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Prioritizing Climate Change-Related Natural Hazards Affecting Nuclear Power Plants: Based on the Delphi Method

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1. Introduction

Since the Industrial Revolution in 1850, the increase in greenhouse gases in the atmosphere has accelerated climate change, including global warming. Climate change is causing abnormal weather events in Korea [1]. In September 2023, Seoul experienced its first tropical night in 88 years [2]. Furthermore, nationwide precipitation in December 2023 reached a record high, approximately 3.8 times the average for the year [2].

Climate change alters extreme values of temperature, rainfall, wind speed, and sea surface temperature, influencing the intensity and frequency of climate-related natural hazards such as typhoons and floods [4]. Nuclear power plants' protection levels should be consistently maintained in natural hazards that increase in strength due to climate change [4,5]. No quantitative assessment methods for natural hazards that reflect climate change for the safety evaluation of nuclear power plants have been established [4,5]. Under these circumstances, conducting detailed assessments for all climate change–related natural hazards would face constraints in terms of time, personnel, and budget [5]. Therefore, it is reasonable to determine—through a prioritization assessment—which climate change–related natural hazards should be addressed for their impact on nuclear power plants [5]. This prioritization is not intended to exclude hazards, but to allocate limited resources so as to achieve the greatest possible reduction in risk.

This study identified climate change-related natural hazards that could impact domestic nuclear power generation and prioritized them using the Delphi method. The results of these priorities can serve as basic data for strengthening the operation and safety of nuclear power plants.

2. Identifying and Prioritizing Climate Change-Related Natural Hazards

2.1 Identifying climate change-related natural hazards affecting nuclear power plants

Considering Korea's climatic characteristics, we identified climate change–related natural hazards that affect the operation and safety of domestic nuclear power plants [5]. To this end, we consulted the Nuclear Power Plant Operating Information System (OPIS) and a wide range of literature, identifying a total of 69 external hazards (both anthropogenic and natural) [4-7]. Only climate change–related natural hazards were identified among all external hazards. Also, climate change-related natural hazards with similar characteristics were grouped, and those with low impact on nuclear power plants were screened out using the qualitative screening criteria proposed in EPRI 102997 [6]. This process was conducted by six experts with more than 25 years of experience in nuclear power plant safety and systems. The final list of climate change–related natural hazards identified for prioritization is presented in Table 1 [5].

Table I: List of natural hazards related to climate change for priority assessment[5]

No.	Natural hazards related to climate change
1	Biological events / Lake- or river-borne material plugging water intakes / organic material in water
2	External flooding
3	Extreme rain
4	Extreme winds and tornadoes / Hurricane / typhoon / Strong winds (other than hurricane or tornado)
5	Forest fire
6	Hail
7	Landslide
8	Lightning
9	High tide / Other extraordinary waves / Storm surge / Waves
10	River diversion
11	Salt Storm
12	Snow (including snowstorms and drifts) / Ice storm/ freezing rain / sleet
13	Strong currents (under-water erosion)
14	Underwater landslide (impact on soil, i.e., not tsunami)

2.2 Priority evaluation of natural hazards related to climate change

In order to derive the priority of natural hazards related to climate change that affect nuclear power plants, 42 nuclear expert panels were convened [5]. Two Delphi survey rounds have been implemented to prioritize the hazards identified. Two Delphi surveys were conducted to determine the priority of identified natural hazards.

This evaluation evaluated each risk from the point of view of "Likelihood" and "Impact". Likelihood and impact were measured on a five-point Likert scale (1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high). Based on the resulting likelihood and impact scores, priorities for the climate change–related natural hazards were determined as in Eq. (1) [5].

$$\text{Score} = \sum_{k=1}^{n}(Likelihood_k \times Impact_k) \qquad (1)$$

Statistics (e.g., mean, median, interquartile range) obtained from the first Delphi survey were provided to the experts in the second survey. To assess the consistency and reliability of expert judgments in prioritizing climate change–related threat factors, we analyzed the coefficient of variation(CV) [5]. In the second Delphi round, the standard deviations and CV values generally decreased relative to those from the first round, indicating that expert ratings became more consistent. Table 2 presents the prioritization results and final scores for the climate change–related natural hazards obtained via the Delphi method.

Table II: Results of prioritizing climate-related natural hazards using the Delphi method [5]

Rank	Delphi methods result	Score
1	Extreme rain	609
2	Extreme winds and tornadoes / Hurricane / typhoon / Strong winds (other than hurricane or tornado)	606
3	External flooding	519
4	Biological events / Lake- or river-borne material plugging water intakes / organic material in water	481
5	Forest fire	395
6	High tide / Other extraordinary waves / Storm surge / Waves	361
7	Landslide	302
8	Lightning	228
9	Salt Storm	198
10	River diversion	197
11	Strong currents (under-water erosion)	178
12	Hail	175
12	Snow (including snowstorms and drifts) / Ice storm/ freezing rain / sleet	175
14	Underwater landslide (impact on soil, i.e., not tsunami)	165

3. Conclusions

The Delphi survey results indicated that “extreme rainfall,” “typhoons,” “external flooding,” “biological events,” and “forest fires” ranked highest in risk. These findings are broadly consistent with domestic nuclear power plant operating experience and will serve as foundational input to decision-making for responding to climate change–related natural hazards. Because the Delphi method is a qualitative approach based on expert consensus, the results should not be construed as absolute indicators. Moving forward, site-specific risks of climate change–related natural hazards should be quantified through assessments that account for the uncertainty and non-stationarity of climate change. Such analyses will enhance nuclear power plant safety and strengthen preparedness for climate risks.

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