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Transient Analysis of Loss of Main Feedwater for SMART Power Plant

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1. Introduction

SMART (System-integrated Modular Advanced ReacTor) developed by KAERI is a small-scale integral-type reactor which contains core, four reactor coolant pumps (RCPs), eight steam generators (SGs) and pressurizer (PZR) within a single reactor pressure vessel (RPV). Steam Generator tube of which shape is helical is the secondary side, which is different with typical Pressurized Water Reactor (PWR).

For the safety enhancement, SMART has the design characteristics of adopting the inherent and passive systems such as Passive Safety Injection System (PSIS) and Passive Residual Heat Removal System (PRHRS).

PSIS prevents core uncovery by injecting water into Reactor Coolant System (RCS). It consists of four mechanically independent trains with a 33% capacity each, and each train is composed of one Core Makeup Tank (CMT) and one Safety Injection Tank (SIT) with related valves, instrumentation equipment, one Safety Injection Line (SIL) and Pressure Balance Line (PBL). As the low-pressure signal in the pressurizer, or the high-pressure signal in the containment building, or the PRHRS actuation signal is initiated by accident, the borated water in CMT will be injected into the RCS, with SIL isolation valves opened by CMT actuation signal.

PRHRS consists of a condensing heat exchanger, an emergency cooling tank, and a makeup tank prevents over-heating and over-pressurization of the primary system in the case of an emergency event. It removes the decay and the sensible heat through a two-phase natural circulation. As a design requirement, two trains of PRHRS should be operable during the shutdown cooling operation.

In this study, the thermal-hydraulic behavior under Loss of Main feedwater (LOMF) is examined. The MARS-KS model has been developed and the thermal-hydraulic behaviors depending on the number PRHRS has been compared. As a result, the success criteria for PRHRS under LOMF are derived and PRHRS design has been verified.

2. MARS Modeling

Nodalization of SMART for LOMF transient analysis is presented in Fig.1. It contains RCS, the secondary system and the passive safety system such as PRHRS, CMT and SIT. A reactor protection system (RPS) is designed to immediately terminate the nuclear chain reaction. RPS critical plant parameters during all plant operating modes initiate a reactor trip when a Limiting Safety System Settings (LSSS) is reached. The value of LSSS is presented in Table. 1

Table.1 LSSS of SMART RPS

Trip Signal	LSSS
Low pressurizer pressure [MPa]	12.13
High pressurizer pressure [MPa]	16.26
Low Main Steam pressure [MPa]	4.2
High Main Steam pressure [MPa]	6.2
Low Feedwater flowrate [kg/s]	4.02

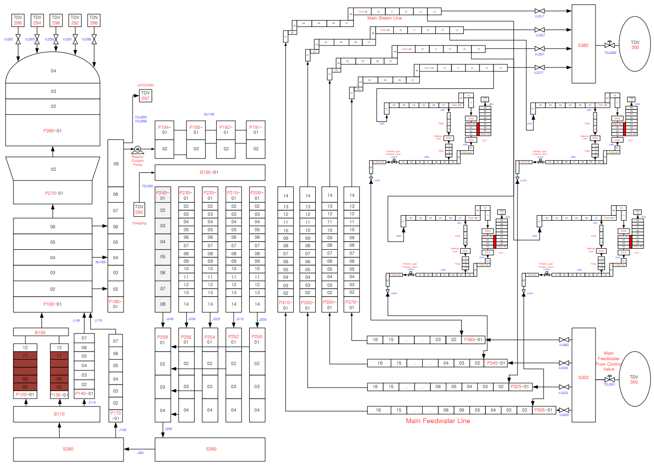

Fig. 1 MARS-KS Nodalization of SMART

3. Steady State Analysis

Initial conditions are calculated by steady state analysis using MARS-KS[1]. It is important to note that core power is assumed to 103 % to consider the uncertainty. The result of steady-state analysis is summarized in Table 2 with design value.

Table.2 Steady-State Result of SMART

Parameter	Design (100%)	MARS-KS Calculation (103%)
Core power [MWt]	330.0	339.9
RCS flow [kg/s]	2090.0	1988.1
Averaged core flow [kg/s]	1973.1	1876.7
Hot assembly flow [kg/s]	33.4	32.0
Core bypass flow [kg/s]	83.6	79.4
Pressure of PZR [MPa]	15.0	15.7

Temperature of PZR [℃]	342.1	345.8
Pressure of core [MPa]	15.0	15.8
1st SG inlet Temp. [℃]	323.0	328.8
1st SG outlet Temp. [℃]	295.7	300.0
PZR level [%]	70.0	55.0
Feedwater flow [kg/s]	160.8	165.6
Feedwater pressure [MPa]	6.0	6.1
Feedwater temp. [℃]	200.0	200.2

4. Loss of Main Feedwater Accident Analysis

The LOMF occurs due to pump failure, valve malfunction or loss of offsite AC power. It results in a reduction cooling capability through the secondary side. SMART has the following features against this accident;

- Reactor trip on Low Feedwater Flowrate or High PZR Pressure
- 4 Train PSIS which consists of CMT and SIT
- 4 Train PRHRS

A detailed analysis using MARS-KS code has been performed to examine the thermal-hydraulic behavior following LOMF. In the analysis, the followings are assumed;

- Loss of Offsite Power (LOOP) occurs with LOMF simultaneously
- The pressurizer spray and the heater is not operable.
- Pressurizer Safety Valve (PSV) open and close set points are assumed to be 17.27 [MPa] and 13.87 [MPa], respectively.

If LOMF occurs, reactor is tripped by low feedwater flow signal. Then, MFIV/MSIV are closed, CMT valve opened, PRHRS actuation initiated. The major event timings are summarized in in Table 3.

In order to estimate the success criteria for PRHRS in LOMF, the simulations with the different number of PRHRS trains are conducted. As can be seen in Fig. 2 and Fig. 3, more than 2 trains of PRHRS would be available to prevent the LOMF accident progression, which means that RCS would be depressurized and cladding temperature is decreased (Fig.3). On the other hands, in case with only 1 PRHRS is available, RCS pressure would be maintained around PSV setpoint (Fig.2), and the cladding temperature would be increased after 66,500 sec, which results in core damage (Fig.3).

Table.3 Major Event Timing

Event	Time [s]
LOMF occurs	0.001
Reach to low feedwater flow set point	0.1
CMT isolation valve open	0.1
Low feedwater flow trip signal LOOP occurs Reactor trip signal Turbine trip Feedwater flow shut off Initiation of RCP coast-down	1.2
Initiation of control rod insertion	1.7
PRHRS isolation valve open MFIV close	5.1
MSIV close	20.1

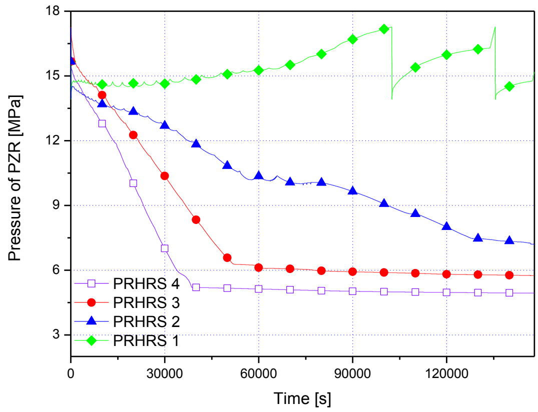

Fig.2 PZR Pressure

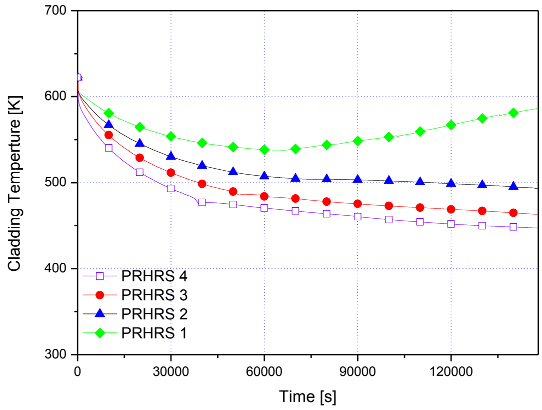

Fig.3 Cladding Temperature

5. Conclusion

The thermal-hydraulic transient analysis has been performed to provide the success criteria for PRHRS under LOMF accident. It has been shown that at least 2 trains of PRHRS shall be available to prevent the accident progression and core damage. As a result, it is verified that the design requirement of PRHRS is conformed.

6. References

[1] MARS Code Manual, KAERI, 2009