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MELCOR Simulation on Steady-State and D-LOFC of HTGR with RCCS

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1. Introduction

High Temperature Gas-Cooled Reactor (HTGR) is one of Generation-IV reactor concept which is being developed to generate high temperature heat for other industrial processes and hydrogen production. Since one of the most important requirements for HTGR is passive safety, most HTGR designs typically use passive reactor cavity cooling system (RCCS) designed to remove all the core afterheat without the use of any active safety systems during all postulated accidents (see Fig. 1).

On the researches of the HTGR licensing technologies in Korea Institute of Nuclear Safety (KINS), MELCOR code[1] is under consideration as a safety evaluation tool for HTGR, which is used for thermal-fluid and accident analysis, including fission products transport release. The latest version of this code, MELCOR 2.1 has been modified for the Next Generation Nuclear Plant (NGNP) by the U.S. Nuclear Regulatory Commission (NRC).

In this study, the MELCOR 2.1 input model of HTGR with RCCS was developed for the design of 600 MWth HTGR which is based on General Atomics' Gas Turbine-Modular Helium Reactor (GT-MHR) to assess the ability of MELCOR to predict the RCCS performance. The characteristics of HTGR were modeled including conduction and radiation heat transfer in RCCS. The normal operation and depressurization accident conditions were analyzed using the developed input model to evaluate the applicability of MELCOR code in HTGR with RCCS.

2. MELCOR modeling for HTGR with RCCS

Figure 2 shows the MELCOR input model for HTGR with RCCS.

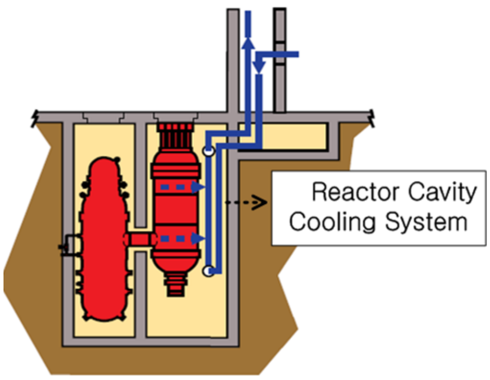

Fig. 1. Schematic of HTGR with RCCS

Fig. 2. MELCOR nodalization for HTGR with RCCS

2.1 Development of Reactor Core Model

The core model of HTGR is based on 'PMR600' input deck provided by NRC. MELCOR 2.1 was mainly updated on core package (COR) to be applied to HTGR. Fuel element in COR represents the fuel compact while cladding element does graphite block. The reactor core is composed of inner reflector, three rings of active core and outer reflector in radial direction while it is composed of upper reflector, active core and lower reflector in axial direction. Tanaka-Chisaka model is used as the heat transfer model considering conduction and radiation of blocks including the effects of the coolant channels and fuel compacts.

2.2 Development of RCCS Model

The RCCS model was developed by Zhen [2] originally. Reactor cavity is divided into two parts by hot riser of RCCS. One part is up-flow region where the air is directly heated by RPV and flows upward. The other is down-flow region where the heated air flows downward between hot riser and downcomer of RCCS. Riser of RCCS and inner/outer cavity around the hot riser are modelled as control volume (CV) for natural circulation and convection of air. Inner/outer surface of riser panel and inner panel of downcomer of RCCS are modelled as heat structure (HS).

3. MELCOR Simulation on HTGR with RCCS

3.1 Steady State Simulation

The analysis results of MELCOR code at normal operation showed accurate prediction capability of the design values of HTGR as shown in Table I. The core conditions including temperature, coolant flow rate and pressure drop are similar to the actual design values. In particular, the maximum fuel and graphite temperature agreed well so that the material property and heat balance were analyzed precisely in normal operation.

The heat removal via RCCS was also predicted well as represented in Table I. Heat removal rate and flow rate of RCCS are calculated with high accuracy. From the simulation results representing accurate prediction capability of heat removal function of RCCS, it is likely to possibly calculate the accident condition using MELCOR code when the heat removal function of RCCS is more important.

3.2 D-LOFC Simulation

Depressurized-loss of forced cooling (D-LOFC) condition is considered to be a limiting event for HTGR which could lead to the highest maximum fuel temperature. In this study, double-ended break of cross vessel was assumed for the D-LOFC simulation. As soon as the accident occurs, both heat exchanger and compressor in power conversion system failed to operate and reactor shut down automatically.

Figure 3 shows the simulation results on D-LOFC of HTGR. The maximum fuel temperature is predicted to be much higher than 1,600 °C above which fuel failure occurs significantly to lead to considerable fission product release. The response time of core temperature is so rapid considering the graphite heat capacity. The analysed temperature of graphite was not reasonable as well considering its heat capacity. These results were completely different from what was expected by normal operation analysis results. These results might be caused by the heat removal capacity of RCCS (see Fig. 4).

Table I: Steady-State Calculation Results

	Design Value		MELCOR
RPV	–		–
Reactor Power (MWt)	600		600
Coolant Flow Rate (kg/s)	320		317
Helium Inlet Temp. (℃)	491 ℃	764 K	765 K
Helium Outlet Temp. (℃)	850 ℃	1123 K	1128 K
Helium Inlet Pressure (bar)	69.728		70.4
Core Pressure Drop (bar)	0.503		0.5
Max. Fuel Temp. (℃)	1218 ℃	1491 K	1527 K
Max. Graphite Temp. (℃)	1142 ℃	1415 K	1448 K
RPV Inside Wall Temp. (℃)	485 ℃	758 K	763 K
Avg. Outside Wall Temp. (℃)	446 ℃	719 K	717 K
RCCS	–		–
Removal Heat (MW)	3.3		–
Riser Air Flow Rate (kg/s)	14.3		14.34
Riser Air Inlet Temp. (℃)	43 ℃	316 K	316 K
Riser Air Outlet Temp. (℃)	274 ℃	547 K	546 K

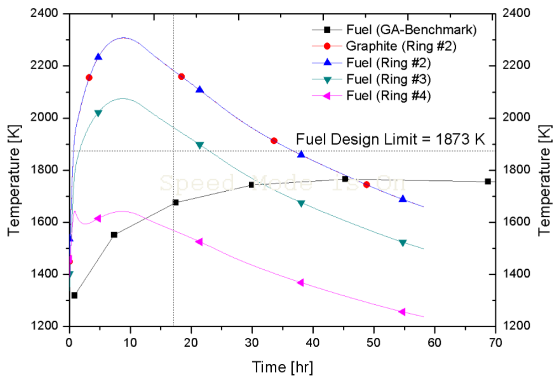

Fig. 3. Simulation results on D-LOFC of HTGR

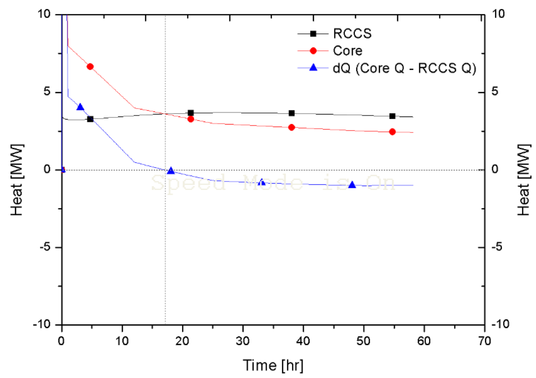

Fig. 4. Comparison of generation heat and removal heat

Therefore, it is necessary to perform further studies for the resolution of these problems. The sensitivities of core afterheat and thermal properties of graphite and fuel including heat capacity and thermal conductivity, the heat removal capacity of RCCS and so on shall be assessed.

3. Conclusions

In order to evaluate the applicability of MELCOR code in HTGR with RCCS, the HTGR input model was developed and the normal and depressurization accident conditions were simulated. Unlike the steady-state results, MELCOR did not predict the D-LOFC results well. It is found that further studies are necessary to improve the results of D-LOFC accident.

ACKNOWLEDGMENTS

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