Safety Issues of VHTR RCCS Design

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1. Introduction

The concept of passive safety is emphasized in VHTR (Very High Temperature Reactor) to accomplish the enhanced safety goal of future reactors compared to the reactors of previous generation. The Reactor Cavity Cooling System (RCCS) is the passive safety system in VHTR designed to remove the residual and decay heat. Large thermal margin, low power density and core configuration with large heat transfer surface in VHTR make passive cooling effective. In addition, RCCS in VHTR is the only safety-related system which should have a high reliability.

Therefore, it is important to study the design characteristics of RCCS and derive safety issues to assure the passive safety of VHTR. In this paper, several safety issues related with RCCS in VHTR were identified and reviewed.

2. Design Characteristics of RCCS

In this section, the general design characteristics such as structure and operational principles of RCCS are described. In this study, the air-cooled RCCS which is chosen as the candidate system for NGNP program is considered rather than the water-cooled RCCS.

2.1 Structure of RCCS

The overall design of air-cooled RCCS is shown in Figure 1. RCCS located between reactor cavity and reactor building is composed of downcomer and hot riser.

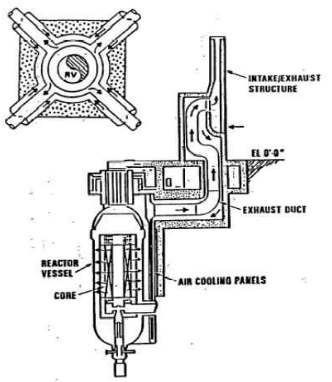

Fig.1 Schematics of air-cooled RCCS

The downcomer is the flow path of the air incoming from the environment while the hot riser is that of the air outgoing to the environment to remove the decay heat from core. Rectangular outlet ducts are linked to the end of the downcomer and the hot riser which are directly exposed to the environment. RCCS is composed of four pairs of inlet/outlet ports. Consequently, RCCS could perform the function even though several ports of that are damaged not to function.

2.2 Operational Principle of RCCS

Uninsulated steel is used as the material of Reactor Pressure Vessel (RPV) of VHTR to provide decay heat removal path from core to cavity when the Heat Transport System (HTS) or Shutdown Cooling System (SCS) are not available during accident conditions. In such events, decay heat is removed by conduction through graphite structure, radiation and convection through the uninsulated vessel. Decay heat is removed passively in this way although the loss of thermal efficiency is caused by the uninsulated vessel in normal operation.

The temperature of air in the region close to RPV in cavity remains high due to the heat released from RPV. The air in the cavity at high temperature transfers the heat to cooling panel of hot riser. Consequently, the air in the hot riser of which temperature gets higher and density decreases moves upward because of the buoyancy force. To supplement the vacant volume of air with high temperature and low density, the air in the downcomer moves to the hot riser. The natural circulation in RCCS occurs continuously by the procedure described above.

3. Safety Issues of RCCS Design

In this section, the safety issues to assure the function of RCCS as an ultimate heat sink in VHTR were derived from the design characteristics of RCCS from regulatory aspect.

3.1 Heat Transport Design

<u>*3.1.1 Heat Transport within the Vessel*</u>

The dominant factors affecting on the maximum fuel and vessel temperature in especially D-LOFC (Depressurized-Loss of Forced Cooling) condition are decay heat and effective thermal conductivity. Therefore, the thermal conductivities of fuel and reflector regions and decay heat curve shall be reliably confirmed. Furthermore, additional margin shall be determined added to decay heat and conductivity predicted reliably.

In addition, the insulation on vessel head could lead to vessel hot spots especially in P-LOFC (Pressurized-Loss of Forced Cooling) condition. Thus reliable data and analytical models and assumptions on the effect of insulation on the temperature of upper head shall be provided.

3.1.2 Heat Transport External to the Vessel

About 90% of the heat directed from vessel to the hot riser panel is transported through radiation. Thus the effective thermal emissivity of vessel and panel which plays an important role in overall heat transfer should be precisely predicted. In this point of view, the effect of coating and painting of surface and surface temperature should be investigated which would affect the emissivity dominantly.

The presence of water vapor caused by the rupture of pipes in reactor cavity in which water flows could lead to the reduction of radiant heat transfer. Especially, water vapor had more influence on the temperature increase of vessel rather than that of fuel [3]. Therefore, it shall be taken into consideration with long-term D-LOFC condition when the integrity of vessel could be deteriorated.

In addition, the downcomer of RCCS shall not be preheated for efficient heat transfer from core to riser. In order to prevent the heat transfer from the hot riser to the downcomer, inner side of downcomer is insulated. However, the insulation shall be optimized as that could have an adverse effect on the ultimate heat transfer to the soil in case of total failure of RCCS.

3.2 Structural Design

The inlet and outlet of the flow path in RCCS shall not be physically blocked and shall be protected by external effects.

The screens are installed in inlet and outlet of rectangular duct to prohibit the access of obstacles to the flow path of RCCS such as birds and wind-borne debris, etc. However, the pressure drop through the screen could have an adverse influence on the effective natural convection. Thus, parameter variation analysis shall be performed to quantitatively obtain the interrelation between the form loss through the screen at inlet and outlet duct and natural circulation in downcomer and hot riser. In this process, optimized design of the screens or the methods to maintain the flow path shall be considered.

In order to assure the residual heat removal function of RCCS, it should be designed to prevent CCF (Common Cause Failure) of natural circulation in RCCS and to protect sabotage. In addition, RCCS shall be designed to maintain its integrity at high temperature environment.

3.3 Considerations of Inspection and Repair

Since we are lack of operating experience of RCCS, an adequate ISI (In-Service Inspection) program shall be established. In the ISI program, disassembly of the RCCS should be taken into account.

In addition, assuming all of HTS, SCS and RCCS are not working, the time available for RCCS repair should be obtained with reliance.

4. Conclusions

The RCCS is considered as the only safety-grade decay heat removal system of VHTR. The key safety issues related to the RCCS design were identified and reviewed. Passive safety in the VHTR is strongly dependent on the thermal performance of the RCCS. Structural integrity, inspection and maintenance are also critical for a reliable functioning of the system. These safety issues related to RCCS should be resolved through the demonstration of the reliability of the RCCS and further research and evaluation are in need.

REFERENCES

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