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Analysis of SBLOCA in SMART Using TASS/SMR-S Code

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1. Introduction

SMART is an advanced integral type of pressurized water reactor with rated thermal power of 365 MW. SMART adopts passive safety systems and inherent safety features that enhance the high level of safety for the plant. This analysis is performed to identify the system thermal hydraulic response during the loss of coolant accident (LOCA), and it is conducted by using the TASS/SMR-S code. This work intends to present the analysis procedure, assumptions, and findings.

2. Description of SMART

SMART is an integral type reactor that contains the major reactor primary components into a single reactor pressure vessel (RPV) without any pipe connections between those components. The reactor coolant is circulated within the reactor coolant system (RCS) boundaries by 4 reactor coolant pumps (RCPs) that installed horizontally to the vessel, above the 8 steam generators (SGs). The pressurizer (PZR) is located at the upper part of the RPV while the core is located at the lower center part of the RPV. The forced circulation of the coolant carries the heat generated in the core to the shell side of the SGs, to be transferred to the secondary system. The feedwater of the secondary side flows inside the helically coiled SG tubes to remove the RCS heat, and it leaves the SG as super-heated steam [1].

The safety features of SMART are enhanced by adopting the passive safety systems; the passive residual heat removal system (PRHRS) and the passive safety injection system (PSIS), and others. Each of the two systems is composed of four trains with a 33% capacity for each train that can deliver the reactor to the safe shutdown condition within 36 hours, and maintain the safe shutdown condition for another 36 hours. Any corrective action by operator or the aid of external AC power is not considered for 72 hours during the design basis accidents. Each train of the PRHRS is composed of one emergency cooldown tank, a PRHRS heat exchanger, and a makeup tank, and related pipes and valves. Each PSIS train is composed of one core makeup tank, one safety injection tank, one safety injection line, one pressure balance line, and related valves. To prevent the single failure of the PRHRS and PSIS train, each train is composed of two parallel piping and two valves are installed in each parallel piping.

3. Accident and Analysis Methodology

3.1 Accident Description

LOCA is a postulated accident causes abnormal decrease in the RCS coolant inventory at a rate that exceeds the reactor makeup system capability. In SMART, the pipe connections between the major primary components are eliminated due to its integral arrangement design feature. Therefore, the large break LOCA is inherently eliminated. However, break or leak in small lines penetrating the RPV can initiate a small break LOCA (SBLOCA). In SMART, the major lines penetrating the RPV and can cause SBLOCA are: safety injection lines (SIL), pressure balance lines (PBL), pressurizer safety valve (PSV) connection lines, and chemical and volume control system (CVCS) lines. The design of SMART restricts the maximum nozzle ID connected to the RPV to 50 mm.

3.2 Analysis Model

The system's thermal hydraulic response during an SBLOCA accident is analyzed using the TASS/SMR-S computer program, which is a thermal hydraulic system analysis code developed for the safety and performance analysis of SMART. Different numbers of models are adopted by the TASS/SMR-S to reflect the specific design characteristics of the SMART such as helical tube SG model, RCP model, PZR model, and others [2].

3.3 Accident Acceptance Criteria

According to the Nuclear Safety and Security Commission (NSSC), the SBLOCA scenarios must satisfy the following acceptance criteria [3]:

1. The maximum calculated fuel cladding temperature shall not exceed 1204 ^{o}C
2. The calculated oxidation shall nowhere exceed 0.17 times the total cladding thickness before oxidation.
3. The calculated total amount of hydrogen generated from chemical reaction of cladding and water or steam shall not exceed 0.01 times the hypothetical hydrogen amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the

cladding surrounding the plenum volume, were to reaction

4. The calculated changes in core geometry shall be such that the core remains amenable to cooling.
5. After any calculated successful initial operation of the emergency core cooling system (ECCS), the calculated core temperature shall be maintained at an acceptable low value.

3.4 Initial/Boundary Conditions and Assumptions

Number of conservative initial/boundary conditions and assumptions are used for this analysis. The initial core power is assumed to be 103% of the nominal value. The initial PZR and secondary system pressure is assumed to calculate the highest values of the limiting conditions for operation. High RCS temperature and low RCS flow rate are assumed. In order to minimize the core power decrease after the accident, the maximum Doppler and minimum moderator density feedbacks are assumed conservatively for the SBLOCA analysis. The loss of off-site power (LOOP) is assumed to occur coincidently with the reactor trip. Therefore, the power supplied to the four RCPs and the feedwater pump is lost, and thus the RCP starts to coastdown and feedwater flow is terminated. In case of the SMART SBLOCA accident, no single failure in the safety system of PRHRS and PSIS is considered.

3.5 Analysis Methodology

Break location spectrum analyses were performed to identify the most limiting SBLOCA location that leads to conservative results. The severity of the initial conditions is measured by the RPV collapsed water level reached during the SBLOCA accident, as the core coverage during the whole period of the transient is an essential safety target. Out of all the branch lines penetrating the RPV, the SIL, the PBL and the PSV line are considered as limiting SBLOCA location. However, the SIL break results in more severe consequences, since the elevation is lower than PBL and PSV line, and thus causing the lowest collapsed water level. In addition, one out of four PSIS tains becomes unavailable during the SIL break. Figure 1 shows the comparison between the lowest collapsed water level reached for different break location.

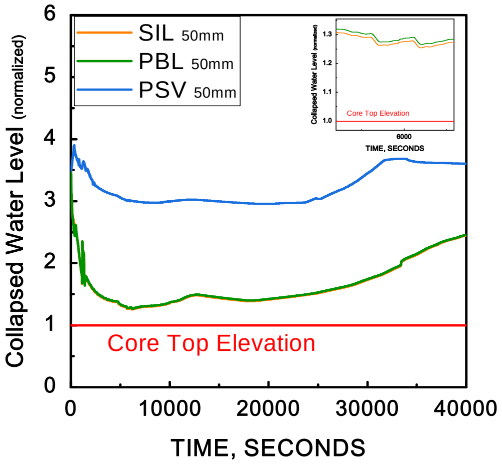

Fig.1. Collapsed water level inside of RPV during SBLOCA at different locations

3.6 Analysis Results

When the break occurs, the RCS pressure decreases rapidly. As shown in Figure 2, the larger the break size, the PZR pressure decrease more rapidly. The reactor trip signal is generated faster in case of 50 mm SIL break.

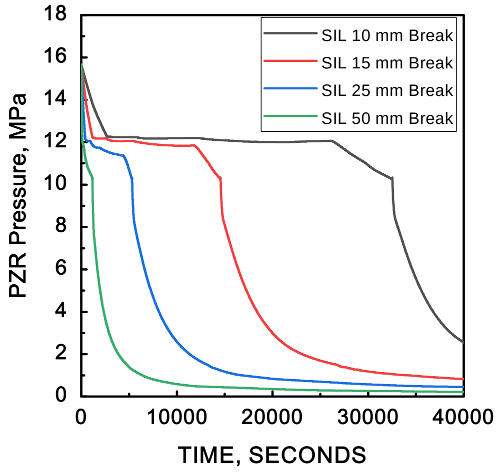

Fig.2. PZR pressure for different SIL break sizes.

The reactor trip signal occurs by the low PZR pressure and simultaneously the turbine is tripped and the offsite power is lost. The collapsed water level inside the RPV is mainly impacted by the break flow rate and the safety injection flow rate. Figure 3 shows the integrated break flow for the SIL break of different size areas. The integrated safety injection flow for the same size spectrum is shown in figure 4.

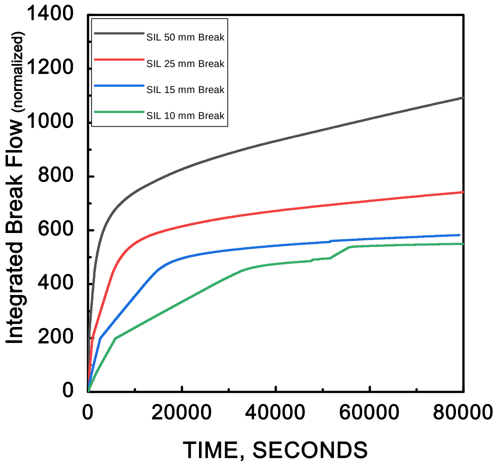

Fig.3. The integrated break flow during the SBLOCA of different SIL break area sizes.

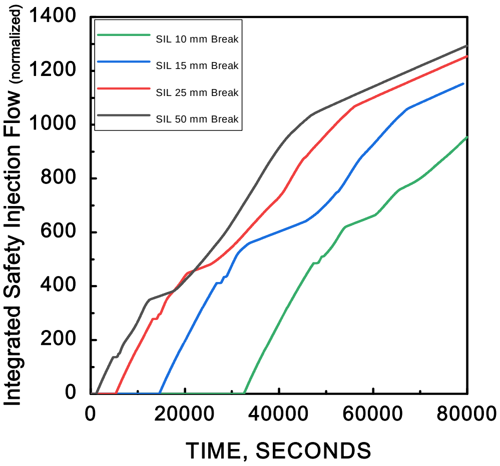

Fig.4. The integrated safety injection flow during the SBLOCA of different SIL break area sizes.

The PSIS and the PRHRS are actuated to compensate the lost coolant and to remove the residual heat form the core, respectively. The lost coolant inventory is compensated by the PSIS and ensures the full coverage of the core during the transient. Figure 5 shows the integrated mass released from and added to the RCS during the 50mm SIL break.

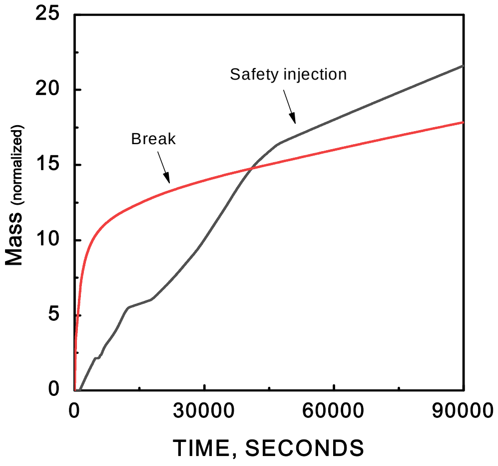

Fig.5. Integrated break and safety injection mass during the 50 mm SIL break.

Figures 6 and 7 show the core exit coolant temperature and the peak cladding temperature behaviors during the accident. The monotonically decreasing temperature indicates that the plant remains in a safe condition.

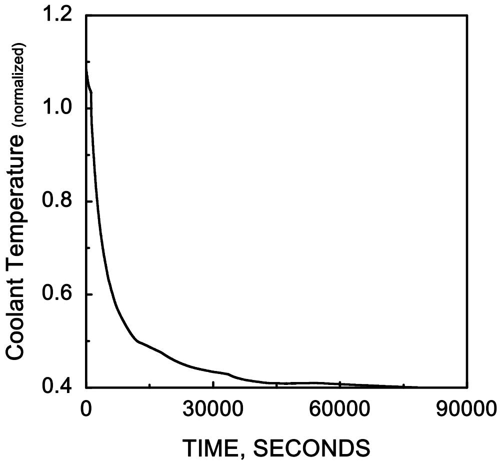

Fig.6. RCS coolant temperature during the 50 mm SIL break.

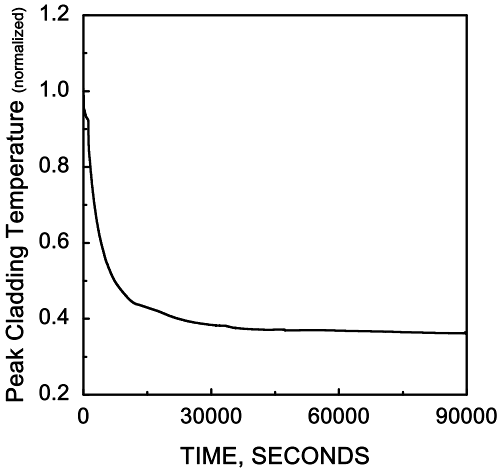

Fig.7. Peak cladding temperature during the 50 mm SIL break.

4. Conclusions

The analysis of thermal hydraulic response of SMART for SBLOCA was performed using the TASS/SMR-S code. The conservative approch was adpoted to select the most limiting initial conditions for the more severe consequences in view point of collapsed water level inside of RPV. The location and size spectrum analyses for the SBLOCA were perfomed. The analysis results of the limiting SBLOCA of 50 mm SIL break show that: During the entire transient, the fuel cladding surface temperature is continuously decreased, and it is expected that the fuel cladding oxidation and hydrogen generation rate are negligible. The rupture of fuel cladding does not occur, so the coolable geometry of the core is maintained sufficiently.

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