Severe Accident Mitigation Strategy for Prevention of Reactor Vessel Failure in SMART100

Rae-Joon Park*, Donggun Son, Hyung Seok Kang
Korea Atomic Energy Research Institute, 989-111, Daedeok-daero, Yuseong-gu, Daejeon, 34057, Republic of Korea
**Corresponding author: rjpark@kaeri.re.kr*

1. Introduction

The Korean integral reactor of SMART (System-integrated Modular Advanced ReacTor) has been developed, which contains core, reactor coolant pumps, steam generators and pressurizer within a single reactor pressure vessel. For the safety enhancement, SMART has the design characteristics of adopting the inherent and passive safety, simplified safety system, and advanced man-machine interface. For the economic enhancement, SMART has the design characteristics of applying the system simplification and the component modularization. For the operation enhancement, SMART design considers the simplified operation strategy and convenient maintenance. The nominal thermal power of SMART is 365 MW. The main severe accident management technology to improve the SMART safety include reactor cavity flooding using the cavity flooding system with the IRWST (In-containment Refueling Water Storage Tank) for IVR-ERVC (In-Vessel corium Retention through External Reactor Vessel Cooling) to prevent the reactor vessel failure [1].

2. Description of SMART for IVR-ERVC

Figure 1 shows the conceptual diagram of SMART for IVR-ERVC. The operator conducts the ERVC to prevent the reactor vessel failure at 30 minutes later when the coolant temperature that passes through the core outlet exceeds 650 ℃, which is the condition to enter the severe accident management guideline (SAMG) from the emergency operation procedure (EOP) in SMART. For ERVC, the ADS (Automatic Depressurization System) valve is opened to reduce the RCS (Reactor Coolant System) pressure to below 1.0 MPa to prevent the reactor vessel creep damage that can occur when the reactor vessel is at high temperature and high pressure.

Since SMART is an integral reactor, the steam generators, pressurizer, and RCP (Reactor Coolant Pump)s are installed inside the reactor vessel. As such, the reactor vessel size according to the thermal output of the core is larger than the conventional pressurized water reactor. Table I shows the key design parameters related to ERVC compared to other power plants in Korea. As shown in the table, the thermal output of SMART is 365 MW_{th} which is only around 1/10 of Optimized Power Reactor (OPR)1000 and APR (Advanced Power Reactor)1400. However, the size of the SMART reactor vessel is larger than that of these power plants. Specifically, the internal diameter of the ART reactor vessel is 5.3 m, which is larger than the 4.7 m of APR1400, and the thickness 0.2 m is larger than APR1400 0.165 m. As such, the heat flux to the outer wall of the reactor vessel is smaller than OPR1000 or APR1400 when the core corium is relocated in the lower plenum of the reactor vessel. SMART has no In-Core Instrumentation (ICI) nozzle, which is negative effect on the IVR-ERVC.

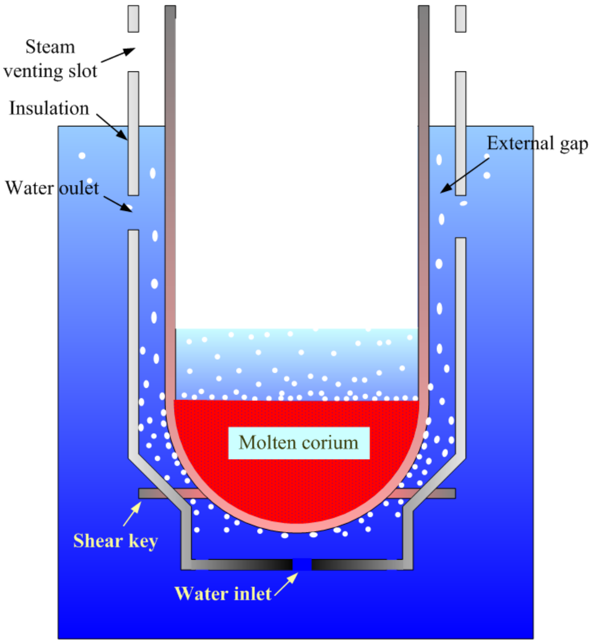

Fig.1 IVER-ERVC concept for SMART

Table I: Comparison of Design Parameters of ERVC between SMART and Other Reactors

Design Parameters	SMART	OPR1000	APR1400
Core Thermal Power (MW)	365	2815	3983
Fuel (UO_2) Mass (ton)	16.3	85.6	120.0
Active Core Zry4 Mass (ton)	4.5	23.9	33.6
Bottom Head Inner Diameter(m)	5.3	4.2	4.7
Bottom Head Thickness (m)	0.2	0.152	0.165
Number of ICI Nozzle	0	45	61

3. Results on IVR-ERVC Analysis

An IVR-ERVC analysis for the SMART, the thermal load analysis for the corium to the reactor vessel wall was performed using a simple model. A two-layer formation of the upper metallic and lower oxidic layers was considered in the lower plenum of the reactor vessel. The thermal load analysis is concentrated on the heat flux distribution in consideration of a focusing effect in a thin metallic layer. This effect of the metallic layer is mainly determined by the molten pool configuration in the lower plenum of the reactor vessel. The melt pool configurations inside the lower plenum affect the initial thermal load to the outer reactor vessel and play a key role in determining the integrity of the reactor vessel. A numerical model had been developed for a thermal load response to the outer RPV during a severe accident. The model was based on a simple mechanistic model using an energy balance equation. The governing equations were solved using a non-linear Newton-Raphson method. From the thermal load analysis in the lower plenum of the reactor vessel, the maximum heat flux from the corium pool to the outer reactor vessel is approximately 0.49 MW/m^2 in the metallic layer, owing to the focusing effect.

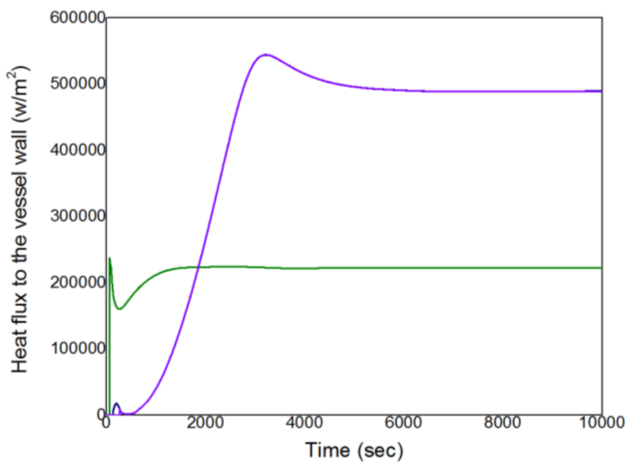

Figure 2 Heat flux from the Corium Pool to the RV Inner Wall

As the thermal load given to the external reactor vessel wall is determined, the two-phase natural circulation flow of coolant between external reactor vessel wall and insulator, and the corresponding CHF which results in the maximum heat removal from external reactor vessel wall have been assessed. In order to increase the natural circulation flow between the external reactor vessel wall and insulator, optimum reactor vessel insulator design is accomplished such as installation of coolant injection hole, steam exhaust, and coolant circulation hole in the reactor vessel insulator.

Assuming that the area of the coolant injection hole of the reactor vessel insulator is 0.5 m^2, the area of steam exhaust is 0.5 m^2, and the area of coolant circulation hole is 0.5 m^2, the two-phase natural circulation flow of coolant has been evaluated using the SPACE computer code. In this calculation, a sensitivity calculation was conducted by changing the heat flux from 0.40 MW/m^2 to 0.49 MW/m^2 and 0.58 MW/m^2 for observing the calculated natural circulation flow rates according to the heat flux variation. As shown in the Table II, the circulation mass flow rate is approximately 405 kg/s when heat flux is 0.40 MW/m^2, approximately 460 kg/s when heat flux is 0.49 MW/m^2, and approximately 490 kg/s when heat flux is 0.58 MW/m$^{2.}$ These results indicate that the calculated natural circulation flow rate increases when the heat flux increases. According to the result of SULTAN experiment performed in CEA, France, and the result of KAIST experiment, when the natural circulation flow rate increases between external reactor vessel wall and insulator, the CHF increases. The CHF at the external reactor vessel wall is approximately 1.3-1.4 MW/m^2 for every heat flux indicating that the CHF is significantly large compared with the heat flux of 0.49 MW/m^2 from the core melt in the lower hemisphere of the reactor vessel to the external reactor vessel wall. Therefore, we can conclude if coolant is properly supplied to the reactor cavity of SMART, the core melt can be sufficiently cooled by ERVC. The thermal margin for success of the IVR-ERVC is sufficient in the SMART, which means that the reactor vessel integrity is maintained.

Table II: Result of SPACE and estimated CHF for the natural circulation flow in the reactor cavity

Heat Flux (MW/m^2)	Coolant Flow Rate (kg/s)	Coolant Mass Flux (kg/m^2.s)	Estimated CHF (MW/m^2)	
			SULTAN	KAIST
0.40	405.0	253-506	1.3	1.3
0.49	460.0	287-575	1.4	1.4
0.58	490.0	306-612	1.4	1.4

ACKNOWLEDGEMENT

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[1] Park Rae-Joon et al., Evaluation of In-Vessel Corium Retention and Cooling during Severe Accident, KAERI/TR-3537/2008, KAERI, February 2008