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Preliminary Design 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. 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 (In-Vessel corium Retention using Ex-Reactor Vessel Cooling) was adopted 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 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 implementation of IVR-ERVC for APR1400, we developed the preliminary design requirement, design specification and conceptual design.

2. Design of ERVC System for APR1400

The ERVC is implemented to APR1400 as a severe accident mitigation used for the purpose of ERVC under hypothetical core-melting severe accident conditions. The ERVC is a function of submerging exterior surface of the reactor vessel under hypothetical severe accident 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 between the reactor vessel and insulator must be secured.

2.1 APR1400 Design

The design parameters and analysis results which are concerned with ERVC system for APR1400 design are summarized in Table 1.

Table 1 Design parameters of APR1400

Item	Value
Thermal power [MWth]	4000
Core Damage Frequency [/RY]	less the 10^{-5}
Contmt. Failure Frequency [/RY]	less the 10^{-6}
Design Life [yr]	60
Total mass of molten core [ton]	201.56 (est.)
Height of oxidic pool [m]	1.58 (est.)
Height of metallic layer [m]	0.52 (est.)

2.2 Cooling Water Supply

For ERVC, related valves, pipes and instrumentation & control (I&C) was designed in accordance with the requirement described in the following sentence. One train of existing shutdown cooling part is used for flooding reactor cavity upto a designated level and one boric acid makeup part is used for refilling the reactor cavity at a designated flow rate. The minimum flow rates of Shutdown Cooling Pump (SCP) and Boric Acid Makeup Pump (BAMP) are 5000 gpm and 170 gpm, respectively, not including bypass flows. The water source for ERVC is In-containment Refueling Water Storage Tank (IRWST). The IRWST is one of the significant design features introduced in APR1400. The basic design feature of the ERVC system for APR1400 is schematically shown in figure 1.

The shutdown cooling part for ERVC is only manually started by MCR operators of field operators after core exit thermocouple (CET) temperature exceeds 1200 ˚F with allowance of Technical Support Center (TSC) and is operated until the reactor cavity level reaches a designated level for ERVC operation. The BAMP is manually started after water level reaches the ERVC operation level, at which the operation of SCP is terminated.

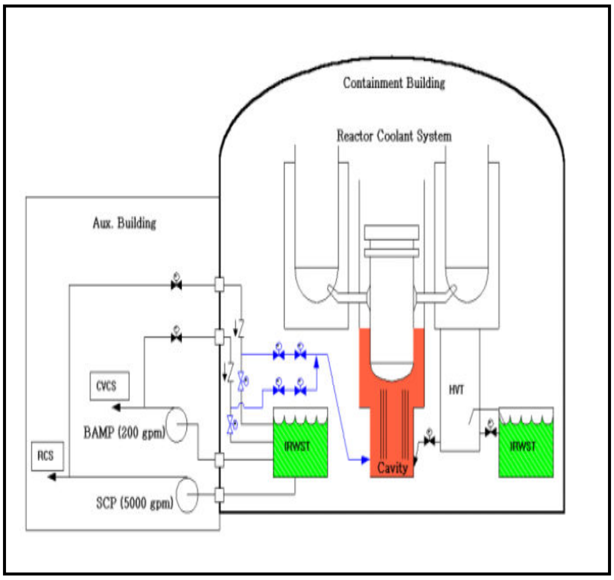

Figure 1 Systematic diagram of ERVC system.

The BAMP is assumed to operate continuously after in-service under severe accident condition if and only if the containment condition meets the design basis of CVCS. The reactor cavity water level and water temperature are measured.

2.3 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 2 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. 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 2.

The total flow areas of ingression and venting devices are designed to enlarge within the limits of possibility for a natural circulation cooling performance. Each device is designed normally closed to prevent an air circulation path through the RV. The ingression device should be passively opened if the reactor cavity is flooded with water. The venting device is passively opened by pressure difference.

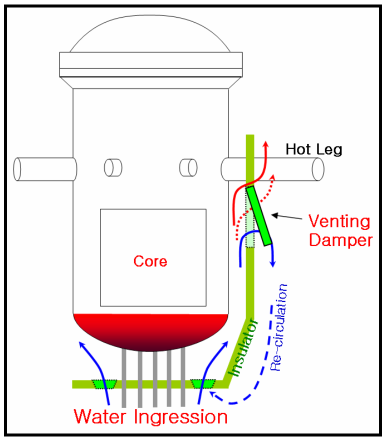

Figure 2 Schematic diagram of APR1400 Reactor Insulation system

The insulation system and its supports is designed to withstand bounding pressure differential across the reactor vessel insulation panels during the period that the reactor vessel is externally flooded with water and the core heat is removed from the vessel wall by water and generated steam is vented.

3. 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.

In the near future, we will prove the performance of the reactor insulation by experiments and analyses of natural circulation cooling, critical heat flux, metal-layer heat concentration, etc.

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.