SACADA Data for HEP Estimates

Yung Hsien James Chang[a], Carmen Franklin[a]
[a] U.S. Nuclear Regulatory Commission, Washington DC, USA

Abstract: The Scenario Authorizing, Characterization, and Debriefing Application (SACADA) software was developed to collect nuclear plants' operator performance information in simulator training to provide data basis to inform human reliability analysis (HRA), specifically human error probability (HEP) estimates. The software supports HRA as well as operator training to achieve objectives of assessing human reliability and improving human reliability. The U.S. Nuclear Regulatory Commission (NRC) sponsors the SACADA software development aiming the software to be regularly used by nuclear power plants (NPPs) in operator simulator training. To achieve this objective, the software provides functions to facilitate operator simulator training such as authoring simulation scenarios, facilitating post-simulation debriefing, expediting crew performance communication, and exporting information for statistical analysis of crew performance. The intention is that NPPs use the software for operator training and share the collected performance information with the NRC for HRA. Since the first version of the software piloted by an NPP in 2012, the software has been used by a few NPPs inside and outside of the United States. In 2017, the NRC awarded contracts to three contractors to perform an independent analysis of the available SACADA data to propose methods of using SACADA data to inform HEP estimates. The contractors presented their proposed methods in an international HRA data workshop on March 15 and 16, 2018 at the NRC headquarters at Rockville Maryland. This paper discusses the SACADA program, a summary of the methods proposed by the three NRC contractors, and the NRC ongoing and planned HRA data activities.

Keywords: HRA, HEP, data analysis Simulator Training, operator performance.

1. INTRODUCTION

In 1995, the U.S. Nuclear Regulatory Commission's (NRC) issued a policy statement on the use of probabilistic risk assessment (PRA) methods in nuclear regulatory activities [1]. The policy statement includes "the use of PRA technology should be increased in all regulatory matters to the extent supported by the state-of-the-art in PRA methods and data" and "PRA evaluations in support of regulatory decisions should be as realistic as practicable and appropriate supporting data should be publicly available for review". Public comments on the draft policy expressed concerns about the NRC might burden NPPs on data collection but with marginal benefits. The Commission agreed that it should make every effort to avoid any unnecessary regulatory burdens in connection with collecting reliability and availability data. As a result, there were no follow-on data collection requirements ever published. Collecting human performance data to support PRA at the time of the PRA policy statement [1] issued was difficult as stated in the commission paper SECY-94-219 [2] "the availability of human performance data is even more problematic. One reason is that lack of established and accepted human performance analysis methods and models upon which to base the collection of human performance data".

In 2004, the NRC issued a commission paper (SECY-04-0118) [3] that provided an action plan to implement a phased approach to PRA quality. SECY-04-0118 identified the development of the Human Event Repository and Analysis (HERA) [4, 5] system to collect operator performance information to support both human factors and HRA applications. Later, HERA operation was phased out and later replaced with the Scenario Authoring. Characterization and Debriefing Application (SACADA) [6] with emphasis on providing data basis to inform human error probability (HEP) estimates. HERA and SACADA are the two recent NRC's main human performance data collection projects to inform HRA. These two projects are discussed in section 2. In 2017, the NRC awarded three contractors to perform independent analyses of the collected operator performance information in SACADA database to propose methods of using the information to inform HEP estimates. The contractors' preliminary proposals were presented at an international HRA data workshop in March 2018 at the NRC headquarters [7]. Section 3 discusses the three contractors' proposals. Section 4 discusses the ongoing and planned SACADA activities with a summary in section 5.

2. HERA AND SACADA HISTORY

The HERA and SACADA projects are two recent NRC main HRA data projects with different emphases. The HERA project's objective is to collect operator performance information to support both human factors and HRA applications. The SACADA narrows down the objective to provide data basis to inform HEP estimates. This section discusses these two projects and the considerations of transitioning from HERA to SACADA.

2.1. HERA

HERA aimed to provide in-depth analyses of human performance events and to document the analysis results in an event repository for people who may interest in the information. Its data collection practice was to have researchers to review event reports and supplement materials of the nuclear events with significant human performance issues then reanalyzing the events to supplement the human performance details and re-documenting the events with an emphasis of human behavior and performance. The event analysis and documentation were performed according to the HERA taxonomy and quality requirements [4, 5]. An NRC in-house independent comparison of human performance information collected for the same event by HERA and documented in the ATHEANA technical report [8] showed that HERA collected all key information shown in the ATHEANA analysis. After completion, the information was stored in the HERA event repository.

The selection of events to be analyzed was primarily based on screening the licensee event reports that were relatively recent then and had significant human performance issues. The data repository was supplemented with safety significant events such as Brown Ferry fire [9] and Davis Bessette's reactor vessel head degradation [10]. As a result, all events in HERA repository have significant human performance issues. The events without significant human performance issues were not analyzed. Before the cease of HERA operation in 2011, there were about 20 events documented in HERA data repository.

Every HERA event was analyzed based a few reports typically at least including licensee event reports, the NRC's inspection reports (e.g., special inspection team reports and augmented inspection team reports), and the NRC's accident sequence precursor analysis. Example events are Brown Ferry fire in 1975 [9], Diablo Canyon "fire in the Unit 1 nonvital 12 kV non-segregated electrical bus and the loss of offsite power to certain 4 kV vital and nonvital buses" in 2000 [11], Fermi 2 "Automatic Reactor Shutdown Due to Electric Grid Disturbance and Loss of Offsite Power" in 2003[12], Fitzpatrick "Main steam relief valve failure" in 1996[13], Ginna "Loss of electrical load" in 2003[14], Indian Point 2 "Loss of electrical load" in 2003 [15], and Indian Point2 "Steam generator tube rupture" in 2000 [16].

Two types of worksheets (Worksheets A and B) were used by HERA event coders to document events. Worksheet A is an analysis of provides an event. Worksheet B is an analysis of a human response in the event, generally applied to analyze a human error. Information in Worksheet A for an event includes general information (e.g., reactor type and event date), event narrative, event timeline, general performance trend/issues in the event, and dependency between the human behavior of the event. The sub-events in the event timeline (e.g., system and human responses) in HERA were generally specified more detail than the event investigation reports. Labels were used to categorize each human sub-event such as human success, human failure, equipment actuation, equipment failure, contextual information, and plant state. Worksheet B provides detail analysis of each important human response in the event (human sub-event), both human success and human error. Information includes

- The job position of the individual(s) involved in the human sub-event
- Factors affect the success or failure of the human sub-event including plant condition
- The traditional performance shaping factors (PSFs) that could have positive or negative effects on human performance
- The primary macro-cognitive function of the human sub-event and the statuses of the PSFs defined in the SPAR-H HRA method [17] when the macro-cognitive function was performed.
- Error types

HERA event analysis document rich information relating to human performance with great detail. A drawback is a low information production rate. This is mainly because the typical event reports do not specifically pay attention to provide information related to human performance. To have the information documented, HERA coders need to have expertise in plant operation and plant system to supplement or guess the missing details. High demand and high hourly cost on the individuals with the expertise resulted in a relatively low production rate. During HERA operation the event was analyzed about at the rate of one event per month.

HERA information is beneficial to have a qualitative in-depth understanding of operator behavior and performance in responding to actual nuclear events to inform HRA. The information does not show clear way to inform HRA quantitatively mainly due to the lack of basic information to calculate a HEP, i.e., the numbers of success and failures of the human responses performed in the (supposedly) same condition. These issues motived the NRC to seek a different approach to collect operator performance information aiming at providing a quantitative basis to inform HRA.

2.2. SACADA

In August 2010, a workshop at the NRC headquarters aimed to identify better information sources than event reports to quantitatively inform HRA. The potential sources discussed included information in the NRC's operator licensing process (initial operator licensing exams, written exams, job performance measures and simulator exercise exams), the NRC's reactor oversight process (i.e., findings from the NRC inspections on NRC's licensees), operating experience, operator training and requalification exam conducted by NRC's licensees, and the CORE-DATA[18]. The workshop gave the sense that operator simulator training and exams were the data to go. Challenges of collecting information from operator simulator exercises in the NRC licensing process would be unable to affect the information to be collected and information won't be available until the exam completion due to exam security requirement. The main challenge of collecting NRC licensees' simulator training information was data sensitivity. The licensees were expected to be reluctant to share the information.

Between 2007 and 2011, the NRC jointed the other organizations conducted two large-scale HRA empirical studies: the international HRA empirical study [19-21] and the U.S. HRA empirical study [22]. The two studies had multiple operating crews performed simulator exercises to respond to a set of events in full-scope simulators. In parallel, multiple HRA teams applied various HRA methods to predict the operating crews' performance in these events. Soon after the August 2010 HRA data workshop, a manager of a U.S. NPP participating in HRA empirical study suggested the NRC work with the NPP to collect operator simulator performance information for HRA. This led to an agreement established between the NRC and the manager's NPP in March 2011 to start a research project to explore the collection of simulator data for HRA. The NRC sponsored a team with the expertise of cognitive engineering, HRA, and probabilistic risk assessment (PRA) to work with the NPP's instructors (i.e., operator trainers) to develop a system that could be used by the NPP's training department to collect operator performance information in simulator training. It was quickly realized that the system to be developed needed to be beneficial to operator simulator training. Without benefit to operator training, the NPP's training department won't put resource into the project. This set the direction to have the system's primary users as the NPPs' training and operations departments, and the plant staff would enter crew performance information into the system, not researchers.

The requirement of being beneficial to operator training directed the development of the data taxonomy to inform HRA as well as improve operator training. The information to inform HRA and to improve operator training is different in several aspects. HRA (specifically HEP estimates) is a predictive analysis. It is to estimate the probability of a typical operating crew failing to perform a task. The required information includes the context of performing the task and the successes and failures of performing the task. The context typically is represented by a set of performance shaping factors (PSFs). The context is specified before performing the simulation. The success and failure are determined after the simulation is complete. On the other hand, improving operator training is a retrospective analysis. The information collected should enable the instructors to identify the performance issues to the level of detail that an effective method to address the performance issues can be specified. As a result, SACADA data taxonomy [6] was developed that included predictive information (context) and retrospective information (performance results). This was a unique approach.

Each SACADA data point is a training objective element (TOE) specified in the operator simulator training. A TOE example is to detect the loss of emergency cooling water (ECW) in an ECW pump failure event. To successfully respond to an ECW pump failure event, a number of TOEs need to be performed such as tripping the emergency diesel generators cooled by the ECW. Each TOE contains predictive information (context) and retrospective information (performance results). The TOEs' context information is provided by the instructors who author the scenarios. The context information typically is provided after the scenario dry run (performed by the instruction crew) but before running the scenario to an operating crew. This context information of a TOE is identical to all crews run the TOE. Only when there is an across-the-crew indication that mismatches between the instructor-specified context and the actual context, the instructor specified context would be revised; otherwise, the context of TOEs will remain not changed. The TOE performance result is entered after a crew is done with the simulation. Different crews could have different performance results of performing the same TOE in the same scenario. With the combination of the context and performance results, the context-similarity data analysis approach [6] can be used to identify the TOEs that have the same context to be grouped together to provide statistical indications of human performance. The context-similarity approach was adopted by the three NRC contractors to develop their data analysis proposals.

Able to support operator simulator training is essential for the SACADA project able to continue. To support operator training, the participating NPPs provided great input to develop SACADA software for the training departments to perform their jobs more efficiently. SACADA software provides a graphical user interface for the instructors to conveniently author simulation scenarios, conduct a post-simulation performance review, generate output for administrative and technical purposes, and promptly notify managers about crew performance to improve management's awareness of crew performance, etc. Operator simulator training is operated in a time constraint environment. This affects the quantity and details of the information able to be practically collected. SACADA software implements a number of neat features to maximize the information collection. Success in the above effort is demonstrated by that the NPP partnering with the NRC to develop the SACADA system has implemented SACADA software in its operator simulator training since 2012 and has a very positive user experience. All the above is to say that SACADA supports two HRA goals: assessing the human reliability and improving human reliability (achieved by improving operator training). Achieving the two HRA goals simultaneously is a unique feature that differentiates SACADA from other HRA data collection projects. This unique feature also gives SACADA a good foundation to operate for a long time. As long as the NPPs in operation, the operator training will continue. This generates data for SACADA. This gives a potential that SACADA could be able to collect a large number of data points to support quantitative HRA.

3. USE OF SACADA DATA TO INFORM HEP ESTIMATES

Demonstrating SACADA data's usefulness to inform HEP estimates was presented at two NRC hosted HRA data workshops in 2015 and 2018. Both demonstrations were presented at the international HRA data workshops held at the NRC headquarters. In 2015 and 2018, about 7000 and 25,000 data points were used for the demonstrations, respectively. A data point is a TOE run by a crew. In SACADA, each data point contains information of context, performance results and performance analysis. Data mining is expected to generate many types of quantitative performance indications for HRA. The 2015 demonstration was performed by NRC staff and later presented in PSAM 13 conference [23]. The 2018 demonstration was performed by three NRC contractors. They performed analysis independent of each other. Their proposed methods of using SACADA data for HEP estimates are presented in this conference [24-26]. These proposals are discussed in this section.

The process of using SACADA data to inform the HEP estimate of a human failure event (HFE) can be summarized in three steps. The first step is to identify the critical tasks of the HFE. The definition and identification of critical tasks can be found in the IDHEAS-Internal Event At Power method [27]. The critical tasks in SACADA are the TOEs critical to the success of responding to the malfunction. The second step is to specify the context of each critical task. In this step, the SACADA taxonomy should be used to specify the critical tasks' context. The context includes the type of cognitive function and PSFs. SACADA specifies four types of cognitive function: detection, diagnosis, deciding, and action. An additional cognitive function of external communication for extensive communication between the staff inside and outside of the main control room was added for operator training purpose. For each type of cognitive function, two classes of PSFs are specified including overarching PSFs and cognitive-function-specific PSFs. The overarching PSFs (e.g., workload and time constraint) affect all cognitive functions. The cognitive-function-specific PSFs only affect a specific cognitive function. For example, the status of alarm windows only affects the reliability of detecting an alarm. It does not affect the other cognitive functions. Proposals to use SACADA data to inform HEP estimates based on context are discussed in [24-26]. The final step is to adjust the HEPs obtained from Step 2 in a simulated environment to HRA (actual event environment). Considerations for the HEP adjustment include differences between operator performance in a simulated training environment (SACADA data) and actual events (HRA) such as task success criteria, crew composition, and stress level, etc. as discussed in [28].

The proposed use of SACADA data to inform HEP estimates [23-26] focus on informing a critical task's HEP (the Step two discussed in the previous paragraph). Chang et al. [23] propose three ways to use SACADA data:

- Context-specific performance indications: A critical task's HEP is calculated based on the number of TOEs in the SACADA database that has the same context characterization as the critical task of analysis. The ratio of the TOEs dispositioned with unsatisfactory performance to the total number of TOEs is a quantitative indication to inform HEP estimates. This is a direct way to use SACADA data to inform HEP estimates. A key weakness of this approach is that the number of TOEs with the same context as the critical task may not be sufficient to provide quantitative indications with sufficient statistical significances.
- PSF effects: Comparing two TOEs with context different in one PSF's status, their ratios of having unsatisfactory performance provide an indication of the PSF's effect on performance. For example, changing the type of diagnosis from rule-based to knowledge-based would change the ratio of having unsatisfactory performance. The difference in the ratio of having unsatisfactory performance is a quantitative indication of the effect of changing diagnosis basis from rule-based to knowledge-based. A PSF's effects could be dependent on the statuses of the other PSFs. HERA data provide context-specific PSFs' effects on human performance. The enables to search for the cliff effects in PSFs combinations. This is more detail than the conventional HRA methods only have a fixed effect for a PSF status.
- Overall difficulty effect: This is using a single difficulty indication to identify the relationship between difficulty and HEP as suggest by psychological literature [17]. In the case, the level of difficulty is simply represented by the number of negative PSF statuses. The expectation was that the HEP would increase slowly as the number of the negative PSFs increases. When reaching a threshold number of negative PSFs, HEP suddenly increases significantly as the

number of negative PSF increases. The HEP change ratio reduced again when the number of negative PSFs reaches the second threshold. This expected behavior was not observed in [23].

Pamela et al.[26] and Katrina et al. [25] proposes using Bayesian Belief Net (BBN) technique to inform a critical task's HEP estimates. On-the-shelf software is available to input SACADA data to generate a large relation table that specifies the quantitative relation between the PSFs' statuses and the ratios of unsatisfactory performance. This approach seems promising for the use of SACADA data to provide quantitative indications to inform HEP estimates. Two considerations of this approach are: (1) The software requires prior distributions to combined with the evidence (i.e., SACADA data) to generate poster distribution (of unsatisfactory performance ratio). The prior distributions need to be specified properly so the SACADA data have proper effects on the posterior distributions, and (2) Many PSFs' statuses combinations do not have data. The proposal of Azarm et al, [24] uses statistical significance tests to determine whether similar-but-not-exactly-identical PSF combinations can be used to represent the performance of the SFs combination with an exact match to the critical task of analysis. Azarm's proposal [24] would be useful in the contexts where SACADA does not have sufficient data.

4. PATH FORWARD

Ensuring data consistency, increasing data quantity, enlarging data coverage and demonstrating data use for HRA and operator training are the four key areas of the SACADA program. The SACADA operation model is that each participating NPP has their own onsite SACADA database. The NPPs send a copy of their data (only the portion relevant to inform HRA) to the SACADA database sponsored by the NRC. The master database data will be used to inform HRA. The data are from different NPP. Even within the same NPP, personnel change would change the individuals to enter data. Ensuring data consistency refers to that the information entered by different plants and different people is entered in a consistent manner to ensure consistency in the master database. To ensure consistency, the NRC requests that the new users receive a NRC-provided two-day training. An NPP instructor experienced in using SACADA would be the primary instructor to deliver the training. This is to establish a good foundation for data consistency. Other mechanisms to improve data consistency include providing technical support to the participating NPPs and supporting the participating NPPs or corporates to establish their own internal SACADA training course.

Increasing data quantity refers to increasing the number of NPPs participating in the SACADA program. This would increase the data inflow rate to the SACADA master database. Because the main users are the NPPs' training and operations departments, the SACADA's strong emphasis on facilitating operator training has a great impact on user acceptability. The NPPs that piloted SACADA software have chosen to continue to use SACADA after piloting the software. This indicates that SACADA software's benefits to operator training are appreciated. The main work in this area would be to outreach to more NPPs to pilot and use the software.

Enlarging data coverage has two implications. The first implication is that analyzing SACADA data may found that certain contexts (i.e., PSF combinations) have little data. This indicates that the operator receives less training in these contexts. The information is beneficial to NPPs to identify the less exercised contexts to perform training in these areas. This also increases the coverage of contexts in the available SACADA data. The second implication is that currently SACADA only collects operator performance information in simulator training. The operator performance information in the actions performed outside of main control room (e.g., job performance measures and deploying portable equipment) and responding to actual events are important to collect. Methods to collect operator performance information in these areas to support both operator training and HRA have not been developed. The NRC is planning to work with NPPs to develop method and tool to collect information in these areas.

Demonstrating data usefulness for HRA and operator training refers to two primary HRA functions: assessing the human reliability and improving human reliability. Assessing human reliability is to provide data basis for HEP estimates in HRA. Section 3 of this paper discusses various ways that SACADA data can be used to quantitatively inform HEP estimates. Improving human reliability is not mentioned in HRA often. However, it should be an important HRA mission to use the analysis results to improve human reliability. SACADA software provides functions to facilitate operator training and improve human reliability as mentioned in section 2.2 of this paper. For example, after saving the crew performance information into the database, the software automatically emails crew performance information to plant managers if there is crew performance met the specified criteria. This improves management awareness to take timely actions if necessary to improve crew performance. The data can be analyzed to identify the contexts in which the TOEs are less exercised, and the TOEs or TOEs or TOEs in certain contexts in which the crews require more training. This knowledge is carried in the SACADA database as part of knowledge management to support a more performance-informed training.

5. SUMMARY

The SACADA's data collection approach is innovative. The differences in comparing with common data collection approaches are shown in Table 1. It aims to be a long-term sustainable data collection program. For an NPP user, SACADA would be used to collect data as long as the NPP training its operating crew. The information frequency of SACADA is consistent with operator training cycle of an NPP. Each year, an operator normally has five to six training cycles. Common HRA data collection methods have the same frequency but typically performed only for a selected time interval. As a result, the SACADA data quantity is expected to be much larger than the other projects. This enables SACADA to practically collect a large number of data points. The individuals to enter data into SACADA databases are plant staff versus the other data collection projects typically use researchers as data enterers. This approach enables SACADA to be practical to operate for a long period of time.

Therefore, it puts great emphasis to provide functions to facilitate and improve operator training so the NPP would like to use on a regular basis. This operation style differs from the traditional data collection methods that data are collected and entered into the database by researchers. Using researchers to collect data has the benefits that data can be collected at a very detail level. But the drawback is that the project typically only lasts for a few years and the collected number of data number are limited.

Table 1. The key differences between SACADA and the common data collection methods

	SACADA	Common HRA Data Collection
Operation Duration	As long as the plants are in operation	Typically, last for a few years
Information collection frequency	Continuously as long as there is crew training taking place	Periodically or only for a certain time interval
Data quantity	Large	Limited
Information Enterer	Plant staff	Researchers
Inform HEP estimates	Yes	Yes
Improve operator training	Yes	No

References:

[1] U.S. Nuclear Regulatory Commission, Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities; Final Policy Statement, Federal Register, Vol. 60, No. 158. 1995.

[2] U.S. Nuclear Regulatory Commission, Proposed agency-wide implementation plan for probabilistic risk assessment (PRA), SECY-94-219. 1994.

[3] U.S. Nuclear Regulatory Commission, Plan for the Implementation of the Commission's Phased Approach to Probabilistic Risk Assessment Quality, SECY-04-0118 (https://www.nrc.gov/reading-rm/doc-collections/commission/secys/2004/). 2004.

[4] Hallbert, B.P., et al., Human event repository and analysis (HERA) system, overview, U.S. Nuclear Regulatory Commission, NUREG/CR-6903, Vol. 1. 2006.
[5] Hallbert, B.P., et al., Human event repository and analysis (HERA): The HERA coding manual and quality assurance, U.S. Nuclear Regulatory Commission, NUREG/CR-6903, Vol. 2. 2007.
[6] Chang, Y.J., et al., The SACADA Database for Human Reliability and Human Performance. Reliability Engineering & System Safety, 2014(125): p. 117-133.
[7] HRA Data Workshop. 2018. U.S.Nuclear Regulatory Commission Headquarters,, Rockville, Maryland.https://www.nrc.gov/docs/ML1807/ML18079A156.html
[8] Barriere, M., et al., Technical Basis and Implementation Guideline for A Technique for Human Event Analysis (ATHEANA), U.S. Nuclear Regulatory Commission, NUREG-1624, Rev. 1. 2000.
[9] Scott, R.L., Browns Ferry Nuclear Power-Plant Fire on Mar. 22, 1975. Nuclear Safety, 1976. **17**(5): p. 592-611.
[10] U.S. Nuclear Regulatory Commission, Davis-Besse Reactor Pressure Vessel Head Degradation, U.S. Nuclear Regulatory Commission, NUREG/BR-0353, Rev.1. 2008. ML082490129
[11] U.S. Nuclear Regulatory Commission, Inspection report on a fire in a 12 kV nonsegregated electrical bus and a subsequent loss of offsite power to the vital 4 kV buses at Diablo Canyon Unit 1, NRC Inspection Report 50-275/00-09; 50-323/00-09. 2000.
[12] DTE Energy, Licensee Event Report No. 2003-002 Revision 1, "Automatic Reactor Shutdown inn Fermi 2 Due to Electric Grid Disturbance and Loss of Offsite Power", NRC Doctet number: 05000341; LER Number: 2003-002-01. 2003.
[13] James A. FitzPatrick Nuclear Power, Multiple Safety Relief Valve Pilot Solenoid Failures Due to Foreign Materials, Vendor Deficiencies and Procedural, Licensee Event Report: NRC Docket Number: 05000333, LER number: 96-004-00. 1996.
[14] Plant, R.E.G.N.P., Loss of electrical load and reactor trip due to Northeast blackout, NRC Licensee Event Report number: LER 244-2003-002-00 2003.
[15] Entergy Nuclear, Automatic Reactor Trip due to Reactor Coolant Pump Trip on Under Frequency Caused by a Degraded Off-Site Grid, NRC Docket No. 50-247, Licensee Event Report No. 2003-005-00. 2003.
[16] U.S. Nuclear Regulatory Commission, Augmented Inspection Report on Indian Power Point 2 steam generator tube failure, NRC Inspection Report No. 05000247/2000-002. 2000.
[17] Gertman, D., et al., The SPAR-H Human Reliability Analysis Method, U.S. Nuclear Regulatory Commission, NUREG/CR-6883. 2005.
[18] Gibson, H., G. Basra, and B. Kirwan, Development of the CORE-DATA database. Safety & Reliability Journal, Safety and Reliability Society, Manchester, 1999. **19**(1): p. 6-20.
[19] Lois, E., et al., International HRA Empirical Study - Phase 1 Report: Description of Overall Approach and Pilot Phase Results from Comparing HRA Methods to Simulator Performance Data, U.S. Nuclear Regulatory Commission, NUREG/IA-0216, Vol. 1. 2009.
[20] Bye, A., et al., International HRA Empirical Study - Phase 2 Report: Results from comparing HRA method predictions to simulator data from SGTR scenarios, U.S. Nuclear Regulatory Commission, NUREG/IA-0216, Vol. 2. 2011. ML11250A010
[21] Dang, V., et al., International HRA Empirical Study - Phase 3 Report: Results from comparing HRA methods predictions to HAMLAB simulator data on LOFW scenarios, U.S. Nuclear Regulatory Commission, NUREG/IA-0216, Vol. 3. 2014. ML14358A254
[22] Forester, J., et al., The U.S. HRA Empirical Study, U.S. Nuclear Regulatory Commission, NUREG-2156. 2016. ML16067A241
[23] Chang, Y.J., C. Franklin, and L. Criscione. Example use of the SACADA data to inform HRA. in 13th International Conference on Probabilistic Safety Assessment and Management (PSAM 13). 2016. Sheraton Grande Walkerhill, Seoul, Korea
[24] Azarm, M.A., et al., Analyses methods and pilot applications of SACADA database, in 14th Probabilistic Safety Assressment and Management (PSAM 14). 2018: UCLA Meyer & Renee Luskin Conference Center, Los Angeles, California.

[25] Groth, K.M., J.D. Tedeschi, and R. Moradi, Transforming HRA using SACADA data, Bayesian methods, and DBNs, in 14th Reliability Safety Assessment and Management (PSAM 14). 2018: UCLA Meyer & Renee Luskin Conference Center, Los Angeles, California.

[26] Nelson, P.F. and C.R. Grantom, Methodology for Supporting the Determination of Human Error Probabilities from Simulator Sourced Data, in 14th Probabilistic Safety Assessment and Management (PSAM 14). 2018: UCLA Meyer & Renee Luskin Conference Center, Los Angeles, California.

[27] Xing, J., et al., An Integrated Human Event Analysis System (IDHEAS) for Nuclear Power Plant Internal Events At-Power Application, U.S. Nuclear Regulatory Commission, Electric Power Research institute, NUREG-2199, Vol. 1. 2017.

[28] Criscione, L., et al., Overview of Licensed Operator Simulator Training Data and Use for HRA, in PSAM11 & ESREL 2012. 2012: Helsinki, Finland.