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Analysis of Operators' Performance under Emergencies using a Training Simulator of the Nuclear Power Plant

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Abstract

It is well known that there are many factors that affect the reliability of nuclear power plants (NPPs). Among them, human reliability has been considered one of the most important factors. Thus, not only in order to quantify human reliability but also to identify main causes that can degrade human reliability, various kinds of human reliability analysis (HRA) methods have been suggested and utilized in many countries. However, to perform a HRA more appropriately, it is needed to collect plant-specific or domain-specific human performance data especially for emergencies because they can be used to generate requisite information for a HRA. In this point of view, simulator studies under emergencies may be considered important sources to obtain human performance data.

In this study, performance of operating crews to cope with emergencies of the reference NPP has been collected and analyzed. Since the number of collected records is over 90, it can be said that extracted/analyzed results are statistically meaningful. Therefore, these analysis results can serve as a basis for building database that can be used not only for HRA input data but also for multiple purposes such as improving emergency operating procedures and developing advanced HRA methods.

1. Introduction

In complex industries such as nuclear, chemical and aviation industry that have emphasized the importance of the safety, one of the main concerns is the identification of key factors that can degrade/enhance it. For example, in case of nuclear power plants (NPPs), several key factors are identified such as basic safety, redundancy/diversity, highly reliable automatic process control systems, service-tested components and qualified personnel (i.e., human errors) [1, 2]. Among them, the last factor has been considered the most decisive one because it has been revealed as a major cause in many events. In case of chemical industry, about 27% of events that occurred in the United States during the period from 1987 to 1996 are due to human errors [3]. Similar statistics can be found in nuclear industry [1, 4], in aviation industry [5] and in the other process industries including military operations [6, 7]. Therefore, to ensure the safety, extensive effort has been spent to reduce human errors.

Among them, one of major activities related to enhance the safety is develop counter measures or methods that can be used not only to quantify the possibility of human errors but also to identify the critical points affecting human errors. This approach is usually called HRA (human reliability analysis), and many researches have been performed to achieve these goals.

In general, several information requirements that are needed to perform HRA methods are summarized as follows [8].

- The description of the tasks and the actions.
- The available procedures.
- Error types and error probabilities.
- The persons or teams that have to perform the task.
- Demand of perception, cognition and action to perform a task.
- The level of experience.
- The available time for diagnosis and correct execution of a task (i.e., allowable time window for action).
- The time needed to perform the task correctly, and so on.

This means that a database that can provide useful information is indispensable to perform HRAs more correctly. Thus, to fulfill this requirement, human performance database (HPDB) is under development in KAERI (Korea Atomic Energy Research Institute).

The goal of HPDB development is the provision of reliable and domestic information that is basically needed to perform HRAs under emergencies. To achieve this goal, more than 100 records for emergency operations have been collected. The record collection period is from September 1999 to April 2001, and in total 24 different operating crews were trained in this period. Based on these records, most of required information to perform HRAs can be extracted. In addition, emergency operating procedures have been analyzed to classify the operators' tasks (what should be done by the operators) under emergencies.

The remainder of this paper is organized as follows. Firstly, background information related to the collection of emergency training records is described in Section 2. In Section 3, the overall structure and the kinds of information included in HPDB is briefly explained. After that, some interesting results obtained from data analyses are discussed in Section 4. Finally, in Section 5, conclusion related to this study is presented.

2. Collection of emergency training records

To analyze operator performance under emergencies, full scope simulator installed in the training center of the reference plant was used. This full scope simulator is a 1000MWe PWR (pressurized water reactor) type plant with conventional control panels and alarm tiles. In addition, this simulator has been used for both training of operating crews and qualifying SRO (senior reactor operator) license since sufficient V&V (validation and verification) activities has been performed so that the functional appropriateness was secured.

In the training center of the reference plant, a set of video equipment was installed in order to not only monitor what actions have been done by the operators but also review and discuss the operators' actions with instructors after each training is finished. Thus, since all kinds of operators' activities such as valve/pump operations or communicating among the crew members can be recorded in videotapes.

2.1 Collection source and participants

The retraining course for the emergency operations was chosen as data source because of two reasons. The first one is that it is possible to obtain data on the performance of somewhat skilled responses to cope with emergencies. As the second, since the operators who have worked in the reference plant have to be regularly trained (in the period of about six months), sufficient number of training records can be obtained without additional burden of the training center.

Each crew in the retraining course typically consists of four operators who have distinct duties. For example, the SROs have a responsibility of entire operations performed under emergencies while the ROs (reactor operators) and TOs (turbine operators) have a responsibility of operations related to the primary side (i.e., nuclear island) and the secondary side (i.e., turbine island), respectively. In addition, SSs (shift supervisors) checks the status of CSFs (critical safety functions) in parallel with emergency operations. In average, SROs have experienced more than ten years, and the other operators have about five years of experience in plant operations.

2.2 Record collection period and training scenarios

Record collection period is from September 1999 to July 2001. During this period, the number of training scenarios was seven, and these scenarios can cover the whole single events (i.e., design basis accidents; DBAs) and one multiple-failure of the reference plant. In addition, in total 24 different crews were retrained during this period. Table 1 shows summarized information for the collection of emergency training records.

< Table 1. Summaries for the collection of emergency training records >

Record collection period	Training scenario	The number of collected records
September 1999 ~ December 1999	SGTR (steam generator tube rupture)	5
	LOAF (loss of all feedwater) + HPSIP (high pressure safety injection pump) failure	5
January 2000 ~ July 2000	LOCA (loss of coolant accident)	18
	ESDE (excess steam dump event)	18
August 2000 ~ December 2000	SGTR	18
	LOAF	18
January 2001 ~ April 2001	LOOP (loss of offsite power)	10
	SBO (station black out)	10
	LOCA	10

Total: 112

In addition, some important plant parameters such as RCS (reactor coolant system) temperature or pressure that can be used to criteria for evaluating the operators' performance indirectly were also recorded.

3. Data extraction

As stated in Section 1, since the purpose of HPDB development is the provision of useful information for HRAs, data to be extracted from collected records is classified on the basis of required information for HRAs. Table 2 shows results of these classifications.

< Table 2. Extracted data from collected emergency training records >

Information for HRAs	Data extraction through	Data that should be extracted
Available procedures	Analysis of EOPs	● The kinds of EOPs (i.e., the LOCA procedure, the ESDE procedure, …)
Description for the tasks and the actions		● Tasks included in each procedure ● Procedural steps included in each task ● Identical steps/tasks shared among different procedures ● Generic steps/tasks included in EOPs
Demand of perception, cognition and action to perform a task		● The amount of information, the logical complexity and the amount of actions included in each procedural step (step complexity) ● The amount of information, the logical complexity and the amount of actions included in each task (task complexity)
The persons or teams that have to perform the tasks	1. Analysis of crew information 2. Trend analysis of plant parameters 2. Protocol and timeline analysis of collected emergency training records	● Crew organization ● Trends of important plant parameters ● Procedure compliance ● Crew communication patterns
The level of experience		● Experience level (i.e., years) of SRO, RO, TO and SS
The time needed to perform the task correctly		● Elapsed time to perform each task (task performance time) ● Elapsed time to perform each procedural step (step performance time) ● Elapsed time to perform diagnosis procedure (diagnosis time)
Error types and error probabilities	Protocol analysis of collected emergency training records	*Not yet considered (error types should be clarified more clearly)*
The available time window for tasks/actions	Thermal-hydraulic analysis	*Out of scope in this study*

It is noted that two kinds of information, as highlighted in a dark color in Table 2, are not considered at this time.

Based on data shown in Table 2, data that can be used for HRAs are under extraction, and Table 3 and Table 4 show a part of identical steps that are spread over procedures and averaged step performance time data for some identical steps, respectively.

< Table 3. Identical steps that are shared by different procedures >

Identical step	ESDE	LOAF	LOCA	LOOP	SBO	SGTR
1			26.0*		14.0	21.0
2	17.0		16.0	8.0	7.0	20.0
3	4.0		4.0			4.0
4	13.0	19.0	21.0	19.0		15.0
5	15.0		23.0			
…						

** This means the step number. For example, 26.0 means 26th step in the LOCA procedure.*

< Table 4. Step performance time data for some identical steps >

Identical step	Step	Step Performance Time (sec) – extracted from records	Number of data	Average (sec)	SD
1	SGTR 21.0	5.0, 7.0, 10.0	3	7.3	2.5
	LOCA 26.0	5.0, 6.0, 6.0, 10.0	4	6.8	2.2
2	ESDE 17.0	8.0, 17.0, 13.0, 13.0, 6.0	5	11.4	4.4
	LOCA 16.0	12.0, 8.0, 10.0, 7.0, 5.0, 6.0, 8.0	7	8.0	2.4
3	SGTR 4.0	8.0, 2.0, 10.0, 26.0, 7.0, 13.0, 14.0, 2.0, 5.0, 4.0, 36.0, 19.0, 8.0	13	11.8	10.0
	ESDE 4.0	18.0, 7.0, 11.0, 7.0, 11.0, 8.0, 8.0	7	10.0	3.9
	LOCA 4.0	14.0, 3.0, 9.0, 12.0, 25.0, 14.0, 10.0, 9.0, 15.0, 9.0	10	12.0	5.8
4	SGTR 15.0	44.0, 31.0, 53.0, 24.0, 34.0, 57.0, 48.0	7	41.6	12.2
	ESDE 13.0	22.0, 43.0, 7.0, 51.0, 91.0, 46.0, 41.0, 61.0	8	45.3	25.1
5	ESDE 15.0	8.0, 22.0, 77.0, 17.0, 14.0	5	27.6	28.1
	LOCA 23.0	66.0, 11.0, 48.0, 34.0, 46.0, 22.0	6	37.8	19.7

In these ways, useful data shown in Table 2 have been extracted from emergency training records, except for records collected during the last period (i.e., from January 2001 to April 2001) that are under protocol and timeline analyses.

4. Empirical findings

Two interesting features are observed during data analysis. They are: 1) very few operators use procedures in an adherent manner and 2) some operators feel difficulty during the diagnosis. In this section, these findings are briefly discussed.

4.1 Procedure compliance

As shown in Table 2, data related to "procedure compliance" were analyzed using protocol analysis from collected records. In this analysis, the degree of procedure compliance of the operators was classified into three classes, as shown below.

- Class 1: the operators strictly performed all actions and all steps included in procedures (i.e., step-by-step manner).
- Class 2: the operators selectively performed actions included in each step or they did not consider the sequence of steps (i.e., in the sequence such as step 1 → step 3 → step 7 → step 2, …).
- Class 3: the operators entirely ignore procedures. That is, they neither perform actions included in each step nor follow the sequence of steps.

Based on these classifications, collected records are analyzed and the results are 1) only few SROs (about 10% of analyzed records) strictly use procedures (Class 1), and 2) six SROs entirely ignore procedures (Class 3).

From these results, it can be thought that the operators regard procedures as "a guide for selecting important actions or steps to effectively cope with on-going events." Although this tendency is far from what we generally expected (i.e., the operators will strictly follow procedures), this one is not new finding because similar tendencies are already reported [9]. In the viewpoint of HRAs, this finding is important because the error (such as omission errors within steps or step omission errors) is defined by "the deviation form predefined sequences of operating procedures [10,11]." However, if the operators do not regard procedures as "written instructions that are absolutely obedient" then the definition of the error has to be reconsidered. In other words, it is necessary to change that the criterion to distinguish "a well-designed procedure," since the operators may want to know somewhat higher information such as "what should be done at this time?" or "does this step have to be performed at this time?" rather than crude one such as "open/close XXX valves."

4.2 The complexity of the diagnosis procedure

The second one is observed during protocol analysis of collected records. That is, it was observed that some operators feel difficulty during the performance of the diagnosis procedure provided in the form of flowchart, because the diagnosis procedure is designed so that the number of possible events is not reduced until the performance of it is completed. For example, when the LOCA occurred, the diagnosis procedure enforce on the operators so that they have to concentrate on the occurrence of other events (such as the ESDE or the SGTR) in order to identify multiple-failures, even if decisive symptoms (such as containment radiation high alarms) that can ensure the occurrence of the LOCA are generated. This means that the operators should check less important or meaningless symptoms until the performance of the diagnosis procedure is finished. Thus, although this approach seems good to identify multiple-failures, the increase of operators' workload may be inevitable. In addition, in the viewpoint of HRAs, the complexity of the diagnosis procedure should be considered, if the diagnosis procedure is in use, since the increase of operators' workload means the increase of error probability.

5. Conclusion

Up to now, in order to develop HPDB that can provide basic information for HRAs, a study on operators' performance under emergencies was explained, based on the full scope simulator of the reference plant. To accomplish this goal, over than 100 emergency training records were collected and analyzed to extract useful data. As the results, two important insights that have to be carefully considered to perform HRAs are observed. Extracted data will serve as a basis for building HPDB, and both HPDB and insights will contribute to enhancement of the quality of HRAs' results. In addition, data included in HPDB can be also used to achieve multiple purposes such as improving emergency operating procedures and developing advanced HRA methods.

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