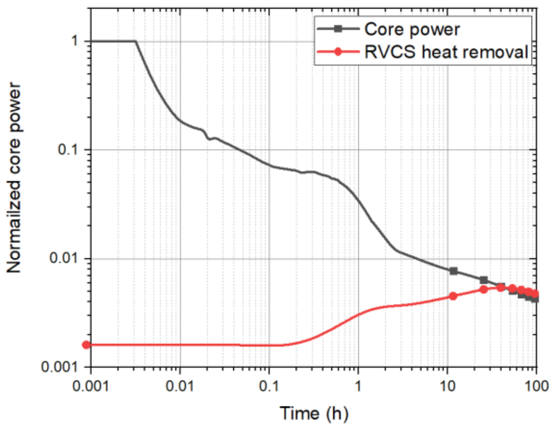

Fig. 5. Normalized power behavior under ULOF scenario

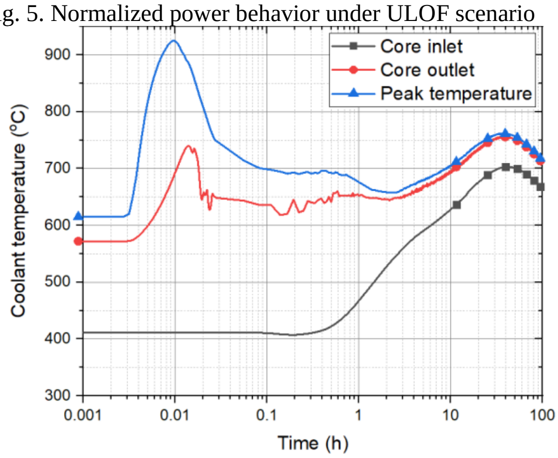

Fig. 6. Coolant temperature behavior under ULOF scenario

4. Conclusion

In this paper, transient conditions on the PGSFR were analyzed to assess whether RVCS maintained the integrity of the PGSFR. In both accidents, reactor core power could be decreased by negative reactivity. The coolant temperature increased until 31 h and 41 h under ULOHS and ULOF scenarios, respectively. And RVCS heat removal rate exceeded the reactor core power, then the coolant temperature decreased and could avoid the boiling temperature of sodium. Consequently, RVCS could prevent the core damage event which was occurred by coolant dry out.

Acknowledgments

This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP: Ministry of Science, ICT and Future Planning) (No. NRF-2017M2A8A4018582)

REFERENCES

[1] C. Choi, T. Jeong, and S. An, "Thermal-hydraulic analyses of passive reactor vault cooling system (RVCS) in PGSFR using MARS-LMR". Annals of Nuclear Energy, Vol. 117, pp. 333-342, 2018.

[2] S. Yeom, J. W. Han, S. Ryu, D. Kim, J. H. Eoh, and S. R. Choi, "Design and evaluation of reactor vault cooling system in PGSFR", Nuclear Engineering and Design, Vol. 365, 2020.

[3] J. Yoo, J. Chang, J. Y. Lim, J. S. Cheon, T. H. Lee, S. K. Kim, K. L. Lee, and H. K. Joo, "Overall system description and safety characteristics of prototype Gen IV sodium cooled fast reactor in Korea", Nuclear Engineering and Technology, Vol. 48, No. 5, pp. 1059-1070, 2016.

[4] K. M. Kim, S. T. Lim, S. H. Kim, D.-W. Jerng, and H. S. Ahn, "Pressure behavior and heat transfer behavior of air natural convection in an asymmetrically heated vertical channel with a damper". International Journal of Heat and Mass Transfer, Vol. 188, No. 122601, 2022