Heat transfer characteristics in depressurized LOFC accidents with a failure of the RCCS in a modular gas-cooled reactor

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1. Introduction

A modular gas-cooled reactor has inherent safety characteristics with its large heat capacity and low power density of the core when compared with conventional light water reactors. The reactor cavity cooling system (RCCS) serves as an ultimate heat sink in a high temperature gas-cooled reactor and is a system for the removal of the decay and residual heat from the uninsulated reactor vessel to ensure a plant safety. To understand the inherent safety features of the designed reactor, analyses for the RCCS performance in various severe accident conditions are required. A depressurized loss of forced circulation (LOFC) accident was considered as an initiating condition. To investigate the safety characteristics of a GCR under the one of the worst accidental scenarios, a simultaneous failure of the RCCS is considered in this study.

2. Characteristics of heat transfer

2.1 Analysis condition and method

A prismatic core gas-cooled reactor with the core exit helium temperature of 950° C was used in the analysis [1] and the multi-dimensional GAs Multicomponent Mixture Analysis (GAMMA+) code was adopted to analyze the thermal hydraulic characteristics in a GCR [2]. In the specified axial power distribution and the sequence of depressurized LOFC accident, the decay heat generated by the fuel is partially removed by a natural circulation of the primary helium and most of the heat is transferred to the RCCS through the reactor vessel [3].

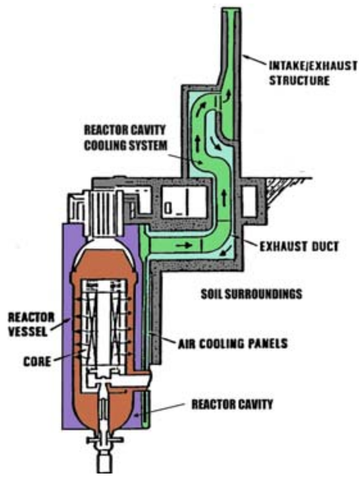


Fig. 1 Schematic of modular gas-cooled reactor

2.2 Analysis results

In the present postulated accident sequences, it is assumed that the RCCS is not available due to the total blockage of RCCS duct. Under such conditions, the heat from the reactor vessel walls would be transferred through the inoperable RCCS panels to the concrete structure and finally to the earth surrounding it. In this study, safety margin and transient thermal behaviors of the reactor design in the RCCS failure condition will be analyzed. During the depressurized LOFC accident with an RCCS failure condition, the maximum temperature of the reactor and the pressure vessel continually increase as shown in Figure 2.

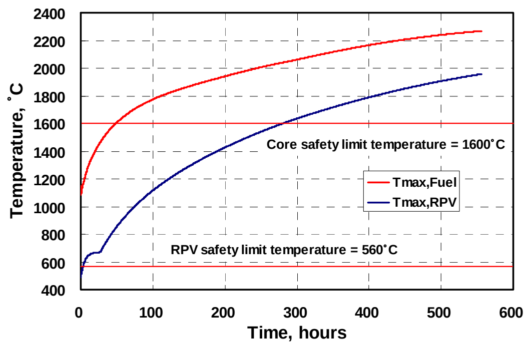


Fig. 2 Maximum temperatures in depressurized LOFC with RCCS failure

Without the heat removal process by the RCCS, the residual heat which is accumulated in the high heat capacity graphite material in the core in the early phase of an accident is slowly transferred to the cavity, concrete and soil.

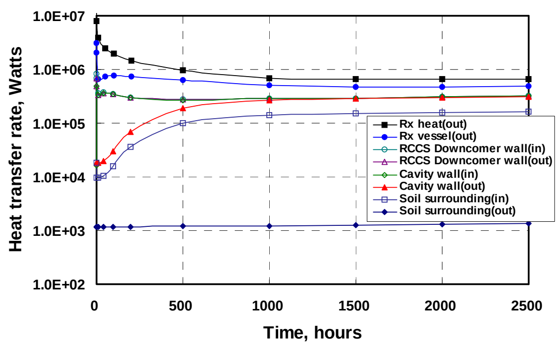


Fig. 3 Heat transfer characteristics in depressurized LOFC with RCCS failure without insulation

To assess the heat transfer characteristics of the cavity region and to investigate the options for a design improvement, transient analyses for the case that the insulation on the cavity wall is removed were carried out. The gap between the heat transfer rate from the reactor vessel and the heat removed through the outer boundary of the soil surroundings is about an order of 10^3. The heat proportional to the energy gap is accumulated in the reactor system as presented in Figure 3.

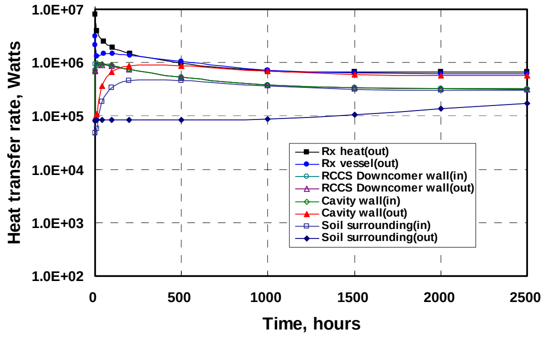
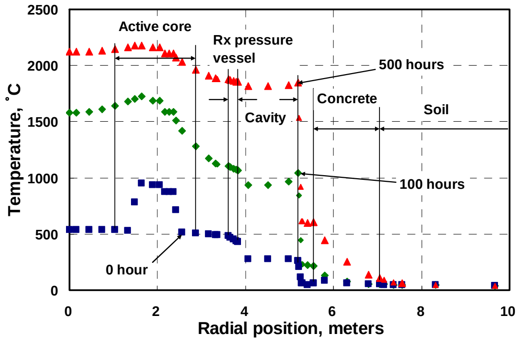


Fig. 4 Heat transfer characteristics in depressurized LOFC with RCCS failure without insulation and with large conductivity for soil and concrete

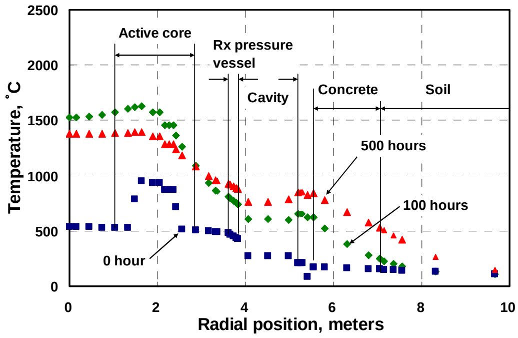
To analyze the sensitivity of the properties of the concrete and soil, extremely large thermal conductivities for the concrete and soil were applied. Using 10 times of thermal conductivities, heat transfer characteristics in was investigated.

The maximum fuel temperature starts to decrease after 100 hours due to the considerable increase of the radial heat transfer to the soil surroundings. In Figure 4, the gap between the heat transfer rate from the reactor vessel and the heat removed through outer boundary of soil surroundings decreased remarkably due to an improvement of the radial heat transfer. The heat transfer resistance of radiation in cavity and the soil conductivity itself were dominant factors which restrict the radial heat transfer in the accident conditions.

The temporal radial temperatures are compared with each other, one can note the heat transfer characteristics of the concrete and soil region. In the reference condition that the insulation on the downcomer wall exists, a sharp temperature drop in the radial direction at the insulation material region was calculated. The heat generated in the core did not effectively removed in the depressurized LOFC with RCCS failure condition as shown in Figure 5(a). With 10 times of thermal conductivities for the concrete and soil, the radial temperature profiles are depicted in Figure 5(b). The heat transfer in the radial direction in the concrete and soil region is improved significantly. However, the reactor vessel temperature exceeds its safety limit. By improving the radial heat transfer, the overheating of the core region could be settled. Nevertheless, the excess of the temperature safety limit in the reactor pressure vessel can not be removed with the extremely large thermal conductivities for the concrete and soil. Also, with a large volume and high heat capacity in the concrete and soil, the response of the sensible heat is slow, so the momentary overheating of the core region could not be accommodated.



(a) Reference condition



(b) Without insulation and with large thermal conductivity for soil and concrete

Fig. 5 Radial temperature distribution

3. Conclusions

The understandings on the heat transfer characteristics of the GCR under the postulated accident conditions are obtained through the analyses. A possible alternate heat transfer mechanism rather than the conduction heat transfer in the outer region of the RCCS and suggestion of design improvement to mitigate accident consequences need to be investigated in the future based on the understandings of the heat transfer characteristics of GCR during the postulated accident condition to improve the inherent safety of a GCR.

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