SBLOCA Analysis to Set-up the Long Term Cooling Plan for the SMART-P

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1. Introduction

SMART-P is a pilot plant of the SMART (System-integrated Modular Advanced ReacTor) producing a maximum thermal power of 65.5 MW. Different from the conventional loop type PWRs, the SMART-P contains the reactor coolant and the major primary circuit components, such as the core, two Main Coolant Pumps (MCPs), twelve SG cassettes, and the PZR in a single Reactor Pressure Vessel (RPV). Due to this integral arrangement of the primary system, only the small branch line break or leak through a component penetrating the RPV is postulated. Also, the reactor building spray system is not adopted in the SMART-P design. Thus, the energy released into the reactor building is removed by the condensation on the surface of the passive heat sinks and is transferred to the reactor building sump.

After a Small Break Loss of Coolant Accident (SBLOCA), the Reactor Coolant System (RCS) pressure decreases rapidly. When the PZR pressure reaches the low-pressure reactor trip setpoint, the control rods drop into the core and decrease the core power rapidly. Simultaneously with the reactor trip, the MCPs start to coastdown, the main steam and feedwater isolation valves are closed, and the Passive Residual Heat Removal System (PRHRS) is connected to the secondary side of the SG. As the RCS pressure decreases to the safety injection actuation setpoint, a safety injection pump starts to deliver the cold coolant from the RWST to the RPV. Afterwards, the Safety Injection System (SIS) and PRHRS cool the RCS to the hot shutdown condition (200^{o}C). When the RWST level reaches a low-level setpoint, Recirculation Actuation Signal (RAS) is generated, which transfers the suction of the SIS from the RWST to the reactor building sump.

Long Term Cooling (LTC) operation after a SBLOCA is continued until the plant reaches a safe temperature level by using the SIS and PRHRS. In the SMART-P, the normal Shutdown Cooling System (SCS) is designed to cool the RCS from the hot shutdown condition (200^{o}C) to the refueling condition (60^{o}C) using two shutdown cooling pumps and heat exchangers. This normal operation of SCS entails taking suction from the MCP lower suction duct, through the shutdown cooling pumps, through the heat exchangers, through the cross-connect piping between the SCS and SIS lines, and then to the RPV. However, for the relatively large size of the SCS line break or CEDM housing break, voids may be formed at the suction inlets of the shutdown cooling pumps, which would lender the SCS inoperable.

To identify the transient behavior and coolant distribution in the RPV during the SBLOCA, the break size spectrum analyses for the limiting break location are performed using a best-estimate code of MARS/SMR. The results of this analysis provide the basis for the LTC plan for the SMART-P.

2. Analysis Methods

2.1 Analysis Model

The thermal-hydraulic response of the system during the SBLOCA is analyzed using MARS/SMR which is a best-estimate system analysis code based on a two-fluid model for two-phase flows. This code is a developmental version of MARS [1] for the safety and performance analyses of an integral type PWR, SMART-P. A number of SMART-P specific models reflecting the SMART-P's design characteristics, such as a helical tube SG, gas pressurizer, and a critical flow with non-condensable gas, have been addressed in the code [2].

2.2 Initial/Boundary conditions and Assumptions

The analysis is performed using the conservative initial/boundary conditions and assumptions.

The initial core power and feedwater flow rate are assumed to be 103% of the nominal values by considering the measurement uncertainty. The initial pressures of the PZR and SG steam are 15 MPa and 3.5 MPa, respectively. A conservative set of the maximum Doppler and the minimum moderator density reactivity feedback is used to minimize the power decrease after the break. The reactor trip and safety injection actuation are assumed to occur when the low PZR pressure reaches 11.09 MPa and 9.02 MPa with a time delay of 1.15 and 30 seconds respectively. A conservative ANS-73 decay heat curve is used with a 1.2 multiplication factor. Loss of offsite power is assumed with the reactor trip and the failure of one Emergency Diesel Generator (EDG) is considered as a single failure assumption.

2.3 Break Location and Size

In the SMART-P design several small branch lines (safety injection line, SCS suction line, PZR-gas cylinder line, and instrument lines, etc.) and components (2 MCPs and 12 CEDM lower pressure vessels) penetrate into the nozzles installed in the RPV cover. Among the breaks through these pipelines and components, the CEDM housing break is limiting since its lower pressure vessel embedding a flow-restricting device (equivalent I.D. ≅ 1") penetrates into the RPV most deeply. Thus, the CEDM housing breaks outside the RPV with an equivalent diameter of 1", 0.75", 0.5", and 0.1" are analyzed.

3. Analysis Results

In this section the results of the break spectrum analyses are presented.

The PZR pressure behaviors with different break sizes are presented in Figure 1. As can be seen from the figure, the RCS pressure decreases rapidly and then reaches a plateau when the safety injection flow matches the break flow. As the break size decreases, the depressurization rate becomes slower and the pressure plateau is formed at a higher value.

Figure 2 shows the behaviors of the coolant temperature in the upper plenum node. For the relatively large size of breaks (1", 0.75", and 0.5"), the coolant temperatures decrease well below the hot shutdown condition (200^{o}C) in a short period of time, since the core heat removal by the safety injection water and that out of the break is sufficient. On the other hand, for the relatively small size of break (0.1"), the coolant temperature decreases slowly. In this case the PRHRS plays a more important role in removing the core decay heat than the break flow and safety injection flow does.

Figure 3 shows the behaviors of the void fraction in the MCP lower suction duct that is the upstream node of the SCS suction pipe. As can be seen in this figure, the inlet node of the SCS suction pipe starts to be voided at 10, 20, and 80 seconds and is completely voided at 350, 860, and 3450 seconds for the 1", 0.75", and 0.5" break respectively. For the 0.5" break case, the node is completely refilled with safety injection water at 22500 seconds. However, for the break sizes with 1" and 0.75", the inlet node of the SCS suction pipe is not refilled even at 10 hours after the break, which prevents a proper operation of the SCS.

Thus, instead of using the normal operation of the SCS, the following SMART-P specific operation of the SCS after a SBLOCA is recommended:

If the RAS is generated after a SBLOCA, the recirculation phase of operation starts by transferring the suction of safety injection pump from the RWST to the reactor building sump. At the same time the suction and discharge of SCS are transferred from the RPV to the reactor building sump. The hot coolant in the reactor building sump is cooled using the shutdown cooling pump and heat exchanger, which is injected into the RPV through the SIS. In this way, a long term cooling is continued for all the sizes of SBLOCAs in the SMART-P.

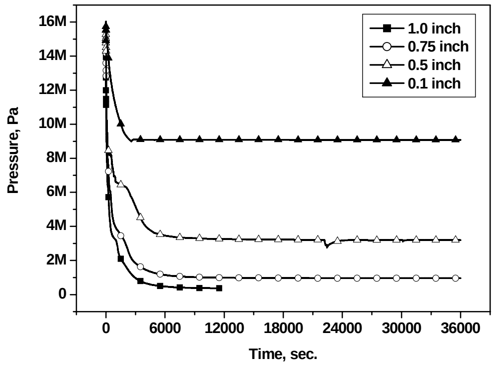

Figure 1. PZR pressure

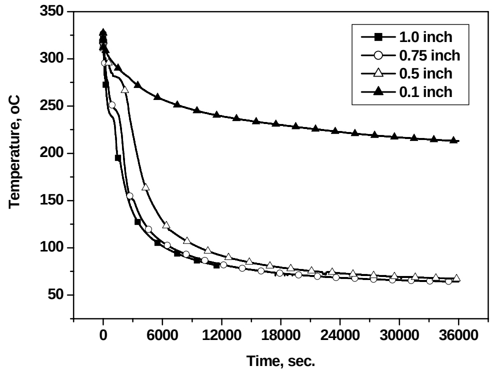

Figure 2. Upper plenum temperature

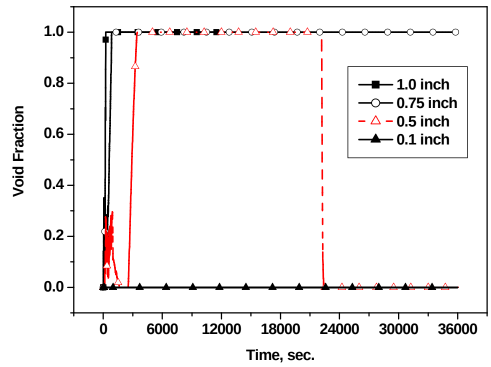

Figure 3. MCP lower suction duct void fraction

3. Conclusion

The break spectrum analysis for the SBLOCAs in the SMART-P is performed using the best estimate code of MARS/SMR. Based on the results of this analysis, the SMART-P specific long term cooling plan independent of break size is developed.

REFERENCES

[1] J.J. JEONG, et al., “Development of a multi-dimensional Thermal-hydraulic System Code, MARS 1.3.1,” Annals of Nuclear Energy, Vol.26, p. 1611–1642, 1999.
[2] K.H. BAE, et al., Safety Evaluation for the SMART Conceptual Design, KAERI, Taejon, 1999.