COMPARISON OF METHODOLOGICAL CHARACTERISTICS BETWEEN EMBRACE AND THE EPRI HRA METHODOLOGY: CASE STUDY ON CRITICAL OPERATOR ACTIONS IN AN ADVANCED CONTROL ROOM

Jaewhan Kim[1], Yochan Kim[2]

[1] *KAERI: 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon, Republic of Korea, 34057, jhkim4@kaeri.re.kr*
[2] *KAERI: 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon, Republic of Korea, 34057, yochankim@kaeri.re.kr*

EXTENDED ABSTRACT

With the modernization of nuclear power plant control rooms, advanced digital interfaces significantly impact operator performance. Human reliability analysis (HRA) methodologies must account for these changes to accurately assess human error probabilities and the influence of computerized systems. Two HRA methodologies, EMBRACE (Empirical data-Based crew Reliability Assessment and Cognitive Error analysis) and the EPRI HRA approach, incorporate digital aspects into reliability assessment. EMBRACE integrates empirical operator performance data and a cognitive error model, while EPRI HRA applies three HRA methods such as the Cause-Based Decision Tree Method (CBDTM), Human Cognitive Reliability/Operator Reliability Experiments (HCR/ORE), and Technique for Human Error Rate Prediction (THERP) to quantify human reliability.

The selected human action for a case study, feed and bleed operation, is evaluated under two distinct event scenarios: (1) loss of all feedwater (LOAF) following loss of main feedwater (LOFW) and (2) LOAF following a small loss of coolant accident (SLOCA). Step-by-step analyses of human error probabilities (HEPs) and methodological evaluations are conducted, highlighting key differences in cognitive error modeling, task structuring, and time reliability estimation.

EMBRACE quantifies human reliability using two primary components: (1) Failure Probability due to Time Performance (FPtp) – Represents the likelihood of exceeding the time available for task completion. FPtp is calculated based on log-normal distribution modeling of operator performance time. (2) Failure Probability due to Cognitive Error (FPce) – Evaluates cognitive errors at each procedural step, integrating performance shaping factors (PSFs) such as task complexity, stress levels, and human-machine interface challenges. FPce derives primitive error probabilities (PEPs) using structured procedural analysis.

EPRI HRA methodology applies multiple techniques to estimate human error probability: (1) CBDTM – Evaluates cognitive errors by categorizing operator failures in plant information processing and procedural adherence. (2) HCR/ORE – Uses empirical data for time-reliability correlations, assessing probability based on response time constraints. (3) THERP – Quantifies execution errors using human error rate data under varying conditions of complexity and stress.

Table I shows the results of EMBRACE and the EPRI HRA approach for the feed and bleed operation at two different event scenarios. For the 'Case 1: Feed and bleed operation at a LOFW sequence', the HEP from EMBRACE is 1.45 times larger than the one from the EPRI approach. For the 'Case 2: Feed and bleed operation at a SLOCA sequence', the HEP from the EPRI approach is 25.8 times larger than the one from EMBRACE. Even though the underlying fundamentals of two methods are different from each other, the main contributions to each Case from each method can be identified as follows.

- In Case 1, the main contributions by the EMBRACE FPce are multiple procedure and step transitions required at the selection of an appropriate response procedure. The main contribution by the EPRI CBDTM is the decision logic misinterpretation that could be arising from the decision logic for judging an unsatisfied condition of the safety function. For time reliability estimation, the EMBRACE FPtp provides a somewhat significant level of HEP, but the EPRI HCR/ORE provides a negligible level of HEP. This difference between two methods comes from the difference in the time span that each method takes it into account in the lognormal time reliability equation. The EMBRACE FPtp considers the total time covering both cognition and execution explicitly in estimating failure probability due to time performance, but the EPRI HCR/ORE primarily focuses on cognition time in estimating the time available and time required parameter.

- In Case 2, the main contributions by the EMBRACE FPce include the application of the situation interpreting (SI) task type to the critical steps requiring a high level cognitive activity, in addition to multiple procedure transitions. The main contribution by the EPRI CBDTM is similar to the Case 1. For the part of time reliability estimation, two methods provide highly different results. The EMBRACE FPtp provides a relatively lower level of HEP compared to the one estimated by the EPRI HCR/ORE equation, which provides a very high level of HEP. The reason for this difference is that the scenario considered in the Case 2 shows a very peculiar characteristics in event progression. For this kind of a peculiar case of time response, the EMBRACE FPtp provides specific guidance on how to determine the actual cue to be used in the time reliability estimation, while the application of the EPRI HCR/ORE equation as is given in the original guidance for the CP2 cue-response type leads to take very long time required for cognition.

TABLE I. Comparison of HEPs between EMBRACE and the EPRI HRA approach

HFE and Event Scenario	HEP from EMBRACE	HEP from the EPRI HRA
Case 1: Feed and bleed operation at a LOFW sequence	1.09E-2	7.50E-3
Case 2: Feed and bleed operation at a SLOCA sequence	1.19E-2	3.07E-1

The comparative case study identifies methodological differences influencing human reliability estimation:

- Cognitive Modeling: EMBRACE integrates structured procedural analysis, mapping individual primitive error probabilities along the procedural path. EPRI CBDTM applies rule-based errors using predefined decision trees.

- Time Reliability Estimation: EMBRACE FPtp explicitly considers both cognitive and execution time within a log-normal framework, while EPRI HCR/ORE primarily models cognitive response time, potentially yielding high failure probabilities in a peculiar scenario case.

- Procedural Transition Complexity: EMBRACE accounts for transitions between procedures and steps explicitly, reflecting computer-based procedure interface design characteristics. EPRI CBDTM focuses on isolated procedural errors without explicitly modeling step transitions.

From the applicability point of view, two methods depend on the analysts' knowledge and expertise on the operators' cognitive activities as well as procedural contents. In order to facilitate the analysts' identification of critical procedure steps and primitive task types for EMBRACE, a computer software is being developed.

ACKNOWLEDGMENTS

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KoFONS) using a financial resource granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. 2106054).

REFERENCES

[1] Y. Kim, et al., *An HRA method for digital main control rooms – Part I: estimating the failure probability of timely performance*, KAERI/TR-7607/2019, KAERI, Daejeon, Republic of Korea (2019).
[2] Y. Kim, et al., *An HRA method for digital main control rooms – Part II: estimating the failure probability due to cognitive error*, KAERI/TR-8065/2020, KAERI, Daejeon, Republic of Korea (2020).
[3] J. Kim and Y. Kim, *Application and review of regulatory-purposed human reliability analysis method for digitalized MCRs*. KAERI/TR-10419/2024. KAERI, 2024.
[4] G. W. Parry, et al., *An approach to the analysis of operator actions in probabilistic risk assessment*, EPRI TR-100259, Palo Alto, California (1992).
[5] J. Julius, et al., *Human reliability analysis for digital environments: Preliminary guidance on HRA data collection, qualitative analysis and quantification*, EPRI TR-3002029331, Palo Alto, California (2024).
[6] W. Jung, et al., "HuREX – A framework of HRA data collection from simulators in nuclear power plants," *Reliability Engineering and System Safety*, 194, 106235 (2020).
[7] A. Swain and H. Guttmann, Handbook of human reliability analysis with emphasis on nuclear power plant applications, NUREG/CR-1278, Sandia National Laboratories, Albuquerque, New Mexico (1983).