Analysis of Heat Removal Strategy during Reactor Coolant Pump Seal Failure

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1. Introduction

Most of the initial events that may be caused by sabotage attacks could be prevented by secondary heat removal strategy operations. However, in the event of a power outage such as Station Black Out (SBO), loss of primary Component Cooling Water (CCW), or loss of primary Essential Service Water (ESW), cooling of the thermal barrier of the reactor coolant pump and injection of sealing water are simultaneously lost, resulting in damage to the seal of the reactor coolant pump. In this case, in order to prevent the core damage, heat removal strategy on the primary system must be performed in addition to heat removal strategy on the secondary system. However, in the case of Westinghouse type plants such as Kori Units 3, 4, since only the secondary heat removal strategy was adopted, the feasibility was analyzed in this study, and as a result, it was confirmed that sufficient time can be secured to damage the core even in the situation of damage to the reactor coolant pump seal. The related analysis results could be applied to other same type power plants in the same way.

2. Analysis of Heat Removal Strategy

2.1 Leakage Rate Analysis

First, for the analysis of heat removal strategy feasibility, reactor coolant pump leakage rate analysis was performed. In order to reduce the possibility of damage to the reactor coolant pump seal caused by injection of sealed water and loss of CCW, the Westinghouse type plants sealing was replaced with an O-ring that could withstand high temperatures. The event tree of the nuclear reactor coolant pump seal failure consists of two events: popping opening and binding failure. Popping open means that opening of the seal faces due to hydraulic instability caused by fluid flashing. Binding failure means that the seal ring against the housing inserts due to secondary seal extrusion. Through these two events, the probability of sealing failure was analyzed. According to the Westinghouse Non-proprietary Class 3 Technical Analysis Report (WCAP-15603, Rev.1-A) [1], the leakage of the reactor coolant pump was analyzed probabilistically after the loss of sealed cooling. It was shown in Table I.

Table I. Leakage (gpm) per reactor coolant pump according to the elapsed time after loss of all sealed cooling

Time after loss of seal cooling (min)	0-13	13-120	120-
Gpm / RCP (probablity)	21(1.0)	21(0.79)	21(0.79)
Gpm / RCP (probablity)	-	76(0.01)	76(0.01)
Gpm / RCP (probablity)	-	182(0.1975)	182(0.1975)
Gpm / RCP (probablity)	-	480(0.0025)	480(0.0025)

As each sealed cooling is lost and the elapsed time elapses from 0 to 13 mins, 13 mins to 120 mins, and more than 120 mins, respectively, the leakage amount of the reactor coolant pump is determined from 21 gpm to 480 gpm according to the probability of occurrence per elapsed time. Based on this leakage rate, the possibility of core damage frequency was analyzed in follow 2.2 chapter.

2.2 Core Damage Frequency analysis

The probabilistic analysis was conducted through the thermohydrodynamic analysis and scenario analysis for the core damage frequency and the spare time until the core damage due to the nuclear reactor coolant pump sealing damage. According to the Westinghouse Non-proprietary Class 3 Technical Analysis Report (WCAP-16396-NP) [2], the 3-loop NSSS type Westinghouse Reactor coolant system (RCS) inventory loss rate, pressurizer water level loss time, and spare time to core exposure were analyzed according to the reactor coolant pump leakage amount and the number of leakage pumps. It was shown in Table II.

Table II. Analysis of core exposure time according to reactor coolant pump leakage

Scenario	RCP leakage units		Loss of RCS inventory (gpm)	Pressurizer water level loss time (hrs)	Core exposure time (hrs)	
	21 gpm	182 gpm			with RCS C/D	with TDAFW only
Case1	3	0	63	1.15	20.8	20.4
Case2	2	1	224	1.05	19.7	18.2
Case3	1	2	385	0.95	18.5	8.1
Case4	0	3	546	0.85	17.1	5.2

In each case 1,2,3,4 showed the case of leakage of 3 units at 21 gpm that the minimum leakage of the reactor coolant pump, 2 units at 21 gpm, and 1 unit at 182 gpm, 1 unit at 21 gpm, 2 units at 182 gpm, and 3 units at 182 gpm in the 3-loop type Westinghouse plant. It could be seen that the loss rate of each RCS inventory increases in proportion to the increase in the amount of leakage, and the time to reach the loss of the pressurizer level decreases in inverse proportion to the increase in the amount of leakage.

As a result, even if the operation of the turbine-driven auxiliary water supply pump (TDAFWP) is secured only, which is the secondary system heat removal strategy without the operation of the reactor coolant cooldown (RCS C/D), the core exposure time is 20.4 hours when the case 1 event occurs. Even in the case of Case 4, which is the largest leakage rate event, it was confirmed that the nuclear reactor integrity was secured even if the initial event caused by sabotage occurred with 5.2 hours of core exposure margin time.

3. Conclusion

In this study, analysis of heat removal strategy during reactor coolant pump seal failure was performed by leakage rate and core damage frequency analyses. Consequently, only the secondary heat removal strategy was adopted without primary heat removal strategy, it was confirmed that sufficient time can be secured to damage the core even in the situation of damage to the reactor coolant pump seal.

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