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Analysis of Small Break LOCA with Loss of Safety Injection for APR1400 using SPACE

Seong Min Hong*, Seok Jeong Park, Jeong Joo Kim, Chan Eok Park, Min Soo Park, Gyu Cheon Lee
Safety Analysis Group, KEPCO-E&C, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Rep. of KOREA
**Corresponding author:hsm8807@kepco-enc.com*

1. Introduction

The Small Break Loss of Coolant Accident (SBLOCA) with Loss of Safety Injection(LOSI) is an accident where the inventory volume of the reactor coolant system(RCS) and the pressure of the RCS are decreased due to the SBLOCA but safety injection is not performed. The RCS pressure is decreased below the safety injection signal due to continuous leakage of the RCS coolant even after reactor shutdown, but the RCS inventory continues to decrease due to failure of the safety injection. Without proper operator action, RCS inventory may decrease and fuel exposure may occur.

The accident was selected as one of the KINS Regulatory Guideline(RG) 16.1[1], "Evaluation of Accident Due to Multiple Failure" and the following items shall be verified by evaluation.

1) The pressure reduction capability of the reactor system through cooling of the secondary system.
2) The ability to remove decay heat from the shutdown cooling system and reach the cold shutdown.
3) Relevant operator action time and basis.

SBLOCA+LOSI analysis using newly developed code, Safety and Performance Analysis Code (SPACE)[2], was performed in order to confirm the above regulation.

2. Analysis Methodology

2.1 Plant Modeling and Initial Conditions

APR1400 plant is two-loop 3,983 MWt pressurized water reactor. Table I shows the initial conditions for SBLOCA+LOSI analysis.

Table I. Initial Conditions for SBLOCA+LOSI Analysis

Parameter	Design Value	Analysis Value
Core Power, MWt	3,983	3,983
Pressurizer pressure, MPa(a)	15.51	15.51
RCS flow rate, kg/s	20,991	20,991
Core inlet temperature, K	563.7	564.5
Secondary pressure, MPa(a)	6.89	6.92
Secondary steam flow rate, kg/s	2,262	2,251
Pressurizer level, %	50	50
Steam Generator level, % NR	50	50

2.2 Assumptions

SBLOCA+LOSI analysis uses a Best Estimate(BE) analysis methodology which interprets accidents using realistic assumptions and conditions.

The size of the SBLOCA break in the PSA methodology is the size that can be mitigated the accident by other functions without safety injection pump when a break occurs. The largest break size of SBLOCA that conforms to the above assumption is determined to be 2-inches dimeter derived from the APR1400 PSA analysis results [3].

Henry-Fauske/Moody critical flow model is used for break model. The decay heat model of ANS79-1 is adopted.

In the case of SBLOCA+LOSI, the Shutdown Cooling System(SCS) can be used to provide injection for RCS inventory control, if the primary system can be depressurized below the SCS pump shut-off head before core damage begins. Depressurization of the primary system is achieved by aggressively cooling the primary system using the secondary heat removal system.

At 30 minutes, an aggressive cooldown was initiated with 100^{o}F per hour by opening an ADV on each steam generator and delivery the auxiliary feedwater to both steam generators.

3. Analysis Results

SBLOCA+LOSI analysis is performed for the following two cases in order to satisfy KINS RG 16.1. Table 2 shows the event sequence with 2-inches cold leg break for each case.

1) Case 1: No operator action.

2) Case 2: Cooling operation of the secondary system by opening the ADVs.

Table II. Event Sequences of SBLOCA+LOSI for APR1400

Sequence \ Time (sec)	Case 1	Case 2
Event Start	0	0
Reactor Trip	49.4	49.4
MSSV open	54.1	54.1
SI injection fail	61.5	61.5
RCP trip	649.4	649.4

Auxiliary feedwater injection	710.1	710.1
ADV open	-	1,800.0
SIT injection	-	4,130.0
Fuel Cladding Temperature start to increase	4,300.0	-
RCS condition recheas the SCP injection mode	-	6,760.0

3.1 Case 1 : No operator action

Figures 2 and 3 show the system pressure and the collapsed core level, respectively. As shown in the table II, the reactor trip occurs at 49.4 seconds due to hot leg saturation signal. The pressure of the pressurizer decreases rapidly as the RCS leaked due to the break. After the RCS temperature reaches the temperature of the steam generator, the pressure behavior of the pressurizer follows the pressure of the steam generator.

Since the RCS pressure remains above the SIT injection pressure, the RCS inventory is not recovered and the core level is continuously decreased. Eventually, the fuel cladding is exposed and the fuel temperature begins to rise as shown in Figure 4.

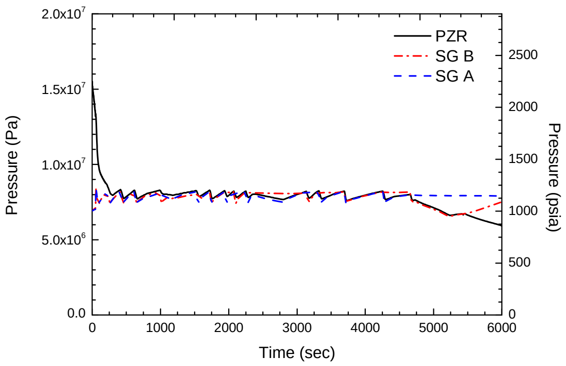

Figure 2. PZR, SG Pressure (Case 1)

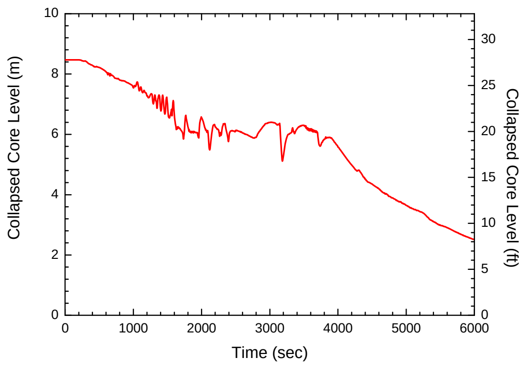

Figure 3. Collapsed Core Level (Case 1)

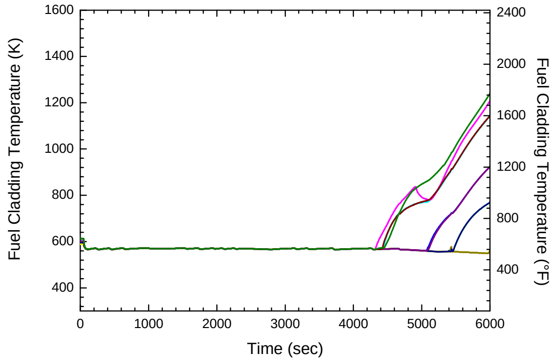

Figure 4. Fuel Cladding Temperature (Case 1)

3.2 Case 2 : Cooling operation of the secondary system by opening the ADVs

Figures 5 and 6 show the system pressure and the collapsed core level, respectively. The RCS pressure drops to the SIT injection pressure, and the core level is recovered as the SIT is injected. As a result, with the recovery of the core level through the ADV operation by the operator, there is no increase in the fuel cladding temperature as shown in Figure 7. The RCS pressure reaches 280 psia at about 6,760 seconds. At this point, SCS injection can begin and RCS inventory control is restored. Note that this result is the result of not modeling the SCS in the accident analysis. If the SCS is modeled, the core level is expected to recover faster.

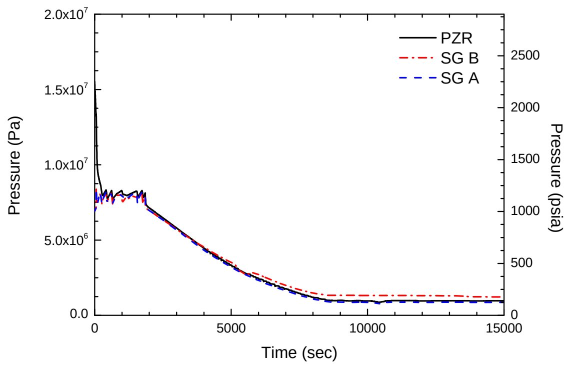

Figure 5. Pressurizer Pressure (Case 2)

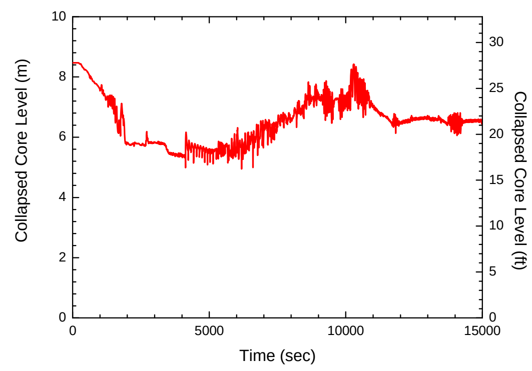

Figure 6. Collapsed Core Level (Case 2)

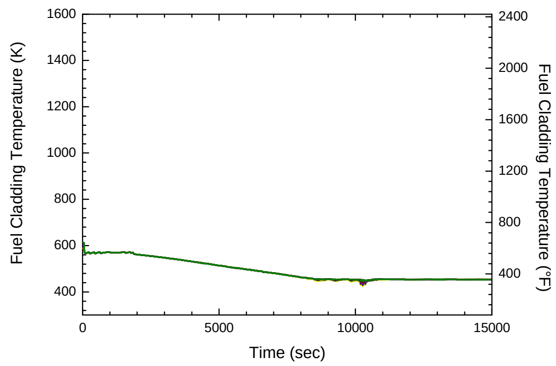

Figure 7. Fuel Cladding Temperature (Case 2)

4. Conclusions

SBLOCA+LOSI, one of the multiple failure accidents, was calculated using the SPACE code. Analyses for the APR1400 plant have shown that if aggressive cooldown using the secondary system is initiated within 30 minutes after the initiation of a small LOCA, the SCS can successively provide RCS inventory control.

ACKNOWLEDGEMENTS

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