Sensitivity study on loss-of-forced-circulation accidents in a modular gas-cooled reactor

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1. Introduction

The GCR has inherent safety characteristics with its large heat capacity and low power density of the core when compared with conventional light water reactors. Accordingly, a temperature change in a GCR core is very slow for a transient variation of the system temperature. One of the remarkable features of the modular GCR is a possibility to remove residual heat through the reactor vessel surface to the heat sink due to natural heat transfer processes.

In the GCR system, graphite (IG-110) is used as a reflector and a core structure material. The uncertainties in the graphite material properties exist in its design and safety analysis processes. Sensitivity study on the major material properties which have an uncertainty in an LOFC accident condition and analyses on the thermal behavior of a reactor in the accident condition to assess the heat transfer characteristics are carried out.

2. Analysis method and Sensitivity studies

2.1 Analysis method

The multi-dimensional GAs Multicomponent Mixture Analysis (GAMMA+) code was adopted to analyze the thermal hydraulic characteristics in a GCR [1].

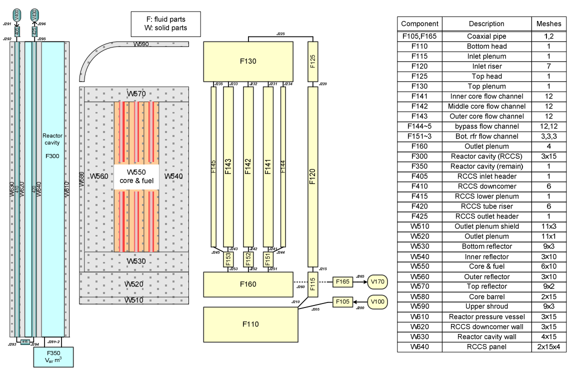


Fig. 1 Nodalization diagram of the reactor

For a safety analysis, a prismatic core gas-cooled reactor modified for the core exit helium temperature of 950° C by the Korea Atomic Energy Research Institute based on the GT-MHR design [2] was used. A model of a reactor system is presented in Figure 1. Multidimensional model is applied for a solid region and a multidimensional fuel-coupled model is adopted for core region. In the cavity region, three-dimensional model for a heat transfer between the RCCS riser and the cavity is used.

2.2 Analysis conditions

In the design basis events, the loss of a forced circulation (LOFC) accident is supposed to be one of the limiting accidents. The sequence of a pressurized and depressurized LOFC accident is summarized in Table I.

Table I. Sequence of LOFC accidents

Parameter	Reference condition	Pressurized	Depressurized
Power	600MWth	Decay curve	Decay curve
Oulet Pressure[MPa]	7.0	7.0 → 5.03 for 8 hr.	7.0 → 0.1013 for 1 sec.
Inlet flow rate[kg/s]	250	250 → 0.0 for 60 sec.	250 → 0.0 for 1 sec.
RCCS	Air-cooled Calculated (Tin,air=43℃)		
Fuel temp. limit	1600℃		
RPV temp. limit	590℃(9Cr1Mo) ASME Section III, Subsection NH [ASME, 2004]		

In the reference condition, the maximum temperature behaviors in the pressurized LOFC accident condition for 100 hours are depicted in Figure 2. The Maximum temperature behaviors in depressurized LOFC condition are similar to those in pressurized LOFC condition.

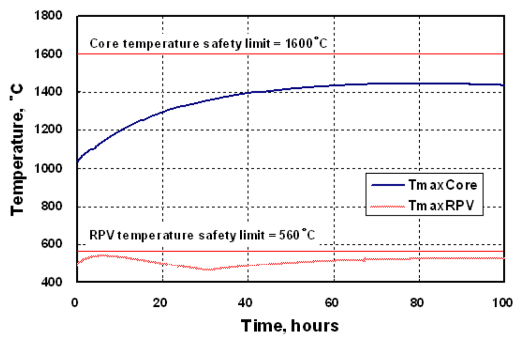


Fig. 2 Temperature behavior in pressurized LOFC

In the early phase of the accident, since the heat transferred to the RCCS is smaller than the generated heat in the core, fuel maximum temperature increases as shown in Figure 2. The maximum temperature of reactor pressure vessel (RPV) shows a temporary decline at about 10~30 hours. This is mainly attributable to change in axial temperature profile. The maximum temperature is plotted in Figure 2 solely among the superposed temperatures of RPV.

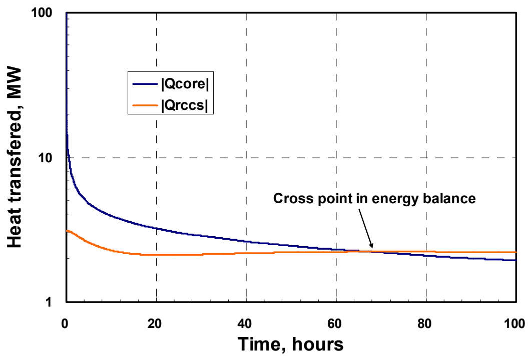


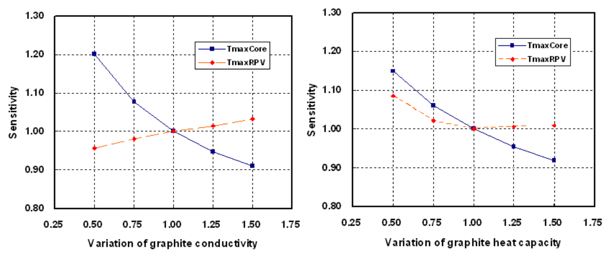
Fig. 3 Energy balance in depressurized LOFC

The energy removed by the RCCS exceeds the decay heat by about 70 hours as one can see in Figure 3 which shows the energy balance of the reactor in the depressurized LOFC.

2.2 Sensitivity analyses

With 50% ~ 150% of the graphite conductivities, the steady state conditions were calculated. The variations of the inlet helium flow rate and the heat removed through the RCCS were below 0.1% for various graphite conductivities. The variations of the volumetric heat capacity had no effect on the steady state condition of the reactor.

In pressurized LOFC accident, with the variation of the conductivity and the volumetric heat capacity, the sensitivities of the maximum fuel and RPV temperature calculated as presented in Figure 4 (a), (b).



(a) for conductivity (b) for volumetric heat capacity
Fig. 4 Sensitivities of the maximum temperature

When the volumetric heat capacities varied 50%~150%, the containable heat in the graphite varies and the variation of the temperature due to the heat flux diminishes. Because of the increase of the thermal inertia, the response time of the system to the energy change is also delayed. Therefore, the peak of the maximum temperature decreases and the time that the peak appears is delayed.

The maximum temperatures with a variation of 50%~150% of the conductivity are shown in Figure 6. By increasing the thermal conductivity of the graphite, the radial heat transfer from the reactor core to the reactor pressure vessel and finally to the RCCS increases. As a consequence, the maximum temperature of reactor decreases and the maximum temperature of reactor pressure vessel increases.

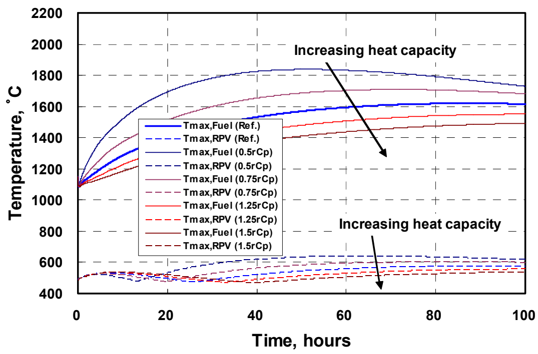


Fig. 5 Maximum temperature characteristics in varying volumetric heat capacity

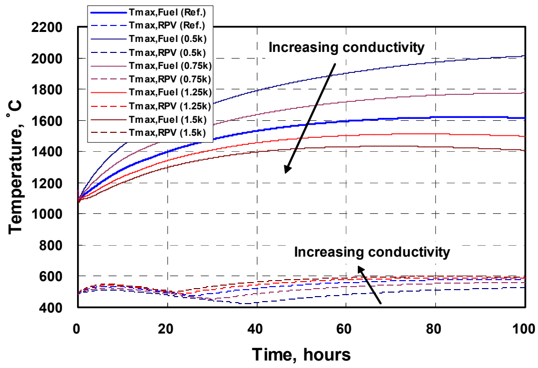


Fig. 6 Maximum temperature characteristics in varying thermal conductivity

The sensitivity of the fuel and RPV maximum temperature in 100 hours were summarized in Table II for the pressurized and depressurized LOFC conditions.

Table II. Summary of sensitivity calculation

	Pressurized LOFC				Depressurized LOFC			
	Conductivity		Volumetric heat capacity		Conductivity		Volumetric heat capacity	
	-50%	+50%	-50%	+50%	-50%	+50%	-50%	+50%
TmaxCore	20.1%	-9.0%	14.9%	-8.1%	24.3%	-11.5%	13.5%	-7.8%
TmaxRPV	-4.3%	3.2%	8.6%	0.9%	-9.1%	3.2%	10.6%	-6.9%

3. Conclusions

Sensitivity study on the material properties which have uncertainty in LOFC accident condition was carried out. Generally, the uncertainty has no impact on the normal operating condition of the reactor design. The sensitivity was up to 24% for the fuel maximum temperature and 9% for the pressure vessel maximum temperature for ± 50% variation of graphite thermal conductivity. In variation of graphite volumetric heat capacity, similar ranges of sensitivities of maximum temperature were calculated.

REFERENCES

[1] H.S. Lim and H.C. No, Transient multicomponent mixture analysis based on ICE numerical scheme for predicting an air ingress phenomena in an HTGR, NURETH-10, Seoul, Korea, October 5-9, 2003

[2] General Atomics, GT-MHR Conceptual Design Description Report, GA/NRC-337-02, 2002