A Concept Proposal for Deriving Design and Assessment Loads for Nuclear Power Plants in the Context of Climate Change

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1. Introduction

The greenhouse gases produced since the late 19th century due to industrial development have significantly impacted the climate [1]. Carbon emissions have continued to accelerate climate change, leading to natural disasters around the world [1]. In August 2023, wildfires in Hawaii destroyed residential areas and caused loss of life [2,3]. Additionally, in September 2023, floods triggered by Mediterranean Cyclone 'Daniel' resulted in numerous deaths in Greece, Bulgaria, Turkey, and Libya [2,3].

When climate change occurs, the intensity and frequency of natural disasters such as typhoons, floods, heavy rainfall, droughts, and wildfires increase [1]. Consequently, climate change is expected to affect various industries, including nuclear power plants [1]. In particular, nuclear power plants, as critical infrastructure, must ensure their operation and safety in the face of climate change-induced natural disasters [1]. However, there have been ongoing incidents where nuclear power plants have been shut down or their operating capacity reduced due to climate change-related phenomena such as typhoons, heavy rainfall, wildfires, cold waves, heatwaves, and marine organisms [1]. For example, in France, nuclear power plants have been forced to shut down or reduce operating capacity due to heatwaves and abnormal high temperatures [1]. In Korea, changes in sea temperature have caused earlier occurrences of marine organisms, leading to the shutdown of nuclear power plants [1].

It is essential to establish protective design and mitigation measures against the impacts of climate change to ensure the safety and operation of nuclear power plants. Generally, The design loads for nuclear power plants are calculated based on historical observational data. This study aims to investigate and discuss climate change scenarios and design loads necessary to secure the safety and operation of nuclear power plants.

2. Climate Change Scenario

A climate change scenario refers to projected future climate information calculated using anticipated greenhouse gas concentrations and climate prediction models, in order to forecast climate changes driven by human activities, such as changes in greenhouse gas emissions. The IPCC's recently published Sixth Assessment Report considers five greenhouse gas emission scenarios (SSP: Shared Socioeconomic Pathways) to predict future climate conditions [4]. Specifically, the five scenarios are: (1) Very high greenhouse gas emission scenario (SSP5-8.5), (2) High greenhouse gas emission scenario (SSP3-7.0), (3) Intermediate greenhouse gas emission scenario (SSP2-4.5), (4) Low greenhouse gas emission scenario (SSP1-2.6), and (5) Very low greenhouse gas emission scenario (SSP1-1.9) [4]. The projected average global surface temperature relative to 1850 is shown in Table 1 [4].

Table I: Projected average global surface temperature under different scenarios[1,4]

Period / Scenarios	2021-2040 Best estimate (℃)	2041-2060 Best estimate (℃)	2081-2100 Best estimate (℃)
SSP 1-1.9	1.5	1.6	1.4
SSP 1-2.6	1.5	1.7	1.8
SSP 2-4.5	1.5	2.0	2.7
SSP 3-7.0	1.5	2.1	3.6
SSP 5-8.5	1.6	2.4	4.4

The IPCC has categorized the physical characteristics of climate into six components—extreme heat and cold, heavy rainfall and drought, wind, snow and glaciers, other factors, and oceans—to present future projections of Climatic Impact Drivers, as shown in Figure 1 [5].

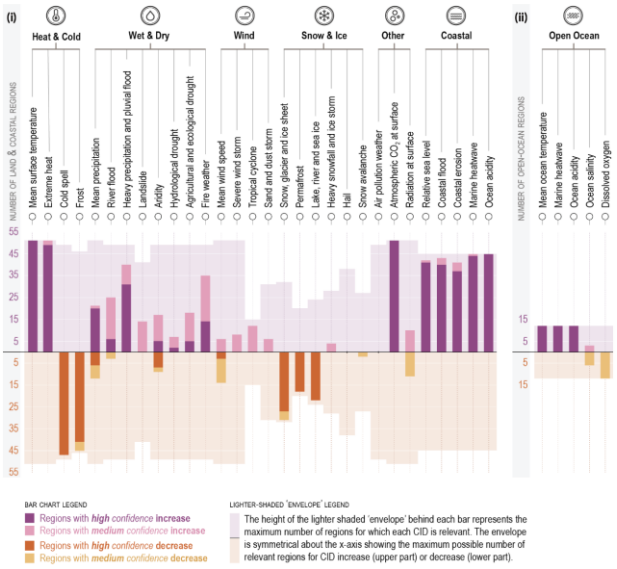

Fig. 1. Climatic Impact-drivers[5]

It is projected that by 2050, the average global temperature will rise in all regions, with extreme heat events becoming more intense and frequent [1,4,5]. Sea surface temperatures are expected to increase in most oceans, except in the Western regions. Additionally, sea levels are predicted to continue rising, and heavy rainfall events are expected to increase [1,4,5]. The average wind speed is forecasted to decrease by 2050, while the frequency of tropical cyclones in the tropics is expected to decrease, although their intensity is likely to increase [1,4,5].

3. Current design methods

The design loads for nuclear power plants are determined based on historical weather data and a 100-year return period. Typical design loads include wind speed, precipitation, snow accumulation, and other. The weather data used for calculating these design loads are sourced from the observational records from weather stations. Next, a distribution is determined from the observational data, which typically exhibits a decaying characteristic similar to an exponential function[6]. Consequently, extremal distributions, such as the Type I extremal distribution and the Gumbel distribution, are commonly used. The design loads for the target return period are ultimately calculated from these extremal distributions.

4. Conclusion and Discussion

Currently, the loads used for the design and safety evaluation of nuclear power plants are calculated by performing extremal analysis on historical data. However, due to climate change, the design loads derived from such analysis of past data may be insufficient. It is essential to ensure the safety and operation of nuclear power plants against natural disasters influenced by climate change. Therefore, it is necessary to calculate design loads that incorporate the effects of climate change.

To determine design loads that reflect climate change, the following three factors must be established:

- Climate change scenarios
- Target time
- Target return period (frequency)

Climate change scenarios can be determined using climate change simulations, the IPCC reports, or Table 1. The target time could be, for example, an arbitrary point in time (e.g., 50 years, 100 years) or the operational license period of the nuclear power plant in question. As climate change is a long-term process, with an increasing likelihood of abrupt changes in weather conditions, it is essential to consider these factors. In addition, since load calculations reflecting climate change have a large degree of uncertainty, we also suggest using a logic-tree methodology. Therefore, design loads that incorporate climate change scenarios, target time, and frequencies must be calculated and evaluated to ensure the long-term safety of nuclear power plants.

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