Consideration of key factors for estimating convocation time of emergency response crews under seismic event occurrence through Japanese case study

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1. Introduction

In the circumstances of a potential or realized nuclear accident arising from external events or analogous momentous incidents within a nuclear power plant, it becomes imperative for the facility's director to institute an emergency response command centre to mitigate accident propagation and protect the environment from the release of fission products.

Convocation time to establish the emergency response centre is critical in mitigating accident progression in the early stages. However, when an external disaster occurs, the convocation time may change a lot due to environmental changes such as injury caused by housing damage, road condition, etc.

Therefore, in this study, we clarify key factors that affect changes in convocation time by considering a Japanese case study of evaluating convocation time under seismic event occurrence.

2. Case Study: Estimation of Convocation time in Onagawa Nuclear Power Plant

In Japan, Act on Special Measures Concerning Nuclear Emergency Preparedness has been enacted, and when a nuclear emergency is declared, the establishment of the Nuclear Disaster Response Headquarters and implementation of emergency response measures are stipulated in accordance with the law[1].

Onagawa nuclear power plant site has 3 units operated by Tohoku Electric Company and located in Onagawa town in Miyagi prefecture.

According to Tohoku electric company's report, 430 crews among about 470 members are expected to be convocated during an emergency [2].

The goal of the convocation is to convocation 54 crew members of the Severe accident response crew within 12 hours of an emergency.

2.1 Procedure of Convocation

When a severe accident condition occurs at night or on holiday, an order of emergency convocation is released to the emergency response crews outside of the site using an automated calling system. If an earthquake of magnitude 6 or higher occurs around the power plant, the crews voluntarily move to the power plant without getting the order of convocation.

When an earthquake damages a family or home, or there is an evacuation order from the local government, it is convened after securing the family's safety.

Crews in a dormitory get gathered at an intermediate stopover and depart to the site after getting information about the site's condition. Other crews outside need to gather at the intermediate stopover before departing to the site. Crews move to the site along 3 designated routes according to their condition.

2.2 Estimation of Convocation time

The convocation time consists of 3 kinds of time elements. Preparation time, Information gathering time, and travel time. It is assumed that 30 mins required as the preparation time, and another 30 mins is necessary to gather information at the intermediate stopover before departure to the site. The travel time is estimated based on travelling on foot.

Table 1 shows the estimated convocation time using 3 different convocation routes. In every case, the crew is assumed to travel along the route on foot.

In the case of nighttime, over half of the crew members (250 members) could be convocated to the site within 6 hours after the event occurrence

Table 1. Estimation of convocation time

	Route 1	Route2	Route3
Distance	18 km	17 km	29 km
Estimated time (Daytime)	230 Min.	220 Min.	370 Min.
Actual travel time on foot	—	193 Min. (5.3km/h)	—

3. Key factor to increase convocation time

When an external event such as a massive earthquake occurs, several kinds of damage are expected to increase the convocation time of the crews.

According to Damage estimation from earthquakes carried out by the Department of Disaster Management of Cabinet Office Japan, a massive earthquake can trigger the following kinds of human damage and damages on infrastructures.

Expected human damages can be caused by building collapse, steep slope collapse, seismic-induced fire, collapsing walls, and falling objects may increase the convocation time of the crews. Some may be unable to escape on their own due to building collapse.

Also, an outage of electricity, and communication may increase the time element of the convocation time.

3.1 Human damage

In the case of preparation time, it is expected that three-time elements will be required.

①Understanding situation: time required to confirm that there are no damages, such as injuries caused by an earthquake right after an earthquake, and to subside after the subsequent aftershocks, etc. It takes about 5 minutes. At night, it takes about 10 minutes.

②Preparation for departure: time required to change clothes for departure or to handle simple matters. In the case of the Great East Japan Earthquake, it takes about 10 minutes. It is assumed that it takes about 10 minutes to exchange information with the power plant right after an earthquake occurs. Possibility of time delay depending on the communication situation.

③Safety confirmation: time required to check the safety of family members, and it takes at least 5 minutes. Depending on the communication situation, the possibility of time delay increases. At this stage, if it is confirmed that an earthquake has injured family members, a long delay is possible.

As shown in Table 2, by comparing estimated damages from 3 different earthquakes, the possibility of human damage could be assumed to be 0.9 % ~ 5.8%. Also, those who cannot escape independently due to building collapse are expected to be 2.0% of the total population in the case of Wakayama pref. Thus, it can be expected that an earthquake can damage 2.0% ~ 7.8% of the population. If crews or their family members get injured by an earthquake, it increases preparation time for the departure. Even convocation can be impossible when crew members are severely injured.

Table 2. Estimated Injured caused by an earthquake

Earthquake*	Tokyo Met. Inland[3] (Tokyo)	Nankai trough[4] (Wakayama Pref.)	Chitose-Japan trench[5] (Kushiro)
Population	9,733,276	940,000	158,802
Injured	84,965	26,000	9,200
Ratio [%]	0.9	2.8	5.8

* Postulated magnitude of the earthquake is over 7.0

3.2 I Damage on infrastructure

When a massive earthquake occurs, infrastructures related to electricity and road can be damaged. East Japan Great Earthquake in 2011 brought the outage of electricity in a wide area, damages on roads caused restrain in transportation.

3.2.1 Outage of electricity

The nuclear power plant will shut down when it experiences an earthquake over magnitude 7.0. Also, supply equipment gets seismic damage, and due to the lack of supply ability of electricity, a wide-range electricity outage will occur.

According to estimated results, the expected electric outage ratio will be 1.6% to 90% in 3 different earthquake cases as shown in Table 3.

Table 3. Estimated electric outage* ratio [3-5]

Earthquake*	Tokyo Met. inland (Tokyo)	Nankai trough (Wakayama Pref.)	Chitose-Japan trench (Kushiro)
Ratio* [%]	about 50	About 2.8	1.6

* It will continue for 24 hours after the earthquake

3.2.2 Communication failure

As a result of an outage of electricity, failure of communication using telephone, mobile phone, and SNS will be expected. According to the estimated result of the ratio of communication failure, 2.4% to about 90% of the landline phone, about 80% to 90% of communication using a mobile phone, maximum of 30% of communication via SNS using mobile data packet will be out of order.

3.2.3 Damage on road

A massive earthquake will damage the road and result in restraint on traffic. For example, in 2011, approximately three damages, such as cracks on the road, exfoliation of the road, and differences in elevation, occurred in every single kilometre. As a result of damage on the road, the vehicle's speed decreases by about 50% on the road with a width of over 6.0 meters. Also, about 50% of the road has a width under 6.0 meters, and the traffic can be impassible.

9.4 % of a highway and about 5% of national roads will experience seismic damage, which decrease traffic speed in case of the Tokyo metropolitan inland earthquake.

4. Estimation of Convocation Time Considering Impact of Seismic Event

4.1 Influence of the Key factors on Convocation time

4.1.1 Human damage

If crews are injured, or if it is difficult to move on their own due to a building collapse induced by an

earthquake, it is assumed that it is difficult to respond to an emergency call. If crew's family members are injured, the crews require several hours to secure their family before the departure to the site.

4.1.2 Outage of electricity

If an outage of electricity occurs at night, the time required to assess the situation (5 min) and prepare for departure (10 min) is doubled.

Also, an outage of electricity in the wide-area causes the loss of traffic signals, and it is assumed that it brings a decrease of 30% of the traffic speed.

4.1.3 Communication failure

When the communication failure occurs, the time required to obtain information over the phone to the power plant and to confirm the safety of family members and the like significantly increase. In the case of a call using a mobile phone, it is thought that more time will be required for information exchange using a wireless phone because the use of the phone was only possible once in 10 times due to the communication volume limit at the time of the Great East Japan Earthquake. Therefore, if it is assumed that contact with the power plant is mainly made using a mobile phone, and confirmation of the safety of family members is mainly used in the order of SNS → cell phone, contact with the power plant is up to 10 times greater, and safety with the family It is assumed that confirmation time increases up to 5 times (when used concurrently with data communication).

4.1.4 Damage on road

When classified into two types, road damage is expected to show the following occurrence rate.

· Large-scale damage: Damage to the extent that it cannot be used for rescue activities and transportation of emergency goods in the short term (impossibility of passage)

· Small-to-medium-scale damage: Due to limited damage, such as partial damage (crack, concrete peeling), damage to the extent that the function of the road can be restored to some extent without emergency restoration.

In the case of large-scale damage, the road becomes impassable, and in the case of small-to-medium-sized damage, it is assumed that the movement speed is reduced by about 50% compared to nominal travel time. Therefore, the traffic speed can decrease up to 80% in case of small or medium-sized damage to the road in a situation where the traffic lights are out of order due to a power outage.

4.2 Estimation of preparation time before departure to site

As we considered in previous chapters, the preparation time is estimated considering the influence of the key factors on the preparation time.

Table 4 shows the estimated preparation time under various conditions. The results show that the preparation time can be increased several times longer than the nominal time without considering the influence of the key factors on the convocation time.

The increase in the preparation time before the departure becomes essential because it will delay the establishment of the emergency response centre on the site. Also, the travel time will increase according to the road condition, bringing more delay on the convocation.

Using the probabilities of occurrence, the event related to the key factors can be used in a stochastic way so that the distribution of the preparation time can be obtained, and this is important information to evaluate the convocation time using a simulation technique such as Agent-based simulation.

Table 4. Preliminary estimation of the preparation time

Case	①	②	③	Total
1-D	5 Min.	10 Min.	5 Min.	20 Min.
1-N	10 Min.	10 Min.	5 Min.	25 Min.
2-D	5 Min.	20 Min.	5 Min.	30 Min.
2-DP	5 Min.	60 Min.	5 Min.	70 Min.
2-DPS	5 Min.	60 Min.	25 Min.	100 Min.

- ①: time for the understanding situation
- ②: time to prepare for the departure
- ③: time to confirm family's safety
- 1: Prompt departure requires 10 min for the preparation
- 2: Delayed departure after done personal matter require 20 min for preparation
- D: Daytime requires 5 min to understand situation
- N: Nighttime requires the doubled time to understand situation
- P: Communication failure requires 10 times longer time (50min) to contact with plant site.
- S: Communication failure requires 5 times longer time to confirm safety of the crew's family member.

5. Conclusion

The convocation time is the key issue to establishing the emergency response centre within a valid time to mitigate accident progression and secure the safety of the nuclear power plant in severe accident conditions. However, environmental changes caused by external events can affect the convocation time. In this study, through the Japanese case of evaluating the convocation time in the Onagawa nuclear power plant, we can clarify critical factors that increase convocation time. Also, the influences of the key factors on the

convocation time and the possibility of occurrence of those influences can be estimated from the literature study on the governmental report on the estimation of damage by three different massive earthquakes in Japan.
The stochastic usage of the obtained result with a simulation technique such as an agent-based simulation can be useful to estimate the convocation time quantitatively.

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