Using a Research Simulator for Validating Control Room Modernization Concepts

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Abstract. The Light Water Reactor Sustainability Program is a research, development, and deployment program sponsored by the United States Department of Energy. The program is operated in close collaboration with industry research and development programs to provide the technical foundations for licensing and managing the long-term, safe, and economical operation of nuclear power plants that are currently in operation. Advanced instrumentation and control (I&C) technologies are needed to support the continued safe and reliable production of power from nuclear energy systems during sustained periods of operation up to and beyond their expected licensed lifetime. This requires that new capabilities to achieve process control be developed and eventually implemented in existing nuclear control rooms. It also requires that approaches be developed and proven to achieve sustainability of I&C systems throughout the period of extended operation. Idaho National Laboratory (INL) is working closely with nuclear utilities to develop technologies and solutions to help ensure the safe life extension of current reactors. One of the main areas of focus is control room modernization. Current analog control rooms are growing obsolete, and it is difficult for utilities to maintain them. Using its reconfigurable control room simulator adapted from a training simulator, INL serves as a neutral test bed for implementing new control room system technologies and assisting in control room modernization efforts across.

1. Introduction

1.1 The Need for Control Room Modernization

Commercial nuclear power plants (NPPs) in the United States (US) need to modernize their main control rooms (MCRs). Many NPPs have completed partial upgrades, but none of the 104 commercial reactors in the US have completed a full control room modernization effort. Existing control rooms are almost entirely analog, hardwired, and manually operated control systems. Since analog technologies are no longer readily available, digital control systems are the required replacement systems for modernization. In the course of analog-to-digital upgrades, it is first necessary to develop a digital backend in which sensors and controls are digitized on a supervisory control and data acquisition (SCADA) system. Once it is possible to monitor and control the plant digitally (with potential redundant analog and mechanical backup I&C), the MCR interface can be addressed. Digital technologies introduce the opportunity for new functionality in the form of advanced displays and automated or soft controls.

Yet, such new functionality may go beyond the current licensing basis of plants and require significant licensing amendments. Moreover, although there is operating experience with digital technologies in other safety critical process control environments, advanced digital instrumentation and control (I&C) is largely untested in the MCRs of NPPs. There are unique challenges to nuclear power plants, including the close proximity of the MCR to the actual plant, which makes it difficult even to find adequate space to stage the components of a replacement control room. Additionally, the short outage windows of the plants require rapid changeout of components in order to maintain targeted production levels for each plant. In many cases there may be no readily available commercial I&C solutions that generalize from other industries to meet the requirements of nuclear power plants. The one-of-a-kind nature of many plants further requires extensive customization by vendors.

There are significant hurdles in adopting new technologies as part of a MCR modernization strategy in nuclear power plants. As such, utilities must decide the extent of modernization that is desired and needed and prioritize the process by which they will achieve that modernization. The plant’s endstate vision outlines both the extent of digital upgrades and the course of deployment. For example, a utility may decide to keep its existing panel-based control room and phase in digital control system (DCS) displays to replace aging analog I&C. Another utility may decide to adopt a complete control room update—doing away with panels completely and moving toward soft controls and plant overview displays at local operator workstations. Yet a third strategy might find a graded approach in which the utility plans for introduction of a DCS backend in the short-term with an eventual goal of introducing a completely new control room concept as part of long-term plant sustainability.

Several NPPs in the US are committed to MCR modernization programs that include modernization of I&C systems and new human-system interface (HSI) designs. Control room modernization, either as a complete overhaul or a stepwise change to a hybrid digital-analog control room, is a challenging task involving I&C and HSI integration issues such as: merging soft controls with existing hard controls, managing increased data availability to the operators, improved alarm management, and computerized procedures, to name a few examples. To help NPP operators and vendors plan, specify, design, implement, operate, maintain, and train for the MCR modernization in a way that takes advantage of digital system and HSI technologies, the Electric Power Research Institute (EPRI) developed 31 guidelines and technical bases for them [1]. These guidelines are grouped in the five areas of (i) plant-specific control room modernization planning, (ii) human factors engineering (HFE) design analyses, (iii) detailed HFE guidelines, (iv) regulatory and licensing activities, and (v) special topics related to operations and maintenance.

In addition to [1], a considerable amount of research, including O'Hara [2], Pirus [3], Woods [4], and Hollan et al. [5], has been conducted on the I&C and HSI challenges that must be addressed in any successful MCR modernization. Typical challenges that are introduced by MCR modernization include: the small display space for information presentation introduces a keyhole or "tunnel vision" effect in operators [4]; soft controls increase secondary tasks [3–4]; increased understanding of automatic functions is required [2]; and soft controls require conscious development of co-operation and communications practice to avoid breakdowns in threeway communications [5].

Operator concerns related to number of visual display units (VDU) are examined in [6]. The paper presents technical and historical reasons for this concern and its implication in the design of complex HSIs. Some of the concerns highlighted include a lack of communication between display designer and operators, difficulty in determining the appropriate amount of information to be displayed, and addressing the trade-off between task relevant displays and data-dense displays.

Salo et al. [7] describe the operator's experience working in a screen-based control room (i.e., sit-down operator workstations vs. traditional stand-up panels). Interviews were conducted at four conventional power plants and one NPP, and involved operators with less than 2 years work-experience and operators with more than 20 years experience at both types of plants. Some of the major differences between conventional and nuclear power plants in terms of the digitalization of the HSI were presented. Salo et al. [7] found the older NPP operators are more uncertain in using soft controls when performing operations than younger operators, and required more training. Additional operator concerns regarding differences associated with working in screen-based control rooms were expressed during the interviews, which were consistent with findings from other studies. These concerns included:

- How situational understanding of the process state is acquired [8–9]
- The effects of the increased level of automation on situation awareness [10]
- How general process knowledge through the new screens is acquired and maintained
- Learning how to navigate and perform operations using the screens
- The effect screens had on communication and coordination, and roles and responsibilities [11]
- Learning the new system and training [12]

It is also interesting to note that the operators in [7] expressed similar concerns that were documented in [12] regarding their lack of experience and involvement in modernization processes, suggesting that the changes made through the modernization should be sufficiently operator-oriented.

In short, the commercial nuclear power industry is well aware of the need to modernize their MCRs and, based on their own operational experience and research, are well aware of the I&C and HSI challenges that must be overcome, including: the increased amount of data available to the operators, the usage and integration of soft controls and VDUs, the effects of increasing automation of systems, the effects modernization has on communication and coordination among operators and concepts of operation (e.g., roles and responsibilities), and the requirements for increased operator training.

1.2 Regulatory Considerations

The US Nuclear Regulatory Commission staff primarily uses the guidance in Chapter 18, "Human Factors Engineering" of NUREG-0800, *Standard Review Plan* (SRP) [13], to review new plant design and modifications of existing control rooms:

> The organization responsible for the review of human performance reviews the HFE programs of applicants (e.g., for a construction permit (CP); operating license (OL); standard design certification (DC); and combined license (COL)) and licensees (e.g., for modifications and changes to a licensee's design or licensing basis). The purpose of these reviews is to improve safety by verifying that acceptable HFE practices and guidelines are incorporated into the plant's design. The guidance provided in this document, and in the supporting documents referenced, is used to conduct these HFE reviews.

The chapter identifies 12 areas of review that are needed for successful integration of human characteristics and capabilities into nuclear power plant design. These areas of review include:

- HFE Program Management
- Operating Experience Review
- Functional Requirements Analysis and Function Allocation
- Task Analysis
- Staffing and Qualifications
- Human Reliability Analysis
- Procedure Development
- Training Program Development
- Human-System Interface Design
- Human Factors Verification and Validation
- Design Implementation
- Human Performance Monitoring

While the process defines 12 areas of review, not all may be applicable to reviewing a particular applicant's or licensee's HFE program, especially when it comes to reviewing HFE aspects of control room modifications and HFE aspects of modifications affecting risk-important human actions.

Though the SRP is the primary review tool used by the staff, it also refers to other significant review documents, e.g., NUREG-0711, *Human Factors Engineering Program Review Model* [14], NUREG-0700, *Human-System Interface Design Review Guidelines* [15]; and NUREG-1764, *Guidance for the Review of Changes to Human Actions* [16]

The NRC is currently in the process of revising NUREGs-0700 and 0711 and will revise Chapter 18 of NUREG-0800 shortly thereafter. The ongoing revisions are based on research that has been performed since 2002 in the nuclear arena and on feedback from user experience. There have been two significant documents that have been published in that time frame that point to the need for further research—NUREG/CR-6947, *Human Factors Considerations with Respect to Emerging Technology in Nuclear Power Plants* [17], and a 2011 Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI) Working Group on Human and Organizational Factors (WGHOF) work report, *Summary of Survey and Workshop Results on Areas of Research in Human Factors for the Design and Operation of New Nuclear Plant Technology* [18].

NUREG-6947 [17] was sponsored by the NRC because of the increased use of automation and other technologies in existing, new, and advanced nuclear power plant designs that has the potential to introduce new HFE challenges. Sixty-four potential human performance research issues associated with the introduction of emerging technologies in nuclear power plants were identified. These potential research issues are organized into seven high-level topic areas:

- Roles of personnel and automation
- Staffing and training
- Normal operations management
- Disturbance and emergency management
- Maintenance and change management
- Plant design and construction
- Human factors engineering methods and tools

The impetus for the WGHOF work report [18] grew out of an NEA CSNI WGHOF Technical Opinion Paper (TOP), titled *Research on Human Factors in New Nuclear Plant Technology* [19], which identified eight broad topic areas that warrant further research:

- Operating Experience (OpEx) from New and Modernized Plants
- Evolving Concepts for the Operation of Nuclear Power Plants
- The Role of Automation and Personnel: New Concepts of Teamwork in Advanced Systems
- Management of Unplanned, Unanticipated Events
- Human System Interface (HSI) Design Principles for Supporting Operator Cognitive Functions
- Complexity Issues in Advanced Systems
- Organizational Factors – Safety Culture
- HFE Methods and Tools

The work report expanded on these topics by suggesting specific research efforts, potential collaborations, and identified research facilities at which the research could be performed.

The WGHOF work report [18] is important because the nuclear community is currently at a stage where existing reactor control stations are undergoing various forms of modernization, new reactors are being built in many countries with screen-based control rooms, and advanced reactors are being designed through international cooperation to support future power generation. With the introduction of advanced plants, there will be new reactor and system designs, new tools to support plant personnel, and changes to NPP staffing configurations. The concepts of operation and maintenance requirements for this new generation of plants are likely to be quite different from those employed in today's plants. It is important that the potential impact of these developments is evaluated and understood by prospective operators and regulators responsible for determining the acceptability of new designs to support human performance in maintaining plant safety.

Many of these new designs will also prove relevant in upgrading MCRs of existing plants. The introduction of new technology is viewed as having promise for improving the safe and efficient operation of existing NPPs. To ensure the appropriate application of technology to support human performance and plant safety, it is important to evaluate the technological advances in terms of both potential negative and positive effects. The research described can provide the technical basis to help ensure that the benefits of new technology are realized and that the potential negative effects are minimized.

Based on the results of these latter two efforts [17–18] there has been a significant amount of new research identified that needs to be done to both support regulatory reviews but also to improve the safety and efficiency of nuclear power. The need for MCR modernization serves as a strong motivator to update regulatory guidance and to conduct research that supports both regulator and industry needs.

1.3 Light Water Reactor Sustainability Program

The US Department of Energy (DOE) is sponsoring research, development, and deployment on light water reactor sustainability (LWRS), in which the Idaho National Laboratory (INL) is working closely with nuclear utilities to develop technologies and solutions to help ensure the safe operational life extension of current reactors. One of the main areas of focus is control room modernization. As noted, current analog control rooms are obsolete, and it is difficult for utilities to obtain replacement parts. Industry must safely and smoothly transition to digital control room interfaces. As technologies are introduced that change the operation of the plant, the LWRS project can help identify their best advanced uses and help demonstrate the safety of these technologies. This research needs to be definitive and timely due to the rigor and duration of the regulatory review process. Also, early testing of operator performance given these emerging technologies will ensure the safety and usability of systems prior to large-scale deployment and costly verification and validation at the plant.

Such early system and operator performance testing is being done at the INL. The INL is developing the state-of-the-art Human System Simulation Laboratory (HSSL). At the heart of the HSSL is a reconfigurable control room simulator that can be used to develop and test the implementation of newer, digital control room systems. Further the INL is procuring a set of touch screen part-task simulators that can be configured to represent a current control room or one that incorporates various digital modifications. These simulators and the HSSL can serve as a key resource for testing emerging technologies for their application in nuclear power plant control rooms. In addition to the hardware and software capabilities, the INL's expertise in human factors and human performance metrics is being used to evaluate operator-in-the-loop alternatives being simulated.

2. THE NEED FOR RESEARCH SIMULATORS

2.1 Background

A simulator is a physical device that replicates the operations of an actual device used in the workplace. Typically, simulators serve to train operators on the proper use of workplace devices, but simulators are also frequently employed in research to evaluate human performance. A 2004 report by the International Atomic Energy Agency (IAEA) highlights the historic development of training simulators in NPPs [20]. Beginning in the 1970s, computerized control room simulators were put in place at centralized facilities to help train control room operators. These simulators were limited by a lack of fidelity in terms of control panel layouts and underlying thermal-hydraulic code, making them useful for teaching basic plant principles but less useful for plant-specific training. By the 1980s, the fidelity and availability of simulators was greatly increased, and by the 1990s, it became commonplace internationally for each plant to have a high-fidelity plant-specific training simulator. In the US, a requirement for training simulators at every plant was introduced so that the US Nuclear Regulator Commission [21] could license operators with a high degree of confidence, which also enabled reactor operators to train on unusual or unlikely events.

Research can be performed using both training and dedicated research simulators. The differences are centered on the types of studies that can be conducted and the types of data that that can be collected from the studies. Where the aim is to collect human performance information from actual crews in current control room configurations, the training simulator offers a logical first stop. Participation in simulator research studies affords a unique opportunity to investigate factors affecting crew performance in current control rooms. Practically speaking, over time, such studies may be used to establish new industry best practices and to improve crew preparedness for unusual plant events. From a research perspective, findings from training simulator studies may inform new or improved methods of human performance or human reliability analysis, or be used to develop a more realistic representation of normal crew performance. Such research may also drive recommendations for the implementation of next-generation control room interfaces, based on principles of crew performance in current control rooms.

However, the practical limitations of training simulators for research must be understood:

- *Limited availability*. Training simulators have as their first priority the training of crews. Research studies may be scheduled as available, but they must not interfere with required training exercises. For this reason, research studies that align closely with training tasks are best suited for training simulators. Crews, trainers, and the simulator facility are limited commodities at the plant, and research studies should complement their primary purpose.
- *Simulator inflexibility*. The flexibility to manipulate plant parameters and operational situations is limited in the training simulator. For particular research questions related to crew performance, it may be desirable to configure the plant parameters in an unusual way (e.g., multiple simultaneous faults). While this level of control should be available in training simulators, the ease with which such manipulations can be made may be limited by the need to create readily configurable scenarios appropriate to training.
- *Limited data collection*. The ability to collect different types of data in the naturalistic setting is restricted. Primarily observational and plant log data may be collected, and advanced data collection techniques such as noted in Tran et al. [22] are not easily or unobtrusively retrofitted to the training simulator.
- *Fixed HSI*. Training simulators are purpose built to mimic the actual HSI of a specific plant. As such, training simulators are not typically well suited for exploratory studies of novel control room interface elements. Though training simulators may be suitable for implementation of equipment upgrades at the plant (e.g., phasing in new control panels and training crews on them prior to installation in the actual plant control room), they are not generally suited for trying out new configurations.

The above limitations of training simulators for research illustrate the importance of maintaining and championing dedicated research facilities for control room simulation. Dedicated research simulators are ideal for:

- *Scheduling flexibility*. Research simulators are generally not in as heavy rotation for use as plant training simulators. Depending, of course, on the number of studies being conducted, it is possible to schedule research simulators for longer periods of time and with greater scheduling flexibility.
- *Configuration flexibility*. Research simulators offer maximum control over plant parameters and do not have to be limited to a specific plant. In fact, research simulators may be reconfigured to different types of plants, including advanced plants that are still under development. For example, a research simulator may be easily reconfigured to be either a pressurized water reactor or a boiling water reactor. Further, a research simulator may be configured to be functionally equivalent to specific plants within those plant types. A research simulator may also be reconfigured in task- or function-specific I&C, such as evaluating operator performance in response to digital alarm systems. It is also possible to couple a research simulator to hard panels that faithfully mimic analog control rooms.
- *Data flexibility*. Research simulators may allow the collection of observational data similar to those data collected in training simulators. In addition, it is possible to collect data such as physiological measures and eye tracking requiring specialized equipment that is not easily retrofitted to training simulators.
- *Crew flexibility*. Reconfigurability makes it possible to study crews from different plants within the same study. The simulator may be configured to match the home plant very closely, or a hybrid approach may be adopted, whereby crews operate on a generic plant that is similar to but not identical to their home plant. For example, studies involving different crews are important for understanding operational culture [23].

2.2 Converting a Training Simulator to a Research Simulator

A full-scope plant simulator comprises several layers of systems as depicted in Figure 1. At the heart are system models that interact to create a realistic model of plant behavior, including thermal-hydraulic software modeling using RELAP, a vendor-specific simulator platform (e.g., simulator software development packages by GSE, WSC, and L-3), and a plant-specific model executed on the simulator platform. These models combine to form the back end called the engineering simulator. The engineering simulator interfaces with the front-end simulator, which consists of the control room HSI that the operator uses to understand plant states and control plant functions. The front-end simulator may take many forms such as an analog hard panel system found in typical U. training simulators or a digital soft control system found in some foreign plants and research simulators. Digital soft control systems may take the form of mimics to analog plant I&C or may represent advanced I&C that incorporates features such as overview displays and information rich trending displays.

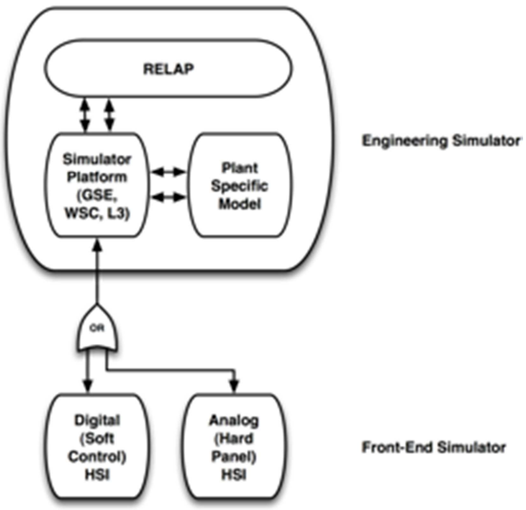

FIG. 1. Simulator architecture

The international nuclear community has for over 25 years been working with Halden Reactor Project in Norway to run control room simulator studies [24]. The Halden Reactor Project has a reconfigurable control room simulator called the Halden Man-Machine Laboratory (HAMMLAB) that can model advanced control rooms for boiling water and pressurized water reactor configurations. These studies, which avail themselves of licensed plant operating crews from Swedish or Finnish plants, are used to determine crew behavior in a variety of normal and off-normal plant operations. The findings are ultimately used to guide safety considerations at plants and to inform human factors and human reliability analysis—for both regulators and industry.

Recently, there has been a strong desire to have access to similar facilities in the US. The HAMMLAB facilities are strictly research facilities. They are not used for training, because they do not map to any current plant. Much of the technology used at HAMMLAB is cutting-edge and is not part of standard plant control rooms. For example, the HAMMLAB control room is all digital, featuring large overview displays, menu-based soft controls, and scrolling alarm lists instead of annunciator displays. The HAMMLAB simulator is optimized for testing and improving new control room technologies, but it is not configured to mimic current control rooms. In the parlance of the IAEA, it would strictly speaking be considered an Other Than Full-Scope Simulator, except to the extent the HAMMLAB simulator comes to be implemented in a newer plant.

There exists no research simulator configured specifically to address the redesign of legacy control rooms in the US nuclear industry. In light of this fact, the INL has undertaken the conversion of a legacy training simulator for use in control room modernization. Through a Cooperative Research and Development Agreement (CRADA) with a US utility, the INL has acquired the software code corresponding to a specific NPP's engineering simulator. While limited displays are provided with the software, the front-end simulator consists of analog panels. There is limited utility in crafting a hardware replica of the analog panels found at the NPP. As such, the INL has reviewed ways to construct a full control room using digital-only technology.

To allow the simulator to display a variety of analog hard controls and allow the operator maximum interaction with the simulator, digital displays with touch interfaces are a viable and desirable solution. Popularly known as touchscreen displays, such displays can be set up in number of ways to mimic any control room configuration. GSE, L-3, and WSC are the three leading vendors currently producing glass top control panels. Figure 2 shows one example, L-3 Communication MAPPS's Orchid® Touch Interface (TI) bay. The bay allows high fidelity panel graphics to be displayed on large touch screen monitors with 1080p (full HD) resolution. The monitors are mounted on frames, known as a bay, and can be adapted to mimic different control room layout configurations. A single bay of Orchid® TI can be used to navigate between different control panels in a simulator. Alternatively, several bays can be configured to represent all the control panels. Orchid® TI is a complete solution as far as control room buildout is concerned using the plant simulator. In addition, Orchid® TI is compatible with other full-scope plant simulators developed by L-3 Communication MAPPS. The authors, at the time of publication, are not aware of any plug-in been developed that would allows Orchid® TI to be compatible with the full-scope simulator developed by other vendors, which may prove a limiting factor in generalizing the utility of the hardware bays across other plants and utilities.

FIG. 2. Glass top panel used for simulator (Courtesty of L-3)

The configuration employed is comprised of three 46-inch LCD displays. The lower two displays feature touch screens to allow operators interaction with virtualized controls. The upper display, which is out of operator reach, is a non-augmented LCD screen without touch interaction. In a faithful mimic of a conventional control panel, the lower and upper panels are mounted at slight angles, with the lower display configured as a bench top area, while the upper display may be reserved for annunciators.

At the INL Human System Simulation Laboratory, the glass top panels are linked together in a horseshoe shape that approximates the shape found in current control rooms. A total of 15 glass top bays will be linked together (see Figure 3), representing faithful mimics of five hardware panels found in a current control rooms. (The sixth panel, which is centered on balance-of-plant and plant support systems, is not immediately part for the plant's control room modernization priorities.) Three bays chained together accurately represent the content of each physical panel in the control room. Each glass top bay serves as a client to a central simulator model. The panels represent functions related to plant auxiliary services, electrical energy, waste heat removal, primary and secondary energy, reactor support systems, and safety systems. The design requires that all analog I&C be represented on the control panels and that multiple operators may work on the composite simulator at the same time.

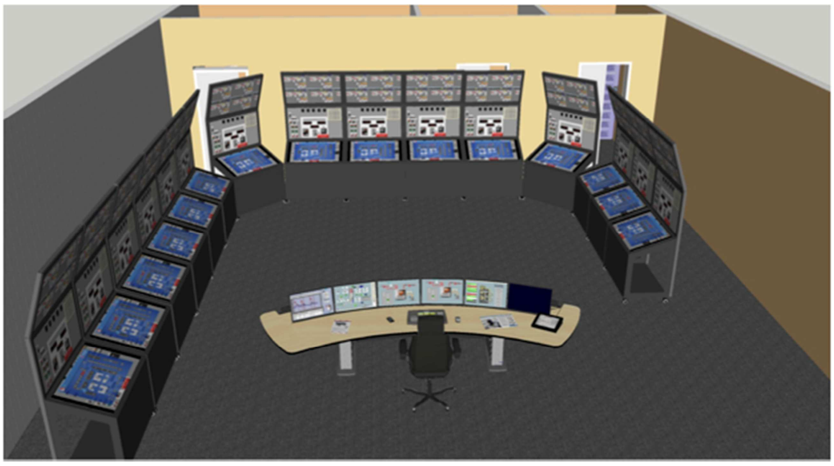

FIG. 3. Proposed control room layout using glass top panels

The key advantage of mimicking current control rooms comes from the ability to implement prototypes of new digital function displays into the existing analog control environment. Prior to full-scale deployment of technologies such as control room upgrades, it is essential to test the performance of the system and the human operators' use of the system in a realistic setting. In control room research simulators, upgraded systems can be integrated into a realistic representation of the actual system and validated against defined performance criteria. In this manner, control room upgrades are being designed, usability tested, and safety validated without the need to use the plant's training simulator.

3. Research Path Forward and Discussion

The control rooms at current nuclear reactors feature analog I&C technology in many cases dating to the 1970s. Although this aging control room technology is adequately maintained to ensure reliability and safety, the cost to maintain such obsolete equipment is approaching or even exceeding the cost of replacement. Yet, there exist financial and regulatory hurdles to modernize control rooms, and vendors have been slow to provide comprehensive solutions that meet industry needs. The time required to perform a full-scale control room upgrade is significant, and the cost of loss of production for utilities reaches up to $2 million per day for a commercial reactor. Thus, wholesale modernization in the form of complete replacement of these control rooms is not likely in the US, and plants are adopting a piecemeal or system-by-system approach to upgrades.

As part of the LWRS Program, the INL is working with utility partners to develop a strategy for long-term control room modernization that will guide the development and deployment of new digital-based control room systems at existing US nuclear power plants. The strategy will address how best to achieve an end-state vision for the control room based on the plant concept of operations. This will include all aspects of operations such as procedures, degree of automation, and potential operator support systems. The INL is reviewing various control room modification strategies and management system principles and technologies for discussion with plant personnel to determine which strategies are most applicable to plants for incorporating digital controls and operator interface design into a traditional analog control room. Based on these discussions, the INL will propose an appropriate approach to establishing an endstate vision for the plant control room and work with the utility partner to develop the vision.

While performing this task, INL personnel will conduct a needs analysis at a representative plant to determine concepts of operation and control room usage patterns and better establish an understanding of how operators use the current panels, displays, and controls and how they interact in a realistic setting. Initially, this will be done in the plant training simulator and will include documentation review, event reviews, procedure review, operator observations, and interviews with operations and maintenance staff, as well as engineering and modification team members and management. The needs will be prioritized in cooperation with the plant modification team.

The goals of this research include:

- Developing guidelines for standardizing operator interface screens based on human factors engineering principles
- Developing an endstate vision for transitioning to a fully modernized MCR
- Developing, prototyping, and evaluating diverse I&C systems in a step-by-step fashion toward overall control room modernization
- Developing integrated digital I&C displays that combine the systems developed in step-by-step upgrades
- Providing first-of-a-kind proof-of-concept demonstrations of innovative HSI concepts

Integrated system validation (ISV) is a well-established concept in the nuclear industry [25]. Prior to full-scale deployment of technologies such as control room upgrades, it is essential to test the performance of the system and the human operators' use of the system in a realistic setting. Where simulator facilities are available such as in control room training simulators, upgraded systems can be integrated into a realistic representation of the actual system and validated against defined performance criteria. Less common, however, is the use of the training simulator as the development platform for novel interface elements.

In this paper, we have briefly discussed the use of a full-scope training simulator for design and pretesting of proof-of-concept interface elements. The system in question is a copy of a nuclear power plant's active training simulator. Instead of buying commercial-off-the-shelf digital replacement systems or contracting custom systems that are developed offsite and only later integrated into the control room, the present approach uses the training simulator as the development platform and test bed. The approach affords considerable advantages over traditional ISV:

- The design process is formative, meaning it is possible to change ineffective elements of system design prior to full scale integration
- The design process is iterative, meaning it is possible to collect operator feedback at early stages of development and apply insights on operator performance into early-stage redesign
- The design process is environmentally driven, meaning it captures and mitigates constraints of the control room and aspects of the conduct of operations that might otherwise hinder successful implementation of an interface
- The design process converges on a standard, meaning the development of system-by-system upgrades affords the opportunity to create a style guide that may be used to drive a consistent design across the control room
- The design process is cost effective, meaning it is possible to take advantage of in-house engineering and human factors expertise to design and evaluate systems as they will actually be used.

In this paper, we offer an example framework for using a training simulator as part of integrated system design in control room modernization projects. The simulator, when repurposed for research, provides the ideal platform for designing, prototyping, and validating new I&C concepts.

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