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Emergency Core Cooling Performance of the Safety System of SMART-P

G.H. Lee, K.H. Bae, H.C. Kim, S.Q. Zee
Korea Atomic Energy Research Institute, 150, Deokjin-dong, Yuseong-gu, Daejeon, Korea 305-353,
khbae@kaeri.re.kr

1. Introduction

SMART-P is an integral-type PWR producing a maximum thermal power of 65.5 MW, which is a 1/5 scaled-down pilot plant of the 330 MWt SMART (System-integrated Modular Advanced ReacTor).

Different from the loop type commercial PWRs, 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 the possibility of a large pipe break is inherently eliminated and only a small branch line break or leak through a component penetrating the RPV is postulated.

Also, SMART-P adopts inherent safety improving features such as a large volume of primary coolant (volume/unit power), substantially large negative moderator temperature coefficients, a low core power density, a large self-controlled N_2 gas PZR, a canned motor MCP without a pump seal, and a modular helically coiled once-through SG cassette. In addition, SMART-P enhances its safety and reliability by adopting the Passive Residual Heat Removal System (PRHRS) and the Reactor Overpressure Protection System (ROPS) equipped with a Pilot Operated Safety Relief Valve (POSRV). Also, four mechanically separated trains of a Safety Injection System (SIS) are adopted in SMART-P design.

The PRHRS cools down the RCS to the hot shutdown condition (200^{o}C) by a natural circulation subsequent to a reactor trip. The PRHRS consists of 4 independent trains and each train is composed of a heat exchanger, a Compensating Tank (CT), and connecting pipelines. The heat exchanger submerged in the Refueling Water Storage Tank (RWST), is located high enough above the SG to provide a sufficient natural circulation flow. The CT, pressurized with N_2 gas, fills up the voids formed during the cooldown process.

The SIS compensates for the primary coolant inventory loss to ensure that the core is always covered with water in the case of a SBLOCA. The SIS consists of four independent trains. Each train consists of a pipeline from the RWST, a safety injection pump, and a pipeline penetrating through the RPV annular cover to the MCP discharge region.

The Shutdown Cooling System (SCS) cools the RCS from the hot shutdown condition to the refueling condition (60^{o}C) by using two shutdown cooling pumps and heat exchangers. This normal operation of the SCS entails a 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.

To evaluate the performance of the Emergency Core Cooling System (ECCS) of SMART-P, a small break spectrum analysis is performed by using the conservative evaluation model of TASS/SMR.

2. Analysis Methods

2.1 Analysis Model

The thermal-hydraulic response of the system during a SBLOCA is analyzed by using TASS/SMR[1], which is a thermal-hydraulic system analysis code developed for the safety and performance analyses of an integral type PWR, SMART-P. A number of SMART-P specific models have been addressed in the code, such as a helical tube SG model, non-condensable gas model, PRHRS heat transfer model, and a critical flow model with non-condensable gas. The governing equations of the TASS/SMR code are based on the drift-flux model so that the accidents or transients accompanying a two-phase flow as well as a single-phase flow can be analyzed. Also this code implements the evaluation models required by the Appendix K of 10 CFR 50 [2].

2.2 Initial/Boundary conditions and Assumptions

The analysis is performed by using conservative initial/boundary conditions and assumptions. The initial core power is assumed to be 103% of the nominal values by considering the measurement uncertainty. The reactor trip and safety injection actuation are assumed to occur when the PZR pressure reaches 11.09 MPa and 9.02 MPa respectively. A conservative ANS-71 decay heat curve is used with a 1.2 multiplication factor. Loss of offsite power is assumed to occur simultaneously 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 and components penetrate into the nozzles installed in the RPV cover. In most of these nozzles a small diameter (ID ≤ 1") flow restricting device is imbedded. Among these branch lines, the PZR-gas cylinder line and the SIS line/the SCS suction line are the largest sized pipes connected to the RPV central cover and annular cover respectively, which are connected to the flow-restricting device in the RPV nozzle with a minimum ID of 1". Thus, a guillotine rupture of the PZR-gas cylinder line, the SIS line, the SCS suction line, and a break at the CEDM housing accompanied by a CEA ejection (equivalent ID: 0.97"), and an inadvertent opening of a POSRV (valve ID: 0.7") are considered in this paper.

3. Analysis Results

The RCS pressure behaviors for various break cases are presented in Fig. 1. As can be seen from the figure, the RCS pressure decreases rapidly for all the break cases. When the PZR pressure reaches the low-pressure reactor trip setpoint of 11.09 MPa, a reactor trip signal is generated. Simultaneously with the reactor trip, the MCPs start to coastdown, the Main Steam Isolation Valves (MSIVs) and Feedwater Isolation Valves (FIVs) are closed, and the PRHRS isolation valves connecting the secondary side of the SG and the heat exchanger submerged in the RWST are opened. Afterwards, the PRHRS removes the core decay heat by a natural circulation. As the RCS pressure decreases to below 9.02 MPa, the Safety Injection Actuation Signal (SIAS) is generated. With a 33 seconds time delay after the SIAS the safety injection pump starts to deliver the cold coolant from the RWST into the RPV and it fills the RCS. Afterwards, the SIS and PRHRS cool the RCS to the hot shutdown condition (200°C).

Fig. 2 shows the RCS coolant temperature behaviors. For all the break cases, the coolant temperatures decrease to well below the hot shutdown condition (200°C) in a short period of time, since the core heat is sufficiently removed by the SIS and PRHRS.

Fig. 3 shows the behaviors of the RPV collapsed water levels. As shown in this figure, the coolant levels of the RPV are kept well above the top of the core for all the break cases, which shows a proper performance of the SIS.

If the RAS is generated after a SBLOCA, the recirculation phase of an operation starts by transferring the suction of the SI pump from the RWST to the reactor building sump. At the same time the suction and discharge of the SCS are transferred from the RPV to the reactor building sump. The hot coolant in the reactor building sump is cooled by 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.

4. Conclusion

The break spectrum analysis for the SBLOCAs in the SMART-P is performed using the conservative evaluation model of TASS/SMR code. The analysis results by using conservative initial/boundary conditions and assumptions show that the actuation of the SIS and the PRHRS maintain the RPV coolant level well above the top of the core and remove the long-term decay heat. Thus, the emergency core cooling performance of the safety system after a SBLOCA in the SMART-P can be assured.

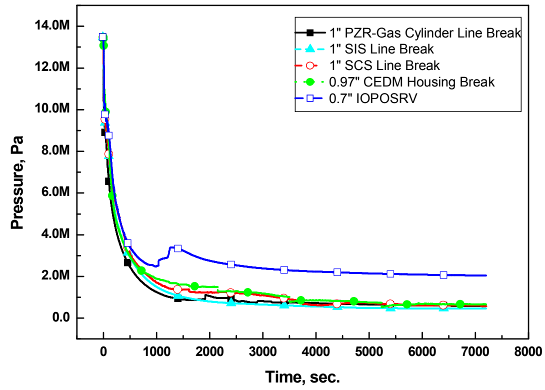

Figure 1. RCS pressure

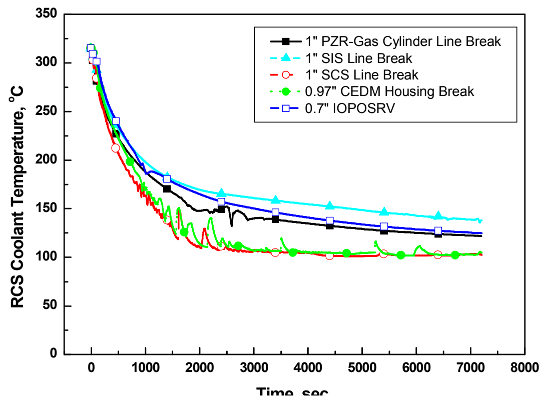

Figure 2. RCS coolant temperature

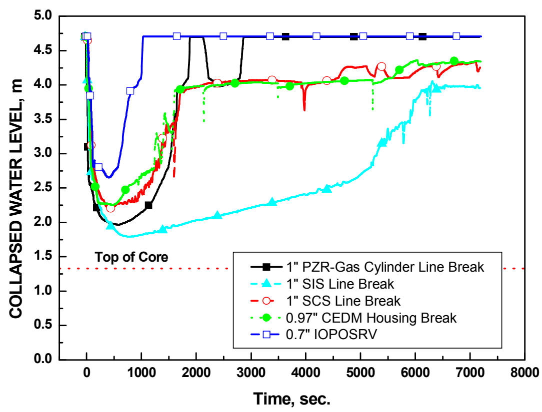

Figure 3. RPV Collapsed Water Levels

REFERENCES

[1] Y.D. HWANG, et al., Model Description of TASS/SMR code, KAERI/TR-3082/2005, Daejon, 2005.

[2] ECCS Evaluation Models, Title 10, Code of Federal Regulations, Part 50, Appendix K, U.S. Nuclear Regulatory Commission, April, 1993.