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Development of Optimized Reactor Insulator for Severe Accident Mitigation of APR1400

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1. Introduction

APR1400, a Korean evolutionary advance light water reactor, has many advanced safety feature to prevent and mitigate of design basis accident (DBA) and severe accident and to improve its safety. To mitigate the harm following severe accident and core melting, APR1400 adopts IVR-ERVC (In-Vessel corium Retention using Ex-Reactor Vessel Cooling) strategy [1]. The Severe Accident Management strategy for APR1400 is intended to aid the plant operating staff to secure reactor vessel integrity in the early stage of the severe accident [2]. As a part of a design project of ERVC system for APR1400, we developed the detailed design of reactor insulator, ingression device and venting device..

2. Design of ERVC System for APR1400

When reactor cooling system (RCS) fails to cooling its core, the core melted down and the molten core gathers together on bottom of reactor vessel. The molten core hurts reactor vessel and is released to containment, which raises the release of radioactive isotopes and the heating of the containment atmosphere. Finally, the corium is accumulated in the bottom of reactor cavity and it also raises the Molten Core and Concrete Interaction (MCCI) and the heating of containment atmosphere.

There are two strategies to cooling molten core. Those are in-vessel retention and ex-vessel cooling. At the early stage of APR1400 design, only ex-vessel cooling which is cooling of the molten core outside the vessel after vessel failure is considered based on EPRI Utility Requirement Document (URD) for Evolutionary LWR. However, a need has been arisen to reflect current research findings on severe accident phenomena and mitigation technologies to Korean URD and IVR-ERVC was adopted to APR1400. The ERVC is not considered as a licensing design basis but based on the defense-in-depth principle and safety margin basis, which is the top-tier requirement of the severe accident mitigation design as stated in the KURD.

The ERVC is implemented to APR1400 as a severe accident mitigation system used for the purpose of in-vessel retention under hypothetical severe accident conditions. The ERVC is a function of submerging exterior surface of the reactor vessel under core-melting condition in order to prevent or delay reactor vessel melt-through by removing decay power inside reactor vessel.

For the success of IVR-ERVC strategy, the RCS should be depressurized sufficiently, cooling water should be supplied to reactor cavity and flow path for the cooling water and steam must be secured.

3. Development of Reactor Insulator for ERVC

3.1 Insulator design

The insulation system is the device designed to minimize heat loss from the Reactor Vessel (RV), to minimize the heat load on the reactor cavity cooling system, and to limit temperatures in the reactor cavity concrete, the ex-core neutron flux monitors and the neutron shielding. During severe accident involving reactor flooding, the insulation system will provide a specified annulus with the outer surface of the reactor vessel and allow water in the reactor cavity to enter the bottom of the annulus for cooling of the reactor vessel. It also allows the free discharge of steam from the top of the annulus. Free convection of air to and from this annulus is inhibited during normal operation.

Figure 1 shows schematic diagram of APR1400 reactor insulation system for ERVC operation. The insulation system includes passive water ingression device and passive steam/water venting device. Water in the reactor cavity enters the space between the insulation and the reactor vessel external wall through the water ingression device at the bottom of the reactor insulation.

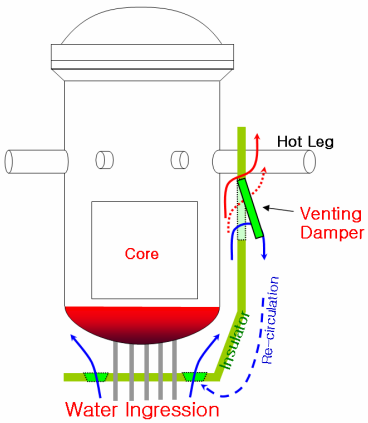

Figure 1. Schematic diagram of APR1400 Reactor Insulation system

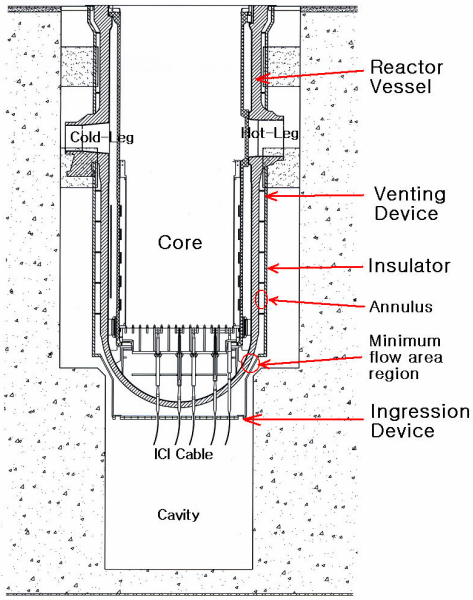

Figure 2. Reactor insulation system for ERVC system

Near the top of the lower insulation segment, there are steam/water venting ducts that provide a flow path for the steam and water within the reactor vessel and insulation annular space to flow back to the reactor cavity. It makes recirculation circuit as shown in Figure 1.

Figure 2 shows the reactor vessel insulation system for ERVC system of APR1400. The insulator and supporters are designed to withstand the static and dynamic pressure differential across the reactor vessel insulation panels caused by the flooding of reactor cavity and boiling of coolant inside insulator. It guarantees that the flow areas near the shear keys satisfy criteria on minimum flow area.

The total flow areas of ingression and venting devices are designed to enlarge within the limits of possibility for a natural circulation cooling performance. Figure 3 shows the bottom view of the insulation system. Since ICI cables are located at the bottom of APR1400 reactor vessel and it is difficult to locate a device on the center region of bottom panel, the ingression devices are located on the outside of ICI cable. Nevertheless some

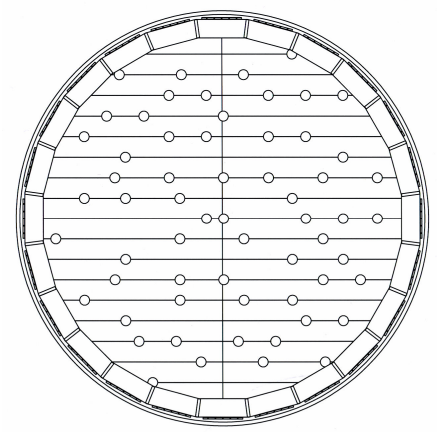

Figure 3. Arrangement of ingression device

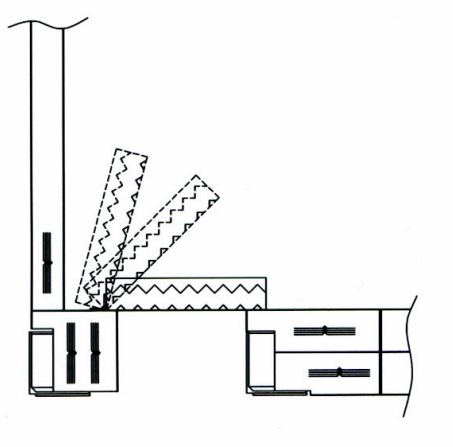

Figure 4. Passive ingression device

ingression can be placed between ICI cables to improve coolant flow abound the bottom of rector vessel and increase the critical heat flux.

Figure 4 shows the passive ingression device located on the bottom panel of insulation system. The ingression device is passively opened if the reactor cavity should flood with water. The venting device is passively opened by pressure difference. Each device is designed normally closed to prevent an air circulation path through the RV.

4. Conclusions and Further Studies

We accomplished the preliminary design of optimized reactor insulator for APR1400 to provide the external reactor vessel cooling for severe accident mitigation. It includes the water ingression device, steam/water venting device and insulator itself which provides cooling flow path during ERVC operation. We will prove the performance of the ERVC system by making experiments on natural circulation cooling, critical heat flux and metal-layer heat concentration.

REFERENCES

[1] "APR1400 Standard Safety Analysis Report", KHNP, 2001

[2] J. W. Park and S.J.OH, Design for the In-Vessel Core Melt Retention and the Overall Severe Accident Management Strategy of the APR1400, Proc. Of ICAPP 05, Seoul, KOREA, May 15-19, 2005.