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SCHEME (Soft Control Human error Evaluation MEthod) for advanced MCR HRA

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1. Introduction

Since the Three Mile Island (TMI)-2 accident, human error has been recognized as one of the main causes of nuclear power plant (NPP) accidents, and numerous studies related to Human Reliability Analysis (HRA) have been carried out. These include the Technique for Human Error Rate Prediction (THERP) [1], Korean Human Reliability Analysis (K-HRA) [2], Human Error Assessment and Reduction Technique (HEART) [3], A Technique for Human Event Analysis (ATHEANA) [4], Cognitive Reliability and Error Analysis Method (CREAM) [5], and Simplified Plant Analysis Risk Human Reliability Assessment (SPAR-H) [6] in relation to NPP maintenance and operation. Most of these methods were developed considering the conventional type of Main Control Rooms (MCRs). They are still used for HRA in advanced MCRs even though the operating environment of advanced MCRs in NPPs has been considerably changed by the adoption of new human-system interfaces such as computer-based soft controls. Among the many features in advanced MCRs, soft controls are an important feature because the operation action in NPP advanced MCRs is performed by soft controls. Consequently, those conventional methods may not sufficiently consider the features of soft control execution human errors.

To this end, a new framework of a HRA method for evaluating soft control execution human error is suggested by performing the soft control task analysis and the literature reviews regarding widely accepted human error taxonomies.

2. Development of a framework for HRA method in consideration of soft control

2.1 Soft control human error mode identification

A soft control task analysis was performed to identify human error modes (HEMs) and develop the framework of a new HRA method considering soft control. The possible human error modes documented in this papers during the process have been classified into eight types.

- Operation selection omission (E_0): An operator omits performing a task when following a procedure (one task in a procedure).
- Operation execution omission (E_1): An operator omits performing a sub task when following a task. (one sub task in a task).
- Wrong screen selection (E_{2SS}): An operator selects a wrong screen when performing a task.
- Wrong device selection (E_{2DS}): An operator selects a wrong control device when performing a task.
- Wrong operation (E_3): An operator performs a wrong operation, such as pressing the 'OPEN' button instead of the 'CLOSE' button. (Pressing 'CLOSE' button is originally intended to perform.)
- Mode confusion (E_4): An operator performs a right operation in a wrong mode.
- Inadequate operation (E_5): An operation is executed insufficiently. All operations that are performed incompletely.
- Delayed operation (E_6): An operation is not performed at the right time.

2.2 A framework for HRA method in consideration of soft controls

A framework for a HRA method which considers soft controls was developed using concepts of secondary tasks, sequential behavior for unit completion, and dependency among subtasks. In our model, a success path (a path where all subtasks succeed) was considered to calculate soft control execution human error probability (HEP) which takes into account dependency among tasks. In other words, the probability of soft control execution error is HEP = 1-[success path probabilities with dependency model]. The suggested model also can be changed to a failure path model.

Two example tasks were selected to show the concept of HEP calculation. One of the example tasks is an artificially generated task (Task 1: Control letdown flow of S/G to 20 liter/sec) and another task (Task 2: Open Aux FW level control valves) was taken from the one of the tasks in the Steam Generator Tube Rupture (SGTR) scenario. In order to complete Task 1, the operator first should succeed in pressing the 'Graphic' button, which is one of the navigation tasks (secondary tasks). Next, the operator should select 'Feedwater system' to find control device 'HV304' (secondary task). The operator then increases the letdown flow to 20 liter/sec and finally pushes the 'OK' button to send a signal to the control device. Similarly, in order to complete Task 2, the operator should press the 'Graphic' button, which is one of the navigation tasks (secondary tasks). Next, the operator should select 'Feedwater system' to find control device 'HV313' (secondary task). The operator then fully opens the valve 'HV313' and pushes the 'OK' button. Next, the operator should select control device 'HV315'. The operator then fully opens the valve 'HV315' and pushes the 'OK' button to send a signal to the control device. In both cases, if the operator fails to perform any subtasks, the failed subtasks must be recovered to continue performing the next subtask. The success probability of each subtask depends on human error probabilities according to the human error modes and their recovery failure probabilities. Recovery failure probabilities according to human error modes are expressed as R_i. The probability that the operator succeeds in each subtask for Tasks 1 and 2 can be expressed respectively. For example, $(1\text{-}E_0R_0)$ represents the probability that the operator succeeds in controlling the letdown flow of S/G to 20 liter/sec without operation selection omission of this subtask. Also, $1\text{-}(E_1R_1+E_5R_5+E_6R_6)$ represents the probability that the operator succeeds in increasing letdown flow to 20 liter/sec without three possible human errors, such as operation execution omission, inadequate operation, or delayed operation. Using this concept and dependency among subtasks, HEP calculation equation is generalized as follows.

$$HEP = 1 - \left\{ (1 - R_0 E_0) \times \prod \frac{1 + K(1 - \sum_{i \neq 0} R_i E_i)}{1 + K} \right\} \quad (1)$$

where

- E_i = human error probabilities for each human error mode
- R_i = recovery failure probabilities for each human error mode
- i = 1, 2SS, 2DS, 3, 4, 5, and 6 according to defined human error modes
- K = 19, 6, 1, and 0 depending on the dependency level

3. Human error probability when using soft controls in NPP Advanced MCRs

In order to measure human error probabilities, experiments with 48 students majoring in nuclear engineering were performed under a specifically developed accident scenario. Since the experiment scenario should include the representative tasks required in EOPs, various soft control human error modes and the results of the experiments should be general, the specifically developed accident scenario is based on the Standard Post Trip Action (SPTA), Steam Generator Tube Rupture (SGTR), and predominant soft control tasks, which are derived from the Loss of Coolant Accident (LOCA) and Excess Steam Demand Event (ESDE). Table I summarizes the information regarding the number of tasks, opportunities, and human errors, to obtain the human error probabilities and 5%, 95% quantiles denoted by q5, and q95 according to human error modes.

Table I: Human error probabilities according to human error modes

HEMs	Error/ opportunity	HEP, [q5, q95]
E_0	5/1274	4.10×10^{-3}, [1.8, 7.7] $\times10^{-3}$
E_1	2/4799	4.53×10^{-4}, [0.12, 1.2] $\times10^{-3}$
E_{2SS}	4/2062	2.00×10^{-3}, [0.8, 4.1] $\times10^{-3}$
E_{2DS}	10/2494	4.10×10^{-3}, [2.3, 6.5] $\times10^{-3}$
E_3	5/1458	3.50×10^{-3}, [1.6, 6.7] $\times10^{-3}$
E_4	8/648	1.2×10^{-2}, [6.7, 21] $\times10^{-3}$
E_5	6/700	8.80×10^{-3}, [4.2, 16] $\times10^{-3}$

4. HEP estimation process

Based on the suggested HEP calculation equation with the developed database including nominal HEPs in Table I, the recovery failure probabilities [7] based on human error modes, and the dependency model, the HEPs of the target tasks were estimated. In other words, once levels of dependency for each subtask was determined, input values (human error probabilities and recovery failure probabilities) from the database were inserted into the equation of HEP estimation.

- Task analysis for the target tasks should be performed to verify which errors could be occurred in the each task.
- The human error probabilities and recovery failure probabilities should be assigned respectively.
- HEPs of each task should be calculated using equation (1) considering the level of dependency among subtasks.
- Finally, PSFs for each tasks should be multiplied by overall HEP results which produces Final HEP (FHEP) by using PSF quantification approach. (It is assumed that PSF effects are negligible in this paper)

By using the detailed HEP calculation process, we can easily calculate FHEP as shown in Table II For example, after task analysis, the human error probabilities and recovery failure probabilities according to the human error modes are assigned. Then, levels of dependency are determined as moderate dependence (MD) due to proximity (control devices are in the same demarcation line and on same display pages or in same display devices.) and repeated action step (unit task includes more than two sub tasks that may be necessary to establish A, B, C, D, and E in a specific sequence.), and low dependence (LD) due to only proximity respectively. After that, overall human error probability could be calculated as 5.15×10^{-03} by using equation (1). Final HEP also estimated by multiplying PSF and overall HEP together.

Table II: HEP estimation

Each task	Human Success Probability	Dep.	PSFs
Increase the SG level using aux. feedwater	$1- E_0R_0$		1
Select the secondary system on the operator console	$1- E_{2SS}R_{2SS}$		
Select AF (Aux Feedwater)	$1- E_{2SS}R_{2SS}$		
Select AT (AF pump turbine)	$1- E_{2SS}R_{2SS}$		
Select the target valve on the screen	$1- E_{2DS}R_{2DS}$	ZD	1
Press the 'Acknowledge' button	$1- E_1R_1$		
Press 'Open' button using the input device for the safe components	$1-(E_1R_1+E_3R_3+E_6R_6)$		
Select AF pump on the screen	$1- E_{2DS}R_{2DS}$	MD	1
Press the 'Acknowledge' button	$1- E_1R_1$		
Press 'Start' button using the input device for the safe components	$1-(E_1R_1+E_3R_3+E_6R_6)$		
Select the valve controller	$1- E_{2DS}R_{2DS}$	LD	1
Maintain the SG level using auto./man. mode	$1-(E_4R_4+E_5R_5+E_6R_6)$		
Total HSP	9.95×10^{-01}		
HEP	5.15×10^{-03}	FHEP	5.15×10^{-03}

5. Conclusions

In this study, the framework of a HRA method for evaluating soft control execution human error in advanced MCRs is developed. First, the factors which HRA method in advanced MCRs should encompass are derived based on the literature review, and soft control task analysis. Based on the derived factors, execution HRA framework in advanced MCRs is developed mainly focusing on the features of soft control. Moreover, since most current HRA database deal with operation in conventional type of MCRs and are not explicitly designed to deal with digital HSI, HRA database are developed under lab scale simulation. These digital environment based HRA database do not only include nominal HEP but also recovery failure probability according to soft control human error modes. Finally, the proposed HRA method is applied to advanced MCR tasks in order to verify how well the proposed HRA framework estimated execution HEPs in advanced MCRs

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