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A Study on Multi-Unit Initiating Event

Seungwoo Lee [a*], Ar Ryum Kim [a], Namchul Cho [a], Hyowon Kim [a], Sokchul Kim, Dohyoung Kim [a]
[a] *Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon, Korea 34142*
[*]*Corresponding author: k735kar@kins.re.kr*

1. Introduction

The Fukushima accident has highlighted among other matters that multi-unit accident can occur in reality [1]. In worldwide, most sites contain two or more nuclear power plant (NPP) units in single site. Especially in Korea, there are four NPP sites and more than six units are operating in each NPP site [2]. Current situation in Korea has raised public's concern on multi-unit risk. However, there are few researches conducted to estimate multi-unit risk since the safety evaluation has been performed based on each unit.

Korea Institute of Nuclear Safety (KINS) has started a long-term research aimed at developing a regulatory framework for multi-unit risk in 2017. As part of research, Kim et al. [2] showed research results on multi-unit initiating events focusing on developing a framework to identify multi-unit initiating events.

This paper, as a part of subsequent research, introduces a systematic process to identify the comprehensive sets of multi-unit initiating events and to estimate their frequencies. This research mainly consists of three parts. First part explains the process to identify the comprehensive sets of initiating events using operational data in Korea and results of failure mode and effect analysis (FMEA) for shared SSCs (Structure, System, and Components). Second part explains the screening process for the multi-unit initiating events. Finally, third part explains a process to estimate the frequencies of these initiating events.

2. Identification of Multi-Unit Initiating Event

2.1 Identification of Multi-Unit Initiating Event using Operational Data

KINS operates the system called OPIS (Operational Performance Information System) which has a comprehensive database system providing data on the events occurred in Korean NPPs. Total number of 726 event data occurred during 1978 to 2017 were selected and these data were analyzed to identify the multi-unit initiating events. Two analysts who have more than 10 years of experience have participated and identified multi-unit initiating events which have been actually happened as well as events which could possibly become multi-unit initiating events.

The reason to consider these two types of initiating events is to identify initiating events as comprehensive as possible. Four multi-unit initiating events such as general transient (GTRN), loss of condenser vacuum (LOCV), loss of offsite power (LOOP) and steam generator tube rupture (SGTR) were derived as possible multi-unit initiating events.

2.2 Identification of Multi-Unit Initiating Event using FMEA for Shared SSCs

According to the Article 16 (Sharing of Structures, Systems and Components) of Regulations of Technical Standards for Nuclear Reactor Facilities Etc., the SSCs important to safety shall not be shared among more than two nuclear facilities. However, the SSCs important to safety may be shared in cases where such facilities meet all the following requirements: 1) For each nuclear facilities, all the safety requirements for the relevant shared facilities are satisfied and 2) In the accident conditions of one of the units sharing SSCs, an orderly shutdown, cooldown, and residual heat removal of the other units shall be achievable [3]

In this section, multi-unit initiating events which could occur due to the shared SSCs were identified and a process described in Figure 1 was used.

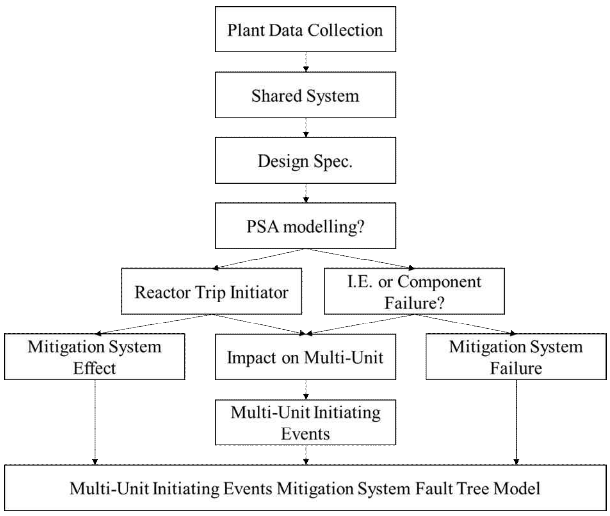

Fig. 1. A Framework for Identification of Multi-Unit Initiating Event from the Shard SSCs

Four systems, offsite power system, circulating water system, instrument air system, and seismic monitoring system were investigated as the shared systems between units or at the site under this study. Components for each system were identified and FMEA was performed for these components. Table 1 shows FMEA results for circulating system which was investigated as one of the shared systems in this study.

Table 1. Example of FMEA for Circulating System

Failure Mode	Effect	Potential Initiating Events	Multi-Unit Effect
Loss of component cooling water (CCW) due to mechanical failure	- Reactor trip due to loss of reactor coolant pump (RCP) seal cooling - Partial loss of related system (e.g., containment heat removal system)	Partial loss of CCW	X
Loss of essential service water due to mechanical failure	- Reactor trip due to loss of RCP seal cooling - Partial loss of related system (e.g., containment heat removal system)	Partial loss of CCW	X
Loss of circulating water due to mechanical failure	- Turbine trip due to loss of condenser vacuum - Partial loss of related system (e.g., turbine building component cooling water)	- Loss of condenser vacuum - Loss of feedwater - Loss of instrument air (LOIA)	X
Loss of condenser pump	- Turbine trip due to loss of condenser vacuum	- Loss of condenser vacuum	X
Loss of ultimate heat sink due to external hazards	- Reactor trip due to loss of RCP seal cooling - Total loss of related system (e.g., essential service water)	- Total loss of CCW - Loss of condenser vacuum	O

Based on FMEA results for the components, multi-unit initiating events such as GTRN, LOCV and LOIA were identified.

2.3 Multi-Unit Initiating Event after Screening Process

Multi-unit initiating events were identified from operational data and FMEA for components. However, it should be noted that external event such as earthquake was excluded since this specific event would be analyzed in a separate manner in another scope of research.

Multi-unit initiating events identified from the step 2.1 and 2.2 were screened using below four screening criteria

1) Accident progression : They have sufficiently slow accident sequence to demonstrate that there is enough time to use suitable mitigation action to eliminate the effects of accident.

2) Accident severity : They are not physically severe to pose threat to plant's safety.

3) Accident frequency : They have significantly low frequency of occurrence which is shown by bounding analysis.

4) Proximity : Plants are not close enough to have impact on plant nearby.

As a result, GTRN, LOOP and LOCV were identified as final multi-unit initiating events in this study.

3. Estimation of Multi-Unit Initiating Event Frequency

For GTRN, LOOP and LOCV, the frequencies of multi-unit initiating events are estimated. Here, as a unit of multi-unit initiating event frequency, the concept of site-year was used. However, there is no widely accepted definition for the site-year so far, the assumption has been made in order to estimate the frequencies of multi-unit initiating events. It is assumed that the first installed NPP for each site has been operated for thirty years and total site-year is estimated as 120 site-year. Also, it is assumed that the number of multi-unit event occurrence for GTRN, LOOP, and LOCV, is 1, 2, and 3, respectively. For the estimation of multi-unit event frequency, maximum likelihood estimate (MLE) and Jefferey's non-informative prior have been used [3]. The frequencies of multi-unit initiating events are shown in Table 2. It should be noted that "the number of occurrence" and "site year" in Table 2 are not actual values, but imaginary values for explanation purpose.

Table 2. Estimation of Multi-unit Initiating Event Frequencies

	The number of occurrence	Site year	Frequency (/site-year)			
			MLE*	Gamma distribution		
				Mean**	α	β
GTRN	1	120	0.8×10^{-2}	1.3×10^{-2}	1.5	120
LOOP	2	120	1.7×10^{-2}	2.1×10^{-2}	2.5	120
LOCV	3	120	2.5×10^{-2}	2.9×10^{-2}	3.5	120

MLE* = (the number of event occurrence) / (site-year)
Mean** = (the number of event occurrence + 0.5) / (site-year)

As shown in Table 2, the frequencies of multi-unit initiating events can be estimated. However, when the number of event occurrence and concept of the site-year are decided, it is expected that more precise frequency could be estimated.

3. Conclusions

In this research, comprehensive multi-unit initiating events were identified from operational data in Korea and FMEA results. These initiating events were screened using four screening criteria and three multi-unit initiating events such as GTRN, LOCV and LOOP were finally selected. Since there is still debate on the concept of site-year, some assumptions were made to estimate the multi-unit initiating event frequency. Although the estimated multi-unit initiating frequency is not actual value, it is expected that more precise value can be estimated when assumptions made during calculations have technical backgrounds.

However, this research which shows a process to identify multi-unit initiating events and to estimate their frequencies could be used to develop a technical foundation for multi-unit risk estimation.

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