A FRAMEWORK OF HRA DATA COLLECTION IN NUCLEAR POWER PLANTS

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A fundamental issue in human reliability analysis (HRA) is a lack of empirical data in terms of either human error probability (HEP) or more lower level information that can be used to estimate HEPs. As a contribution to resolve this problem, the Korea Atomic Energy Research Institute (KAERI) is carrying out research to develop a data collection framework to build an HRA database that can be used as a technical basis not only to generate HEPs but also to understand the interrelation between performance shaping factors and human error. This paper introduces the framework of a simulator data collection for HRA and the preliminary results of HEPs generated using a set of simulator data obtained from the training simulators of nuclear power plants in Korea.

I. INTRODUCTION

According to many PSAs (probabilistic safety assessments) and operational evidence in the field of NPPs (nuclear power plants), human error was a major contributor to the safety of an NPP. In order to exactly assess and properly enhance the safety of an NPP, anticipated human errors should be identified systematically and evaluated with a sound technical basis. However, estimating HEPs (human error probabilities) in a PSA has been done mostly based on the type of generic data and/or expert judgment, most of which were generated from the early 1970s until the late 1980s. HEPs in the THERP Handbook, whose draft version was developed in the middle of the 1960s, are still popularly used or referred to for an HRA no matter which HRA method is applied. This is not because the HEPs in THERP are perfect, but because no one can replace them with a sound technical basis in the nuclear industry. This means that a fundamental issue of an HRA is still a lack of empirical data in terms of either an HEP or more lower level information that can be used to estimate HEPs or address the effects of the performance shaping factors (PSFs) on an HEP (Refs. 1, 2).

In this regard, the collection of a sufficient amount of information that is helpful for understanding the nature of human error under a given situation (especially an accident condition) is very important for a reliable estimation of HEPs. Unfortunately, the collection of necessary information under accident conditions is not easy because the frequency of an accident in a real environment is extremely low. One of the promising solutions to unravel this problem is to use training simulators because the variation of human performance, which plays an important role in understanding the nature of human error, can be observed under diverse situations that are difficult to experience from a real environment. For this reason, a huge amount of effort has been spent over several decades all over the world (Refs. 3). In addition, several data collection guidelines that describe what kinds of information should be collected from simulators were suggested by many researchers (Refs. 4).

Nevertheless, one of the frequently raised issues is still the lack of available technical data that support more reliable as well as a clear understanding regarding human performance variations. Therefore, it is evident that, before collecting HRA data, we need an appropriate framework of HRA data collection with guidelines that specifies what type of and how information can be gathered from simulators. This paper briefly introduces a framework of simulator data collection and analysis to support HRAs of NPPs in Korea.

II. PREVIOUS STUDIES

Many organizations have tried to collect HRA data from diverse sources, such as event reports (e.g., maintenance reports, accident/event investigation reports, and near miss reports), training simulators, laboratory experiments, expert judgments, and interviews with plant personnel (Refs. 5, 6). Of them, for many decades, operating experience and simulator studies have been used as major sources for collecting HRA data (Refs. 1, 7). TABLE 1 exemplifies some of the HRA databases with their associated sources of data. However, the HRA data collection from event reports seems to be difficult because of a scarcity of data.

TABLE 1. Typical HRA Databases (Refs. 8)

Data source	Database	Reference
Event report	HPED (Human Performance Event Database)	Trager (1997)
	CAHR (Connectionism Assessment of Human Reliability)	Sträter (2000)
	HERA (Human Event Repository and Analysis)	Hallbert et al. (2006)
Simulator	HCR/ORE (Human Cognitive Reliability/ Operator Reliability Experiments)	Moieni et al. (1994)
	OPERA (Operator Performance and Reliability Analysis)	Park and Jung (2007)
	SACADA (Scenario Authoring, Characterization, and Debriefing Application)	Chang et al. (2013)
Multiple sources	NUCLARR (Nuclear Computerized Library for Assessing Reactor Reliability)	Gertman et al. (1988), Reece et al. (1994)
	CORE (Computerized Operator Reliability and Error)	Kirwan et al. (1997)

A simulator is the only feasible way to observe human behavior during an emergency in an NPP. The distinctive advantage of a simulator study is that it has the capability to provide evidence on the variability of human performance under accident conditions, which will be helpful in understanding the nature of human error potential (Refs. 9). In addition, the result of comparisons between actual events and simulated events have revealed that the use of data obtained from simulators is positive because "information particularly needed for PSA (e.g., response times or deviations) seems to be very similar during simulations and in real situations, although it is difficult to generalize these comparison results to all the other situations (Refs. 10)." Park, Kim and Jung (Refs. 11) also showed empirical results demonstrating that the response times observed from a simulated condition are directly comparable with those from actual stressful conditions. Consequently, to some extent, it can be said that full-scope simulators are the most promising source of HRA data.

Although a simulator is the only means of obtaining HRA data, and several simulator studies have been undertaken worldwide, there are a few large obstacles in using the available simulator data for an HRA. A common trait of the existing HRA databases is that they are primarily intended for internal use within the organization that is collecting the data. For example, a set of data produced from a simulator study for a specific HRA application (or method) is not suitable for other HRA applications (or methods) because of discrepancies in the data items and/or levels of detail. In addition, most of the existing HRA databases do not fully provide their technical bases, such as analysis procedures, raw or intermediate datasets, to generate the final HRA data such as HEPs. Thus, it is hard for HRA analysts to directly use the existing HRA database for their HRA work. To overcome the limitation of previous studies, a new approach that is independent of an HRA method would be needed to build a more powerful HRA database.

III. A FRAMEWORK OF SIMULATOR DATA COLLECTION FOR HRA

In order to generate HRA data for supporting the HRAs of Korean NPPs, KAERI has developed a framework of simulator data collection called HuREX (Human Reliability data Extraction) (Refs. 3, 8, 12). HuREX is a framework of data collection from simulators or event reports to generate HRA data. It provides the process, methods, and taxonomy to answer the questions of what information should be gathered, how to collect and analyze them to produce HRA data that can be used directly to perform an HRA, or to develop a new HRA method as a technical basis. Using HuREX, we are developing a HRA database that will be used to ultimately produce HEPs of a set of generic emergency tasks to support HRAs of NPPs in Korea.

Many previous simulator studies for HRAs were performed to identify error types, error occurrence mechanism, and relevant PSFs. Such information helps the HRA analysts understand the performance of the crews of the PSA reference plant. Therefore, we can say that the most important output of the previous simulator studies are insight on the human performance and errors during emergencies. However, such insight may be considered as supplementary information rather than direct HRA data such as generic HEPs. Considering the resources needed for a simulator study, it is not easy to recognize the necessity of the study simply for obtaining such kind of supplementary information.

Fig. 1 shows an overview of HuREX. The process of HuREX can be divided into two parts: data collection and data analysis. The data collection part comprises a method, process, and guidelines that are needed to identify human errors and to gather all relevant information regarding the tasks and context from simulator records or event reports. A simplified cognitive model and the taxonomies of the tasks and errors are also supplied for the data collection. All information gathered through the data collection process is stored in a HRA database called OPERA (Operator Performance and Reliability Analysis). the second part, a data analysis, provides the methods for analyzing the collected data statistically to generate a final set of HRA data that include the performance times and HEPs of generic tasks during emergency procedures.

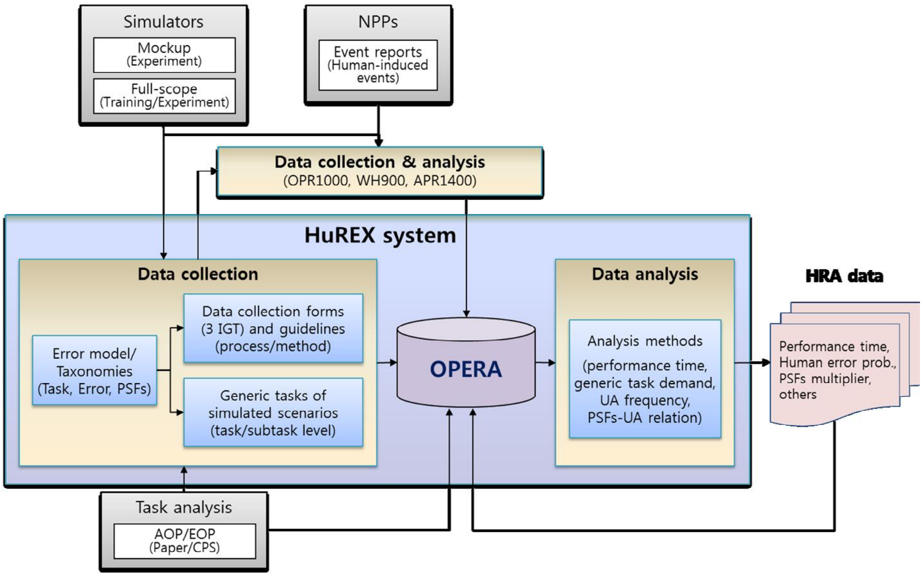

Fig. 1. A framework of HRA data collection - HuREX

III.A. Taxonomies of task, error, and PSFs

To develop HuREX, we defined a human model and a set of taxonomies for the simulator data collection and analysis. As a human model for an HRA, a couple of simplified cognitive models originated from the Rasmussen's decision ladder model have proposed by many previous studies (Refs. 13, 14). We adapted the simplified cognitive model used in the ATHEANA (Refs. 14) for HuREX, which encompass four cognitive activities: (1) detection/observation, (2) situation assessment, (3) response planning, and (4) execution. Taxonomies on the generic tasks and errors are determined based on a comprehensive task analysis of the abnormal and emergency procedures of the reference plants in Korea. We defined the taxonomy of tasks that are compatible with the four cognitive activities. Table 2 shows the generic type of emergency tasks that are needed for the data collection and analysis.

Regarding the error taxonomy, we followed a typical classification of the error mode, errors of omission (EOO), and errors of commission (EOC). The EOC was classified in detail based on observations and insights obtained from a pilot study as follows: (1) wrong object (i.e., selecting an incorrect control device), (2) wrong direction (e.g., adjusting a component to an incorrect status, such as close a certain valve instead of open it), (3) wrong quantity (e.g., setting up an incorrect input to a control device), (4) inadequate timing (e.g. manipulating too early/late), and (5) unauthorized manipulation or decision making.

TABLE 2. Cognitive activities and generic task type (Refs. 8)

Cognitive activity		Generic task type
Detection/observation	Information gathering and reporting - checking discrete state	Verifying alarm occurrence
		Verifying state of indicator
		Synthetically verifying information
	Information gathering and reporting - measuring parameter	Reading simple value
		Comparing parameter
		Comparing in graph constraint
		Comparing for abnormality
		Evaluating trend
Situation assessment	Situation interpreting without explicit guide of document	Diagnosing
		Identifying overall status
		Predicting

Response planning	Response planning and instruction	Entering step in procedure
		Transferring procedure
		Transferring step in procedure
		Directing information gathering
		Directing manipulation
		Directing notification/request
Execution	Manipulation	Manipulating simple (discrete) control
		Manipulating simple (continuous) control
		Manipulating dynamically
	Notifying/requesting to the outside of a MCR	Notifying/requesting to the outside of a MCR

III.B. Process of the data collection and analysis

As shown in Fig.2, the process of the data collection and analysis can be summarized as follows:

1) Preparation of a study including experimental design of the simulation,
2) Simulation and collection of records/logs,
3) Task analysis on the procedures that operators need to respond to the simulated scenarios,
4) Operators' response analysis to understand what, when, and how the crew responds under simulated situations,
5) Unsafe act (UA) analysis to identify erroneous behaviors and collect all related information,
6) Finally, a statistical data analysis to generate HRA data such as HEPs of the generic tasks, performance times of each procedural task, and weighting factors of each PSF.

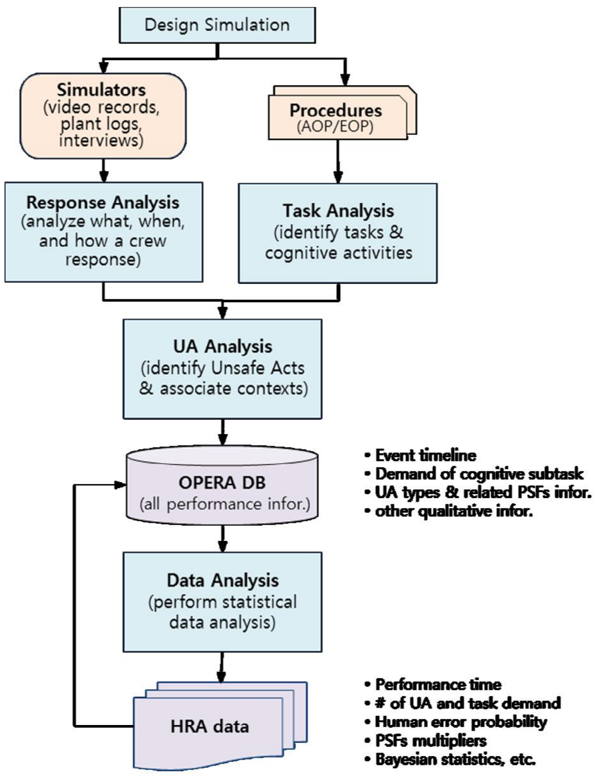

Fig. 2. Process of Simulator Data Collection and Analysis for HRA

To support the simulator data collection, we designed information gathering templates (IGTs), which are a kind of worksheet supporting the data collection systematically. IGTs provide an identification process for any erroneous behavior, known as an UA, and the data items to be collected for context information affecting human reliability.

IGTs consist of an overview, response, and UA IGTs. Using an overview IGT, the following information can be obtained: (1) overall information about the plant and simulations, such as the plant type or simulation completion time; (2) operator information such as age, work experience, and operational licenses; (3) training experience; (4) environmental issues; (5) observed procedural path; (6) scenario information including initiating events and failed systems or components; and (7) crew characteristics and dynamics, such as the leadership styles of shift supervisors and the cooperative attitude of board operators. How successfully the operators have performed the given tasks are evaluated and recorded in the response IGT with the following information: (1) task type, (2) typical performer of the task, (3) component type, (4) component index, and (5) system type. The UA IGT provides a data field for the variables pertaining to (1) an overall description of the identified UA and its causality, (2) related plant/system issues, (3) time pressure, (4) task familiarity, (5) task complexity, (6) procedure clarity and description quality, (7) interface quality, (8) communication quality, and (9) recovery information.

The data input process in the IGTs starts with the insertion of the basic scenario and environmental information. The audio-visual record of the given simulation is analyzed to identify the procedural path used by the operator based on the EOPs. If a communication log of the audio-visual record exists, the log can also be employed during the entire input process for analyzing the operator's communication contents. From the procedural path, the tasks that succeeded or failed are determined based on the UA identification process. The task characteristics of all successful and failed tasks are then analyzed and inputted in the response IGT and the related context information with the identified UAs is recorded in the UA IGT. Finally, crew information regarding the operators' performances overall are added to the overview IGT.

IV. A SIMULATOR STUDY FOR HRA AND A PRELIMINALY HRA DATA

In order to investigate the applicability of HuREX, simulator records collected from the full-scope training simulators of Korean NPPs were analyzed using HuREX. Table 3 summarizes the inventory of simulator records gathered by KAERI.

TABLE 3. Summary of simulator records analyzed by KAERI (Refs. 8)

Plant type	Event	Scenario[1]	Supplementary information	Remark
OPR1000	Abnormal	Diverse abnormal scenarios (112)	• Communication logs • Process parameter logs	• Collected in 2007
		Diverse abnormal scenarios (304)	• Communication logs • Process parameter logs • Event logs • Action logs	• Collected from 2008 to 2011
Westinghouse 3-loop PWR	DBA	• ISLOCA (10)[2] • Multiple events (8)[3]	• Communication logs • Process parameter logs • Event logs • Action logs	• Collected from 2009 to 2010

[1]Each number in parentheses denotes the amount of collected simulator records.
[2]ISLOCA means Interfacing System LOCA.
[3]Multiple events imply a MSLB (Main Steam Line Break) followed by an SGTR (Steam Generator Tube Rupture).

Table 4 shows the preliminary results of HEPs derived from the simulator data in Table 3. Although these HEPs were estimated based on a sufficient number of task opportunities (in total 8,584), additional data analyses are indispensable because several task types were not observed from the simulation records. For example, as can be seen from Table 4, there is no UA opportunity for the tasks of 'Identifying the overall status' and 'Predicting' from the simulation records. In addition, the preliminary HEPs are calculated through a Bayesian update with the non-informative prior of the Beta distribution.

TABLE 4. Preliminary results of HEPs of the generic task types (Refs. 8)

Cognitive activity	Task type	Opportunity	UA (EOO)	UA (EOC)	HEP (EOO)	HEP (EOC)
Information gathering and reporting – checking discrete state	Total	2223	2	0*	2.500E-03	9.001E-04
	Verifying alarm occurrence	266	0*	0*	7.301E-03	7.301E-03
	Verifying state of indicator	1852	2	0*	3.000E-03	1.101E-03
	Synthetically verifying information	105	0*	0*	1.850E-02	1.850E-02
Information gathering	Total	1248	0*	12	1.600E-03	1.510E-02

and reporting – measuring parameter	Comparing for abnormality	372	0*	0*	5.201E-03	5.201E-03
	Comparing parameter	367	0*	5	5.301E-03	2.680E-02
	Comparing in graph constraint	20	0*	0*	9.061E-02	9.061E-02
	Evaluating trend	370	0*	6	5.301E-03	3.030E-02
	Reading simple value	119	0*	1	1.630E-02	3.290E-02
Situation interpreting without explicit guide of document	Total	13	0*	6	1.351E-01	6.797E-01
	Diagnosing	13	0*	6	1.351E-01	6.797E-01
	Identifying overall status	0**	0**	0**	-	-
	Predicting	0**	0**	0**	-	-
Response planning and instruction	Total	4295	72	21	2.030E-02	6.901E-03
	Entering step in procedure	627	3	-	1.120E-02	-
	Directing information gathering	2692	8	4	5.101E-03	3.100E-03
	Directing manipulation	622	49	15	9.911E-02	3.620E-02
	Directing notification/request	163	3	1	4.330E-02	2.400E-02
	Transferring procedure	116	1	1	3.380E-02	3.380E-02
	Transferring step in procedure	75	8	0*	1.762E-01	2.530E-02
Execution	Total	646	12	0*	2.920E-02	3.000E-03
	Manipulating dynamically	125	0*	0*	1.550E-02	1.550E-02
	Manipulating simple (discrete) control	507	12	0*	3.720E-02	3.800E-03
	Manipulating simple (continuous) control	14	0*	0*	1.261E-01	1.261E-01
	Notifying/requesting to the outside of the MCR	159	1	1	2.460E-02	2.460E-02
Other	Unauthorized or unguided manipulation	-	-	11	-	-

* Since the corresponding UA was not observed from simulation records, its preliminary HEP was estimated by the 95 percentile estimated of the Bayesian update with a non-informative prior for Beta distribution.
**The corresponding task type was not observed from simulation records.
***EOC was not considered for the task type of 'Entering step in procedure.'

V. CONCLUSIONS

In order to resolve the lack of empirical data for an HRA, we proposed a framework of HuREX that can be used to collect raw data from simulators and generate the HEPs of generic emergency tasks using the collected data. This framework supplies a set of methods and processes with guidelines to support simulator data collection and analysis for HRA purposes. In addition, the validity of the proposed framework is investigated by estimating HEPs from 85 simulation records that were gathered from the full-scope simulators of a Westinghouse 3-loop PWR (i.e., 18 simulation records) and OPR1000 (i.e., 67 simulation records). As a result, the proposed framework seems to be feasible because in total 37 preliminary HEPs are successfully quantified for 21 generic task types. Because all UA types considered in Table 2 are compatible with human error types that are embodied in other HRA methods or databases, it is strongly expected that the proposed framework would be a good starting point to enhance the quality of HRA results by providing a technical basis for extracting HRA data from the simulation records.

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