Sensitivity Analysis of Core Damage from Reactor Coolant Pump Seal Leakage during Extended Loss of All AC Power

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1. Introduction

The Fukushima accident was caused by tsunami resulted in Station Black Out (SBO) followed by the reactor core melt-down and release of radioactive materials. After the accident, the equipment and strategies for the Extended Loss of All AC Power (ELAP) were recommended strongly. In this study, in order to comprehend the Fukushima accident, the sensitivity analysis was performed to analyze the behavior of Reactor Coolant System (RCS) during ELAP using the RELAP5/MOD3.3 code.

2. Modeling for Sensitivity Analysis

The RELAP5/MOD3.3 code has been developed for best-estimate transient simulation of reactor coolant system during accident [1]. This code is a tool that allows users to model the coupled behavior of the reactor coolant system and reactor core during accidents. The reactor coolant system behavior is calculated using a two-phase model, which allows unequal temperatures and velocities for the two phase flow.

The objective of this analysis is to have insights on the behavior of the RCS in a sequence of the time to boil-off, fully Steam Generator (SG) dry-out, core uncovery and core damage etc.

The modeling of the OPR1000 type NPP has been developed using the design data. Fig.1 shows the nodalization model of OPR1000 type Nuclear Power Plant (NPP) for the analysis. Hanul Units 3&4 was chosen as a reference plant. The nodes of reactor are composed of the down-comer, lower plenum, upper plenum, core, and junction to connect with the hot leg.

In this study, the core power is considered to be 102% of full-power. In addition, the decay power is conservatively determined to use the Fission Product Yield Factor 1.2 and data of ANS-73.

The pressurizer includes the 10 sub-control volumes and imaginary control volume to maintain the pressure uniformly during the steady state. However, this volume is removed during the transient state.

The secondary side of SG includes the nodes of the main feed-water system, economizer, evaporator, riser, separator, and dome. The main feed-water system is divided to inject into the downcomer and economizer. The inputs of four RCPs of OPR1000 type NPP are referred to the specific design data for the operation. [2]

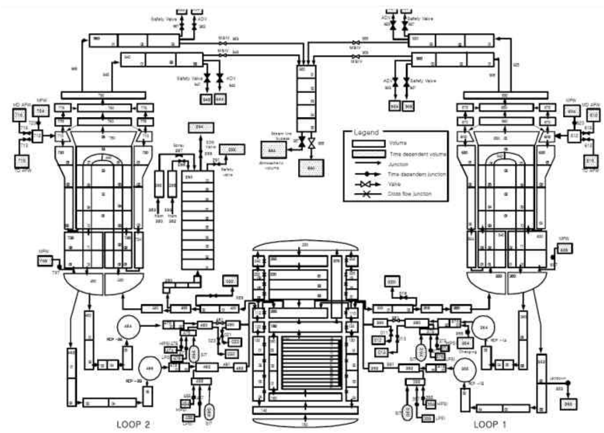

Fig.1. Nodalization Model of OPR1000 Type NPP

3. Analysis Methodology and Results

3.1 Assumption

In order to comprehend the RCS behavior, the detailed condition is assumed as follows. Firstly, the different leakage rates of RCP are considered. It is assumed that the leakage rates are 50 gpm, 300 gpm, and 5 gpm respectively. The minimum leakage rate (5 gpm) and maximum leakage rate (300 gpm) are assumed to limit the RCS behavior. In addition, the mid-leakage rate (50 gpm) is assumed to demonstrate the behavior representatively. Lastly, the accident with the operator action is investigated to demonstrate the cooling effect in the SBO and the risk related to the RCP.

3.2 Scenario

As mentioned above, in order to demonstrate the RCS behavior after the SBO, All of the scenarios for six cases were studied: (1) the different leakage rate of RCP (50, 300, 5 gpm), and (2) the operator action that the secondary side was depressurized using Turbine driven Auxiliary Feed-water Pump (TDAFP) and SG Atmosph eric Dump Valve (ADV) to reduce the leakage of RCP seal. It is necessary to compare the sensitivity cases of the different leakage rates. Thereby, the cases have different conditions with minimum leakage rate of 5 gpm, mid-leakage rate of 50 gpm, and maximum leakage rate of 300 gpm.

3.3 Results

In the Case-1~3, the leakage rate of RCP is assumed 50, 300, 5 gpm/RCP without cooling of secondary side by operator action. Fig.2 shows pressurizer pressure. As soon as the reactor trips, the pressure of pressurizer has initially decreased rapidly. Thereafter, the pressure is gradually decreased with cooling by the steam generator and the leakage of RCP. However, cooling of pressurizer is over due to the S/G dry-out. The leakage of RCP is not sufficient for the depressurization. Finally, the pressure of pressurizer reaches the set-point of opening the Pressurizer Safety Valve (PSV). The RCS inventory began to decrease rapidly, since coolant was discharged through the PSV in addition to RCP seal leakage. Fig.3 shows fuel cladding temperature. Eventually, upper core was completely uncovered at 4,800sec, and core damage time was 5,670sec (Case 1). In Case 2, upper core was completely uncovered at 3,633sec and core damage time is 4,640sec. In Case 3, upper core was completely uncovered at 4,922sec and core damage time is 5,820sec.

In Cases 4~6, the leakage rate of RCP is 50, 300, 5 gpm/RCP with cooling of secondary side by operator action. Fig.4 shows pressurizer pressure. As soon as the reactor trips, the pressure of pressurizer has decreased rapidly in the early. Thereafter, the pressure of that is gradually decreased with the cooling by the steam generator and the leakage of RCP. In Cases 4~6, the PSV is not opened due to the cooling by SG secondary side. The RCS inventory began to decrease rapidly, since coolant was discharged through the PSV in addition to RCP seal leakage. Fig.5 shows fuel cladding temperature. Eventually, upper core is completely uncovered at 216,617sec and core damage time is 243,166sec (Case 4). In Case 5, upper core is completely uncovered at 31,700sec and core damage time is 35,400sec. In Case 6, core is not uncovered.

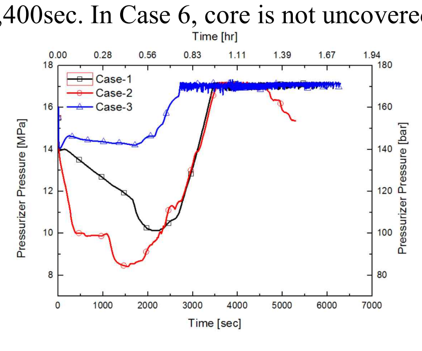

Fig.2. Pressurizer pressure (Cases 1~3)

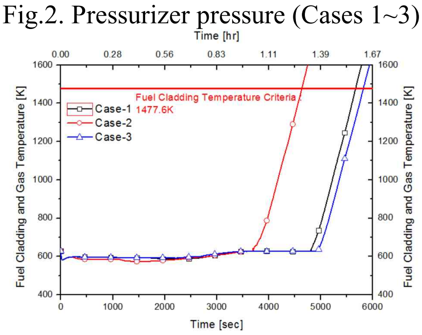

Fig.3. Fuel cladding temperature (Cases 1~3)

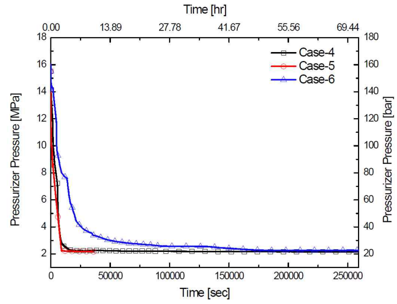

Fig.4. Pressurizer pressure (Cases 4~6)

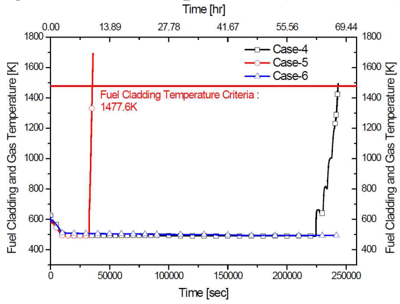

Fig.5. Fuel cladding temperature (Cases 4~6)

4. Conclusions

In this analysis, sensitivity studies for the RCP seal failure of the OPR1000 type NPP were performed by using RELAP5/MOD3.3 code. Six cases with different leakage rate of RCP seal were studied for ELAP with operator action or not. The main findings are summarized as follows:

(1) Without the operator action, the core uncovery time is determined by the leakage rate of RCP seal. When the leakage rate per RCP seal are 5 gpm, 50 gpm, and 300 gpm respectively, the core uncovery time are 1.62 hr, 1.58 hr, and 1.29 hr respectively. Namely, If the leakage rate of RCP seal was much bigger, the uncover time of core would be shorter.

(2) In case that the cooling by SG secondary side was performed using the TDAFP and SG ADV, the core uncovery time was significantly extended. However, if there is much leakage rate of RCP seal, the extension of core uncovery time is limited.

REFERENCES

[1] NUREG/CR-6150, "SCDAP/RELAP5/MOD 3.3 CODE MANUAL," Rev.2, Vol.3, Jan, 2001.
[2] NUREG/CR-5535/Rev P3-Vol Ⅱ App A.
[3] Westinghouse, Reactor Coolant System Response to the Extended Loss of AC Power Event for Westinghouse, Combustion Engineering and Babcock & Wilcox NSSS Designs, WCAP-17601-P Revision 0, August 2012.