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Light Water Reactor Sustainability Program

Strategy for Migration of Traditional to Hybrid Control Boards in a Nuclear Power Plant

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July 2014

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ABSTRACT

This strategy document describes the NUREG-0711 based human factors engineering (HFE) phases and associated elements required to support design, verification and validation (V&V), and implementation of new digital control room elements in a legacy analog main control room (MCR). Information from previous planning and analysis work serves as the foundation for creating a human-machine interface (HMI) specification for distributed control systems (DCSs) to be implemented as part of nuclear power plant (NPP) modernization. This document reviews ways to take the HMSI specification and use it when migrating legacy displays or designing displays with new functionality. These displays undergo iterative usability testing during the design phase and then an integrated system validation (ISV) in the full-scope control room training simulator. Following successful demonstration of operator performance using the systems during the ISV, the new DCS is implemented at the plant, first in the training simulator and then in the MCR. This document concludes with a sample project plan, including a 15-month timeline from DCS design through implementation. Included is a discussion of how the U.S. Department of Energy's Human System Simulation Laboratory (HSSL) can be used to support design and V&V activities. This report completes a Level 4 (M4) milestone under the U.S. Department of Energy's (DOE's) Light Water Reactor Sustainability (LWRS) Program.

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CONTENTS

FIGURES

TABLES

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ACRONYMS

DCS	distributed control system
DOE	Department of Energy
EOF	emergency operations facility
HFE	human factors engineering
HMI	human machine interface
HSI	human-system interface
HSSL	Human System Simulation Laboratory
I&C	instrumentation and controls
INL	Idaho National Laboratory
ISO	International Standards Organization
ISV	integrated system validation
LWRS	Light Water Reactor Sustainability
LOC	local control station
MCR	main control room
NRC	U.S. Nuclear Regulatory Commission
NPP	nuclear power plant
NUREG	Nuclear Regulatory Document
PPC	plant process computer
OP	operating procedure/output
RO	reactor operator
RSF	remote shutdown facility
SPDS	safety parameter display system
TCS	turbine control system
U.S.	United States
V&V	verification and validation

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1. INTRODUCTION

This strategy document describes the human factors engineering (HFE) phases and associated elements required to support design, verification and validation (V&V), and implementation of new Plant Process Computers (PPCs) and Turbine Control Systems (TCSs) at representative U.S. nuclear power plants (NPPs).

The HFE phases discussed in this document are described in the U.S. Nuclear Regulatory Commission's (NRC) *Human Factors Engineering Program Review Model*, NUREG-0711, Revision 3, published November 2012. Each phase (see Table 1) consists of one or more elements. Each element contains a description of the review criteria applied by the NRC HFE staff to assess the acceptability of an applicant's submittal regarding safe plant operation. This scoping document describes the planned HFE activities to develop information that satisfies the NRC acceptance criteria. In addition, the planned HFE activities will develop information that satisfies the utility's plant performance and economic goals.

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

The scope of work described in this document is part of a larger HFE program to support fleetwide NPP PPC and TCS modernization projects. These upgrades are typical of the types of stepwise upgrades undertaken in the U.S. nuclear industry (Joe et al., 2012), in which the control boards are maintained in the main control room but selective systems are migrated from analog to digital. In the case of the PPC, an existing obsolete computer system is being modernized to a contemporary distributed control system (DCS). In the case of the TCS, a primarily mechanical control system is being upgraded to a digitally controlled system, complete with digital human machine interface (HMI).[1] The HFE for such upgrades

[1] HMI is used interchangeably with human system interface (HSI) across different guidance documents referenced in this report.

focuses on the DCI HMI, which takes the form of a digital display mounted on the control boards, coupled with a suitable input device. In addition, such displays may be incorporated into displays at desk workstations available to the operators and others in the control room. However, in the case of desktop versions of these systems, they are in read-only mode specifically to maintain controls at the boards per the plant operating license.

Previously, the program scope encompassed the Planning and Analysis phase of NUREG-0711, which is described further in Hugo et al. (2013). By request of the utility's project management team, two elements were excluded from the documentation for that phase. These out-of-scope elements were:

- Staffing and Qualifications—which are not currently subject to change due to any modifications to the PPC or TCS;
- Treatment of Important Human Actions (formerly Human Reliability Analysis)—the safety impact of which was also determined not to change due to any modifications to the PPC or TCS.

This document outlines concrete next stages to design, verify and validate, and implement the PPC and TCS in NPP main control rooms (MCRs). These systems are representative of other computer upgrades and control system modernization efforts at NPPs, and the strategy outlined in this document can readily be generalized to other systems in the MCR.

1.1 Scope for Design, V&V, and Implementation Phases

The scope of the HFE Program described in this document is limited. The scope includes the following:

- Main control room (MCR) HFE HMI design issues. HFE issues related to the technical support center (TSC), emergency operations facility (EOF), remote shutdown facility (RSF), and local control stations (LCSs) are considered out of scope, except for displays, controls and annunciators that may be relocated to or from the MCR.
- HMIs involved in maintenance activities are considered in this HFE Program, if their use is related to MCR operations. For example, if a maintenance technician uses an HMI to support troubleshooting and that HMI is also available to a MCR operator to support cooperation between maintenance and operations, then activities related to this HMI are within the scope of the HFE Program.

This document extends previous work on Planning and Analysis (Hugo et al., 2013) to the next NUREG-0711 phases, including Design, Verification and Validation (V&V), and Implementation and Operation. For the Design phase, this document focuses on HMI design, excluding:

- Procedure Development—which is not required but recommended, since the new DCS directly supports existing procedures at a high level;
- Training Program Development—the objectives, requirements, and frequency of which are not changed as a result of the modernized PPC or TCS, although it is expected that understanding and using the HMI will be included in the training, as will skills associated with operating the plant in the event of DCS failure. Again, these do not constitute a change in the training regimen, just a transition in training from existing PPC and TCS to the new DCS.

This proposal includes all elements of the V&V (i.e., Human Factors Verification and Validation). It includes the Design Implementation element of the Implementation and Operation phase. It omits:

- Human Performance Monitoring—which represents a long-term activity aimed at maintaining the system. Should deficits be detected through long-term human performance monitoring, the Design phase should be revisited. If satisfactory human performance cannot be maintained through increased training, the HMI design element should be revisited.

The scope of this document is concerned only with MCR HMI design issues. Therefore, elements reviewed by the NRC HFE staff not involving HMI design are considered not in scope for this strategy document. Detailed information is provided in this document regarding the planning, objectives, approach, scheduling, budgeting, and deliverables for each element that is included in each phase of activity.

Section 2 presents the HMI design activities. The V&V element is provided in Section 3. Section 4 covers the design implementation element. An overall plan for carrying out these phases is included in Section 5.

1.2 Composition of the Design Team

NUREG-0711, Rev. 3, has an appendix that discusses the composition of the team required to carry out an HFE program. Not all personnel identified in NUREG-0711 are relevant to the design phases addressed in this report. The relevant personnel for PPC and TCS modernization are:

- Technical project management
- Systems engineering (Design engineering)
- Instrumentation and control (I&C) engineering
- Architect engineering
- Human factors engineering
- Plant operations
- Computer system engineering
- Personnel training
- Procedure writers
- DCS vendors

NUREG-0711 does not expressly call out Simulator engineers (although they are often included under the general umbrella of training organizations at NPPs). Simulator engineers are uniquely important for Planning and Analysis phases and V&V due to their unique knowledge of the plant simulator.

These roles will be discussed in Section 5, which includes a project plan.

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2 HMI DESIGN ELEMENT ACTIVITIES

As described in NUREG-0711, Rev. 3, “The HSI design process represents the translation of function and task requirements into HSI characteristics and functions.” This section explains how previous work performed in the Planning and Analysis phase feeds into the actual design of the HSI. This section also illustrates the process by which existing PPC displays may be migrated to the new DCS platform as well as the process by which new functionality can be introduced to the control room. In addition, an existing system on the panel, the TCS, is being converted to a DCS, and this section contains guidance to ensure the new design is successful.

As depicted in Table 2, the elements of the Planning and Analysis phases each provide key information that is used in the design of the new HMI for the control room. Note that these elements were previously completed in support of the PPC and TCS upgrades for NPPs owned by a partner utility (Hugo et al., 2013). This general information is combined with a specification for each HSI display used in the DCS. The specification may be developed according to the sections below, corresponding to migrated vs. new HSIs. A key assumption is that the DCS HMI will take the place of existing displays or standard instrumentation and controls on the control boards.

Table 2. Use of HFE Program Elements in HSI Design.

HFE Program Element	Use in the HMI Design
Operational Experience Review	Lessons learned on previous system use and identification of important human actions
Functional Requirements Analysis/Function Allocation	Opportunities for automation of displays and system controls; required role of operators in controlling the system
Task Analysis	Information and tools required by operators to support task execution
HMI Style Guide	Requirements for controls, navigation, visual presentation, and other HMI elements

2.1 HMI Specification

Each HMI display specification should include a general name of the display (corresponding to plant naming and numbering conventions), a description of the function of the display, a description of the placement of the display (e.g., some displays may be statically located, while others may be pulled up from any DCS display), assumptions regarding the hardware (e.g., size and resolution of display), information about the control mechanism (e.g., soft controls using a touchscreen vs. mouse or keypad control), and version information. Additionally, the specification should address the required information found in Figure 1, namely the relationship between operator/system inputs, the program logic, and the operator/system outputs. The system inputs (e.g., temperature at a certain sensor point) and outputs (e.g., valve close signal) may not in all cases be displayed to the operator, but their background use should be clearly documented in the specification. The specification should also feature documentation about any design considerations from the Planning and Analysis phases depicted in Table 2 that influenced the design. The design background information is crucial should later design modifications or license review be required.

Figure 1. Required Information for DCS Display Specification.

2.2 Migrating an Existing HMI Display

At the partner plants, a number of displays—most notably the Safety Parameter Display System (SPDS)—are slated for migration from the existing platforms to the new DCS platform. These displays have been demonstrated to be of use to operators, and it is desirable to carry those displays forward to the new DCS. While no new functionality is required for these legacy displays, an effective migration needs to consider the characteristics of the DCS versus the predecessor system. Relevant factors include:

- Navigation—if the DCS has a standardized navigation scheme, the legacy displays may not conform to that standard. For example, displays may feature primarily command-line execution, whereas the navigation of the DCS is mainly menu driven. This disparity must be reconciled. Fortunately, the decision how to handle navigation is a one-time decision that can be applied across the entire suite of migrated displays rather than piecemeal for individual displays. The general navigation solution should be complemented by a display-specific navigation, e.g., where the display fits in menus or navigation groupings.
- Display characteristics—the DCS displays will likely be higher resolution than the predecessor systems, which may require some scaling conventions. Moreover, the DCS may feature reserved areas (e.g., designated alarm areas or navigation panes) that may not conform to the layout of the existing displays. The legacy displays may require additional updates to conform to the current HMI style guide. These display characteristics will need to be considered for each legacy display, although a few general display migration rules should suffice for the majority of displays.
- Additional functionality—for most purposes, the addition of features to legacy displays should be minimized. However, there may be some features that are required for continuity with newer DCS displays. For example, alarm functionality not found in the legacy displays may be desirable or even expected to harmonize the look and feel of the DCS displays. The decision must be made to what extent the legacy displays look or behave differently than newer DCS displays. It is preferable not to have multiple conventions and styles within the DCS. However, the cost of adding or harmonizing features to legacy displays must be considered. Note that operators will tend to prefer displays with which they are familiar. An initial preference to retain the look and feel of legacy displays should be re-evaluated after operators have opportunity to gain experience with the new DCS. Also note that core functionality of a legacy HMI display should in most cases remain the same despite any aesthetic upgrades.

The following (Table 3) provides a step-by-step list of questions to consider in the migration of legacy display to the new DCS. The decision process behind these questions should be documented with the display specification. The checklist should be used to help finalize the design specification for each migrated HMI display. Following development of the specification, the HMI displays should be prototyped to verify appearance, functionality, and completeness. Operators should review each migrated HMI display prior to performing the formal V&V activity. Designs that do not meet initial operator satisfaction should be iterated to improve the design. Documentation of the migrated design should explain how changes are consistent with earlier HMIs and the plant's Safety Analysis Report.

Table 3. HMI Design Migration Checklist.

1. Do any lessons learned from the Operational Experience Review apply to this display, and are any changes required as a result?
   a. If YES, what changes are required? If significant changes[2] are required, follow the process outlined in Section 2.3 on designing new HSI displays.

2. Is any additional functionality suggested by the Functional Requirements Analysis or Function Allocation?
   a. If YES, what changes are required? Should the changes be made to this display, or should a new display be created? Follow the process outlined in Section 2.3 on designing new HSI displays.

3. Is all required information identified in the Task Analysis present in the display to support task execution?
   a. If YES, what changes are required? If significant changes are required, follow the process outlined in Section 2.3 on designing new HSI displays.

4. Does the existing display adhere to the present HSI Style Guide?
   a. If NO, what changes are required? Do the graphics translate or scale to the new DCS displays? Does navigation require updates? Are there conflicts (e.g., reserved areas on the DCS displays) between the existing display and the DCS? If significant changes are required, follow the process outlined in Section 2.3 on designing new HSI displays.

5. Are any required changes to the existing displays universal? In other words, can changes made to one legacy display be used as a template for other displays?
   a. If YES, document these changes (e.g., how to switch from command-line navigation to menu navigation) as an addendum to the HSI Style Guide, specifically as an HSI Migration Style Guide. This should eliminate the need to redesign each legacy display according to Section 2.3.
   b. If an HSI Migration Style Guide is available, follow it. If there are any required exceptions to this style guide, note them.

[2] Significant changes to the HSI display would be those that change the actions the operator takes or the information provided to the operator by the display.

2.3 Designing New HMI Displays

The Functional Requirements Analysis/Function Allocation and Task Analysis workshops and accompanying report (Hugo et al., 2013) identified new functionality that would be advantageous to the operators in the modernization of the PPC and TCS. Example new functions that were identified include:

- Procedure support displays—which can be called up to support walking through commonly used or complex procedures (e.g., a display to bring up plant parameters required to step through E-0)
- Automated calculations—which have to be calculated manually by operators from separate and sometimes distally located indicators in the current control room configuration (e.g., leak rate calculation)
- Shot clocks—which help the operator keep track of time required for continuous action steps, including multiple simultaneous continuous actions
- Prioritized alarms—which help the operator focus on the most safety critical tasks at hand.

These new features should be developed in accordance with a standard user-centered design method such as ISO 9241-210 (2010), *Ergonomics of Human-System Interaction—Part 210: Human Centred Design for Interactive Systems*, and ISO 9241-11 (1998), *Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs)—Part 11: Guidance on Usability.* An example approach tailored for DCS design can be found below in Figure 2. The approach has five basic steps:

1. Identify the desired features and functions of the DCS display—whereby insights are extracted from the Operational Experience Review (to the extent there may be deficits in the existing HSI), the Functional Requirements Analysis and Function Allocation, and the Task Analysis. There should be a clearly documented need for the new functionality as demonstrated by an existing performance deficit (e.g., as an cumbersome or error-inducing HMI) or the opportunity for operator performance improvement (e.g., increased reliability through automation or improved operator response time). While operator desires for new features may be considered, the basis for new features and functions should remain grounded in opportunities for improved reliability, safety, and performance.
2. The desired features and functions are turned into a specification. The HMI display specification should conform to the requirements outlined in Section 2.1. This display specification should conform to the HMI Style Guide for the DCS.
3. The specification is prototyped to a degree suitable for evaluation. The prototype can be as simple as a line sketch of the interface or involve using the DCS graphics development tools to create an early version (i.e., prototype) of the final implemented DCS (Lew et al., 2014). The prototype should contain sufficient fidelity such that dimensions and colors can be depicted accurately. If the native DCS environment is used in the prototype, it is not necessary to enable all functionality. The prototype will be evaluated, but it is important that the prototyping phase not be considered as part of the end development and deployment stage. Each iteration of the prototype may be discarded in favor of better designs during usability testing.
4. The prototype is usability tested. Usability testing is the process of assessing the degree to which the target user can use the designed system effectively. Success metrics range from user satisfaction to user performance. In the case of the usability evaluation of the DCS displays, the foremost goal is to ensure that operators understand the HMI elements and can operate the system, from navigating between different displays in the DCS to controlling different plant systems using the DCS. The usability evaluation is ideally *formative*, meaning it is used not only to verify the usability of the designed system but also to help specify the design in an iterative fashion. There are two accepted ways of conducting formative usability testing:

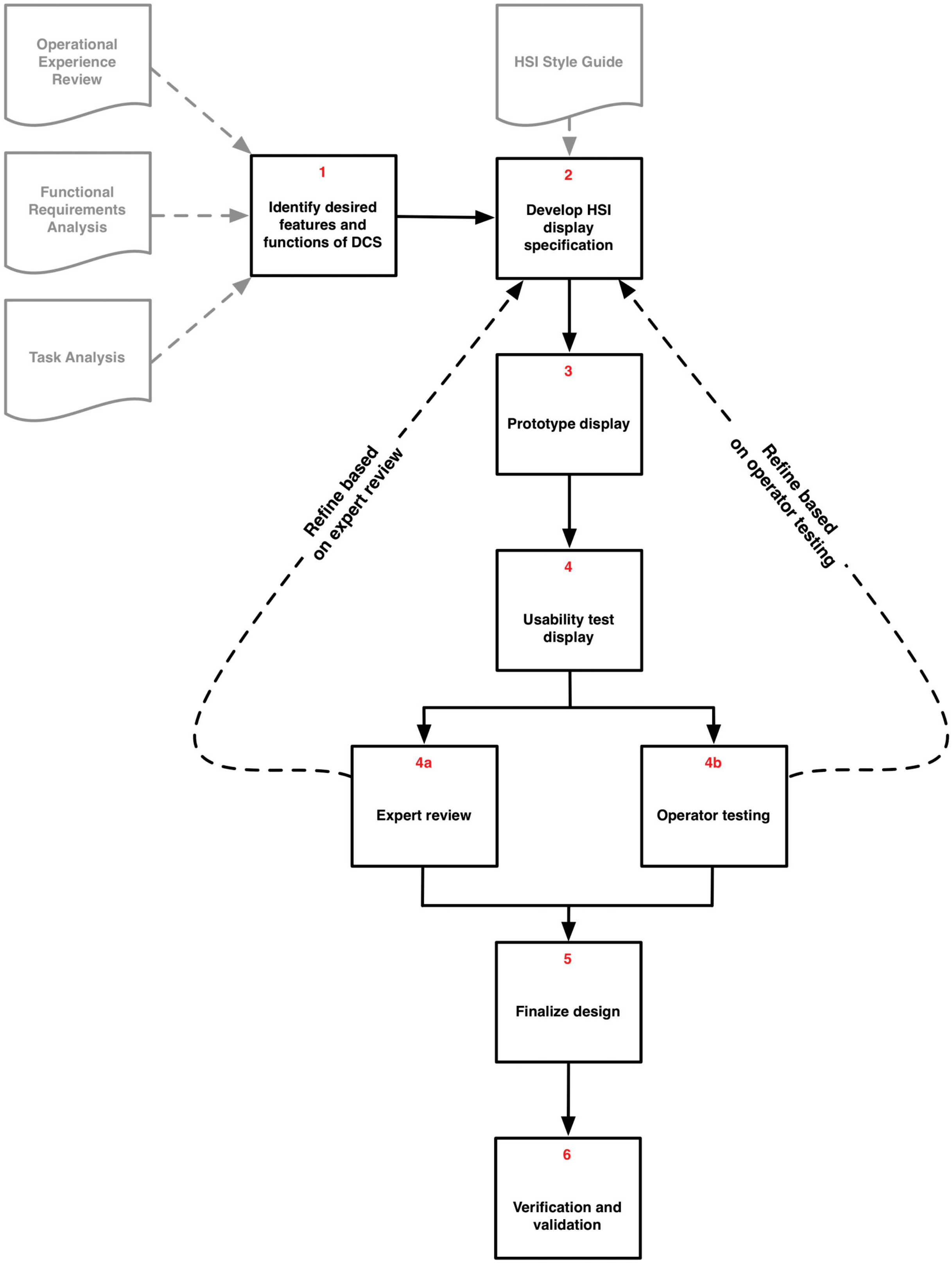

Figure 2. Flow Diagram for Developing New HMI Displays for DCS.

   a. Expert review—in which subject matter experts in HFE, nuclear operations, or control systems review the HMI. This review may follow specific usability criteria called heuristics (e.g., Ulrich et al., 2012) or provide an overall impression of how the HMI would be used and note any potential deficiencies. Expert reviews are especially useful early in the design phase, when a full-scale V&V will be conducted later in the development cycle.

   b. Operator testing—which can range from walkthroughs with nonfunctional mockups to scenario testing using fully functional prototypes. The level of fidelity and functionality is a product of the resources of the design team and the degree to which the new functionality diverges from current plant operations. Note that operator testing at this stage will typically focus on the DCS HMI alone and not in the overall context of the control room. Integrated system validation (ISV)—testing of the new DCS with the full control room—occurs at the V&V phase.

   Results from the formative usability testing phase should be used to refine the design. If there are design deficiencies, the design should be revised and the process iterated starting at Step 2. See Boring et al. (2014), for a discussion of formative versus summative usability testing.

5. The design is finalized. Once the prototype has been evaluated and it has been determined that operators in the control room can use the HMI successfully and safely, the design specification and supporting documentation are assembled. This information is used as the basis of implementation and should be retained for licensing support. Additionally, it is not anticipated that new HMI functionality incorporated into the control room would require a change in plant operating procedures. As the design is finalized, the adequacy of existing procedures should be documented.

6. The finalized design will be used in the V&V phase, which is documented in the next section.

3 HUMAN FACTORS V&V OF THE HMI

The HMI design process described in Section 2 encompasses many of the HMI testing requirements for V&V outlined in NUREG-0711. In fact, this approach is explicitly endorsed in Chapter 11 of NUREG-0711, Rev. 3. The specific phase of V&V that must be conducted independently of usability testing as described in Section 2 is integrated system validation (ISV). The steps for an ISV on the modified or new HMIs for PPC and TCS encompass the following steps:

1. The prototyped system is implemented as a fully functional variant in the full-scope control room simulator. The actual DCS should be imbedded in the simulator to minimize the need for later detailed analysis of the as-tested versus as-deployed system. As such, the DCS should follow careful software and hardware quality assurance requirements as part of the ISV. Note that a glasstop simulator (Boring et al., 2012 and 2013) using the underlying plant model from the training simulator may serve as a surrogate for the actual plant training simulator. This process can avoid the need to physically modify the training simulator (e.g., change hard panels to introduce displays) until the implementation phase. This avoids potential conflicts between training for the plant as-is versus the plant as-it-will-be once modified.
2. A representative sample of scenarios is selected to walk through the new DCS HMIs with operators. These should be scenarios that encompass actual use of the DCS, test operator knowledge, test operator interactions with each other in the control room, and represent potential accident sequences. Note that the scenarios previously used in the Functional Requirements Analysis/Function Allocation and Task Analysis workshops fulfill these criteria. The same scenarios that were run previously can be run during the V&V phase. These scenarios thereby also serve to benchmark operator performance before and after the new DCS HMI implementation.
3. The DCS should be pilot tested with a group of operators or qualified personnel (e.g., not-yet-licensed reactor operators, qualified trainers, recently retired reactor operators) to ensure the proper functioning of the system.
4. Operators are trained on the use of the new DCS HMIs. A stand-alone training program will be developed in cooperation with the training organization. In addition, trainers and procedure writers will review the scenarios to ensure that the operating procedures do not require modifications as used in conjunction with the new DCS. If procedure modifications are required, these modifications should be completed.
5. Operators perform the selected scenarios using the new DCS HMI for PPC and TCS. A combination of systems engineering, HFE, and training personnel oversee the scenario walkthroughs to ensure:
   - The DCS implementation functions per the design specification.
   - The operators are able to complete the scenario tasks successfully (i.e., correctly, completely, within time requirements, and without confusion or misunderstandings) using the new DCS. HFE personnel will assess situation awareness and workload to ensure these are within acceptable bounds.

   More than one set of operators should walk through the scenarios, and the order of the scenarios should be randomized to ensure performance on particular scenarios does not reflect learning effects.
6. The results of the ISV should be documented. Any deficiencies (e.g., human engineering discrepancies) should be resolved, and that resolution should be documented. Significant deficiencies should revisit the HMI Design process in Section 2, although in most cases, a repeat of the entire ISV is usually not necessary assuming usability testing of redesigned HMIs is conducted.

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4 DESIGN IMPLEMENTATION OF THE DCS HSI

As outlined in Section 3, the DCS is actually completed and tested as part of the ISV process. A final phase involves installing the new DCS and HMI. There are several stages to this installation:

1. The underlying DCS is installed in the plant simulator and plant. This installation includes any required vendor hardware for the DCS, any architectural backbone upgrades necessary to send and receive information between the DCS and plant sensors and controls, and any configuration protocols and simulator upgrades necessary to send and receive information between the DCS and the simulator. The DCS may be installed ahead of the HMI deployment, which provides a window in which to verify the DCS configuration integrity prior to HMI deployment.
2. The DCS HMI for PPC and TCS is deployed in the control room simulator for training purposes.
3. Operators are trained on the DCS HMI for the PPC and TCS. This training includes DCS fundamentals (operation, navigation, etc.) and specific training on the PPC and TCS. Training should include backup operations in the event of the failure of the DCS. Note that it may be possible to maintain both a legacy and DCS HMI in the training facilities until the deployment of the DCS HMI in the MCR. Glasstop simulators available at many plants would be ideal for maintaining a second configuration of the PPC and TCS as long as needed. All operators must receive the DCS training prior to HMI deployment in the MCR.
4. The PPC and TCS DCS HMI are deployed in the MCR. This will involve removing some existing legacy hardware instrumentation and controls (I&C) from the hard panels for the TCS and replacing legacy PPC displays and hardware elsewhere. This task is only accomplished during plant outage, as both systems are integral to plant operations. As such, the target date for final deployment of the PPC and TCS DCS HMI will likely need to be calibrated to correspond with a scheduled refueling outage at the plant.

With separate DCS hardware backbone and DCS HMI deployments, the deployment of the DCS would logically span a period between two scheduled outages at the plant. It is, however, possible to compress this cycle. The DCS, including both the backbone and the HMI, may be deployed in a single refueling outage. Alternately, portions of the DCS backbone may be installed piecemeal, without major obstruction to regular plant operations.

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5 SAMPLE PLAN FOR DESIGN, V&V, AND IMPLEMENTATION PHASES

This final section provides a sample plan that encompasses the design, V&V, and implementation phases for the DCS HMI. NUREG-0711 calls for detailed implementation plans for each phase, and this section may serve as a template for a plant-specific implementation plan for the PPC and TCS modernization activities. This section can also serve as a useful guide for aligning subcontractors and their statements of work to the upgrade project.

5.1 Assumptions

The sample plan assumes the vendor for the DCS has been selected (e.g., Honeywell or Westinghouse). This plan also assumes that necessary infrastructure upgrades to the main control room have been implemented and that the DCS is in place or could be deployed outside of a refueling outage. This plan also assumes that the requisite planning and analysis phases of NUREG-0711 have been conducted. Furthermore, it assumes that a glasstop simulator is available to conduct usability and pre-ISV activities independently of the plant training simulator, either at the plant or at another facility. If these assumptions do not hold, additional activities and time must be built into the plan.

5.2 Participants

The design and deployment of the DCS HSI will require a variety of plant and outside personnel. The legend below identifies the primary stakeholders required to carry out the plan.

Table 4. Participants in DCS Modernization.

Plant Personnel	Non-Plant Personnel/Subcontractors
PM Technical project management	**DC** DCS vendor
SE Systems engineering	**HS** HSI vendor
IC Instrumentation and control engineering	**HF** Human factors engineering
AE Architect engineering	
PO Plant operations	
CS Computer system engineering	
PT Personnel training and simulator operations	
PW Procedure writers	

5.3 Project Plan

The project plan for a 15-month design, V&V, and implementation of the new DCS HSIs is presented in Table 5 below. This project plan includes duration for the project phases. The exact level of effort for each participant (listed in the personnel column) will need to be determined based on available staff to support each activity. Note that some activities like Task 2 and 3 to migrate existing PPC displays to the new HMI will take more staff hours to complete due to the large number of PPC legacy displays than it will take to develop a few new displays in Tasks 7 and 8. These are assumed to be parallel activities, with resources divided between the tasks accordingly.

Table 5. Project Plan for Design, V&V, and Implementation for DCS HSI in the Main Control Room.

			Month															
Task	Activity	Report Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Personel
1	Implementation Plan	5																PM,SE,IC,AE,PO,CS,PT,DC,HS,HF
2	Legacy PPC Displays Design Specification	2.1																SE,IE,HS,HF
3	Legacy PPC Displays Migration	2.2																PO,HS,HF
4	Legacy PPC Displays Simulator Implementation	3 (1)																HS,SE,IC,AE,CS
5	Legacy PPC Displays Scenario Selected and Validated	3 (2) - (5)																PM,PT,PW,HF
6	Legacy PPC Displays ISV Documentation	3 (6)																HF
7	New PPC Displays Design Specification	2.1																SE,IE,HS,HF
8	New PPC Displays Design and Test	2.3																PO,HS,HF
9	New PPC Displays Simulator Implementation	3 (1)																HS,SE,IC,AE,CS
10	New PPC Displays Scenario Selected and Validated	3 (2) - (5)																PM,PT,PW,HF
11	New PPC Displays ISV Documentation	3 (6)																HF
12	New TPC Displays Usability Test	2.3																PO,HS,HF
13	New TPC Displays Simulator Implementation	3 (1)																HS,SE,IC,AE,CS
14	New TPC Displays Scenario Selected and Validated	3 (2) - (5)																PM,PT,PW,HF
15	New TPC Displays ISV Documentation	3 (6)																HF
16	All New Displays Deployed in Training Simulator	4 (2)																SE,IC,AE,CS,DC,HS
17	Operators Trained on All New Displays in Training Simulator	4 (3)																PO,PT,PW
18	All New Displays Deployed in Main Control Room	4 (4)																SE,IC,AE,CS,DC,HS
19	Project Management	N/A																PM

5.4 Sample Task Outline for TCS Upgrade

In this section, we present an outline of tasks related a TCS upgrade at a participating plant. The tasks center on using the Human System Simulation Laboratory (HSSL) housed at the Idaho National Laboratory to complete design and evaluation activities for the plant.

5.4.1 Glasstop Simulator Installation

An INL simulator manager will install the full-scope simulator of the representative plant on the HSSL glasstop panels. The plant simulator personnel and simulator vendor will provide support for the installation. Training on the use of the simulator and graphics development within the simulator platform is also provided.

5.4.2 HSSL Familiarization Workshop

The INL hosts a workshop at the HSSL with vendors, plant, and DCS stakeholders to introduce the HSSL and the design and evaluation process. The workshop includes reactor operators from the plant, who verify the fidelity of the installation.

5.4.3 HMI Ergonomics and Layout Workshop

The plant hosts a workshop with engineering staff to support possible and practical board rearrangements to make room for the new DCS displays and input devices on the control boards and at workstations. The rearranged boards must take into consideration physical constraints such as support structures and the behind-the-boards size of components. The rearranged boards are prototyped on the HSSL for ergonomic and operator assessment.

5.4.4 Input Device Trade Study

The INL evaluates operator preference and device effectiveness for trackpad, mouse, trackball, and touchscreen input devices that could be adopted for the TCS HMI. The evaluation can be conducted at the plant using a standalone mobile system developed for hardware evaluation.

5.4.5 Static Interface Evaluation

Initial displays developed by the HMI vendor are integrated into the HSSL glasstop boards to test initial operator response to the designs. The feedback will be augmented with HFE reviews against applicable standards and style guides for potential usability issues. Design recommendations are provided to improve the DCS HMI.

5.4.6 Rapid Prototype Development

The improved design is implemented in a dynamic, functional prototype suitable for operator scenario walkthroughs. This prototype is typically not in the native DCS platform and is considered a research prototype. The prototype interfaces with the underlying plant model to provide appropriate response to operator actions and accurately model plant transitions.

5.4.7 Dynamic Prototype Evaluation

The INL hosts a workshop at the HSSL in which operators walk through TCS scenarios using the legacy (existing) plant boards and the modified boards with the new DCS HMI prototypes. Results of this usability testing include operator feedback and usability performance measures.

5.4.8 Fully Integrated DCS Simulator Installation

Using the previously installed simulator architecture, plant simulator staff provides the INL with the appropriate DCS hardware and updated simulator plant model to install at the HSSL. The glasstop version of the DCS needs to support picture-in-picture representation of the DCS and input devices suitable for evaluation of the actual DCS HMI.

5.4.9 Pre-ISV Workshop

The INL hosts a workshop that walks through the formal ISV process at the HSSL. Operator performance data is collected using the HSSL to demonstrate successful implementation. The pre-ISV workshop serves as a dry run for the final ISV.

5.4.10 ISV Workshop

An ISV needs to be conducted by independent HFE experts using crews not previously involved in design and V&V activities. The workshop may be hosted at the HSSL if installation of the DCS HMI is not possible at the host plant's simulator. The approach supports the ISV benchmark method, with a comparison of operators using the original TCS and new TCS DCS. The ISV will adopt a graded approach that attempts to gather sufficient data for ISV using available crews in the time available for the study. The ISV serves as the operator equivalent of a "factory acceptance test" for the TCS HMI.

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