Case study for increment of ultimate heat sink temperature due to increase of seawater temperature

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1. Introduction

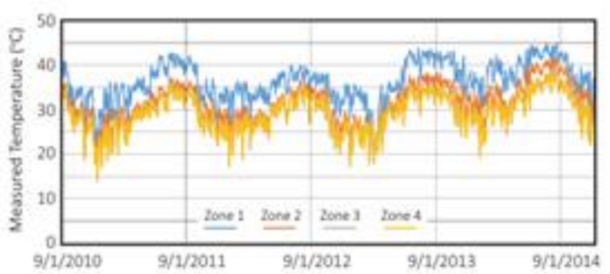
From 1901 to 2015, the global seawater temperature increased by an average of approximately 1°C, with some regions near the equator experiencing even greater temperature variations [1]. The impact of this climate change-induced rise in seawater temperature on the cooling systems of nuclear power plants is becoming increasingly significant. The cooling water used in nuclear power plants calls not only remove heat but also plays a crucial role in safety features such as the Containment Spray System (CSS) which are activated to reduce the internal temperature and pressure in the event of an accident [2]. CCS performs spraying through a total of two heat exchange processes [3]. At process, the cooling water acts as ESW to cool CCW, and CCW is used to cool the water sprayed into the reactor building [3]. Therefore, many nuclear power plants that use seawater directly to cool equipment without installing separate cooling towers have been using the upper limit of seawater temperature as one of the operational regulation factors Recently, due to the rise in sea temperature, sea temperature has been observed at a level that has not been observed historically, and accordingly, there are cases where each country has relaxed the upper limit of sea temperature regulations to an appropriate level [4]. Based on these contexts, countries including South Korea have been conducting research and implementing safety measures in response to the rising seawater temperature. This review paper examines cases where nuclear power plants have increased their Ultimate Heat Sink (UHS temperature limits and related studies to analyzing the impact of seawater temperature rise on nuclear power plant regulation.

2. Case studies for NPPs UHS temperature changes

Table 1 lists the nuclear power plants that requested a UHS temperature rise between 2005 and 2023. The common reason cited for the temperature rise at these plants was the temperature rise of cooling water sources such as fresh water and seawater. However, certain plants provided additional justification for their requests: Turkey Point, Shin-Kori, and Catawba. In this chapter, we will conduct additional analysis on three nuclear power plants.

2.1 Turkey point 1,2 plants

In the case of Turkey Point, as shown in the Figure 1, temperature measurements taken during July–August 2014 showed higher temperatures compared to previous records. During the investigation period from 2010 to 2014, the cooling water intake recorded a maximum daily average temperature increase of 4.7°F, reaching 113°F. This exceeded the 4.4°F maximum allowable temperature increase approved by the Nuclear Regulatory Commission (NRC) in 2014 for the same area [5].



“Figure 1: Temperature measurement in CCS” [4]

Through this process, the Turkey Point nuclear power plant increased the temperature limit at its intake and based on evaluations conducted by Emergency Safety Functions (ESFs) and the original equipment manufacturer, the Nuclear Regulatory Commission (NRC) ultimately concluded that there were no safety issues regarding the operation of the reactor [6]. Each evaluation measured wear caused by the impact on the ICW (Intake Cooling Water) system and the seals, and both aspects were verified for stability. As a result, it was concluded that even in the event of a design basis accident, there would be no issues with the spray system [6].

2.2 Shin Kori 3,4 Plant

In order to secure operational margin for the UHS design temperature in Shin-Kori Units 3 and 4, a plan is being promoted to increase the ESW (Essential Service Water) supply temperature from 31.6℃ to 34.9℃ [7]. The methodology established to set the design seawater temperature is divided into normal conditions and accident conditions in which DBAs such as Loss-of-Coolant Accident (LOCA) and Main Steam Line Break (MSLB) occur [3]. The steady-state seawater design temperature is a value set for efficient operation of the power plant [3]. Even if the seawater temperature exceeds the design temperature during normal operation, there is no separate countermeasure because the generator output is only affected by the change in the CCW vacuum value [3]. However, in order to monitor the seawater temperature, it is necessary to prepare for additional seawater temperature increases, such as heat load checks, when the design seawater temperature approaches in the event of an accident [3]. In accident conditions, the heat removal performance of the heat exchanger should be evaluated, and the heat removal performance and system effectiveness (suction head, visual design temperature, piping integrity) should be verified at the evaluation temperature (design temperature, temperature measurement uncertainty - 0.35-) [3]. In case of accident situation, the safety margin is determined by the maximum pressure of the reactor containment building when the spray system is activated in the event of a design basis accident (DBA), such as a Loss-of-Coolant Accident (LOCA) or a Main Steam Line Break (MSLB) [3]. At this time, the difference between the peak containment pressure and the safety limit must be at least 10%. Currently, the cooling water temperature boundary condition in the safety analysis is 43.33°C [3]. If the impact of seawater temperature rise due to climate change remains below 43.33°C, a conclusion similar to that of Turkey Point can be drawn, indicating no issues with the spray system. However, if the temperature exceeds this threshold, additional safety analysis will be required

2.3 Catawba 1,2 plants

In the case of the Catawba 1,2, it is a case of disturbing the temperature in the control room.
The basis for the temperature increases at the Catawba nuclear power plant originated from regulations concerning the internal temperature of the control room [8].

Table 2. Before and After change about control room's regulation of Catawba 1,2 [8]

Division	Before	After
Control room temperature limit	Maintain below 90°F	Maintain below 80°F (if both CRACWS are inoperable
Control room temperature during normal operation	Maintain 74°F	Maintain 74°F
Temperature maintenance range during emergency operation	84°F	84°F
Case that control room temperature exceeds the limit	Shut down reactor immediately if above 90°F	If above 80°F, additional mitigation measures are implemented and if above 90°F, reactor shutdown
When two CRACWS are inoperable	Shut down reactor	If below 80°F, recovery is possible within 24 hours, then reactor shutdown is required

As shown in Table 2, the control room temperature regulations are categorized into normal and emergency operations, and the temperature regulation changes for each situation are as follows: The most important aspect of the regulation change at Catawba Nuclear Power Plant is related to the control room. Ultimately, this revision was made to account for the potential for a decrease in control room cooling performance due to an increase in the UHS temperature. A conservative standard was applied, and additional mitigation measures were implemented to prevent an immediate shutdown of the reactor [8].

3. Conclusion

This study investigated cases where the UHS temperature of nuclear power plants increased due to seawater temperature increase. Among them, Shin-Kori and Turkey point focused on the spray temperature and Catawba focused on the Control room temperature [3][8]. If seawater temperature continues to increase at the current rate or increases further, additional design changes are likely to be required to minimize the impact on nuclear power plants. Appropriate safety margin assessment is needed to cope with such situations, and this case study provides a direction for assessing such margins by analyzing the ESW, CCW, and CSS systems. Despite the various existing research, there is only limited research to define and analyze safety margin for whole systems according to the UHS rise scenario. Due to the significance of climate change issues, more political back-up and concerns of scholars would be needed for this UHS sensitivity analysis field in the near future.

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Table 1. UHS increased case nuclear reactor

Name	Type	Date	Previous temperature limit(°F)	Changed temperature limit(°F)	Reason for temperature limitation change
Shin kori 3,4 [6]	PWR	2022.7.21	88.88(31.6°C)	94.75(34.89°C)	UHS temperature rises Approaching operating limit
Turkey points 3,4 [6]	PWR	2014.8.08	100(37.78°C)	104(40°C)	UHS temperature rises Approaching operating limit
Surry 1,2[10]	BWR	2006.8.01	95(37.78°C)	100(38.61°C)	maximum service temperature replaced is 100°F, the heat exchanger meets the design requirements for fouling and membrane tube force conversion.
Sequaoyah 1,2 [11]	BWR	2022.03.14	85(29.4°C)	88(31.11°C)	Using temperature data
Hope creek [12]	PWR	2007.9.28	84.5(29.17°C)	87(30.56°C)	Temperature limit exceeded
Lassale 1,2[13]	PWR	2007.10.3	95(35°C)	100(37.78°C)	To ensure safety margin due to seasonal variations and long-term climatic changes