Sensitivity Analysis at the Time of MACST Action in Severe Accidents caused by Station Black Out (SBO)

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1. Introduction

After the Fukushima Dai-ichi accident, a lot of study has been conducted on DBA accidents and severe accidents. Among them, through the stress test, a variety of flexible coping strategies (FLEX) were applied to create the need to cope with severe accidents. At the Nuclear Energy Institute (NEI), FLEX is a strategy to mitigate power plant damage by restoring or maintaining various safety functions in the event of accidents using installed portable equipment. Korea nuclear power plant has begun developing a multi-barrier incident response strategy (MACST) based on a general understanding of FLEX as a strategy to cope with the concept of multiple defenses, a mix of European stress test and FLEX strategies of US.

In this study, using the MELCOR, station black out (SBO) accident by an extreme disaster was simulated. As a MACST strategy, the accident mitigation using mobile safety equipment (eq. mobile power generator) was simulated, and the results were analyzed according to the time of installation and operation.

2. Methods and Results

SBO is an accident in which all AC power in the power plant is lost due to the inability to use the on-site emergency diesel generator (EDG) and alternative AC diesel generator (AAC DG) in the event of a loss of power (LOOP). When SBO, all AC power sources, both inside and outside of the building, are lost, and the only 125V DC power supplied from the storage battery is the only power source. Therefore, only the secondary side heat removal operation using the turbine-driven auxiliary water supply pump (TD-AFW) is available, and if the AC power is not restored within a certain time, it will proceed to core damage. In this study, it is assumed that it is impossible to use the TD-AFW due to the loss of in-house battery power by extreme disasters.

In this study, the critical accident time point was defined as a CET temperature of 923K, and assumed a mobile generator installation after progressing from a power failure accident to a severe accident, and the operation status up to 72 hours after the accident occurred. The mobile generator was defined as supplying electricity to a safety-grade charger to supply power to a high-pressure safety injection pump (HPSI), a low-pressure safety injection pump (LPSI), a containment spray pump, a motor-driven auxiliary water supply pump, and other essential safety information display systems and hydrogen concentration sensors.

2.1 Model Description

In this study, the MELCOR version 1.8.6, a major severe accident analysis code, was used to simulate the power plant accident of the Korean Standard Nuclear Power Plant and to analyze the detailed thermal hydraulic power up to the breakdown of the reactor pressure vessel. The nodalization of the used Korean standard nuclear power plant is shown in Figure 1. The reactor coolant system (RCS) is a reactor vessel, a reactor core, a hot leg, a cold leg, a coolant pump, a steam generator, a pressurizer, HPSI, LPSI, and safety injection tank (SIT). The reactor vessel is composed of a downcomer, a lower plenum, a core, a bypass, and an upper plenum. Two high-temperature pipes are connected to the upper hemisphere, of which a pressurizer is connected to one high-temperature pipe. Two safety relief valves are simulated in the pressurizer, and the pressurizer safety valve is set to open and close under a certain pressure condition. The high temperature tube is connected to the U-Tube of the steam generator. HPSI, LPSI, and SIT are connected to the low-temperature pipe. The secondary system consists of the main water supply system (MFW), the auxiliary water supply system (AFW), the atmospheric release valve (ADV), the main steam safety valve (MSSV), and the condenser dump valve system (CDV). In case of main water supply system and auxiliary water supply system, the flow rate is controlled according to the water level of SG. The containment building was modeled in four volumes, including the reactor cavity.

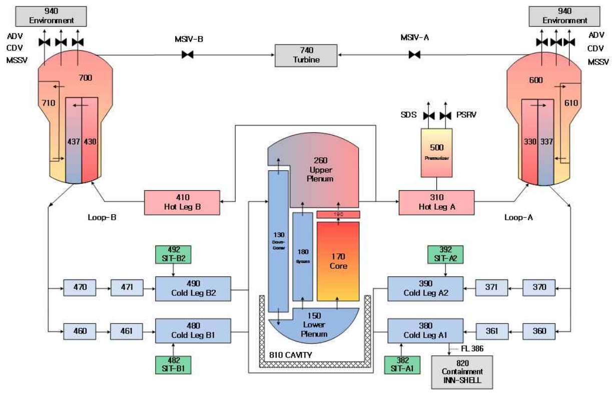

Fig. 1. Nodalization of OPR1000

2.2 Method of analysis

Table I shows the accident sequence of unmitigated SBO. At 0 seconds, the reactor and reactor coolant pumps were stopped. The steam generator was depleted after 1.06 hours due to the overheating of the decay heat after the reactor trip. After the steam generator was exhausted, the reactor pressure vessel was overheated and pressurized, and oxidation of zircaloy cladding occurs in 2.31 hours. After oxidation occurs, the cladding melts at 2.36 hours by the heat of oxidation and the nuclear fuel starts to melt at 2.83 hours. Since it was maintained at a high pressure, the water of SIT was not injected and the reactor pressure vessel was failed at 3.78 hours. The pressure of the RCS at the time of breakage is 16.2 MPa, thus it is expected that the core melt will release at a high pressure.

Table I: Accident sequence of SBO

Sequence	Time (sec)
Rx trip	0.0
RCP trip	0.0
MFW trip	0.0
All SG dryout (< 1,000 kg)	3817.8
PSRV first open	4958.7
Core uncovery start	7015.1
SAMG entrance (CET > 923 K)	8305.2
oxidation start	8316.8
Gap release (cladding failure)	8478.1
Cladding melt	10186.4
UO2 relocation to Lower head	16704.6

RPV failure	17169.8
SIT injection	17282.9

To analyze the effect of FLEX strategy according to the time of installation and operation, different operator actions time were selected: unmitigated accident (Case 1, Base Case), onset of severe accident entry condition (Case 2), delayed from the severe accident entry condition (Case 3: 1 hour delayed, Case 4: 4 hours delayed).

2.3 The Results of mitigated accident

In this analysis, the main accidents are as follows. As shown in Figures 2 and 3, RPV failure did not occur in the case of immediate mitigation at the time of entering the severe accident and mitigation after 1 hour. However, RPV breakage occurred at 4.7h, respectively, after 4 hours.

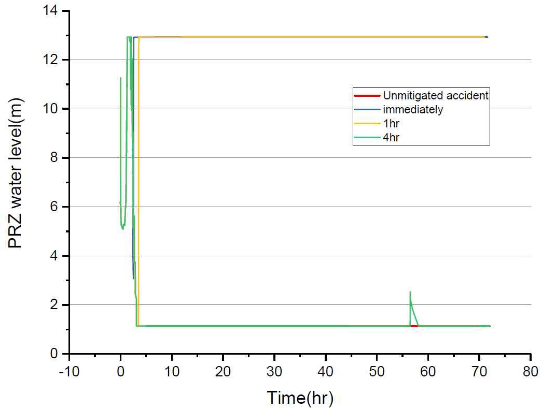

Fig. 2. PZR water level

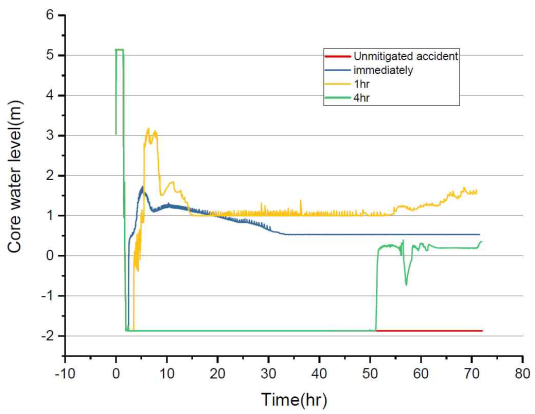

Fig. 3. Core water level

As shown in Figure 4, it is shown that the CET temperature is consistently stable when the immediate relief is performed and after 1 hour. The graph shows that the cooling was successful based on one of the conditions for the termination of a severe accident, CET <644.1K.

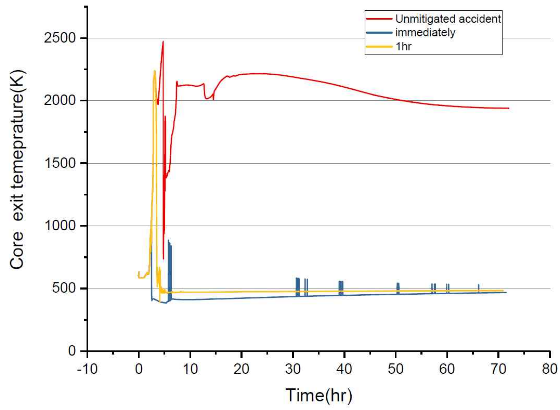

Fig. 4. Core exit temperature

Figure 5 shows the containment pressure. In the case of the containment pressure, the maximum of 0.84Mpa for the four cases was found, and it did not exceed 1.44Mpa at the time of breakage of the containment, indicating that the integrity of the containment was maintained.

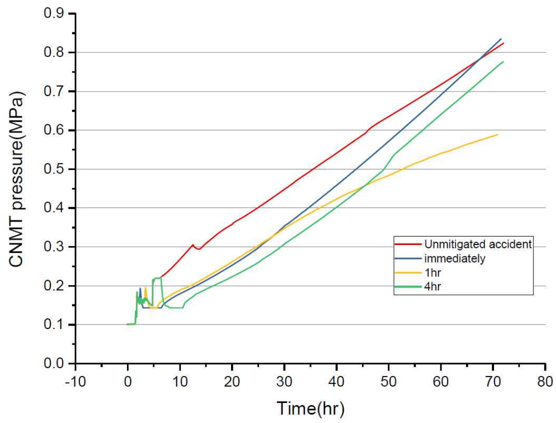

Fig. 5. Containment pressure

3. Conclusions

In this study, the power plant behavior in case of mitigation by restoring power using a mobile power generator with a time difference after a severe accident occurred in the event of a SBO due to an extreme disaster was confirmed. As a result, when the power source using a mobile power generator was restored from the time of entry into the severe accident until 1 hour later, it was confirmed that the RPV was not damaged, and the CET was satisfied the one of criteria for severe accident termination condition. However, after 4 hours, it was confirmed that the RPV was damaged when using a mobile power generator. In the case of the containment building pressure, it can be seen that even if the recirculation of spray water was unavailable, the containment building damage pressure does not exceed 1.44 Mpa. Therefore, it was confirmed that power recovery using a mobile power generator should be performed within a maximum of one hour after entering a severe accident due to SBO.

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