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Light Water Reactor Sustainability Program

Planning and Analyses Performed to Install Halden's Advanced Control Room Concept in the Human Systems Simulation Laboratory

Jeffrey C. Joe and Robert McDonald

July 2018

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Approved by:

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EXECUTIVE SUMMARY

The United States (U.S.) Department of Energy (DOE) sponsors the Light Water Reactor Sustainability (LWRS) Program, which has the goal of sustaining U.S. nuclear assets through conducting high-quality, value-added research and development (R&D) that provides the technical bases to extend the operating life of commercial nuclear power plants (NPPs). One area in the LWRS program is the Plant Modernization pathway, which includes human factors R&D, human factors engineering (HFE), and ergonomics, conducts targeted R&D to address aging and reliability concerns with the legacy instrumentation and control (I&C) and related information systems in NPPs.

For the last few years, LWRS program researchers have been conducting R&D that enables the modernization of the I&C technologies in NPP main control rooms. All of the LWRS control room modernization R&D performed thus far in collaboration with various U.S. utility partners has been on upgrades that position these legacy control rooms for further full nuclear plant modernization. The LWRS program is now in the position to further collaborate with utilities as they continue to upgrade their control rooms (i.e., to full control room modernization).

Thus, the purpose of this LWRS R&D activity is to start developing an advanced control room interface concept for legacy NPPs and to demonstrate it in the Human Systems Simulation Laboratory (HSSL) at Idaho National Laboratory (INL) so that utility partners can see what a potential end state is for their control room upgrade activities. The end state is the result of HFE and I&C work to transition the existing control room and its concept of operations to a new advanced control room configuration, and will therefore show what a fully modernized control room looks like and how it works.

This report documents the planning and analyses performed to install an advanced control room concept in the HSSL. Future LWRS reports will document the process to configure the HSSL and install the generic Pressurized Water Reactor simulator model with an advanced Human System Interface (HSI) developed by the Institute for Energy Technology.

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ACRONYMS

BOP	Balance of Plant
CRS	Control Room Supervisor
DCS	Digital Control System/Distributed Control System
DOE	Department of Energy
gPWR	Generic Pressurized Water Reactor
HAMMLAB	Halden Human-Machine Laboratory
HFE	Human Factors Engineering
HSI	Human System Interface
HSSL	Human Systems Simulation Laboratory
HVAC	Heating, ventilation, and air conditioning
I&C	Instrumentation and Controls
IAEA	International Atomic Energy Agency
IFE	Institute for Energy Technology
INL	Idaho National Laboratory
ISV	Integrated System Validation
LWRS	Light Water Reactor Sustainability
NRC	U.S. Nuclear Regulatory Commission
NSR	Non-safety Related
NSSS	Nuclear Steam Supply System
PWR	Pressurized Water Reactor
R&D	Research and Development
RO	Reactor Operator
SRO	Senior Reactor Operator
TCS	Turbine Control Systems
U.S.	United States

Planning and Analyses Performed to Install Halden's Advanced Control Room Concept in the Human Systems Simulation Laboratory

1. INTRODUCTION

Affordable, abundant, and reliable electricity generation is essential to fueling a nation's robust and globally competitive economy. In the United States (U.S.), according to the Energy Information Administration, commercial nuclear power plants (NPPs) account for approximately 19% of reliable and cost-competitive base load electricity generation. Many of the NPPs in the U.S., however, are approaching the end of their original licensing period, or are already in their first license extension period. Many commercial NPPs are evaluating the technical and economic issues with continuing to operate into a second license extension, because other technologies that reduce reliance on fossil fuels and provide base load electricity cost-competitively at a national scale are still under development. Thus, without suitable replacements for nuclear power, the generating capacity of nuclear energy in the U.S. must be continued through the safe and efficient operation of commercial NPPs.

The U.S. Department of Energy (DOE) Office of Nuclear Energy sponsors the Light Water Reactor Sustainability (LWRS) program, which has the stated goal of sustaining U.S. nuclear assets through conducting high-quality, value-added research and development (R&D) that provides the technical bases to extend the operating life of commercial NPPs. One area in the LWRS program is the Plant Modernization pathway, which includes human factors R&D, human factors engineering (HFE), and ergonomics, conducts targeted R&D to address aging and reliability concerns with the legacy instrumentation and control (I&C) and related information systems in NPPs. The two primary goals of the Plant Modernization pathway are: (1) to ensure that legacy analog I&C systems are not life-limiting issues for the LWR fleet, and (2) to implement digital I&C technology in a manner that enables broad innovation and business improvement in the NPP operating model.

Within the Plant Modernization pathway, LWRS program researchers have been conducting R&D for the last several years on control room modernization. The LWRS sponsored R&D on control room modernization has expanded on the Plant Modernization pathway goals by further specifying the following objectives:

- Demonstrate that the performance of the upgraded control room is at least as good as, and ideally better than, the performance of the existing control room
- Demonstrate that no new human error traps have been introduced and/or safety-critical human engineering discrepancies are present
- Bring about needed changes to improve the human system interface (HSI) and the functionality of the underlying control logic of digital I&C solutions that are deployed in U.S. NPP main control rooms

LWRS program researchers have been conducting R&D that enables the modernization of the I&C technologies in NPP main control rooms and have authored numerous reports on those research activities. All of the LWRS control room modernization R&D performed thus far in collaboration with various U.S. utility partners has been on upgrades that position these legacy control rooms for further full nuclear plant modernization. The LWRS program is now in the position to further collaborate with utilities as they continue to upgrade their control rooms (i.e., to full control room modernization).

That is, the control room upgrades that U.S. utility partners have done in recent years in partnership with the LWRS program correspond to the "Partially Modernized I&C and HSI" oval shown in Figure 1 in that utilities have performed upgrades that involve both equipment replacement and updates to the I&C architecture.

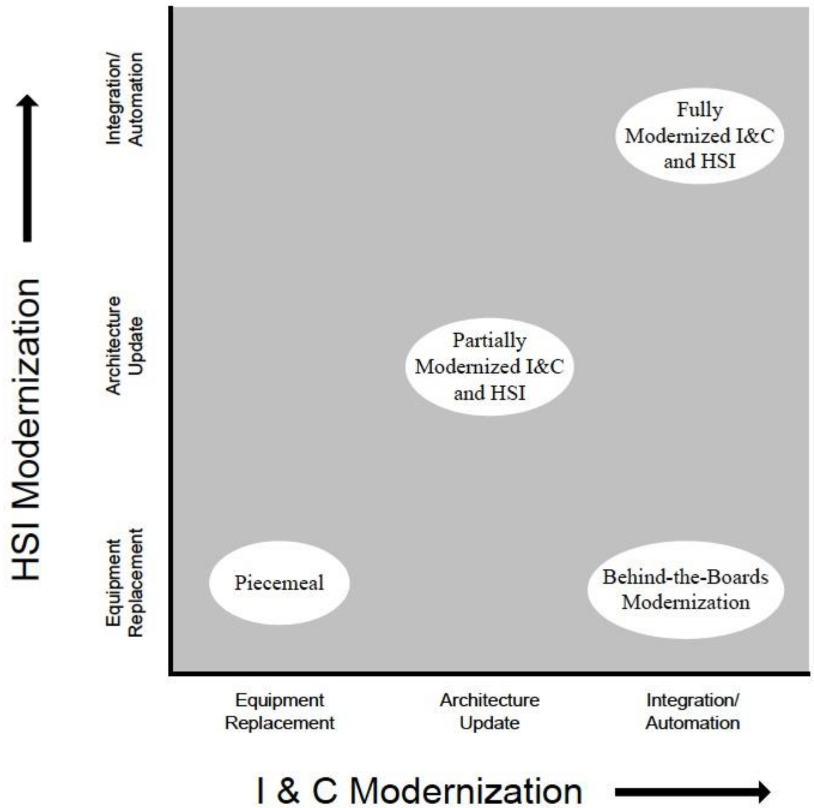

Figure 1. Control Room Modernization Strategies.

This has positioned many currently operating NPP units in the U.S. to be ready for full modernization of their control room I&C and HSI, or for a "Fully Modernized I&C and HSI" (Figure 1). Full modernization of a control room means that new advanced digital I&C systems are implemented and integrated into the control room, thereby changing the concept and conduct of operations, primarily through a redesign of the control room layout, redesigning how systems are represented and controlled, and usually through an increased use of automation.

Thus, the purpose of this LWRS R&D activity and milestone report is to start developing an advanced control room interface concept for legacy NPPs and to demonstrate it in the Human Systems Simulation Laboratory (HSSL) at Idaho National Laboratory (INL) so that utility partners can see what a potential end state is for their control room upgrade activities. The end state is the result of HFE and I&C work to transition the existing control room and its concept of operations to a new advanced control room configuration, and will therefore show what a fully modernized control room looks like and how it works.

This report documents the planning and analyses performed to install an advanced control room concept in the HSSL. Specifically, LWRS research partners at the Institute for Energy Technology (IFE) in Halden, Norway are developing an advanced HSI based on the generic Pressurized Water Reactor (gPWR) simulator model. The gPWR is a simulator model used for a variety of research purposes across the U.S. at various institutions, including the U.S. Nuclear Regulatory Commission (NRC), INL, various Universities, and Sandia National Laboratory. The gPWR is also based on an existing NPP currently operating in the U.S. – specifically a 3-loop Westinghouse Pressurized Water Reactor (PWR). Given that there are multiple 3-loop Westinghouse PWRs in operation in the U.S.[a], the gPWR is a good common platform upon which to develop an advanced control room interface, because it provides a common end state for multiple currently operating NPPs.

This report documents the initial planning and the analyses performed that are needed to install an advanced control room concept in the HSSL at INL. Section 2 documents the prior LWRS sponsored R&D performed on control room modernization to position a number of utilities and their upgraded NPP control rooms for further upgrading to an advanced digital control room. Section 3 summarizes a few of the advanced control room concepts and designs that are currently either in operation, or are expected to enter into operation soon. Section 4 documents some specific planning and analysis activities performed to help guide IFE's or Halden's development and the installation of an advanced control room concept in the HSSL, and Section 5 provides a conclusion and identifies next steps.

[a] According to the NRC Technical Training Center Reactor Concepts Manual on PWRs, Beaver Valley 1 and 2, Farley 1 and 2, H. B. Robinson 2, North Anna 1 and 2, Shearon Harris 1, V. C. Summer, Surry 1 and 2, and Turkey Point 3 and 4 are all 3-loop Westinghouse PWRs.

2. Summary of Prior Control Room Modernization R&D

This section documents the prior LWRS sponsored R&D performed on control room modernization that has helped position a number of utilities and their upgraded NPP control rooms for further upgrades to an advanced digital control room. Given the fact that many in the industry are positioned for full control room modernization, it can be argued that it is timely and appropriate for the LWRS program to start developing and demonstrating advanced control room concepts so that these industry leaders can visualize the future end state of their modernization activities.

2.1.1 LWRS Duke Energy Control Room Modernization Project

LWRS program researchers are collaborating with Duke Energy to support their efforts to upgrade the legacy turbine control systems (TCSs) at their Brunswick, Robinson, and Harris plants. This TCS upgrade involves installing a common distributed I&C system platform through which multiple systems can be integrated as the associated control rooms are modernized over time. LWRS program experts established a common look and feel to the HSI. LWRS program researchers also helped guide the development of the underlying control logic for the I&C system, and in doing so, ensured that there would be consistency in the digital control system's (DCS) functionality and behavior from one subsystem (e.g., TCS) to another (e.g., plant process computer).

To accomplish the work summarized above, one of the first activities LWRS researchers performed was to develop an HFE program plan to help map Duke HFE activities to NUREG-0711 (NRC, 2012). As seen in Figure 2, this HFE program plan served as a roadmap for the different types and phases of HFE R&D that would be performed. See Boring, Hugo, Hanes, Thomas, and Gibson (2013), and Boring, Joe, and Ulrich (2014) for more details.

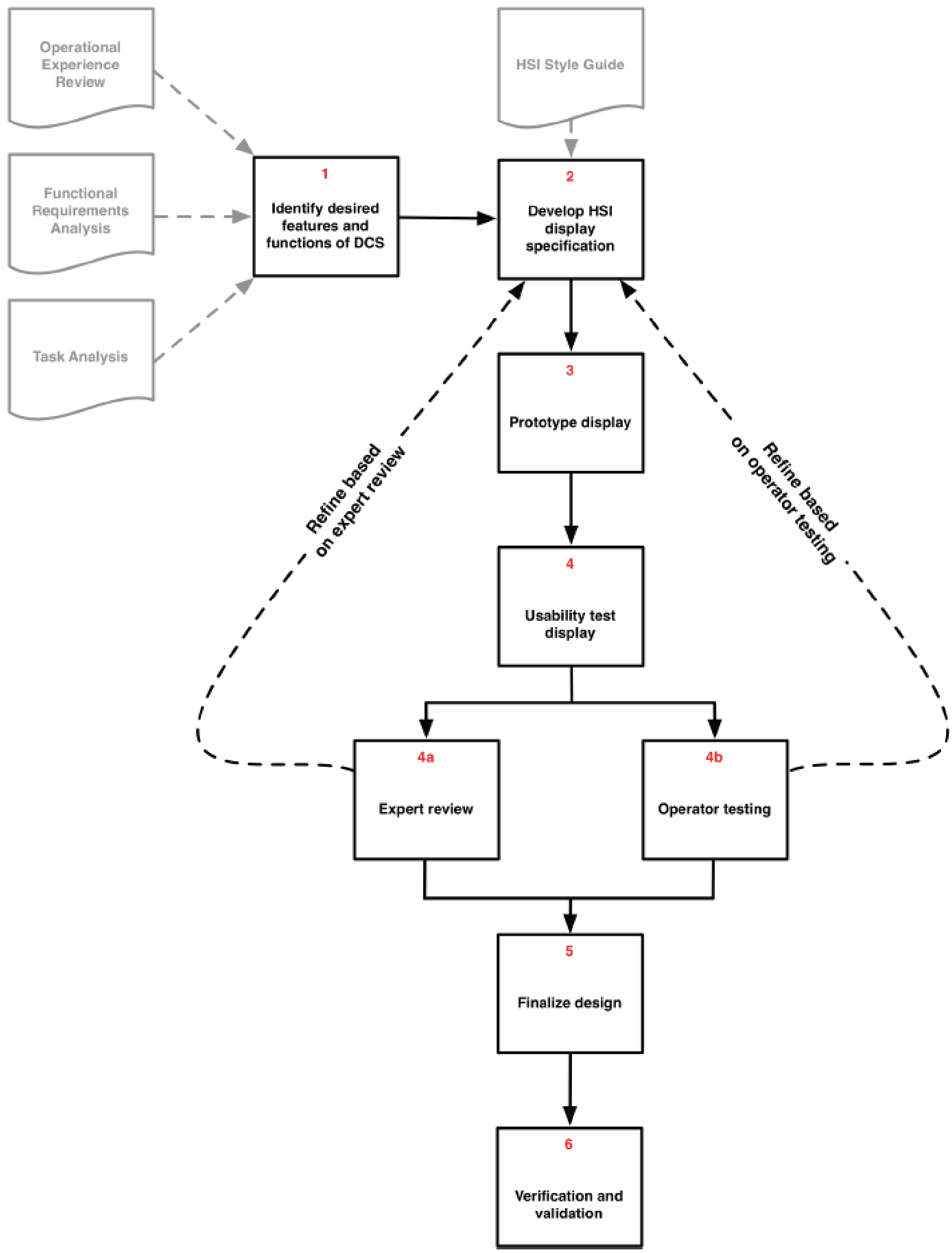

Figure 2. HFE Process Roadmap for the Duke Control Room Upgrade Activities

That is, Figure 2 shows how key HFE activities LWRS program researchers performed roughly correspond to the four phases of NUREG-0711 (NRC, 2012). The researchers applied considerable emphasis on HFE involvement in the earlier phases to ensure success at later phases. For example, early analytical HFE work, including developing an HFE program plan (Boring, Hugo, Hanes, Thomas, & Gibson, 2013), was performed for these Duke upgrades. Additionally, Hanes, Hugo, Boring, Berg, Forbes, & Gibson, (2013) performed an operational experience review to understand what historical events and previous issues the industry had encountered that may provide lessons learned for these upgrades.

The latter stages of the LWRS HFE R&D work with Duke involved interactions with plant personnel in the HSSL and at purpose-built glass-top simulators located at each of the three stations (i.e., Brunswick, Harris, and Robinson). For all three stations undergoing the TCS upgrade, a series of workshops were held first, whereby a prototype of the TCS and its HSI would be developed and evaluated in a series of usability tests using the full scope, full scale simulator in the HSSL. Expert reviews of the TCS HSI would also be performed at this time to provide early feedback to the TCS vendor on the design of the interface such that changes to the layout and functionality of the HSI could be made before the system was implemented. Later, when the TCS had been developed by the vendor, LWRS program researchers performed an HFE verification and validation of the TCS's design as implemented through an activity called an integrated system validation (ISV). Three ISVs were performed at each of the stations on their respective control room glass-top simulators. The reports that correspond to these workshops and activities are shown in Table 1 below.

Table 1. Summary of HFE Activities Performed with Duke Operators and Other Personnel

Station	**Activity**	**Report**
Brunswick	Static workshop	INL/LTD-14-33939 Joe, Lew, Boring, Hanes, Lawler, & Boaz (2014)
Brunswick	Dynamic workshop	INL/LTD-15-37234 Kovesdi, Hanes, Joe, Kuffel, Lew, Medema, Knuth, & Savchenko (2015)
Brunswick	ISV	IFE/HR/F-1689 Braarud & Svengren (2018) INL/LTD-18-44618 Braarud, Svengren, Ulrich, Boring, Joe, & Hanes (2018)
Harris	Static workshop	INL/LTD-14-33313 Lawler, Fleischer, Boring, Hanes, Thomas, Lew, & Joe (2014)
Harris	Dynamic workshop	INL/LTD-15-34660 Joe, Lew, Ulrich, Hanes, Boring, & Lawler (2015)
Harris	ISV	INL/LTD-18-44933 Ulrich, Joe, Boring, & Hanes (2018)
Robinson	Static workshop	INL/LTD-14-31607 Lawler, Fox, Boring, Lew, Ulrich, & Joe (2014)
Robinson	Dynamic workshop	INL/LTD-14-32869 Lawler, Fox, Boring, Lew, Joe, Medema, Hanes, & Miyake (2014)
Robinson	ISV	INL/LTD-18-45707 Joe, Braarud, Svengren, & Hanes (2018)

The work with Duke Energy demonstrates a full life cycle approach where HFE is integrated into the larger systems engineering process to upgrade a main control room. Additionally, this Duke Energy collaboration demonstrates a fleetwide HFE solution whereby a common upgrade process and platform is deployed in a manner where efficiencies can be realized through the installation of a common DCS across multiple NPP stations.

2.1.2 LWRS Exelon Control Room Modernization

A collaboration with Exelon started in 2016 and involved performing cost-shared R&D activities on control room modernization at four of its commercial NPPs. For this R&D project differences in performing control room upgrades in unregulated (i.e., deregulated or merchant) markets needed to be considered because different decision factors weigh on investment decisions. Thus, a key objective was to demonstrate methods and techniques for modernization and investment in NPPs in these settings.

Exelon is in the process of upgrading at four of its commercial NPP units the non-safety related (NSR) nuclear steam supply systems (NSSS) and balance of plant (BOP) systems. Exelon decided that performing these upgrades presented an opportunity to improve equipment reliability, reduce the likelihood of plant transients, and in general improve safety margins. The changes to the control room included: 1) the deletion of a number of analog controls and indicators, 2) the addition of soft controls and DCS based alarm points on video display units on the control boards and 3) changes to procedures, the conduct of operations, and training. Given these changes, this HFE R&D focused on the effects a hybrid HSI could have on the human-system performance of the control room, including issues such as: changes and inconsistencies in HSI design and operation, and impacts on operator workload, situation awareness, and the conduct of operations.

At the beginning of the project, a number of technical HFE R&D activities for control room modernization were performed (see Kovesdi, Hugo, Clefton, & Joe, 2017; Kovesdi, Joe, & Clefton, 2018). The focus was on performing ergonomic and other HFE technical analyses of digital I&C system hardware that was going to be installed, and in particular, the DCS's HSI.

Figure 3 shows the results of ergonomic and HFE analyses of the I&C hardware and evaluations of the DCS's HSI. Using three-dimensional modeling software, researchers were able to identify that physical placement of touch screen monitors on the control boards was beyond the reach of some operators. Additionally, other aspects of their design (e.g., font size) and placement (e.g., viewing angle) affected screen legibility and were not consistent with HFE design recommendations.

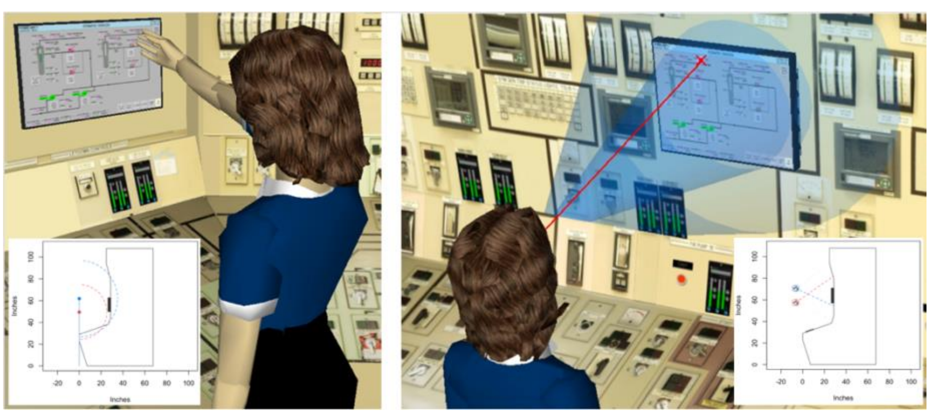

Figure 3. Ergonomic and HFE evaluations using three-dimensional modeling to evaluate the human factors of digital I&C upgrades.

The latter stages of the project involved conducting operator-in-the-loop studies at the utility's control room simulators (Kovesdi, Joe, Hugo, & Clefton, 2018). The purpose was to validate the planned control room I&C upgrades for the four NPP units, and had the objective of identifying potential HFE issues with the upgrades prior to installation.

The operator-in-the-loop workshops entailed direct observations and assessments of key operator interactions with the existing and new HSIs across a number of normal, abnormal, and emergency scenarios. The scenarios were designed to evaluate the functional ergonomic and human factors aspects of the existing and upgraded I&C systems, with particular emphasis on the ability of the new I&C system to support operators' cognitive processes and their ability to facilitate the operators' ability to perform the correct control actions.

The evaluation strategy focused on assessing plant safety and overall human-system performance, using measures of usability, workload, and situation awareness. Changes in time available for operator action, as well as information availability, were also assessed during the scenarios.

The results of the workshop showed that the upgraded HSIs did not adversely affect the operators' mental models of the plant, particularly with respect to their ability to perform their critical safety-related actions. That is, the upgrades supported operators in emergency operation tasks in that they did not adversely affect operator performance in highly complex scenarios where the operators' responses to transients and casualties that challenge the safety of the plant are important. Results also showed they were able to complete these tasks without losing global situation awareness. For normal and abnormal operating conditions, the operators were also able to successfully complete the tasks correctly, completely, and without confusion or misunderstanding using the upgraded HSIs. The operators were sufficiently alerted, provided with usable controls, and received adequate feedback from the HSIs. Overall, the results showed that the control room upgrades do not challenge the continued safe operations of the four units.

2.1.3 LWRS Southern Nuclear Control Room Modernization

LWRS program researchers collaborated with Southern Nuclear Company to support the upgrades of their General Electric Mark II TCS to the Mark VI-e TCS for Vogtle units 1 and 2. As documented in Kovesdi and Joe (2016), HFE experts worked with Southern to perform independent HFE reviews of the HSI of the Mark VI-e TCS. The purpose of the human factors independent review was to provide a technical basis that Southern could use while working with General Electric to implement desired changes to the HSIs. LWRS program researchers conducted both an expert screen-by-screen review of the HSI, and then a second review of the HSIs with operators and TCS experts. The researchers also performed a preliminary evaluation of other digital HSIs in service at Vogtle (i.e., the HSIs for the integrated plant computer and digital feedwater system), and performed a screen redesign mini-evaluation in order to gain additional insights into how to improve the design of the TCS HSI.

The results of the expert screen-by-screen review identified a number of features of the HSI that were not consistent with design guidelines specified by NUREG-0700 (NRC, 2002), with information salience being the most significant design issue. The screen-by-screen review with operators also identified a number of issues with the design. Their comments centered on labeling and abbreviations used on the HSIs, and also on the legibility of the text both in terms of font size and information salience. The reviews of the integrated plant computer and digital feedwater system HSIs also identified a number of inconsistencies in their design relative to the style and design conventions implemented in the TCS, and the mini-evaluation produced some additional insights into how the design of the TCS HSIs could be further improved.

Overall, the TCS upgrades Southern performed at their Vogtle units 1 and 2 is another example of a U.S. utility owner making the decision to perform digital upgrades to the main control rooms of their commercial NPP units, based on the business case (i.e., economic and safety justification) they established. This LWRS activity and report helps utilities like Southern, and others, by designing and demonstrating an end state for full control room modernization that utilities can strive towards once the future business case and technical path forward to an end state are established.

3. Advanced Control Room Concepts and Designs

The advanced control room concept that is being designed and developed by IFE for the HSSL is new and is expected to include a number of innovations that push the envelope for the state-of-the-art in control room design. In other respects, the advance control room concept will not be completely novel in that it will leverage design principles and practices that can be seen in advanced control rooms already designed and implemented. This section summarizes some of the notable advanced control room concepts and designs that are currently either in operation, or are expected to enter into operation soon.

3.1.1 AP-1000

Perhaps the most well-known example in the U.S. of a new NPP with an advanced digital control room is Westinghouse's AP-1000 NPP. The control room consists of multiple large overview displays positioned at the front of the control room to provide overall situation awareness of the plant's state to everyone in the control room. The horseshoe shaped desk closest to the large overview displays is where the reactor operators at the controls sit. There are two operator workstations at each corner of the horseshoe, and in between are the safeguards controls, which are analog and directly connected to the safety systems. Behind the reactor operator (RO) desk is the desk for the senior reactor operator (SRO). There is another workstation there, which along with providing redundant indication of the plant's state, also houses the computer-based procedure system. Alarms are tile-based and are presented on a group display in the center and also on the operator workstations. Trending is also provided and has an auto-scaling feature to address parameters that have a wide and narrow range. This arrangement of the main control room is shown in Figure 4.

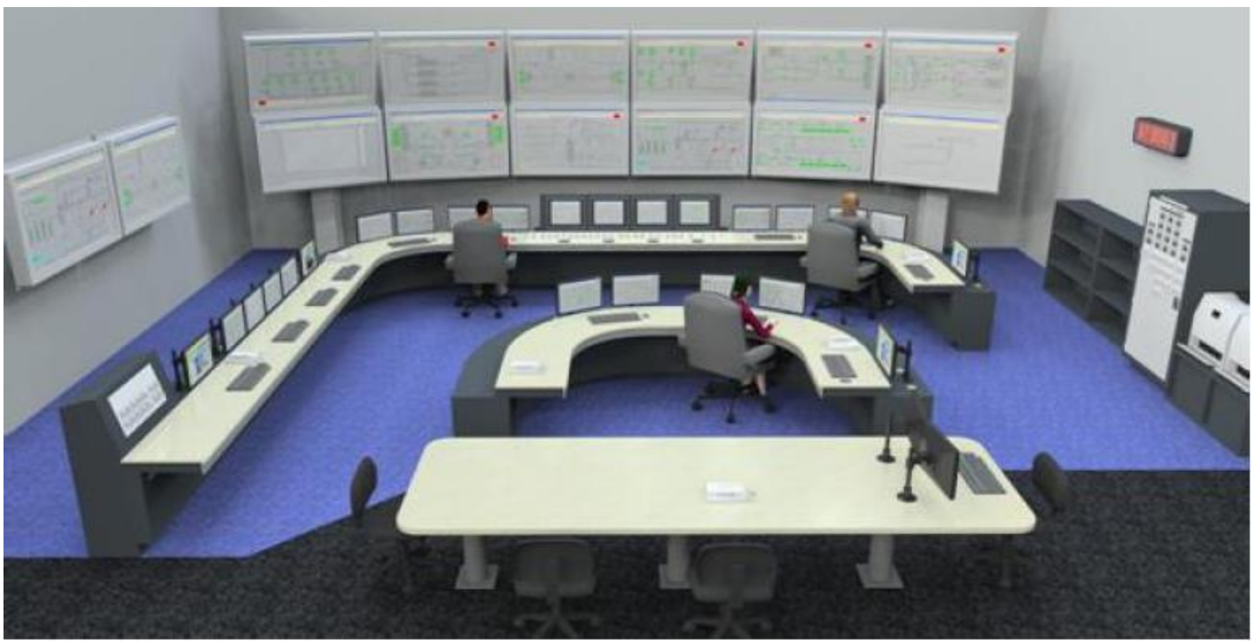

Figure 4. Rendition of the Westinghouse AP-1000 Main Control Room.

3.1.2 Digital Control Rooms for Other New Commercial Nuclear Power Plants

3.1.2.1 APR1400

The Korean Electric Power/Korean Hydro and Nuclear Power APR1400 is equipped with a digital I&C system, and has a workstation-based HSI in the control room. As stated by (Kim, 2005):

The APR1400 MCR design is characterized by 1) redundant compact workstations for operators, 2) seismically qualified Large Display Panel for overall process monitoring of the plant to be shared among operating crew, 3) multi-functional soft controls for discrete and modulation control, 4) computerized procedure system to provide on one of the workstation CRTs with context sensitive operation guides, operational information, and navigation links to the soft controls for normal and emergency circumstances and 5) safety console for dedicated conventional miniature button type controls provided to control essential safety functions. CRTs and Flat Panel Display are extensively used for presentation of operational information. (pg. 5).

Furthermore, according to Status report 83 (IAEA, 2011) HFE was a core consideration in the design of the MCR in that, "A multidisciplinary team of human factor specialists, computer specialists, system engineers, and plant operators worked together as a team from the stage of conceptual design through the validation process." (pg. 20). The control room concept for the APR1400 design, as implemented at Barakah in the United Arab Emirates, is shown in Figure 5.

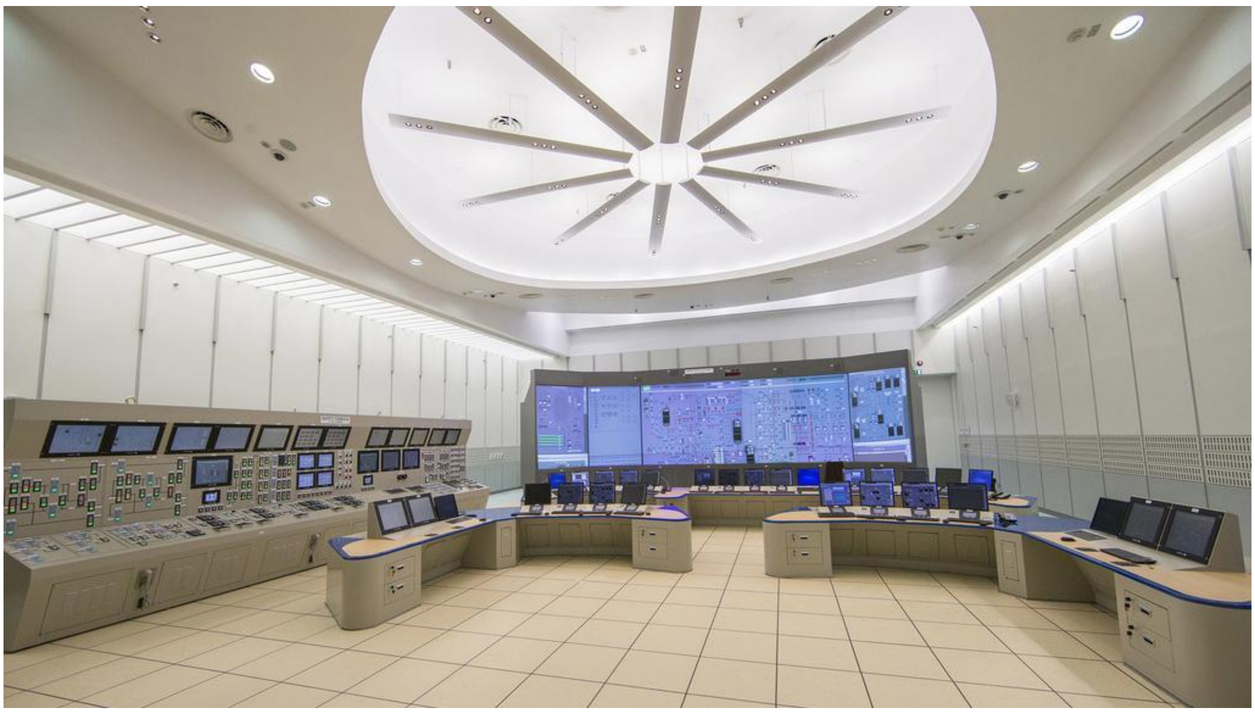

Figure 5. Simulator for the Main Control Room of the APR-1400 at Barakah, UAE

3.1.2.2 NuScale Small Modular Reactor

The main control room for the NuScale small modular reactor is conceptually very similar in its design to the AP-1000 and APR1400 in that it is also in a 'mission control' configuration and has work stations for the operators. The key difference in the design, of course, is that the NuScale main control room is monitoring multiple units at the same time. As such, the front display monitors are arranged in a semi-circle and are segmented into thirteen groups. Twelve of the 13 groups have four smaller displays that provide status indications for a single unit, and then one larger display to monitor shared systems (e.g., power blocks). The thirteenth group of displays is in the middle and is the equivalent of a traditional large overview display in that it provides mutual awareness to the crew on the status or condition of the whole station.

The three workstations closest to the front display monitors are where the ROs sit and manage multiple small modular units. Behind the RO desks is the control room supervisor's (CRS) desk. This configuration is depicted in Figure 6.

Figure 6. Simulator for the Nuscale Small Modular Reactor Main Control Room.

3.1.3 IFE Halden Human-Machine Laboratory

In Norway, IFE has built the Halden Human-Machine Laboratory (HAMMLAB), which has been a central tool and capability that has allowed IFE to conduct cutting edge human factors and HFE R&D for many years. Currently the HAMMLAB is configured to represent another advanced control room concept. The Halden concept is similar to the advanced reactor designs previously summarized, in that it consists of a large screen overview display and operator workstations with 2-5 screens per computer. As shown in Figure 7, in the HAMMLAB there are:

- 2 workstations with 5 screens in total for the RO
- 2 workstations with 5 screens in total for the turbine operator
- 2 workstations with 4 screens in total for the CRS or SRO

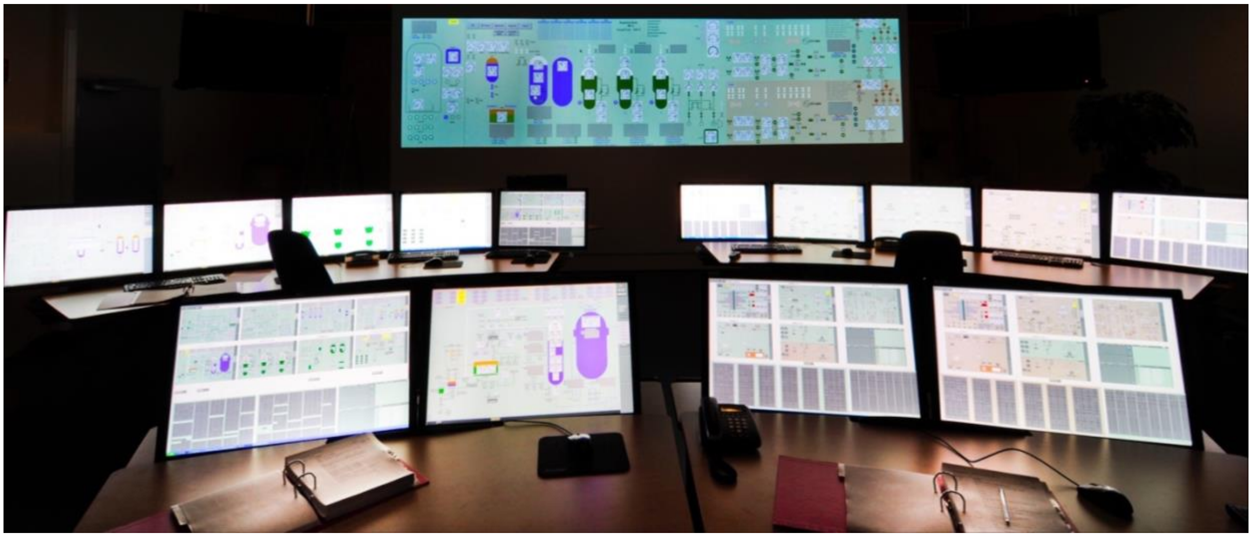

Figure 7. HAMMLAB Advanced Control Room Concept.

It is expected that what IFE will eventually install in the HSSL will be very similar in concept and design to what currently resides in the HAMMLAB. Nevertheless, it is incumbent upon LWRS program researchers to plan and perform analyses, including establishing specifications and design requirements for IFE, such that the advanced control room concept they install in the HSSL is well defined and is built in a manner that meets the LWRS program objectives.

4. Planning & Analyses and Path Forward to Implement an Advanced Control Room Concept in the HSSL

This section documents the initial planning and analyses performed to install an advanced control room concept developed by IFE in the HSSL. The main planning and analysis activities performed thus far and documented below are the formulation of the first stages of an overall program management plan, and the development of an initial set of specifications and design requirements for the advanced control room concept. These two activities are described in more detail in the following sections.

4.1 Planning and Analysis Activities

Similar to the HFE program review model described in NUREG-0711, and consistent with a general systems engineering approach, planning and analysis are the first steps that need to be performed in order to successfully install an advanced control room concept in the HSSL. For this particular engineering activity, the following planning and analysis activities are proposed.

I. Define the objective. This includes formulating the problem statement and developing a preliminary value proposition.

II. Identify end users, resources, and activities. This is the step where the end users of the advanced control room interface are identified as well as what their needs are. Identification of the resources needed, the activities that need to be performed, and the legal agreements that are needed to codify the nature of the collaboration is also performed in this step.

III. Develop the business case and the technical and licensing bases. Full plant modernization is a multi-disciplinary activity, and given the magnitude of its scope and its potential impact on plant operations and safety, it is essential that a business case is established in this planning and analysis phase. It is equally important that the technical and licensing bases for full plan modernization are established before proceeding.

IV. Develop specifications and design requirements based on an updated value proposition for full plant modernization.

V. Perform early design HFE activities as described in NUREG-0711. These activities include performing an operating experience review, performing function analyses and a function allocation, performing task analyses, examining staffing levels needed and minimum operator qualifications, and performing analyses that identify important human actions and determining how they will be managed to ensure safety and efficient operations.

The order and flow of these proposed planning and analysis activities is depicted in Figure 8. The expected result of this is a well-developed and well-designed demonstration of an advanced control room concept that is installed in the HSSL.

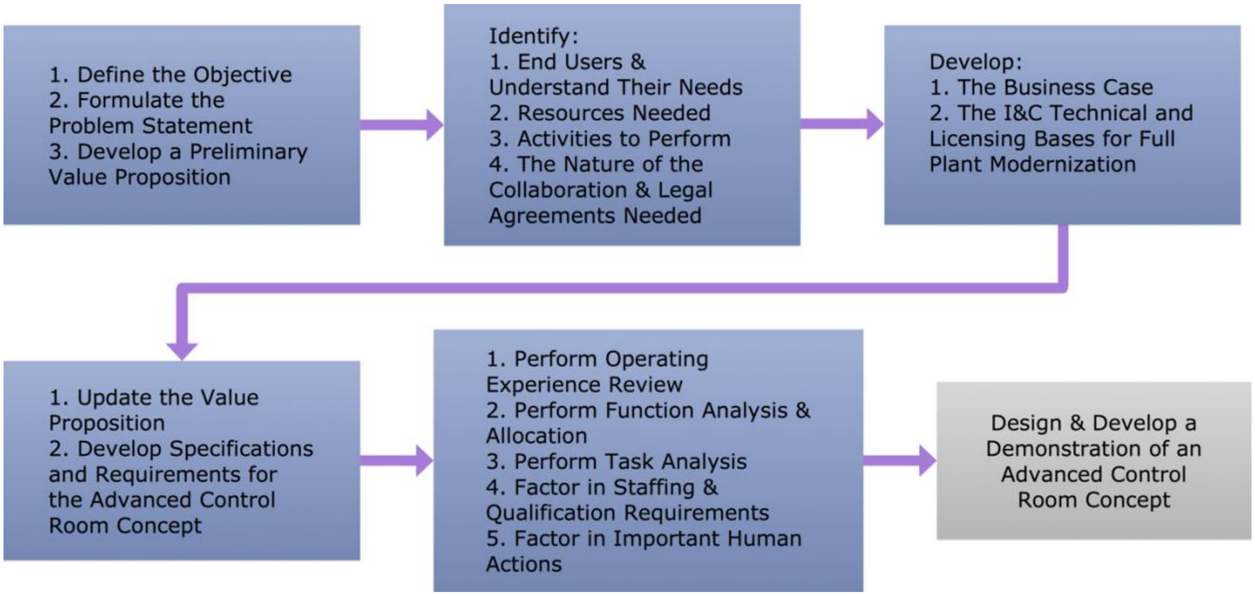

Figure 8. Proposed Planning & Analysis Activities Needed to Design & Develop an Advanced Control Room Concept

4.2 Initial Set of Design Requirements and Specifications

As part of the planning and analyses needed to install an advanced control room concept in the HSSL, LWRS program researchers have developed an initial set of requirements for its design and functionality. These requirements and specifications are meant to help guide the development of this advanced I&C system and its HSI, but are only an initial set, and can be revised and updated as needed.

1. The HSI and control functionality needs to conform to an existing human factors style guide. One example of a style guide is IFE's report, *Human System Interfaces: Best Practices for the Nordic Nuclear Power Plants* (Braseth, 2014).[b]
2. An overview display or large screen overview that only provides indication of the plant's state is needed to facilitate crew decision making. It needs to provide indication at a plant overview level to the entire crew. The information it provides should come from the same information source as the workstation control screens or HSIs (described below).
3. Workstation control screens are needed for the SRO/CRS and ROs. These are the screens that the operators will use to monitor all systems and sub-systems of the NPP, respond to and manage alarms, and use to perform control actions.
    a. Screen navigation: An intuitive and sensible layout of the workstation control screens and navigation scheme/philosophy that is consistent across all screens is needed.
        i. For the control screen layout, a dedicated space on the main screens is needed for a breadcrumb trail showing the last 2-4 screens visited to make it easy for the operator to return to the last/previous few screens. A dedicated space on the screen for systems that operators need to navigate to in 1 click is also needed (e.g., a screen showing the status of Safeguards, an Alarms and Events screen, and a screen showing Trends).

[b] This IFE style guide has apparently gained wide-acceptance in Nordic NPPs. Whether this style guide and its conventions would be deemed acceptable to U.S. NPPs and conform to regulatory guidance such as NUREG-0700 (NRC, 2002) and NUREG-0711 (NRC, 2012) would need to be evaluated.

   ii. A navigation scheme along the bottom of the screen is requested - where tabs are used to identify and select different system and sub-system control screens. The layout could be similar to the way the systems are laid out on the existing control board of the gPWR, or in some configuration with which the SRO and ROs are already familiar.

b. An additional navigation capability from one system screen to another system screen (besides selecting tabs) is needed for some screens. For example,

   i. Page connectors between screens that display a system and its related sub-systems is needed. For example, a page connector could be needed for the screen displaying control room heating, ventilation, and air-conditioning (HVAC) and any additional pages of HVAC controls. Another example where a page connector makes sense is between the Reactor Control screen and a screen for the Rods that displays individual rod positions.

   ii. A ‘return to last/previous screen’ button is needed. It should be located in the same spot and accessible on all screens.

c. Symbols displaying systems, structures, and components need to be well human factored and implemented consistently across all screens in the advanced HSI. Examples of symbols that need to be standardized include:

   i. Valves (and a convention to differentiate motor valves from air operated valves).

   ii. Pumps

   iii. Switches (both those that lock in position and those that “spring return”).

   iv. Meters

   v. Mini trends

   vi. Tanks

d. All critical indicators and controls need to be present on the screens. For example, for reactor control: Power indications (power ranges), Rod indications, and Rod control need to be displayed.

e. Components need not be limited to being displayed on only one screen.

f. Indication on the screen when an operator has selected a device that can be operated needs to be well human factored and implemented consistently across all screens in the advanced HSI.

g. The use of colors should be based on the systems (e.g., use one color for primary circuit water and a different color for electric current), and implemented consistently across all screens in the advanced HSI.

h. For safety purposes, operators should be required to make two control actions to change the state of a device, component, or system. For example, operators should have to select a device/component first, which will then produce a popup either near the component, or off to the side in a faceplate zone. Operators must then perform the control action in the popup in order to cause a change in the plant. This allows for concurrent verification if required and reduces probability or errant mouse click causing activations.

i. For safety purposes, once dynamic devices (e.g., pumps, valves, switches) are selected at one workstation, no other operators can control that device from any other workstation.

j. For safety purposes, safeguard activation switches (e.g., reactor trip switch, safety injection switch) should be in a color that stands out from the background (e.g., red).

k. If the traditional alarm tiles are not used in the advanced control interface (only retaining those needed to align to procedures), an alarms list screen that is well human factored is needed. Additionally, the following capabilities are needed:

    i. A means to indicate that an alarm is active and not responded to (i.e., alarm flashes fast on the alarm list).

    ii. A capability to silence alarms, where the audible annunciator ceases but the alarm still flashes.

    iii. The capability to acknowledge a single alarm or all alarms.

    iv. A repetition number to record the number of times an alarm is active and acknowledged.

    v. A means to indicate when an alarm is active.

    vi. A visible and an audible annunciation for when an alarm is cleared.

    vii. A means to reset individual and all alarms.

    viii. A unique siren to indicate a reactor trip or a turbine trip.

    ix. A capability for the SRO to silence alarms temporarily (e.g., for 10 minutes).

    x. An auto scroll feature that can be enabled/disabled as the operator wishes.

l. A well human factored events list screen that lists chronologically when the status of a device changes (e.g., change in valve position, pump start/stop, operator changing a set point) is needed.

    i. An auto scroll feature that can be enabled/disabled as the operator wishes is also needed.

m. A well human factored dedicated screen for trends is needed.

    i. A set of predetermined trends should be developed based on what information needs to be trended for a given NPP. An additional screen where operators can create customized trends is also requested.

        1. The means by which the operator selects custom trends needs to be intuitive and user-friendly.

    ii. Trend limits (i.e., upper and lower range) need to be established and consistently implemented.

    iii. Control limits should be preset by the expected range of operation and have a default value. The operator, however, also needs to be able to change these limits. Default values should be restored when the simulator is reset.

    iv. The time line history should be operator selectable at established time intervals (e.g., 5, 10, 20, or 60 minutes) but also have an established default time interval.

n. A dedicated screen for Safeguards and Reactor Protection is needed on all workstations and should be in a dedicated location that is easily accessible.

o. A well human factored screen for Safeguards is needed. This screen provides a summary of all safeguards for a particular condition, and indicates whether the devices that provide the safeguards are aligned (e.g., with a green check mark), or misaligned (e.g., with a red 'X').

It is expected that LWRS program researchers will iterate on these specifications and design requirements with the IFE staff as the design and development of the advanced control room concept matures.

5. CONCLUSION

Many aspects of current NPP operations rely on outdated technologies and processes. The result is an operating model that is no longer competitive in today's energy market. LWRS program researchers conduct cutting-edge R&D that furthers DOE's objective to support the long-term sustainability of the light water reactor fleet by ensuring the human factors aspects of control room upgrades are addressed. By performing R&D that addresses reliability and obsolescence issues of legacy analog control rooms, and by demonstrating and documenting the human factors processes that utilities should undertake to perform control room modernization, the LWRS program provides the technical bases that help reduce the uncertainty and risk of modernizing control rooms, thereby helping provide incentives for the industry to make the investments required for nuclear power operation periods to 60 years and beyond.

The research specifically described in this milestone report is part of a larger goal to collaborate with utilities to develop a strategy for full nuclear plant modernization that will enhance the safety and economic performance of plants. This strategy is shown in Figure 9. The strategy for full plant modernization replaces the piecemeal, like-for-like replacement approach many in the industry have used, and enables research, development, demonstration, and deployment of advanced digital technologies, that will modernize our existing plants by automating work functions reducing staff requirements and making better use of plant information. The result will be the enhancement of the safety and economic performance of these plants through improved human-system performance.

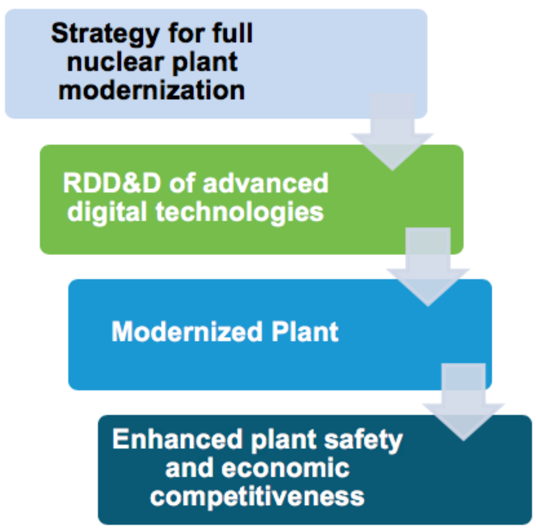

Figure 9. Strategy, Process, and Expected Outcome for Full Nuclear Plant Modernization

Collaborations with current utility partners demonstrate the soundness of this strategy - as evidenced by the fact that some utilities are positioning themselves to adopt this approach. In working with our utility partners, it is clear that many utilities have, or are in process of installing, a common digital I&C platform in their control rooms. These digital I&C platforms serve as a digital backbone for the control room that can and will host multiple plant I&C systems as the plants continue to modernize.

Future LWRS reports will document the process to set up the HSSL and the gPWR with the HSI developed by IFE, and then document how LWRS program researchers at INL and Halden are supporting the capability to conduct future studies by creating additional HSIs that support control room modernization.

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