The Effect of Cooling Rate applied in a Small Break LOCA Scenario in which HPSI system is not available in view of OPR-1000 Risk Reduction

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1. Introduction

According to the emergency operation plan (EOP) of OPR-1000, the maximum cool-down rate of the reactor coolant system (RCS) in any transients or accident conditions is limited within a prescribed range of 55℃/hr [1]. The main concern of this limitation comes from a pressurized thermal shock (PTS) of the RCS components including the reactor vessel. As a continuous effort on the PTS phenomena, the knowledge of the phenomena has been comparatively enhanced and it is known that the risk by PTC will be relatively small compared to other risks [2]. Furthermore, this limitation can be an important defect for increasing other risks which can be generated by hindering an appropriate operator action for the mitigation of an accident. In the present study, we investigate the effect of the cooling rate on the accident mitigation, especially focused on the small break LOCA scenario in which a high pressure safety injection (HPSI) system is unavailable.

2. Calculation Procedure and Tools

To estimate the risk reduction of a NPP by changing a cooling rate, a couple of codes are needed for the calculation of the RCS pressure boundary failures, mainly focused on the reactor vessel, and risk changes from the probabilistic safety assessment (PSA). For the calculation of the reactor vessel, we used the FAVOR code [3]. This code requests the time history of the thermal/hydraulic (T/H) state of the reactor vessel. We used the MARS 3.0 code [4] for the calculation of the T/H condition of the reactor vessel. Finally, we also utilized the OPR-1000 PSA model, named PRIME 2.0 [5].

2.1 Calculation Logic

Figure 1 shows the overall calculation structure for the quantification of a risk change. For the risk calculation by a PTS event, the input for the information of the accident sequences and frequencies of the occurrences should be transmitted to the T/H analysis code, MARS and the probabilistic fracture mechanics (PFM) code, FAVOR. T/H analysis code calculates the RCS state as a function of time and PFM code utilize this information for the through wall cracking probability (TWCP). Finally, the frequency from the PSA model is multiplied by this TWCP to calculate the risk by the PTS events. On the other hand, for the risk reduction effects by a change of the EOP procedure due to cooling rate changes, the event tree (ET) is changed according to the EOP modification, then the risk change is calculated by the PRIME model.

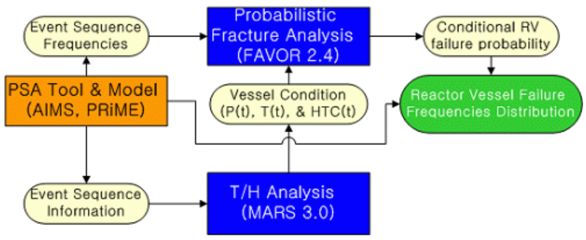

Figure 1. Calculation structure for the PTS related risk evaluation

2.2 T/H calculation

The break size of the small break LOCA is ranged from 3/8 inch to 2 inch in diameter for most of PSA models. We chose the maximum size of small break LOCA since it will give the worst results. The overall result is shown in figure 2 and 3.

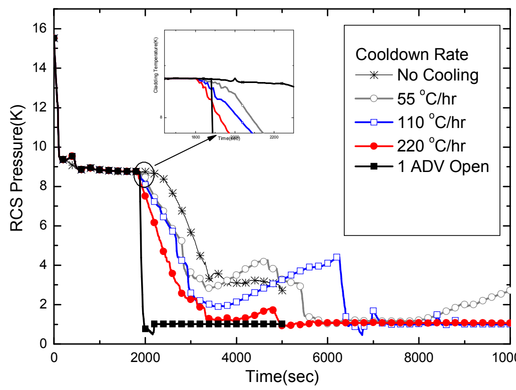

Figure 2. RCS pressure change due to the variation of cooling rate

As shown in the figures, if an operator starts a cooling operation at 30 minute after the accident, the pressure of the RCS is rapidly decreased in proportion to the cooling rate. Also, a core heat-up is prevented under the condition that the cooling rate is sufficiently increased (see figure 3).

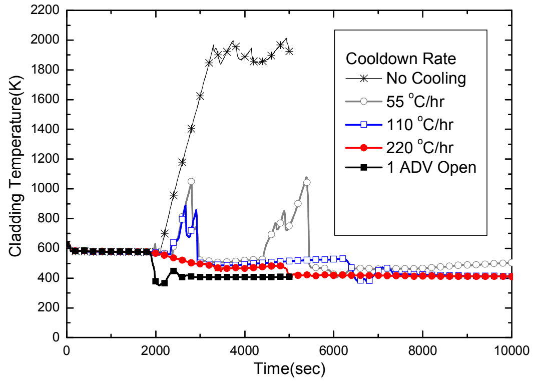

Figure 3. Peak Cladding Temperature change due to the variation of cooling rate

2.3 PFM analysis

The risk (conditional probability of failure (CPF)) was estimated using FAVOR 2.0 which use a Monte-Carlo simulation. For a effective full power year (EFPY) of 23 and 40 year, the OPR-1000 reactor vessel has a zero CPI (conditional probability if crack initiation) and therefore no CPI (Table 1). The main reason for such a zero CPF is due to the fact that OPR-1000 reactor vessel does not experience a pressurization after a rapid cooling. Also, it is due to the fact that OPR-1000 has good material characteristics. Reactor vessel of the OPR-1000 has low contents of copper which lower the RT_{NDT} as shown in table 1

Table 1. FAVOR Calculation Results for 23 and 40 EFPY of OPR-1000

EFPY(yr)	23			
Cooling Rate (^{o}C/hr)	55	110	220	ADV Dump
RT_{NDT0}(^{o}C)	-12	-12	-12	-12
RT_{PTS}(^{o}C)	73.51	73.51	73.51	73.51
CPI	0	0	0	0
CPF	0	0	0	0
EFPY(yr)	40			
Cooling Rate (^{o}C/hr)	55	110	220	ADV Dump
RT_{NDT0}(^{o}C)	-12	-12	-12	-12
RT_{PTS}(^{o}C)	87.74	87.74	87.74	87.74
CPI	0	0	0	0
CPF	0	0	0	0

2.4 Overall risk changes

A rapid cool-down operation can be applied to a small break LOCA including steam generator tube rupture (SGTR) in view of the OPR-1000 PSA. The risk changes with respect to the core damage frequencies (CDF) before and after the application of a rapid cool-down operation are shown in figure 4. As shown in figure 4, there is a 6.5 percent CDF reduction effect.

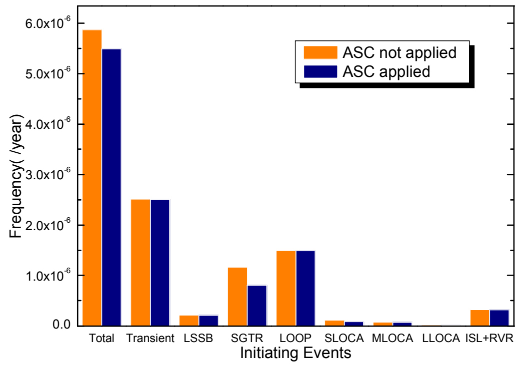

Figure 4. Fraction of counts lost with voltage and charge sensitive preamplifiers as a function of the true count rate

3. Conclusion

In this paper, we performed integrated risk analysis using the T/H code, PFM code, and PSA model. For the integrated risk analysis, the information needed for each code and model should be properly transmitted to each other. As a pilot application, we estimated that there will be a 6.5% risk reduction effect if a rapid cool-down is applied to a small LOCA scenario in which the HPSI is not unavailable.

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