HUMAN RELIABILITY DATA FOR MODERN CONTROL ROOMS, A SURVEY

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Instrumentation and control (I&C) of nuclear power plants were originally designed with analog interfaces and hardwired controls, and existing methods for Human Reliability Analysis (HRA) are therefore primarily based on data considering this type of I&C. In modernized power stations and especially in new builds, fully computer-based interfaces and controls are used, often without any analog counterpart, and which facilitate new features such as digitized procedures and advanced alarm systems. This development may also be accompanied by new operating philosophies, differences in human-automation interaction (and indeed the role of automation) and different types of human-system interfaces. Such features may introduce new types of error modes and failure mechanisms for the operating crews.

EDF Energy Nuclear Generation Limited (ENGL) in the UK is interested in understanding whether the data used for current HRA methods support such modernized systems. As a first step, CRA (Corporate Risk Associates Limited) and IFE (Institute for energy technology) undertook an exploratory study to obtain an overview of what HRA data are being collected from modern systems. The study consisted of a literature review and semi-structured interviews with international HRA experts.

The findings can be used to provide guidance on how HRA methods could be updated to assess modern systems. The results are classified in eight dimensions: 1) global activities in HRA data collection; 2) datasets from current research that are publicly available; 3) the benefits and limitations of data collection studies and what data can and cannot be adopted for a UK context; 4) lessons learned and best practices for data collection exercises on modern systems; 5) the current data needs and unknowns for modern systems and how these will be addressed within the international community; 6) details on future planned data collection exercises; 7) approaches used for HRA on modern systems; 8) current challenges/considerations when undertaking HRA for modern systems.

This paper summarizes the methodology and the main findings from the study.

I. INTRODUCTION AND BACKGROUND

Nuclear power plants (NPP) were originally designed with analog interfaces and hardwired controls. Increasingly, control room design has allowed functionality using computer-based interfaces and controls as systems are refurbished or added, leading to different types of so called ‘hybrid’ systems. However, in modern nuclear power stations, information and control is now primarily provided through computerized systems, which may introduce new features and technologies, and which are much less likely to include any analog counterpart.

ENGL seeks to understand whether their Human Reliability Analysis (HRA) methods can be used on the new modern systems in the same way as before, or if they need modification. This includes whether the current HRA methods can analyze the new features of the modern control rooms, and whether the data underlying the current methods support the use of the method in modern control rooms. As a first step, CRA and IFE undertook a study to obtain an overview of what HRA data are being collected from modern systems, and to obtain an overview of the main challenges in performing HRA for new control rooms. ENGL utilizes the Nuclear Action Reliability Assessment (NARA) technique for human reliability quantification, and the final goal is to investigate the usage and application of this technique for modern control rooms, and the way in which NARA needs to be adjusted to support modernized systems that implement aspects such as increased automation, touch screen technology, and electronic portable procedures. Whilst NARA is a holistic method that defines constituent tasks at a broad psychological level, the introduction of new operating philosophies, increased human-automation interaction and types of human work performed mean that the task/error definitions and underlying data may not be directly applicable for tasks performed using modern systems.

The study consisted of a literature review and semi-structured interviews with international HRA experts to collect data on several key HRA data topics. The key questions posed were:

- What data collection exercises on modern systems are currently being undertaken/planned?
- Can international data collection exercises be adapted to the UK context and what are the associated benefits/limitations?
- What new approaches in HRA are being used for modern systems?
- What challenges have been encountered when undertaking HRA for modern systems?
- What are the data needs for modern systems and are these being addressed in the international community?
- What are the best practices for data collection?

Based on these questions, the final goal is to explore what the implications for NARA might be.

Whilst the research project was conducted with the implications for the NARA method in mind, the findings of this data collection exercise provide insights on generic HRA data needs and challenges, summarize current international HRA efforts and practices to date and present views from a significant portion of the international HRA community.

II. METHOD

II.A. Literature Review

A literature review was performed to identify relevant research pertaining to HRA data collection for modern systems. The literature review was based upon three methods of obtaining literature:

1. Literature already available and known to CRA and IFE.
2. Literature obtained or referred as a result of the semi-structured interviews.
3. Literature collected from a focused literature review using the ‘SCOPUS’ literature database, and a review of papers suggested using the ‘Google Scholar’ search algorithms. The keywords applied for the literature review were a structured mix of HRA, data collection and digital control rooms. A series of coarse filters and abstract reviews were made to provide a list of 265 papers for detailed review.

II.B. Semi-Structured Interviews

Semi-structured interviews were conducted with prominent experts and researchers in the HRA community. Interviews were conducted with 23 international experts from 16 organizations across Europe, America and Asia to gain a variety of views and sources of information on HRA and modern digital systems.

Experts were identified using CRA/IFE contacts and referrals from the international HRA community, including UK experts. Each participant was provided with a script of the semi-structured interview and a consent form prior to the interview taking place. A majority of the experts operate in the nuclear power sector.

III. RESULTS

The resulting literature review and expert interview data collection exercises have been distilled to provide guidance on how HRA methods could be updated or designed to assess operator reliability in modern systems. An existing literature review into HRA and modern systems has also been conducted by VTT in Finland where Porthin et al.[1] highlights a number of initial international research efforts into HRA for modern systems.

III.A. Global Activities in HRA Data Collection

HRA data are currently being collected in several international projects. The U.S. Nuclear Regulatory Commission (NRC) is collecting data in their Scenario Authoring, Characterization, and Debriefing Application (SACADA) project[2,3], in a joint effort with training departments at plants, in which instructors collect the data. Contextual data in the form of cognitive functions and situational factors are collected for each training objective element, at a task level that fits with their training scenarios. The SACADA task level is a more granular level than the normal human failure events observed in Probabilistic Risk Assessment (PRA). The NRC is currently exploring how to quantify Human Error Probabilities (HEPs) based on the SACADA database, and are planning to extend the data collection to training simulators at new plants with digital control rooms.

The Korea Atomic Energy Research Institute (KAERI) is collecting HRA data in their data collection framework Human Reliability data Extraction (HuREX)[4,5], both for analogue and digital control rooms. The data are collected based on specific HuREX definitions of generic task types. The data collection is extensive with data collected from several plant simulators in Korea. KAERI is developing a new HRA method, Empirical data-Based crew Reliability Assessment and Cognitive Error analysis (EMBRACE), which is built on the same categories of tasks and factors that are collected in HuREX. EMBRACE thus utilizes the HuREX structure and its data closely in the quantification of human error probabilities. KAERI have published quite extensively on the HuREX framework in the public domain, and therefore it should be possible for the international community to evaluate to which extent the same framework can be used in other settings and for other methods.

The OECD Halden Reactor Project (HRP) has collected data using the Halden huMan-Machine LABoratory (HAMMLAB), some of which are specifically tailored for HRA applications.[6,7] HAMMLAB is a simulator laboratory with BWR and PWR simulators with digital interfaces, sometimes utilizing modern concepts like computerized procedures, but also paper procedures. Work is ongoing to make a human performance data repository that allows results and data to be more easily available for Halden Project members. Collected data are in the form of quantitative data that are useful for the evaluation of nominal values of simple tasks, qualitative narratives, Performance Shaping Factors (PSFs) multipliers and as general knowledge for HRA practitioners.

The Idaho National Lab (INL) is collecting data in both their HSSL laboratory,[8] and at plants as part of modernization projects. The data cover modern systems, emulations of analogue panels on digital surfaces and data from analogue plant simulators. As with Halden, they cover a spectrum of task levels, although the modernization projects are normally limited to upgrades of secondary systems like turbines, not the safety critical core surveillance systems. Recently INL has explored data collection utilizing micro-worlds to investigate lower-level task performance.[9] This is similar methodology as the Halden Reactor Project has explored using “micro-tasks”.[10]

In China there are many HRA data collection programs, and very many simulator data collection activities going on as part of their human factors engineering validation programs for their new plants. As far as we have managed to investigate, most if not all these programs are proprietary. Chinese researchers do continue to publish their studies,[11,12,13] therefore it may be possible to access relevant information from these sources. It is noted that many studies have tended to focus on the quantitative aspects of HRA methodologies and there is a shortage of proportionate qualitative research.

EPRI has an active HRA program together with the NRC and the U.S. nuclear fleet through the EPRI HRA User Group, where they have worked to standardize the HRA data collection and analysis process using the EPRI HRA Calculator.[14] They are actively looking into HRA data collection for modern systems and it is expected that research activity will increase in the coming years.

In the Czech Republic, ÚJV Řež, a. s. have initiated a data collection project at the Temelin NPP (VVER-1110 design with Westinghouse I&C systems) that incorporates some features of modern control rooms that may be suitable to inform a revised HRA approach for modern systems.[15]

The NEA have been organizing data collection workshops with HRA experts, many of which have contributed to this study.[16,17] In the future, the HRA Society seems to be the primary platform where the various stakeholders and the active HRA researchers meet and can discuss activities. However, whether concrete funded activities will be initiated from the HRA Society remains to be seen.

III.B. Datasets from Current Research that are Publicly Available

Most data originating from NPP training simulators are not open to the public. This is the case for SACADA data and KAERI data collection activities, as well as all the data collection we are aware of in China. Data from research organizations are normally publicly or semi-publicly available though, including data from INL and HRP activities. This may vary from case to case, depending on whether the data collection took place at the research site or at NPP training simulators.

All the results and data (anonymized data) from HRP are available to organizations that are affiliated with Halden via the research sharing agreement, though they are not necessarily publicly available. Some data are easily utilized for HRA, whilst other data sets may need adapting for use in HRA methods. The Halden data currently in SACADA are also publicly available.

III.C The Benefits and Limitations of Data Collection Studies and What Data Can and Cannot Be Adopted for a UK Context

This research study presented a split of opinion as to whether data could be usefully adapted from different contexts, and great care should be taken to fully understand the data sources to ensure that they can be used to inform an HRA method.

SACADA is an example of a data collection that combines the HRA data goals with the plant’s goal of improving operator training. In this way a larger quantity of data can be gathered with minimal extra resources put in from the instructors at the plant. This is seen as a highly effective way to get the plant/operators on board with data HRA collection and it minimizes the required efforts from the researchers. The limitation of these data is that they normally do not cover more complex actions that typically occur during severe accident scenarios. To include these data, one needs dedicated scenario runs, either at training simulators or at specific research sites such as HRP or INL.

Many of the interviewees emphasized that to get data that can be generalized to real control rooms, one should collect as much data as possible from full-scale simulators in close to real environments, with licensed operators as test subjects. Various types of data should be collected for various purposes. Difficult accident scenarios should be investigated to study human performance in the full range of plausible actions for HRA. Data on specific PSFs may be collected with more directed methods such as micro-task methods, given that the results can be generalized to real situations. However, the barriers when accessing and using full-scale simulators mean that other data sources, such as virtual environments and extrapolation techniques may need to be relied upon in additional to full scope simulators. It is hoped that automated data collection techniques in modern simulators and live environments will provide an abundance of data for certain Generic Task Types (GTTs) and PSFs.

When adapting data for UK context, one needs to ensure that the cultural aspects that may affect the data are accounted for, as many cultural and organizational factors directly impact human performance, and therefore cannot be ignored. This is not only the case between countries, but also between nuclear power plants (NPP) which possess different conduct of operations.

In conclusion, if data can be collected for the same conduct of operations, and in the same basic structure as the HRA methods in the UK, then they should be easily adopted. If any of these are different, they may also be adopted taking into consideration the differences mentioned. It is important that these things are considered.

III.D. Lessons learned and best practices for data collection exercises on modern systems

No international best practices are used by the data collection activities we have identified. Each activity uses their good practices, some of which are documented (e.g. HRP, KAERI). There is a desire in the HRA community for best practice documents to be produced using a combination of all current available literature, however no formal plans have been made to undertake this exercise.

III.E. The current data needs and unknowns for modern systems and how these will be addressed within the international community

It is important to understand the new human failure mechanisms and error modes that may be introduced by modern systems, and whether failure rates for existing mechanisms are likely to change and how. These new failure mechanisms are necessarily not dependent on whether the system is digital or not, but on the implementation of the digital system. E.g. navigation and situational awareness effects may be present in some modern systems, while in others they are not present.

There is a need for data on computerized procedures and automated solutions possibly linked to these, and new HMI solutions, e.g., navigation effects. On the positive side one may need new data on e.g., the effect of good overview displays.

The international community does not have a unified plan for addressing these needs, but each country is targeting the data needs based on their needs and based on the HRA methods they are using.

III.F. Details on future planned data collection exercises

We have identified further data collection exercises including SACADA, EPRI, and INL in the U.S., KAERI in Korea, HRP in Norway and ÚJV Řež, a. s. in the Czech Republic.

III.G. Approaches used for HRA on modern systems

Some HRA methods may be used directly on modern systems, depending on their level of detail in the approach. Methods such as HuRECA, MERMOS, SPAR-H and Petro-HRA are seen as suitable for modern systems since they either possess task descriptions and data for digital systems, or leave the analyst to judge the quality of the system (e.g. the HMI) for a given task or mission. The resource intensive nature of MERMOS means that it may not see widespread use, and the proprietary nature of HuREX (the data framework underlying the HuRECA method) limits the benefits that external HRA practitioners can gain from the method. For SPAR-H and Petro-HRA, the quality of the result from the analysis depends heavily on the qualitative analysis made by the analyst, and her/his understanding of the context for the specified task. Methods such as THERP, which goes into details of the HMI in the method itself, would need a considerable upgrade for all the details in the method that are different from the analog to the digital systems.

III.H. Current challenges/ considerations when undertaking HRA for modern systems

For NARA, it is considered that the broad GTT and PSF (noting that NARA uses a different definition known as 'Error Producing Conditions' instead of PSFs) descriptions would make it easier to update the method as opposed to a technique such as THERP. However, a thorough understanding of the nature of tasks and their potential failure modes in modern systems would be required, as well as an activity to carefully re-define generic tasks and PSFs. Aspects such as automation and looping procedures may provide the greatest challenges when undertaking such an update.

The diversity of modern systems and their configurations will present a challenge for data collection, particularly using data from diverse sources. Data will often be collected for different contexts, and therefore an enhanced understanding will be required on how data can be used and whether they can be generalized from one system to another.

Commercial barriers and intellectual property rights/confidentiality have traditionally been a limitation for HRA data collection, and remain a barrier to industry information sharing.

IV. CONCLUSIONS

This study identified a number of HRA data collection activities around the world, including the U.S. NRC (SACADA), KAERI (HuREX), INL, OECD Halden Reactor Project, EPRI (HRA calculator), UJV Rez, and in China. Some of the results are publicly available, and some are proprietary. Apart from research studies, concrete data tends to be proprietary, although general results can be shared and utilized by the public.

Many of the results can be applied to the international context although for this study utilization for the UK context was in focus. However, one needs to take care and adapt results both to a national context as well as considering the type of HRA method the data is expected to support. Most of the interviewees considered it important to understand the new human failure mechanisms and error modes that may be introduced by modern systems, which forms the next phase of research for CRA and IFE on behalf of ENGL.

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