Industry R&D Plans for the Site Risk Management and Safety Goal in Korea

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In this paper, R&D plans of Korea Hydro & Nuclear Power (KHNP) for multi-unit risk were summarized. Fukushima Daiichi accident occurred in 2011 shows that severe accidents of multiple Nuclear Power Plants (NPPs) concurrently can occur at site by natural disasters. The accident has made a change in existing safety goals and risk assessment philosophies. As a result of this accident, many countries have stopped construction and operation of plants, while other countries maintaining nuclear power program have to made efforts to develop the safety goal, regulatory requirements, and the methodology for multi-unit sites risk assessments as well as to the safety enhancements. These activities are important and necessary to quantitatively estimate the risk and also to correspond with the public concerns for the safety of plants. However, the research associated with multi-unit risk is still in the beginning stages internationally, because existing techniques have been developed to assess only the risk of single-unit risk. For this reason, many countries have actively performed various research projects to meet the needs of their own.

The purpose of multi-unit risk assessment is to improve the social acceptance for the comprehensive safety of nuclear facilities raised by Fukushima accident. Currently, this issue is being magnified with the construction permits of two new NPPs in Korea, both of nuclear industries and publics have concerned with that. Generally, quantitative risk surrogates such as Core Damage Frequency (CDF) and Large Early Release Frequency (LERF) have been used to check whether the safety goal is satisfied or not. However, it is expected that there are many difficulties to secure the public acceptance using existing surrogates because they were established based on single-unit risk information. Hence, the technique for estimating and managing the risk in terms of site should be developed to improve the safety and the public acceptance for NPPs.

I. Introduction

Fukushima Daiichi accident occurred in 2011 shows that severe accidents of multiple Nuclear Power Plants (NPPs) can occur by natural disasters which affect a wide area. After the accident, several countries have stopped the construction and operation of plants, while other countries which are maintaining the nuclear power program have made efforts to develop the safety goal, regulatory requirements, and the methodology for multi-unit site risk. These activities are important to quantitatively assess the risk and also to correspond with the public concern for the safety of NPPs. However, the research phase for estimating the multi-unit risk is still in the beginning stages internationally, because existing techniques have been developed only to assess the risk of single-unit. For this reason, many countries have actively performed various researches to meet the needs of their own.

In Korea, due to its geographical characteristics, many plants have been constructed and operated at a single site (four sites, each site has more than four NPPs). This is above the average level or number of plants per site in the world. For this reason, the public concerns for the safety of nuclear facilities have increased after the Fukushima Daiichi accident. As a result, comprehensive risk assessment and management for the sites which have multi-unit plants were required. Currently, many research projects focusing single unit have been carried out by industries, research centers, and regulatory agency to solve it. Especially, because KHNP is mission to construct and operate the NPPs in Korea, it must be in charge of all kinds of R&D associated with multi-unit issues.

In this paper, R&D plans of KHNP for multi-unit risk are summarized. Firstly, the needs of multi-unit Probabilistic Safety Assessment(PSA) are reviewed. International research status to estimate multi-unit risk is introduced in the second part. Finally, R&D activities and plans of KHNP on the multi-unit risk assessment are introduced.

II. Safety Goal and Site Risk

II.A. Safety Goal for Nuclear Power Plants

The safety goal is an answer associated with the safety of nuclear facilities to the question of "How safe is safe enough?" [1]. Many countries operating and managing plants have established the safety goal to assure the safety of NPPs. It means that there should be no additional risks to the public and environment as a result of nuclear facilities operation. As a simple example, International Atomic Energy Agency (IAEA) has established and shared the safety goals and principles that can be commonly used in the world. It recommended member countries to appropriately apply the safety goals as their circumstances because the applications of the safety goals were a key point to the safety framework. Generally, the safety goal has a hierarchy structure that consists of qualitative and quantitative goals [2]. The representative example of qualitative safety goals commonly used in the world was "to protect the people and environment from harmful effects of ionizing radiation". Most of qualitative safety goals can appropriately be used to communicate with the public [3]. However, it is not enough to use the qualitative safety goals alone for judging the safety of nuclear plants. For this reason, the quantitative safety goals are used with the qualitative safety goal. The quantitative safety goal widely used is "the risk caused by nuclear facilities is less than 0.1% of other industries". For that, the risk surrogates such as Core Damage Frequency (CDF) and Large Early Release Frequency (LERF) are used as a risk measure of quantitative safety goal.

II.B. Safety Goal for Multi-unit Site

The Fukushima accident has made a change in existing safety goal and the risk assessment. Before the accident, in terms of safety of nuclear facilities, nuclear industries, publics and regulatory agency had concern for the single-unit accident. It is because there are no experiences of multi-unit accidents and their frequencies expected by several studies which were limitedly performed are negligibly low. Therefore, single-unit based information was used to establish the safety goal and Quantitative Health Objective (QHO). To check whether the safety goal based on single-unit is satisfied or not, PSA based on single-unit was also developed and performed. In other word, it means that existing PSA has estimated the risk under an assumption that other units excluding the target unit are safe. However, as shown that the existing assumption was inadequate by Fukushima accident, the concern for multi-unit accident and risk (site risk) was increased. For this reason, some countries have made an effort to develop the safety goal, regulatory requirements, and assessment methodologies for a site. For example, CANDU Owner Group suggested Large Off-Site Release Safety Goal (LORSG) and Site Severe Core Damage Frequency (Site SCDF) and their definitions are as follows ;

- Large Off-Site Release Safety Goal (LORSG): The aggregate of frequencies, LRF, of all event sequences that can lead to a total release from the site to the environment of more than X (Becquerel) of Y (radionuclide) should be less than Z_{LRF} per site year
- Site Severe Core Damage Frequency (Site SCDF): The aggregate of frequencies of all event sequences that can lead to significant core degradation in any of one or more reactors on the site should be less than Z_{SCD} per site year.

Especially, in Korea, the issues related with multi-unit site have become more important because many plants have been constructed and operated at a single site compared with other countries. This assessment is an important and practical issue by nuclear industries to get the public acceptance. Currently, there are no clear and comprehensive methods for above issues. Therefore, various researches are needed to systematically and appropriately address them.

III. Current Status of Multi-unit PSA

Multi-unit issues had attention as a result of the Fukushima accident, but some research associated with multi-unit risk was performed from before. The representative one of these research studies was multi-unit PSA performed in 1986 for the Seabrook nuclear power plant site which was planned to construct two units at the same site [4]. In this research, multi-unit risk for initiating events such as seismic that can concurrently affect multiple units was performed, which was mainly driven by NRC. In USA, the adequacy of existing QHO established by single-unit risk information was discussed in the design certification of Small Modular Reactor (SMR) that was to be constructing and operating multiple units at a same site. And, the necessity of multi-unit PSA was more highlighted by Fukushima accident.

In multi-unit PSA, there are many issues in accordance with geographical/environmental characteristics, nuclear energy policy, plant design, and the technical capability of PSA [5]. Firstly, issues of each country in terms of geographical/

environmental characteristics, nuclear energy policy are following; (1) the construction and operation of multiple units at the same site (Canada, Japan, and Korea), (2) the frequent occurrence of extreme external events such as earthquake, extreme weather condition) (Japan and Europe), and (3) high population density nearby NPP sites (Korea, Japan, and Europe). The plant design characteristic means that how many shared systems are existed between units. Finally, the technical capability of PSA developed based on single-unit was also an important issue. The related issues are;

- Identification and classification of multi-unit initiating events by failure of shared systems
- Frequency estimation of multi-unit initiating events
- Inter-unit Common Cause Failure (CCF)
- Human Reliability Assessment (HRA) for adjacent unit's operation when severe accidents is occurred at a certain unit
- Correlation between units for external events
- Multi-unit risk metric
- Quantification of multi-unit PSA model
- Multi-unit off-site consequence analysis

Currently, there are many difficulties to assess the multi-unit risk using the existing assessment framework by above technical issues that were not considered in single-unit PSA before. To solve that, various researches have been performed or considered internationally.

III.A. International Research Status

Although the United State is leading the PSA field, the number of NPPs at a site is less than that of other countries, and they have advantageous geological locations in terms of population density. They made an effort to assess the multi-unit risk through various research projects [6, 7] such as scoping estimation. In case of Japan, external events such as seismic and tsunami are frequently occurred compared with other countries. For this reason, they have considered multi-unit accident caused by seismic in the past. Especially, the research with respect to CCF by seismic correlation was actively performed [8, 9]. The research status of other countries and institutes are followings;

- IAEA
  - Establish the safety assessment guidelines for multi-unit site
  - Review the operating experience for multi-unit site and current research status
  - Establish multi-unit risk measures
- Advanced Safety Assessment Methodologies: Extended PSA (ASAMPSA_E)
  - Identification of vulnerabilities of single-unit PSA and development of multi-unit PSA
  - Researches related to the technical issues such as risk metrics, HRA, and so on.
- Canada : Extend the scope of PSA (consideration of multi-unit effect)
- Finland : Assessment of multi-unit effect by Loss of Off-site Power (LOOP)

III.B. Korean Research status

In Korea, the research level related with multi-unit risk and PSA is also in the beginning stage. Currently, various research projects for assessing multi-unit risk and establishing the site based safety goal are being performed or planned. The research studies are the identification of Korea specific issues related with the multi-unit risk assessment and the development of the risk assessment framework. Detailed contents are followings;

- Research institute
  - Define the site risk and construct top logical structure of site risk model
  - Develop individual unit logical risk model (Level 1 & 2)
  - Identify and select site based external events
  - Treat dependencies between units (initiating events, shared systems, CCF, and so on)
  - Quantify multi-unit risk model
  - Perform preliminary off-site consequence analysis and develop multi-unit risk profile
- University research project supported by regulatory authority
  - Summarize technical issues of multi-unit PSA
  - Review the current research status of multi-unit PSA

- Review the current research status of other industrial cases
- Survey accident cases of each industry by CCF

- Regulatory authority
  - Establishing the research roadmap for the regulation of multi-unit PSA
  - Develop the failure database by CCF
  - Review the effect of multi-unit risk in existing PSA framework and regulatory requirements
  - Develop multi-unit risk measures
  - Suggest the plan to improve existing PSA model considering the effects of shared structures, systems, components

IV. R&D Plan of KHNP for Site Risk Management

The main purpose of multi-unit risk assessment is to improve the social acceptance for the comprehensive safety of nuclear facilities raised by the Fukushima accident. Currently, this issue is being magnified in regard to construction of two new units in Korea. Nuclear industries have been concerned with that. Generally, quantitative risk surrogates such as Core Damage Frequency (CDF) and Large Early Release Frequency (LERF) have been used to check whether the safety goal is satisfied or not. However, it is expected that there are many issues in acquiring the public acceptance using existing surrogates because they were established based on single-unit risk information. Hence, the technique for assessing and managing the risk in terms of site should be developed to initiatively improve the safety and the public acceptance for plants.

KHNP has carried out and updated PSA on all units with engineering companies and research centers such as Korea Atomic Energy Research Institute and KEPCO Engineering & Construction and so on, which is mainly driven by Central Research Institute of KHNP. KHNP is in charge of all kinds of researches to assess and manage the multi-unit risk. For that, KHNP have made efforts focused on how to extend PSA up to Low Power/Shutdown and Level 3 PSA that have not been carried out yet. In addition, many research projects associated with the systems of newly designed NPPs have been also performed.

IV.A. Single-unit Risk Assessment

Basically, multi-unit PSA will be performed by integration of single-unit PSA models considering the multi-unit dependencies such as shared systems, organization factors, and so on. In other words, to assess the realistic multi-unit risk, single-unit PSA models in accordance with the design and operation mode of each unit should be prepared. For this reason, KHNP performed various research projects associated with the single-unit model which is needed to assess the multi-unit risk.

- Performed Low Power Shutdown (LPSD) PSA for all NPPs
  - Update full power PSA model of operating NPPs
  - Develop LPSD PSA model based on updated full power model
- Develop Level 2&3 considering state-of-art technology
  - Review the knowledge and technique for analyzing severe accidents
  - Construct off-site consequence model and perform optimized risk assessment considering methodologies and techniques of SOARCA project
  - Construct risk management framework based on optimized safety assessment model

IV.B. Multi-unit Risk Assessment

Currently, KHNP began the research project “Multi Unit Risk Assessment of Pilot Plants based on Focused Probabilistic Safety Assessment Model” by various needs mentioned above. There are many difficulties to assess the reliable risk because of technical limitations. For this reason, the multi-unit risk based on scenarios identified by analyzing causes which can affect multi-units will be firstly assessed. Using that, we have ultimately targeted to improve the safety in terms of multi-unit site.

This project consists of two parts (long and short term purpose). The long term objective was the establishment of a roadmap to systematically manage the multi-unit site risk. It was divided into two categories: (1) establish the roadmap for assessing and managing the multi-unit risk, and (2) analyze the dependencies of systems, maintenances, operations which can affect multiple units. The short term purpose is to preliminarily assess the multi-unit risk based on focused scenarios. Details are;

- Multi-unit Risk Assessment Roadmap (long term)
  - Establish multi-unit risk metrics to manage the risk(just technical analyses purpose)

- Identify multi-unit accidents and estimate their frequencies
- Suggest the method for assessing the multi-unit risk based on focused scenarios
- Identify and analyze the shared or common structures, systems, and components
- Sensitivity study based on multi-unit dependencies

- Multi-unit risk assessment based on accident scenarios (short term)
  - Characteristic on multi-unit dependencies for expected multi-unit accident scenarios
  - Review Korea-specific multi-unit risk for expected multi-unit accident scenarios
  - Establish the safety improvement measures by review of multi-unit risk
  - Estimate preliminary multi-unit risk based on accident scenarios

To perform preliminary risk assessment in the short term, we will consider, above all, use of the methodology developed by national research institute mentioned above section III.B. The first step of this method is to identify multi-unit IEs based on historical data from Korean NPPs, and then multi-unit PSA models for each IE are developed using existing single-unit models. In this step, dependencies between units are also considered and applied. Finally, multi-unit models are quantified using Monte Carlo sampling to estimate the risk. To get more detailed information on method, refer to the paper "Study on Quantification for Multi-unit Seismic Model using Monte Carlo Sampling" presented by Oh [10].

In the long term, it is expected that they will be used as basic data to develop the detailed risk models and regulatory frameworks which consider Korea specific characteristics of plant's site.

V. Conclusions

In this paper, we summarized the R&D plans of KHNP to estimate the risk for multi-unit sites. The Fukushima accident has made many changes in the nuclear industry. As a result of this accident, several countries stopped the construction and the operation of NPPs, while other countries which are maintaining the operation were strongly asked to suggest answers for solving various issues associated with prevention and mitigation of multi-unit accident. Therefore, many research projects have been internationally performed. These activities, in terms of keeping the operation of NPPs and national policy of nuclear energy, were important and necessary to correspond with the public concern raised by Fukushima. Because of Korean geographical characteristics, the number of plants per site in the world being constructed and operated at a single site is above the average. The population density at each site is considered to be higher than that of other countries. After getting the construction permit for two new units by the regulatory authority, a site will have nine units. For this reason, KHNP is covering all kinds of R&D associated with multi-unit issues and makes an effort to improve the public acceptance.

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