HUMAN RELIABILITY ANALYSIS METHOD DEVELOPMENT IN THE US NUCLEAR REGULATORY COMMISSION

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Human Reliability Analysis (HRA) is used in the US Nuclear Regulatory Commission (NRC) mainly to support the NRC's risk-informed, performance-based regulatory framework. The NRC uses probabilistic risk assessment (PRA) techniques to provide input to the risk-informed regulatory framework. HRA is an important technical element of PRA techniques. The major functions of HRA are to provide a human-in-the-loop view of the scenario progression to identify the important human actions for protecting the plant and public safety in the scenarios and to assess the probabilities that these actions cannot be performed successfully, i.e., human error probability (HEP). The NRC uses HRA methods to achieve these objectives. This paper discusses the NRC's ongoing efforts in and outlook of developing the Integrated Human Event Analysis System (IDHEAS) HRA methods.

I. INTRODUCTION

Human Reliability Analysis (HRA) is used in the US Nuclear Regulatory Commission (NRC) mainly to support the NRC's risk-informed, performance-based regulatory framework. The NRC uses probabilistic risk assessment (PRA) techniques to provide input to this framework, and HRA is an important technical element of PRA techniques. The major functions of HRA are to provide a human-in-the-loop view of the scenario progression to identify the important human actions for protecting the plant and public safety in the scenarios and to assess the probabilities that these actions cannot be performed successfully, i.e., human error probability (HEP). The NRC uses HRA methods to achieve these objectives.

The NRC has developed a number of HRA methods for particular application purposes. These methods have provided a continuous improvement to HRA quality and scope of coverage. The mostly known HRA methods developed by NRC include THERP[1], ASEP[2], SLIM-MAUD[3], ATHEANA[4], and SPAR-H[5]. Other efforts in ensuring HRA quality include developing the HRA good practices[6], evaluating HRA methods against the good practices[7], and conducting the International[8] and the U.S.[9] HRA Benchmark Studies to compare HRA methods' predictive results against the licensed operator's performance in simulator-based scenarios. The Commission directed the NRC via Staff Requirements Memorandum (SRM-061020)[10] "to evaluate the different Human Reliability models in an effort to propose either a single model for the agency to use or guidance on which model(s) should to be used in specific circumstances." Since the issuance of SRM-061020 in 2006, the NRC staff has worked to develop the Integrated Human Event Analysis System (IDHEAS) series of HRA methods.

II. IDHEAS DEVELOPMENTAL FRAMEWORK

The specific IDHEAS development plan has evolved over time, figure 1 presents the up-to-date IDHEAS developmental framework. Figure 1 is divided into two portions: model and implementation. The model portion includes four levels of products. The top level product is to provide a scientific basis for IDHEAS development. This task was completed and documented in NUREG-2114[11] "Cognitive Basis for Human Reliability Analysis." NUREG-2114 documents an extensive literature review in psychology, cognition, behavioral science, and human factors. The review aims to model human performance in nuclear power plant operations. The results are synthesized into a cognitive framework that consists of five macrocognitive functions: (1) detecting and noticing, (2) understanding and sensemaking, (3) decisionmaking, (4) action, and (5) teamwork. For each macrocognitive function, the proximate causes for why the cognitive function may fail, cognitive mechanisms underlying the failures, and factors that influence the cognitive mechanisms and may lead to human performance errors are identified. The information provides basis of the causal relationships between human failure modes and causal factors.

The second level is the general guidance for developing application-specific HRA methods. The NRC recognizes that there is a wide spectrum of HRA applications for nuclear fuel safety and radioactivity medical materials safety. It is not practical to have a single HRA method for all applications. The more practical approach is to have an HRA method for each specific application. This is because each HRA application may have unique human performance considerations and quality requirements. Developing application-specific HRA methods would simply the efforts in method development and implementation. Nevertheless, these application-specific HRA methods require solid scientific bases. To achieve this objective, the staff is developing general guidance that provides technical components and instructions to develop the application-specific HRA methods. This general guidance is named as the ISHEAS general methodology (IDHEAS-G). The IDHEAS-G provides the technical components that are needed to perform an HRA and instructions of how to use these technical components. For example, factor-based and expert elicitation are two main approaches to estimate HEPs. IDHEAS-G provides both options for users to choose. Regarding the factor-based approach, IDHEAS-G provides a comprehensive sets of factors, including macrocognitive functions, cognitive failure modes (CFMs) and performance influencing factors (PIFs), and the effects of these factors affecting HEPs. The users can customize the IDHEAS-G factors (e.g., combine, split, or remove) for the users' specific HRA applications. Regarding the expert elicitation approach, IDHEAS-G refers to the published documents on this topic. Other technical components provide the following HRA functions: preparation (forming a project team and team interactions, etc.), performing the qualitative analysis (e.g., how to collect information for HRA, scenario narrative, event timeline, scenario and time analyses, and crew response diagram), estimating independent HEPs (identification of human failure events and critical tasks, macrocognitive functions, CFMs, PIFs, and expert elicitation), estimating task dependency and effects, estimating uncertainty, and documentation. The IDHEAS-G development mainly based on NUREG-2114 supplemented with empirical data (mainly from psychological experiments), additional literature that is not included in NUREG-2114, human factors practices, and the selected technical components of the existing HRA methods. These supplementary information is shown in the fourth level of Figure 1.

The third level is the HRA methods for specific applications. For example, the IDHEAS-internal, at-power HRA method was specifically developed for HRA applications for nuclear power plant internal events, at-power PRA. The method addresses post-initiating, internal, at-power events. It assumes that the crews being modeled are the nuclear power plant control-room crews that have been trained to work together within pre-defined team structures and work processes. Therefore, it models the errors made by trained crews performing required responses to plant disturbances. Within this specific implementation scope, assumptions can be made to reduce the modeling complexity. In addition to the application for internal at-power PRAs, other HRA applications could include condition and event assessment (part of NRC's Reactor Oversight Process), the implementation of the industry's Flex initiative, and the digital instrumentation and control of nuclear power plants. The IDHEAS-internal, at-power HRA method was jointly developed by NRC and the Electric Power Research Institute (EPRI). .

The fourth level is the supporting documentation. For example, developing the IDHEAS internal events, at-power method required the extensive use of expert judgment/elicitation and a formal process to test the method. The supporting documents include a report providing a detailed account of how the expert judgment/elicitation is used to develop the IDHEAS internal events, at-power method, a report documenting the process and results of the formal testing of the method, and a users' guide for how to use the method. The IDHEAS-G provides the PIFs' effects on human performance. The supporting documents are expected to include a literature review on the PIFs' effects on human performance and the applicable human performance indications from the NRC's Scenario Authoring, Characterization, and Debriefing Application (SACADA) system[12]. This document indicates that the IDHEAS-G will be gradually improved by incorporating new human performance evidence and improvements in the existing technical components.

The implementation portion of Figure 1 shows the development of IDHEAS software to facilitate the use of the IDHEAS methods and documentation. The concept of the IDHEAS software development is still preliminary. It is discussed here only to illustrate the current state of thought. The concept is that because every application-specific IDHEAS HRA method will use the IDHEAS-G's technical components, these methods may select from the IDHEAS-G technical components for their particular application (e.g., not considering certain PIFs or providing pre-thought-through options for HRA users to choose from). However, the functions of the technical components should remain the same. IDHEAS-G contains the master set of technical components to perform an HRA. These technical components are sufficient for any HRA application.

The IDHEAS software developmental concept is to contain all of the IDHEAS-G technical components in the software environment. These components are designed with flexibility for the users to directly use or modify for their applications. An example is that the IDHEAS-internal, at-power method calculates the independent HEPs and only uses subsets of CFMs and PIFs of IDHEAS-G. Therefore, to develop an independent HEP quantification module for the IDHEAS-internal events, at-power application, only the subsets of CFMs and PIFs need to be displayed for the HRA applications to interact. The definitions of the PIFs and their statuses have to be specified by the method developers. Because the IDHEAS-internal, at-power method has been through a formal expert elicitation process to specify PIF combination effects on HEPs (represented in the method's decision trees), the PIFs' effects on HEPs provided in the IDHEAS-G do not need to be used.

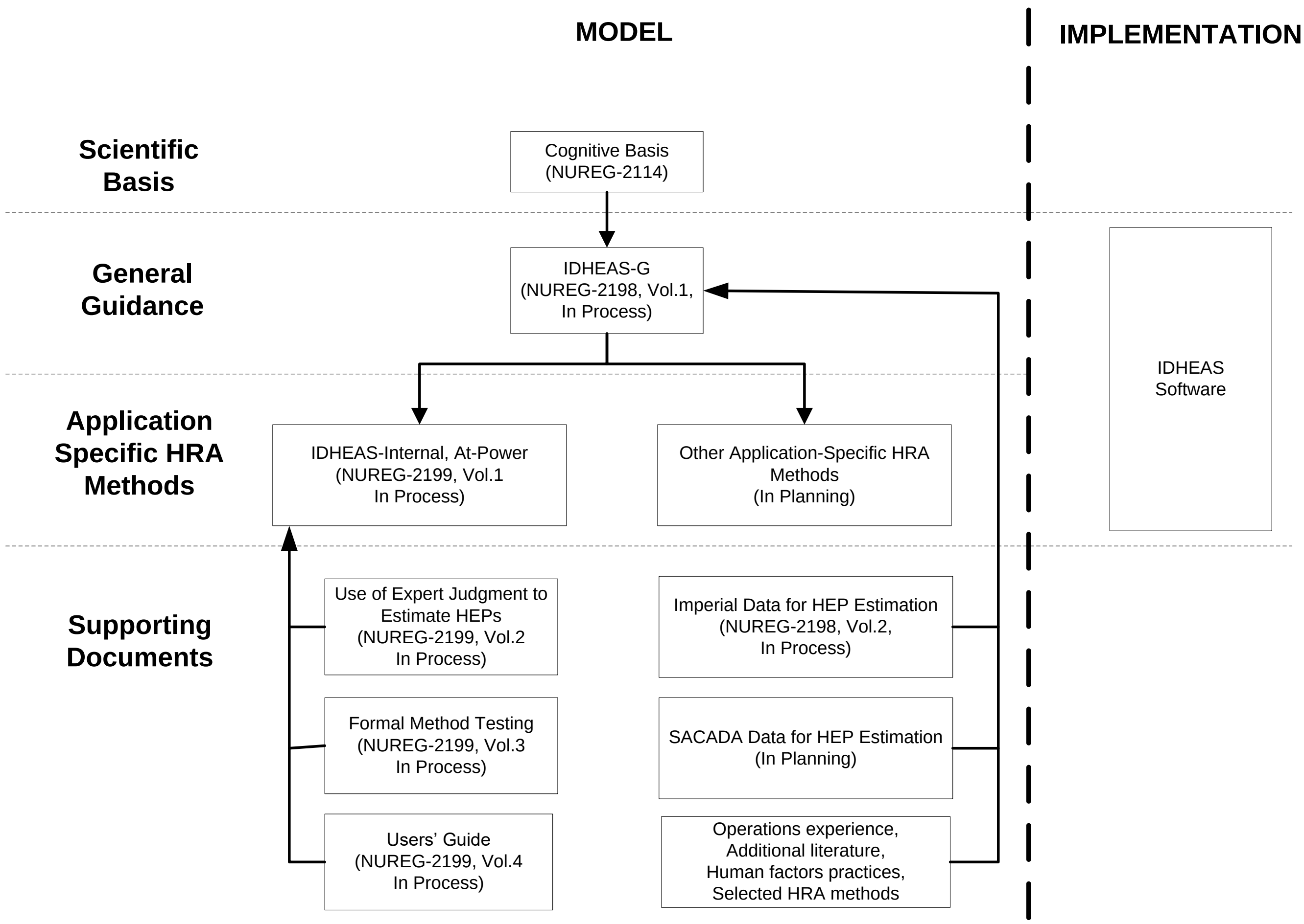

Fig. 1. The IDHEAS developmental framework

The NUREG-2114 "HRA cognitive basis" was published in January 2016. The IDHEAS for Nuclear Power Plant Internal Events At-Power method is complete. It is expected to be published in early 2017. The supporting documents to the IDHEAS-internal, at-power method are expected to be published in 2017 and 2018 time frame. The first peer review of the draft IDHEAS-G method was completed in August 2016. A revision is expected to be ready in late 2016 for the second round of peer review. The staff plans to organize and publish the empirical data used in IDHEAS-G to support estimating HEPs in 2017. The SACADA system collects licensed operator performance information in simulator training and experiments. The database currently has more than 10,000 data point for analysis. An analysis of the available SACADA data is planned to be performed starting by the end of 2016 and is expected to be completed in mid-2017. Another IDHEAS application-specific HRA method is for event and condition assessment (IDHEAS-ECA) of the NRC's Significance Determination Process and Accident Sequence Precursor program. NRC staff began this application development in the summer of 2016. Additionally, the staff plans to begin the IDHEAS software development by the end of 2016. These statuses are summarized in Table 1.

Table 1 The statuses of the IDHEAS related tasks.

Task	Status
NUREG-2114 “HRA cognitive basis”	Published in 1/2016
IDHEAS-internal, at-power method	Completed in 2016, publish in 2017
IDHEAS-internal, at-power method’s supporting documents	Publish in 2017 and 2018
IDHEAS-G	Second round of peer review in late 2016
IDHEAS-G empirical data	Draft report in 2017
SACADA data analysis	Analysis results in mid-2017
IDHEAS-ECA method	Development started in 2016
IDHEAS software	Development starts by the end of 2016

III. CONCLUSIONS

This paper describes the NRC’s plan to develop the IDHEAS series to address the SRM-061020 regarding HRA methods. The effort started with a large scale literature review to develop the scientific foundation. The foundation work is documented in the NUREG-2114. The literature review results were utilized to develop IDHEAS-G, which provides the technical components and instructions for developing HRA methods (or HEP quantification methods) for specific applications. This structure ensures that application-specific HRA methods are developed from the same scientific and data basis as IDHEAS-G, thereby promoting consistency amongst the developed methods.

REFERENCES

1. Swain, A.D., and H.E. Guttmann, “Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications,” NUREG/CR-1278/SAND80-0200, Sandia National Laboratories for the U.S. Nuclear Regulatory Commission, Washington, DC, August 1983
2. Swain, A.D., “Accident Sequence Evaluation Program Human Reliability Analysis Procedure,” NUREG/CR-4772/SAND86-1996, Sandia National Laboratories for the U.S. Nuclear Regulatory Commission, Washington, DC, February 1987
3. Embrey, D.E., P. Humphreys, E.A. Rosa, B. Kirwan, and K. Rea, “SLIM-MAUD: An Approach to Assessing Human Error Probabilities Using Structured Expert Judgment,” NUREG/CR-3518, Vols. I & II, Brookhaven National Laboratory for the U.S. Nuclear Regulatory Commission, Washington, DC, 1984.
4. U.S. Nuclear Regulatory Commission , “Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA),” NUREG-1624, Rev. 1, May 2000.
5. Gertman, D.I., H.S. Blackman, J. Byers, L. Haney, C. Smith, and J. Marble, “The SPAR-H Method,” NUREG/CR-6883, U.S. Nuclear Regulatory Commission, Washington, DC, August 2005
6. Kolaczkowski, A., Forester, J., Lois, E., and Cooper, S. “Good Practices for Implementing Human Reliability Analysis (HRA)” NUREG-1792, U.S. Nuclear Regulatory Commission, 2005
7. Forester, J., Kolaczkowski, A., Lois, E., and Kelly, D. “Evaluation of Human Reliability Analysis Methods Against Good Practices” NUREG-1842, U.S. Nuclear Regulatory Commission, 2006
8. Lois, E., Dang, V., Forester, J., Broberg, H., Massaiu, S., Hildebrandt, M., Braarud, P, Parry, G., Julius, J., Boring, R., Mannisto, L., and Bye, A., “International HRA Empirical Study - Phase 1 Report: Description of Overall Approach and Pilot Phase Results from Comparing HRA Methods to Simulator Performance Data,” 2009, NUREG/IA-0216, Vol. 1, U.S. Nuclear Regulatory Commission.
9. Forester , J., Liao, H., Dang, V.N, Bye, A., Lois, E., Presley, M., Marble, J., Nowell, R., Broberg, H., Hildenbrandt, M., Hallbert, and B., Morgan, T. “The U.S. HRA Empirical Study - Assessment of HRA Method Predictions against Operating Crew Performance on a U.S. Nuclear Power Plant Simulator”,NUREG-2156, U.S. Nuclear Regulatory Commission, 2016
10. U.S. Nuclear Regulatory Commission http://www.nrc.gov/reading-rm/doc-collections/commission/srm/meet/2006/m20061020.pdf, 2006
11. Whaley, A.M., Xing, J., Boring, R.L., Hendrickson, S. M. L., Joe, J.C., Le Blanc, K. L., and Morrow, S. L. “Cognitive Basis for Human Reliability Analysis”, NUREG-2114, U.S. Nuclear Regulatory Commission, 2016
12. Chang, Y.J., Bley, D., Criscione, L., Kirwan, B. Mosleh, A., Madary, T., Nowell, R., Richards, R., Roth, E.M., Sieben, S., Zoulis, A. “The SACADA Database for Human Reliability and Human Performance” the journal of Reliability Engineering and System Safety, 125(2014) 117-133.