SMART Natural Circulation Cooldown Performance Analysis using MARS-KS

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1. Introduction

The SMART (System integrated Modular Advanced ReacTor) is first small and modular reactor (SMR) which received standard design certification from the NSSC (Nuclear Safety and Security Commission), Korean nuclear regulatory agency. Its primary side which includes reactor core, pressurizer, reactor coolant pumps (RCPs), and steam generators (SGs) is implemented inside the reactor vessel. It also has passive residual heat removal system (PRHRS) in the secondary side to remove core decay heat. After the Fukushima accident, SMART further enhanced its safety system for a fully passive safety system through implementing 4 trains of passive safety injection system (PSIS) which contains core makeup tank (CMT) and safety injection tank (SIT) as well as the pressure balance line (PBL) in each train.

In this study, preliminary analysis for the SMART natural circulation cooldown is performed based on the analysis methodology of the SMART natural circulation cooldown using MARS-KS [1]. According to the analysis methodology, passive safety system should cooldown reactor to safe shutdown condition within 36 hours and maintains safe shutdown condition until 72hours after the reactor trip without any operator actions.

2. Analysis Methods

2.1 Analysis Methodology

In natural circulation cooldown analysis [2] for the SMART standard design, it was shown that the active systems successfully cooldown the reactor from reactor trip to shutdown cooling system (SCS) entry conditions, and satisfy the acceptance criteria of long term cooling. But SMART design was enhanced with fully passive safety system, and thus the system should satisfy acceptance criteria not for the active safety system but for the passive safety system. However, there is no domestic licensing acceptance criteria for the passive safety systems. Therefore, analysis methodology for the SMART natural circulation cooldown has been developed in reference to the USNRC acceptance criteria [3,4] and AP1000 Design Certification (DC) [5] and combined construction and operation licensing application (COLA) for the Levy County Unit 1 & 2 [6]. According to the SMART natural circulation cooldown analysis methodology, the passive safety systems should cooldown reactor and an average core coolant temperature reaches safe shutdown condition (215 ^{o}C) within 36 hours after the reactor trip and maintain until 72 hours.

2.2 Nodalization

MARS-KS nodalization of the SMART is shown in Figure 1. MARS-KS nodalization [2] and design data of the SMART standard design are used. Even the SMART design is improved after standard design approval, its design data are not accessible for this study. Therefore the SMART PSIS design is assumed in this study to evaluate natural circulation.

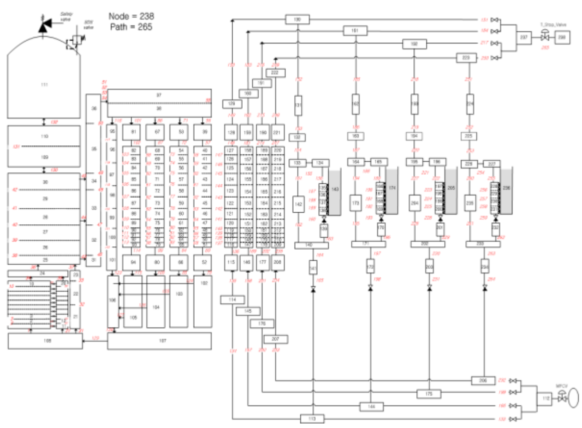

Fig. 1. MARS-KS nodalization for SMART [2]

2.3 Initial and Boundary Conditions

For the natural circulation cooldown performance analysis of the SMART, Loss Of Offsite Power (LOOP) is assumed as an initiating event, and analysis is performed up to 72 hours of operator grace time. The nominal thermal hydraulic conditions of the Limiting Conditions for Operation (LCO) are used as initial and boundary conditions for the natural circulation cooldown analysis such as,

- Core power
- Core inlet coolant temperature
- Pressurizer pressure
- RCS flow rate
- Main steam line pressure
- Pressurizer level

For the performance analysis, best estimate initial and boundary conditions, and all trains of passive safety system actuation are assumed.

3. Analysis Results

3.1 Sequence of Events

The sequence of events of the natural circulation cooldown performance analysis are shown in Table I. The reactor trip is caused by a low RCP speed trip signal. The PRHRS and CMT isolation valves are opened as the low feedwater flow rate setpoint is reached. The SIT isolation valves are opened by low-low pressurizer pressure, and calculation is terminated at 72 hours.

Table I: Sequence of events

Events	Remarks
LOOP	RCP trip
Reactor trip signal	Low RCP speed
Feedwater isolation valve closing	Reactor trip
Reactor and Turbine trip	Reactor trip with delay time
PRHRS isolation valve opening	Low feedwater flow rate
CMT isolation valve opening	PRHRS actuation
Safe shutdown condition reached	215 ºC, 3 hours
SIT isolation valve opening	Low-Low PZR pressure
End of Calculation	72 hours

3.2 Results

The preliminary analysis for the SMART natural circulation cooldown is performed. Figures 2 through 5 are the transient behaviors of major parameters of the primary side. When the LOOP is initiated, RCS is run in a coastdown mode as shown in Figure 2. When the low RCP speed setpoint is reached, the reactor and turbine are tripped and power decreases as shown in Figure 3. Figures 4 and 5 are pressurizer pressure and PSIS flow rate, respectively. As the feedwater isolation valves are closed due to reactor trip signal and feedwater flow rate reaches low feedwater setpoint, PRHRS and CMT of the PSIS are actuated. While power is decreases to decay heat level and safety systems such as PRHRS and CMT are actuated, pressurizer pressure decreases due to the primary cooldown. After that, SIT of the PSIS is actuated due to low-low pressurizer pressure setpoint. During these cooldown phase, the reactor coolant temperature decreases and the average core coolant temperature reaches safe shutdown condition (215 ºC) at 3 hours after the LOOP and is maintained until 72 hours as shown in Figure 6.

In Figure 5, there are fluctuations in PSIS flow. The first PSIS flow fluctuation at 5 hour is due to the SIT injection. When the SIT actuation valves are opened, the SIT flow suddenly increases and CMT flow is also affected due to the pressure changes. The SIT injection also makes pressurizer level increase and the core temperature decrease, and thus causes the primary pressure sudden decrease. The second fluctuation at 30 hours is also related to the pressurizer level. When the pressurizer water level is recovered, the steam in the pressurizer is condensed, and thus primary pressure suddenly decreases. It then causes drastic increase of the PSIS flow.

On the other hand, Figure 7 is the water level of emergency cooldown tank (ECT) which is the ultimate heat sink of the PRHRS. While the PRHRS removes decay heat from the RCS with natural circulation, ECT temperature increases. The water level increases initially due to thermal expansion until saturation. After reaching saturation temperature, water level starts to decrease due to evaporation. ECT water level decreases to about 80% even at 72 hours, and thus it means that the PRHRS has sufficient heat removal capacity.

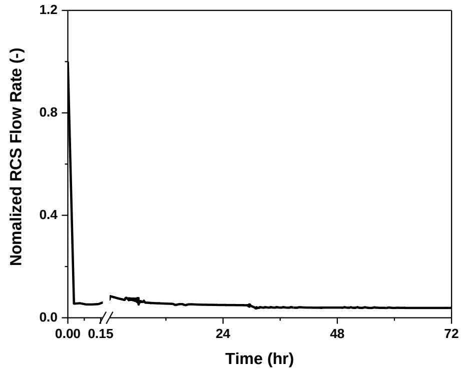

Fig. 2. Nomalized RCS Flow Rate

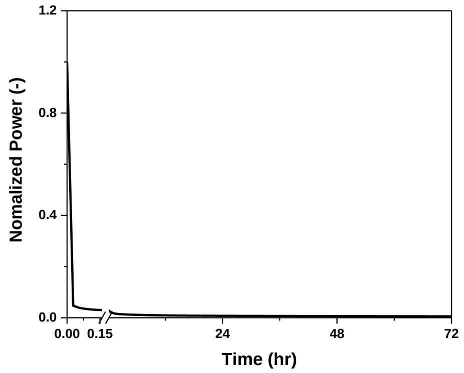

Fig. 3. Nomalized Power

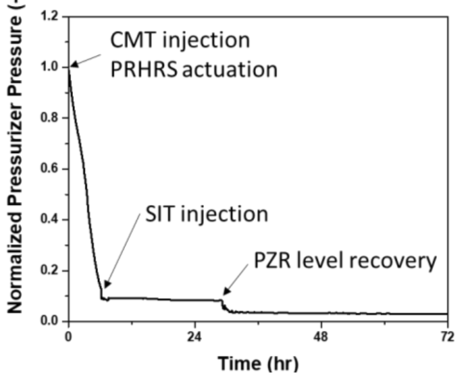

Fig. 4. Nomalized Pressurizer Pressure

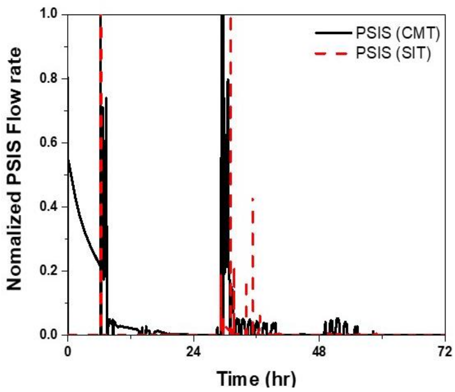

Fig. 5. Nomalized PSIS Flow Rate

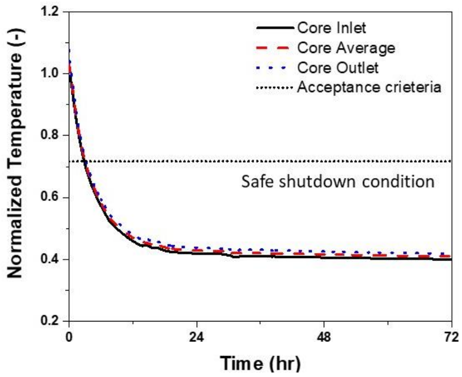

Fig. 6. Nomalized Reactor Coolant Temperature

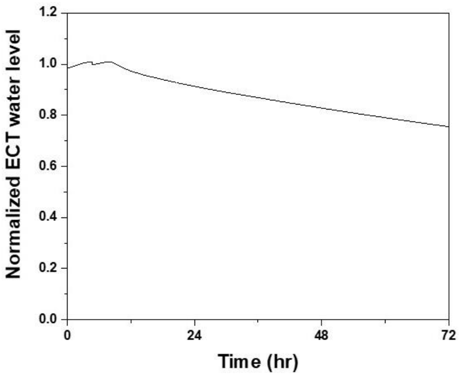

Fig. 7. Nomalized ECT Water Level

4. Conclusions

The SMART natural circulation cooldown performance analysis is performed using MARS-KS. The design data and MARS-KS nodalization of the SMART standard design as well as the safe shutdown acceptance criteria for the passive safety systems are used in this study. As a result, the average core coolant temperature decreases due to cooldown by the passive safety systems and reaches safe shutdown conditions of 215 ºC at 3 hours after the LOOP and maintains safe shutdown condition until 72 hours of operator grace time. Thus, it is shown that the SMART satisfies the natural circulation cooldown acceptance criteria using such passive safety systems as the PRHRS and PSIS. Furthermore, since the ECT water level is maintained above 80% even after 72 hours, the PRHRS has sufficient cooldown capacity. In further study, it is needed to consider detailed design change of the SMART fully passive system, and perform additional sensitivity study.

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