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Review of the impact on power plants based on accident scenarios caused by typhoon-induced extreme natural hazard

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1. Introduction

An extreme natural hazard is a natural hazard that exceeds the external factors considered as design criteria for nuclear reactor facilities and refers to damage caused by natural phenomena including earthquake, typhoon, flood and tsunami [1]. Among these phenomena, the possibility of typhoons exceeding the design criteria has increased due to climate change, and the need to assess the impact of extreme natural hazards caused by typhoon has been raised. Therefore, the aim of this study is to investigate the accident scenarios caused by typhoon-induced extreme natural hazards and to assess the effects on nuclear power plants.

2. Results

2.1 Accident scenarios caused by typhoon-induced extreme natural hazards

A typhoon is a local weather phenomenon accompanied by a strong storm with a maximum wind speed of 17 m/s or more near the center of a tropical cyclone that occurs in the tropical sea. It can cause natural hazards such as high winds, heavy rain (local intense precipitation), storm surges.

In the case of high winds, the resulting wind load may affect structures or equipment and cause abnormal operation. However, since this load is small compared to the seismic load generated by an earthquake, it is difficult to affect safety-related facilities. Therefore, damage from high winds can mostly occur in non-safety related facilities and can lead to accident scenarios such as loss of off-site power (LOOP) and loss of main feed-water (LOFW) [2].

If a typhoon causes local intense precipitation, rainwater may accumulate above the design flood level, causing flooding of non-safety related structures and equipment. Thus, the same accident scenarios as with high winds can occur, and the loss of essential service water system in essential service water intake structure and safety-related electrical equipment in auxiliary building can occur due to flooding.

Also, when a storm surge occurs and a high tide due to tidal phenomena occurs at the same time, the seawater level may rise above the breakwater, causing flooding damage due to seawater inflow into the power plant. Therefore, accident scenarios due to a storm surge is the same as the accident scenario due to local intense precipitation described above.

Causes of accident scenarios of typhoon-induced extreme natural hazard are shown in Table I.

2.2 Impact on nuclear power plants

In order to assess the impact of each accident scenario on the nuclear power plant, the probability of core damage occurring in the event of each accident scenario was calculated by referring to the PSA (Probabilistic Safety Assessment) model for internal event [3].

In the event of LOFW, the auxiliary feed-water (AFW) system is automatically operated to supply feed-water to the steam generator and operation of decay heat removal is performed through a steam generator. If the above operation fails, heat removal operation through safety relief valves in the reactor coolant system and safety injection pumps can be performed. The event tree of LOFW caused by typhoon-induced extreme natural hazards is shown in Figure 1.

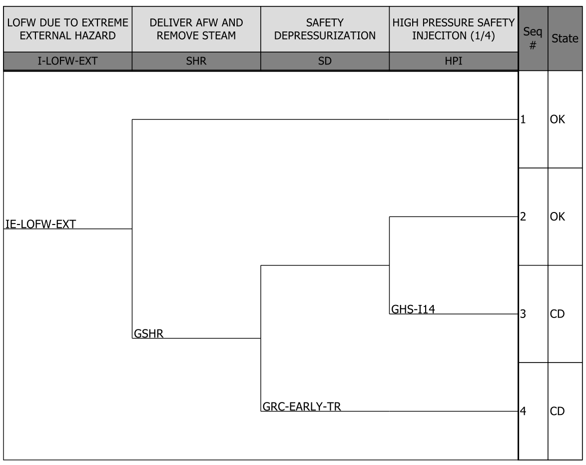

Fig. 1. Event tree of LOFW caused by typhoon-induced extreme natural hazards.

Table I: Causes of accident sequences of typhoon-induced extreme natural hazards

Hazard type	Failure mode	Related Accident Scenario
High wind (HW)	- Damage to main feed-water pumps or related piping due to high winds (impact on collapse of turbine building)	Loss of main feed-water (LOFW)
	- Collapse of transmission towers or on-site electrical facilities (ex. transformers) - Damage of switchyards caused by wind-borne missile	Loss of off-site power (LOOP)
Local intense precipitation (LIP) / Storm surge (SS)	- Main feed-water pump inoperable due to flooding inside the turbine building - Circulating water pump inoperable due to flooding inside the circulating water intake structure	Loss of main feed-water (LOFW)
	- Loss of off-site power due to flooding of switchyard or other off-site power related facilities	Loss of off-site power (LOOP)
	- Essential service water pump inoperable due to flooding inside the essential service water intake structure	Loss of essential service water (LOESW)
	- Loss of essential power due to flooding of electrical facilities in auxiliary building	Loss of essential power (LEP)

When LOOP accident occurs, it takes long time to restore the off-site power. Therefore, it is necessary to supply the power using alternative power sources located in the power plant. First, the emergency diesel generator (EDG) can automatically start up and supply power after the occurrence of LOOP. If the emergency diesel generator fails to start, the operator can manually start the alternate AC diesel generator (AAC DG). When power is supplied, decay heat removal operation can be performed through the steam generator or through safety relief valves in the reactor coolant system and safety injection pumps. The event tree of LOOP caused by typhoon-induced extreme natural hazards is shown in Figure 2.

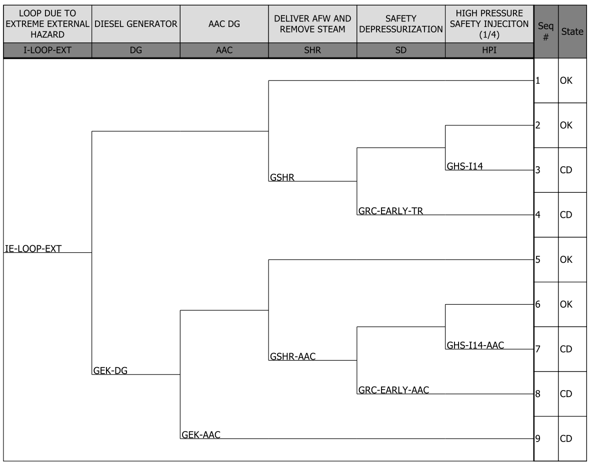

Fig. 2. Event tree of LOOP caused by typhoon-induced extreme natural hazards.

In the event of LOESW due to local intense precipitation or storm surge, it may cause loss of component cooling water, resulting in the unavailability of safety-related facilities. Also, a number of safety-related electrical facilities, including 4.16kV switchgear and 480V load center, are located on the ground floor of the auxiliary building. Thus, if that floor is flooded, most of the safety-related system will become unavailable due to loss of essential power. Therefore, in above two cases, it is assumed that no accident mitigation are possible.

Regarding the LOFW accident, the equipment that are not available may vary depending on the hazard type. In the case of HW, from a conservative perspective, it is assumed that the turbine building is collapse and all facilities inside the building is also unavailable. Thus, in addition to the failure of the main feed-water system, the unavailability of the unit auxiliary transformers due to damage to the generator circuit breaker is additionally considered.

But, flooding of generator circuit breaker caused by LIP or SS is unlikely as a significant amount of water is necessary to reach the floor level where the equipment is installed. Therefore, in these cases, the analysis is performed considering only the loss of the main feed-water system.

As a result of the analysis, the probability of core damage in a LOFW accident due to HW was evaluated as very low as 6.98E-8, and was mostly derived from the failure of the operation of AFW system and opening of safety relief valves.

The probability of core damage in a LOFW accident caused by LIP or SS was estimated as 6.92E-8, which was not much different from that in the case of HW.

In the case of the LOOP accident, structures and equipment related to accident mitigations are located inside concrete structures, so no equipment is affected by high winds. However, there is a possibility that equipment inside the EDG building and the AAC DG building may be flooded due to local intense precipitation or storm surge. Therefore, the analysis is performed considering this.

As a result of the analysis, the probability of core damage in a LOOP accident is 1.45E-4. It was assessed that there was a possibility of core damage of approximately 0.01% in the event of an accident. The main cause of this was the failure of EDGs and AAC DG. When power supplied successfully, the probability of core damage was assessed to be very low, at around 3.46E-7.

In case of LIP or SS, EDG building or AAC DG building may occur along with the occurrence of LOOP accident. If EDG building is flooded, only AAC DG can be used as alternative power sources. Therefore, the probability of core damage was assessed at 5.77E-2, causing by failure of AAC DG. In contrast, when the AAC DG building is flooded, since two EDGs can supply the power, the probability of core damage was assessed to be relatively high at 2.50E-3. If both buildings are flooded, no accident mitigation are possible because there is no power available.

3. Conclusions

In this study, we investigated accident scenarios that could occur due to typhoon-induced extreme natural hazards that exceed design criteria and assessed the impact on nuclear power plants.

Accident scenarios caused by typhoon-induced extreme natural hazards include loss of off-site power and loss of main feed-water. In addition, in the case of LIP and SS, loss of essential service water system in essential service water intake structure and safety-related electrical equipment in auxiliary building can occur due to flooding.

Among these scenarios, the impact on the power plant due to LOFW accident was assessed as very low, but the impact of LOOP accident was evaluated to be relatively large. Moreover, in case of LIP and SS, the probability of core damage was assessed to be higher because the EDG building and AAC DG building could be flooded along with the LOOP accident.

And, in the event of LOESW and loss of safety-related electrical facilities inside the auxiliary building due to LIP or SS, it was assumed that there was a high possibility of core damage because most of the safety-related system become unavailable.

In summary, it can be said that among typhoon-induced extreme natural hazards, the impact on power plants due to high winds is small, but the impact of external flooding such as local intense precipitation and storm surge is relatively large. In terms of plant design, safety related facilities such as the EDG building, essential service water intake structure, and auxiliary building are equipped with flood protection facilities, so the possibility of flooding is significantly low. However, if those protection facilities becomes unavailable, it can be said that the impact on power plant is significant. Therefore, if the integrity of facilities related to accident mitigation is confirmed before typhoon occur, the safety of power plants against typhoon-induced extreme natural hazards is expected to be improved.

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