The Impact of Climate Change on Swedish Nuclear Facilities - a Literature Review

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Abstract: This paper presents preliminary results of a literature review regarding the impact from climate change on nuclear power plants. In the safety analyses that are carried out for a nuclear power plant, the analysis of external events plays an important role. From a purely operational perspective, weather-related external events are also interesting because these can affect the ability to operate the nuclear power plant at full power.

There are several guides that describe the approach when analyzing external events. One of the more important guides that has been used in Sweden was produced by the Swedish Radiation Safety Authority in 2003. The goal of that work was to develop a method that could be used for the facilities in the Nordic region when working with the analysis of external events.

The question of how the safety analyzes are affected by the ongoing climate changes is therefore appropriately done by assessing how the results from previous work regarding external events are affected by climate change. An important aspect is also the economic aspects of events occurring more often, or less often, or with greater magnitude. For example, an increased seawater temperature can lead to a nuclear power plant having to run with reduced power, or shut down completely, as the cooling capacity in the heat exchangers is not sufficient. This leads to reduced availability and thus a loss of revenue. On the other hand, the effect of the increased temperature can be counteracted by fetching the cooling water from a greater depth. This in turn means investments that are not necessarily profitable. When reviewing existing literature, it is therefore important to take the economic aspects into account and read the reports from that perspective as well.

Keywords: PRA, PSA, External Events, Climate Change, Safety Analysis

1. INTRODUCTION

Climate change poses a multifaceted threat to various aspects of human infrastructure, including nuclear power plants. Rising temperatures, sea-level rise, and extreme weather events, all linked to climate change, present operational challenges, and safety risks to nuclear power plants.

One of the primary concerns is the availability and temperature of cooling water. Higher ambient temperatures and droughts can lead to water scarcity, affecting plant efficiency and potentially causing shutdowns. Additionally, coastal nuclear plants face the risk of flooding from rising sea levels and intensified storms, which can damage critical infrastructure and lead to hazardous situations.

Moreover, climate change-induced extreme weather events such as hurricanes, heatwaves, and heavy rainfall can disrupt power supply and cooling systems, increasing the risk of accidents. The changing climate also necessitates the reevaluation of safety and design standards for existing and future nuclear facilities to ensure they can withstand these new environmental conditions.

Addressing these challenges requires a proactive approach, including integrating climate resilience into the planning, operation, and regulation of nuclear power plants to safeguard their role in a low-carbon energy future.

There are several ongoing initiatives related to Climate change, for example EPRI has done work about climate change, such as the guideline *Climate Vulnerability Assessment Guidance for Nuclear Power Plants*, [1], and started *Climate READi*, [2], WANO organized a workshop about climate change impact on NPPs in June 2023, the Nuclear Energy Agency, NEA, has developed the report *Climate Change: Assessment of the*

Vulnerability of Nuclear Power Plants and Approaches for their Adaptation, [3] and The Swedish Energy Research Centre (”Energiforsk” in Swedish) has issued the report *The Impact of Climat Change on Nuclear Power,* [4].

Therefore, the Swedish members of the organization NPSAG[1] has decided to perform a literature review and summarize conclusions from the above-mentioned initiatives and other work that has been done in the area. Aspects related to safety analyses is the focus, but a broad view is taken considering all possible consequences of climate change for the participating nuclear facilities (Ringhals NPP, Forsmark NPP, Oskarshamn NPP and SKB)[2].

The project is ongoing, and, in this paper, some preliminary results and findings are presented.

2. METHODOLOGY

The starting point for the literature review is the above-mentioned reports and initiatives:

- EPRI 3002023814 - ”Climate Vulnerability Assessment Guidance for Nuclear Power Plants”, 2022
- EPRI 3002026313 - ”Climate Vulnerability Considerations for the Power Sector: Nuclear Generation Assets (Climate READi), 2023
- WANO Workshop – ”Climate Change Impact on NPPs”, 2023
- NEA – ”Climate Change – Assessment of the Vulnerability of NPPs and Approaches for their Adaptation, 2021
- Energiforsk – ”The Impact of Climate Change on Nuclear Power, 2021

These reports are included in the review, together with the references to the reports. Members of the NPSAG have also provided valuable input about interesting reports to include. As the project still is ongoing, the complete list of references to include in the review has not been finally settled but at this point the list of consists of about 30 reports. It is highly likely that some reports will be added, and some removed, as the project progresses.

As the focus of the work is to gather insights from various initiatives on how climate change affects the safety analyses of the NPPs, the included references must be read from that perspective. An efficient way of structuring the work is to use the list of external events that are used in many safety analyses (a comprehensive list can be found in [5]) and focus on the events that may be affected by climate change. This approach leads to the following table of events:

[1] NPSAG (The Nordic PSA Group) is a common forum for discussion of issues related to probabilistic safety assessment (PSA) of nuclear utilities, with focus on research and development needs. The members are the nuclear utilities in Finland and Sweden. The regulators are associated members.
[2] SKB is the Swedish Nuclear Fuel and Waste Management Company.

Table 1. Relevant External Events

Event	Description
A01	Strong winds
A02	Tornado
A03	High air temperature
A04	Low air temperature
A05	Extreme air pressure (high/low/gradient)
A06	Extreme rain
A07	Extreme snow (including snow fall)
A08	Extreme hail
A09	Mist
A10	White frost
A11	Drought
A12	Salt storm
A13	Sandstorm
A14	Lightning
G01	Land rise
G02	Soil frost
G06	Above-water landslide
G07	External fire
W01	Strong water current (under water errosion)
W02	Low sea water level
W03	High sea water level
W04	High sea water temperature
W05	Low sea water temperature
W06	Under-water landslide
W07	Surface ice
W08	Frazil ice
W09	Ice barriers
W10	Organic material in water (algae, sea weed, fish, sea mussels, etcetera)

When reading the reports, it is noted for the events mentioned in the report, which trend the authors foresee and which geographical area that is studied. The information is gathered in an Excel-file so that the data can be analyzed in various ways.

3. RESULTS

The work is still ongoing, and the presented results are thus highly preliminary. In this chapter, two graphs are shown that illustrate the observed trends for analyzed external events for Europe and North America.

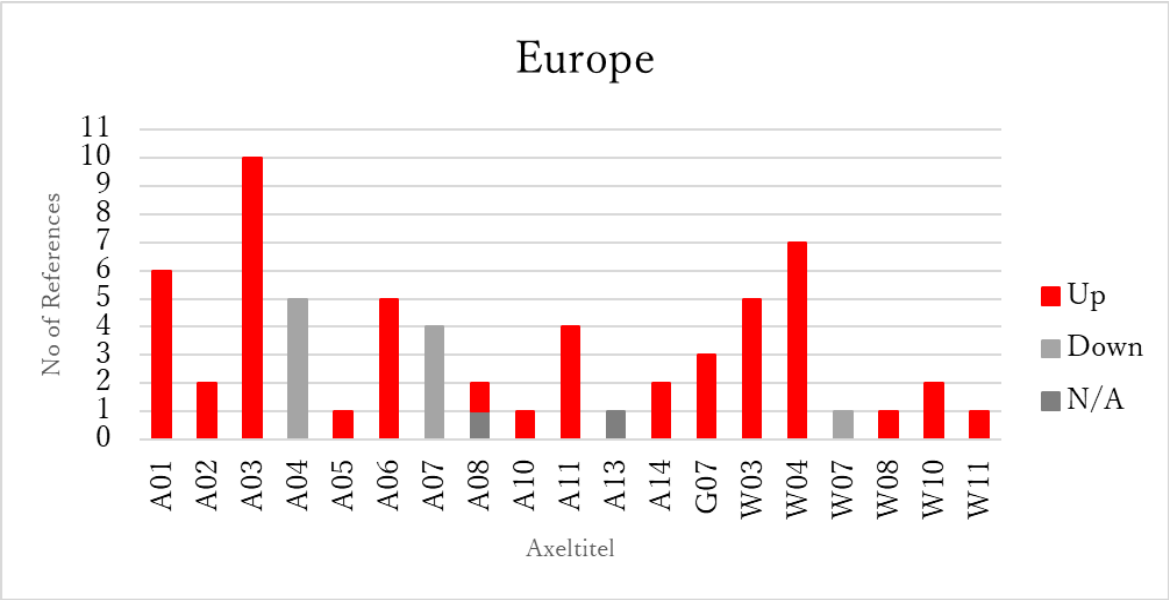

Figure 1. Trends Europe

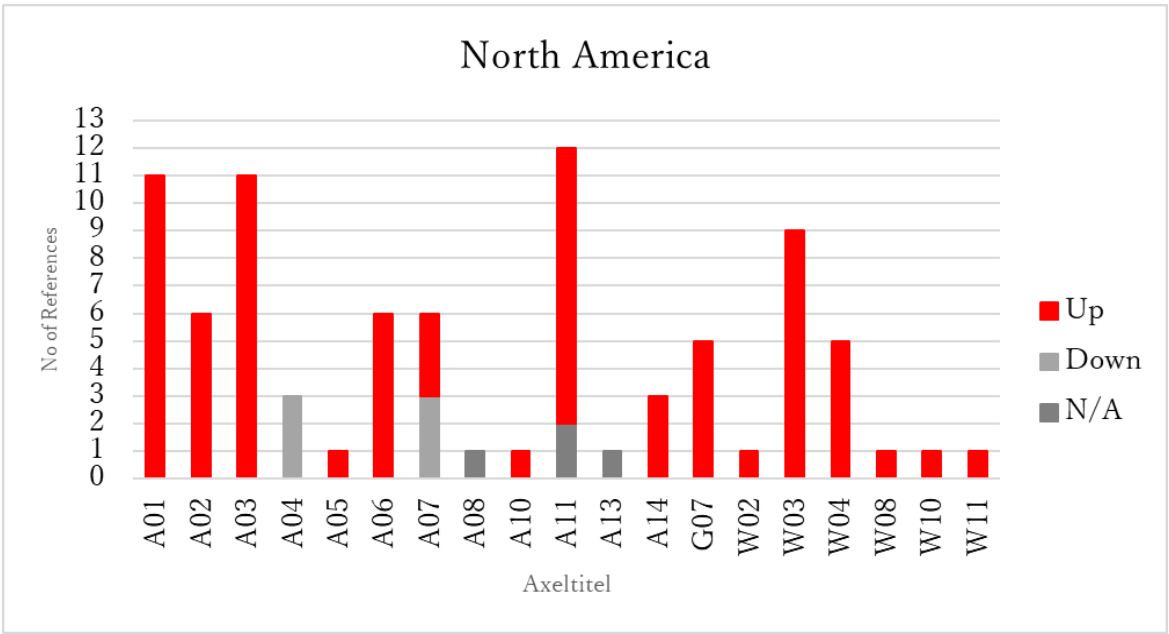

Figure 2. Trends North America

The y-axis represents the number of references that covers the event. For example, for event A03, high air temperature, there are 10 references that points out that the trend regarding air temperature is rising. The number of references is a good indication of which events that are most interesting to study further.

As can be seen in the figures, the assumed development of the strength of relevant external events is similar for both Europe and North America. For example, the trend regarding A03 is the same.

There are some obvious differences, for example regarding the event A11, drought, where the future severeness due to climate change seems to be higher in North America than in Europe. Also regarding A01 and A02, strong wind and tornado, the impact on the nuclear power plants may be higher in North America.

3. CONCLUSIONS

Finally, a few notes about some of the external events. These notes should be treated with care since the project, when this paper is written, is not finalized.

3.1. Wind (A01 and A02)

Event A01 is defined as the damage to the nuclear power plant that occurs due to strong winds, both directly from the pressure of the wind and indirectly from missiles that can travel with the wind. Event A02 is defined as the damage caused by a tornado and is separated from A01 due to the differences in duration, wind speed and frequency. It is highly likely that these events will become more common, and more powerful, in the future. From a safety perspective, strong winds can cause severe damage to the power grid, thus resulting in long power cuts. Also, damage to infrastructure can be expected, although the buildings in a nuclear power plant in general is designed to withstand extreme forces. Strong winds are also relevant to study in combination with for example loss of the seawater intake (if such exists for the specific plant). In conclusion, wind events are important to keep updated in the analysis of external events.

3.2. Air Temperature (A03 and A04)

The global average temperature will increase in the coming decades and extreme heat is projected to become both more frequent and more intense. The consequences that follow high air temperature are defined as event A03. High air temperature can affect the capacity of air conditioners and heat exchangers and result in insufficient cooling of components and spaces at nuclear power plants. Higher air temperature also results in lower power in the steam turbines and therefore results in lower electricity production.

High air temperature has no major impact on the safety of nuclear power plants, as they can be reduced in power during prolonged periods of hot weather. For nuclear power plants located inland and using recirculated cooling, high air temperature can affect availability as the air temperature strongly links to cooling capacity.

The nuclear power plants that exist in Sweden do not recirculate the cooling water and are therefore less sensitive to high air temperatures. High air temperatures can also have an impact on staff safety as staff can be forced to work in very hot areas. Periods of very low temperature appear to be fewer and less extreme globally. The consequences from low air temperature are defined as event A04.

3.3. Precipitation (A06, A07 and A11)

Several reports have stated that there is a high probability that extreme precipitation will increase around the world. With increased precipitation, flooding is also expected to increase and become more powerful. Event A06 is defined as the damage that occurs to the nuclear power plant after extreme rainfall. The A06 includes both damages caused by the rain's load on buildings and damage from flooding caused by the rain. The safety margins for nuclear power plants are in general sufficient to cope with today's extreme floods. However, it is not certain how operation and availability may be affected or how the safety margins will hold up in the future with more extreme flooding.

For event A11, drought, the trend is clearly going upwards, both in Europe and in North America. A limited effect on nuclear safety and availability is expected in Sweden since the Swedish nuclear power plants use sea water for cooling. Drought has in general not been considered a problem regarding nuclear safety in Sweden but this may need to be re-evaluated in order to ensure that this conclusion is still valid in the coming decades.

Acknowledgements

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References

[1] EPRI, ”*Climate Vulnerability Assessment Guidance for Nuclear Power Plant”*, 3002023814, 2022
[2] EPRI, “*Climate Vulnerability Considerations for the Power Sector: Nuclear Generation Assets”,* Climate READi, 3002026313, 2023
[3] Nuclear Energy Agency, NEA,”*Climat Change – Assessment of the Vulnerability of NPPs and Approaches for their Adaptation*”, 2021
[4] Energiforsk, ”*The Impact of Climat Change on Nuclear Power”, 2021*
[5] SKI, *”Guidance for External Events Analysis”, 2003*