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Performance Evaluation of Emergency Rapid Depressurization Function in APR1400

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1. Introduction

A depressurization system connected to primary system is usually used when the high pressure accident sequences occur to prevent high pressure melt ejection (HPME)[1][2]. In previous design of APR1400 (SKN 3&4)[3], four pressurizer POSRVs were used for that purpose and new version of APR1400 (SKN 5&6)[4] has two train of emergency rapid depressurization valves (ERDVs). The ERDVs are the system dedicated to severe accident and new version of APR1400 has two systems to prevent HPME

In this study, the ERDVs performances of the new version of APR1400 was evaluated using MELCOR1.8.6[5] and several sensitivity studies of the key parameters were performed.

2. Technical Background

SAMG strategies of APR1400 were examined in view of RCS depressurization.

2.1 SAMG

APR1400 SAMG adopted the several high level actions which could be available for the operators and plant staffs. In general, high level actions in the PWR can be performed by the injection of the reactor pressure vessel/reactor coolant system (RPV/RCS), to depressurize the RPV/RCS, to restart reactor coolant pumps (RCPs), to depressurize steam generators and to inject into the steam generators. In APR1400 SAMG, the following procedure was adopted.

a. Depressurize the RPV/RCS
b. Depressurize steam generators and inject into the steam generators
c. Inject into the RPV/RCS

The coolant injection into RPV/RCS would be delayed due to the time for filling steam generators. Moreover, current procedure to depressurize the RPV/RCS does not specify any corrective actions after checking RCS coolant injection.

2.2 MELCOR code Description

MELCOR is a fully integrated, engineering-level computer code that models the progression of severe accidents in light water reactor nuclear power plants. MELCOR is being developed at Sandia National Laboratories (SNL) for the U.S. Nuclear Regulatory Commission (USNRC) as the successor to the Source Term Code Package.

3. Methods and Results

MELCOR modeling and initial conditions and boundary conditions of the accident are described.

3.1 System Modeling

The RCS model includes the core, primary, and secondary coolant systems. The core is modeled as 5 radial rings and 16 axial levels including top- and bottom-end fittings. It also includes 2 steam generators, 4 reactor coolant pumps, and direct vessel injection from the Safety Injection System to the RCS (see Figure 1). The 51-cell containment model consists of 32 subcompartments, 1 environment, and the 18-cell IRWST with 3 axial levels in which 6 cells are azimuthally separated (see Figures 1).

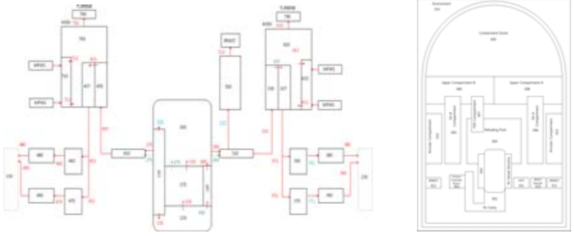

Figure 1. APR1400 MELCOR1.8.6 Nodalization

3.2 Accident Sequences and Boundary Conditions

The station blackout accident was selected in this study, which is one of representative high pressure accident scenarios. As summarized in Table 1, the accident assumes that the reactor trip, feedwater pump trip, and reactor coolant pump trip was assumed at time 0. Due to loss of all electrical power except DC, all active systems and components such as safety injection system, containment spray system are not available. As passive system, four safety injection tank (SIT), safety valves and several essential valves such as POSRVs, main steam atmospheric dump valves (MSADV) are available. The MELCOR1.8.6 achieved steady state conditions are listed in Table 1.

Table 1. MELCOR 1.8.6 Steady State Condition

Parameters		Desired	Simulated	Errors
RCS	Core Thermal Output, 100% (MW$_{th}$)	3,983	3,983	0.00%
	Pressurizer Pressure (MPa)	15.5	15.7	1.29%
	RPV Outlet Temperature (℃)	323.9	336.3	3.83%
	RPV Inlet Temperature (℃)	290.6	299.9	3.20%
	RCS Flow (Mlb/hr)	166.6	140.8	15.5%
SG	Steam Pressure (MPa)	6.89	7.22	4.79%
	Steam Temperature (℃)	285.0	288.0	1.06%
	Feedwater Temperature (℃)	232.2	232.2	0.00%
	Total Steam Flow (kg/s)	2277.8	2265.9	0.52%

Table 2. Differences between POSRVs and ERDVs

Parameters	SKN 3&4	SKN 5&6	Remarks
System Name	POSRV	ERDV	
Number of Trains	4	2	
Design Pressure (MPa)	17.58	17.58	
Design Temperature (℃)	371	371	
Valve Type	Pilot Operated Safety Relief	Motor Operated	ERDV : 1-Globe, 1-Gate in a train
Design Capacity (Ton/Hr)	244.9	449.1	1 Train Capacity

4. Results and Discussions

The Station Blackout sequence was analyzed and several sensitivity studies of the key parameters were performed.

4.1 Base Case

At time 0, the loss of offsite power is occurred with a concurrent demand failure of both the emergency diesel generators and the alternate AC generator. Therefore, the reactor, steam turbine and RCP trip occur at time 0 and MSIVs are closed at the same time. All active systems in RCS are stopped and the forced circulation heat transfer is changed to natural circulation. At 3582 seconds, steam generators are dried out and primary pressure increase upto the set points of pressurizer POSRVs, 17.37MPa (2500psia). Pressurizer POSRVs start to open at 4650 and uncover of the core occurred at 6470 seconds. Core exit thermocouple (CET) temperature exceeds 1200^{o}F at 8200 seconds and operator can start to use the SAMG.

Because the purpose of this study is new ERDVs performance evaluation, first operation to open POSRV is performed at 9600seconds. As RCS pressure decrease, SITs start to inject and all coolant is injected during several hundred seconds. After second core uncovery, core melting restarts and finally, reactor pressure vessel lower head penetration has failed at 12740seconds.

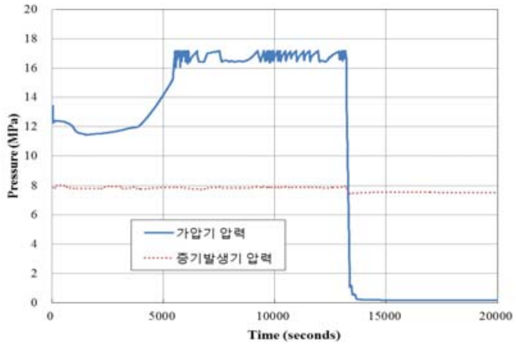

Figure 2. Pressurizer Pressure

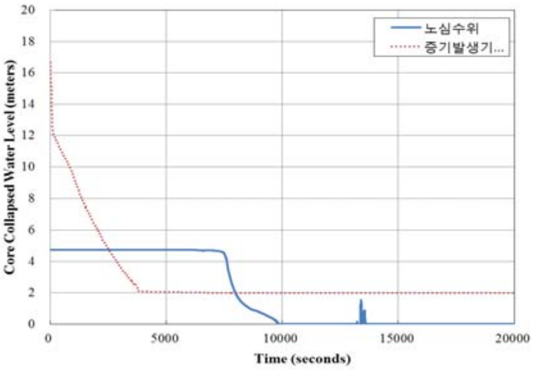

Figure 3. Core Collapsed Water Level

4.2 Sensitivity Cases

In order to evaluate the performance of ERDVs, the timing of the operator actions are selected as sensitivity parameter.

As shown in table 4, the case 2 is ERDV 1 train is opened 1 hour after first POSRVs lift. In this case, the RCS pressure at vessel breach is 1.46MPa, which is less than 1.78MPa (Criteria of DCH). Except case 4, other cases are satisfied by the above criteria.

Table 4. Effectiveness of the Operator Action

Events	Case 1	Case 2	Case 3	Case 4	Case 5 (POSRVs)
Accident Initiation(s)	0.	0.	0.	0.	0.
First POSRV open	5570.	5570.	5570.	5570.	5570.
CET > 1200^{o}F (s)	8200.	8200.	8200.	8200.	8200.
ERDVs Open*(s) (No. of Train)	N/A	9170.s (1 Train)	10970.s (1 Train)	11870. (2 Train)	9000. (2 Train)
UO2 Melting(s)	8443.	8443.	8443.	8443.	8443.
Complete Core Uncovery(s)	9340	9240.	9340	9340	9280.
RCS Pressure at Vessel failure (MPa)	16.7	1.46	0.6	2.23	1.51
Vessel Failure(s)	12740.	20054..	15240..	13126.s	23580.

* Operator Action time is considered using First POSRV open time.

In table 4, the interesting points are the ERDVs operation can delay the severe accident sequences in view of reactor vessel failure. Earlier opening of ERDVs shows that vessel failure times are greatly delayed. Early operation of ERDVs can be recommended.

In view of comparisons between case 3 and 5, ERDVs are more effective than POSRVs because ERDVs can give ~1500 seconds margins in operator action time.

5. Conclusions

Analysis for APR1400 using MELCOR 1.8.6 was performed to evaluate the performance of ERDVs and the following conclusions were identified.

a. ERDVs can provide dedicated system for severe accident and the reliability of depressurization function seems to increase because two systems might be available for this purpose.
b. ERDVs have enough capability to depressurize RCS before reactor vessel failure under the severe accident conditions
c. ERDVs are more effective than POSRVs because ERDVs can give more margins in operator action time.

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