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Sensitivity Analysis on LOCCW of Westinghouse typed Reactors Considering WOG2000 RCP Seal Leakage Model

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1. Introduction

After Fukushima accidents, Korea Hydro & Nuclear Power (KHNP) decided to develop Low Power and Shutdown (LPSD) Probabilistic Safety Assessment (PSA) models and upgrade full power PSA models of all operating Nuclear Power Plants (NPPs). As for upgrading full power PSA models, we have tried to standardize the methodology of CCF (Common Cause Failure) and HRA (Human Reliability Analysis), which are the most influential factors to risk measures of NPPs. Also, we have reviewed and reflected the latest operating experiences, reliability data sources and technical methods to improve the quality of PSA models [1].

KHNP has operating various types of reactors; Optimized Pressurized Reactor (OPR) 1000, CANDU, Framatome and Westinghouse. So, one of the most challengeable missions is to keep the balance of risk contributors of all types of reactors. In this paper, we focus on risk insights of Westinghouse typed reactors. We identified that Reactor Coolant Pump (RCP) seal integrity is the most important contributor to Core Damage Frequency (CDF). As we reflected the latest technical report; WCAP-15603(Rev. 1-A), "WOG2000 RCP Seal Leakage Model for Westinghouse PWRs" instead of the old version, RCP seal integrity became more important to Westinghouse typed reactors [2]. This paper presents the method of new RCP seal leakage model and the sensitivity analysis results from applying the detailed method to PSA models of Westinghouse typed reference reactors.

2. Method and Results

2.1 Review of WOG2000 RCP Seal Leakage Model

As being established as Generic Safety Issue (GSI) 23, "RCP Seal Failure" by US NRC, RCP seal integrity has been considered as the main contributor to the risk of Westinghouse typed reactors [3]. Westinghouse Owner Group (WOG) developed WOG2000 model to address RCP seal leakage following a loss of all seal cooling for Westinghouse typed reactors that use high-temperature O-rings. WOG2000 model addresses the combination of RCP seal component failures that could occur and the resultant leakage rate with considering three kinds of failure modes;

- Popping-open : opening of the seal faces due to hydraulic instability caused by fluid flashing
- Binding : binding failure of the seal ring against the housing inserts due to secondary seal extrusion
- O-ring extrusion : overheating of the secondary sealing elastomers, allowing excessive leakage

The probabilities of popping-open and binding failure modes were evaluated as a single failure mode since they had the same seal leakage consequences in WOG2000 model. Based on WCAP-10541, Rev. 2, the failure probability for the first seal stage was estimated as xx (intentionally avoid the value), and the expert judgement value of 0.2 as the failure probability for the second seal stage was consistently used.

The probability of O-ring extrusion failure was estimated as zero for the high-temperature O-rings, as long as the pressure of the reactor coolant condition being less than 1,710 psi within 2 hours. Based on these technical data, WCAP-15603(Rev. 1-A) was endorsed by US NRC.

We applied the technical data and methods to the PSA models for Westinghouse typed reactors with the following assumptions,.

- The timing to the binding/popping-open failure of the second seal stage should be 13 minutes after the loss of RCP seal cooling.
- All RCPs should experience the same leakage scenario.
- Cool down the reactor coolant system less than 1710 psi within 2 hours.

2.2 Current Method of Considering RCP Seal Integrity in PSA Models

RCP seal failure could be considered in some specific initiating events in PSA, such as Loss of Component Cooling Water (LOCCW), station blackout, main steam line break, which cause the loss of RCP seal injection and cooling condition. Fig. 1 shows the event tree for LOCCW of typical PSA models, and the last heading in circle is for RCP seal failure.

If using the typical modeling method in Fig. 1, the probability of RCP seal failure has direct impact on core damage frequency. While upgrading the PSA models for Westinghouse typed reactors, we have identified that the CDF related to RCP seal failure forms over 50 percent of the total CDF. Therefore, we have tried to improve the modeling method to reflect a recovery action to makeup reactor coolant inventory after RCP seal failure. Fig. 2 shows the event tree considering recovery actions after RCP seal failure. As for the recovery actions, we could maintain the functions of safety injection pumps by providing the cooling water to the pumps from alternative cooling water sources. Although design change can be required, these recovery actions have an effect on improving safety of Westinghouse typed reactors.

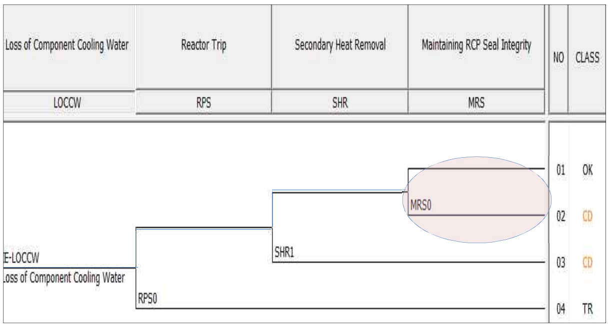

Fig. 1. Event Tree of typical PSA models, related to RCP seal failure.

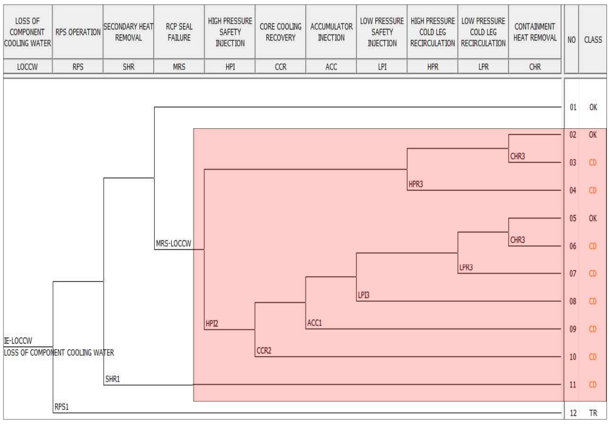

Fig. 2. Event Tree of the current PSA models, related to RCP seal failure.

2.3 Method Improvement of Considering RCP Seal Integrity in PSA Models

According to WCAP-15603(Rev. 1-A), there are three scenarios resulting from RCP seal failure after loss of all seal cooling event. The technical report provides the probabilities and leakage rate of each scenario. In the current PSA models of Fig. 2, however, we have considered the three cases of RCP seal failures as a scenario with single probability and single leakage rate based on a kind of engineering judgment.

To ensure the technical adequacy of the modeling method and engineering judgment, we developed detailed event tree by reflecting all cases of RCP seal failure as shown in Fig. 3 in this paper. As for RCP seal failure, two headings for the first seal stage and the second seal stage were considered in the event tree. Also, we performed T/H analysis by using the probabilities and leakage rates for each scenario. As for each leakage rate of three scenarios, the results of total allowed time were estimated 60, 130 and 300 minutes, which are the main input data for human reliability analysis (HRA).

Based on the T/H analysis and HRA, we quantified the new event tree to identify CDF, and compared it to the CDF of the current PSA models. As a result, we identified CDF to increase about 6%. The scenario of 182gpm leakage case was estimated as the main contributor to CDF. Also, the scenario of 480gpm leakage case still had some impact on CDF, although the RCP failure probability is very low.

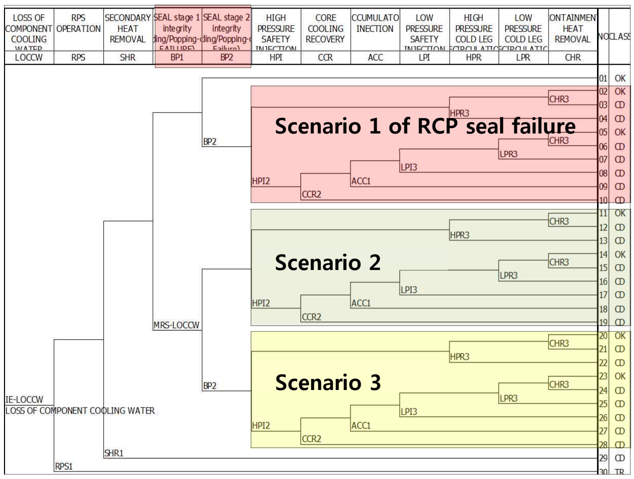

Fig. 3. Detailed Event Tree developed by reflecting all cases of RCP seal failure

3. Conclusions

To perform the sensitivity analysis on LOCCW of the reference Westinghouse typed reactors, we reviewed WOG2000 RCP seal leakage model and developed the detailed event tree of LOCCW considering all scenarios of RCP seal failures. Also, we performed HRA based on the T/H analysis by using the leakage rates for each scenario. We could recognize that HRA was the sensitive contributor to CDF, and the RCP seal failure scenario of 182gpm leakage rate was estimated as the most important scenario. Based on these insights, it is considered that further research is necessary to optimize the modeling method related to RCP seal failures.

REFERENCES

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