A Preliminary Site Risk Assessment for the Reference Site in Korea

Sunghyun Park, Seunghyun Jang, Hoyoung Shin, Dohyun Lim, Yein Seo and Moosung Jae*
Department of Nuclear Engineering, Hanyang University, Seoul, 04763, Republic of Korea
**Corresponding author: jae@hanyang.ac.kr*

1. Introduction

Probabilistic Safety Assessment (PSA) for domestic nuclear power plants have been limited to single unit Level 1, 2 PSA of internal events and some external events. Thus, there is no representative risk profile in Korea. In order to assess site risk, a Multi-Unit PSA (MUPSA) should be performed additionally.

A target of single unit PSA is a unit. In contrast, a target of MUPSA can be all units on a site. The scope of this study, therefore, was limited to a reference site in Korea. And, this study was performed with reference to a lot of researches studied so far.

In chapter 2, a site risk matrix used in this study is described. In chapter 3, the main step of evaluating site risk and the improvements of Level 1, 2, 3 PSA model are described briefly. In chapter 4, point estimation fractions of individual early fatality and latent cancer fatality are presented.

2. Site Risk Matrix

The reference site in this study consists of one unit of WH600 reactor type, two units of WH900 reactor type, two units of OPR1000 reactor type, and two units of APR1400 reactor type.

The site risk can be constructed as the sum of risk from Single Unit Initiator (SUI-risk) and risk from Common Cause Initiator (CCI-risk) [1].

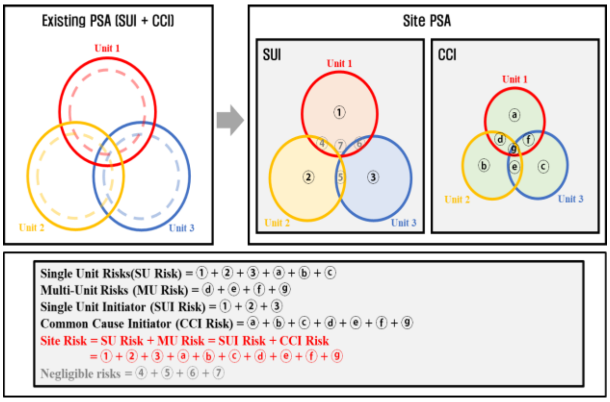

Fig. 1. Venn Diagram Depicting Site Risk

SUI is an initiator that occurs at one unit, and affecting the unit. The SUIs considered in this study are the initiating events that were considered in the previous single unit PSA. CCI is an initiator that simultaneously occurs at multi-unit in the site, and affecting the multi-unit. The CCIs considered in this study are Multi-Unit Loss Of Offsite Power (MULOOP), Multi-Unit Loss Of Condenser Vacuum (MULOCV), and Multi-Unit General Transient (MUGTRN).

3. Methodology

The site risk assessment involves the following key steps.

- Define site risk
- Define initiating events
- Modeling single, multi-unit Level 1/2 PSA
- Modeling single, multi-unit Level 3 PSA
- Assessment of single, multi-unit risk

3.1 Single and Multi-Unit Level 1/2 PSA

The single unit Level 1 PSA model used in this study is the improved model by reflecting the latest design information based on Multi-Purpose Analysis Safety (MPAS) model [2, 3, 4].

The factors considered in the Level 1 MUPSA model are as follows.

- Calculation of CCI frequency
- Inter-unit Common Cause Failure (CCF) modeling
- Calculation of power recovery probability
- Application of Alternative AC Diesel Generator (AAC DG) priority

The frequencies of MULOOP, MULOCV, and MUGTRN were calculated. The number of years of site operation was assumed to be the period from the start of commercial operation of the first reactor on the reference site to 2017 [5]. And, Multi-Unit Data Analysis Program (MUDAP) was developed for Bayesian updating of the frequencies [6]. In addition, the initiating event frequencies of LOOP, LOCV, and GTRN for SUI was newly calculated by separating it from the frequencies of CCI.

In order to consider dependency of the same components, inter-unit CCF modeling was considered in MUPSA. The methodology of inter-unit CCF modeling is based on Swain Dependency [7]. In addition, the components to which inter-unit CCF modeling was applied was selected by an importance analysis. The components selected for each initiating event are shown in Table I.

Table I: Inter-Unit CCF modeling Components for each IE

CCI	CCF components
MULOOP	EDG, EDG room fan, ECW chiller, ESW pump house fan, Processor module
MULOCV	ECW pump, ECW chiller, ESW pump, EW pump house fan, AFW check valve
MUGTRN	ECW chiller, ESW pump, ESW pump house fan
EDG: Emergency Diesel Generator ECW: Essential Chilled Water ESW: Essential Service Water	

The MULOOP accident can occur simultaneously, which requires a relatively long time for offsite power recovery. Therefore, the failure probability of power recovery was recalculated and applied to the model [8].

AAC DG is a representative shared component. The AAC DG, however, cannot be used simultaneously in the multi-unit. Therefore, unavailability by connection to another unit have to be considered. The connection priority rules were assumed as follow. First, AAC DG operation was considered according to the priority of each unit and when the accident occurred. Second, since Station Black Out by EDG fail to run (SBO-R) occurs later than Station Black Out by EDG fail to start (SBO-S), AAC DG operation was considered preferentially for the unit in which SBO-S occurred. The priority of AAC DG considered in this study is shown in figure 2.

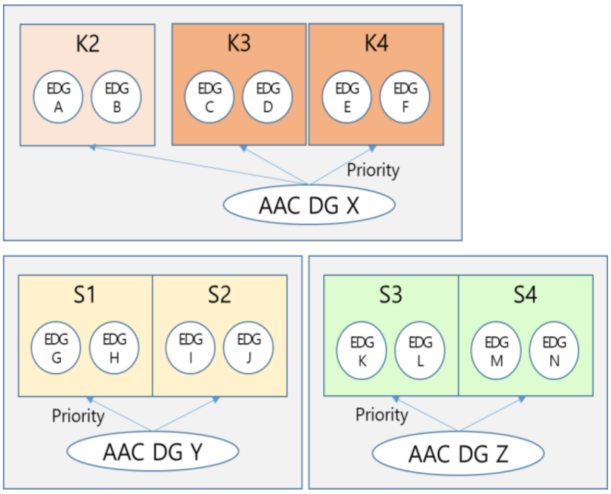

Fig. 2. Priority of AAC DG in the Reference Site

In case of single unit Level 2 PSA, Plant Damage State Event Trees (PDS ET) were developed by considering containment mitigation systems such as containment isolation system, hydrogen mitigation system, containment heat removal system, cavity flooding system and etc.. In addition, Plant Damage State Logic Diagram (PDS LD), Containment Event Tree (CET), Decomposition Event Tree (DET), and Source Term Category Logic Diagram (STC LD) were developed in consideration of each plant characteristics.

The peak pressure of late containment failure was calculated using MELCOR to calculate the DET branch probability of the late containment failure [9, 10]. The peak pressure of early containment failure was also calculated using MELCOR and Two Cell Equilibrium (TCE) code to calculate the DET branch probability of the early containment failure [9, 11].

The accident sequence with the highest frequency was assumed as the representative accident of STC and severe accident analyses for each STC were performed by MELCOR [9].

In this study, it was assumed that the effects of severe accident to another unit are ignored. The Level 2 MUPSA modeling and quantification were performed by using the mapping table methodology [12].

3.2 Single and Multi-Unit Level 3 PSA

The single and multi-unit Level 3 PSA were performed by WinMACCS [13]. The Level 3 PSA model developed in advance was used in single and multi-unit PSA. Some input parameters were improved and the improved input parameters are as follows [14].

- Evacuation Time Estimates (ETE)
- Update of weather data and sensitivity analysis of weather sampling methods
- Development of plume segmentation method and its application
- Calculation inventories by ORIGEN-ARP code

In order to construct a realistic emergency response model in WinMACCS, ETE using TSIS-CORSIM was performed [15].

The recent weather data of 2018 excluding mixing height that is referenced in the environmental evaluation report was used in this study [16]. In addition, we compared the error of the result obtained by the stratified random sampling which was assumed as true value and the result obtained by the non-uniform bin samplings with different bin criteria. A non-uniform bin sampling with less error was applied into single and multi-unit Level 3 PSA.

A small number of plume can underestimate or overestimate consequence. Therefore, the number of plume should be increased for accurately estimating consequence. However, increasing the number of plumes also increases the code calculation time, which limits multi-unit Level 3 PSA. Therefore, the results of the 72 plumes after the start of release were compared with the results various segmentation methods in this study. As a result, 24 plumes are released during the 24 hours after the first release. After 24 hours after the first release, two plumes are released.

The core inventory for each reactor type was calculated by ORIGEN-ARP code. The newly calculated inventory was used in WinMACCS. The conservative result of cycle was used.

Since the multi-unit accident release different source terms to the environment, the number of combination of source term can increase exponentially as increasing the number of units. The increasing number of combinations is one of the important issues in multi-unit Level 3 PSA. In order to solve this problem, there have been recently developed mapping table methodology and STC re-grouping methodology [12, 17]. These methodologies, however, have uncertainties and some limitations. Therefore, the consequence calculation for all combination derived from Level 1 and 2 PSA results was performed in this study. It is shown in Table II.

Table II: The Number of STC Combinations

Initiator	Type (cut off value: 10-15)	The number of STC combination	The number of consequence calculation
SUI	K2	13	13
	K3	17	17
	K4	17	
	S1	15	15
	S2	15	
	S3	15	15
	S4	15	
	TOTAL	107	60
CCI	MULOCV	129	46
	1-MULOCV	83	0
	2-MULOCV	46	46
	MUGTRN	95	7
	1-MUGTRN	87	0
	2-MUGTRN	8	7
	MULOOP	2115	1849
	1-MULOOP	100	0
	2-MULOOP	1296	1130
	3-MULOOP	713	713
	4-MULOOP	6	6
	TOTAL	2339	1902
TOTAL		2446	1962

The 'Multi Source Term' function in WinMACCS was used to simulate multi-unit accidents. However, the current version 3.11.2 of WinMACCS can set only single release point. Therefore, it was assumed that the release point of multi-unit accidents is a weighted average point of thermal power of each reactor.

4. Results

The risk is the product of the frequency calculated by Level 2 PSA and the consequence calculated by Level 3 PSA. In this paper, population-weighted risk of Early Fatality (EF) and Latent Cancer Fatality (LCF) are presented. Radii of 2km, 5km for EF and 16km, 26km for LCF were considered respectively. All risks in Table III are expressed as a percentage of site risk. All EF risks in 2km, 5km occurred by only SUI (ISLOCA), not by CCI. In contrast, LCF risks in 16km, 26km occurred by both SUI and CCI. The LCF risk by SUI is dominant, and most of LCF risk by CCI is attributed to 1-MULOOP. LCF risk by CCI in two or more units have a high consequence but has an extremely low frequency. Therefore, the LCF risk is estimated to be significantly lower than the other LCF risks.

5. Conclusion

Since the Fukushima accident, interest in multi-unit risk has increased worldwide. In this study, the preliminary site risk assessment for the reference site in Korea was performed. In the Level 1 PSA, calculation of CCI frequency, inter-unit CCF modeling, calculation of power recovery probability, AAC DG priority modeling were performed. In the Level 2 PSA, PDS ET, PDS LD, CET, DET, STC LD for each reactor type were developed. Severe accident analysis by MELCOR was performed. In the Level 3 PSA, ETE by TSIS-CORSIM, update of weather data and sensitivity analysis of weather sampling methods, development of plume segmentation method, and calculation core inventory were performed. Population-weighted EF and LCF risks by SUI and CCI were calculated in this study.

Table III: Fraction of Population-Weighted Risk of Early Fatality and Latent Cancer Fatality

Type	EF(~2km)	EF(~5km)	LCF(~16km)	LCF(~26km)
SUI(ISLOCA)	100	100	80.92	81.34
1-MULOOP	0	0	17.52	17.21
1-MULOCV	0	0	0.12	0.11
1-MUGTRN	0	0	0.14	0.14
2-MULOOP	0	0	1.27	1.18
2-MULOCV	0	0	0	0
2-MUGTRN	0	0	0	0
3-MULOOP	0	0	0.02	0.02
4-MULOOP	0	0	0	0
Site Risk	100	100	100	100

All risk by SUI are dominant, and most of LCF risk by CCI is attributed to 1-MULOOP.

The site risk assessment has a lot of uncertainties such as uncertainty of frequency, source term, consequence. The model in this study will be updated to reduce the uncertainties. This study will contribute to development of site risk assessment methodology.

Acknowledgement

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KOFONS), granted financial resource from the Multi-Unit Risk Research Group (MURRG), Republic of Korea (No.1705001).

REFERENCES

[1] Martian A. Stutzke, Scoping Estimates of Mulitunit Accident Risk, Probabilistic Safety Assessment and Management 12 (PSAM12), June 22-27, 2014, Hawaii, USA.
[2] Mijung Hwang, et al., Development of Guidance for Level 1 PSA Modeling, KAERI/TR-7539/2018, 2018.
[3] K. H. Jin, et al., Development of Full-Power Internal Event Level 1 PSA Model in Gori Unit 3, 4 for Site Risk Assessment, NSTAR-XXXX, 2019.
[4] C. K. Seong, et al., Development of Full-Power Internal Event Level 1 PSA Model in Shin-Gori Unit 1, 2 for Site Risk Assessment, NSTAR-XXXX, 2019.
[5] Dohyung Kim, et al., Collection and Analysis on Essential Data for Multi-unit Risk Assessment, KINS/RR-1810, 2017.
[6] W. J. Song, et al., Initiating Event Frequency Analysis using A Bayesian Computer Code, ASRAM2017-1099, 2017.
[7] Seunghyun Jang, et al., A Case study of Methodology for Common Cause Failure modeling in Multi-unit PSA model, Transactions of the Korean Nuclear Society Autumn Meeting, 2018.
[8] Y. I. Seo, H. Y. Shin, and M. S. Jae, Modeling of the Off-site Power Recovery in the Multi-Unit PSA, Transactions of the Korean Nuclear Society Autumn Meeting, 2018.
[9] Gauntt, et al., MELCOR computer code manuals, NUREG/CR-6119, 2000.
[10] Seok-Jung Han, et al., An Approach to Estimation of Radiological Source Term for a Severe Nuclear Accident using MELCOR code. Journal of the Korean Society of Safety, 27(6), 192-204, 2012.
[11] M. M. Philch, et al., The Probability of Containment Failure by Direct Containment Heating in Zion, NUREG/CR-6075 Supp. 1, 1994.
[12] Hogon Lim, et al., Development of Site Risk Assessment & Management Technology including Extreme External Events, KAERI/RR-4225/2016, 2017.
[13] Nathan Bixler, et al., MELCOR Accident Consequence Code System (MACCS) User's Guide and Reference Manaual(Draft Report), US NRC, NUREG/CR-XXXX.
[14] M. S. Jae, et al., A Study on MACCS Input Parameters for A Level 3 PSA Model for Regulation Verification, NSTAR-18NS12-24, 2018.
[15] Sunghyun Park, et al., Evacuation Time Estimates on the Reference Nuclear Power Plant, NSTAR-19RS42-62, 2018.
[16] KHNP, Radiation Environmental Evaluation Report, 2016.
[17] W. J. Song, Development of A Multi-Unit Consequence Analysis Methodology, Master Thesis, Hanyang University, 2019.