Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

An Evaluation of the RCS Depressurization Strategy using the SCDAP/RELAP5 Computer Code

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1. Introduction

Depressurization of the RCS (reactor coolant system) is a very important strategy to mitigate severe accident. This can be achieved by a secondary depressurization using the feed & bleed operation and by a direct RCS depressurization using the SDS (safety depressurization system). The positive effects of this strategy are to be able to supply the coolant into the RCS, to prevent the HPME (high pressure melt ejection) at a reactor vessel failure, and to prevent a RCS pipe line failure. Also, this strategy may have negative effects, such as, an increase of in-vessel steam explosion possibility, a decrease of the RCS coolant inventory, over-pressurization of the containment, and so on. The consequences on the RCS coolant inventory are different for the different types of depressurization. For this reason, this strategy of severe accident management should be evaluated in detail.

The RCS depressurization strategy to mitigate the severe accident in OPR (Optimized Pressure Reactor)1000 has been evaluated using the SCDAP/RELAP5 computer code[1]. In this study, two high pressure sequences of a 1.35 inch break LOCA (loss of coolant accident) without SI (safety injection) and a TLFW (total loss of coolant accident) were selected as initial events. The secondary depressurization using the feed and bleed operation was evaluated in the 1.35 inch break LOCA without SI. The direct primary depressurization using the SDS was evaluated in the TLFW. Sensitivity studies on depressurization timing and its capacity have been performed.

2. SCDAP/RELAP5 Input Models

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 SIT (safety injection tank)s are connected to the cold legs. Two SDS valves for direct depressurization of the RCS are connected to the top of the pressurizer.

The steam generator secondary side consists of a cylindrical shell, a downcomer through which the main feedwater is supplied, a separator, and a steam dome. The main feedwater is modeled as time dependent volumes to simulate a normal operation. MSSV (main steam safety valve)s, and a MSIV (main steam isolation valve) are also modeled for a steady state simulation of the OPR1000. The turbine is modeled as a time dependent volume. Eight CDV (condenser dump valve)s and four ADV (atmospheric dump valve)s are 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 component in order to simulate a ballooning and relocation after a rupture of the fuel cladding accurately, 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 is divided into 234 nodes and 204 elements. For the RELAP5, the SCDAP, and the COUPLE input data for the reactor vessel, the specifications outlined in the safety analysis report of the OPR1000 were primarily utilized.

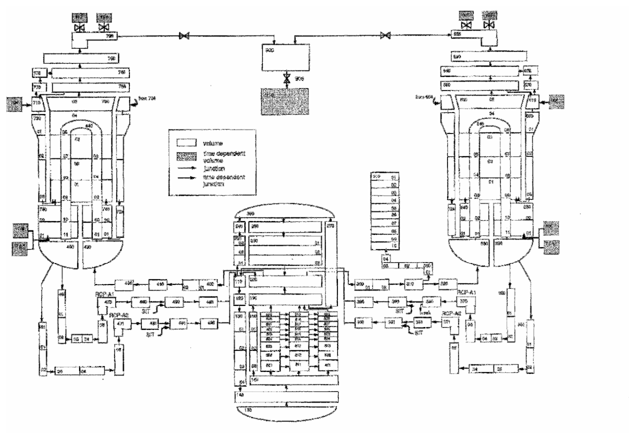

Figure 1. SCDAP/RELAP5 input model for OPR1000.

3. Results and Discussion

Table 1 shows the SCDAP/RELAP5 results on the RCS pressure at a reactor vessel failure in the 1.35 inch break LOCA without SI. Fig. 2 shows the RCS pressure history. It was assumed that the auxiliary feed pump was actuated at 1,265 sec. The entrance condition of the SAMG (severe accident management guidance) is 650 ℃ of the core exit temperature. In the base case of 1.35 inch break LOCA without SI, the SAMG entrance time was 4,636 sec and the reactor vessel failure time was 6,330 sec. For this reason, the selected secondary depressurization times were at 1, 5, 6, 7, 10, 16 minutes after the SAMG entered. The depressurization capacity was from 1 to 8 CDVs and 1 to 4 ADVs.

As shown in Table1 and Fig. 2, the secondary feed and bleed operation can depressurize the RCS, but it can not depressurize the RCS to 2.86 MPa (RCS depressurization condition) at a reactor vessel failure. For this reason, more RCS depressurization is necessary in the 1.35 inch break LOCA without SI. The proper RCS depressurization time and capacity lead to postpone the reactor vessel failure time from 7.5 to 10.7 hours.

Table 2 shows the SCDAP/RELAP5 results on the RCS pressure at a reactor vessel failure in the TLFW. Fig. 3 shows the RCS pressure history. In the TLFW, the direct RCS depressurization using the SDS was evaluated, because the secondary feed and bleed operation was not possible. In the base case of the TLFW, the initial opening time of pressurizer SRV (safety relief valve) was 1,606 sec and the reactor vessel failure time was 6,115 sec. For this reason, the depressurization times were at 5, 10, 30, 40, 50, and 60 minutes after initial opening of the pressurizer SRV. The depressurization capacity was 1 and 2 SDS valves.

As shown in Table 2 and Fig. 3, an opening of two SDS valves can depressurize the RCS sufficiently. The proper RCS depressurization time and capacity lead to postpone the reactor vessel failure time of approximately 5 hours. The opening of one SDS valve can not depressurize the RCS sufficiently.

Table 1. RCS pressure at reactor vessel failure in

Case	SIT Act. Time (s)	RV Failure Time (s)	RCS Pressure at RV Failure (MPa)
Base	-	6,330	6.72
CDV1-1 minutes	5,032	33,500	3.65
CDV1- 6 minutes	5,328	34,030	3.34
CDV8 + ADV4- 6 minutes	5,050	44,780	3.41
CDV1- 7 minutes	6,494	6,775	4.2
CDV8 + ADV4- 7 minutes	6,580	7,525	3.04

the 1.35 inch break LOCA without SI.

Table 2. RCS pressure at reactor vessel failure in the TLFW.

Case	SIT Actuation Time (s)	RV Failure Time (s)	RCS Pressure at RV Failure (MPa)
Base	-	6,115	15.2
SDS2- 30 minutes	4,142	23,705	0.85
SDS2- 50 minutes	5,090	5,995	3.1
SDS1- 5 minutes	4,904	6,438	4.08
SDS1- 30 minutes	4,930	10,655	3.17

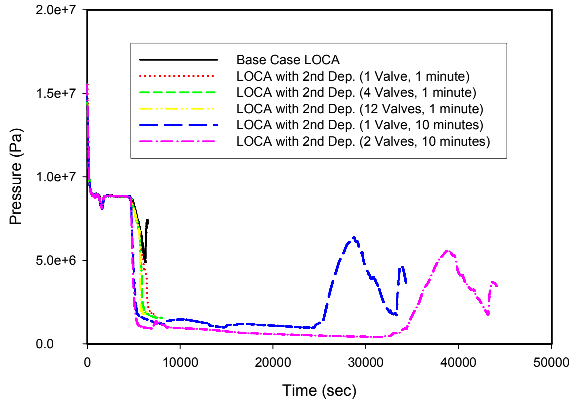

Figure 2. RCS pressure history in the 1.35 inch break SBLOC without SI.

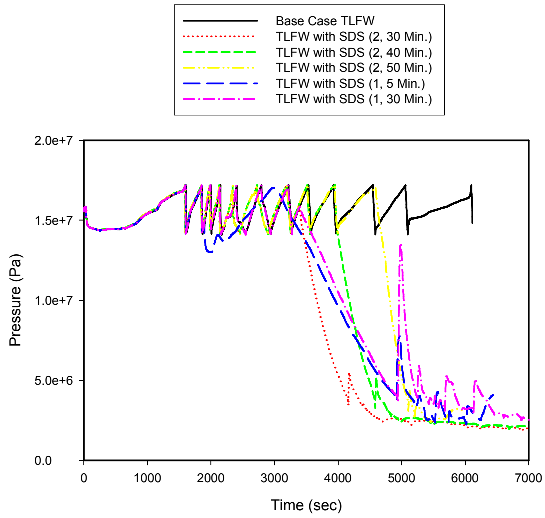

Figure 2. RCS pressure history in the TLFW.

4. Conclusion

The RCS depressurization strategy to mitigate the severe accident in OPR 1000 has been evaluated using SCDAP/RELAP5 computer code. The secondary feed and bleed operation can depressurize the RCS, but it can not depressurize the RCS sufficiently. For this reason, more RCS depressurization is necessary in the 1.35 inch break LOCA without SI. The proper RCS depressurization time and capacity lead to postpone the reactor vessel failure time from 7.5 to 10.7 hours. The opening of two SDS valves can depressurize the RCS sufficiently. The proper RCS depressurization time and capacity lead to postpone the reactor vessel failure time of approximately 5 hours. The opening of one SDS valve can not depressurize the RCS sufficiently.

ACKNOWLEDGMENTS

This study has been carried out under the Nuclear R&D Program by the Korean Ministry of Science and Technology.

REFERENCES

[1] L. J. Siefken et al., "SCDAP/RELAP5/MOD3.3 Code Manual, Vol. I-V," NUREG/CR-6150, 2001.