An Evaluation of a Coolant Injection into an In-Vessel with a RCS Depressurization during a SBLOCA in OPR1000

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1. Introduction

Coolant injection into an in-vessel with a RCS (reactor coolant system) depressurization is a very important strategy to prevent a reactor vessel failure during a severe accident. This can be achieved by the operation of the safety injection system with a RCS depressurization by using the safety depressurization system (SDS) and the steam generator. The positive effects of this strategy are to cool down the core, to prevent a reactor vessel failure, and so on. The negative effect of this strategy is an enhanced hydrogen generation and so on. For this reason, this strategy of a severe accident management should be evaluated in detail.

A coolant injection into an in-vessel with a RCS depressurization to prevent a reactor vessel failure in OPR (Optimized Pressure Reactor) 1000 has been evaluated by using the SCDAP/RELAP5 computer code[1]. In this study, a small break loss of coolant accident (SBLOCA) was selected as an initial event, because this is a dominant severe accident sequence in the OPR1000. The safety injection into the in-vessel with a RCS depressurization by using the steam generators has been evaluated for a SBLOCA. Sensitivity studies on coolant injection timing and its capacity have been performed to determine the proper operation time.

2. SCDAP/RELAP5 Input Model

The input model for the SCDAP/RELAP5 calculation of the OPR1000 was a combination of the RELAP5, SCDAP, and COUPLE input models. Heat structures for the fuel rods and the lower part of the reactor vessel in the RELAP5 input model were replaced by SCDAP and COUPLE input models, respectively. In the RELAP5 models, the reactor core was simulated as 3 channels to evaluate the thermal-hydraulic behavior in detail and each channel was composed of 10 axial volumes, as shown in Fig. 1. A surge line and a pressurizer were attached to one of the hot legs in the primary coolant loop. Four SITs (safety injection tank) were connected to the cold legs. One SDS valve for a direct depressurization of the RCS was connected to the top of the pressurizer. Three safety injection lines of the high pressure safety injection (HPSI) and the low pressure safety injection (LPSI) were connected to the cold legs without a broken loop, respectively. As a secondary feed system during the transient, the auxiliary feedwater system was modeled. Eight condenser dump valves (CDVs) and four atmospheric dump valves (ADVs) for a depressurization of the steam generator were modeled in the main steam line.

In the SCDAP input model, the component numbers for the fuel and the control rods were 3 and 3, respectively, in this study. The axial node number of the fuel and control rods was 10 in each, and the radial node numbers for the fuel and the control rods were 6 and 2, respectively. In the COUPLE input, the lower part of the reactor vessel was divided into 234 nodes and 204 elements.

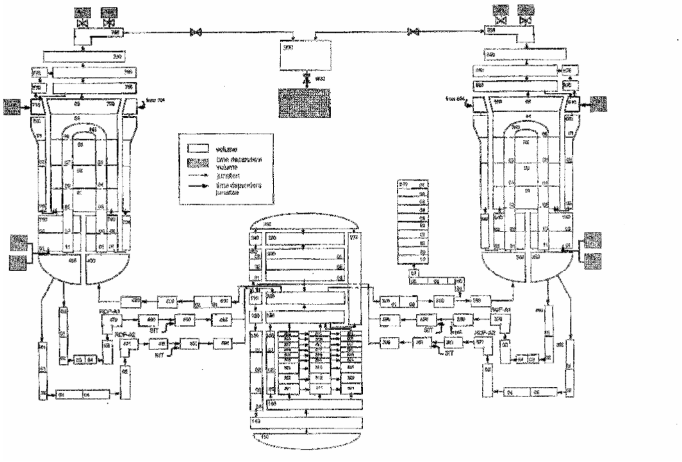

Figure 1. SCDAP/RELAP5 input model for OPR1000.

3. Results and Discussion

The base case of the SBLOCA was initiated by producing 1.35 inch of equivalent diameter breaks in the cold leg. The reactor and the RCPs were assumed to be tripped at an accident initiation time. The secondary side of the steam generator was fed by auxiliary feedwater pumps. The RCS water inventory rapidly decreased and a boiling started in the core because the safety injection pumps were not actuated. The fuel began to heat up when the core was uncovered. The relatively thin ZrO_2 shell ruptured at about 2,700 K because the shell strength decreased with the temperature increase. The bottom of the core dried out because a hot mixture of the liquefied fuel and cladding had relocated downward. Debris was formed at the bottom of the fuel rods, where the liquefied mixture had resolidified. The melted core material had relocated to the lower plenum of the reactor vessel. Finally, the reactor vessel was failed by a creep through a melt thermal attack.

Table 1 shows the SCDAP/RELAP5 results for the significant events for a SBLOCA. In the Table, CDV1-6 min means that one condenser dump valve is opened at

6 minutes after the SAMG is initiated, and SDS1-32500 means that one SDS valve is opened at 32,500 second after the transient is initiated. LPSI3 and HPSI1 mean the three train injections of the LPSI and one train injection of the HPSI, respectively. In the base case of a SBLOCA without SI, the SAMG implementation time was 4,636 sec and the reactor vessel failure time was 6,330 sec[2].

Table 1. Significant events for SBLOCA in OPR1000.

Case	SIT Act. Time, SI Act. Time (s)	RV Failure Time (s)	RCS Pressure at RV Failure (MPa)
Base	-	6,330	6.72
CDV1- 6 min	5,328(SIT)	34,030	3.34
CDV1- 6min, SDS1-32500	5,328(SIT)	33,095	2.25 < (2.9 MPa)
CDV1-6 min, LPSI3	5,328(SIT), 7,832(LPSI)	40,200	3.30
CDV1-6 min., HPSI1-30000	5,328(SIT), 30,000(HPSI)	No RV failure to 50,000 s, Fuel Melting = 30,359 s	
CDV2-6 min., LPSI1	5,152(SIT), 5,782(LPSI)	No RV failure &Core Melting to 50,000 s	
CDV1-6 min, LPSI1, SDS1-32500	5,328(SIT), 7,832(LPSI)	No RV failure &Core Melting to 50,000 s	

As shown in Table 1, only one train operation of a HPSI at 30,000 seconds with a RCS depressurization by using one CDV valve at 6 minutes after an implementation of the SAMG prevents a reactor vessel failure. In this case, only the LPSI operation without the HPSI does not prevent a reactor vessel failure. Only the LPSI operation without the HPSI with a RCS depressurization by using two CDV valves at 6 minutes after an implementation of the SAMG prevents a reactor vessel failure. Only the LPSI operation without the HPSI with a RCS depressurization by using one CDV valve at 6 minutes after an implementation of the SAMG and one SDS valve opening at 32,500 seconds prevents a reactor vessel failure for the SBLOCA.

Fig. 2 shows the pressurizer pressure during the SBLOCA. After the LOCA occurs at 0 sec, the pressurizer pressure rapidly decreases to the saturation pressure corresponding to the hot leg temperature at the beginning of the transient. As the coolant began to boil, the expansion of the coolant caused by a boiling was able to compensate for the break flow, and the pressure maintained a saturation pressure. When the operator opened the secondary bleed system, the pressurizer pressure was decreased rapidly. The steady decrease in the pressurizer pressure stopped after the SITs began a coolant injection to the RCS. When the injected liquid entered the core, it boiled, thus raising the pressurizer pressure. This increased pressure was terminated by the no coolant injection from the SITs, and the pressure decreased again. When the pressure was low enough, the coolant was injected again. This cycling of the SITs actuation leads to reducing the RCS pressure slowly. In case of no operation of the safety injection, when the molten core material is relocated to the lower plenum, the pressurizer pressure increased because of a coolant boiling in the lower plenum. When the safety injection was actuated, the pressurizer pressure was not decreased by a boiling of the injected water.

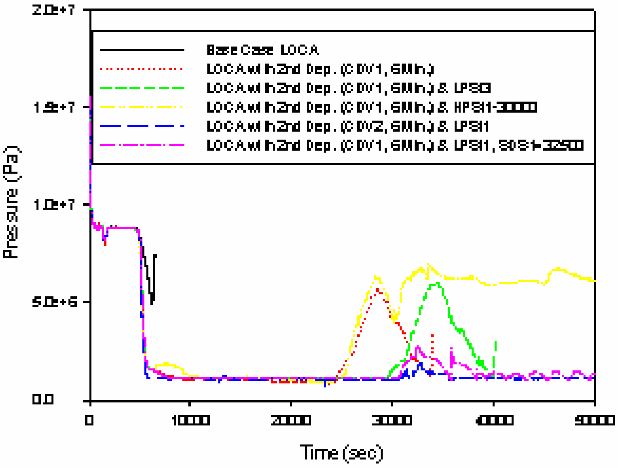

Figure 2. Pressurizer pressure for the SBLOCA

4. Conclusion

A coolant injection into an in-vessel with a RCS depressurization to prevent a reactor vessel failure has been evaluated during a SBLOCA in the OPR1000. The SCDAP/RELAP5 results have shown that that only one train operation of the HPSI at 30,000 seconds with a RCS depressurization by using one CDV valve at 6 minutes after an implementation of the SAMG prevents a reactor vessel failure for SBLOCA. In this case, only the LPSI operation without the HPSI does not prevent a reactor vessel failure. Only the LPSI operation without the HPSI with a RCS depressurization by using one CDV valve at 6 minutes after an implementation of the SAMG and one SDS valve opening at 32,500 seconds prevents a reactor vessel failure

ACKNOWLEDGMENTS

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