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Regulatory Considerations of Multi-Unit Site Risk

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1. Introduction

Multiple nuclear power units are typically built on the same site in order to increase power generation for the regional grid, and for economical or other reasons. In the case of the Republic of Korea, the four nuclear plant sites are each expected to hold 6 to 10 units in the near future. Although little attention has been paid to the integral risk of multiple units on the same site thus far, there is a surge of interest in the multi-unit site risk these days especially because of simultaneous, radiological releases at several units (including spent fuel pools) of the Fukushima Daiichi Nuclear Power Station. This paper discusses historical considerations of the site risk in regulatory arena as well as recent developments in this area.

2. Regulatory Considerations of Site Risk

In nuclear power community, the possibility of simultaneous core damage events on the same site is taken into account particularly in connection with systems design and siting criteria as discussed below [1].

General Design Criterion (GDC) 5: A total of 64 General Design Criteria (GDCs) is included in Appendix A to Part 50 of the Code of Federal Regulations (CFR) to establish minimum design requirements for water-cooled nuclear power plants, encompassing diverse topics to ensure nuclear safety. Among them, GDC 5 [2] limits the sharing of systems, structures and components (SSCs) important to safety among nuclear power units unless it can be shown that such sharing will not significantly impact their ability to perform their safety functions, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units. The justification for sharing SSCs among several units on a site presumably used to be made without due consideration of adverse environmental conditions as caused by extreme natural hazards (thereby limiting accessibility to locations where mitigation measures can be taken, hindering the communication among plant staff due to lack of electrical power, etc.).

Subpart A to 10 CFR Part 100: The Reactor Site Criteria [3] provide requirements for determining the exclusion area, the low population zone, and the population center distance for multi-unit sites. An overly conservative assumption was made such that: if the reactors are interconnected to the extent that an accident in one reactor could affect the safety of operation of any other, the size of the exclusion area, low population zone and population center distance shall be based upon the assumption that all interconnected reactors emit their postulated fission product releases simultaneously.

In addition, the NRC considered the need to establish additional regulations to reduce the likelihood and consequences of multi-unit accidents following the accident at Three Mile Island in 1979 [4]. The subject of multi-unit risk was also considered during development of the Commission's Safety Goal Policy Statement [5], which was issued in 1986.

Furthermore, during the State-of-the-Art Reactor Consequence Analysis (SOARCA) project [6], completed in 2012, the project staff identified "Multi-Unit Core Damage Events" as a proposed Generic Issue (GI). Such events can potentially occur as a result of random or common cause failures of onsite emergency diesel generators following a loss of offsite power, or due to failures of structure, systems, and components (SSCs) resulting from common cause initiators such as internal flooding or seismic events. Multi-unit events impact not only the potential source terms, but also the implementation effectiveness of mitigation measures since the plant staff must now deal simultaneously with accidents in more than one unit.

As pointed out by M. A. Stutzke of the U.S. NRC [1]: "The 2011 accident at Fukushima Daiichi in Japan has reemphasized the fact that multi-unit accidents can happen, and that it is important to understand their risks." As small modular reactors (SMRs) like NuScale are designed so that as many as 12 modular reactors will form an integral set, the NRC's Office of New Reactors established a Working Group in 2012 to consider how to address the risk of accidents that affect small modular reactors in the design certification and combined operating licensing processes. A draft criterion to evaluate multi-module risk was proposed by the NRC staff without establishing any quantitative risk criteria in such a way that multi-module risk (core damage, large release) should be systematically addressed [7].

It is also notable that in developing the Technological Neutral Framework (TNF) as a generic licensing structure encompassing both water-cooled and non-water-cooled advanced reactors, the NRC reconfirmed that the integral risk from multiple units should satisfy the safety goals [8]. For instance, the regulatory requirements set forth in the frequency-consequence (FC) curve of Fig. 1 is supposed to be satisfied for accident sequences for the new reactors at a site. Although the integral risk of multiple units was required to be applied to the FC curve, the TNF study did not actually show how the integral risk could be evaluated.

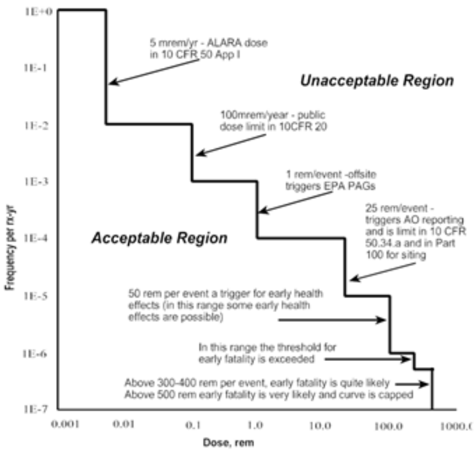

Fig. 1 Frequency-consequence (FC) curve

Following an in-depth review of the Fukushima accident, the NRC's Near-Term Task Force (NTTF) made the following recommendations [9]:

- 4.2 Prolonged Loss of AC Power: Order licensees to provide reasonable protection for equipment currently provided pursuant to 10 CFR 50.54(hh)(2) from the effects of design-basis external events and to add equipment as needed to address multi-unit events while other requirements are being revised and implemented.

- 9.1~9.4 & 10.1~10.3 Emergency Preparedness Considerations for Multi-Unit Events and Prolonged Station Blackout: Rulemaking and contingency measures are needed for emergency preparedness (EP) enhancements for multi-unit events in personnel and staffing; dose assessment capability; training and exercises; equipment and facilities; emergency response data system (ERDS); command and control, etc.

'The equipment provided pursuant to 10 CFR 50.54(hh)(2)' in the NTTF Recommendation 4.2 above imply the so-called B.5.b portable equipment that were added to nuclear power plants of the United States following the September 11, 2001, terrorist attacks; along this line, Extensive Damage Mitigation Guidelines (EDMG) [10] were also developed and implemented in all the plants. In the NTTF Recommendation 4.2, the equipment further added to address multi-unit events means the FLEX equipment that have been newly augmented in all the U.S. nuclear power plants following the Fukushima accident in accordance with the NRC-endorsed NEI document [11]. One can also note that although site risk is accounted for in developing EP program under overly conservative assumptions, the NTTF Recommendations 9.1~9.4 and 10.1~10.3 require further enhancements in diverse areas of relevance (e.g., staffing, training, data, command structure) reflecting lessons from the Fukushima accident.

Recently, the NRC stated that the issue of multi-unit risk would be addressed as part of the full-scope site Level 3 PRA project (SECY-12-0105 and associated Staff Requirements Memorandum). Although a double-unit site of Southern Nuclear Operating Company (i.e., Vogtle Units 1 and 2) was selected as a sample site, the result of this project is expected to provide considerable insights into simultaneous multi-unit accidents and their associated risk.

The Level 3 PRA project [12,13] will build on the state-of-the-art reactor consequence analysis (SOARCA) work to gain a better understanding of potential radiological effects of postulated accident sequences, particularly in the analysis of accidents at multiple units on a site and from the additional source terms contributed by spent fuel pools and dry casks.

3. Concluding Remarks

The multi-unit accident is primarily caused by extreme natural hazards (e.g., earthquake, tsunami, flooding, typhoon) that exceed the design basis of nuclear power plants. Therefore, it is necessary to further clarify the regulatory framework such as safety goals, defense-in-depth or safety margins with respect to beyond-design-basis-events (BDBA) as shown in Fig.2 [14], based on the facts as from the Fukushima accident or other multi-unit events along with reasonable assumptions with respect to human, technological and organizational factors [15].

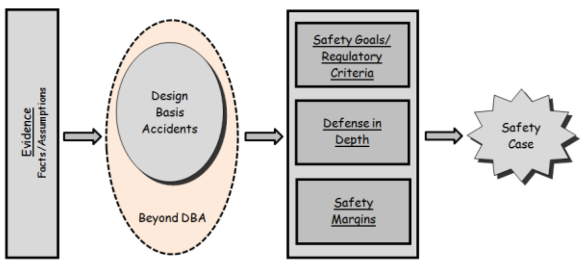

Fig. 2 General safety evaluation framework

In particular, the following recommendations are made to help address the issue of multi-unit site risk associated with the high-density nuclear power plants of Korea:

1. Every reasonable effort should be made to minimize the effects of extreme natural hazards (i.e., potential common-cause-initiators) on the nuclear plant site and resultant public safety, because the Fukushima accident clearly showed that extreme events and scenarios could take place in reality even though they are expected to occur very rarely. Examples include reinforcement of waterproof barriers, seismic strengthening of plant systems and structures. Also important is the resolution of staffing and command-in-control issues associated with multi-unit events resulting from common-cause initiators.
2. In light of the lessons from the Fukushima accident, considerable progress is being made to enhance coping capabilities against extreme events in Korea (e.g., portable equipment, Extensive Damage Mitigation Guidelines). However, it appears that especially site emergency management must be upgraded for public safety as early as possible since it is the last layer of defense
3. In Korea, nuclear emergency involving even a single core-damage might lead to a chaotic situation due to the adverse environmental condition caused by the evolving accident and its potential negative impact on human performance for other nuclear facilities on the site as well as possible inter-unit interactions. There might be also an impact of a reactor or containment involved accident on the associated spent fuel pool within a single unit. These kinds of aspects are not yet properly accounted for in the current nuclear licensing and regulatory structures of the world. Therefore, future research needs to be focused on gaining insights that could be practically applied in enhancing site safety.

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