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Results of Multi-unit Seismic PSA in KHNP Project and Sensitivity Study on Seismic Correlation

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1. Introduction

The multi-unit issues were firstly highlighted as one of the most challenges during the licensing process of new build units in the site which have more than existing six units in Korea. So, Korea Hydro & Nuclear Power (KHNP) has started the project on Multi-Unit Probabilistic Safety Assessment (MUPSA), which is planned to be done by June 2020. This project consist of two phases. In first phase which was done on June 2018, we developed the overall framework of multi-unit PSA and performed the preliminary assessment for pilot site with some limitations and assumptions.

In preliminary assessment, we considered three Multi-Unit Initiating Events (MUIEs) based on the operating experience: Loss of Off-site Power (LOOP), Loss of Condenser Vacuum (LOCV), and General Transient (GTRN). In addition to the above MUIEs, seismic also was included as a multi-unit initiator. Many research projects related to MUPSA in the world have considered seismic as an important MUIE.

In this paper, we introduced the result of preliminary assessment for seismic event and performed the sensitivity analysis on seismic correlation.

2. Multi-unit Seismic PSA

Currently, the pilot site in KHNP project have seven units: four Westinghouse (one unit was permanent shutdown in 2017), two OPR-1000, and two APR-1400. By adding two new units of APR-1400, total nine units will be operated in the future. To address the effect of the risk increase by adding the new build units, multi-unit PSA model consists of two cases. The first case was developed for the existing site containing seven units. The other was for nine units.

- Case 1: existing seven units
- Case 2: existing seven units + two new units

2.1 Modeling approaches and assumptions

Multi-unit PSA model for seismic was divided into five seismic groups according to the magnitude (i.e., peak ground acceleration: 0.1g, 0.3g, 0.5g, 0.7g, and 0.9g). For each seismic group, MUPSA models have been developed. Seismic-induced initiating events were identified and selected by primary event tree as shown in Fig. 1. For each initiating events considered in primary event tree, major components causing the initiating event were identified, and then the frequencies of each initiating events were estimated by using PRASSE developed by Korea Atomic Energy Research Institute (KAERI) with the fragility of components and seismic hazard information. As for the seismic correlation, we used 0.0 (fully independent) or 1.0 (fully dependent). That is, the components, which had the same location, fragility and installation level, were assumed to be fully dependent, and others were independent. It is noted that seismic correlation was only applied between twin units. Fig.2 shows the modeling of seismic correlation. In single-unit PSA, seismic-induced failure probabilities of components were connected with random failure by "or" gate. In multi-unit PSA, the components, which were assumed to be fully correlated between twin units, were modeled as a same basic event name in each units. For example, when Emergency Diesel Generator (EDG) in unit 1 fail by seismic, EDG in unit 2 also fail.

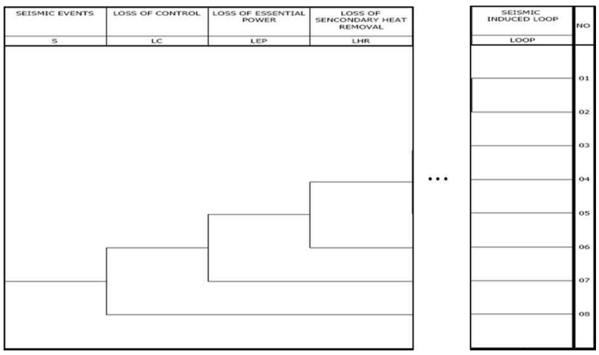

Fig. 1 Primary Event Tree in Seismic PSA

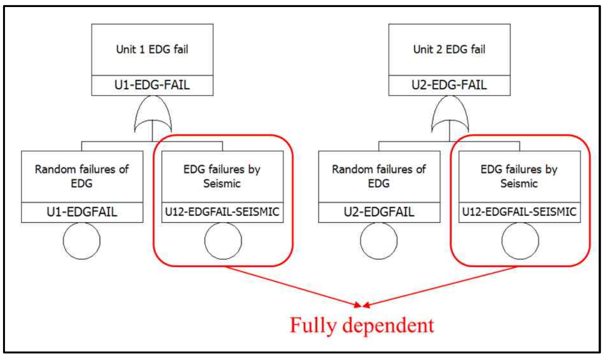

Fig. 2 Modelling of Seismic Correlation

The other issues for developing multi-unit PSA model such as Human Reliability Analysis (HRA) and Common Cause Failure (CCF) were described in previous paper [1].

2.2 Results of Multi-unit Seismic PSA

In this paper, we used FTeMC, which was developed by KAERI [2], for quantifying multi-unit models. Site

Core Damage Frequency (SCDF) and Multi-unit Core Damage Frequency (MUCDF) were used as risk metrics. SCDF is the sum of frequencies in all case where the core damage occurs in one or more unit on the same site. MUCDF is the sum of frequencies excluding one unit CDF of SCDF. Fig. 3 shows the results of preliminary assessment. In the first case, MUCDF accounts for about 54% of SCDF. In the other case, MUCDF accounts for about 56% of SCDF. In multi-unit context, CDF of any two units was most dominant compared to that of any three or more units in both cases. Compared to case 1, SCDF and MUCDF of case 2 increased by 1.9% and 1.3%, respectively, due to adding new build units.

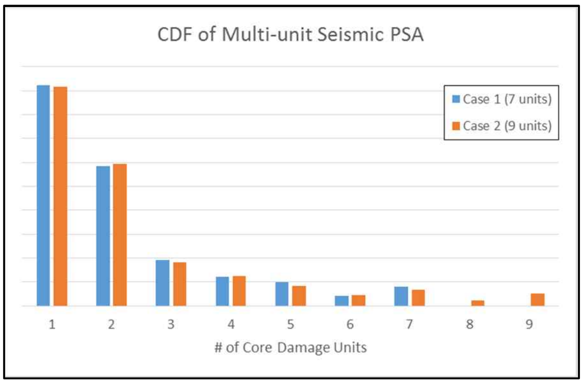

Fig. 3 Results of Multi-unit PSA for Seismic Event

3. Sensitivity analysis on Seismic Correlation

As mentioned above, we assumed seismic correlation as 1.0 (fully dependent) between twin units. Seismic correlation is one of the major factors causing multi-unit core damage. So, we performed the sensitivity analysis on seismic correlation of 0.0, 0.25, 0.5, and 0.75. Fig.2 shows the modeling of partial correlation.

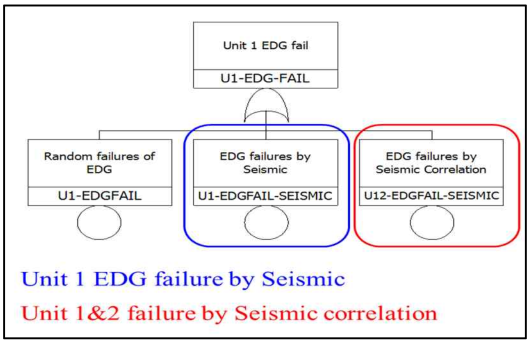

Fig. 4 Modelling of Partial Seismic Correlation

In case of partial correlation, two basic events related to seismic were modeled; one was considering the independent failure by seismic regardless of the correlation, the other was considering the dependent failure by partial correlation. The probabilities of each basic events were estimated by multiplying the correlation factor to the seismic-induced failure probability used in single-unit seismic PSA. If partial correlation factor is assumed to be 0.75, the independent failure has 25% of the failure probability used in single-unit seismic PSA and the dependent failure has 75%. Fig. 5 and 6 show the results for case 1 and 2. In the first case, the portion of MUCDF for SCDF decreased from about 54% to 36% according to the correlation. In the other case, the portion decreased from about 56% to 37%.

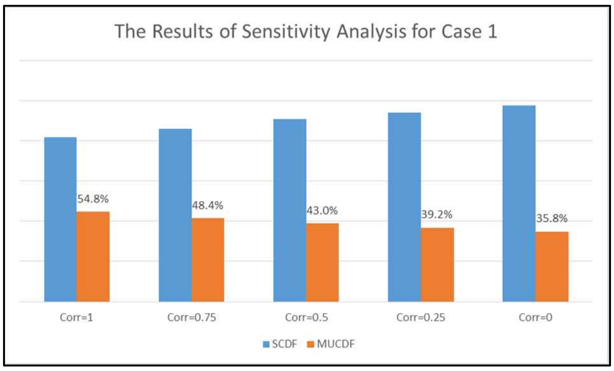

Fig. 5 Results of Sensitivity Analysis for Case 1

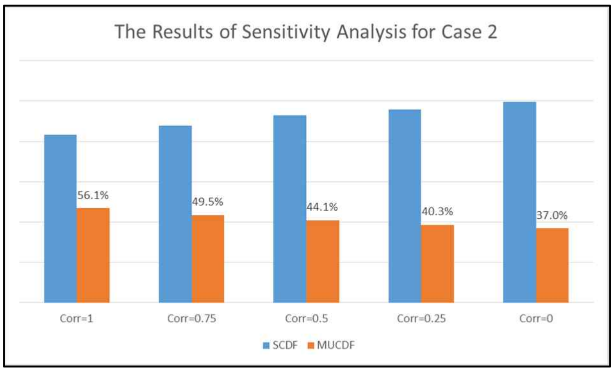

Fig. 6 Results of Sensitivity Analysis for Case 2

4. Conclusions

KHNP has launched the project for multi-unit PSA, in which, we aim to develop a methodology and to apply it to a pilot site. In this paper, we briefly introduced the modeling concept and the results for seismic event. The multi-unit risk by adding two new units increased by less than about 2%. This is because single-unit risk of new units are lower than one order compared to that of older unit that have most high risk in pilot site.

And, we also performed the sensitivity analysis on the seismic correlation of 0.0, 0.25, 0.5, 0.75. When we used the correlation as 0.0, the portion of MUCDF decreased by about 18% and 19%, respectively. The risk reduction according to the correlation is not greater than expected. This is because there is no or little change in the risk depending on the correlation in the interval 0.7g or more.

REFERENCES

[1] Kyemin Oh, et al., "Modelling Approaches in KHNP Multi-unit PSA Project", Transactions of the Korean Nuclear Society Autumn Meeting, October 25-26, 2018

[2] S. Han, H. Lim, Top event probability evaluation of a fault tree having circular logics by using Monte Carlo method, Nucl. Eng. Des. 243, 2012