INL/CON-15-34403
PREPRINT

Baseline Evaluations to Support Control Room Modernization at Nuclear Power Plants

ANS NPIC-HMIT

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February 2015

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ABSTRACT

For any major control room modernization activity at a commercial nuclear power plant (NPP) in the U.S., a utility should carefully follow the four phases prescribed by the U.S. Nuclear Regulatory Commission in NUREG-0711, *Human Factors Engineering Program Review Model.* These four phases include Planning and Analysis, Design, Verification and Validation, and Implementation and Operation. While NUREG-0711 is a useful guideline, it is written primarily from the perspective of regulatory review, and it therefore does not provide a nuanced account of many of the steps the utility might undertake as part of control room modernization. The guideline is largely summative—intended to catalog final products—rather than formative—intended to guide the overall modernization process. In this paper, we highlight two crucial formative sub-elements of the Planning and Analysis phase specific to control room modernization that are not covered in NUREG-0711. These two sub-elements are the usability and ergonomics baseline evaluations. A baseline evaluation entails evaluating the system as-built and currently in use. The usability baseline evaluation provides key insights into operator performance using the control system currently in place. The ergonomics baseline evaluation identifies possible deficiencies in the physical configuration of the control system. Both baseline evaluations feed into the design of the replacement system and subsequent summative benchmarking activities that help ensure that control room modernization represents a successful evolution of the control system.

Key Words: baseline, human factors engineering, evaluation, control room modernization

1 INTRODUCTION

The currently operating commercial nuclear power plants (NPPs) in the United States (U.S.) were originally licensed to operate for 40 years. As these plants reach the end of their 40-year operating licenses, the majority are applying for license extensions for another 20 years, and there is already consideration of another 20 years license extension beyond the extended 60-year operating license. The importance of these NPPs as part of the overall electric supply in the U.S. cannot be overstated. It is estimated that these plants account for about 22% of the electric baseload supply in the U.S. [1]. While new plants are being built, the five new NPPs currently under construction only scarcely make up for the six reactors permanently shut down in the past year. Nuclear energy must compete with low-cost carbon sources of electricity generation like natural gas fired plants. Alternative clean energy sources of electricity are not readily available for large scale deployment, making nuclear energy the primary zero carbon emitting electrical source in the U.S. As such, nuclear energy continues to be an essential part of the energy mix in the U.S.

It is important that as these NPPs achieve license extensions, they continue to operate safely, reliably, and efficiently. Moreover, it is important that where they can gain efficiencies to maintain cost effectiveness, these efficiencies must be incorporated into the plants. Technology is one key source of efficiency, and it is common to see advances in electric production made possible through improved components like newer steam generators and steam turbines. An additional source of efficiency can be achieved through control room modernization. The current main control rooms at NPPs largely follow the original designs, with several minor improvements over time required to improve safety, such as the incorporation of safety parameter display systems (SPDS) in the control room to allow operators to monitor key plant parameters better.

The U.S. Department of Energy (DOE) has put in place the Light Water Reactor Sustainability (LWRS) program to aid the U.S. commercial nuclear industry in extending the life of the current fleet of NPPs. Within the LWRS program, there is the Advanced Instrumentation, Information, and Control Systems pathway [2], which includes pilot program initiatives on control room modernization. The control room modernization pilot project is a joint government-industry collaboration that seeks to establish the processes by which control room modernization can best be achieved at NPPs and to demonstrate these processes by working directly with utilities to perform first-of-a-kind upgrades. The experience gained on the control room modernization pilot project is documented in the form of reports that are disseminated to industry and the regulator. These reports act as templates that utilities may follow to streamline their own efforts at control room modernization. The LWRS program breaks down the barriers to control room modernization by documenting the processes to be followed and providing relevant real-world demonstrations of these processes.

This paper is aimed at addressing gaps in the guidance for initiating control room modernization. Specifically, this paper outlines the process for conducting baseline evaluations on existing control systems that will be modernized in the control room. These baseline evaluations drive the design of the new replacement system but also provide invaluable comparative performance data for later benchmarking of the new system.

It must be noted that the baseline process documented in this paper assumes a partial, stepwise upgrade in the control room. As opposed to an infeasible full control room replacement, we assume that a single control system (e.g., turbine control system) is being upgraded from the analog system currently in place to a digital replacement system. The resulting control room is a hybrid control room with the new digital control for a specific system coexisting with legacy analog I&C on the control boards. It is further assumed that the new digital control system largely mirrors the functions of the existing analog control system, although the design may be optimized to the operators, e.g., consolidating indicators and alarms in a more efficient manner than the legacy control boards or automating some functions in order to reduce operator workload. The purpose of the baseline evaluations is to understand the current operator process and identify potential areas for operational improvements as the control system is evolved.

2 THE BASELINE EVALUATION PROCESS

2.1 Review of NUREG-0711

Human factors engineering (HFE) is defined by the U.S. Nuclear Regulatory Commission (NRC) as ([3], p. 114):

> The application of knowledge about human capabilities and limitations to designing the plant, its systems, and equipment. HFE affords reasonable assurance that the design of the plant, systems, equipment, human tasks, and the work environment are compatible with the sensory, perceptual, cognitive, and physical attributes of the personnel who operate, maintain, and support the plant or other facility.

More specifically, HFE entails the process of optimizing operator interactions with control systems such as the I&C in the main control room of an NPP.

The U.S. NRC publishes the *Human Factors Engineering Program Review Model* [3], which outlines a formal process that U.S. NRC staff follow in reviewing human-machine interface (HMI) designs. NUREG-0711 provides the formal process to support the more general *Standard Review Plan* (NUREG-0800) for *Human Factors Engineering* [4]. The U.S. NRC reviews a variety of documentation sources under the umbrella of Chapter 18 submittal by the licensee, and further specifies three applications for HFE review by the U.S. NRC:

- New plant designs
- Control room modifications
- Modifications affecting risk-important human actions

The U.S. NRC exercises a graded approach to reviewing control room modifications, with a particular emphasis on safety functions of the plant, e.g., the reactor control system. Modifications to any systems documented in the plant's Final Safety Analysis Report (FSAR), including changes to the HMI, are subject to license amendment under 10 Code of Federal Regulations (CFR) Part 50, Section 59, "Changes, Tests, and Experiments." It is important to note then that secondary (non-safety) control room systems may therefore not be subject to a full Chapter 18 review, although it is good practice to follow a vetted and regulator-supported HFE process.

NUREG-0711 outlines four phases of HFE, each with sub-elements, as depicted in Table 1. These phases comprise the Planning and Analysis, Design, Verification and Validation (V&V), and Implementation and Operation phases. By reviewing licensee submittals through these four phases, the U.S. NRC achieves its goal of ensuring a thorough and systematic HFE process was carried out throughout the life cycle of the system.

Table 1. HFE Phases Covered in NUREG-0711, Rev. 3 [3].

Planning and Analysis	Design	Verification and Validation	Implementation and Operation
HFE Program Management	Human-System Interface Design	Human Factors Verification and Validation	Design Implementation
Operating Experience Review	Procedure Development		Human Performance Monitoring
Function Analysis & Allocation	Training Program Development		
Task Analysis			
Staffing & Qualification			
Treatment of Important Human Actions			

In terms of control room modernization, NUREG-0711 considers several methods of modernization that might be undertaken by the licensee. These mirror similar approaches to control room modernization outlined in an earlier report by the Electric Power Research Institute [5]:

- Many small modifications (ERPI: piecemeal modernization)
- Large modifications during a single outage (EPRI: full modernization)
- Large modifications during multiple outages (ERPI: partial modernization)
- Both old and new equipment left in place (ERPI: partial modernization)
- New non-functional HMIs in place with old functional HMIs (EPRI: behind-the-boards modernization)

We previously conducted a survey of U.S. utilities [6] and determined that, in the U.S., utilities were likely to go about a partially modernized control room process, resulting in a hybrid control room of legacy analog I&C and newer digital HMIs. Systems are likely to be upgraded one at a time across outages, resulting in the gradual stepwise modernization of the main control room. As noted in NUREG-0711, this process of gradually introducing new HMIs to the control room, typically starting with non-safety systems, is an approach that ensures operators are comfortable with the HMIs long before safety systems are upgraded.

While NUREG-0711 covers both new builds and control room modernization, the majority of the guidance specific to control room modernization is contained in the Implementation and Operation phase under the sub-element on Design Implementation. Because of the graded approach, some control room modernization activities are below the threshold for formal Chapter 18 review by the U.S. NRC. Licensees considering control room modernization activities may therefore be confused about the applicability of NUREG-0711. Further, much of the emphasis in NUREG-0711 is on final product review, and the HFE process outlined may omit many steps that would be helpful en route for the licensees. Finally, the guidance in NUREG-0711, Rev. 3, while more comprehensive than earlier versions, does not provide extensive guidance specific to control room modernizations. To redress these challenges to a licensee who wishes to undertake control room modernization and follow an HFE plan, this paper (and a companion report by Boring et al. [7]) seeks to fill in gaps in NUREG-0711. In most cases, the information contained in these two sources is implied in NUREG-0711, but it is helpful to capture some additional steps that will aid the licensee in control room modernization. We begin our discussion in the next section with an overview of two key types of HFE processes that are essential to control room modernization—baseline and benchmark evaluations.

2.2 Baseline vs. Benchmark

It is important to make a distinction between a performance *baseline* vs. a performance *benchmark*. The terms are often paired but used in vastly different domains. For example, a human resources definition would suggest that baselining is to compare current performance to historic performance, while benchmarking is to compare performance to others' performance (e.g., compare pay in one company to pay across the industry). More generally, while benchmarking implies a comparison (see [8]), baselining does not necessarily require a comparison of different data points. Baselining can be an assessment of performance for a system at a particular point in time. The baseline measures can be used for trending, but they may also be used as standalone data. For the purposes of control room modernization, we define the two terms thus:

- A *baseline* is an evaluation of operator or system performance at a given point in time. A baseline may be used to evaluate the usability and ergonomics of an as-built system such as a particular HMI in the control room. Baseline findings may be used to catalog performance for use in longitudinal trending (over time) or to gather insights to inform the design of a replacement system.
- A *benchmark* is a comparative evaluation of operator or system performance. A benchmark may be used to evaluate the usability and ergonomics of two systems, such as when comparing an existing

system vs. an upgraded system. Baseline findings may be used as part of a benchmark. A benchmark is often part of the validation of completed systems and is used to gauge the efficacy of a replacement system against its predecessor. In some cases, a benchmark may also be used to decide between competing prospective off-the-shelf system solutions.

For control room modernization purposes, the key distinction between a baseline and a benchmark is the stage at which it is employed. A baseline evaluation will be performed on an existing system *before* it is upgraded in order to inform the design of its replacement system. A baseline evaluation may also be performed periodically *after* a system is employed as part of maintenance and operations (M&O) to trend and ensure continued successful performance. In contrast, a benchmark is performed *during* the Design and V&V phases to ensure a new system performs at least as well as the system it is replacing. In human factors terms, the benchmark ensures that the operators using the new system perform at least as reliably, efficiently, or safely as they did when using the predecessor system that is being replaced.

2.3 Gaps in NUREG-0711

2.3.1 Planning and Analysis Phase

The sub-elements within the Planning and Analysis phase of NUREG-0711—namely Operating Experience Review, Function Analysis & Allocation, Task Analysis, Staffing & Qualification Review, and Treatment of Important Human Actions—are certainly applicable to control room modernization, as they are to new builds. As documented in [12] and depicted in Table 2, several of these sub-elements directly gather information that is useful to the design of the system, which is discussed in the next section. That is not to say, however, that these sub-elements are not important for control room modernization applications. However, what is missing from the NUREG-0711 guidance, which is particularly relevant to control room modernization, is collection of baseline data.

Table 2. Relationship between Planning and Analysis Sub-Elements to Design and V&V Activities.

	Operating Experience Review	→	Function Analysis and Allocation	→	Task Analysis	→	Design Activities	→	Verification and Validation
Goals	What happened before? Identify where existing system could be improved and where similar systems have provided relevant insights.		What is system vs. operator controlled? Identify opportunities to improve performance by indentifying modifiable functions.		What can be changed? Define information and control needs for operators to perform new and existing functions.		What's the new design? Develop conceptual designs for the HSIs.		Does it work? Test the designs and make sure all required information and controls are there and work.

Baseline performance evaluation, as noted earlier, entails collecting observations on how the existing system is used. The assumption here is that in control room modernization, there is not a need to hypothesize and determine the types of tasks operators will perform, because they are already doing them. Similarly, the upgrade to the control room will in most cases not introduce significant new functionality to the plant; rather, it will introduce new technology to the control room that will aid the operators in monitoring, diagnosing, and operating the plant. In some cases, additional functionality may be added, (e.g., new sensors as part of a turbine control system upgrade may allow new control automation such as automatic synchronization to grid). However, new functionality represents the evolution of the existing process control, not the introduction of completely new processes. We do not wish this to be a limiting statement. It is impossible to anticipate what new functionality may in the future be added to nuclear power plants. However, at the current time in the U.S., the authors are not aware of any plant upgrades that would introduce significant new processes or capabilities to the plant. Control room modernization is centered on upgrading existing, typically analog I&C to new digital technology, with only minor increments in automation or functionality.

As such, the design goals are not large departures from the existing system. For example, the Function Analysis and Allocation sub-element of NUREG-0711 typically produces a functional hierarchy that includes components, systems, processes, safety functions, and goals. Where the purpose of a control room upgrade is to replace the I&C associated with a particular system in the plant, there would generally be no substantial change to the underlying components, systems, processes, safety functions, or goals. Therefore, a change in the HMI does not require a substantial reworking of the Function Analysis and Allocation associated with the predecessor system, unless significant new functions including new automation are planned as part of the upgrade. Similarly, if the overarching tasks performed by the operators are not significantly changed by the upgrade, the Task Analysis need only focus on those changes associated with operators retrieving plant status information or performing control actions on the plant systems. These are not new tasks, just refinements of existing tasks.

Grandfathered systems may not have originally undergone a NUREG-0711 process review, in which case the utility should undertake the Planning and Analysis sub-elements in order to align plant design documentation with current standards.

A first step of control room modernization is a baseline evaluation of the current system already in place and currently being used. The baseline evaluation takes the form of a review of the usability and ergonomics of the current system.

- *Usability* in this case refers to the ease and reliability with which the operators perform required tasks. In order to conduct a usability evaluation, relevant scenarios related to use of the system should be selected and run in the plant training simulator or similar high fidelity simulator like the Human Systems Simulation Laboratory (HSSL) at INL [13-14]. The objective of the walkthroughs is to identify any opportunities for improvement in the HMI for the tasks performed by the operators. For example, a walkthrough of an existing turbine control system might note the requirement to have three reactor operators at the panels, because synchronization to the grid requires two operators at the turbine controls. Debrief interviews with the operators would identify why there is a need to have extra operators for that task and could identify specific tasks that are particularly resource demanding. Such information may be the basis for reevaluation of the Task Analysis or Function Analysis and Allocation. Ultimately, the usability evaluation will tell the design team what aspects of current operations are satisfactory, what information the operators rely on to complete tasks, and what improvements might be sought through an upgrade. These baseline data can also serve as comparison data points later when the replacement system is benchmarked against its predecessor.
- *Ergonomics* is the study of operators' physical interaction with the system. In this case, a baseline ergonomics evaluation will account for cases where physical strain is observed in or mentioned by the operators. For example, an operator might express that the process of closing a valve takes considerable time, during which the operator is unable to perform other tasks in the control room and the illuminated button actually becomes uncomfortably hot to the touch. Additionally, measures of the existing control boards should be taken and assessed to ergonomic standards like NUREG-0700, *Human-System Interface Design Review Guidelines* [15]. The goal of the ergonomics review is to identify which areas of the physical layout of the boards (relative to the system being upgraded) are not optimized for use. Particularly the introduction of digital displays and input devices like trackpads to replace physical indicators, switches, and dials offers opportunity to consolidate the control boards.

The ergonomics review will highlight areas where the consolidation should result in improved placement of sources of operator interaction with the system.

2.3.2 Design and V&V Phase

Where we previously espoused augmenting NUREG-0711 requirements for the Planning and Analysis phase, in this section we also point out that the Design and V&V phases have process gaps that need to be redressed from a utility perspective. In previous reports, we have discussed human factors specific to the Design phase of control room modernization. For example, [7] highlights operator performance measures that can be employed as part of design phase evaluations. We identified that the strict delineation between the Design phases and V&V phases overlooked an important opportunity for iterative design and evaluation. In other words, it is not good practice for human factors to complete the design and only then evaluate it. Rather, early design concepts should be evaluated and then refined, evaluated again, and the process repeated until a design with minimal operator performance issues is finalized. Throughout this process, prototypes should be used to afford rapid refinement and redesign as needed [9-11]. Only after the design is finalized and implemented is a formal integrated system validation (ISV) prescribed in NUREG-0711. There is a clear delineation between the Design phase and the formal V&V phase, but V&V is indeed necessary and desirable at the Design phase to help arrive at the final design. As described in [7], there is a need for formative evaluation of the interface during the Design phase, coupled with summative evaluation of the completed design prior to implementation. *Formative* evaluation is used to help shape the design, while *summative* evaluation is used to validate the finalized design. NUREG-0711 only addresses summative evaluation at length, but the licensee will greatly benefit from using formative evaluation throughout the design cycle. Human factors is considered least effective at the summative stage, when issues may prove entrenched in the design of the system and prove costly and time consuming to correct. Formative evaluation allows earlier discovery and correction of issues prior to implementation of the system.

The summative V&V phase in NUREG-0711 serves to document that the end product of the design operates as desired. Logically, the U.S. NRC, in reviewing licensee submittals related to control room modernization, is most interested in the results of the summative V&V in the form of the ISV study. However, while not explicated in NUREG-0711, an iterative design-evaluation cycle should be performed formatively during the Design phase to arrive at a satisfactory final design suitable for ISV. There may be reluctance on behalf of the utility to document to the regulator the findings of formative evaluations, since these evaluations will not represent rarified designs and will feature many issues that are ultimately resolved en route to the completed design. A design in progress is not a perfect design, and it is expected that there will be significant issues. Still, the fact that a systematic HFE process was followed to optimize the design is significant. The shortcomings of early designs should not be hidden; rather, there is value in documenting the evolution of the design. Even though documenting the evolution of the design through design-evaluation cycles is not required per NUREG-0711, the fact that such a process was followed lends considerable credibility to the final design.

2.4 Example Baseline Evaluations

2.4.1 Example of Usability Baseline Review

This section illustrates the process for a baseline usability review conducted in conjunction with the evaluation of initial static prototypes and subsequent fully functional dynamic prototypes in the HSSL using plant crews on a glasstop virtualization of the actual control room. These studies are documented in greater detail in [16-17]. Below follows a brief excerpt of the baseline human factors method used to establish performance of the existing system.

A utility engaged in control room modernization of their turbine control system enlisted INL to assist with the HFE of the new system. A series of Planning and Analysis studies were conducted (see [12]) prior to initiation of the turbine control system design. These workshops were conducted at the plant and at the HSSL and were used generally to determine what operator tasks might be made more efficient through the addition of digital control systems in the control room. This general information was then augmented by the baseline usability study of the existing turbine control system. The important characteristics of the study were:

- We developed scenarios specific to the full range of operations involving the turbine control system. These scenarios were developed in coordination with an instructor at the plant and ranged between normal and abnormal operations. The scenarios were not as detailed as the operator licensing or just-in-time training, and the objective was not to teach or test operators on their use of the system, but rather to review their use of the control system across the scenarios.
- We held the study in the HSSL using the full-scope plant simulator represented on the glasstop panels. We surveyed the operators to ensure the fidelity of the simulator experience. In principle, it would have been possible to conduct the baseline study at the utility's training simulator, since the purpose was to evaluate operators' use of the as-built control room. However, since it was not possible to alter the training simulator to the extent needed to conduct a realistic test of the new turbine control system, it was decided to use the glasstop simulator. The virtual nature of the HSSL allows alteration of the boards to accommodate a representation of the new digital control system that would replace the existing turbine control system. The HSSL also had the advantage of it being the same reconfigurable research simulator that would be used to test new prototypes,.
- We ran each scenario two times—the first time in real-time, and the second time using a think-aloud protocol. The real-time walkthrough allowed the operators to move through the scenario in uninterrupted fashion, affording realistic data collection on time to complete tasks and crew communications. The second walk-through featured the operators narrating what they were doing, with pauses to allow the observers to ask questions about control process, plant behaviors, and operator decisions or actions. This guided walkthrough added measures like workload, situation awareness, and overall operator impressions of the process and existing I&C.
- Following each scenario, there was a facilitated debrief in which we reviewed our observations for accuracy with the operators and challenged the operators to identify areas for improvement in the process. This approach yielded several suggestions that were later reviewed for incorporation in the design of the new turbine control system. Note that such open-ended responses can result in a wish list of features by the operators, not all of which will be possible or feasible to implement.

The study resulted in objective operator performance data (e.g., path to complete tasks, time on tasks), insights into the operator mental models (e.g., what information they expected, why they performed particular actions), subjective feedback (e.g., what the operators liked and didn't like, what tasks were difficult or easy), and design recommendations (e.g., what features would make particular tasks easier, and what information operators would like to see trended on a display). These baseline data became the building blocks for the initial design of the replacement turbine control system. These data also served to identify how the process is typically performed, where there are potential error traps or difficulties in the process, and how the process might be improved.

2.4.2 Example of a Baseline Ergonomics Review

The following is a simple example of how an ergonomics baseline review of a turbine control system proceeded at the NPP discussed previously. The general goal of this baseline review was to evaluate the ergonomics of the existing system and identify any problems that needed to be documented, such that they could be addressed in the new digital HMI design or control board layout. The characteristics of the evaluation were as follows:

- The ergonomics evaluation was conducted at the plant training simulator, because the HSSL was not deemed a suitable environment for the ergonomics baseline evaluation due to the fact that the control board mimics are scaled for display on the glasstop panels. The dimensions of the training simulator (e.g., heights of particular controls) were confirmed to conform exactly to the dimensions in the actual main control room.

- Exact dimensional drawings of the control boards were obtained, as were photographs of the board layout. These aided in measurements.
- The controls and indicators used as part of the usability baseline evaluation scenarios were identified, and they were measured for conformance to ergonomic height, reach, and visibility requirements in NUREG-0700 for operators in the standing position as they would normally be operated. Because the list of applicable ergonomic requirements is extensive, NUREG-0700 was screened by ergonomics experts for only the applicable requirements for control panel operation. This compressed list significantly shortened the review time required.
- The control systems used for turbine control system operation were reviewed against the utility's HMI style guide and against available human engineering deficiencies catalogued by EPRI (see Table 6.6 in [5]).

Deficiencies in ergonomics were noted and applied both to the design of the digital control system and the control board layout. For example, when the operators expressed difficulty reading a particular indicator on the existing control panels while standing at the adjacent control board, this indicator was subsequently embedded in the digital control system in a manner clearly legible from several feet away from the display. Since many physical controls will be retained for redundancy even after the upgrade, several controls were repositioned to be at a more accessible location on the benchboard. The goal in incorporating these changes in the Design phase is to ensure ready operability of the controls, proper legibility of the indicators, and reduced physical strain to the operators in interacting with the control panels in the main control room.

2.5 Revised NUREG-0711 Process Model for Control Room Modernization

Table 3 presents a summary of proposed additions to the NUREG-0711 HFE process model as proposed for control room modernization in this paper. In the Planning and Analysis phase, new sub-elements called "Baseline Usability Evaluation" and "Baseline Ergonomic Assessment" are included. For the Design phase, the control boards must be reconfigured to accommodate the new digital control system, a design task requiring careful ergonomic review. This is represented as a new box entitled "New Control Panel Layout." Also in the Design phase, an "HMI Style Guide" sub-element is added, which serves to direct the design elements of the replacement system (see [18]). The sub-element "Formative Evaluation" is also added to account for the iterative design-evaluation cycle described in Section 2.3.2 of this paper. For the V&V phase, a sub-element called "Summative Benchmark Evaluation" is added, in which the performance on the completed design is compared to (or benchmarked against) baseline measures. The Summative Benchmark is an appropriate treatment of ISV as described in NUREG-0711. No new sub-elements are proposed for the Implementation and Operation phase, but it should be noted that Human Performance Monitoring would resemble the periodic longitudinal baseline evaluations for M&O described in Section 2.2 of this paper.

These modifications are neither expected nor endorsed by the U.S. NRC. It is our belief, however, that these changes represent appropriate additions to the HFE process for the utility to perform as part of control room modification. The additions complement the process outlined in NUREG-0711 and strengthen the HFE process in two critical ways:

- These new sub-elements are relevant to the utility. Whereas NUREG-0711 is geared primarily for U.S. NRC use and focuses on summative documents, these additional tasks ensure completeness of the HFE process by the licensees through the formative stages of control room modernization.
- NUREG-0711, as noted, is largely geared toward new builds. These steps help customize the HFE approach to the requirements of control room modernization.

Table 3. NUREG-0711 Process Model with Added Steps Appropriate to Control Room Modernization.

Planning and Analysis	Design	Verification and Validation	Implementation and Operation
HFE Program Management	New Control Panel Layout*	Human Factors Verification and Validation	Design Implementation
Operating Experience Review	Human-Machine Interface Style Guide*	Summative Benchmark Evaluation*	Human Performance Monitoring
Baseline Usability Evaluation*	Human-System Interface Design		
Baseline Ergonomic Assessment*	Formative Evaluation*		
Staffing & Qualification	Training Program Development		
Treatment of Important Human Actions			

*Proposed additional activities by utility in support of control room modernization.

3 CONCLUSIONS

In this paper, we have bridged previous discussions on augmenting the Design phase of NUREG-0711 (see [7]) with additional guidance relevant to the Planning and Analysis phase. While NUREG-0711 provides solid guidance on HFE, this guidance largely addresses new builds. Additionally, NUREG-0711 is written in terms of regulatory review of summative information, thereby omitting some of the process details that would be useful for the licensee to complete formatively as part of control room modernization. The addition of new elements to NUREG-0711 is not meant as a critique of that guideline. In fact, NUREG-0711 remains the most comprehensive document to support the HFE process in the nuclear domain. Instead, this paper is simply meant to align the utility with the overall HFE process prescribed in NUREG-0711 by engaging HFE more fully and iteratively in early phases of the control room modernization process.

In this paper, we have highlighted two new elements that should be considered as part of the Planning and Analysis phase of NUREG-0711. These sub-elements are two types of baseline evaluations. Baseline evaluations are conducted on a system already in place to gather useful insights into the current use of the system. Specifically, this paper advocates the inclusion of baseline usability and ergonomics reviews that can serve as starting points for aligning the design to build on the strengths of the existing control system and address any shortcomings in it. In practice, these baseline measures support the other sub-elements in Planning and Analysis such as Task Analysis and Function Analysis and Allocation.

Additionally, these baseline measures may be compared against the finished design as a benchmark in the V&V phase. As such, these additional evaluations are a seamless part of the existing NUREG-0711 process, optimized to collecting operator data on a control system that is undergoing modernization.

Combined with guidance previously published in [7], this paper outlines steps utilities can follow to ensure successful HFE across the control room modernization process. This approach identifies six new HFE process steps. The goal of adding these process steps is not to increase the cost and burden of exercising HFE as part of control room modernization. It is believed that these steps are in fact crucial milestones toward project success and that following them ultimately decreases the need for do-over or redesign in implementing modernized control systems. The processes outlined emphasize important feedback and operator involvement early in the design process. This operator-centered feedback refines the design prior to implementation, thereby minimizing the opportunity for design issues to surface as part of the summative V&V. It also maximizes operator acceptance of the new control system upon implementation, since the operators have been involved firsthand in the design process.

It is hoped that these new baseline steps, as well as other HFE process steps identified under this LWRS research project, will become process checklists for use by industry. Further, it is hoped that outlining specific formative steps toward control room modernization will align with regulatory expectations for a comprehensive HFE program at the utilities. Future work under LWRS will further document the use of these added HFE steps as part of upgrade activities at partner utilities and capture lessons learned that can streamline industry adoption of HFE in support of control room modernization.

4 ACKNOWLEDGMENTS

This work of authorship was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights. Idaho National Laboratory is a multi-program laboratory operated by Battelle Energy Alliance LLC, for the United States Department of Energy under Contract DE-AC07-05ID14517.

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