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Performance Evaluation of SMART Passive Safety System for Small Break LOCA Using MARS Code

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1. Introduction

Standard design approval (SDA) for SMART (System-integrated Modular Advanced ReacTor), a 330-MWt integral reactor developed by KAERI, was issued on July 4, 2012 by the Korean nuclear regulatory body. SMART has significantly enhanced safety by reducing its core damage frequency to 1/10 that of a conventional nuclear power plant. In addition, the adoption of a passive safety system has received attention as a solution to overcome the weakness of an active safety system, which may lose electric power like at the Fukushima accident.

Therefore, KAERI is developing a passive safety injection system to replace the active safety injection pump in SMART. It consists of four trains, each of which includes gravity-driven core makeup tank (CMT) and safety injection tank (SIT). This system is required to meet the passive safety performance requirements, i.e., the capability to maintain a safe shutdown condition for a minimum of 72 hours without an AC power supply or operator action in the case of design basis accidents (DBAs). The CMT isolation valve is opened by the low pressurizer pressure signal, and the SIT isolation valve is opened at 2 MPa. Additionally, two stages of automatic depressurization systems are used for rapid depressurization [1].

Preliminary safety analysis of SMART passive safety system in the event of a small-break loss-of-coolant accident (SBLOCA) was performed using MARS code. In this study, the safety analysis results of a guillotine break of safety injection line which was identified as the limiting SBLOCA in SMART [2] are given.

2. MARS Code Modeling and SBLOCA Results

2.1 MARS Code Modeling

The passive components of CMTs, SITs, and related pipes and valves were introduced to replace the active safety injection pump in SMART. Thus, based on the nodalization of the original SMART system [3], newly introduced passive safety system was modeled as shown in Fig. 1.

The CMT consists of 30 volumes, with 10 volumes each for the top head, cylindrical section, and bottom head. The initial condition for CMT is reactor coolant system (RCS) pressure and room temperature. The thermal-front model was used for the volume. When the CMT isolation valve is opened, steam flows into the CMT from the RCS. This steam causes a temperature distribution in the water of the CMT. The MARS code default model calculates the temperature difference between volumes, but it cannot model the temperature distribution in a volume. To consider the temperature distribution in a volume, a thermal-front model was introduced as an option [4]. The condensation in the CMT is a very important parameter for determining the CMT injection performance, and the temperature at the surface of the water greatly affects the condensation. Thus, a thermal-front model was used in this analysis. SIT modeling follows a concept identical to that of CMT nodalization.

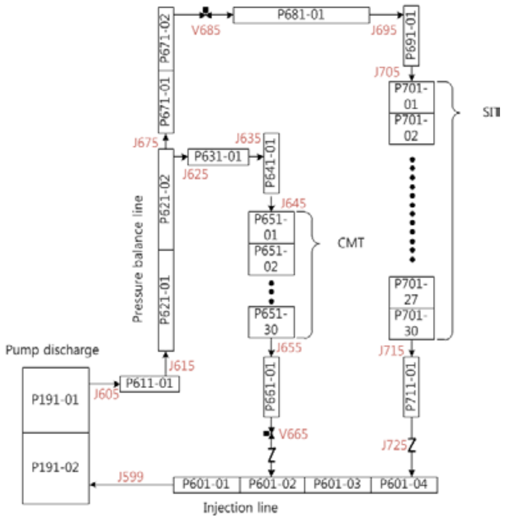

Fig. 1. MARS nodalizaiton of passive safety system in the SMART PSS

2.2 SBLOCA MARS Analysis Results

Upon the guillotine break at safety injection line, single phase coolant is released, and the RCS pressure decreases rapidly. When the RCS pressure reaches 10.26 MPa, the reactor trips. Simultaneously, the turbine trips, and main feed water pump and reactor coolant pump start to coastdown. Because the opening set point of the CMT isolation valve is the same as that of reactor trip signal, the CMT isolation valve is opened at this time. When the CMT isolation valve is opened, the RCS and CMT pressures are balanced through a pressure balance line, and cold safety injection water is delivered into the RCS by the gravity force. In this process, the steam condensation in the CMT affects the CMT injection performance. When the RCS pressure reaches 2 MPa, the SIT isolation valve is opened, and the cold safety water is injected. SIT injection continues for a minimum of 72 hours.

The accident scenario of SI line guillotine break is summarized in Table I. During a SBLOCA, the collapsed liquid level inside the core support barrel is maintained sufficiently high above top of active core by the sufficient passive safety injection flow from the CMT and SIT, as shown in Fig. 2. This results in a consistent decrease in fuel cladding temperature throughout the transient, as shown in Fig. 3.

Table I: Sequence of Events for SI line guillotine break

Time (sec.)	Event
0.0	Break occurs
570.4	Reactor trip signal by low PZR Pressure - Turbine trips - Loss of off-site power occurs - Main feedwater pumps trip - RCPs trip
570.4	CMT isolation valve is opened
2,894.8	SIT isolation valve is opened
3,880.0	Minimum collapsed liquid level inside the core support barrel (7.42 m) reaches
18,851.3 (~ 5.2 hours)	First ADS valve is opened
32.015.0 (~ 9 hours)	CMT is emptied
197,762.0 (~ 55 hours)	Second ADS valve is opened
72 hours	Calculation is stopped

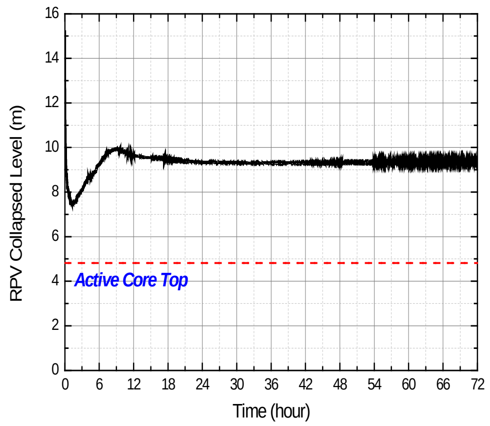

Fig. 2. Collapsed liquid level inside the core support barrel during SBLOCA

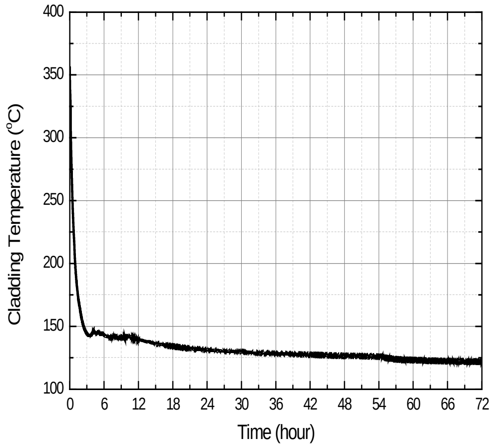

Fig. 3. Fuel cladding temperature during SBLOCA

3. Conclusions

The preliminary safety analysis of a SBLOCA for the SMART passive safety system was performed using the MARS code. The analysis results of the most limiting SI line guillotine break showed that the collapsed liquid level inside the core support barrel was maintained sufficiently high above the top of core throughout the transient. This means that the passive safety injection flow from the CMT and SIT causes no core uncovery during the 72 hours following the break with no AC power supply or operator action, which in turn results in a consistent decrease in the fuel cladding temperature. Therefore, the SMART passive safety system can meet the passive safety performance requirement of maintaining the plant at a safe shutdown condition for a minimum of 72 hours without AC power or operator action for a representing accident of SBLOCA.

Acknowledgments

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