Preliminary Analysis of a Steam Line Break Accident with the MARS-KS code for the SMART Design with Passive Safety Systems

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1. Introduction

SMART has been developed by KAERI [1], and SMART-Standard Design Approval (SDA) was recently granted in 2012. A SMART design with Passive Safety System (PSS) features (called SMART-PSS) is being developed and added to the standard design of SMART by KAERI to improve its safety system. Active safety systems such as safety injection pumps will be replaced by a passive safety system [2], which is actuated only by the gravity force caused by the height difference. All tanks for the passive safety systems are higher than the injection nozzle, which is located around the reactor coolant pumps (RCPs).

In this study, a preliminary analysis of the main steam line break accident (MSLB) was performed using the MARS-KS code to understand the general behavior of the SMART-PSS design and to prepare its validation test with the SMART-ITL (FESTA) facility [3].

2. Methods and Results

2.1 SMART-SDA Design

Fig. 1 shows the MARS-KS nodalization scheme for the SMART-SDA, which includes all of the reactor coolant systems, a safety injection system, and PRHRS [4, 5].

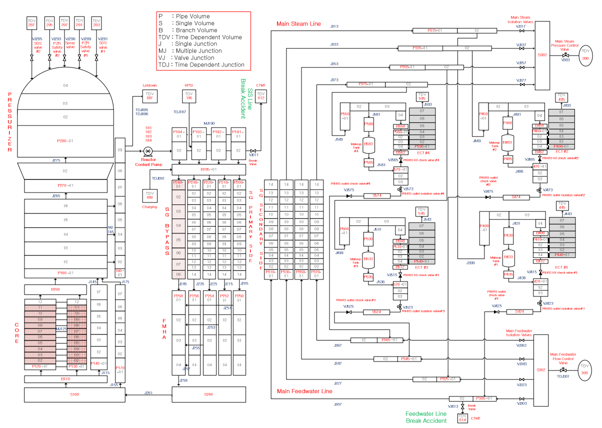

Fig. 1 MARS-KS nodalization scheme for SMART-SDA

2.2 SMART-PSS Design

Fig. 2 shows the MARS-KS nodalization scheme for the SMART-PSS, in which the passive safety systems are added to the SMART-SDA instead of the active safety systems. The passive safety system is composed of four Core Makeup Tanks (CMT), four CMT isolation valves and check valves, four Safety Injection Tanks (SIT), four SIT isolation valves and check valves, connecting pipes, two Auto Depressurization System (ADS) valves, etc.

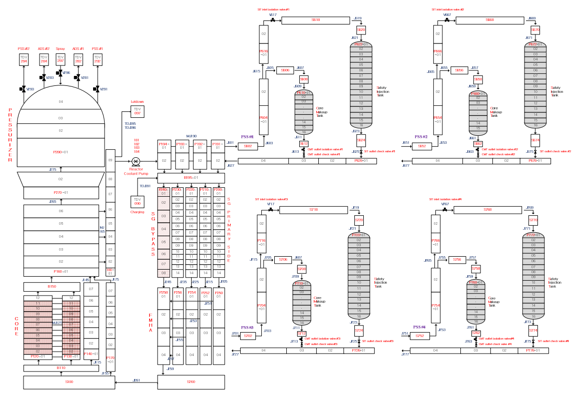

Fig. 2. MARS-KS nodalization scheme for SMART-PSS

Individual tanks are connected with the pressure-balanced pipes on the top side, and injection pipes on the bottom side. This system is operated when the small break loss of coolant accident (SBLOCA) or the steam line break (SLB) occurs. There are no active pumps on the pipe lines to supply the coolant. This system is only actuated by the gravity force caused by the height difference because all tanks are higher than the injection nozzle around the reactor coolant pumps (RCP).

2.3 MSLB Accident Scenario and Modeling

To simulate the viewpoint of a safety analysis, the core power is adopted to be 103% of full power according to the 10CFR 50.46 Appendix K. The total core power is produced at about 339.9 MWth. As for the conservative core power condition, the ANS 73 decay curve with a 1.2 multiplication factor was used in the transient calculation. The reactor trip signal was operated with a low pressurizer pressure (LPP) signal or PHHRS operation signal.

A break system modeling was used to assess the main steam line break accident, as shown in Fig. 3. The break system was modeled using the valve component (C011, C013) and time dependent volume component

(C012, C014). Each valve area is modeled with 0.05196 m^2 according to the SSAR table 15.1.5-7 [6]. The critical flow model selected is a Henry-Fauske critical flow model as a default option, and the discharge coefficient was set to 1.0 and the thermal non-equilibrium constant was set to 0.14.

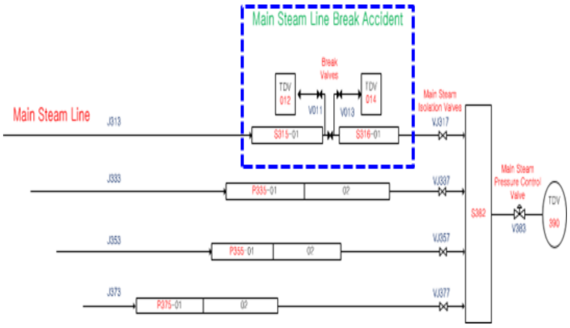

Fig. 3. Nodalization scheme of the main steam line break system

In the SMART standard design stage [6], the most conservative initial condition for the MSLB was identified as high core power, low RCS flow, high core inlet temperature, high pressurizer pressure, and low pressurizer level. For the current calculation, it is considered reasonable to assume the same initial condition as that of the SMART standard design because there is no change in RCS or other main systems.

2.4 Results and Discussion

To simulate the main steam line break accident, the break systems are initiated by opening the break valves at 0.0s after a steady-state condition. Table 1 shows the sequence of events for the main steam line break accident. Figs. 4 through 13 show the results of the main steam line break accident during 72 hours without AC power or operator action.

Table 1. Sequence of events for the MSLB accident

Events	Set-point	Time, sec
MSLB Accident Occur	-	0.0
MSLP Signal	P_{MSLP}	0.3
Reactor trip Signal -LOOP -Feedwater Stop -RCP Coastdown Start	MSLP signal	0.3
CRA Insertion Start	MSLP signal + 0.5s	0.8
PRHR Operation Signal -FW/MS IV Close -PRHRS IV Open	 Stroking time : 20s Stroking time : 5s	0.3 22.67 7.67
LPP & CMT IV Open Signal	P_{LPP}	22370.0
SIT IV Open Signal	P_{SIT}	-
ADS #1 Valve Open Signal	CMT level < 35%	-
ADS #2 Valve Open Signal	SIT level < 20%	-

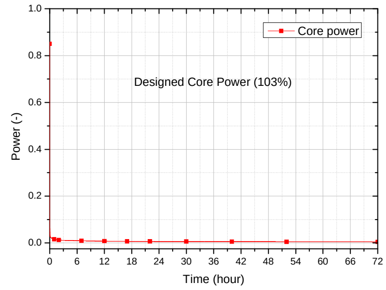

Fig. 4. Core power

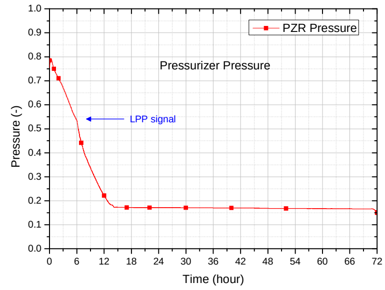

Fig. 5. Pressurizer pressure

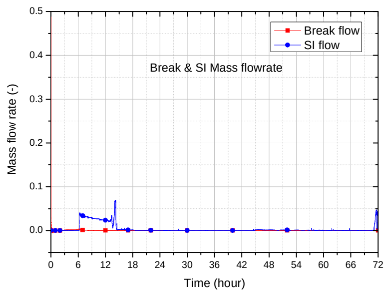

Fig. 6. Break & SI flow

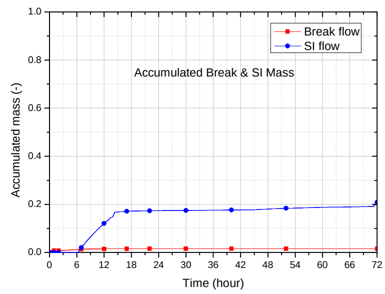

Fig. 7. Accumulated break & SI flow

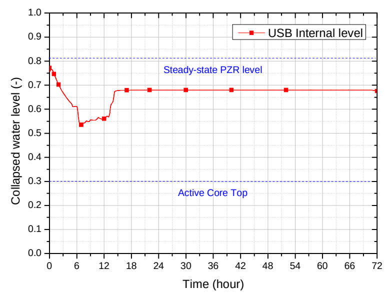

Fig. 8. CSB internal collapsed water level

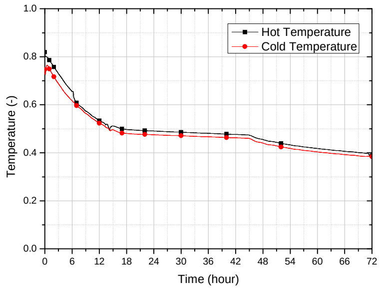

Fig. 9. Primary system temperature

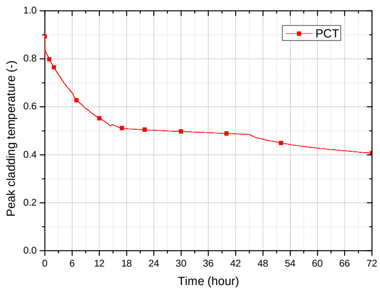

Fig. 10. Peak cladding temperature

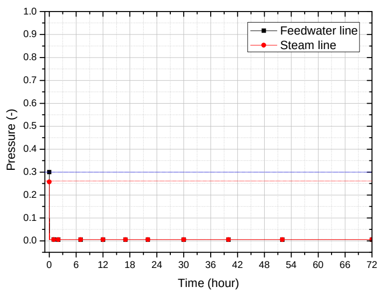

Fig. 11. Secondary system pressure

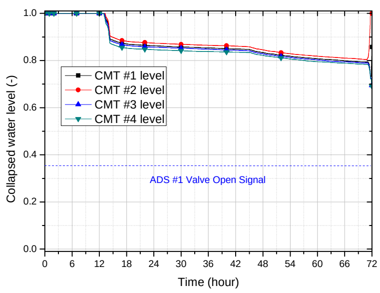

Fig. 12. Core Makeup Tank (CMT) collapsed water level

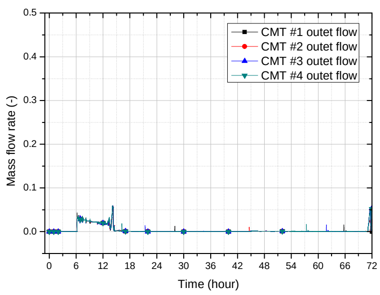

Fig. 13. Core Makeup Tank (CMT) injection flow

The core power was tripped with a delay of 0.5 seconds after the main steam low pressure signal. The core power was reduced according to the reactivity table and decay power curve in the kinetics component, as shown in Fig. 4.

When the steam line pressure decreased and reached a low steam line set pressure of P_{MSLP}, as shown in Fig. 11, a MSLP signal was generated at 0.3 seconds.

When the pressurizer pressure decreased and reached a low pressurizer set pressure of P_{LPP}, as shown in Fig. 5, a LPP signal was generated. The four CMT isolation valves were opened with a LPP signal at 22,370 seconds (6.2 hours).

Fig. 6 shows the flow rates of the break and safety injection flow. Fig. 7 shows the accumulated mass of the break and safety injection flow. The break flow was discharged sharply in the early period from the broken steam line. The borated water of CMT was injected into the RCS to prevent a return to power at 6.2 hours.

Fig. 8 shows a variation of the collapsed water level of an internal core support barrel (CSB). The collapsed water level was maintained higher than the collapsed water level of a fuel assembly plate in the transient. It can be seen that the capability of an emergency core cooling system is sufficient during the transient. Therefore, the temperature of the primary system and the peak cladding temperature were decreased respectively, as shown in Fig. 9 and 10.

Fig. 12 shows the collapsed water level of the CMT. The CMT isolation valve is opened at the LPP signal. 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 gravity force. In this process, the steam condensation in the CMT affects the CMT injection performance. Fig. 13 shows the flow rate of the borated water in the CMT.

A SIT isolation valve open signal did not occur during the transient. Also, ADS #1 and 2 valve open signals did not occur.

3. Conclusions

An anticipated accident for the main steam line break (MSLB) was performed using the MARS-KS code to understand the thermal-hydraulic behaviors of the SMART-PSS design. The preliminary analysis provides good insight into the passive safety system design features of the SMART-PSS and the thermal-hydraulic characteristics of the SMART design. The analysis results of the MSLB showed that the core water collapsed level inside the core support barrel was maintained high over the active core top level during the transient period. Therefore, the SMART-PSS design has satisfied the requirements to maintain the plant at a safe shutdown condition during 72 hours without AC power or operator action after an anticipated accident.

ACKNOWLEDGEMENT

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