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# Evaluation Plan for Multi-unit PSA Considering Operating Modes in a Reference Site

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## 1. Introduction

After the Fukushima accident in 2011, the concerns about the safety of nuclear power plants (NPPs) have been increased throughout the world. The accident highlighted the importance of considering the risk from multi-unit accidents caused by external hazards at a site [1]. However, most Probabilistic Safety Assessments (PSAs) have been performed based on a single unit, and most countries focused on PSAs for internal events for risk managements and Risk-informed Applications (RIAs). In addition, PSA had been mostly performed for only full power operation. Through the lessons learned from the accident, the issues on PSA for Low Power and Shutdown (LPSD) operation have also been arisen.

Most nuclear sites in the world have two or more reactor units. Especially, all the nuclear sites in Korea contain six or more reactor units. One of the most important challenges is to consider the combination of units when making multi-unit PSA models. The more units we need to consider, the larger size of models we should develop. If we also consider the operating modes of all units as well, the number of combinations, which we should model, would be increased a lot. As we need to consider a reference site which contains nine operating reactor units, this paper presents the modeling and the quantification concepts with considering the operating modes.

## 2. Methods and Results

### 2.1 Review of Long-term Overhaul Schedules

To develop multi-unit PSA models, the combinations of all units in the reference site should be selected, including consideration of the operating modes. Therefore, we reviewed the historical experiences of overhaul (O/H) and the long-term plan for the O/H schedules of all the units of the reference site. According as a new unit started commercial operation, the number of reactors at the site has been increased one by one. In the early stage, four units at the site had been operated for over twenty years. Even though considering four units, we identified O/H experiences almost every year. However, two is the maximum number of the units in O/H simultaneously.

In this paper, we reviewed the long-term plan for the O/H schedules of nine units, which are operated at the same time in the later stage. And, we identified that at most three units could be in O/H operating mode simultaneously. From the long-term O/H schedules for seventeen years, we could get the average duration of two units and three units in O/H operating modes, which are forty-one days and ten days respectively. And, the maximum values are sixty-nine days and forty-two days individually.

There is another important element, which is the reactor type of a unit. This is because four different reactor types of units are assumed to be operated in the reference site. According to the reactor types, the results of each single unit PSA are shown to have a very wide range. The difference between the oldest unit and the newest unit is identified by around ten times. Therefore, we also considered the PSA results as one of the main factor, when developing the top level of multi-unit PSA models.

The other element, which we reviewed, is that Alternative AC Diesel Generator (AAC DG) would be maintained during the O/H of which unit. As a result from considering the above elements, we could decide two possible combinations of the two-unit O/H and the three-unit O/H at the same time as shown in Table 1.

Table 1. Combinations of units considering operating mode

| Proposed Cases | Units on full power | Units in O/H |
|---|---|---|
| Case 1 of 2 O/H | K3, K4, K5, K7, K8, K9 & K10 | K2 & K6 |
| Case 2 of 2 O/H | K2, K3, K6, K7, K8, K9 & K10 | K4 & K5 |
| Case 3 of 3 O/H | K3, K4, K5, K8, K9 & K10 | K2, K6 & K7 |
| Case 4 of 3 O/H | K2, K3, K5, K6, K8 & K9 | K4, K7 & K10 |

In Table 1, Case 1 and Case 3 were selected because the risk measures from a single unit PSA of K2 are higher than any others. And, we also proposed Case 2 and Case 4, considering AAC DG maintenances. After estimating preliminary models of each Case in the future, we are going to select two cases, one from 2 O/H cases and the other from 3 O/H cases.

### 2.2 Modeling Concept considering Operating Modes of all units

At current stage, we consider developing multi-unit PSA models only for the initiating events, which cause the concurrent reactor trips of multi units, such as multi-unit Loss of Off-site Power (LOOP), seismic hazard, tsunami hazard, and so on. We will select the final initiating events for multi-unit PSA based on historical operating experiences and hazard analysis in further study.

This paper presents modeling concept with focusing on multi-unit LOOP. According to operating experiences, multi-unit LOOPs have occurred due to typhoon, heavy snowfall, etc. If multi-unit LOOP occurs, we would assume that LOOP cause reactor trip in all the units of the reference site simultaneously.

Although both event tree and fault tree are used in a single unit PSA models, we decided to use fault tree for developing multi-unit PSA models. And, Station BlackOut (SBO) would be modeled as one of the accident sequences of LOOP in one fault tree. The simplified structures of LOOP fault tree are shown in Figure 1 and 2.

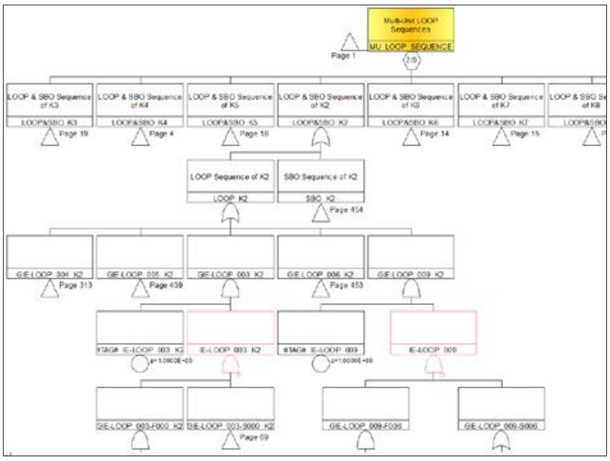

Fig. 1. Simplified FT Structure for multi-unit LOOP (1)

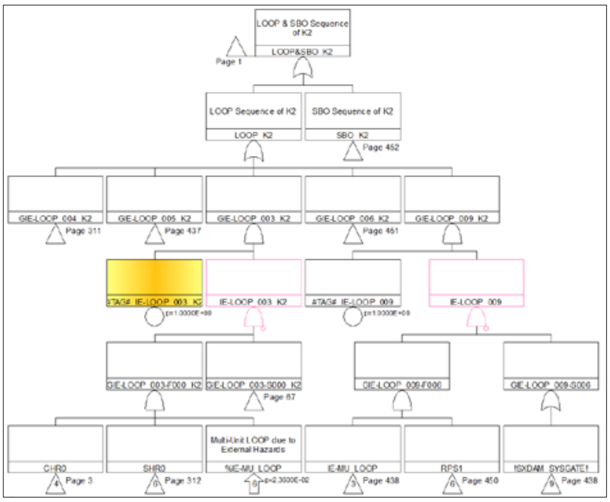

Fig. 2. Simplified FT Structure for multi-unit LOOP (2)

Related to operating modes of all units, we would develop three fault trees for multi-unit LOOP. The first is for the case that all the units are on the full power operation. The second is for the case that seven units are on the full power operation and two units are in O/H mode. The third is for the case that six units are on the full power operation and three units in O/H mode. After dividing one year into three durations from the three cases, we would aggregate the risk metrics from the three cases. The durations of each case would be estimated by using the long-term plan for the O/H schedules.

### 2.3 Quantification Concept considering Operating Modes of all units

One of the challenging issues for multi-unit PSA is the capacity of PSA software because the size of the multi-unit PSA models is much larger than that of a single unit PSA models. According to the first research project on multi-unit PSA in Kora, performed by Korea Atomic Energy Research Institute (KAERI), developing the new software based on Monte Carlo method was required to quantify multi-unit PSA models [2]. If we use Monte Carlo method to quantify PSA models, we could get the more exact results; however, we could not get detailed information such as cutsets. Therefore, we would simplify the models, and use one combination gate, which is two out of nine units, and the unit based tag event for every accident sequence. Then, we expect to generate the cutsets, which cause core damages in more than two units. Although regulatory guides or quantitative safety goals for multi-unit PSA have not been set up yet, we consider estimating the risk metrics of multi-unit PSA based on the number of units, which get core damaged, such as the CDF from two units, the CDF from three units and so on. Therefore, we need to make software to manage the cutsets by using the unit based tag information, and we have a plan to make it in further study.

## 3. Conclusions

This study is a kind of starting point to develop multi-unit PSA. Considering the large number and the various types of units at a site, we proposed the fault tree modeling concept based on reviewing the site specific long-term O/H schedules. As for the operating modes of the units, three cases, based on the number or units in O/H operating modes, are decided to be modeled. Also, we introduced simplified fault tree structures for multi-unit LOOP and the quantification concept considering operating modes of all units at the reference site.

And, we derived some items, which we should resolve in further study; to decide the final cases from the proposed O/H cases in section 2.1, to select the final initiating events as mentioned in section 2.2, and to consider new software to manage the cutsets by using the unit based tag information.

## REFERENCES

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[2] S.C. Jang, et al., "Development of the Integrated Risk Assessment Technology for Multiple Risk", Research Report, KAERI/RR-XXXX/2015, Korea Atomic Energy Research Institute, Daejeon, 2015