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Changing the World's Energy Future

Jooyoung Park, Han Bao, Tate H Shorthill, Jisuk Kim, Ronald Laurids Boring PhD, Edward Chen

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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INVESTIGATION OF HUMAN RELIABILITY ANALYSIS METHODS FOR ANALYZING PRE-INITIATORS

As a type of human actions defined in human reliability analysis (HRA), pre-initiator refers to the human actions that may lead to the unavailability of systems, typically committed during maintenance, test, or calibration. This paper investigates representative HRA methods used for analyzing pre-initiators. The HRA methods are Technique for Human Error Rate Prediction (THERP), Korean Standard HRA (K-HRA) and Standard Plant Risk HRA (SPAR-H). In this paper, characteristics of each HRA method are compared for qualitative and quantification aspects. Two pre-initiators, i.e., a calibration task and a valve restoration task, are analyzed using the HRA methods to compare human error probabilities. Then, insights from the analysis and additional research requirements are discussed in this paper.

INTRODUCTION

Human Reliability Analysis (HRA) is a technique for analyzing critical human actions as well as providing human error probabilities (HEPs) for application in probabilistic risk assessment (PRA) (Swain & Guttmann, 1983). In HRA, three types of human actions, i.e., 1) pre-initiator, 2) human-induced initiator, and 3) post-initiator, have been defined and considered as the main categories that affect accident mitigation strategies of nuclear power plants (NPPs). These are also called: 1) Category A action, 2) Category B action, and 3) Category C action, respectively (Parry, et al., 1992). First, pre-initiator refers to the human action that leads to the unavailability of systems, typically committed during maintenance, test, or calibration. As a latent error, it includes a miscalibration error and failure to restore the valves after test and maintenance. Second, human-induced initiator contains the actions leading to an initiating event. Any human action directly causing a reactor trip could be an example of human-induced initiator. Generally, it is not analyzed within HRA, but assumed that it is already considered in the PRA side. Third, post-initiator includes human errors that occur during response to a disturbance after the initiating event. For example, omitting a step in the procedure and forgetting to open a valve or operate a pump during the event correspond to post-initiators.

Most HRA methods currently available mainly concentrate on analyzing post-initiators (Park, et al., 2019). Still, pre-initiators are vital to predicting and preventing accidents. Mostly, approaches derived from the methods for analyzing post-initiators have been used as is or modified for analyzing pre-initiators. In fact, HRA researchers have considered post-initiators more importantly rather than pre-initiators. Within HRA, it is evaluated that error possibility for post-initiators is generally higher than that for pre-initiators. However, pre-initiators may potentially play a critical role in mitigating an accident scenario by being combined with post-initiators. For example, mis-calibrated values (e.g., water level of reactor coolant system) in an accident scenario may make operators confused to adequately understand situations by giving the wrong information, thus contributing to the scenario failure.

To address the need to understand and account for pre-initiators, this paper investigates representative HRA methods used for analyzing pre-initiators. The HRA methods are the Technique for Human Error Rate Prediction (THERP; Swain & Guttmann, 1983), Korean Standard HRA (K-HRA; Jung et al., 2005) and Standard Plant Risk HRA (SPAR-H; Gertman et al., 2005). In this paper, characteristics of each HRA method are compared in terms of qualification and quantification. Two pre-initiators, i.e., a calibration task and a valve restoration task, are analyzed using the HRA methods to compare HEPs. Then, any insights from the analysis will be discussed. We conclude the paper with a presentation on what research is additionally required to better evaluate pre-initiators.

HRA METHODS FOR ANALYZING PRE-INITIATORS

THERP

THERP (Swain & Guttmann, 1983) is a comprehensive HRA approach developed for the U.S. Nuclear Regulatory Commission (U.S. NRC). THERP has been used more frequently than any other HRA method across a variety of industries. The THERP method calculates HEPs for pre-initiators using unavailability equations, which are found in the fault tree theory of PRA (Vesely, et al., 1981). The THERP equations are below:

$$HEP = HER \times MDT \tag{1}$$

$$HER = (Nominal\ HEP \times PSFs) \times RFP/\ T \tag{2}$$

$$MDT = H_1 + C_1H_2 + C_1C_2H_3 + \cdots + C_1C_2 \ldots C_{m-1}H_{m-1} \tag{3}$$

where

- *HER:* human error rate
- *MDT:* mean down time (due to human error)
- *Nominal HEP:* a default error rate that serves as the basic or generic value for a given task
- *PSF:* performance shaping factor; any factor that influence human performance
- *RFP:* recovery failure probability; the failure probability of an action that is carried out to restore an initial human error
- *T:* test/maintenance/calibration cycle (period)
- *H:* checking cycle (period)
- *C:* failure probability for checking
- *m:* the number of checking

In the method, a pre-initiator is decomposed into sub-tasks. The equations above are used for estimating HEPs for the sub-tasks. Then, the final HEP for a pre-initiator is calculated by summing all HEPs for sub-tasks.

K-HRA

K-HRA (Jung, et al., 2005) is an HRA method developed by the Korea Atomic Energy Research Institute (KAERI). Its basic background comes from Accident Sequence Evaluation Program (ASEP) (Swain, 1987) and THERP. The method uses the same quantification approach as THERP, but suggests a structured and specified analysis procedure, quantification rules, and criteria for minimizing the deviation of HRA results caused by different analysts based on a consensus between HRA user organizations.

SPAR-H

The SPAR-H method (Gertman, et al., 2005) developed for the U.S. NRC has been widely used by both industry and regulators in its intended area of use (i.e., nuclear power plants [NPPs] in the United States), as well as in other industries (Rasmussen, et al., 2015). In the SPAR-H method, PSFs are mainly used for differentiating HEPs. To evaluate pre-initiators, this method adapts the same approach used for analyzing post-initiators as below.

$$HEP = Nominal\ HEP\ \times PSF_{Composite} \qquad 4)$$

$$HEP = \frac{Nominal\ HEP\ \times PSF_{Composite}}{Nominal\ HEP\ \times \left(PSF_{Composite} - 1\right) + 1} \qquad (5)$$

ANALYSIS OF HRA METHODS FOR QUALIFICATION AND QUANTIFICATION

Differences between HRA methods depend on the qualification and quantification processes.

Table 1 summarizes the differences in HRA methods on qualification (task type, PSF, and recovery factor) and quantification (nominal HEP, PSF multiplier, and RFP).

Task Type in Qualification

THERP defines various task types. The details on the THERP task types can be found in (Swain & Guttmann, 1983). However, THERP does not provide specific guidelines for how to assign them to given tasks. The HRA practitioner should select appropriate task types to tasks needed to be analyzed. On the other hand, K-HRA and SPAR-H do not define or distinguish any task types in their methodologies.

PSF in Qualification

The PSFs suggested in each method are different respectively. SPAR-H uses the most numerous PSFs among the HRA methods, while THERP and K-HRA each adopt three PSFs respectively, although the three differ between the methods.

Recovery Factor in Qualification

THERP and K-HRA provide relatively specific recovery factors in each method, while SPAR-H does not consider recovery factors in the HEP calculation.

Nominal HEP in Quantification

THERP suggests nominal HEPs for various task types defined in THERP, while K-HRA and SPAR-H use a single value for describing nominal HEPs. Note that SPAR-H has two nominal HEPs, but only the nominal HEP for Action applies for pre-initiators.

PSF Multipliers in Quantification

The multipliers for all three HRA methods have been determined by expert judgement. Although the background of all multipliers came from THERP, the THERP method only increases HEPs, but K-HRA and SPAR-H consider a multiplier (i.e., x1/2) for reducing HEPs to credit positive influences on performance.

RFP in Quantification

THERP includes RFPs for various recovery factors. K-HRA uses the dataset suggested by THERP. On the other hand, SPAR-H does not suggest any RFPs in the method.

COMPARISON OF HEPS FROM THE THREE HRA METHODS

This study additionally compared HEPs calculated from THERP, K-HRA and SPAR-H. General calibration and valve restoration tasks with their normal working environment in NPPs have been assumed for estimating HEPs.

Table 1. Comparison of HRA Methods on Qualification and Quantification (Draft Version)

		THERP	K-HRA	SPAR-H
Qualification	Task Type	• Various task types in the THERP Tables	N/A	N/A
	PSF	Stress level, experience, and task type	Procedure complexity, procedure management, and human-system interface	Available time, stress / stressors, experience / training, complexity, ergonomics, procedures, fitness for duty, and work processes
	Recovery Factor	• Various recovery factors in the THERP Tables	• Type I: functionality testing • Type II: the second checker (the same organization in the same institute) • Type III: the second checker (the similar organization but different institute) • Type IV: the second checker (the different organization and institute) • Type V: independent check after test / maintenance / calibration • Type VI: self-checking • Type VII: shift-checking	N/A
Quantification	Nominal HEP	• Nominal HEPs for various task types	5.0e-3	1.0e-3
	PSF Multiplier	x1, x2, x4, x5, x10	x1/2, x1, x2	x1/2, x1, x2, x5
	RFP	• RFPs for various recovery factors	• Type I: 1.6e-2 (THERP T20-6 #1) • Type II: 5.8e-1 (THERP T20-22 #1) • Type III: 2.8e-1 (THERP T20-22 #1) • Type IV: 2.03e-1 (THERP T20-22 #1) • Type V: 1.61e-1 (THERP T20-22 #1) • Type VI: 1.61e-1 (THERP T20-22 #1) • Type VII: 1.61e-1 (THERP T20-22 #1)	N/A

Table 2. HEPs from THERP, SPAR-H, and K-HRA

	THERP	SPAR-H	K-HRA
Task I: Mis-calibration error	1.46e-3	5.00e-5	2.95e-3
Task II: No valve restoration after test and maintenance	5.67e-6	2.50e-5	1.64e-4

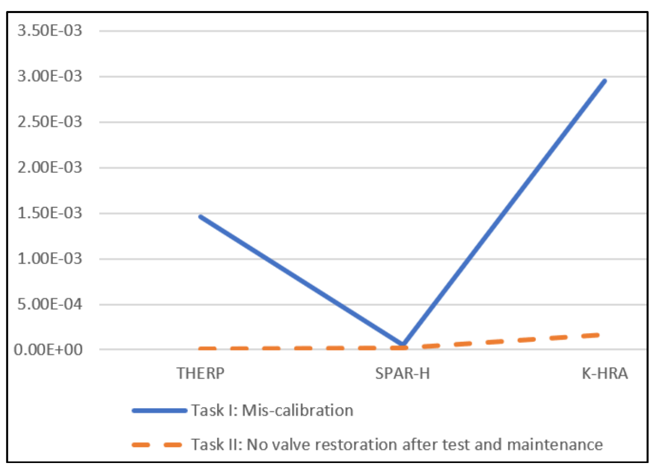

Figure 1. Comparison of HEPs from THERP, SPAR-H, and K-HRA

DISCUSSION

Table 2 and Figure 1 show the HEPs for the two tasks from THERP, K-HRA and SPAR-H. The HEPs are similar or lower when compared to nominal HEPs from the methods. HEPs for the mis-calibration task are higher than those for the valve restoration task. For the mis-calibration task, THERP and K-HRA estimate higher HEPs than SPAR-H. On the other hand, THERP, K-HRA, and SPAR-H represent similar HEP values on the valve restoration task. K-HRA indicates the biggest difference between HEPs for the two tasks, while SPAR-H shows the smallest difference.

This paper investigated how to analyze pre-initiators in THERP, K-HRA and SPAR-H. The characteristics of these methods were compared in qualification and quantification aspects. Also, HEPs for two pre-initiators, i.e., a calibration task and a valve restoration task, were estimated using the HRA methods, then compared one another. From the investigation, the following paragraphs summarize what is to be improved and further researched to better evaluate pre-initiators.

First, all the methods may not be adequate to reasonably assign task types and their nominal HEPs to pre-initiators including recovery factors and their error probabilities. As mentioned in the previous section, THERP provides various data sets required for analyzing pre-initiators but does not give HRA practitioners a structured way on how to use them in detail. It may contribute to generate different HEPs depending on HRA practitioners. In the case of K-HRA and SPAR-H, these do not distinguish task types for pre-initiators. Accordingly, these methods use a single nominal HEP (i.e., 5.0e-3 for K-HRA and 1.0e-3 for SPAR-H) for any pre-initiators. These are challenged to differentiate characteristics of pre-initiators (e.g., mis-calibration vs. the valve restoration) and evaluate them reasonably within HRA.

Second, which PSFs are influential to pre-initiators and how to estimate their effects need to be further researched. The three HRA methods use different sets of PSFs with different number of PSFs. The range of PSF multipliers in each method is also different, even if all the methods assume them using the data from THERP.

Third, it is questionable on whether the current approach to analyzing pre-initiators is enough to evaluate potential risk that pre-initiators have. The current approach focuses on risk for pre-initiators themselves only. Although we see relationships between pre-initiators and other basic events modeled in PRA via cutsets, these generally indicate low risk matrix value and are not importantly considered in the PRA analysis. However, pre-initiators may potentially play a critical role in mitigating an accident scenario by being combined with other basic events like post-initiators. Actually, in the Three Mile Island (TMI) accident (Toth, et al., 1986), a pre-initiator (a valve used for testing auxiliary feed water system was not restored after test and maintenance) directly affected the failure of a post-initiator (running auxiliary feed water system to provide water to steam generators). Furthermore, as one of the pre-initiators, mis-calibration error in an accident scenario may make operators confused to adequately understand situations by giving the wrong information, thus contributing to the scenario failure. It can be also confused with cyber-attack scenarios or software errors.

CONCLUSION

This paper is a starting point to better understand what pre-initiators are and better evaluate pre-initiators. Additional research is necessary to account for the qualitative and quantitative aspects of pre-initiators in order to arrive at a more comprehensive understanding of accident causes and progression.

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