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Examination of post-Fukushima action items for Korean NPPs from multi-unit dependency perspective

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1. Introduction

Most of Probabilistic Safety Assessment (PSA) of nuclear power plants has examined the risk of a single unit. However, the recent Fukushima accident showed the importance of multi-unit dependency. The issue of multi-unit risk was recognized early on. In performing Seabrook PSA in 1983, multi-unit effect was examined [1]. With the Fukushima accident, PSA community recognized the importance of multi-unit dependency and it has become one of active research area in PSA.

In light of Fukushima event, all IAEA member nations adopted an action plan on nuclear safety to strengthen nuclear safety worldwide. In Korea, the special team organized by the government led special safety inspection to Korean nuclear facilities, which resulted in identifying 56 plant improvements. Most of these improvements have been implemented and all of the improvements will be implemented by the end of 2015 [2]. One important area of improvement is to strengthen the mitigation capability against extreme events such as extended SBO utilizing portable equipment

This paper examines qualitatively the adequacy of the above improvements from multi-unit dependency point-of-view. We chose an extended SBO scenario and utilized extensive damage mitigation guidelines [3] to make the examination more realistic.

2. Multi-unit dependencies

Multi-unit dependencies are categorized as; initiating events, shared connections, identical components, proximity dependencies, human dependencies, and organizational dependencies [4]. In this section, Fukushima event and the mitigation plan of Korean NPPs are reviewed and multi-unit dependencies are categorized accordingly. We chose Shin Kori 3&4 as an example plant of Korean NPPs

A special report on Fukushima accident [5] prepared by INPO is reviewed to identify multi-unit dependencies of the plant. Table 1 summarizes the list of multi-unit dependencies of Fukushima Daiichi nuclear power plant.

There was a main control room shared by adjacent reactors. For each control room there was only one shift supervisor with the responsibility of making decisions during the course of the accident concerning the control and operation of both units, and reporting all basic information necessary to the emergency response organization.

Fukushima Daiichi had three fire engines at site. Only one fire engine was immediately available to support the emergency response. The mobile generators were limited in their effectiveness because they could not be connected to the station electrical distribution system as a result of the extensive physical damage caused by the tsunami and flooding.

Table 1: Fukushima Daiichi multi-unit dependencies

	Description
Initiating events	Earthquake, Tsunami, LOOP
Shared connections	Fire engine, Main control room, Containment vent stack, Mobile generator
Identical components	EDG, DC battery, Portable pump,
Proximity dependencies	None
Human dependencies	Shared operating crew by two units (Mental slip)

Table 2: Shin Kori 3&4 multi-unit dependencies

	Description
Initiating events	Typhoon, heavy rain, LOOP
Shared connections	Fire engine, Mobile generator
Identical components	EDG, AAC, DC battery, Portable pumps
Proximity dependencies	Switchyard Intake structure
Human dependencies	Emergency onsite organization

For SKN 3&4, four items among 56 improvements are directly related to the mitigation of the extreme scenarios; water-tight doors for EDG rooms, a mobile generator, a fire engine, and portable diesel driven pumps.

Water-tight doors are used for internal flood protection of EDG rooms. The components to be protected from flooding are diesel generator, diesel fuel oil transfer pump, and exhaust fan. Mobile generators with a capacity of 3,200 kW are placed in all of nuclear power sites. One mobile generator is available per site. External water injection for spent fuel pool and reactor provides emergency cooling water through an additional line using fire engines and portable diesel driven pumps. In addition to one fire engine placed in a nuclear power site, two portable diesel driven pumps are equipped for each unit in SKN 3&4. Table 2 shows the list of multi-unit dependencies of Shin Kori 3&4 nuclear power plants which are related the mitigation of the extreme scenarios.

3. Case study: Extended SBO

The NRC SBO rule [6] requires that each nuclear power plant must be able to cool the reactor core and maintain containment integrity for a specific duration of an SBO. The specific duration is based on the following factors:

1) The redundancy of the onsite emergency ac power sources
2) The reliability of the onsite emergency ac power sources
3) The expected frequency of loss of offsite power
4) The probable time needed to restore offsite power

The NRC Near-Term Fukushima Task Force (NTTF) has recommended to strengthen SBO mitigation capability at all operating and new reactors for design-basis and beyond-design-basis external events initiated to require licensees (Recommendation 4):

1) Establish a minimum coping time of 8 hours for a loss of all AC Power
2) Establish the equipment, procedures, and training necessary to implement an extended SBO coping time of 72 hours for certain Critical Safety Functions
- Core cooling
- Spent Fuel Pool (SFP) cooling
- Reactor Coolant System (RCS) and primary containment integrity

For SKN 3&4, four improvements are directly related to the items above (strengthen SBO mitigation capability); water-tight doors for EDG rooms, mobile generator, fire engine, and portable diesel driven pumps. In this section, extended SBO scenario and extensive damage mitigation guidelines are used to examine the adequacy of the above improvements from multi-unit dependency point-of-view.

From the level 1 PSA of SKN 3&4, three dominant accident sequences of SBO are chosen for examination. The three dominant accident sequences are:

1) Case 1: LOOP – EDGs failed – RCP seal intact – TDAFW unavailable due to battery depletion– Failure of AC power recovery – CD
2) Case 2: LOOP – EDGs failed – AAC failed – RCP seal failed – CD
3) Case 3: LOOP – EDGs failed – AAC failed – TDAFW unavailable – Failure of AC power recovery – CD

Fig. 1 presents the modified fault tree considering mobile generator (MG) which is connected to 4.16 kV Class 1E SWGR A. In this evaluation, failure probability of mobile generator supplying power is assumed two times bigger than that of AAC DG. When the mobile generator is added in the system, the failure probability of power unavailable to 4.16 kV SWGR SW01A is decreased from 5.46E-03 to 8.39E-04. The improvement for the unit connected with MG is substantial showing the benefit of the MG. However, only one unit in the site can take effect of failure probability decreasing.

A new event 'SGI-P' (SG injection by portable pump (PP)) is added to model the secondary side injection using portable pump. Failure probability of the event is modeled with a simple fault tree with several elements: human error, CCF, and failure of the pump. Now, multiunit dependencies affect both human error and the pump failure. The relative magnitude of the human failure and pump failure shows that the contribution by human failure (3.75E-01) is higher and the common cause failure (2.05E-04) of portable pump contribution is small in comparison.

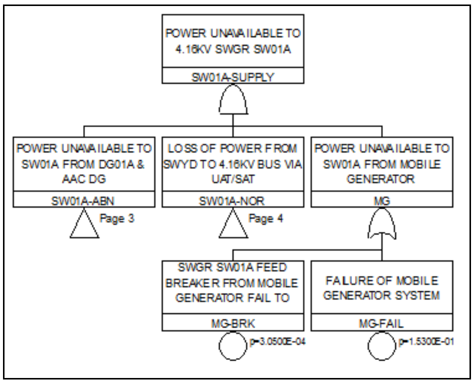

Fig. 1. Modified fault tree considering mobile generator.

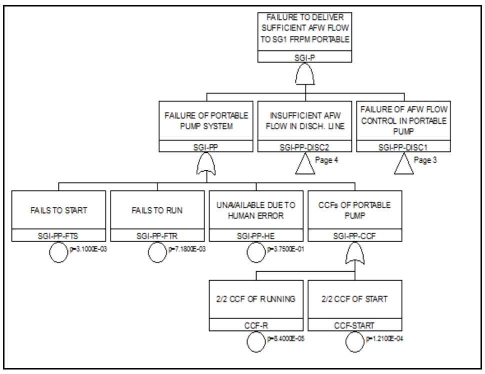

Fig. 2. Fault tree considering mobile generator.

4. Conclusions

In this study, we examined qualitatively the improvement of Korean NPP against extreme events such as extended SBO from the multiunit dependency perspective. The benefit of mobile generator is substantial in reducing the failure probability of power unavailable to 4.16 kV SWGR. Though there are multiunit dependency in portable pumps (using identical pumps), its impact due to common cause seems to be smaller than other contribution such as human error. Considering the consequence of common cause failure of portable pumps, the cost aspect of having two different types of pumps needs to be evaluated.
Overall, the multiunit perspective would give an opportunity to further optimize and improve the response against extreme events such as an extended SBO.

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