Development of Human Error Probability Evaluation Model: Direction and Report Between Emergency Operations Facility and External Locations

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Abstract: Since the Fukushima Daiichi Nuclear Power Plant accident, Human Reliability Analysis (HRA) has become necessary to assess Human Error Probability (HEP) for tasks performed under extreme conditions, such as earthquakes, tsunamis, and other events. The Nuclear Risk Research Center of the Central Research Institute of Electric Power Industry (CRIEPI) has developed HEP evaluation models for tasks under extreme conditions. This study introduces the HEP evaluation model for direction and reporting between emergency operations facility and external locations (e.g., main control rooms, work sites, etc.) among tasks under extreme conditions. Existing HRA methods primarily evaluate responses within the main control room to internal events and do not directly estimate the HEPs of transmission and receipt of direction and report. This is because error recovery is considered more feasible in face-to-face interactions. However, when multiple actors perform operations or work at different locations, especially under extreme conditions, transmission and receipt between actors via radios or telephones may occur. This situation can lead to miscommunication due to differences in Performance Influence Factors (PIFs) compared to those in the main control room. This study conducted two expert elicitation workshops to develop a method for estimating the HEP of transmission and receipt of direction and report in non-face-to-face interactions between emergency operations facility and external locations. The first workshop identified relevant PIFs for three Cognitive Failure Modes (CFMs): "forget to transmit," "transmission error," and "reception error." These were then organized into decision trees representing the presence or absence of PIFs. In the second workshop, experts estimated the HEPs of each terminal value. The decision trees developed are expected to contribute to the estimation of HEPs for communication between emergency operations facility and external locations.

Keywords: HRA, Expert Elicitation, Emergency Operations Facility, Direction and Report.

1. INTRODUCTION

Since the Fukushima Daiichi Nuclear Power Plant accident, Probabilistic Risk Assessment (PRA) and Human Reliability Analysis (HRA) have gained increasing importance in enhancing the safety of nuclear power plants [1]. HRA is now essential for evaluating Human Error Probability (HEP) during tasks performed under extreme conditions such as earthquakes, tsunamis, and other events. The Nuclear Risk Research Center of the Central Research Institute of Electric Power Industry has developed HEP evaluation models for tasks under extreme conditions [2][3]. This study introduces the HEP evaluation model for direction and reporting between emergency operations facility and external sites during extreme conditions.

During extreme conditions, such as those experienced during the Fukushima Daiichi accident, non-face-to-face direction and reporting between emergency operations facilities and external locations (e.g., main control rooms, work sites, etc.) may be necessary. Previous quantification methods primarily focused on evaluating responses to internal events, typically conducted within main control rooms. Consequently, these methods do not directly assess the error probabilities associated with transmitting or receiving direction and reports, as error recovery is more feasible during face-to-face interactions (HEP = 0) [4]. However, when multiple actors are engaged in operations across various locations, communication between them often occurs via radios or telephones. This mode of communication can lead to miscommunication due to challenges in understanding each other's circumstances. Given that the Fukushima Daiichi accident revealed instances of information-sharing failures between emergency operations facility and its external locations, it is crucial to evaluate the Human Error Probability (HEP) for direction and reporting.

In 2021, the Nuclear Regulatory Commission (NRC) developed IDHEAS-G (Integrated Human Event Analysis System - General Methodology) [5]. As IDHEAS-G serves as a universal methodology for conducting Human Reliability Analysis (HRA) across various nuclear tasks, it stands out as one of the few approaches suitable for application not only to internal events but also to the external events mentioned earlier. Therefore, the present study aims to develop an HEP evaluation model for direction and reporting between emergency operations facilities and external locations under extreme conditions, drawing upon the concepts of IDHEAS-G.

2. Method of developing the HEP evaluation model with reference to IDHEAS-G

IDHEAS-G, depicted in Figure 1, views human activities as comprising multiple tasks, designates task failures as Cognitive Failure Modes (CFMs), and subsequently assesses which Performance Influence Factors (PIFs) affect the CFM. Subsequently, the HEP is determined for all combinations of PIFs.

IDHEAS-G includes a list of 71 CFMs. When assigning CFMs to a specific task, a model developer can select one or more suitable CFMs from the IDHEAS-G list or identify additional ones based on the task requirements. Likewise, IDHEAS-G contains a list of 20 types of PIFs with a total of 149 items. The model developer can choose PIFs that affect CFMs from the provided list or identify additional ones as needed.

Finally, the HEP is quantified for the set of PIF states in the relevant CFM. If there is available human error data (such as the number of tasks performed with a given CFM or the number of errors for a given set of PIF states), it should be utilized. If such data is lacking or insufficient, the HEP should be estimated through expert elicitation, which involves gathering opinions from multiple experts. Since data on human error under extreme conditions are limited, this study estimates HEP through expert elicitation.

The NRC concludes that the recommendations detailed in the Senior Seismic Hazard Analysis Committee (SSHAC) guidelines provide a reasonable framework for implementing expert elicitation and provides a white paper as guidance in adapting the SSHAC process to other technical areas to implement expert elicitation [6]. Therefore, this study referred to the white paper to design a methodology for implementing expert elicitation.

3. Development of HEP evaluation model

3.1 Identification of possible CFMs

For the direction and report task, IDHEAS-G offers CFMs like "decision incorrectly communicated." However, it is unclear whether this failure originates from the transmitter or the recipient. In this study, "forget to transmit" and "transmission error" were designated as Cognitive Failure Modes (CFMs) for the transmitter, while "reception error" was assigned as a CFM for the recipient.

3.2. Identification of possible PIFs that can cause CFMs

PIF candidates contributing to each CFM were compiled from PIFs listed in IDHEAS-G and those identified during comprehensive disaster management trainings. Then, PIFs relevant to each CFM were determined through an expert elicitation workshop involving a total of nine experts in various fields. These experts included electric power officials familiar with the task at hand, cognitive psychologists knowledgeable about human error and PIFs, and HRA analysts experienced in HEP evaluation. Consequently, as indicated in Tables 1 through 3, a total of 14 PIFs were identified across three CFMs, including unique factors specific to this context, such as the "availability of targets where transmission error may occur."

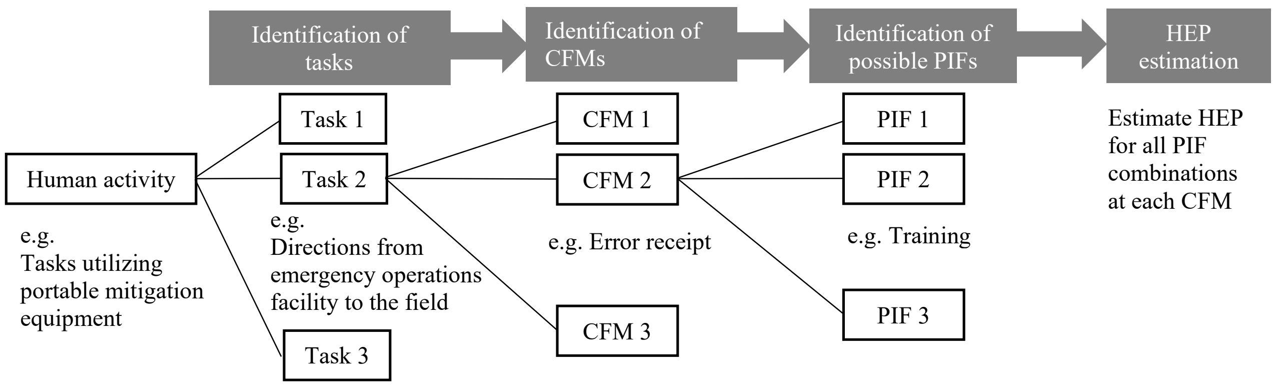


Figure 1: Flowchart of the HEP evaluation model development referencing IDHEAS-G

Table 1: PIFs of the CFM (forget to transmit)

PIF	Immediacy	Workload	Training	Recovery Potential
Contents	- Is this transmission is intended to restore or initiate critical functions necessary to stabilize plant conditions, rather than something that can be done later. - This transmission is considered (by training or procedure) the highest priority for this PRA scenario. - The timing of scenario deployment is such that the conditions for making this call can be met before other competing responses.	- There are frequent or prolonged interruptions before initiating the transmission. - There is another task that could cause distraction before initiating the transmission. - There are cognitively demanding tasks, long work hours, sleep deprivation, circadian rhythm disturbances, air quality abnormalities, etc., before initiating the transmission. - There is stress (e.g., anxiety) on the progress of the event, such as the severity of the event (e.g., reactor core damage) or the speed of the event's progress, before initiating the transmission.	- There is inadequate periodic training (e.g., training that includes a task in which the transmitter of information communicates decisions made by the emergency operations facility to recipients in the field) to ensure that information is transmitted appropriately. - The content of the instructions or reports is unknown or unfamiliar to the transmitter. (e.g., contents not experienced or not anticipated in training, etc.)	- Detailed implementation items are confirmed and information shared within the team using memos, whiteboards, etc. with the content of the transmission. - The staff members around the transmitter, such as those involved in the chain of instructions, can be expected to point out any failure to transmit. - The receiving side can be expected to point out any forget to transmit. - There is a practice for the transmitter to recite and report the completion of transmission. - There is a practice of regularly inquiring about progress by the transmitter and receiver.

Table 2: PIFs of the CFM (error of transmission)

PIF	Availability of targets where transmission error may occur	Workload	Training	Enforcement of communication rules	Recovery Potential
Contents	- Directions and reports include objects, equipment, work, etc., that may cause transmission error (e.g., same equipment in adjacent units, same equipment located in different locations with the intention of location dispersion, equipment with the same function (GTG/power supply vehicles, etc.), directions for multiple operations, instructions to multiple locations, multiple tasks that may be performed, etc.)	- There are frequent or prolonged interruptions during communication. - Another task is present during communication that may be a source of distraction. - The communication is accompanied by cognitively demanding tasks, long work hours, sleep deprivation, circadian rhythm disturbances, air quality abnormalities, etc. - There is insufficient time to complete the communication. - There is stress (e.g., anxiety) on the progress of the event at the time of communication, such as the severity of the event (e.g., core damage) or speed of progress of the event.	- There is inadequate periodic training (e.g., training that includes a task in which the transmitter of information communicates decisions made by the emergency operations facility to recipients in the field) to ensure that information is transmitted appropriately. - The content of the instructions or reports is unknown or unfamiliar to the transmitter. (e.g., contents not experienced or not anticipated in training, etc.)	- There is a lack of thorough implementation of speech rules for accurate communication (e.g., recitation, three-way communication, use of phonetic codes, use of memos with the content of the message, phrasing to avoid ambiguity, declaring the content of the message such as directions, emergency contact, and reports before speaking, etc.). - Appropriate tools such as procedure manuals and drawings are insufficiently used to ensure communication during training.	- Detailed implementation items are confirmed and information shared within the team using memos, whiteboards, etc. with the content of the transmission. - The staff members around the transmitter, such as those involved in the chain of instructions, can be expected to point out any transmission errors. - The receiving side can be expected to point out any transmission errors. - There is a practice for the transmitter to recite and report the completion of transmission. - There is a practice of regularly inquiring about progress by the transmitter and receiver.

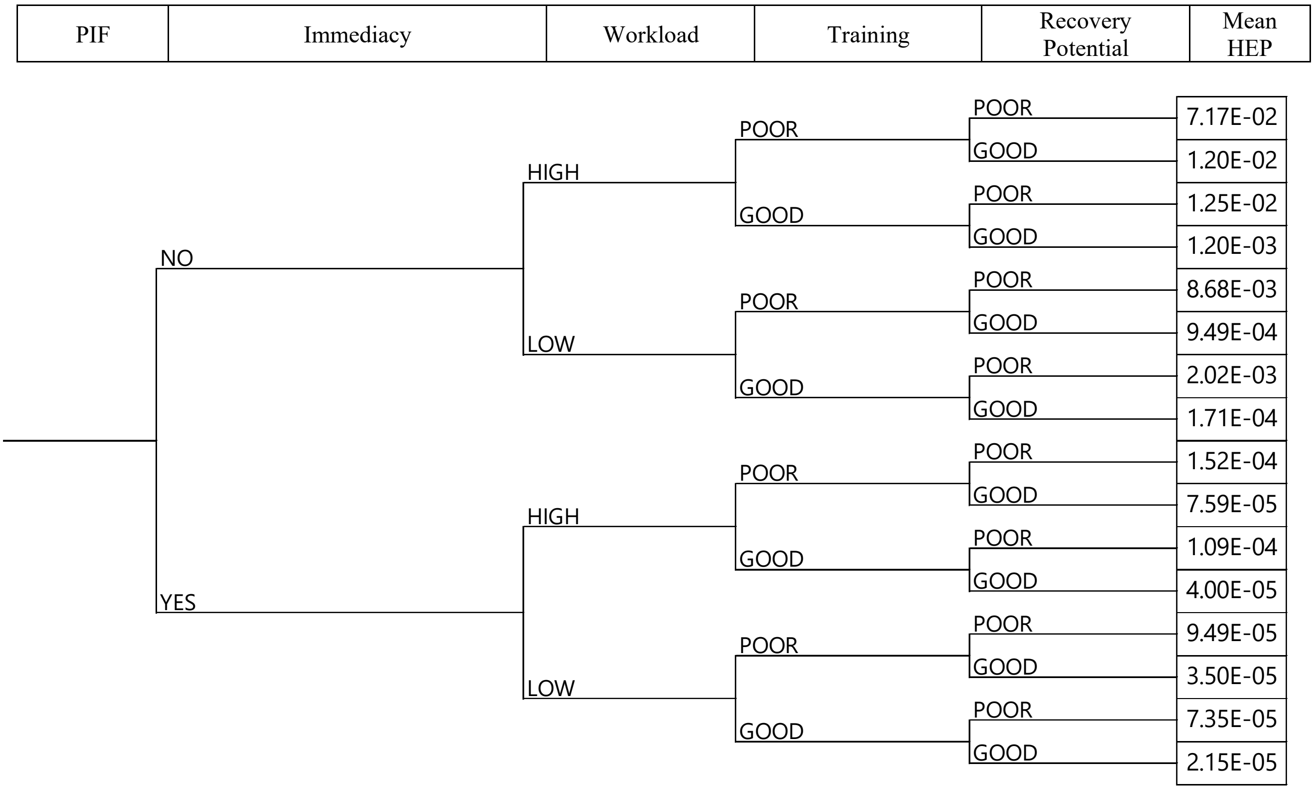
Table 3: PIFs of the CFM (reception error)

PIF	Availability of targets where reception error may occur	Workload	Training	Enforcement of communication rules	Recovery Potential
Contents	- Directions and reports include objects, equipment, work, etc., that may cause reception error (e.g., same equipment in adjacent units, same equipment located in different locations with the intention of location dispersion, equipment with the same function (GTG/power supply vehicles, etc.), directions for multiple operations, instructions to multiple locations, multiple tasks that may be performed, etc.)	- There are frequent or prolonged interruptions during communication. - Another task is present during communication that may be a source of distraction. - The communication is accompanied by cognitively demanding tasks, long work hours, sleep deprivation, circadian rhythm disturbances, air quality abnormalities, etc. - There is insufficient time to complete the communication. - There is stress (e.g., anxiety) on the progress of the event at the time of communication, such as the severity of the event (e.g., core damage) or speed of progress of the event. - Are there any obstacles to communication such as ambient noise, malfunctioning communication equipment, low clarity of communication equipment, callers wearing protective masks, etc.	- There is inadequate periodic training (e.g., training that includes a task in which the transmitter of information communicates decisions made by the emergency operations facility to recipients in the field) to ensure that information is transmitted appropriately. - The content of the instructions or reports is unknown or unfamiliar to the transmitter. (e.g., contents not experienced or not anticipated in training, etc.)	- There is a lack of thorough implementation of speech rules for accurate communication (e.g., recitation, three-way communication, use of phonetic codes, use of memos with the content of the message, phrasing to avoid ambiguity, declaring the content of the message such as directions, emergency contact, and reports before speaking, etc.). - Appropriate tools such as procedure manuals and drawings, insufficiently use to ensure communication, during training.	- Detailed implementation items are confirmed and information shared within the group using memos, whiteboards, etc. with details of what was received. - The staff members around the receiver, such as those involved in the chain of instructions, can be expected to point out any reception error. - There is a practice of regularly inquiring about progress by the transmitter and receiver.

3.3 Decision Tree Development and HEP Estimation

To represent the combination of impacts of all PIFs, a decision tree was developed for each CFM with the impact of each PIF (two choices) as a branch, and the expert elicitation workshop (with the same experts as in 3.2) was held again to estimate HEPs for all terminations (upper half of Figure 2 to upper half of Figure 4). An overview and description of each PIF in the decision tree and the criteria for branching were also developed (lower half of Figure 2 to lower half of Figure 4), which served as the HEP evaluation model for each CFM.

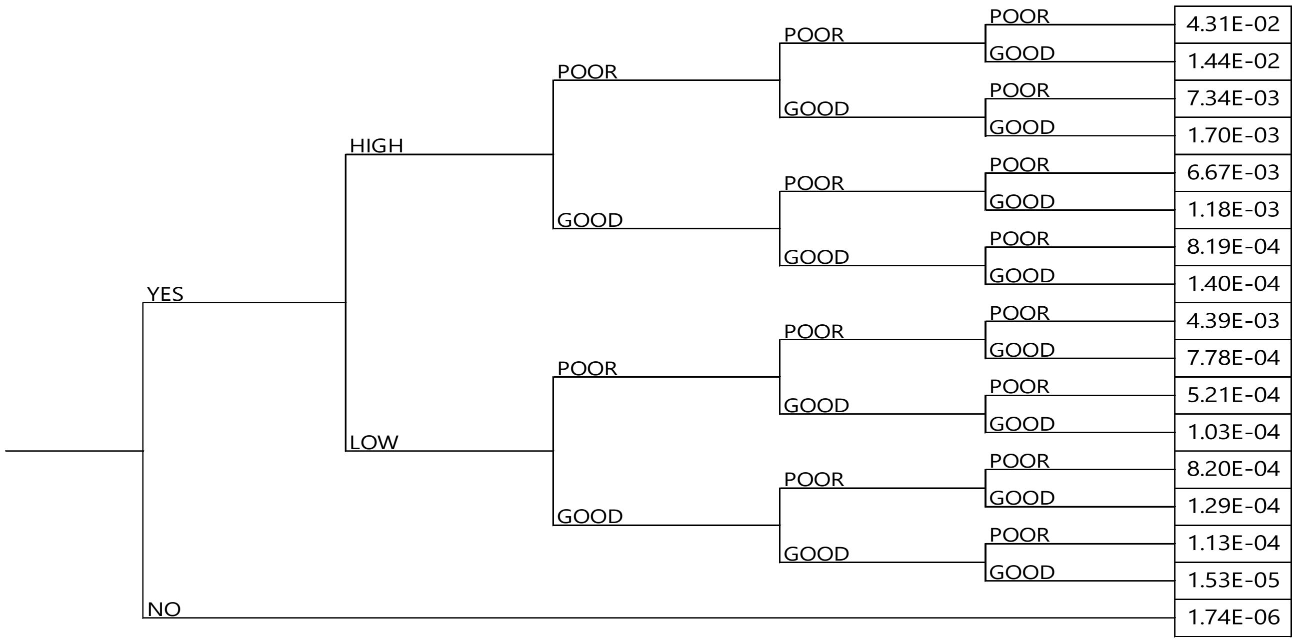
With these decision trees in the HEP evaluation model, it became possible to evaluate the HEPs of the three CFMs by assessing the branches of the PIF based on the specific situation being evaluated.



PIF	Immediacy	Workload	Training	Recovery Potential
Description/ Overview	Evaluate whether this transmission is the highest priority task to be performed in the predefined scenario (considering the event's content and progress, available equipment, and separate work in progress) at the time it is made. It is assumed that the transmitter understands the immediacy of this transmission. If the transmission needs to be performed immediately (i.e., it is a top priority), the transmitter is less likely to forget to transmit. Conversely, if it does not need to be performed immediately (i.e., it is not the highest priority), the likelihood of forgetting to do so is high.	This branch evaluates whether the transmitter forgets to transmit due to a heavy workload. For instance, workload might be elevated if the transmitter is concurrently handling multiple tasks, experiencing mental fatigue or emotional stress due to the situation, etc. Time constraints are also considered as part of the workload.	This branch evaluates whether the information transmitter can convey information appropriately during periodic trainings. These trainings involve tasks where information transmitters relay decisions to recipients in the field in response to directives from the emergency operations facility. If information is inadequately transmitted during training sessions, it may contribute to instances of forgetting to relay the information when needed.	This branch evaluates whether the transmitter, receiver, and their surroundings can recognize and recover from the failure when it occurs.
Branching criteria	Take the "YES" branch if all contents of the same PIF in Table 1 apply; otherwise, take the "NO" branch.	Take the "HIGH" branch if any one of the contents of the same PIF in Table 1 apply; otherwise, take the "LOW" branch.	Take the "POOR" branch if any one of the contents of the same PIF in Table 1 apply; otherwise, take the "GOOD" branch.	Take the "GOOD" branch if any one of the contents of the same PIF in Table 1 apply; otherwise, take the "POOR" branch.

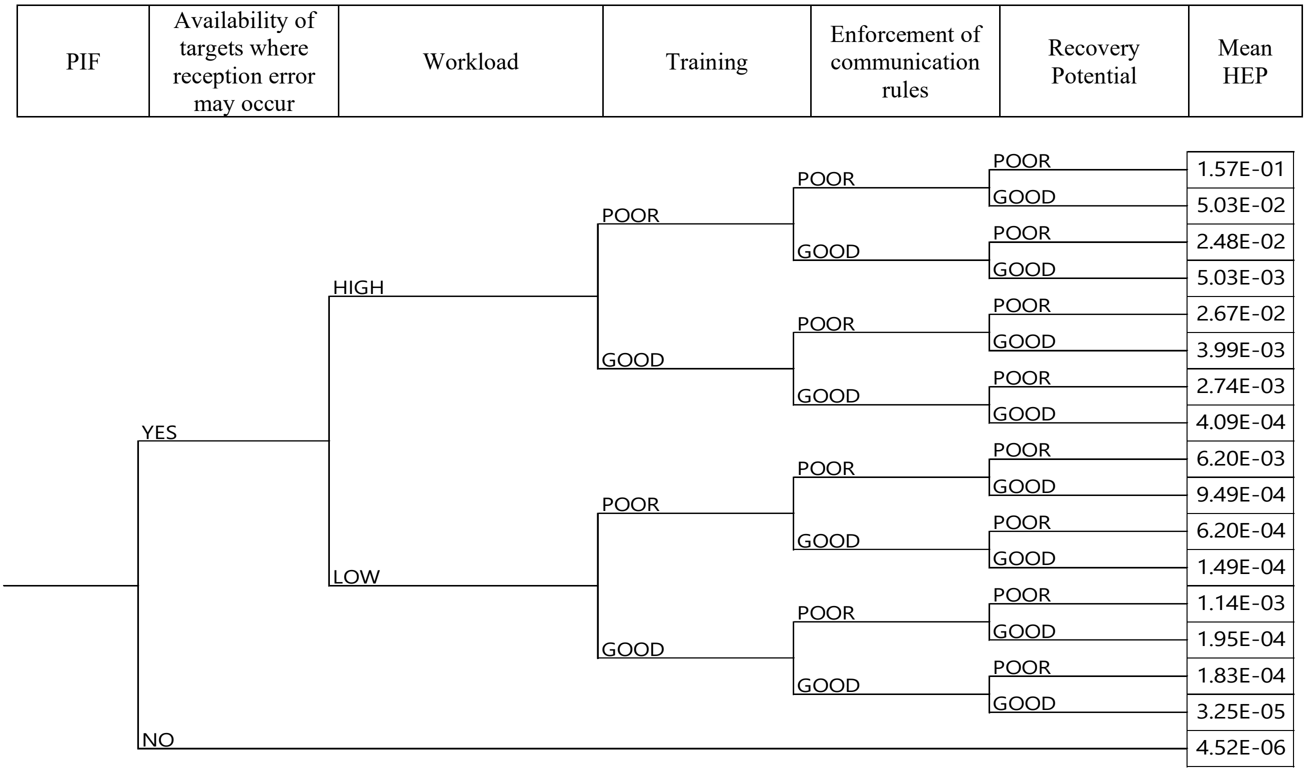
Figure 2: Decision Tree and HEP estimation results for the CFM (forget to transmit)

PIF	Availability of targets where transmission error may occur	Workload	Training	Enforcement of communication rules	Recovery Potential	Mean HEP



PIF	Availability of targets where transmission error may occur	Workload	Training	Enforcement of communication rules	Recovery Potential
Description/ Overview	This branch evaluates whether there are objects, facilities, operations, etc., that may cause transmission error. For example, it examines whether there are similar objects/equipment/work to the object/equipment. If there are no similar objects, facilities, or operations, the possibility of transmission error is the lowest.	This branch evaluates whether transmission error occurs due to a heavy workload. For instance, workload might be elevated if the transmitter is concurrently handling multiple tasks, experiencing mental fatigue or emotional stress due to the situation, etc. Time constraints are also considered as part of the workload.	This branch evaluates whether the information transmitter can convey information appropriately during periodic trainings. These trainings involve tasks where information transmitters relay decisions to recipients in the field in response to directives from the emergency operations facility. If information is inadequately transmitted during training sessions, it may contribute to instances of transmitting the wrong information.	This branch evaluates whether the transmitter of information is trained to be thorough in the communication rules so that transmission errors do not occur (and even if they do occur, the transmitter is able to recognize the error). If the transmitter is not thoroughly trained in the communication rules, it may be a factor that causes transmission error.	This branch evaluates whether the transmitter, receiver, and their surroundings can recognize and recover from the failure when it occurs.
Branching criteria	Take the "YES" branch if the content of the same PIF in Table 2 applies; otherwise, take the "NO" branch.	Take the "HIGH" branch if any one of the contents of the same PIF in Table 2 applies; otherwise, take the "LOW" branch.	Take the "POOR" branch if any one of the contents of the same PIF in Table 2 applies; otherwise, take the "GOOD" branch.	Take the "POOR" branch if any one of the contents of the same PIF in Table 2 applies; otherwise, take the "GOOD" branch.	Take the "GOOD" branch if any one of the contents of the same PIF in Table 2 applies; otherwise, take the "POOR" branch.

Figure 3: Decision Tree and HEP Estimation results of the CFM (transmission error)



PIF	Availability of targets where reception error may occur	Workload	Training	Enforcement of communication rules	Recovery Potential
Description/ Overview	This branch evaluates whether there are objects, facilities, operations, etc., that may cause reception error. For example, it examines whether there are similar objects/equipment/work to the object/equipment. If there are no similar objects, facilities, or operations, the possibility of reception error is the lowest.	This branch evaluates whether reception error occurs due to a heavy workload. For instance, workload might be elevated if the recipient is concurrently handling multiple tasks, experiencing mental fatigue or emotional stress due to the situation, etc. Time constraints are also considered as part of the workload.	This branch evaluates whether the information recipient can receive information appropriately during periodic trainings. These trainings involve tasks where information transmitters relay decisions to recipients in the field in response to directives from the emergency operations facility. If information is inadequately received during training sessions, it may contribute to instances of reception error.	This branch evaluates whether the recipient has been trained in similar scenarios and thoroughly trained in the communication rules to avoid misunderstanding the content of the information received. If the recipient does not understand his or her role or is not thoroughly trained in the communication rules when receiving the information, this could be a factor that causes reception error.	This branch evaluates whether the transmitter, receiver, and their surroundings can recognize and recover from the failure when it occurs.
Branching criteria	Take the "YES" branch if the content of the same PIF in Table 3 applies; otherwise, take the "NO" branch.	Take the "HIGH" branch if any one of the contents of the same PIF in Table 3 applies; otherwise, take the "LOW" branch.	Take the "POOR" branch if any one of the contents of the same PIF in Table 3 applies; otherwise, take the "GOOD" branch.	Take the "POOR" branch if any one of the contents of the same PIF in Table 3 applies; otherwise, take the "GOOD" branch.	Take the "GOOD" branch if any one of the contents of the same PIF in Table 3 applies; otherwise, take the "POOR" branch.

Figure 4: Decision Tree and HEP Estimation results of the CFM (reception error)

4. CONCLUSION

Drawing from the IDHEAS-G approach, an HEP evaluation model was devised for the three CFMs ("forget to transmit," "transmission error," and "reception error") within the direction and report task between the emergency operations facility and external locations. By employing the decision trees depicted in Figures 2 through 4, the HEP estimation of each CFM became feasible by scrutinizing the branches of the PIF relative to the assessed situation. This development of the HEP evaluation model demonstrates that IDHEAS-G can be used to develop HEP evaluation models for tasks under extreme conditions.

In this study, HEP estimation was conducted through workshops, but it should be noted that HEP estimation by expert elicitation is a subjective probability. Although it may not be possible to collect data under actual extreme conditions, it is important to verify the validity of the estimated HEP values based on expert elicitation and to update the HEP values by, for example, collecting data during simulator trainings and/or comprehensive disaster management trainings that simulate extreme conditions and creating a database.

References

[1] Nuclear Emergency Response Headquarters. Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety- The Accident at TEPCO's Fukushima Nuclear Power Stations -, Government of Japan, 2011.

[2] Y. Kirimoto, K. Nonose, Y. Hirotsu, and K. Sasou. Guide for Qualitative Analysis in The Human Reliability Analysis (HRA) with Emphasis on Narratives (FY 2018 Edition)", CRIEPI Report O18011, 2019. (in Japanese)

[3] D. Takeda, Y. Kirimoto, K. Hayase, K. Nonose. Human Error Probability Evaluation Method for Direction and Report between Emergency Operations Facility and Outside, Atomic Energy Society of Japan Annual Meeting Proceedings, 2021. (in Japanese)

[4] US Nuclear Regulatory Commission. Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications, NUREG/CR-1278, Final Report, 1983.

[5] US Nuclear Regulatory Commission. The General Methodology of an Integrated Human Event Analysis System (IDHEAS-G), NUREG-2198, 2021.

[6] Jing Xing & Stephanie Morrow. "White Paper: Practical Insights and Lessons Learned on Implementing Expert Elicitation". US Nuclear Regulatory Commission. 2016.