GAMMA Validation with the HTTR RCCS Mockup Test for the Assessment of Decay Heat Removal of GCRs under Accident Conditions

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1. Introduction

The GAMMA (multi-dimensional GAs Multi-component Mixture Analysis) code developed to analyze the thermal-hydraulic transients as well as chemical reactions during an air ingress accident in an HTGR, is applied to the assessment of the heat removal characteristics in the reactor cavity cooling system (RCCS) which performs the passive safe function to remove the afterheat under accident conditions. We chose the JAERI's HTTR RCCS mockup test selected as one of benchmark problems in IAEA CRP on "Heat Transport and Afterheat Removal for GCRs under Accident Conditions." [1]

2. Test Facility and Simulation Results

2.1 HTTR RCCS Mockup

As shown at Fig. 1, the test facility consists of a pressure vessel (P.V.) with 1 m in diameter and 3 m high, a heater block with 0.6 m in diameter and 2 m high simulating decay heat, the tube-type three cooling panels surrounding the P.V., and the cavity wall with 2 m in diameter and 4 m high occupied by air at the atmospheric pressure. Table 1 shows all the tests conducted with different kinds of fluids in a P.V. (vacuum, He, or N_2) and cooling panels (air or water), total heating powers, axial power shapes, and P.V. top head with/without the stand pipes simulating the control element driving assembles.

Table 1. Experimental Cases Simulated

Test Cases	1	2	3	4	5	6	7
Item of gas	Vacuum	He	N2	He	He	He	He
Pressure, MPa	1.3e-6	0.73	1.1	0.47	0.64	0.96	0.98
Heat input, kW	13.14	28.79	93.93	77.54	29.71	2.58	7.99
Heater segment, kW							
No. 1	1.01	1.16	5.90	5.63	1.80	0	0
No. 2	2.31	3.11	16.05	19.60	5.23	0	0
No. 3	2.64	3.52	19.88	21.59	5.68	0	0
No. 4	2.46	5.10	22.24	22.70	11.26	0	0
No. 5	3.76	10.42	22.13	0	0	0	0
No. 6	0.96	5.49	7.72	8.00	5.74	2.58	7.99
Cooling panel	Water	Water	Water	Water	Air	Air	Air
Stand pipes	No	No	No	With	With	With	With

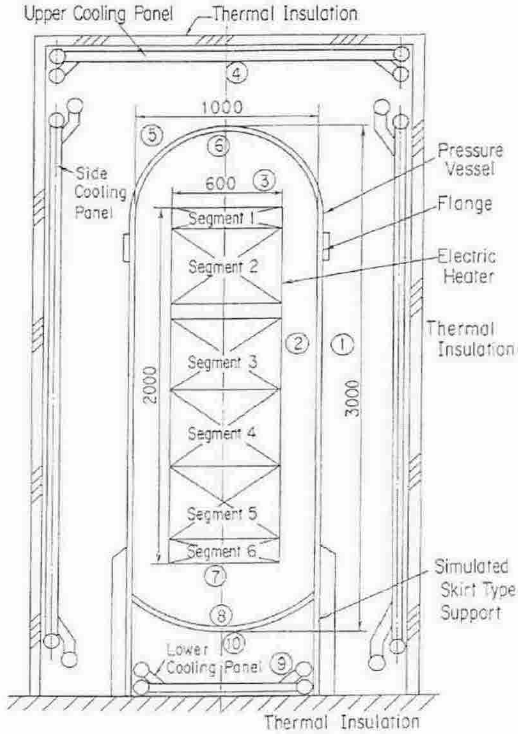

Figure 1. Schematic of HTTR RCCS mockup

2.2 Simulation Method

We used the axi-symmetric mesh layout by assuming the rotational symmetry of the apparatus and considered the radiation heat transfer in each enclosure by using the irradiation/radiosity method [2] for the gray and diffuse surface. Since the heat removal contribution by natural convection is not negligible, proper correlations are selected and applied to specific surface types: Thomas and de Vahl Davis's correlation [3] for the annular cavities between the outside surface of the heater and the inside surface of the P.V. and between the outside surface of the P.V. and the inside surface of the cavity wall, Fishenden and Saunders's correlation [4] at the bottom and top surfaces of the heaters and at the bottom and top head surfaces of the P.V., Churchill and Chu's correlation [4] for the outside of the cooling panel tubes, and an assumed value of $Nu=10$ for the P.V. flange. For the simulation, the temperature distribution of cooling panels is used as a boundary condition.

2.3 Simulation Results

Figure 2 shows the calculated surface temperature profiles for one representative case (vacuum in a P.V.). The temperatures of the pressure vessel are well predicted, demonstrating that the GAMMA code can be used to evaluate the hot spots on the P.V. and heat removal by thermal radiation and natural convection.

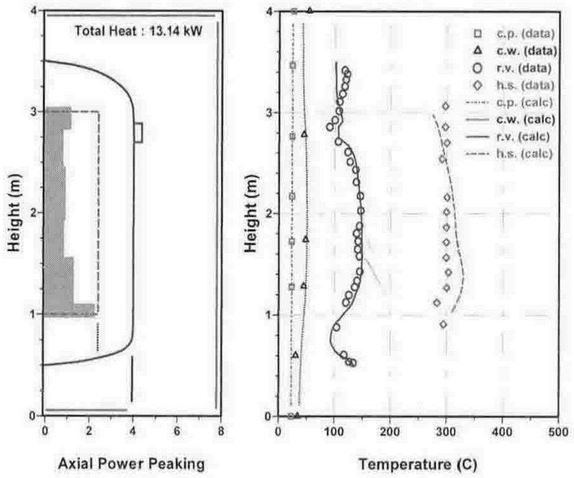

Figure 2. Calculated results of surface temperature profiles of heater, P.V., and cavity wall for the vacuum case 1

Figure 3 shows the relative contribution of thermal radiation to total heat removed from the outside of the pressure vessel. The calculated ratio of heat transferred by thermal radiation to the total heat input is about 68%-97%, comparable to that of the other analysis codes. It has been observed that radiation heat increases with the increase in temperature and pressure. The GAMMA code predicts well the heat removal by free convection while some of other analysis codes slightly underestimate it.

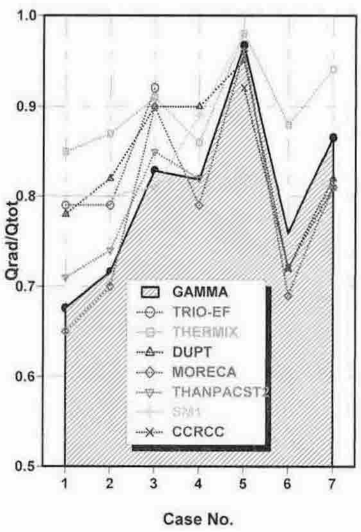

Figure 3. Calculated relative contributions of thermal radiation to total heat removal for all the test cases

3. Conclusion

The GAMMA simulation results for the HTTR RCCS mockup tests show good predictions, comparable to those of other analysis codes. Radiation heat occupies over 70% of the total heat removed from the outside of the pressure vessel and therefore acts as a major role for decay heat removal under accident conditions. As well, the heat removal characteristics by natural convection in both the inner cavity and the reactor cavity are well described, using the existing convective heat transfer correlations.

REFERENCES

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[4] F. P. Incropera, D. P. DeWitt, Fundamentals of Heat and Mass Transfer, John Wiley & Sons, New York, 2003.