Models and Knowhow for Human Reliability Analysis on Portable Equipment

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Abstract: The use of portable equipment such as mobile diesel pumps may be necessary to respond to severe accidents at nuclear power plants, and thus human reliability analysis (HRA) on it is important for risk assessment; however, development and application of HRA methods for portable equipment is scarce in the world. Our past study described models and knowhow for HRA on portable equipment we developed and their application example in tsunami probabilistic risk assessment. It showed definitions of types of steps, examples of application rules of the table of estimated human error probability (HEP) in THERP method for the on-site operation/work, and task timeline diagram developed for organizing actors, locations, and time information (e.g., time required for executing a task). The present study has improved them and prepared for additional models and knowhow for HRA on portable equipment, as shown in the followings: 1) example of application rule of Cause-Based Decision Tree Method for the emergency operations facility, 2) re-definition of types of steps and policy on minimum HEP of essential steps, 3) example of application rule of the table of estimated HEP in the THERP method for the on-site operation/work for equipment not covered in the THERP method (especially for error recovery to error of commission), 4) evaluation method for repetitive work such as refueling to portable equipment in long-term response, and 5) evaluation method for transmission/receipt of directions and report. An example of a policy for assessing execution task steps in portable mitigation equipment operation and work is also shown. Although this study focuses on the use of portable equipment, the know-how and models described can be applicable for tasks, for example, performed in a main control room. They will be useful for utilities to conduct HRA on different tasks performed in actual plants.

1. INTRODUCTION

Since the Fukushima Daiichi Nuclear Power Station Accident in 2011, the use of probabilistic risk assessment (PRA) has been emphasized for assessing residual risk (risks remaining after a risk is addressed) in order to improve the safety of nuclear power plants as well as deterministic safety analysis which is a conservative approach for risk assessment. In order to improve PRA, advances have been made in refining data and improving methods for assessing hazards relating to external events, the fragility of buildings/equipment, accident sequences, probability of equipment failure, and other aspects.

In addition to facility and equipment failures, PRAs need to also take into account human failure events (HFE) which are events happening in situations where operators/other personnel are executing certain tasks and are unable to achieve the task objective or fail to accomplish the task, thereby significantly impacting an accident. The probability of failing at such a task is known as human error probability (HEP) and assessment of this probability is a required part of human reliability analysis (HRA). In conducting HRA, it is pointed out that it is important to specifically understand the situation in which human tasks are performed in qualitative analyses [1, 2]. The NRRC of the CRIEPI has published the HRA Guide [3] that compiles qualitative analysis methods to collect plant-specific and scenario-specific conditions that affect human performance as "narratives", reflecting the latest research trend.

Since the Fukushima Daiichi Nuclear Power Station Accident in 2011, it has been emphasized to consider the response to an accident caused by external events such as seismic and tsunami events in HRA. The response to external events may include many operations under extreme conditions such as outdoors, long hours, and high stress in rapid accident progression [4, 5]. Because the use of portable equipment such as mobile diesel pumps can be a critical task under extreme conditions, it is important for risk assessment to conduct HRA on it; however, development and application of HRA methods for portable equipment is scarce in the world. The previous HRA has mainly covered response to internal events and assumed that one crew in the main control room mainly performed "cognitive tasks" which are subtasks related to detection of a cue, understanding the situation and decision making of the actions, and "execution tasks" which are subtasks related to operations based on the decision-making.

Meanwhile, in the case of tasks performed under extreme conditions, the actors of "cognitive tasks" (e.g., general manager and chief manager at the emergency operations facility) and that of "execution tasks" (e.g., on-site emergency operations personnel) may differ, or multiple "execution tasks" may be performed in different locations once directions are given [6]. It is also necessary to evaluate new subtasks related to the transmission and receipt (directions and report of completion via communication equipment such as phones) of information between the actors.

Our past study [7] described models and knowhow for HRA on portable equipment we developed and their application example in tsunami probabilistic risk assessment. It showed definitions of types of steps, examples of application rules of the table of estimated human error probability (HEP) in THERP method [8] for the on-site operation/work, and task timeline diagram developed for organizing actors, locations, and time information (e.g., time required for executing a task).

The present study has improved them and prepared for additional models and knowhow for HRA on portable equipment, as shown in the followings: 1) example of application rule of Cause-Based Decision Tree (CBDT) Method [9] for the emergency operations facility, 2) re-definition of types of steps and minimum HEP of essential steps, 3) example of application rule of the table of estimated HEP in the THERP method for the on-site operation/work for equipment not covered in the THERP method (especially for error recovery to error of commission), 4) evaluation method for repetitive work such as refueling to portable equipment in long-term response, and 5) evaluation method for transmission/receipt of directions and report.

2. ADDITIONAL MODELS AND KNOWHOW FOR HRA ON PORTABLE EQUIPMENT

2.1 Example of Application Rule of CBDT Method for the Emergency Operations Facility

Particularly in extreme conditions, an emergency operations facility is established where important strategic and tactical decisions (mobilization of portable mitigation equipment, etc.) are made with the aim of resolving the situation. While there are different methods premised on there being a main control room (e.g., HCR/ORE method, CBDT method [9]) for evaluating decision-making (cognitive tasks), there is currently no method for evaluating decision-making at an emergency operations facility. However, assuming that there is enough time for understanding situation and decision-making, the present study has determined that the CBDT method is the most appropriate method for evaluating decision-making at an emergency operations facility among several methods and an approach is shown that applies the CBDT method to evaluating decision-making at an emergency operations facility.

In an emergency operations facility, managers and function teams act as one crew with the head manager as commander. Also, information is collected from the Safety Parameter Display System (SPDS), main control room, and communications from the field, and various cognitive tasks are carried out. It is necessary for developing application rules to consider these characteristics. Presented in Table 1 are items, which have been excerpted, that are deemed particularly necessary in cases premised on application of the CBDT method to an emergency operations facility in terms of "key points for application/ supplementary interpretation." The evaluation covers procedures used by the emergency operations facility. For example, if standards for making determinations on the mobilization of portable mitigation equipment have been established, then the documents in which such procedures are noted are subject to assessment as procedures for cognition and determination.

Table 1: Example of Application Rule of CBDT Method for the Emergency Operations Facility

Decision tree	Node	Guidance as Stated in EPRI TR-100259 (Excerption of [9])	Key points for application/ supplementary interpretation
p_ca: Data Not Available	(1)	Is the required indication available in the control room?	"Emergency operations facility" is substituted for "control room." In cases where the indicators displaying the minimum necessary information for making this determination (e.g., SPDS screen) is available in the "emergency operations facility", in cases where information from the main control room can be shared smoothly in the emergency operations facility, or in self-evident cases, then "Yes." If it is unavailable, then "No."
p_cb: Data Not Attended to	(2)	Is the operator required to perform a one-time check of a parameter, or monitor it until some specified value is reached or approached?	In cases where information is provided by the main control room, or perceived on an SPDS screen or other viewer, "Check"
	(3)	Is the indicator to be checked displayed on the front panels of the main control area, or does the operator have to leave the main control area to read the indications?	In cases where information is provided by the main control room, then "Front," and, if it needs to be switched on the SPDS or other screens, then "Back."
p_cc: Data Misread or Miscommunicated	(1)	Are the layout, demarcation, and labeling of the control boards such that it is easy to locate the required indicator?	[emergency operations facility parameter display console] is substituted for "control boards."

The CBDT method expects error recovery by personnel outside a main control room in addition to error recovery by Self Review for cognitive tasks in the main control room. Similarly, various personnel are involved in the emergency operations facility, and thus it is necessary to organize how to consider error recovery by them (Table 2). Considering that emergency operations facility is composed of various functional teams, such as functional teams in charge of planning strategies and functional teams in charge of portable equipment, and that error recovery can be mutually expected, it is assumed that error recover by them are included in the error recovery by Self Review.

Table 2: Evaluation of error recovery relating to cognitive tasks

Recovery Factor of CBDT method (EPRI TR-100259) (Excerption of [9])	Example of application to decision-making in the emergency operations facility
Self Review	Error recovery performed by managers of the emergency operations facility or emergency operations facility personnel involved in making the decision in question (managers, recovery team, etc.).
STA (shift technical advisor) Review	If error recovery can be expected to be done by a subject that is independent from the managers of the emergency operations facility and the personnel, error recovery by them may be expected.
Shift Change	Error recovery performed by a replacement shift at the emergency operations facility.
ERF (emergency response facility) Review	Not anticipated. Because the emergency operations facility performs cognitive tasks, this error recovery is the same as the Self Review.
Extra Crew	Error recovery performed by personnel other than the aforementioned (main control room personnel, etc.)

The emergency operations facility and main control room may be regarded as organizations each of which is able to maintain different information sources and this point may be interpreted as the two being separate organizations, so error recovery performed by the main control room crew is able to be classified as performed by an extra crew. On the other hand, in more serious situations such as core damage, the main control room calls for determinations to be made by the emergency operations facility and there are other such situations conceivable where the main control room may not always be regarded as having the capability to perform error recoveries. A determination on this point is needed that is suited to the reality of the situation.

2.2. Re-definition of Types of Steps in Execution Task and Minimum HEP of Essential Steps

2.2.1 Re-definition of Types of Steps in Execution Task

Essential steps for establishing portable equipment in the on-site operation outdoors sometimes include the large number of steps, which are qualitatively different from operations in main control room. For example, actions that are simple for which advanced proficiency has been achieved and are performed automatically (skill-based actions) are sometimes included in establishment of portable equipment and necessary to be evaluated. The present study has reviewed and revised the definition of steps in our past study in order to clarify how to evaluate such steps (Table 3). It is noted that all steps are considered subject to assessment for time progression information (time for execution, etc.).

Table 3: Types of Steps and Description

Type	Description
Essential step	[Steps subject to quantitative assessment] A step that is necessary for establishing accident mitigation function through performance of the tasks, that does not achieve the objective of the task if the step fails, and that may be anticipated to fail.
	[Steps outside the scope of quantitative assessment] The following steps are steps necessary for the establishment of accident mitigation function through the performance of tasks and these are steps where the objective of the task is not achieved if the steps fail, but HEP=0 in quantitative assessments and essentially these are not subject to a quantitative assessment. ・Steps for which failure is difficult to conceive of. ・Operations that are simple and their success or failure can be seen on the spot, and, if they did not succeed, any subsequent operations are not possible ・Actions that are simple for which advanced proficiency has been achieved and are performed automatically (skill-based actions)
Error recovery step	[Steps subject to quantitative assessment] A step to check implementation of the essential step and recover it (do it again) in case of failure.
Steps identified other than those indicated above	[Steps outside the scope of quantitative assessment] Steps other than those stated above (not directly affecting operation failure or error recovery) are not subject to a quantitative assessment. These include operations performed for reasons of work safety, operations performed for long-term protection of equipment, actions that are confirmations but do not confirm the results of implementation of essential steps, and actions of confirmation that are not used as error recovery steps in actual operations.

In addition, the following should be considered for identifying and organizing error recovery steps. First, as part of their basic behaviors, operators and workers generally have the skill of verifying the results after an operation or work step is performed, and they possibly have the skill of confirming work of their colleagues as well as their own. For this reason, even though it is not written in the procedures, error recovery may also be anticipated not only by the person performing the step but also by others. Also, to verify operation results, in addition to the clues indicated in procedures, it is also possible that clues used customarily as well as clues used realistically such as sound or vibration after an operation may also be used. It is important to anticipate these actions, clarify them through surveys, and reflect them in the assessments.

It is also possible that confirming whether expected results have been obtained as a result of performing all operations may be expected to be error recovery steps (ex. performing a cooling water injection operation and checking at the end whether cooling water is being injected). In such a case, the steps can be considered to be error recovery steps for the essential steps up to that point.

2.2.2. Policy on Minimum HEP of Essential Steps

Considering the above, there are many cases where multiple error recovery steps may be anticipated for one essential step. A matter of concern is that the error probability of an essential step may be too small due to a large number of recovery steps for an essential step. NUREG/CR-1278 [8] states that if the HEP is smaller than 10^{-6} in a case where recovery by others (double-check) for an essential step is included or 10^{-5} in case where recovery by others are not included (only self-check), it may be unnatural in HRA, and it might be better to reconsider the recovery steps in terms of their number and dependencies. For example, the recovery steps are moderated according to the following way. The first way is to reconsider the level of dependencies. The second way is to set the minimum value as 10^{-6} in case where recovery steps by others (double-check) are included for an essential step or 10^{-5} in a case where recovery steps by others are not included (only self-check).

A further way is to exclude a part of recovery steps from calculating the error probability of the essential step. For example, NUREG/CR-1278 [8] states that, depending upon the particularities of the operation, error recovery is not necessarily expected by another person not required in the procedures and that checks by the third or subsequent person are not anticipated after assembling a component during normal situation. Similarly, Shimakura et al. [10] also pointed out that the contribution of a third or subsequent check to the detection of error is low. Based upon such information, in principle, the number of error recovery steps is regarded to be a maximum of two, and steps expected to be more directly useful in error recovery of an essential step that precedes them be regarded as the most representative error recovery steps.

However, if the step entails high risk and is important, it is natural that there be multiple checks performed, so it is important to appropriately reflect the results of interviews and surveys conducted on site in the assessment. If the results are determined to be appropriate, they may also be used as is done in reassessing cases where the HEP is too low.

2.3. Example of Application Rule of the Table of Estimated HEP in the THERP Method for the On-site Operation/work for Equipment Not Covered in the THERP Method (for Error Recovery to Error of Commission)

With the THERP method [8], equipment addressed in assessments of field operations and work is limited to circuit breakers, cable connectors, manual valves, etc., and, in field operations and work under extreme conditions and other such situations, operations and work have been observed where equipment has been used that is not handled by the THERP method. Accordingly, our past study gives examples of application rules of the table of estimated HEPs for error of commission of essential step concerning equipment not handled by the THERP method. The present study gives examples for error recovery steps (Table 4).

Table 4: Example of Application Rule of the Table of Estimated HEP Based on the On-Site Operation/Work (for equipment not covered in the THERP method) [Error recovery to error of commission]

Manner of confirming operation results	Table of Estimated HEP of THERP method [8]
Displays such as indicators	[selection error] Table 20-9： Estimated probabilities of errors in selecting unannunciated displays for quantitative or qualitative readings [error in reading] Table 20-10： Estimated HEPs for errors of commission in reading and recording quantitative information from unannunciated displays (from Table 11-3) Table 20-11: Estimated HEPs for errors of commission in check-reading displays
Annunciators	Table 20-23: The Annunciator Response Model: estimated HEPs for multiple annunciators alarming closely in time
Vibration	Table 20-11 item 7: Confirming a status change on a status lamp (HEP=0) [Explanation] The possibility of failing to detect mechanical vibration when portable equipment is started up or at other time is regarded as sufficiently low that it may be ignored, so the above is applied.
Clear change in status noticed at a glance	Table 20-11 item 7: Confirming a status change on a status lamp (HEP=0) [Explanation] Operations for which the result is very clear and may be confirmed immediately on site are regarded as having a sufficiently low possibility of failure to ascertain any change in status that they may be ignored, so the above is applied.
Confirmation using valve or lever status	While continuing to take into consideration whether there are any clear changes in status and the absence or presence of a position injector, the same item of the table selected in the evaluation of failure of the preceding essential step may be selected. [Explanation] In cases where there is a position injector, reading it is the error recovery, but that act is performed at the same time as the operation, so the same HEP as the operation is applied. In cases where there is no position injector, error recovery is regarded as possible by performing the operation once again. Such is taken into consideration and the same item of the table selected in the evaluation of failure of the preceding essential step is selected for the error recovery step performed by oneself or another person (e.g., if the preceding essential step is Table 20-14 Item 4, then the error recovery step for that is also Table 20-14 Item 4).
Cases where confirmation is difficult	The error recovery step is expected to be the confirmation of phenomena that occurs as a result after all operations have been performed.

2.4. Evaluation Method for Repetitive Work Such as Refueling to Portable Equipment in Long-term Response

When performing tasks under extreme conditions, the same elemental task, such as refueling to continuously operate a pump, may be performed again and again over a long-term response. Accumulating the HEP of refueling for the number of repetitions may result in an unrealistic evaluation where the HEP is greater than 1. When humans repeat a task, they become more proficient at that task and are less likely to make mistakes. Therefore, for more realistic analysis, the present study proposes a way to express the proficiency by adjustment of the dependence between essential steps.

For example, it is assumed that the proficiency level starts with “Low”, increases to “High” and finally “Extremely high” while repeating an elemental task composed of essential steps 1-3 five times (for convenience, the proficiency is assumed to progress step by step every time), evaluation equations are assumed as shown in Table 5.

In this example, even if the level of proficiency is "Extremely high", the total HEP does not fall below the HEP of the initial step; however, it is conceivable that the HEP of the initial step also decreases with proficiency in real. In order to reflect this, it is possible, for example, to adjust the HEP of the initial step using the equation for assessing dependence while keeping in mind the types of actions.

Table 5: Evaluation Equations for Learning Effects of Repetitive Work (Example)

No. of repeats	Proficiency	Evaluation equations
1st time	Low	$STEP1 \times ZD(STEP2) \times ZD(STEP3) = E1 + E2 + E3$
2nd time	Middle	$STEP1 \times LD(STEP2) \times LD(STEP3) = E1 + \frac{19}{20}(E2 + E3)$
3rd time	High	$STEP1 \times MD(STEP2) \times MD(STEP3) = E1 + \frac{6}{7}(E2 + E3)$
4th time	Very high	$STEP1 \times HD(STEP2) \times HD(STEP3) = E1 + \frac{1}{2}(E2 + E3)$
5th time	Extremely high	$STEP1 \times CD(STEP2) \times CD(STEP3) = E1$

ZD (STEP n): dependence level between STEP n and STEP n-1(preceding step) is ZD.
En： HEP of STEP n

2.5. Evaluation Method for Transmission/receipt of Directions and Report

The quantification methods developed in the past decades cover evaluation of response to internal events mainly performed in the main control room. Because of this, these quantification methods do not directly estimate the error rate of transmission/receipt of direction and report by the reason that error recovery is more feasible due to face-to-face interaction (HEP = 0) [8]. Therefore, even under extreme conditions, the error probabilities of face-to-face transmission/receipt of direction and report are estimated using the same way. However, when multiple actors perform operation/work at multiple locations, transmission and receipt between the actors by radios or telephones occur. This situation can cause miscommunication due to difficulties in understanding each other's situations.

Therefore, an evaluation method of the error probabilities of transmission/receipt of direction and report is needed. The following provides methods to evaluate transmission and receipt of direction and report by applying the THERP method [8] and the IDHEAS method [2] as an example. The transmission/receipt of and report mentioned in the following are about directions for transmitting diagnosis results (decisions) and operation completion, not about their operation processes. In addition, error recovery may be anticipated based on surveys of communication rules and situations when communication devices are used to transmit and receive directions and reports.

2.5.1. Error Receipt (Failure to Hear, Mishear)

"SA-3: Critical Data Misperceived" of Crew Failure Mode in the IDHEAS method [2] originally assumes information obtained from annunciators and indicators. Assuming information receipt in direction and report as equivalent, the following shows an example of evaluation of the error probability of "Error receipt" using an applicable decision tree and a format of collecting and compiling information to develop narratives as shown in Table 6.

In cases where it is difficult for an error to arise in the content received (simple work completion report or instruction for start-up) and error recovery may be sufficiently anticipated, the HEP for error receipt is regarded as sufficiently small that it may be ignored, so it may be set as HEP=0 in the calculation.

Table 6: Example of application rule of "SA-3: Critical Data Misperceived" of Crew Failure Mode in the IDHEAS method to "failure to transmit"

Decision node	(1) HSI/Environment	(2) Workload	(3) Training	(4) Recovery potential
Apply a part of expression in description in [2] so that it fits to "failure to transmit	Good if all the following items are Yes, Poor for other cases. ・Is information clear? ・Is information easily heard? ・Is environment of the workplace (noise, temperature, humidity) fine?	Low if both of the following are not applicable, High for other cases ・Many requirements of attention/possibility of interruptions ・No time margin	Good if both of the following are Yes, Poor for other cases. ・Is training provided as to response when contents of information are difficult to understand or difficult? ・Is importance of obtaining information correctly communicated?	Yes, if the following is applicable. No for other case. ・It is expected that the people around the individual will notice an error in receiving the transmission immediately on the spot and initiate error recovery.

2.5.2. Forget to Transmit

"E-3: Failure to Initiate Execution" of Crew Failure Mode in the IDHEAS method [2] assumes failure to initiate action such as response operation in an accident. Assuming transmission of information such as direction and report as a part of this action, the following shows an evaluation example of the error probability of "Forget to transmit" using an applicable decision tree and a format of collecting and compiling information to develop narratives as shown in Table 7.

In cases where individuals nearby anticipate the operation and are expected to confirm the operation results and progress, error recovery for forgetting to transmit may be sufficiently anticipated and the HEP is regarded as sufficiently small as to be able to be ignored, so it may be set as HEP=0 in the calculation.

Table 7: Example of application rule of "E-3: Failure to Initiate Execution" of Crew Failure Mode in the IDHEAS method to "Forget to transmit"

Decision nodes	(1) Immediacy	(2) Workload	(3) Recovery potential
Apply a part of expression in description in [2] so that it fits to "failure to transmit"	Yes, if all the following questions are yes, no if any of the following is No. ・Necessity of immediate response ・High functional priority ・High time priority	Low if both of the following are not applicable, High for other cases ・Multiple response actions at the same time ・Possibility of interruption	Cases corresponding to the following item, Yes Other cases, No ・It may be anticipated that individuals nearby point out that the directions or report has forgotten to be issued.

2.5.3. Error of Transmission

Table 20-5 "Estimated HEP per item (or perceptual unit) in preparation of written material" in the THERP method [8] assumes partial omission or wrong information in creating documents such as procedures. Assuming information transmission of direction and report as equivalent, they can be evaluated as follows using the same table (Table 8).

Table 8: Example of application rule of the THERP method to "Error of Transmission"

Type of Error	Table of Estimated HEP of THERP method [8]
Partial omission of information in transmission (partial misstatement)	Table 20-5 "Estimated HEP per item (or perceptual unit) in preparation of written material" Item 1: Omitting a step or important instruction from a formal or ad hoc procedure or a tag from a set of tags (mean HEP $=4.84\times10^{-3}$)
Transmission of incorrect information (misstatement)	Table 20-5 "Estimated HEP per item (or perceptual unit) in preparation of written material" Item 3: Writing an item incorrectly in a formal or ad hoc procedure or on a tag (mean HEP $=4.84\times10^{-3}$)

In cases where the specifics detailed in procedures are communicated, some examples of communication rules to reduce errors in transmission are to communicate such details while verifying the procedures, to communicate such details while looking at notes made specifying the details to be communicated, and to have the recipient also verify the details while looking at the same procedures. In cases where such actions are performed, error transmission may be assessed by setting the HEP for error recovery, for example, as indicated in Table 9 and considering its dependence and stress level.

In cases where it is difficult for an error to occur in the content transmitted (simple work completion report or instructions for startup) and error recovery may be sufficiently anticipated, the HEP is regarded as sufficiently small that it may be ignored, so HEP=0 may be set in the calculation.

Table 9: Example of application rule of the THERP method to Recovery of Transmission Error

Type of Error Recovery	Table of Estimated HEP of THERP method [8]
Error recovery when communicating while looking at procedures or notes or the recipient also verify the same procedures	Table 20-7： Estimated probabilities of errors of omission per item of instruction when use of written procedures is specified) Item 3: When procedures without checkoff provisions are used, or when checkoff provisions are incorrectly used: Short list, < 10 items (mean HEP: 3.8×10^{-3}) (If a tabular format corresponding to the columnar format shown as good practices in "Chapter 15. Oral Instructions and Written Procedures" was used, the HEP value in Table 20-7 may be set at 1/3.)

3. PART OF AN APPLICATION EXAMPLE

The application example of portable equipment we prepared focuses on an operation to supply make-up seawater to a pit using portable mitigation equipment (portable equipment) (a large-capacity water pump truck and a submersible pump) at a virtual plant. This also includes the work of supplying fuel to refuel portable equipment. Figure 1 shows the overview of the operation.

Due to the number of pages, it is impossible to show the entire descriptions of HRA of the application example; therefore, as part of the description, the present study shows an example of a policy for assessing execution task steps in portable mitigation equipment operation and work (Table 10), including reasons. This example was set based on hypothetical on-site interviews and surveys. When evaluating portable equipment in actual plants, on-site interviews and surveys should be conducted and a policy should be determined based on them.

Figure 1: Overview of operation for supplying make-up seawater to pit by portable equipment

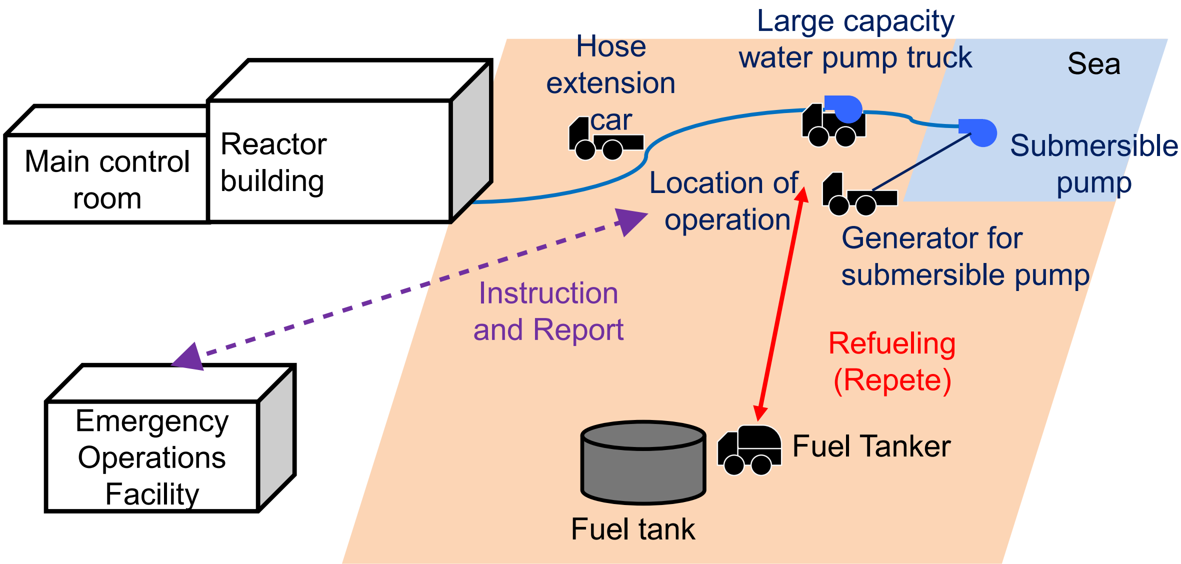

Table 10: Example of a Policy for Assessing Execution Task Steps in Portable Mitigation Equipment Operation and Work (1/2)

Type of operation and work	Assessment policy and reason
Movement	・The error probability is determined to be sufficiently small and thus it may be ignored (treated as HEP=0 in calculations). [Reason] As a result of on-site surveys, it was found that personnel are able to move around without getting lost if they are properly aware of where they are going and that roads have been improved and there is no inconvenience to vehicle movement.
Hose installation	・The error probability is determined to be sufficiently small and thus it may be ignored (treated as HEP=0 in calculations). [Reason] As a result of on-site interviews, it was found that, although it is important to lay the hose without any sharp bends or twists, some bends or twists do not affect the establishment of hose function and recovery is possible also when verifying that water is passing through the hose, and that error recovery is also simple.
Hose connection	・Selection error is taken into account only in cases where there are multiple connections (however, in cases where hose connections are failsafe, selection error is not taken into consideration). ・The insufficiency of connections is determined to have a sufficiently small error probability due to the following reasons and thus it may be ignored (treated as HEP=0 in calculations) [Reason] As a result of on-site interviews, it was found that, even though there may be some looseness in the connection, water passes through it and, if for some reason the hose becomes uncoupled, the personnel on site realized this quickly and error recovery is able to be easily performed.
Operation removing the cap covering the hose connection port on a large capacity water pump truck	・The error probability is determined to be sufficiently small and thus it may be ignored (treated as HEP=0 in calculations). [Reason] The operation of removing the cap is very simple and must be done when connecting hoses, and it was found based upon on-site surveys that it is very difficult to conceive that this operation would fail.

Table 10: Example of Policy for Assessing Execution Task Steps in Portable Mitigation Equipment Operation and Work (2/2)

Valve operation of a large capacity water pump truck	・There are multiple valves that are the target of this operation and consideration is given to selection error only in cases where a selection needs to be made from among these valves (however, selection error is not taken into consideration in cases where the same operation is performed for all valves in no particular order). ・The operation is performed using a lever handle and, in cases where it may be seen at a glance whether the valve is fully open or closed, the error probability of an operation failure or verifying the operational state is determined to be sufficiently small that this operation may be ignored (treated as HEP=0 in calculations). [Reason] Because the interfaces were surveyed and it was found that a fully closed or fully open state is understandable at a glance and that easily-operated lever handles are used, that water passes through the valves even in cases where the state may be somewhat insufficient, and that, even in cases where abnormality arises in the operation state caused by an operation failure because the valve to be operated is close to a large capacity water pump truck, this is quickly noticed and the valve operation is redone or the pump is able to shut down.
Pump engine startup operation	・If the operation is simple such as pushing a button, the error probability is determined to be sufficiently small that it may be ignored (treated as HEP=0 in calculations) (however, in cases where the operation of two or more steps is necessary to prevent malfunction, an assessment is performed commensurate with such operation). [Reason] Because as long as the engine startup button operation is not performed, all other operations are impossible and the operation is simple and it is able to be easily determined on-site that the pump engine has not started
Operation of a four-way selector switch cock	・The appropriate item is selected from Table 20-14 of the THERP method [8] and the same HEP is applied also to error recovery. [Reason] As a result of a survey of the interface, it was found that this is a lever operation and that lettering is printed for the selector switch state. Reading of the selector switch position is the error recovery, but that is performed at the same time as the operation, so the same HEP as the operation is applied to.
Attachment of refueling port cap and operation and collection of the fuel filling gun	The error probability is determined to be sufficiently small and thus it may be ignored (treated as HEP=0 in calculations) [Reason] Because this is an operation that is regarded as a skill-based action performed automatically at a high level.

4. CONCLUSION

The present study has improved and added the know-how and models developed in our past study for improving HRA on portable equipment. These know-how and models can contribute to better evaluation on, for example, cognitive task conducted by the emergency operations facility, essential steps and recovery steps of execution tasks of portable equipment, repetitive tasks, and communication between multiple actors. Although this study focuses on the use of portable equipment under extreme conditions, the know-how and models described in this study can be applicable for tasks, for example, performed in a main control room. They will be useful for utilities to conduct HRA on tasks performed in a main control room and other places as well as portable equipment in actual plants.

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