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Review of existing cases and IAEA documents for combination of external hazards

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1. Introduction

The safety of nuclear power plants against external hazards is essential to ensure continuous energy procurement, so considerations are made for specific external hazards, such as earthquakes, during the design phase. The design and assessment of safety for external hazards are focused on a single hazard, and those for a combination of multiple hazards are not considered due to their perceived low probability. However, the need for the design and safety assessment of nuclear power plants against the combination of hazards has increased following the significant accident caused by the earthquake and subsequent tsunami in the Fukushima nuclear power plant in 2011. Particularly, with the recent increase in the frequency and the magnitude of external hazards such as heavy rainfalls and unexpected low- and high-temperature due to climate change, securing safety against the combination of hazards has become even more urgent.

While the likelihood of a combination of hazards occurring is relatively low, they have the potential to cause more severe accidents than a single hazard. However, assessing the combination of hazards is challenging due to the diverse and complicated nature of hazard mechanisms, frequencies, intensities, and correlations. Motivated by this context, the EESS (External Events Safety Section) in the IAEA (International Atomic Energy Agency) is preparing a technical report to summarize methodologies for assessing the safety of nuclear power plants in the face of a combination of external hazards [1]. Based on the draft of the technical reports, this paper introduces the cases and the relevant IAEA documents related to the combination of the external hazards.

2. Existing cases of the combination of the external hazard to the nuclear power plant

The existing cases of the combination of external hazards to nuclear power plants are introduced by three categories: consequential, correlated, and coincidental hazards.

- Consequential hazards generally refer to sequential hazards where subsequent hazards occur following the initial hazard, and representative examples include earthquake-induced fires and flooding. In 2007, a fire was caused at the Kashiwazki-Kariwa nuclear power plant in Japan due to electrical arcing caused by seismic motion. Similarly, at the Onagawa nuclear power plant in 2011, a fire occurred when an earthquake caused a short circuit in a switchgear cabinet installed on the underground floor of the turbine building. On the other hand, a typhoon and subsequent internal fire broke out at the Fukushima Daiichi nuclear power plant in 1985. Rainwater induced by the typhoon infiltrated through the gap of the cable duct outside the turbine building, and then it induced HEAF (High Energy Arcing Faults) in the 6.9kV bus, resulting in a fire.

- Correlated hazards refer to cases where two or more hazards induced by a common cause initiator have an impact and can mainly include extreme weather hazards. For example, an extreme winter storm in France 1999 caused extreme tidal and biological hazards near the Le Blayais nuclear power plant. The resultant water plants blocked the power plant's cooling water inlet, damaging some safety-related systems. If we assume the meteorological conditions are a common cause. Another case occurred at the Chooz nuclear power plant in France in 2009. The very low winter temperatures formed frazil ice and icing the protective grid at the water intake, almost causing problems in the pumping system. Through the rapid response of the operator, the system returned to normal conditions with breaking ice.

- Coincidental hazards refer to independent hazards occurring simultaneously without a common cause or sequence. Another crucial point about coincidental hazards is that simultaneous occurrence may not necessarily mean exactly the same time. Cases in which another hazard occurs when the consequence of one hazard has not been fully recovered also need to be considered as a combination of the external hazards. An example is the 2011 scenario at the Fort Calhoun NPP in the United States, where long-lasting riverine flooding and an independent internal fire significantly challenged the facility.

2. IAEA Documents related to the combination of the external hazards

According to documents from the International Atomic Energy Agency (IAEA), SSR-1[2], SSR-2/1 Rev. 1[3], SSG-3 Rev. 1[4], SSG-67[5], SSG-68[6], SSG-64[7], SSG-77[8], all credible risk combinations must be considered during design, operation and re-evaluation. SSR-1[2] specifies that the possibility of a combination of events occurring simultaneously and within a short time frame is evaluated, and SSR-2/1 Rev.1[3] mentions that the impact of the combination of hazards considered may be consequential, and that the impact of the hazard combination occurring after the flood may be consequential. An earthquake was mentioned as an example. SSG-3 Rev.1[4] specifies that possible hazard combinations be identified and developed into a list for Level 1 Probabilistic Safety Assessment.

SSG-67[5] requires an appropriate margin to be secured in the SSC to prevent radioactive release in the event of an earthquake exceeding the design. In this case, it is mentioned that the possibility of other hazards caused by an earthquake should be assumed to be high in an earthquake exceeding the design, such as seismic-induced internal fire and flood. SSG-68[6] mentions several conditions under which external hazard combinations shall be considered. There are cases where hazards cause another hazard, such as earthquakes and tsunamis, and cases where external hazards cause multiple hazards, such as impact, explosions, and vibrations caused by aircraft impact, or cases where they occur simultaneously.

SSG-64[7] identifies three categories: consequential, correlated, and coincidental hazard combinations. It also specifies that a hazard combination sequence should be used to determine the loading and magnitude of the hazard, the duration it is applied, and the sequencing of the occurrence of other hazards. SSG-77[8] recommends the performance-based approach to manage hazard combinations, considering their interactions and the duration of consequential effects. Furthermore, specific guidance for evaluating seismic hazards (SSG-9 Rev. 1[9]), meteorological and hydrological hazards (SSG-18[10]), volcanic hazards (SSG-21[11]), and protection against internal hazards (SSG-64[7], SSG-77[8]) is provided in the perspective of deterministic and probabilistic approaches.

3. Conclusions

This paper summarizes cases where a combination of external hazards affected nuclear power plants and IAEA documents related to a combination of hazards based on the contents of a technical report being prepared by the IAEA. Through experienced cases, it was acknowledged that external hazards act more complicatedly on nuclear power plants than expected, and many demands for safety evaluation of the combination of external hazards are included in the overall IAEA documents. However, it is identified that a specific method has not been established due to difficulties such as insufficient experience and data and complicated mechanisms of a combination of hazards.

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