A PROCESS FOR IDENTIFYING UNSAFE ACT FOR HEP QUANTIFICATION WITH SIMULATED OFF-NORMAL TRAINING RECORDS

Sun Yeong Choi[1], Yochan Kim, JinKyun Park, Seunghwan Kim, and Wondea Jung

[1] *Daedeok-daero, 989-111,Yuseong-gu, Daejeon, 305-353, sychoi@kaeri.re.kr*

It is a well-known fact that human error is one of the most critical factors affecting the safety of complicated systems such as NPPs (Nuclear Power Plants). Consequently, a huge amount of effort has been spent to reduce the possibility of human error, and one of the most disseminated approaches is to conduct an HRA (Human Reliability Analysis) because it allows us to assess the risk of a system attributable to human error as well as to come up with practical ways to reduce the vulnerability of a system due to human error. Thus, HRA data are an important prerequisite for improving the HRA quality. Research to develop a HRA data handbook with simulator training records has been performed by KAERI. To this end a standardized guideline to specify how to gather HRA data from simulator training records was developed and three kinds of IGT (Information Gathering Template) specifying what kinds of measures should be observed during the simulations were designed. A UA (Unsafe Act) occurrence path model and interactions between crew members to suggest a practical UA type classification scheme under a procedure driven operation was identified. Based on the data collection framework, data collection to analyze a UA with simulator training data about various scenarios that require an AOP (Abnormal Operation Procedure) or EOP (Emergency Operation Procedure) operations for HEP (Human Error Probability) calculation are performed. In this paper, a process to identify UA during an AOP/EOP operation with simulator training records was described and to select UA through a case study under ISLOCA (Interfacing System Loss of Coolant Accident) was expressed.

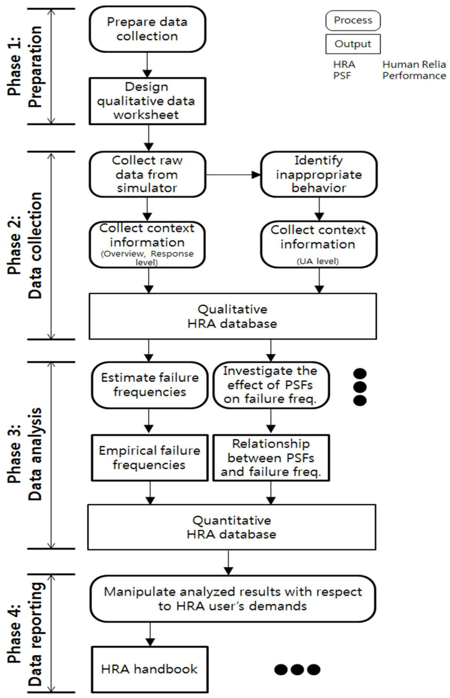
I. INTRODUCTION

It is a well-known fact that human error is one of the most critical factors affecting the safety of complicated systems such as NPPs (Nuclear Power Plants). Consequently, a huge amount of effort has been spent to reduce the possibility of human error, and one of the most disseminated approaches is to conduct an HRA (Human Reliability Analysis) because it allows us to assess the risk of a system attributable to human error as well as to come up with practical ways to reduce the vulnerability of a system due to human error. Thus, HRA data are an important prerequisite for improving the HRA quality.

Data sources for HRA data collection generally fall into three main categories, event data from operating experience, simulator data from simulator training, and expert judgment including interviews with operating personnel [1-2]. The operating experience data would be best to understand operator behaviors if the incidents/events involve operators. However it is not easy to collect HRA data from operating experience because real events including human performance do not occur frequently. Expert judgment for HRA data collection depends on subjective opinion and thus may have a lack of objectivity. Therefore, a lot of efforts to collect HRA data using a simulator of NPP have progressed. [3-5].

For this reason, KAERI (Korea Atomic Energy Research Institute) has been performing research to develop a HRA data handbook with simulator training records. Fig.1 shows a process for HRA data collection/analysis and key related items. To this end we developed a standardized guideline to specify how to gather HRA data from simulator training records, and created IGT (Information Gathering Template) specifying what kinds of measures should be observed during the simulations [6]. Based on the data collection framework, we selected a UA (Unsafe Act) including human error during an AOP (Abnormal Operation Procedure) or EOP (Emergency Operation Procedure) operation with simulator training records, which is an inappropriate human behavior that has a potential for leading the safety of NPPs toward a negative direction [7]. We also identified a UA occurrence path model and interactions between crew members to suggest a practical UA type classification scheme under a procedure driven operation [8]. We are performing data collection to analyze UA with simulator training data about various scenarios which require AOP or EOP operations for HEP (Human Error Probability) calculation.

The purpose of this paper is to present a process to identify UA during an AOP/EOP operation with simulator training records we suggested, and to describe a case study to select UA simulator training data. This paper mainly focuses on Phase 2 (data collection) in Fig. 1.



Phase	Representative technical challenges
1st: Simulation preparation	• What kinds of simulation scenarios are necessary? • What kinds of data items (e.g., the inventory of key process parameters to be stored in a process parameter log) should be collected? • How to create data collection forms needed for storing necessary data contents?
2nd: Data collection	• What are practical measurements and/or methods to secure necessary data contents?
3rd: Data analysis	• What kinds of human operators' responses should be marked as erroneous behaviors? • How are we able to distinguish (or classify) erroneous behaviors? • How are we able to estimate the likelihood of erroneous behaviors? (e.g., HEPs) • How are we able to distinguish the effect of task contexts on the performance of human operators? (e.g., providing the catalog of dominant PSFs and their multipliers indicating the effect of their influence on the likelihood of erroneous behaviors)
4th: Data reporting	• What kinds of information should be provided to HRA practitioners? (e.g., How are we able to customize HRA data to support HRA practitioners?)

Fig. 1. Process for HRA Data Collection/Analysis & Key Items

II. UA DEFINITION

This section describes how to identify UA based on a UA definition.

II.A. Screening UA Candidates

A UA is defined as an inappropriate human behavior that has a potential for leading the safety of NPPs toward a negative direction in this research. From this concern, all kinds of deviations from the following operating procedures (e.g., AOPs and EOPs) can be regarded as UA candidates, because these operating procedures contain many tasks to be done by operating personnel, which are very important to reduce the consequences of accident sequences.

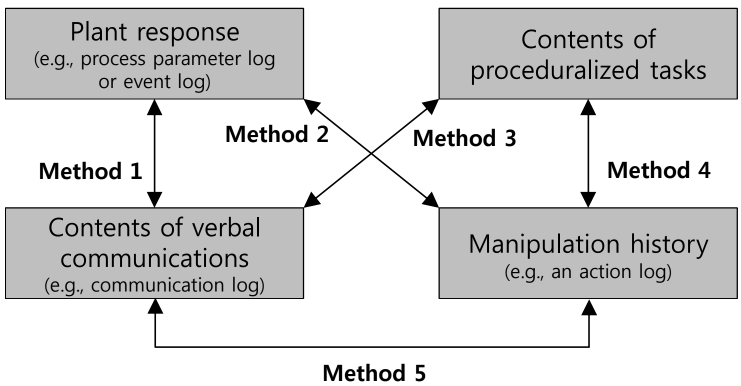


Fig. 2. Criteria for identifying UA candidates from simulation records

Fig. 2 illustrates five methods to distinguish UA candidates from simulation records based on supplementary information (i.e., various kinds of logs recordable from a full-scope simulator). After the supplementary information is secured, the behaviors of MCR operators can be scrutinized in detail along with the progress of each simulation record. For example, if we are able to compare a process parameter log with a communication log, it is possible to clarify whether or not a BO (Board Operator) reports what an SS (Shift Supervisor) wants to know with a correct reading (i.e., Method 1). Similarly, a comparison between a communication log and an action log can be used to manifest whether or not a BO manipulated a wrong device (i.e., Method 5).

II.B. Determining UA

As mentioned above, a UA is defined as an inappropriate human behavior that has a potential for leading the safety of NPPs toward a negative direction in this research. After UA candidates are selected based on Fig. 2, UAs leading to negative consequences are identified among the UA candidates. The consequences of UAs and detailed examples are summarized in Table 1.

Table 1. UA Consequence and Related Example

Consequence by UA	Detailed example
Inappropriate component manipulation	• A wrong component is operated. • A targeted component is not operated when its operational condition was satisfied. • A targeted component is operated when its operational condition was not satisfied.
Inappropriate procedure transfer	• A wrong procedure is performed (i.e., transferred to a wrong procedure). • A procedure transfer is omitted.
Inappropriate notification/request	• An important announcement or request to other department and/or organizations is omitted (e.g., site area emergency and/or alert based on a technical specification did not properly declared) • A wrong announcement is proclaimed.

III. UA Type

In this section, we provide a UA classification to exclude a subjective judgment by considering crew interactions under a procedure driven operation and simulator training environment. As mentioned above, a UA is defined as an inappropriate human behavior that has the potential for leading the safety of NPPs toward a negative direction. Basically, AOPs and EOPs have been developed to recover or restore an off-normal status of a plant to a safety condition. In this paper, we classify a procedure driven operation as four steps considering the crew interaction such as an instruction and response to categorize a UA type. Namely, AOP/EOP operations by crew interaction in an MCR consist of four stages, as shown in Fig. 3.

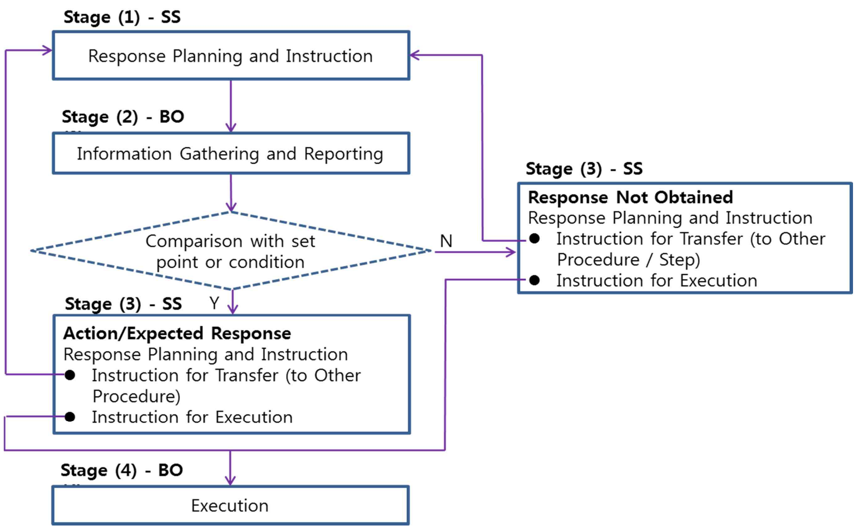


Fig. 3. Process of Procedure Driven Operation

- Stage (1): Response planning and instruction stage by SS for information gathering such as process parameter or component status
- Stage (2): Information gathering and reporting stage by BO based on SS's instruction for information gathering
- Stage (3): Response planning and instruction stage for execution or procedure (or step) transfer by SS after a comparison observed value with a set point
- Stage (4): Execution stage by BO based on instruction for execution by SS

In Fig. 3, SS compared an observed value with a set point specified in a procedure when an operation process is moved from stage (2) into stage (3). If the comparison is satisfied, an SS instructs descriptions in the 'Y' direction (the part of 'action/expected response' in the case of an EOP). If not, an SS should follow instructions in the 'N' direction (the part of 'response not obtained' in the case of an EOP). In stage (3), for the case of 'instruction for a transfer' in both cases of the 'Y' direction and the 'N' direction, the procedure driven operation process moves into stage (1), while stage (4) is for the 'instruction for execution' of stage (3). The execution includes a component manipulation and a notification. Therefore, the consequences by UAs are defined as an improper execution including extraneous acts and improper transfers against the procedure. Therefore, we classify the type of UAs into 'Response planning and instruction UA', 'Information gathering and reporting UA', and 'Execution UA' by considering the initiation time and initiator of the UA. According to the classification we suggested, UAs occurring during the 'Response planning and instruction stage for information gathering' and 'Response planning and instruction stage for execution/transfer' all belong to the 'Response planning and instruction UA', not only because they are initiated at the instruction stage by the SS, but also because the details of UA sub-categorization for both stages are identical. Table 2 shows the UA type classification scheme and consequences.

Table 2. UA Type Classification

Type of UA	Type of UA - Details	Consequence
Response planning and instruction UA	• Response planning and instruction UA-EOO • Response planning and instruction UA-EOC	Inappropriate transfer Inappropriate execution
Information gathering and reporting UA	• Information gathering and reporting UA-EOO • Information gathering and reporting UA-EOC	Inappropriate transfer Inappropriate execution
Execution UA	• Execution UA-Manipulation-EOO • Execution UA-Manipulation-Wrong object • Execution UA-Manipulation-Wrong direction/quantity • Execution UA-Manipulation-Unauthorized • Execution UA-Notification-EOO • Execution UA-Notification-EOC	Inappropriate execution

IV. CASE STUDY

In this section, we describe examples for screening UA candidates and determining UA under an ISLOCA scenario. For the case study, we collected data on simulated emergency operation training for the two kinds of scenarios at a Westinghouse 3-loop PWR (Pressurized Water Reactor).

IV.A. Examples of UA

The first example is a UA related to an inappropriate component manipulation, in particular, an EOO (Error of Omission). Fig. 4 shows the related procedure instruction. An SS instructed the 'Action/expected response' of Step 1.2 to check the RCP trip parameter (pressure) and BO responded that the RCP pressure was 104. Because the containment was adverse due to radiation at that time, the pressure was satisfied with the set point. Therefore, the SS should instruct the 'Action/expected response' of Step 1.3. However, he did not direct the 'Action/expected response' to instruct the 'RNO' of Step 1.2 to cause an inappropriate component manipulation. That is, all RCPs that should have stopped continued on. In this case, we screened this operator behavior as a UA candidate by Method 3 in Fig. 2 because the SS omitted the reasonable path and instructed a different path. We also select this UA candidate as a UA (Response planning and instruction UA-EOO) because the consequence resulted in an inappropriate component manipulation.

ACTION/EXPECTED RESPONSE	RESPONSE NOT OBTAINED (RNO)
1. Check If RCPs Should Be Stopped:	
1. SI pumps - AT LEAST ONE RUNNING 1. Charging/SI	1. Go to Step 2.
2. RCP Pressure - LESS THAN 96 kg/cm^2 (105 kg/cm^2 FOR ADVERSE CONTAINMENT)	2. Go to step 2.
3. Stop all RCPs	

RCP: Reactor Coolant Pump
SI: Safety Injection

Fig. 4. Example of Procedure Related to UA Leading to Inappropriate Component Manipulation

The next example is about a UA related to an inappropriate procedure transfer. Fig. 5 shows the related procedure instruction. While performing the 'Action/expected response' of Step 24.0, an SS instructed Step 25.0 even though an RO reported that the containment radiation was abnormal. He should transfer to E-1 based on the instruction of 'RNO' of Step 24.0. Therefore, this behavior was regarded a UA candidate by Method 3 in Fig. 2, and a UA due to its consequence resulting in an inappropriate procedure transfer.

ACTION/EXPECTED RESPONSE	RESPONSE NOT OBTAINED (RNO)
24. Check If RCS is Intact • Containment radiation - NORMAL • Containment pressure - NORMAL • Containment recirculation sump level - NORMAL	Go to E-1, LOSS OF REACTOR OR SECONDARY COOLSNT, Step 1.

RCS: Reactor Coolant System

Fig. 5. Example of Procedure Related to UA Leading to Inappropriate Procedure Transfer

IV.B. Examples of UA Candidate but Not UA

In Fig. 6, an SS instructed the 'Action/expected response' of Step 15.3 and Step 16.0 after the 'Action/expected response' of Step 15.2; however, the SS should instruct 'Go to Step 16' based on the 'RNO' of Step 15.2 because the RCS pressure did not meet the set point of Step 15.2. Four of ten crews involved in the case study showed similar behavior, from Step 15.2 to Step 15.3, even though the RCS pressures were more than the set point. Thus, we regarded the behavior as an UA candidate; however, did not classify the UA candidate into an UA. The reason is that performing the task of 'checking the flow of RHR pumps' does not cause any consequence of the UA criteria in Table 1. In addition, the RHR pumps were idling at that time.

ACTION/EXPECTED RESPONSE	RESPONSE NOT OBTAINED (RNO)
15. Verify SI Flow:	
1. Charging/SI pump flow indicators – CHECK FOR FLOW	1. Manually start pumps and align valves.
2. RCS pressure – LESS THAN 15 kg/cm^2 (25 kg/cm^2 FOR ADVERSE CONTAINMENT)	2. Go to step 16.
3. RHR pump flow indicators – CHECK FOR FLOW	3. Manually start pumps and align valves.

SI: Safety Injection
RCS: Reactor Coolant System
RHR: Residual Heat Removal

Fig. 6. Example UA Candidate but Not UA (1)

The next example describes an UA candidate due to omission. Some SSs did not perform Step 17.0 and 18.0 during E-0 in Fig. 7. That is, they performed Step 16.0 and then 19.0. Even though it is an UA candidate, we do not regard it as an UA since the valves related to Step 17.0 and 18.0 are interlocked with AFAS (Auxiliary Feedwater Actuation Signal) and SIAS (Safety Injection Actuation Signal) separately and those signals were actuated at the early stage of the simulation. That is, the valves of Steps 17 and 18 were opened by the two kinds of signals.

ACTION/EXPECTED RESPONSE	RESPONSE NOT OBTAINED (RNO)
17. Verify AFW Valve Alignment – PROPER EMERGENCY ALIGNMNET 1. AFW flow control valve: OPEN 2. AFW pump supply valve from CST: OPEN	17. Manually align valve as necessary
18. Verify SI Valve Alignment – PROPER EMERGENCY ALIGNMNET 1. BIT isolation valve: OPEN 2. Accumulator discharge isolation valve: OPEN	18. Manually align valve as necessary

AFW: Auxiliary Feed Water
CST: Condensate Storage Tank
BIT: Boron Injection Tank
SI: Safety Injection

Fig. 7. Example UA Candidate but Not UA (2)

IV.C. Results of Case Study

The total number of UA candidates and UAs for ten cases of simulator training under an ISLOCA is 119 and 28, respectably. That is, the portion of UAs among UA candidates is 24%. Table 3 summarizes the UA types and consequences. The average number of UA occurrences per team for the ISLOCA is 2.2. An UA for response planning and instruction by SS dominates the UA results. The portion of response planning and instruction UAs is 79%. Two kinds of execution UAs are unauthorized manipulations. That is a BO stopped two RHR pumps during the simulation; however, a set point for the pump stop was not satisfied at that time and an SS did not instruct the pumps stop to the BO. Therefore, the behavior was regarded as UAs.

Table 3. UA Types and Consequences from Case Study

UA Type	UA Type - Details	Consequence	Number of UAs	Number of Recovered UAs
Response planning and instruction UA	Response planning and instruction UA-EOO	Inappropriate component manipulation	8	1
		Inappropriate procedure transfer	9	
		Inappropriate notification/request	2	
	Response planning and instruction UA-EOC	Inappropriate component manipulation	2	
		Inappropriate procedure transfer	1	
Information gathering and reporting UA	Information gathering and reporting UA-EOC	Inappropriate procedure transfer	4	1
Execution UA	Execution UA-Manipulation-Unauthorized	Inappropriate component manipulation	2	

V. CONCLUSION

In this paper, we described a process to identify a UA during an AOP/EOP operation with simulator training records and express a UA type classification by considering crew interactions under a procedure driven operation and simulator training environment. We performed a case study to implement the UA type classification and to define the consequences due to a UA with the ISLOCA scenario simulator training recording. We also showed examples of UAs and UA candidates. From the ten case studies, a total of 28 UAs occurred among 119 UA candidates, and two of them are recovered. A UA for response planning and instruction by SS dominates the UA results.

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