Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

A Technical Survey of Methodology for the Multi-Unit Probabilistic Safety Assessment

Seunghyun Jang, Dohyun Lim and Moosung Jae*
Department of Nuclear Engineering, Hanyang University, Seongdong-gu, Seoul, 04763, Korea
Corresponding author: jae@hanyang.ac.kr

1. Introduction

Nuclear power plants (NPPs) in Korea currently have 25 NPPs on four sites, and there are at least 6 units located on a site.

In Fukushima accident that occurred in March 2011, 3 of 6 units caused core damage concurrently due to external hazard such as earthquakes and tsunamis, resulting in large radiation release to the public. As a result of this accident, there is a growing interest in multi-unit probabilistic safety assessment (MUPSA).

As described above, since the number of NPPs within a site is increasing because of the geographical characteristics of Korea, the necessity of a MUPSA is high. Therefore, in this study, we would like to review the previous study that is related to a MUPSA.

2. Literature Review

2.1 Technical Approach for MUPSA

This report [1] describes major issues and the technical approach methodology developed for a MUPSA through the review of recent studies and operating experiences in multi-unit sites. And the appropriate risk metrics for the MUPSA to describe the integrated risks from multi-unit sites are suggested.

2.1.1 Technical issue for MUPSA

In order to identify the main issues in the MUPSA, several studies such as the Fukushima accident, the Seabrook station Level 3 PSA report, and the NPP operating experience data of multi-unit sites were reviewed.

Through the review, it was identified that the core damage frequency (CDF) and large early release frequency (LERF), which were considered as a single-unit risk metric, were not suitable for evaluating the multi-unit risk. Therefore, it was also suggested to develop the new site-based risk metrics that can be used for MUPSA.

And, it was confirmed that internal and external factors that can affect two or more NPPs at the same time and the shared system between multiple units had a major impact on the multi-unit site risk.

Therefore, in order to perform the MUPSA, the new site-based risk metrics need to be developed in a process of analysis and impacts on shared system between multiple units are considered in MUPSA model.

2.1.2 Overall process of MUPSA

As seen in Figure 1, MUPSA can be performed through the eight steps. Figure 1 shows the overall process of performing MUPSA.

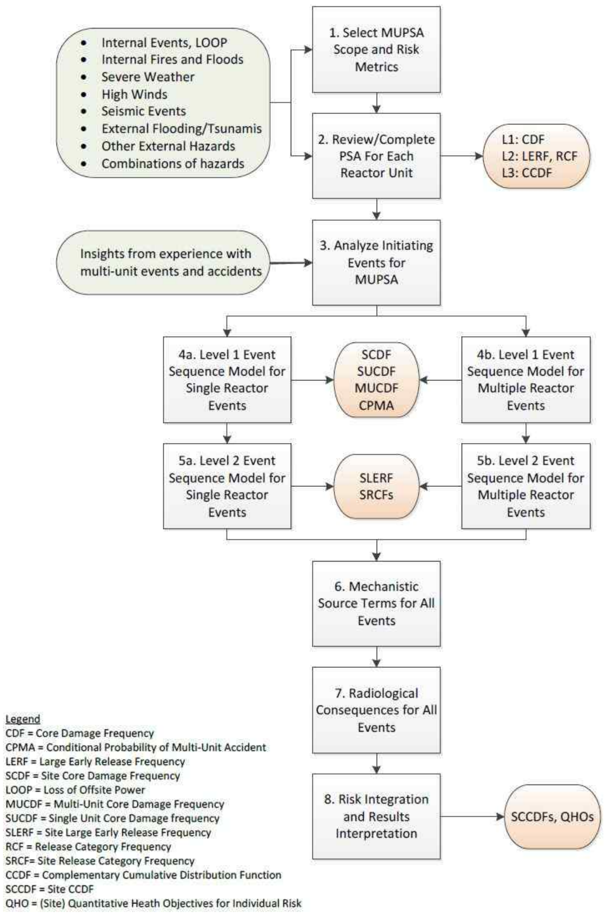

Fig. 1. Overview of process for MUPSA [1].

First, we have to select MUPSA scope and risk metrics. Risk metrics can be considered as either the level 2 PSA results which are presented by site core damage frequency (SCDF) and site large early release frequency (SLERF) or level 3 PSA results such as the complementary cumulative distribution functions (CCDF) for public health and safety impact.

Next, we can perform a single-unit PSA for each reactor according to the previously selected PSA scope and risk metrics. In this process, the initiating events that may affect multiple units and dependencies between multiple units can be also identified.

After performing a single-unit PSA, initiating events which affect a single unit only and those which have an impact on multiple units are selected to develop the event sequence model.

The event sequence models are developed according to the selected initiating events. The model which involves single unit only is based on those which were developed in a single-unit PSA. In case of the event sequence model involving two or more units, a new model is developed to confirm the accident sequence that results in core damage. Using these models, quantification is performed to calculate SCDF, SLERF, and site release category frequencies (SRCFs).

In order to develop the event sequence model, the event sequence diagram as shown in Figure 2 can be used to provide guidelines for constructing event trees and fault trees of MUPSA. Figure 2 shows the example of the event sequence diagram for two reactor units and the symbols used in the diagram are presented in Figure 3.

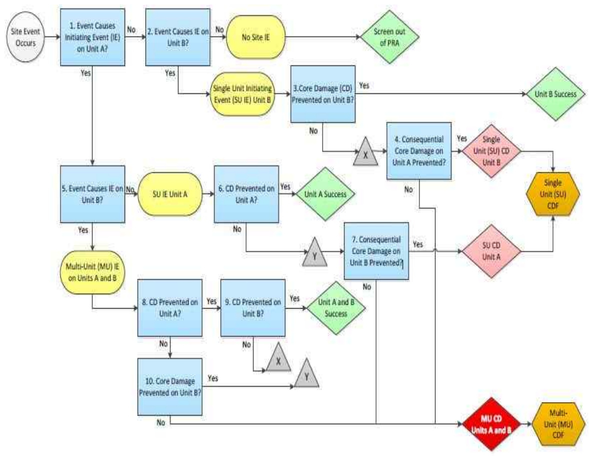

Fig. 2. Event Sequence Diagram for a Site Event at a Two-Reactor Unit Site [1].

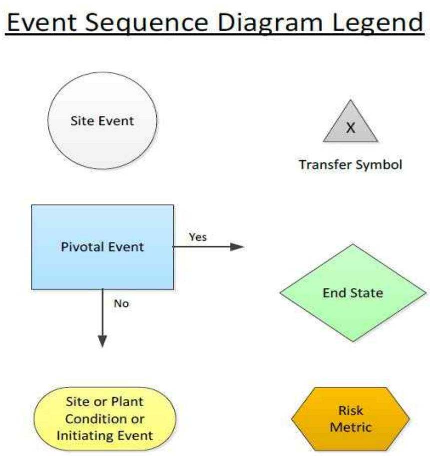

Fig. 3. Event Sequence Diagram Symbols [1].

Finally, if level 3 PSA results are selected for risk metrics, consequence analysis for all the events and release categories are performed to develop level 3 risk metrics such as the Site CCDF and Quantitative Health Objectives (QHOs). A summary of risk metrics for the MUPSA is shown in Table I.

Table I: Summary of Risk Metrics for MUPSA [1]

Risk Metrics	Applicability
Core Damage Frequency (CDF)	Level 1 Single-Unit PSA
Large Early Release Frequency ($LERF$)	Limited Scope Level 2 Single-Unit PSA
Site Core Damage Frequency ($SCDF$)	Level 1 Multi-Unit PSA
Single Unit Core Damage Frequency ($SUCDF$)	
Multi-Unit Core Damage Frequency ($MUCDF$)	
Conditional Probability of Multi-Unit Accident ($CPMA$)	
Site Large Early Release Frequency ($SLERF$)	Limited Scope Level 2 Multi-Unit PSA
Release Category Frequency (RCF)	Full Scope Level 2 Single-Unit PSA
Site Release Category Frequency ($SRCF$)	Full Scope Level 2 Multi-Unit PSA
Complementary Cumulative Distribution Function ($CCDF$)	Level 3 Single-Unit PSA
Site $CCDF$ ($SCCDF$)	Level 3 Multi-Unit or Multi-Facility PSA
Quantitative Health Objectives ($QHOs$)	

2.2 An event classification schema for evaluating site risk in a MUPSA

This report [2] describes the classification of unit-to-unit dependencies that can be considered in the MUPSA and presents existing methodologies to quantify those dependencies.

From a MUPSA perspective, there are many types of dependency between multiple units. In this study, six main classifications have been established: initiating event, identical component, human dependency, shared connection, proximity dependency, and organizational dependency. These six classifications are presented in Figure 4.

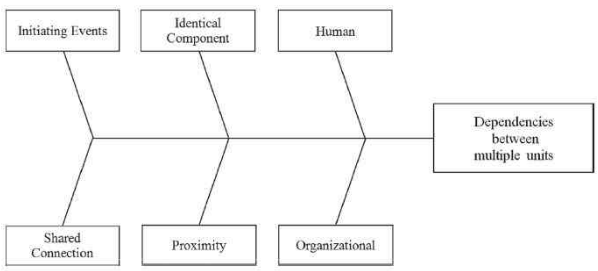

Fig. 4. Commonality classification of dependent events [2].

2.2.1 PSA methods for multi-unit dependencies

In order to evaluate the six classes of multi-unit dependencies, five different methods have been identified: combination, parametric, causal-based, extension, and external event type methodologies.

The combination method is simply considered to combine existing single-unit PSAs into a multi-unit PSA.

The parametric methods are commonly used in traditional PSAs for common cause failure events. The parameters that are derived using these methods are used to quantify the conditional probability of occurrence of events. These methods are divided into two major categories: shock models including Binomial Failure Rate (BFR) and non-shock models including alpha factor, beta factor and Multiple Greek Letter (MGL) model.

The causal-based method requires that all events have to be mapped back to a root problem, whether the event is related to a physical failure or an organizational deficiency. The causal-based modeling can take many techniques such as process modeling method, regression-based method, deterministic dynamic method, and Bayesian Belief Network (BBN).

The extension method simply extends the traditional PSA model, which typically consists of a combination of event trees and fault trees.

The final method uses the existing external event type methodologies and applies them to a wider subset.

2.2.2 Application of methodologies

The five methodologies that have been described above are not applicable to all of the classifications. Specific methodologies are reasonable for individual classifications. The table II shows the applicability and workability of methodologies accounted for each of the unit-to-unit dependencies.

Table II: Applicability of methodologies for each classification [2]

Classification & subclass	Applicable methodology
Initiating event	
Definite Conditional	Combination Parametric or causal
Shared connection	
Single Time sequential	Combination Parametric, causal, or extension
Standby	Causal or extension
Identical Component	Parametric or causal
Proximity	Extension or external event type
Human	
Pre-initiating event Post-initiating event	Parametric or causal Parametric or causal
Organizational	Extension or causal

3. Conclusions

In Korea, all NPP sites include multiple units and are located near densely populated areas. Therefore, the multi-unit risk management needs to be more focused. This report reviewed the existing studies to find the methodology for a MUPSA. In the first study of literature review, risk metrics and the flow chart for a MUPSA were described and the event sequence diagram method that can be used for the MUPSA modeling was identified. In the second study of literature review, dependencies between multiple units, which are considered to be important in a MUPSA, were classified into six groups and applicable methodologies were identified.

From this report, major issues in the MUPSA such as risk metrics, dependencies between multiple units were figured out and will need to be managed carefully in the later study.

Acknowledgements

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KOFONS), granted financial resource from the Nuclear Safety and Security Commission (NSSC), Republic of Korea (No. 1305008).

REFERENCES

[1] International Atomic Energy Agency, Technical Approach to Multi-Unit Site Probabilistic Safety Assessment, Safety Report Series No. XX (Draft), 2014.

[2] S. Schroer and M. Modarres, An Event Classification Schema for Evaluating Site Risk in Multi-Unit Nuclear Power Plant Probabilistic Risk Assessment, Reliability Engineering and System Safety, Vol. 117, pp.40-51, 2013.