IDHEAS Suite for Human Reliability Analysis
- An Overview and Recent Developmental Focuses

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Abstract: The U.S. Nuclear Regulatory Commission (NRC) is continuing the development of the Integrated Human Event Analysis System (IDHEAS) suite for performing human reliability analysis (HRA). The IDHEAS Suite aims to be a comprehensive tool set to perform all HRA functions and the technical and data bases of these tools. At a high level, HRA performs qualitative and quantitative assessments. The tool set includes models, methods, guidance, data, and a software application to perform these functions. The IDHEAS suite has a mature tool to perform qualitative assessments. Current work focuses on enhancing quantitative assessment capabilities, i.e., estimating human error probabilities (HEPs). The IDHEAS suite for quantitative assessment includes functions to estimate HEPs due to cognitive error, HEPs due to time inadequacy, probability of error recoveries, HEP impacts due to dependency, and HEP uncertainty. The current IDHEAS Suite work focuses on using the IDHEAS for event and condition assessment (IDHEAS-ECA) method to assess HEPs. Specifically, developing technical and data bases and guidance to assess time uncertainty, error recoveries, and HEP uncertainty are in progress or are planned. Recently, an NRC workgroup applying IDHEAS-ECA to assess HEPs of the operator actions modeled in NRC's probabilistic risk assessment models identified the need to improve IDHEAS-ECA's guidance on assessing cognitive error probabilities. This identification led to the development of the IDHEAS-ECA desktop guide. This paper provides an overview of the IDHEAS suite and discussions of the ongoing and planned work on IDHEAS-ECA.

Keywords: PRA, HRA, IDHEAS.

1. INTRODUCTION

The Integrated Human Event Analysis System (IDHEAS) suite is the product of a large project of the U.S. Nuclear Regulatory Commission (NRC) to modernize its human reliability analysis (HRA) capacities. The project was initiated with a Commission direction to recommend human reliability model(s) for NRC use [1]. The Commission later issued another two directions on HRA data [2] and on developing application-specific HRA guidance (method) [3]. An objective of these Commission direction was to reduce the variability observed in performing HRA by different analysts and with the use of different HRA methods.

These Commission directions resulted in generating multiple HRA products. Notable products include a literature review to establish a cognitive basis for HRA [4], a general methodology for performing HRA (IDHEAS-G) [5], which also serves as a technical components repository for developing application-specific HRA methods, the HRA empirical studies [6-10] that evaluate various HRA methods by comparing their assessments against the operator performance in simulated events, the application specific methods which include for level-1 at-power applications [11] and for event and condition assessment applications (IDHEAS-ECA [12]) for the NRC's significance determination process [13], the IDHEAS-ECA software tool, and the Scenario Authoring, Characterization and Debriefing Application (SACADA) [14] to collect operator reliability information in simulator training of nuclear power plants and its associated data basis [15]. In addition, the NRC has ongoing activities to enhance the IDHEAS-ECA method. The products to be developed to enhance IDHEAS-ECA would also be included in the IDHEAS suite. This paper discusses these anticipated products and their objectives and technical challenges.

2. IDHEAS-ECA ENHANCEMENTS

The IDHEAS suite is the proposed HRA models for the NRC to use in response to the Commission's request. IDHEAS-ECA will be the primary tool to Assess HEPs in NRC's risk-informed applications, e.g., significance determination process (SDP) [13] and accident sequence precursor (ASP) program [16]. IDHEAS-ECA and its related technical components perform the following HRA technical functions to assess HEPs: assessing individual (or independent) HEPs, estimating the likelihood of error recoveries, assessing dependency impacts on HEPs, and assessing HEP uncertainty. In developing these products, the NRC emphasizes having explicit technical and data bases. In addition, every product is expected to be peer reviewed. This section provides brief discussions of these technical products.

2.1. Assessing Individual HEPs

Individual (or independent) HEP generally refers to the HEP assessment and does not explicitly consider the scenario impacts on the human action (i.e., human failure event (HFE)) of analysis. The scenario impacts here are referred to as dependence. IDHEAS-ECA divides the individual HEP into two contributors: HEP due to insufficient time and HEP due to incorrect cognitive responses. These two HEPs are denoted as P_t and P_c, respectively. An NRC workgroup [17] used the IDHEAS-ECA method to analyze the HFEs modeled in the NRC's Standardize Plant Analysis Risk (SPAR) probabilistic risk assessment (PRA) models. The HFEs include operator actions responding to internal events and implementing the diverse and flexible coping strategies (FLEX) [18]. The workgroup identified two areas of improvements to assess individual HEPs: guidance on specifying time uncertainty and guidance on identifying the cognitive failure modes (CFM) and performance influencing factor attributes (PIFA). The following subsections discuss these two areas.

Specifying Time Uncertainty

IDHEAS-ECA calculates P_t by convolution of the uncertainty distributions of the time-required (T_{req}) and time-available (T_{avail}). T_{reqd} is the time for a crew to complete the tasks of analysis. Different crews have different paces of performing tasks that represents T_{reqd} uncertainty. T_{avail} is the time that the tasks need to be completed based on the scenario and system design. If the tasks are not completed before T_{avail}, the operator actions are considered no longer beneficial to the scenario. Scenario uncertainty (including operator interferences) could affect T_{avail} that contribute to T_{avail} uncertainty. It is common in PRA documentation that only point estimates, but not uncertainty distributions, are available for T_{reqd} and T_{avail} estimations. As a result, providing guidance on specifying time uncertainties is essential to assist analysts to assess P_t when only point estimates of T_{req} and T_{avail} are available.

Requested by the NRC, the Pacific Northwest National Laboratory (PNNL) analyzed the operator response time data documented in the Operator Reliability Experiments (ORE) [19] conducted by the Electric Power Research Institute (EPRI) and provided recommendations on specifying T_{reqd} uncertainty distribution [20]. In addition, the NRC staff performed a separate analysis [21] with additional operator response time data provide by the Halden HAMMLAB [22]. The operator action time data provided by Halden HAMMLAB include the international [9, 10] and US [7] HRA empirical studies and other studies (e.g., [23] and [24]). Summaries from the analyses are:

- Lognormal distributions, in general, fit better to the data in comparison to other distributions.
- IDHEAS defines T_{reqd} as the time to complete the HFE without making cognitive errors. This definition would exclude the data points of T_{reqd} where the operator committed cognitive errors (e.g., used an incorrect procedure initially and returned to the correct procedure in a later time). All the T_{reqd} data mentioned above include T_{reqd} with and without committing cognitive errors. Preliminary analysis [21] shows large uncertainties when the T_{reqd} of control room actions are short (e.g., less than 20 minutes) and the uncertainty reduces with increased T_{reqd}. The ORE data [19] show that the error factor (EF), which is the 95th percentile divided by the 50th percentile in a lognormal distribution, could reach to six. An EF of two seems a reasonable bound for the human actions with long T_{reqd}. Nevertheless, more data analyses would be needed to develop guidance on assessing T_{reqd} uncertainty.
- There is little T_{reqd} data for the tasks performed outside of main control rooms. It would be essential to have this data to develop guidance on assessing T_{reqd} uncertainties for the actions performed outside of control rooms.
- There is little information about developing T_{avail} uncertainty. T_{avail} is usually determined by the system parameters exceeding their thresholds, e.g., steam generator water level reaching to the entrance of the main steamline. Operator actions (e.g., adjusting feedwater flow rate) would affect the T_{avail}. As a result, the T_{avail} uncertainty issue may be more suitably addressed by dynamic PRA/HRA techniques. For conventional PRA, until guidance is developed, fixed values for T_{avail} would be the interim solution.

The NRC is working on developing operational guidance to assess P_t. This guidance, once developed, would be part of the IDHEAS Suite.

Identifying CFMs and PIFAs

IDHEAS-ECA uses a three-level hierarchical structure to calculate cognitive error probability of an HFE, including critical tasks, CFMs, and PIFs/PIFAs. IDHEAS-ECA [12] stresses to have a systematic analysis of the scenario, HFE, task, and PIFs (Steps 1 to 4 of IDHEAS-ECA analysis procedure) before calculating HEPs. Without a systematic analysis, the selections of applicable CFMs and PIF attributes may underrepresent the context challenges to human performance, which can underestimate the risk; misrepresenting the context with the wrong CFMs. Based on limited analyses of the NRC workgroup [17], all internal event HFEs only use one critical task to calculate their HEPs. The FLEX HFEs, which require transporting, setting up, and operating the FLEX equipment, use multiple critical tasks. The NRC workgroup found that the existing IDHEAS-ECA guidance on identifying critical tasks is adequate. However, the guidance on CFMs and PIFAs require enhancement. IDHEAS models five CFMs, i.e., failures of detection, understanding, decisionmaking, action execution, and interteam coordination. The main problem identified by the NRC workgroup [17] on CFM guidance is when the understanding and decisionmaking CFMs can be excluded from the analyses. The problems with the PIFAs are that the guidance does not provide sufficient detail for analysts to determine whether a PIFAs applies to a specific context. Some PIFA impacts on HEPs are divided into ten levels. The analysts could not confidently determine the correct PIFA level for their analyses based on the existing guidance. Other associated considerations are potential double counting of the impacts on HEPs between PIFAs and assessment consistency that affect HRA quality. These considerations led to the decision to develop an IDHEAS-ECA desktop guide. The desktop guide aims to enhance IDHEAS-ECA guidance to improve reliability and consistency in applying IDHEAS-ECA method. Newly available human reliability data will be incorporated in the desktop guide development. The desktop guide is discussed later in this paper.

2.2. Error Recovery

In general, IDHEAS-ECA includes error recoveries in its PIFAs' quantitative effects on HEPs. If a task is performed by an individual without peer check, a PIFA that represents not having the benefit of a peer check should be selected to reflect the impact on the HEP. IDHEAS-ECA has the following PIFAs to represent the effects:

- Staffing (STA2) "lack of backup or lack of peer check or cross-checking"
- Work practice (WP1) "lack of practice of self- or cross-verification"
- Work practice (WP2) "lack of or ineffective peer-checking or supervision"

The above three PIFAs each addresses a specific condition affecting human reliability. The problem is that the short description of each PIFA is difficult for the analysts to clearly know whether a PIFA applies to the specific condition of an analysis and decerning one PIFA from another for an analysis. This issue again emphasizes the need for developing the IDHEAS-ECA desktop guide.

Besides the above mentioned "penalty" on error recovery, currently, IDHEAS-ECA guidance on error recoveries need to be enhanced to determine whether a specific error recovery consideration is already included. For example, whether the error recovery opportunities that naturally become available as the scenario progresses, especially with long T_{avail} that provides adequate time for error recoveries have been included. These ambiguities are expected to be addressed by the planned error recovery guidance and desktop guide.

2.3. Dependency

The NRC developed IDHEAS-DEP [25] to assess the dependency effects quantitatively. The dependency effect currently is limited to the effect of the failure of a human action (HFE) on the subsequent human actions (HFEs) of the same event sequence. IDHEAS-DEP does not take the conventional approach (e.g., [26-28]) that divide five levels of dependence (Zero, Low, Medium, High, and Complete dependence) to calculate the dependent HEPs. Instead, IDHEAS-DEP assesses dependency effects by assessing the statuses of the following five dependency relationships:

- Functions or systems: the equipment or component, which the two HFEs interact with, perform the same function or part of the same system.
- Time proximity: Either the two HFEs are performed close in time or their cues are received close in time.
- Personnel: The two HFEs are performed by the same individuals or crew.
- Location: The two HFEs are performed in the same location.
- Procedure: The two HFEs are performed using the same procedure.

In a nutshell, the above five dependence considerations are similar to the high-level considerations of other dependence models, such as same crew, location, cue, and time [26]. The main difference is that IDHEAS-DEP implements a three-level analysis to address the specific dependence considerations within the five dependence categories. The three levels of analysis include predetermination, screening, and detailed analyses. Based on the information availability of the analyses, the analysts choose appropriate level of analysis to assess the dependence impacts. Currently, the NRC is interacting with stakeholders to comment on IDHEAS-DEP [25] and to publish the final report as a NUREG report after consolidating reviewers' comments.

2.4. HEP Uncertainty

THERP [28] and ASEP [29] methods use lognormal distribution to represent HEP uncertainty. Every HEP in these two methods have corresponding uncertainties, which are represented by error factors (EFs). ATHEANA provides qualitative guidance using an expert elicitation approach to assessing HEP uncertainty. The other HRA methods rarely discuss HEP uncertainty. However, including uncertainty in the HEPs calculated based on empirical data is a common practice, e.g., [30-32]. Currently, IDHEAS-ECA requires performing sensitivity analysis but falls short of providing quantitative guidance on specifying HEP uncertainty. Enhancing the guidance on specifying HEP uncertainty is a planned activity.

2.5. Additional Guidance

Two notable guidance products, in addition to the guidance mentioned above, are in development, including the IDHEAS-ECA desktop guide and the guidance to integrate data from various sources for IDHEAS.

IDHEAS-ECA Desktop Guide

The main purpose of developing the desktop guide is to improve the reliability and consistency to implement the IDHEAS-ECA method between analysts. The error recovery examples discussed in section 2.2 show that it would require revisiting the data sources used for developing IDHEAS-ECA guidance to discern the differences between similar PIFAs and to enhance the guidance. The desktop guide will provide updated guidance for all CFMs and PIFAs. Newly available data will be incorporated in the process. If necessary, the quantitative impacts of PIFAs could be revised as well. The desktop guide development benefited from the NRC workgroup [17]. The workgroup had specific questions about certain PIFAs from performing the analyses. These questions led to a closer look at these PIFAs and the development of the IDHEAS-ECA desktop guide.

An importance data source to be added into the desktop guide is simulator data, specifically data from the Scenario Authoring, Characterization and Debriefing Application (SACADA [14]) and Human Reliability Data Extraction (HuREX, [33]). IDHEAS-DATA includes some data from SACADA and HuREX. The new data are from performing additional analyses or are data that became available to the NRC. Preliminary, limited comparisons of the simulator data with other data sources (e.g., maintenance data) indicate that human reliability discrepancies between these data sources cannot be neglected. It requires more analyses to identify the causes of these differences to provide revised guidance, as necessary. In addition to quantitative differences, the simulator data provide information with the scenario details that are not provided by other information sources. This information detail enables us to make more precise guidance.

Table 1 shows an example of the information details provided by SACADA for a scenario. This scenario is used for operator simulator training that includes three sequential system/component malfunctions: loss of 1A component coolant pump (CCP), total loss of reactor colling pump (RCP) seal cooling, and small break loss of coolant accident (LOCA). The expected operator responses for each malfunction are identified explicitly, as shown in Table 1. Operator performance in simulator training is evaluated against these expected responses. Fourteen crews ran through the scenario. One of the crews failed the first expected response "Determines 1A CCW pump has tripped" (as pointed to by the maroon arrow in Table 1). Not shown in Table 1 is that SACADA requires characterizing the context for each expected response. This expected response was characterized as (1) a cognitive function to detect information, (2) the alarm panels is 'dark' immediately before this expected response, (3) detecting the information relies on operator's self-awareness of the situation and does not rely on procedures, and (4) there is no foreseeable factor that would negatively affect detecting that the 1A CCW pump has tripped. The performance comments about the crew who failed this expected response include "Key alarm not seen due to poor practices" and "lack of questioning attitude." Such information is very useful to draw consensus between guidance developers. In base PRA models, detecting the cues for an HFE are typically directed by procedures (e.g., emergency response procedures and abnormal operating procedures) explicitly, instead of relying on self-awareness. SACADA data shows that the crew failed to detect a signal mostly because it relied on self-awareness. This information suggests that HEPs for detecting cues by self-awareness versus by procedure instruction could be significantly different. This insight helps in the development of more specific guidance. The SACADA taxonomy is available in [14].

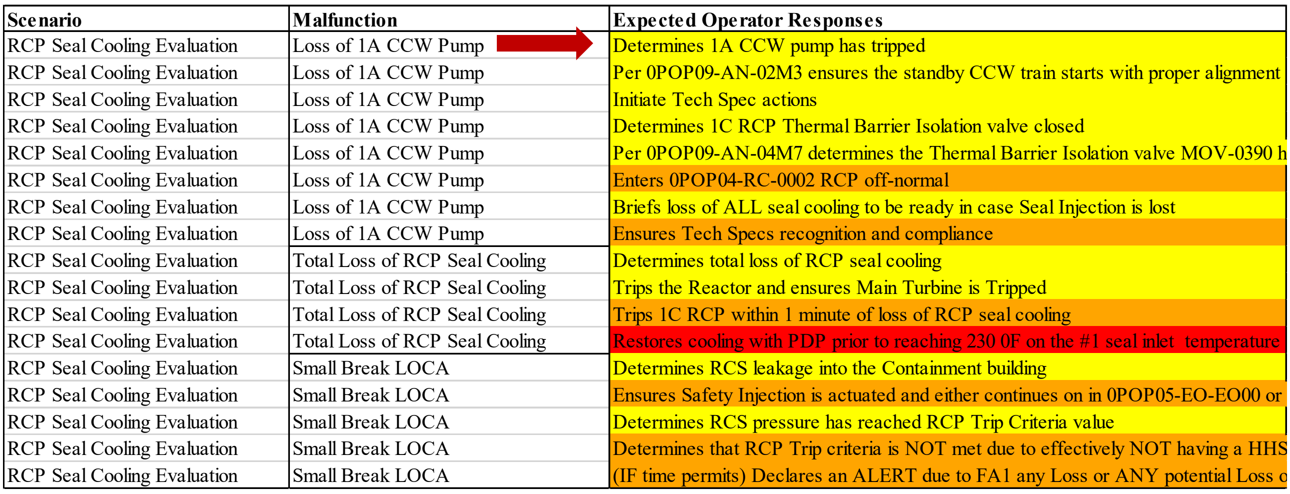
Data Integration

The data used to establish the parameters' values of IDHEAS-ECA for HEP estimations are from diverse sources that can be classified into the following categories [15]:

- Nuclear simulator data (e.g., [14, 33]) and operational (maintenance) data (e.g., [31, 32])
- Operation performance data from other domains (e.g., air traffic control operational errors)
- Experimental data reported in literature
- Expert judgment data
- Inference data (statistical data, ranking, categorization, etc.)

The data credibility, data applicability to nuclear facility operational environments, considerations in incorporating a data point for use in IDHEAS-ECA and drawing conclusions from multiple related data points to inform the quantitative effects of an IDHEAS-ECA parameter, etc. are among the considerations on integrating data for IDHEAS-ECA. The guidance on IDHEAS-ECA data integration to be developed would provide instruction on how to integrate additional data in the future for IDHEAS-ECA.

Table 1 A SACADA scenario



Scenario	**Malfunction**	**Expected Operator Responses**
RCP Seal Cooling Evaluation	Loss of 1A CCW Pump	Determines 1A CCW pump has tripped
RCP Seal Cooling Evaluation	Loss of 1A CCW Pump	Per 0POP09-AN-02M3 ensures the standby CCW train starts with proper alignment
RCP Seal Cooling Evaluation	Loss of 1A CCW Pump	Initiate Tech Spec actions
RCP Seal Cooling Evaluation	Loss of 1A CCW Pump	Determines 1C RCP Thermal Barrier Isolation valve closed
RCP Seal Cooling Evaluation	Loss of 1A CCW Pump	Per 0POP09-AN-04M7 determines the Thermal Barrier Isolation valve MOV-0390 h
RCP Seal Cooling Evaluation	Loss of 1A CCW Pump	Enters 0POP04-RC-0002 RCP off-normal
RCP Seal Cooling Evaluation	Loss of 1A CCW Pump	Briefs loss of ALL seal cooling to be ready in case Seal Injection is lost
RCP Seal Cooling Evaluation	Loss of 1A CCW Pump	Ensures Tech Specs recognition and compliance
RCP Seal Cooling Evaluation	Total Loss of RCP Seal Cooling	Determines total loss of RCP seal cooling
RCP Seal Cooling Evaluation	Total Loss of RCP Seal Cooling	Trips the Reactor and ensures Main Turbine is Tripped
RCP Seal Cooling Evaluation	Total Loss of RCP Seal Cooling	Trips 1C RCP within 1 minute of loss of RCP seal cooling
RCP Seal Cooling Evaluation	Total Loss of RCP Seal Cooling	Restores cooling with PDP prior to reaching 230 0F on the #1 seal inlet temperature
RCP Seal Cooling Evaluation	Small Break LOCA	Determines RCS leakage into the Containment building
RCP Seal Cooling Evaluation	Small Break LOCA	Ensures Safety Injection is actuated and either continues on in 0POP05-EO-EO00 or
RCP Seal Cooling Evaluation	Small Break LOCA	Determines RCS pressure has reached RCP Trip Criteria value
RCP Seal Cooling Evaluation	Small Break LOCA	Determines that RCP Trip criteria is NOT met due to effectively NOT having a HHS
RCP Seal Cooling Evaluation	Small Break LOCA	(IF time permits) Declares an ALERT due to FA1 any Loss or ANY potential Loss o

2.6. Developing Analysis knowledge Base

The IDHEAS-ECA developers worked with NRC's risk analysts who applied the method to perform HRA for NRC's SDP [13] and ASP program [16] to demonstrate using IDHEAS-ECA for these applications. In addition, an NRC workgroup [17] performed more analyses on using IDHEAS-ECA on SPAR models. These analyses are stored in a knowledge base repository, which would be an invaluable resource to promote consistency in applying IDHEAS-ECA.

2.7. Software tool

The IDHEAS developmental team developed a software tool to facilitate implementation of IDHEAS-ECA. Any new function of or change to IDHEAS-ECA is planned to be reflected in the software tool.

3. CONCLUSION

This paper provides an overview of the IDHEAS suite and the ongoing and planned work to enhance the IDHEAS Suite. Current work focuses on completing the technical components for HEP quantifications. Main works include developing HRA technical elements to specify time uncertainty, assess likelihood of error recoveries, assess HEP uncertainty, and enhance the IDHEAS-ECA desktop guide. The emphasis of having explicit technical and data bases provides a foundation for systematic improvements of the IDHEAS suite when new knowledge and data become available.

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