Analysis of Success Criteria for POS5 in OPR-1000 using MARS-KS

Dohun Kwon, Eojin Jeon, Gyunyoung Heo[*]
Kyung Hee University, Yongin-si, Gyeongi-do, 17104, Korea
[*]*Corresponding author: gheo@khu.ac.kr*

1. Introduction

This study was carried out as a part of the 'Development of Multi-unit PSA Regulatory Verification Technology' project, and it would introduce the analysis of success criteria regarding operator action time for Plant Operating State(POS) 5, aiming for Low Power and Shutdown(LPSD) PSA.

At the POS5, the coolant inventory is maintained at the mid-loop level of the hot legs, and there is not much quantity that can be filled by injection of coolant because of the open man-ways of the steam generators for the installation of the nozzle dam [1]. It is well known that operator actions to return the functionality of shutdown cooling when it fails are extremely important [2]. Therefore, in order to cross-check the available time for operator actions, in this study, we developed the thermal-hydraulic models using the MARS-KS 1.5 under the operating conditions of POS5 for OPR-1000 and investigated the related success criteria [3, 4].

2. Modeling Processes

2.1 Steady State Modeling

The model was referred from the nodalization for the full-power mode of Korean standard Nuclear Power Plants(NPPs) [5]. The model was revised to simulate the LPSD operating modes by reflecting the particular operation situation and conditions.

The initial conditions of the steady-state were set as the first step. The RCS(Reactor Coolant System) pressure was setup as an atmospheric pressure, and a boundary condition was also given as the same one at the top of the pressurizer. The working fluid at the interface was set to the air. The RCS temperature was assumed to be a standard condition, 330.15 K. The inventory inside the steam generators was assumed to be zero to simulate the complete drain. The reactor power was assigned as the value of decay heat at the timeline of POS5 after shutdown. The RCP(Reactor Coolant Pump) is stationary. The total flow rate of the SCS(Shutdown Cooling System) was regarded as the design flow rate of a single LPSI(Low Pressure Safety Injection) considering the plant configuration in POS5. All numerical data were confirmed through the references that can be viewed in relation to the research aforementioned.

The following figures are the graphs of the main parameters during the steady state in POS5.
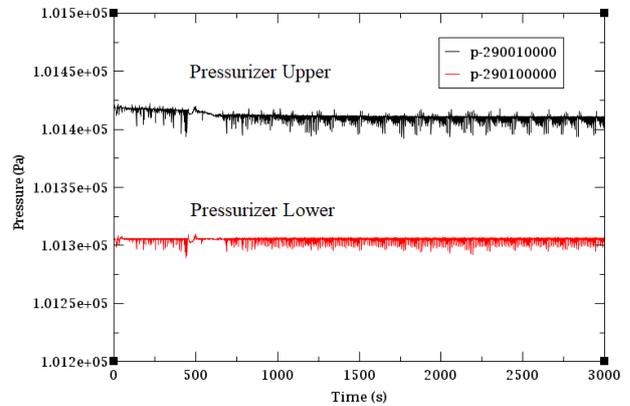
Fig. 1. Pressurizer Pressure
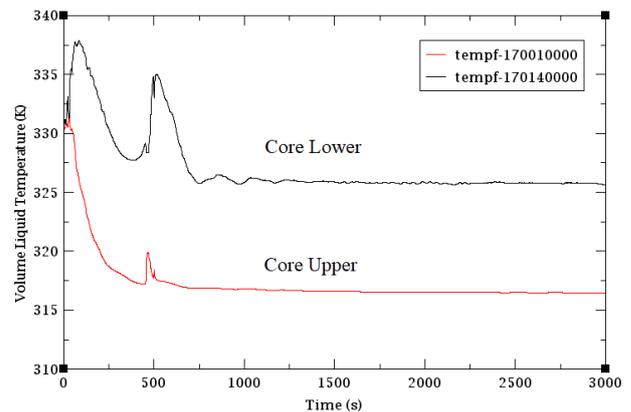
Fig. 2. Core Temperature
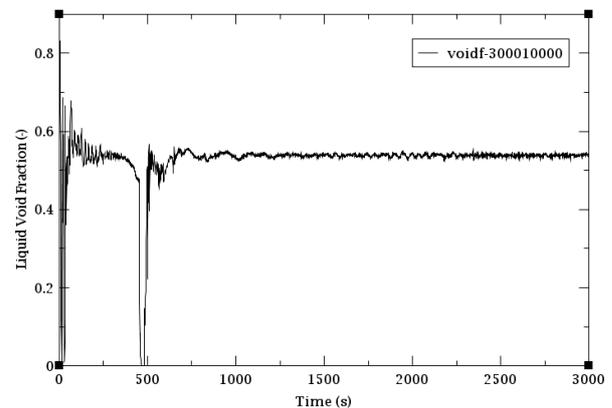
Fig. 3. Hot Leg Liquid Volume Ratio

Fig. 1 shows that the pressure at the top of the pressurizer would be stabilized near atmospheric pressure. In Fig. 2, the core temperature was also confirmed to be maintained under 330 K. Besides, the hot leg liquid volume

ratio was found to be stabilized near 0.5. In conclusion, the steady state was well established upon the above phenomenological results.

2.2 Transient Analysis

The initiating events for this study include: RCS Over-draining due to SCS(SO), Low level of RCS due to SCS(SN), Station Blackout(SBO) after Loss of Offsite Power (LOOP), Recoverable loss of SCS(S1), Unrecoverable loss of SCS(S2), Recoverable LOCA(Loss of Coolant Accident) due to SCS(HL), and Unrecoverable LOCA due to SCS(JL).

Total 8 initiating events have been reviewed in terms of their similarity of sequences and divided into four groups, SO/SN, S1/S2, HL/JL, SBO after LOOP. We also developed and analyzed the models turned for representative 'OK' sequences of each group's event tree.

For all modeling, it was assumed that the success criteria for the redundant systems and the available time for operator actions would be the same as the data that can be referred from plant utility's information.

2.2.1 SO/SN Event

SO or SN are the accidents where the level in the hot leg is drained lower than the mid-level of a leg. At this time, it is assumed that the hot leg level ratio gets decreased down to 0.3. The event sequence follows (1) initiating event, (2) failure of inventory makeup, and (3) success of feed by at least one of HPSI(High Pressure Safety Injection), LPSI, or CVCS(Chemical and Volume Control System). In this study, CVCS was assumed to operate due to conservatism.

2.2.2 S1/S2 Event

S1 or S2 are the accidents when the residual heat removal function stops. The event sequence follows (1) initiating event, (2) failure of restoring SCS, and (3) success of feed by at least one of HPSI, LPSI, or CVCS. CVCS was also assumed to operate due to conservatism.

2.2.3 HL/JL Event

HL or JL occurs when there is leak in an RCS or the others. The event sequence follows (1) initiating event, (2) success of LOCA isolation, and (3) success of SCS startup.

2.2.4 SBO after the LOOP Event

SBO happens when all electrical power sources from inside (i.e. LOOP) and outside are cut off. The event sequence follows (1) initiating event, (2) failures of supply electrical power from ACC(Alternate AC), and (3) success of offsite power recovery, and (4) success of feed by HPSI or LPSI. In this case, the availability of CVCS is excluded.

3. Simulation Results

3.1 SO/SN Results

Fig. 4 and Fig. 5 show the variation of core level and cladding temperature in case of SO or SN over time.
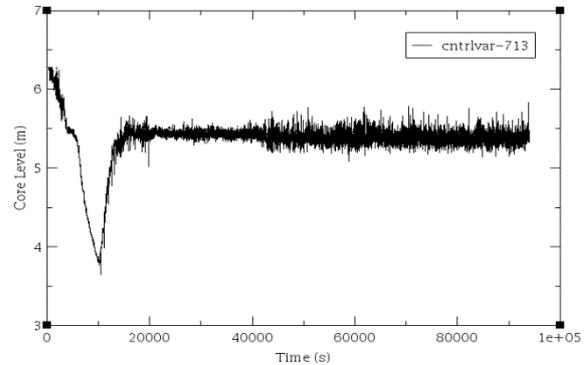
Fig. 4. SO/SN Core Level
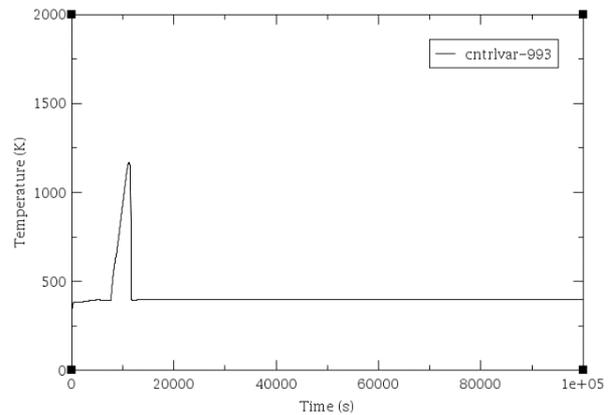
Fig. 5. SO/SN Cladding Temperature

When SO or SN occurs, SCS fails to work due to the failure of inventory makeup, causing core level decreased and cladding temperature increased. CVCS then starts by an operator within an available time. As a result, the cladding temperature is recovered to a safe state.

3.2 S1/S2 Results

Fig. 6 and Fig. 7 show the variation of core level and cladding temperature in case of S1 or S2 over time.
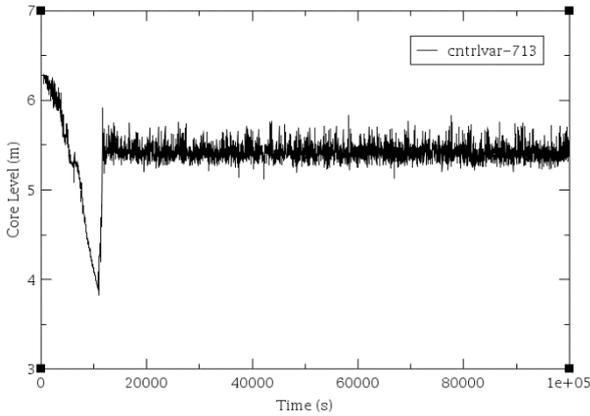
Fig. 6. S1/S2 Core Level
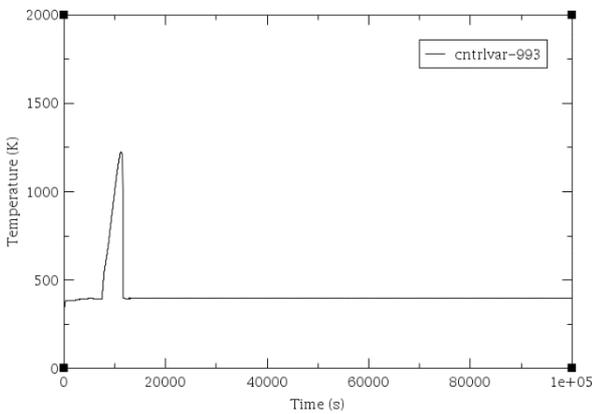
Fig. 7. S1/S2 Cladding Temperature

When S1 or S2 occurs, SCS fails to work due to the failure of restoring SCS, causing core level decreased and cladding temperature increased. CVCS then starts by an operator within an available time. As a result, the cladding temperature is recovered to a safe state.

SN/SO and S1/S2 has the same criteria in terms of operator's available time (about 10,000 seconds) after the failure of inventory makeup and restoring SCS, respectively. Therefore, the patterns of SN/SO and S1/S2 show similar ones.

3.3 HL/JL Results

Fig. 8 and Fig. 9 show the variation of core level and cladding temperature in case of HL or JL over time.
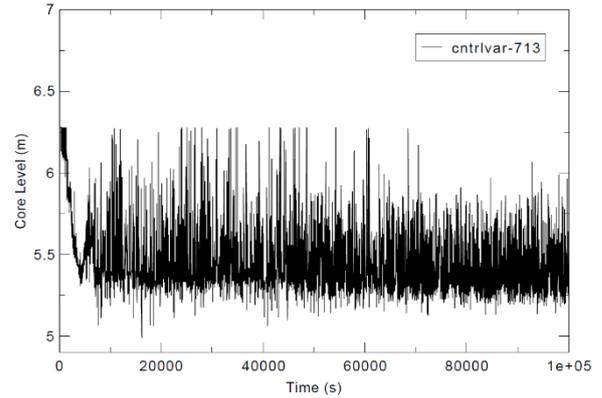
Fig. 8. HL/JL Core Level
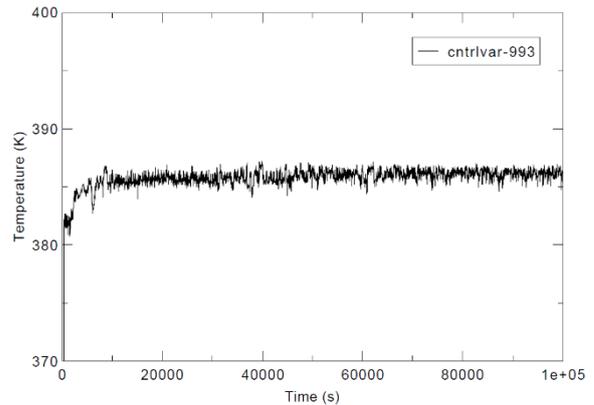
Fig. 9. HL/JL Cladding Temperature
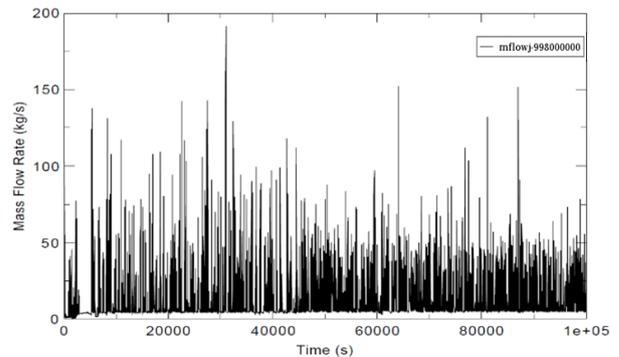
Fig. 10. HL/JL Mass Flow Rate in Broken Part

When HL or JL occurs, reactor coolant leaks through a broken part in Fig. 10, causing core level decreased and cladding temperature increased. After the accident, HPSI starts up by an operator, which is the success criteria of isolating of LOCA location and making up inventory. In this case, HPSI is used due to HL/JL usually occurs in near the places where CVCS and SCS are connected. Comparing to other groups, the injection starts earlier so the cladding temperature is not increased so much. Obviously, the cladding temperature is recovered to a safe state.

3.4 SBO after LOOP Results

Fig. 11 and Fig. 12 show the variation of core level and cladding temperature after SBO over time.
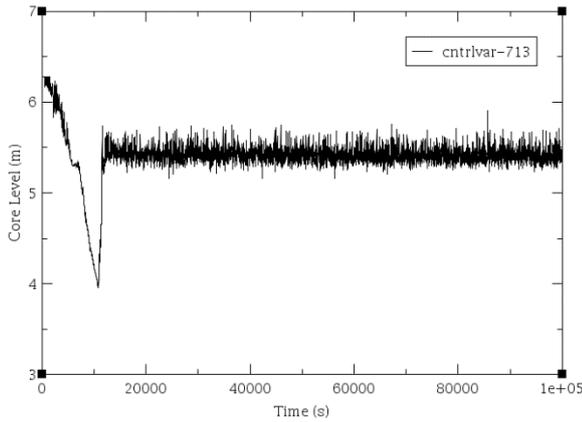
Fig. 11. SBO after LOOP Core Level
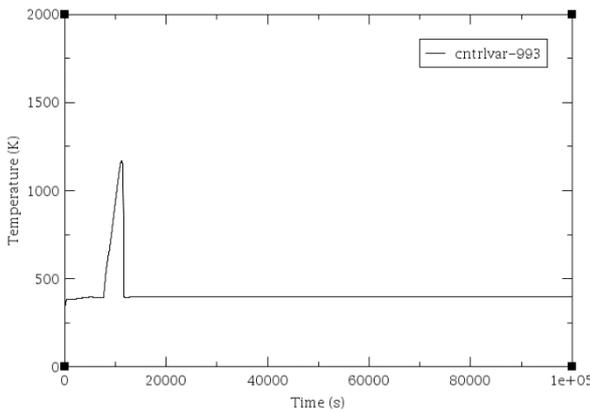
Fig. 12. SBO after LOOP Cladding Temperature

When SBO occurs, SCS fails to work due to power loss, core inventory is evaporated through the pressurizer, causing core level decreased and cladding temperature increased. After the success of offsite power recovery and the feed by HPSI actuated by an operator, as a result, the cladding temperature is recovered to a safe state.

4. Conclusions

In this study, the accident scenarios for the LPSD POS5 of OPR-1000 were modelled and the success criteria were checked with focusing on the available time for operator actions using MARS-KS. As a result of representative sequences from each group, it was observed that safe recovery would be achieved without core melting at the suggested operation action timing.

It should be noted that the reference model may be a little bit different depending on a specific OPR-1000, so detailed results may be also interpreted considering design specifications.

REFERENCE

[1] Y. S. Son, Thermal-Hydraulic Accident Analysis During Low Power/Shutdown Operation at Korea Standard Nuclear Power Plant, Dongeui University, 2005.
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[5] KAERI, "Development of the MARS Input Model for Ulchin 3/4 Transient Analyzer, KAERI/TR-2620/2003, 2003