Next Generation Human Reliability Analysis – Addressing Future Needs Today for Digital Control Systems

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Abstract: This paper addresses issues and insights related to applying current human reliability analysis (HRA) techniques to the probabilistic risk assessment of digital control systems. Digital control systems are being used in new, advanced nuclear power plants as well as being implemented in older plants as upgrades. The use of digital control systems has been accompanied by challenges in PRA modeling because of several, unique features related to these newer systems. Among these is the fact that current human reliability models and data were developed before the digital systems and thus may need modification in order to properly assess the risk of nuclear power plant operation and to determine the risk of PRA applications, including being able to assess the impact of upgrading to digital controls. This paper summarizes the EPRI HRA User Group activities as background information and summarizes the EPRI HRA User Group experience with the Halden benchmarking project, then suggests modifications to HRA methods and data in order to support assessments with digital controls.

Keywords: PRA, HRA, Digital Controls

1. INTRODUCTION

The purpose of this paper is to address issues and insights related to applying current human reliability analysis (HRA) techniques to the probabilistic risk assessment of digital control systems. Digital control systems are being used in new, advanced nuclear power plants as well as being implemented in older plants as upgrades. The use of digital control systems has been accompanied by challenges in PRA modeling because of several, unique features related to these newer systems. Among these is the fact that current human reliability models and data were developed before the digital systems and thus may need modification in order to properly assess the risk of nuclear power plant operation and to determine the risk of PRA applications, including being able to assess the impact of upgrading to digital controls.

This problem is further complicated by the dynamic nature of human reliability analyses. Even before the introduction of digital controls much has been written of developing and applying human reliability analysis (HRA) methods in nuclear power probabilistic risk and safety assessments (PRA/PSA). Although we have 40-years of operating history for plants and nearly 30-years of analysis, HRA methods can produce significantly different results. These inconsistencies potentially affect the ability to develop insights and to make risk-informed decisions as part of PRA/PSA applications. In order to address these needs, the EPRI HRA Users Group was founded in the year 2000. Since 2000, the EPRI HRA Users Group has grown significantly to represent most of the USA power plants as well as vendors and international members.

The primary objective of the EPRI HRA Users Group is to develop a software tool, and to provide associated training and HRA guidelines which standardize the selection and application of HRA methods in developing human failure events into human error probabilities. There are two goals associated with this objective. The first goal is to obtain comparable human error probability results when evaluating human interactions of similar tasks on plants of similar design, training, procedures, and cues. The second goal is to improve the reproduceability and traceability of the human reliability analysis such that it clearly demonstrates compliance with the human reliability (HR) elements of the ASME/ANS Combined PRA Standard [1]. The long-term goal for the group is to enable and promote convergence on a set of common HRA methods.

As part of the long term goal, the HRA methods and data need modification to address the needs of current users (such as PRA modelers of advanced nuclear power plants) and also to address changes in the state-of-the-art in HRA. In helping to advance the state-of-the art in HRA, the developers of the EPRI HRA Users Group have participated in several joint projects with the US NRC, including an international study to benchmark predicted human error probabilities against empirical data collected on the Halden simulator. During the Halden benchmarking project, EPRI participated in both the assessment (control) group of the study and also (independently) as one of the groups predicting results.

This paper summarizes the EPRI HRA User Group activities as background information and summarizes the EPRI HRA User Group experience with the Halden benchmarking project, then suggests modifications to HRA methods and data in order to support assessments with digital controls.

This paper is organized as follows.

1. EPRI HRA Users Group Overview (mission, membership, activities, approach, and applications of HRA methods)
2. HRA Methods (selection, integration, and addressing dependencies)
3. Halden Benchmarking Experience (study overview and applicability to digital controls)
4. HRA Modifications for Digital Controls
5. Conclusions
6. References

2. EPRI HRA USERS GROUP OVERVIEW

EPRI historically sponsors many initiatives in the development of both probabilistic risk assessment (PRA) and human reliability analysis (HRA) tools and techniques to improve the consistency, quality and capability of nuclear power plant PRAs and HRAs in the United States, and in member countries internationally. Scientech has collaborated with EPRI, utilities, and other industry participants; and has been a key contributor in support of these efforts. Scientech has developed new tools and techniques, and has also put into practice many of these initiatives. One such initiative that started in the year 2000 was to establish the EPRI HRA User Group. The EPRI HRA User Group facilitates the standardization of the HRA process through development of an EPRI HRA Calculator® software tool. The EPRI HRA Calculator® is a software tool to quantify and document individual human error probabilities, and to automate a substantial part of the dependency analysis for PRAs. One of the main objectives in developing the EPRI HRA Calculator® was to demonstrate compliance with the ASME/ANS Combined PRA Standard [1] as implemented by USNRC Regulatory Guide 1.200 [2].

During the US Individual Plant Examination era, when every US plant was required to develop a plant-specific PRA, EPRI HRA projects focused on developing a framework for conducting a human reliability analysis [4, 5] and on the development of cognitive HRA methods [6, 7] to complement the USNRC methods [8, 9]. These efforts were conducted between 1984 and 1992. In the year 2000 the EPRI HRA Users Group was formed with a different focus. The new focus was to develop a consistent approach to HRA based upon the strengths of existing methods used in the United States nuclear power industry.

<u>Mission</u>. The primary objective of EPRI HRA User Group is to assist the industry in converging on a consistent, common approach to human reliability in order to enable different analysts to obtain comparable results when using similar inputs. The specific objectives of the EPRI HRA Users Group are listed below.

1. Allow the HRA models to produce consistent, realistic results through development of a software tool.

2. Help assure the HRA receives addresses supporting requirements of the ASME/ANS Combined PRA Standard in order to develop quality analyses as confirmed during industry PSA Certification Reviews.

3. Coordinate the development of HRA methods with other groups such as the USNRC, for example spatial/external events, severe accident management, and shutdown.

4. Provide the capability to electronically interface HRA results through the EPRI R&R Workstation for input to PRA Tools (such as CAFTA, WinNUPRA, RISKMAN, and Risk Spectrum).

Membership. The members of the EPRI HRA / PRA Tools User Group direct the development of the EPRI HRA Calculator®. Since 2000, the EPRI HRA / PRA Tools Users Group has grown to represent all of the USA nuclear power plants in the United States, complemented by the US Nuclear Regulatory Commission and corporate members (AREVA-Framatome, Bechtel-Bettis, Rolls Royce, Westinghouse, and Scientech). Additionally, the EPRI HRA Users Group has included international members such as members EdF-France, EPZ-Netherlands, ESKOM and PBMR-South Africa, RELKO-Slovakia, Angra-Brazil, UNESA-Spain (representing eight plants), KEPCO E&C-Korea and the CANDU Owner's Group.

HRA Users Group Activities. The HRA Users Group conducts several activities annually. Each year starts with a user's group meeting where the priorities and plans for the year are established. The annual meeting also provides users a good forum to exchange "best practices" as well as "lessons learned" in the development and application of HRA. Additionally, guest speakers are typically invited to provide a presentation on a particular aspect of PRA. For example, for several years the HRA Users Group followed the human performance studies being conducted in Norway at the Halden Reactor Project.

For the first five years, the primary historical activity sponsored by the HRA Users Group was the development and improvement of the EPRI HRA Calculator® software [10]. This software tool assists the analyst in conducting the HRA of an individual basic event in a comprehensive, systematic approach designed to satisfy the requirements of the ASME/ANS Combined PRA Standard [1] as implemented by USNRC Regulatory Guide 1.200 [2]. Recently, this was supplemented by a module to automate and document the HRA dependency analysis. In the last few years, the focus on the EPRI HRA Users Group has been on joint EPRI/USNRC projects such as Fire HRA and Halden benchmarking. For 2012 and 2013 the primary technical focus of effort was to develop/refine HRA methods and to develop guidelines for the HRA modeled in Seismic and External Events PRAs [3].
The EPRI HRA Users Group also conducts one to two training sessions per year to allow PRA analysts to develop the skills to evaluate human interactions in a systematic, consistent manner.

HRA Users Group Approach. The HRA approach applied in the EPRI HRA Calculator® is summarized below.

- HRA Framework. The ASME/ANS Combined PRA Standard high level requirements nominally follow the EPRI SHARP and SHARP1 framework [4, 5], defining the fundamental process and framework for evaluating all types of human interactions. This framework has been incorporated into the EPRI HRA Calculator®.

- Human errors consist of two elements (generally): a cognitive element for detection, diagnosis, and decision-making; and an execution element modeling the manipulation or implementation of a task.

- Cognitive methods. The EPRI Cause-Based Decision Tree Method (CBDTM) [10] is the default method, and either the Human Cognitive Reliability/Operator Reactor Experiments

(HCR/ORE) [10] or the ASEP time-reliability correlation methods [9] is used for time-critical actions.

- Execution modeling. Techniques for Human Error Rate Prediction (THERP) [8] for quantification of execution errors of omission and commission is the approach for both latent (pre-initiator) human interactions as well as dynamic (post-initiator) human interactions. Additionally the Accident Sequence Evaluation Procedure (ASEP) [9].

- Recovery. Both cognitive and execution errors have the potential to be mitigated by recovery actions.

- Dependency between Human Failure Events. The software tool also has a module to support the dependency analysis, identifying combinations of operator actions within the same cutset(s), calculating the importance of the combination, flagging where operator actions overlap in time, and applying rules to provide suggestions on levels of dependence.

- The EPRI HRA Users Group approach follows the ASME/ANS Combined PRA Standard high level activities for HRA (identification, screening, definition, quantification, dependency evaluation, and documentation)

This approach is conducted for all types of human failure events (HFEs), whether pre-initiator (latent) or post-initiator (dynamic). However, some elements may not apply to certain types of human failure events. For example, the cognitive portion is not applicable to latent (pre-initiating event) human errors such as miscalibration and restoration failures. The software has developed and matured since 2001 and the current software [10] addresses dependency modeling between human failure events and adds the capability to conduct SPAR-H modeling [11].

<u>HRA Users Group Applications</u>. PRAs in the USA are used as a tool for day-to-day operations, and additionally for licensing considerations (such as for the evaluation of risk-informed prioritization and risk-significance). The EPRI HRA Calculator® has been used in the following applications of a typical PRA analyst.

- PRA Update – quickly and consistently update the HRA models for internal events, and also to support the development of Fire PRA and External Events PRAs.

- Configuration Risk Management and Significance Determination Process (SDP):
    - Update/alter existing HFEs based on current plant deviations from the "average" PRA model.
    - Add new recovery actions for scenarios.

- Training – through the identification of PRA-important scenarios and procedures.

- PRA Quality Certification Review – to develop consistent, traceable HRA documentation that can be easily shown to comply with PRA standard requirements.

- Evaluate Licensing Issues - such as the impact of plant design modifications on human errors or the impact of timing/ instrumentation changes on the PRA.

- Prioritization such as for component design basis inspections.

- Significance Determination Process - the ability of the EPRI HRA Calculator® to evaluate human error probabilities (HEPs) via multiple methods provides insights that have been useful during SDP events where none of the individual methods provides an exact fit to the situation.

As shown above, PRA models are being employed in a wide variety of applications. These applications have typically led to a wider audience and closer scrutiny of the HRA by both plant and regulatory reviewers. Feedback from these reviewers has identified limitations in current HRA methods and techniques. This led the EPRI HRA Users Group members to initiate activities to verify and validate the approach and results of the methods used in the EPRI HRA Calculator®. The approach is to examine how well the results and insights obtained from using the EPRI HRA Calculator® compare with those obtained from other methods using insights from the Halden Reactor project. This project started in 2006 and was conducted jointly with the USNRC and their research laboratory partners such as Sandia and Idaho National Laboratories.

3. HRA METHODS

This section summarizes the selection and integration of HRA methods in order to support the different types of operator actions being modeled in a typical PRA (e.g. latent errors and post-initiator operator actions of a Level 1 PRA). The intent was to produce a "tool box" of methods within the EPRI HRA Calculator® software to best fit the type of operator action and the performance shaping factors. The integration of these methods required some evolutionary, minor modifications to methods in order to apply these methods in a consistent manner and to address lessons learned during the last 20 years. The selection and integration process is summarized below.

HRA Method Selection and Integration. This section summarizes the selection and integration of methods, a method to address dependencies, and considerations for methods when looking beyond internal events.

Execution errors are modeled for both pre-initiator operator actions (human interactions) as well as post-initiator operator actions. For quantifying post-initiator execution errors, the user identifies the critical steps in the applicable procedure then enters the data into the software. The nominal HEPs and performance shaping factors such as stress associated with each procedural step are selected from built-in THERP tables [8]. The final step in the execution modeling considers recovery. The modeling of latent (pre-initiator) operator actions also follows this approach, or a very similar one to implement the ASEP method as outlined in NUREG/CR-4772 [9]. However, the THERP implementation was supplemented by lessons learned and refinements in approach based on 20 years of usage. The following changes were made in the implementation of THERP in the EPRI HRA Calculator®.

- Errors of Omission. The errors of omission values from the THERP tables are divided by three based on notes in Chapter 15 of the THERP handbook [8]. These notes describe adjustments to the nominal Swain values, in particular to credit the layout of the procedures into a "response/response not obtained" format.

- Errors of Commission. An entry was added into the table for selection errors in the control room, for switches or controls that unique or distinct from all others (such as if the safety injection actuation switch has a cover and is painted a different color than its surroundings). The failure probability for this type of switch is "negligible". This addition is based on Swain's HRA course notes where it was explained that this was an oversight in the original text.

- Converted Medians to Means. The median HEPs presented in the THERP tables were converted to mean values as means can be propagated mathematically while medians can not, to produce an overall point estimate.

- Selection of Stress. THERP contains a table with low, moderate, or extreme stress levels. The EPRI HRA Calculator® software contains an additional decision tree that looks at objective performance shaping factors such as complexity, plant responding as expected, and environmental conditions to reduce the subjectivity in developing stress factors.

The EPRI Cause-Based Decision Tree Method [7] (CBDTM) is the default approach to modeling and evaluating cognitive errors (those associated with the detection, diagnosis, and decision-making of the operator action). This method systematically looks at four failure mechanisms for the man-machine interface, and four more for the man-procedure interface. Evaluating post-accident cognitive errors is implemented as on-screen, interactive forms that the user fills in. The user enters context information such as the PRA scenario (initiating event and the sequence of successes and failures that have occurred up to the point where the modeled action is in the model). The user also enters subjective information such as the procedures used, timing data, and cues.

The user then reviews each decision tree one at a time and selects the appropriate branch associated with each failure mechanism, from a drop-down type list box. For example, if the information is misleading and there is not training or warning of this condition then the human error probability for that particular failure mechanism will contribute to the total. For each failure mechanism, the user is able to select a recovery factor (also from a drop-down list). Based on the data entered, the cognitive error probability is calculated with and without recovery. The changes summarized below were made in the implementation of the EPRI CBDTM in the EPRI HRA Calculator®.

- Limitations on the Amount of Recovery. While the original method allows for multiple recoveries of each failure mechanism, the EPRI HRA Calculator® suggests limiting recovery to one mechanism. This is to prevent over-crediting recovery and to promote defensibility. Note the software does allow an over-ride for those longer time frame scenarios where multiple recoveries are justifiable. These limitations are being reviewed and revised to allow consideration of multiple recoveries when the time available is long (e.g. several hours).

- Recovery Credit Automatically Considers Time Available. Each of the cognitive failure mechanisms considers five recovery mechanisms: self-review, extra crew, shift technical advisor (STA) review, shift change, and Technical Support Center/Emergency Response Facility (TSC/ERF) review. Based on the timing data entered, recovery mechanisms that take a longer time to implement (such as shift change or TSC/ERF) are not allowed if the time available is too short.

- Recovery Dependency. The amount of credit given to some of the recovery factors is a fixed value (e.g. 0.5) and a variable value for others (e.g. X), where X is a function of dependency. The EPRI HRA Calculator® implements the THERP dependency levels for X based on the time available for recovery.

Cognitive errors for immediate actions or time-critical actions should also be quantified using the EPRI HCR/ORE method [7]. Quantifying post-initiator cognitive errors using the HCR/ORE correlation also follows on-screen, interactive forms. The user enters additional information such as the duration of time window available, the median response time, the manipulation time, and the variation between crews. The following changes were made in the implementation of the EPRI HCR/ORE method in the EPRI HRA Calculator®.

- Deletion of HCR. The original HCR method [6], a pre-cursor method to the HCR/ORE, postulated a correlation between the HEP and the type of action (skill, rule or knowledge-based), but this was not borne out based on simulator experiments. Instead, a correlation was found between the HEP and the cue-response structure, which became the HCR/ORE correlation.

- Low HEPs. When the time available for an action is very long, the HCR/ORE method often produces HEPs that can be extremely low (e.g. lower than 1E-7). The EPRI HRA Calculator® limits the HEP result to a lower bound that is specified by the analyst (typically 1E-4). On the other end of the spectrum, the maximum HEP by this method is limited to 0.5 Thus, if the time available exactly matches the time required, then the HCR/ORE method produces an HEP of 0.5. This HEP may be too conservative for very well practiced actions such as manual reactor trip. For both of these cases, it is recommended that the CBDTM also be applied, and the most appropriate HEP selected for usage.

- Development of Sigma. It was postulated in the HCR/ORE development that the variation between crews was a function of performance shaping factors for procedures, training, stress, and time available for recovery. This also was not proven during the simulator experiments and has been removed from the approach.

Dependencies. Dependencies within a HFE (through recovery modeling) are addressed in both the cognitive and execution models via THERP zero, low, medium, high, complete levels of dependence based on performance shaping factors such as time available. Dependencies between HFEs are addressed in the documentation process during the qualitative identification and characterization of the human failure event, which allows for links such as common cognitive elements between HFEs. Once the HFEs are modeled, the most recent version of the EPRI HRA Calculator® (Version 5.0) employs a new tool to identify and evaluate combinations of HFEs. This version has the capability to import and filter cutsets from WinNUPRA or CAFTA or RISKMAN, and to use newly developed importance measures to focus the dependency analysis process. Once the combinations of events have been identified then the dependency level is evaluated using a similar approach to that used within an HFE (e.g. zero, low, moderate, high or complete). The HRA Calculator software facilitates the efficient conduct of the dependency analysis portion of the HRA through the identification of sequences of multiple HFEs and the evaluation of their importance.

4. HALDEN BENCHMARKING EXPERIENCE

Benchmarking Study Overview. Reference 12 provides a detailed overview of the Halden benchmarking study. A summary of that paper has been reprinted below. The Halden benchmarking study evaluated the ability of a set of HRA methods to predict the human performance observed in a simulator. The assessment was based on the following:

- Predictive HRA analysis, performed without knowledge of the experimental results
- The collection of empirical data through simulator experiments
- A comparison of the experimental results with HRA method predictions

The overall design of this study was to divide the effort into two portions – the first portion being the HEP predictions and the second portion being the development of the empirical data. In the initial (pilot) phase, twelve (12) teams of HRA analysts participated. The collection and analysis of simulator data was performed by Halden reactor staff. The comparison of HRA predictions with experimental outcomes was the responsibility of the assessment group.

The Empirical Study has been conducted in three phases. Phase 1 was a pilot to test the study methodology. In Phase 1, the HRA teams performed HRA analyses to predict human error probabilities for nine (9) human failure events (HFEs). The first sets of scenarios were two variations of Steam Generator Tube Rupture (SGTR) scenarios, one scenario was a simple SGTR case and the other scenario was a complex SGTR case. All the empirical data was collected during Phase1, but only two HFE comparisons were conducted. In Phase 2, the remaining SGTR HFE and HEPs were evaluated for qualitative as well as quantitative insights. During Phase 3, feed and bleed HFEs were evaluated. The first two phases were designed to pilot the approach and to allow the study participants (Halden, assessment/evaluation group, and the HRA teams) to review the study methodology and the initial results and, in particular, the HRA teams to provide feedback on the methodology. A workshop on the first pilot phase was held in October 2007 and the second phase in March 2009. This first phase is documented in a Halden Working Report (HWR) [13] and an associated international NUREG report [14]. The overall design of the study is summarized in [15].

Human Error Probability Predictions. Most existing HRA methods were initially developed to model the impact of operator actions in the context of PRAs/PSAs of nuclear power plants. However, some HRA methods only provide methods and guidance to conduct the quantification of an HEP and do not address other aspects of the HRA process such as HFE identification. The current study focused on the analysis in support of estimating the failure probability of an HFE (including the qualitative analysis performed in support of this quantification) but not on the identification or definition of the HFEs.

In Phase 1, EPRI used the Cause-Based Decision Tree and THERP method. The insight from this phase was that the blended EPRI HRA approach (CBDTM supplemented by HCR/ORE) was better, especially for time-limited HEPs. The blended EPRI HRA approach was then used for the remaining SGTR and Loss of Feedwater in Phases 2 and 3. The March 2009 workshop showed that the EPRI predictions matched well the overall magnitude and trend in the HEPs (meaning that the easier HFEs had lower HEPs empirically, and this matched the EPRI predictions). The Phase 3 evaluations are currently ongoing.

Study Insights. The first phase was only used to develop insights into the method and the approach, and not the HRA methods. The first phase of established a methodology for an assessment of HRA methods based on empirical data obtained in a simulator study. The experience, feedback, and results show that the developed methodology is working fairly well. Some considerations for improvements were identified and implemented in Phases 2 and 3. The comprehensive reports on the first phase of the empirical study, revised to account for the feedback and inputs obtained from the study participants during and following a workshop, are available for review [13, 14].

Phases 2 and 3 were initiated in 2008. Phase 2 consisted primarily of completing the comparisons based of the SGTR scenarios. These comparisons addressed the quantitative HRA predictions as a measure of the level of difficulty associated with the complete set of HFEs. The methodology for the comparison of the HRA quantitative results with the data will be tested. By addressing more HFEs and an additional set of scenarios (the two LOFW variants in Phase 3), these phases are also intended to allow a more conclusive, broader-based assessment of each method. In particular, it is important that the assessment of each method’s performance are based on a more representative set of operator actions, reflecting more of the range of actions and performance conditions that need to be addressed in a PRA.

The results of the Halden empirical study to date have demonstrated the value of performing comparisons of HRA predictions with empirical data. For instance, the pilot has identified specific areas where additional guidance for HRA would be beneficial, notably in the scope and detail of the qualitative analysis. Other sources of variability in HEPs were not addressed in the international empirical study. One example is the variability among teams applying a given method, which would require a study design with multiple teams applying each method. This study was undertaken in the USA but the results have not yet been published.

5. HRA MODIFICATIONS FOR DIGITAL CONTROLS

Issues. Incorporation of digital control systems into plant operations has the potential to significantly improve plant response. There are several design features that have the potential to assist the operators in determining and conducting the correct response. For example, digital systems that include error checking between channels and those that link the instrumentation to the procedures are designed to assist in diagnosing system and plant performance. Potentially offsetting these improvements, however, is the potential for the new systems to also present new failure modes. For example, if the operators develop an over-reliance on the digital controls or if there is some form of common cause failure that affects both the instrumentation and the indication of what procedure should be executed. In these examples it may be harder for the operator to recognize the error, and recovery of the initial operator failure may need to be limited or removed. These operator errors could occur if there is an error or system failure that is not readily apparent such as a software operating system error or coding error. Additionally, there may be new failure modes (or a change in error rates for existing error modes) related to selection of controls, or selection errors in reading indications. For example, some system designs may have controls that have the same "look and feel" for all components. Similarly, some displays may not distinguish between safety and non-safety components. These issues are related to the HRA of the dynamic operator actions which occur in response to an initiating event.

Some new operator actions also may need to be included in the PRA to model test/maintenance of these systems that could be latent human errors. Additionally, the "hardware" failure rate related to digital control systems needs to address potential software issues in addition to the traditional mechanical and electrical faults.

Insights. The current HRA approach and models apply to systems with digital controls, but some additional modifications and considerations must be employed. First, the HRA process framework consisting of identification, definition, qualitative analysis and quantification still applies. The use of cognitive and execution elements as contributing to each human failure event still applies. The four man-machine interface mechanisms in the EPRI CBDTM also apply but may have new failure modes related to digital controls. Similarly, the four man-procedure interface mechanisms in the EPRI CBDTM also apply but may have new failure modes related to digital controls. The impact of digital control systems appears primarily in control stations such as the main control room, such that execution actions performed outside of the main control room in the plant are unaffected. The Halden project showed the importance of a good qualitative analysis conducted on the first principles of understanding the PRA scenario and associated plant context, followed by the plant systems and operator response given the scenario; and this applies to plants with digital controls. Current HRA methods can be used to assess HEPs while additional research and operating experience accumulates more data and insights. However, probabilistic risk assessments of plants with digital control systems should conduct a range of uncertainty and sensitivity evaluations in order to assess the potential impact of changes to operator failure rate data or new failure modes. For example, varying the amount of recovery credit and varying the assessed level of dependence between operator actions.

6. CONCLUSIONS

EPRI in collaboration with Scientech has been at the forefront of the development of analytical tools and methods for use in HRA. The objective of these analytical tools is to improve human error modeling techniques in PRAs and thereby improve understanding of nuclear plant safety. These projects are developed under the direction of EPRI and Scientech, with the participation of utilities, industry experts, and researchers.

The EPRI HRA User Group developed the EPRI HRA Calculator® software as a tool to provide a standardized approach to HRA. The EPRI HRA Calculator® incorporates the most widely used HRA methods into an analytical tool that provides a comprehensive and well documented approach to HRAs. Version 5.0 of the EPRI HRA Calculator® has recently been released. This version of the EPRI HRA Calculator® interfaces seamlessly with other PRA tools such as CAFTA and WinNUPRA, and with other tools via a comma separated value file. Version 5.0 also facilitates the efficient conduct of the dependency analysis portion of the HRA through the identification of sequences of multiple human interactions and the evaluation of their importance.

The EPRI HRA Users Group has grown to represent all nuclear plants in the United States and includes the US Nuclear Regulatory Commission as a user. Additionally, the EPRI HRA Users Group has seen strong corporate and international growth. The EPRI HRA Calculator® has been successfully used in an HRA update at dozens of plants. Additionally, several plants have used the HRA

Calculator® to develop and document the HEPs of recovery events that were added to the PRA model in support of a Phase 3 significance determination process (SDP) evaluation where a quick, comprehensive, consistent evaluation was necessary.

Feedback from the users of the EPRI HRA Calculator® has proven that the software is a valuable tool for the consistent development and documentation of human error probabilities. The work of the EPRI HRA Users Group is focusing on evaluating existing EPRI HRA methods with empirical data from Halden, and developing HRA guidelines to support fire, seismic and external events analyses.

Future HRA work is planned to address digital control systems and other HRA issues such as shutdown HRA and severe accident management guideline implementation. Current HRA methods and data can be used to assess HEPs while additional research and operating experience develops new data and insights. However, probabilistic risk assessments of plants with digital control systems should conduct a range of uncertainty and sensitivity evaluations in order to assess the potential impact of changes to operator failure rate data or new failure modes. For example, varying the amount of recovery credit and varying the assessed level of dependence between operator actions.

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