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Framework for estimating response time data to conduct a seismic human reliability analysis – its feasibility

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1. Introduction

After the Fukushima accident, it is highly recommend to conduct the vulnerability analysis of nuclear power plants (NPPs) being faced with conditions similar to the Fukushima accident. In this light, it is demanded to reevaluate the safety of NPPs with the consideration of severe accident conditions that were largely screened out in the probabilistic safety assessment (PSA) framework due to extremely low frequencies [Yang, 2014]. This is because the PSA has been used for several decades as the representative tool to evaluate the safety of NPPs.

To this end, it is inevitable to evaluate human error probabilities (HEPs) in conducting important tasks being considered in the PSA framework (i.e., HFEs; human failure events), which are able to significantly affect the safety of NPPs. In addition, it should be emphasized that the provision of a realistic human performance data is an important precondition for calculating HEPs under a seismic condition.

Unfortunately, it seems that HRA methods being currently used for calculating HEPs under a seismic event do not properly consider the performance variation of human operators. For this reason, in this paper, a framework to estimate response time data that are critical for calculating HEPs is suggested with respect to a seismic intensity.

2. HRA methods being currently used

It is evident that the performance of human operators varies along with the intensity of a seismic intensity. For example, Hara [1] pointed out that there are the performance of human operators can be affected by three groups of factors when an earthquake has occurred. The first one is an external environment in which human operators work (e.g., Noise, Vibration, and Oscillation), and the second factor is a wrong or inappropriate operation of indicators that provide the status of critical components and/or the process information of NPPs. In addition, the third factor is pertaining to psychological stressors, such as fear or threats of failure, which are able to directly influence the performance of human operators. With these factors, the results of existing literatures commonly reported that the actual variation of human performance is largely dependent on the intensity of an earthquake.

According to Ohta and Ohhashi, the level of the psychological stress felt by people increases with respect to the increase of a seismic intensity. In addition, Shibata and Fukuda [3] experimentally showed that the failure rate of a given task does not significantly different from that of a normal situation (i.e., non-seismic situation). However, it was observed that the failure rate rapidly increased when the level of a vibrational acceleration in the experiment reached 0.4g.

Unfortunately, it seems that HRA models being currently used for calculating HEPs under a seismic event do not properly consider these variations. For example, in the case of NPPs operating in Rep. of Korea, the HEP of a certain HFE in a seismic event is equally defined by 10 times of its HEP calculated without considering the seismic event [4]. Although there are several NPPs that use different multipliers along with the increase of the seismic intensity [4], the underline idea seems to be not quite different.

3. HRA data dependent on a seismic intensity

If the variation of human performance is largely affected by the level of a seismic intensity, it is necessary to identify its relation with HRA data. For example, let us assume that a certain HRA method needs two kinds of HRA data, such as D_1 (the existence of a relevant procedure) and D_2 (diagnosis available time). In this situation, it is expected that the effect of a seismic intensity on D_1 is negligible because the existence of a procedure is invariant for the whole spectrum of the seismic intensity. In contrast, time to be available for diagnosing what is going on could be drastically varied with respect to the level of the seismic intensity. This means that, in order to apply the given HRA method to calculating HEPs under a seismic event, different sets of HRA data should be provided for D_2. In this light, it would be helpful to review K-HRA method.

3.1. K-HRA method

K-HRA (Korean-HRA) that has been developed KAERI (Korea Atomic Energy Research Institute) is a first-generation HRA method stem from the ASEP (Accident Sequence Evaluation Program) HRA and the THERP (Technique for Human Error Rate Prediction) method [5]. In the K-HRA, the HEP of an HFE can be calculated by summing the results of two parts (e.g., diagnosis and action part) being quantified by different techniques. Fig. 1 depicts how to calculate the HEP of the given HFE [5].

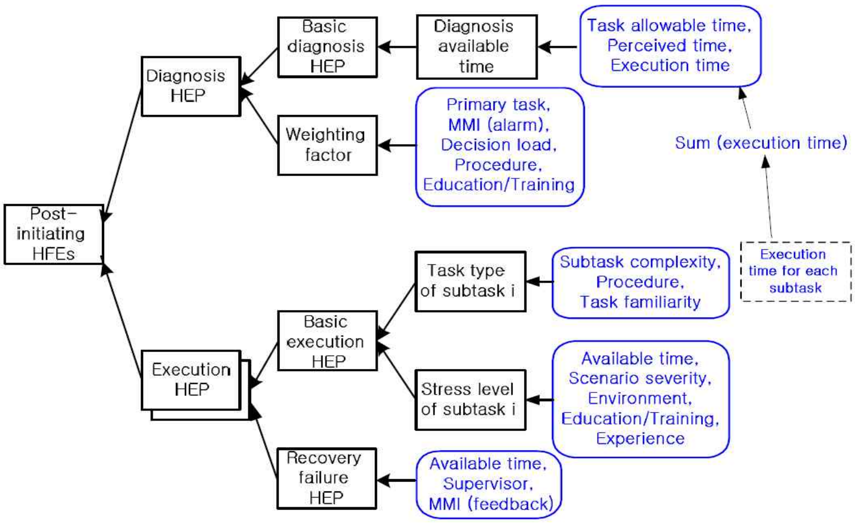

Figure 1. Framework of the K-HRA method (adopted from Ref. [5])

As can be seen from Fig. 1, various kinds of HRA data are needed to calculate HEPs. Table 1 summarizes a part of HRA data to be needed in the K-HRA method [5, 6].

Table 1. HRA data to be needed in the K-HRA method

Purpose	Necessary data
Calculating diagnosis HEP	Available time for diagnosis
	HMI quality (alarm/indicator)
	Procedure quality
	Experience/Training level
	Decision load
Calculating execution HEP	Subtask complexity
	HMI quality (switch layout)
	Procedure quality
	Task familiarity
	Available time
	Subtask execution time
	Work environment

3.2. Time information

From Table 1, it seems that most of HRA data being required by the K-HRA are invariant. In other words, HRA data that are used to calculate the HEP of an HFE without considering a seismic event can be also applied to the quantification of the HFE under a seismic condition. For example, the *quality of HMI* (such as alarms, indicators, or switch layouts) does not change even an earthquake has occurred. However, it is obvious that *Work environment* varies with respect to the level of a seismic intensity. That is, for example, the pathway to reach a certain pump room would be blocked when an earthquake with a high seismic intensity has occurred. Similarly, the level of a noise and/or vibration will be very different along with the level of a seismic intensity.

However, the more serious problem is the provision of time-related HRA data. For example, Table 1 denotes that *Available time for diagnosis* is necessary for calculating the diagnosis HEP of an HFE. This is because the diagnosis HEP can be represented as the function of the *Available time for diagnosis* in the K-HRA method as depicted in Fig. 2 [7].

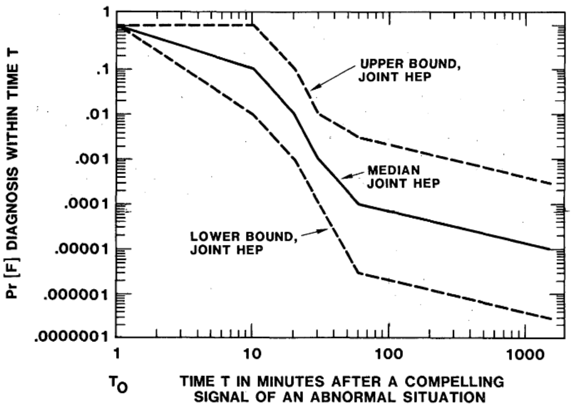

Figure 2. Diagnosis HEP as the function of an *Available time for diagnosis* (adopted from Ref. [7])

Unfortunately, as mentioned in Section 2, it is strongly expected that the *Available time for diagnosis* will drastically vary with respect to the level of a seismic intensity. That is, human operators have to diagnose the nature of an on-going event based on uncertain indications (e.g., a large portion of them could be failed or show wrong information) with psychological stressors (e.g., fear). Similarly, in the case of *Subtask execution time*, it is apparent that human operators will spend more time to accomplish a given subtask when an earthquake has occurred.

Unfortunately, in reality, it is not easy to secure response time data (e.g., *Available time for diagnosis* and *Subtask execution time*) under a seismic event. As a simple way to resolve it practically, an alternative method can be considered to properly assume the performance of human operators exposed to a seismic event. In this regard, one promising solution is to use response time data collected from simulated emergencies that are initiated by design basis accident (DBA) conditions without considering seismic events.

4. Framework for estimating response time data

Without loss of a generality, it is possible to assume that human operators will face with three kinds of hypothetical situations in accordance with the level of a seismic intensity (see Table 2).

Table 2. Four kinds of hypothetical situations to be faced with human operators when an earthquake has occurred

Situation	Description	Seismic intensity
1	No damaged indications but higher stress level	Low
2	A couple of indications are damaged and providing wrong information	Intermediate
3	Catastrophic failure	Very high

because most of tasks being conducted by NPPs are institutionalized in procedures.

In this regard, huge amount of response time data included in the OPERA (Operator Performance and Reliability Analysis) database [9] could be a good reference to estimate the response time data of the first situation. For example, Fig. 3 shows the distribution of task performance time data observed from the full scope simulator of domestic NPPs [10]. According to this distribution, it can be said that the average response time of human operators to accomplish each procedural step is about 22.1s (e.g., 50 percentile). Therefore, if human operators are faced with a stressful condition, it is possible to assume that their response times would be 94.2s (e.g., 95 percentile).

If the abovementioned approach is feasible, then it is strongly expected that response time data related to the second situation in Table 2 can be determined from the review of existing documents.

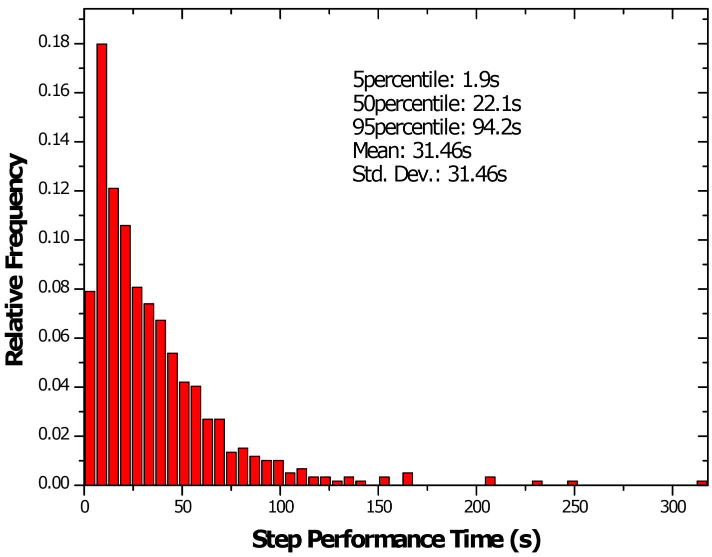

Figure 3. Distribution of response time data observed from the full scope simulators of domestic NPPs

From Table 2, it is obvious that there is no meaning in conducting HRA when the last situation has occurred, because all the systems, structures and equipment in NPPs could be damaged. In this light, it is very interesting to point out that the important feature of the first situation, compared to a situation without an earthquake, is the level of stress. In other words, if there is a correlation between response time data and the level of stress, then it is possible to systematically estimate response time data.

Fortunately, Park et al. [8] claimed that, if human operators have to accomplish required tasks based on procedures, their response times under stressful conditions can be soundly estimated based on response time data collected from less stressful conditions. This result seems to be very important for estimating response time data pertaining to the first situation,

5. Concluding remark

This paper suggested a systematic framework for estimating response time data that would be one of the most critical for calculating HEPs. Although extensive review of existing literatures is indispensable for identifying response times of human operators who have to conduct a series of tasks prescribed in procedures based on a couple of wrong indications, it is highly expected that response time data for seismic HRA can be properly secured through revisiting response time data collected from diverse situations without concerning a seismic event.

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