

Light Water Reactor Sustainability Program

Connecting LWRS Human Factors Engineering R&D to NUREG-0711 Elements and Modification Activities in Nuclear Power Plants

Gordon Cleifton, Jeffrey C. Joe, and Casey Kovesdi

May 2018



U.S. Department of Energy

Office of Nuclear Energy

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**Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517**

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INL/EXT-18-45149

May 2018

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EXECUTIVE SUMMARY

This report documents the connection between Human Factors Engineering (HFE) research and development (R&D) activities conducted under the Department of Energy as part of the Light Water Reactor Sustainability (LWRS) program at Idaho National Laboratory (INL), and the technical content of NUREG-0711, “Results Summary Reports.” Since the current and most recent LWRS HFE activities are associated with modernization and modification of nuclear power plants, this report will limit its scope to these topics.

The content of NUREG-0711 Results Summary Reports is shared with United States (U.S.) nuclear power plants by LWRS program HFE staff through INL HFE technical reports to identify potential human engineering deficiencies with planned upgrades. With this information, utilities have confidence that their upgraded human machine interfaces, operating procedures, conduct of operations, and training with the upgraded systems will ensure their continued safe control of a nuclear plant. The utilities use the HFE technical reports as basis documents in their licensing processes used to modify the plant (license amendment request or plant modification under 10 CFR 50.59).

For plant modifications, LWRS HFE R&D activities commence as early as an agreement is reached between the utility and the LWRS program staff. The multiple interfaces usually result in the two organizations meeting at INL, at the utility’s site, and at the vendor’s facility.

Since there generally is a shortage of utility based HFE experience, LWRS HFE staff supports the HFE related utility modernization and modification activities whenever requested.

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ACRONYMS

DCS	Digital Control System/Distributed Control System
DOE	Department of Energy
EPRI	Electric Power Research Institute
GONUKE	Guideline for Operational Nuclear Usability and Knowledge Elicitation
HED	Human Engineering Discrepancies
HFE	Human Factors Engineering
HMI	Human Machine Interface
HSI	Human System Interface
I&C	Instrumentation and Controls
INL	Idaho National Laboratory
LAR	License Amendment Request
LWRS	Light Water Reactor Sustainability
NASA-RTLX	National Aeronautics and Space Administration Raw Task Load Index
NEI	Nuclear Energy Institute
NRC	U.S. Nuclear Regulatory Commission
R&D	Research and Development
RSR	Results Summary Reports
SART	Situation Awareness Rating Technique
SEQ	Single Ease Question
SME	Subject Matter Expert
TCS	Turbine Control Systems
U.S.	United States

Connecting LWRs Human Factors Engineering R&D to NUREG-0711 Elements and Modification Activities in Nuclear Power Plants

1. INTRODUCTION

The nuclear power electrical generation industry is aligned in the belief that removing barriers that currently prevent wide application of digital technology is among the most important and urgent needs to support safe and reliable operation of the fleet on a sustained basis. Thus, the United States (U.S.) Department of Energy's Light Water Reactor Sustainability (LWRs) program sponsors researchers at Idaho National Laboratory (INL) to work with nuclear utilities and vendors to optimize modernization and modification activities, specifically in human factors engineering (HFE).

1.1 The Purpose of LWRs HFE

The purpose of the U.S. Nuclear Regulatory Commission (NRC) staff's HFE review is to support the NRC's safety mission of protecting people and the environment by verifying that accepted HFE practices and guidelines are incorporated into a plant's physical design and programs.

This report describes how LWRs program researchers use their HFE research and development (R&D) experience, as well as industry guidance, standards, and regulations, to assist plants in modernizing or modifying these instrument and control (I&C) systems in an efficient, effective manner.

1.2 Background

1.2.1 HFE History

In meeting safety and reliability requirements while controlling operating costs, managers of nuclear power plants must be able to replace and upgrade equipment in a cost-effective manner. Upgrades to plant equipment and especially I&C systems typically involve either replacement of analog devices with more modern digital technology or updating existing digital equipment. The use of digital technology is raising new design, implementation, and integration issues. For example, existing guidance on modifications involving a digital upgrade present a number of human factors challenges that are difficult to interpret in ways that ensure regulatory compliance. These challenges are primarily related to difficulties that licensees face in the analyses required to accurately respond to some of the questions in 10 Code of Federal Regulation 50.59 (10 CFR 50.59) evaluations.

HFE became less important to the nuclear industry after the lessons learned from the Three Mile Island event in 1979 were incorporated. As expected, many construction and modification skill sets were lost because the industry stopped building new plants. As the electrical generation industry maintained its status quo, normal personnel reductions resulted in an associated loss of knowledge base. Additionally, regulatory uncertainty effectively stopped safety-system modifications although digital modifications and modernizations were quite prevalent in the secondary side of the plant.

Since control room modernization projects are still relatively uncommon in the U.S. nuclear industry, the knowledge and experience required to manage the HFE aspects of projects, especially applying HFE guidance, appear to be lacking. This lost art of HFE drives the R&D under the I&C pathway of the LWRs program. LWRs program researchers at INL now offer R&D to address HFE aspects of the processes that utilities incorporate when they embark on plant modification projects.

1.2.2 HFE Resources

Under the LWRS program, researchers at INL have been using their HFE skills to assist the nuclear industry in plant modernization and modifications. The LWRS program has the overall objective to develop a scientific basis to extend existing nuclear power plant operating life beyond the current 60-year licensing period and to ensure their long-term safety, reliability, productivity, and security.

Since there is a general shortage of utility based HFE experience, LWRS HFE staff supports HFE related utility modernization and modification activities whenever requested. With an increased interest in implementing digital modifications, plants will soon appreciate the LWRS HFE resources that are available. HFE integration has recently been demonstrated with Arizona Public Service (APS), Exelon, Duke-Energy, and Southern Nuclear Company. Additionally, HFE has been promoted within DOE, the Nuclear Energy Institute (NEI), and the Electric Power Research Institute (EPRI) as an important feature of developing safe, reliable, and efficient modification packages.

1.2.3 HFE Driver

All NRC guidance must support at least one specific federal regulation. For human factors engineering, the regulatory drivers are 10 CFR 50.34(f)(2)(ii&iii) and 10 CFR 52.47(a)(8). Subsections ii & iii of 10 CFR 50.34(f)(2) state:

- (ii) Establish a program, to begin during construction and follow into operation, for integrating and expanding current efforts to improve plant procedures. The scope of the program shall include emergency procedures, reliability analyses, human factors engineering, crisis management, operator training, and coordination with INPO and other industry efforts. (Applicable to construction permit applicants only) (I.C.9)
- (iii) Provide, for Commission review, a control room design that reflects state of the art human factor principles prior to committing to fabrication or revision of fabricated control room panels and layouts. (I.D.1)

Subsection 8 of 10 CFR 52.47(a) states:

- (8) The information necessary to demonstrate compliance with any technically relevant portions of the Three Mile Island requirements set forth in 10 CFR 50.34(f), except paragraphs (f)(1)(xii), (f)(2)(ix), and (f)(3)(v);

The relationship between these federal regulations and NRC HFE activities is listed in Table 1.

Table 1. Regulatory Bases for Human Factors Engineering

Why	Regulations:	10 CFR 50.34(f)(2)(ii&iii) and 10 CFR 52.47(a)(8)
Who	NRC Program:	NRC staff's HFE program
How	NRC Guidance:	NUREG-0711
What	NRC product:	HFE Safety Review for SER
When	Timing:	NRC reviews applications for changes to or original: Construction permits (CPs), operating licenses (OLs), standard design certifications (DCs), and combined licenses (COLs).

2. LWRs HFE ACTIVITIES

The most recent LWRs HFE activities are associated with modernization and modification of nuclear power plants.

One focus area for the LWRs HFE staff is the nuclear power plant's main control room because many of the I&C system technologies installed, while highly reliable and safe, are now difficult to replace. These outdated technologies may limit the operating life of the plant and unnecessarily challenge operators.

For plant modifications, LWRs HFE R&D activities commence as early as an agreement is reached between the utility and the LWRs program staff. The multiple interfaces usually result in the two organizations meeting at INL, at the utility's site, and at the vendor's facility. The LWRs HFE staff work to verify that accepted HFE practices and guidelines are incorporated into the plant's physical design and programs. They will use their HFE R&D experience, as well as industry guidance, standards, and regulations, to assist the plant in modernizing their I&C systems in an efficient, effective manner.

2.1 I&C Versus Human System Interface Modernization

As shown in Figure 1, I&C modernization and modifications are related to human-system interface modernization. A well-thought-out implementation plan is necessary to ensure that progress is achieved without requiring undoing of earlier installed improvements in the plant's design.

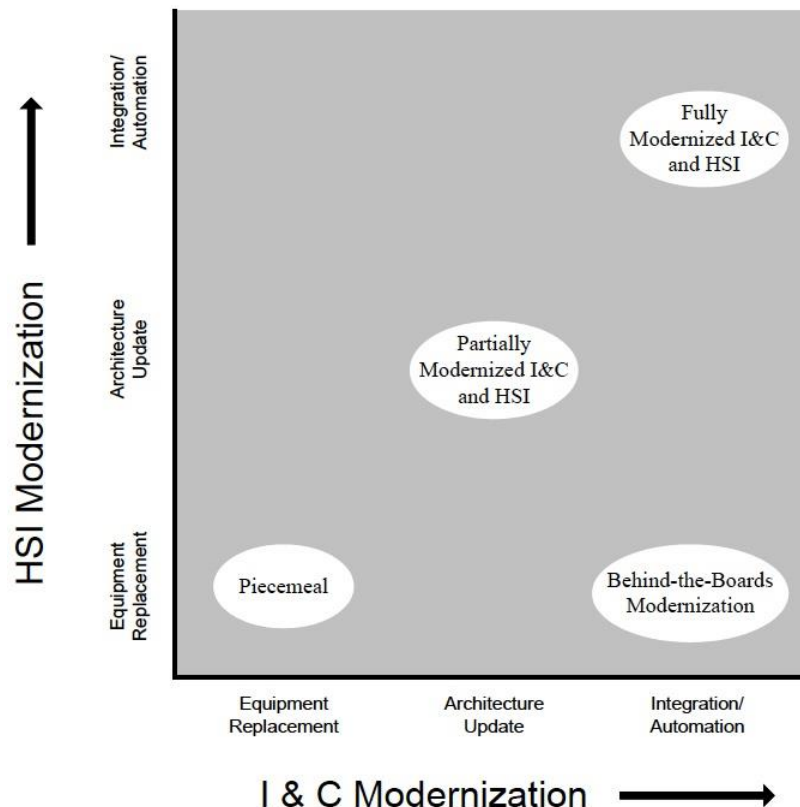


Figure 1. Control Room modernization strategies.

2.2 Aging Management Programs

From NEI's second license renewal roadmap, one can see that R&D by DOE through the LWRS program is a major contributor to successful aging management at a plant (see Figure 2). Using the results from LWRS HFE activities and the resulting technical reports ensures that appropriate HFE considerations were addressed in developing effective aging management programs.

Continual Improvement of Aging Management Programs

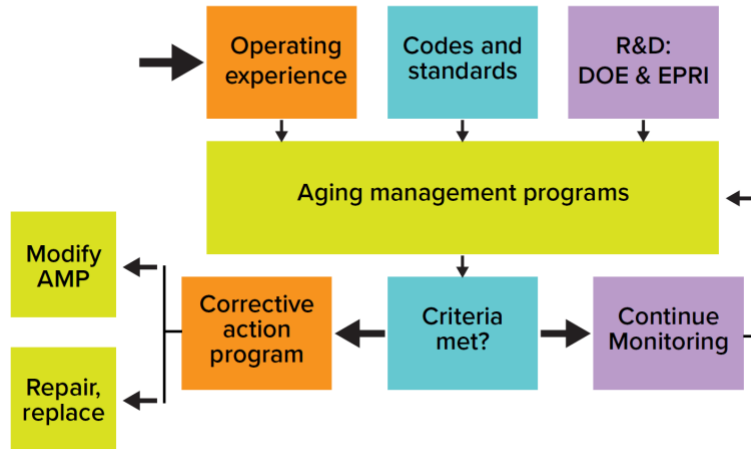


Figure 2. Continual improvement of aging management programs.

2.3 HFE Technical Reports

LWRS HFE technical reports record observations, findings, and deviations from recognized HFE standards or applicable regulations. When presented to the utility, the technical report provides HFE recommendations and generally addresses three main elements of the twelve in an NRC HFE safety review:

- Human system interface design
- Human factors verification and validation
- Human performance monitoring.

The twelve HFE elements of an NRC staff's HFE safety review are shown in Figure 3.

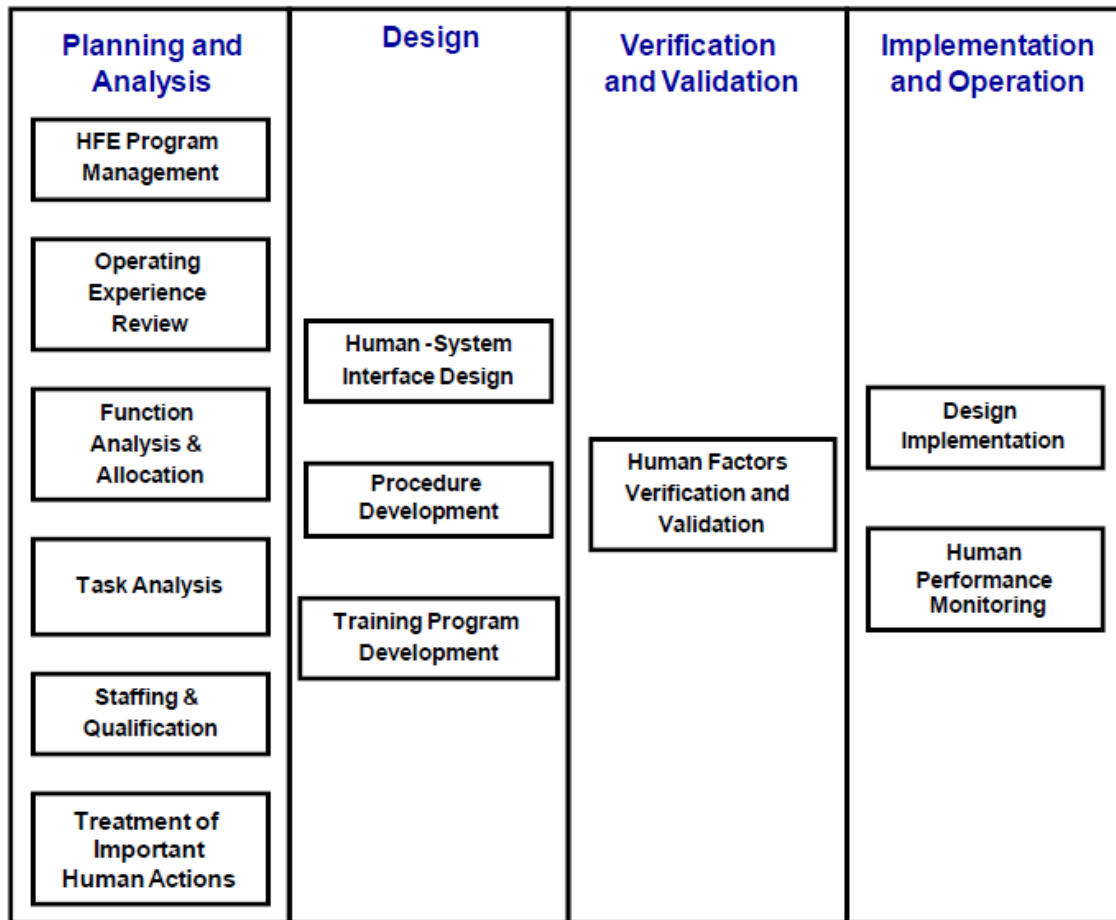


Figure 3. The twelve HFE elements of NUREG-0711.

Thus, an LWRs HFE technical report addresses three main categories of an NRC HFE safety review:

- Design
- Verification and validation
- Implementation and operation

These LWRs HFE technical report elements contain the criteria for reviewing the utility's HFE program and design. Each element is divided into five sections:

- Background
- Objective
- Applicant products and submittals
- Review criteria
- Bibliography

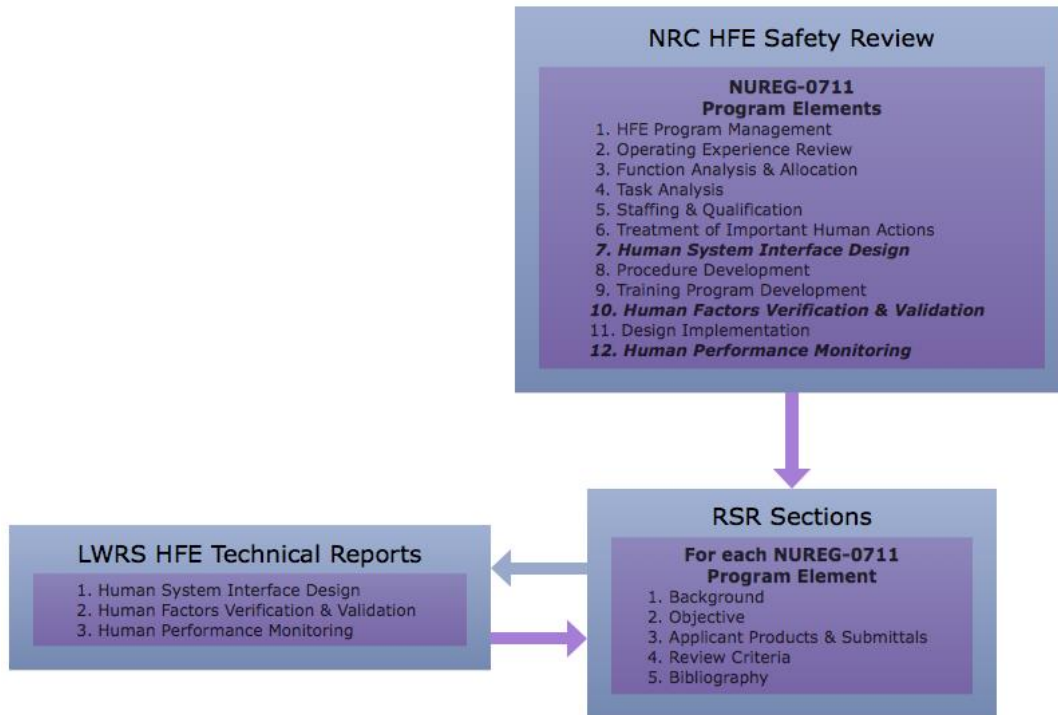


Figure 4. The relationship between NUREG-0711 and LWRS HFE technical reports.

2.4 NUREG-0711 Results Summary Reports

NUREG-0711 results summary reports (RSRs) are used by LWRS HFE staff to identify potential human engineering discrepancies (HEDs) in planned upgrades. The contents of RSRs provide the basis for the HFE technical reports provided to the utilities. With this information, utilities have confidence that their upgraded Human Machine Interfaces (HMIs), operating procedures, conduct of operations, and training in the upgraded systems will ensure their continued safe control of the nuclear plant.

Each NUREG-0711 RSR summarizes the results of a completed NUREG-0711 element and cites documents or files that led to the report's results. The LWRS HFE staff use material documented in the RSRs to create the HFE technical reports provided to the utility. Thus, a traceable paper trail exists for each of the recommendations so that a documented technical basis is available, if necessary.

2.5 Utility Use of HFE Technical Reports

The path chosen by a plant in modernizing or modifying plant equipment is determined by the screening and evaluation process of 10 CFR 50.59. Simply stated, the 10 CFR 50.59 process results in a decision to proceed in one of two paths: license amendment request (LAR) process directly with the NRC or plant modification process, later reviewed by the NRC.

After determining that a proposed activity is safe and effective through appropriate engineering and technical evaluations, the 10 CFR 50.59 process is applied to determine if an LAR is required prior to implementation. NEI 96-07 describes three basic steps: (1) applicability and screening, (2) evaluation, and (3) documentation and reporting.

The LWRS HFE staff contributes to the 10 CFR 50.59 process by providing subject matter expertise to the utility as they proceed through the screening and evaluation steps. The HFE activities result in a documentation flow that goes from NUREG-0711 RSRs to LWRS HFE technical reports to utility documents supporting 10 CFR 50.59 process steps to utility approval. Similarly, the LWRS HFE staff contributes to the LAR process by providing subject matter expertise to the utility as they proceed through phases of acquiring NRC approval. HFE activities result in a documentation flow that goes from NUREG-0711 RSRs to LWRS HFE technical reports to utility documents supporting the LAR process steps to NRC approval by reviewers conducting the modification's safety evaluation (see Figure 5).

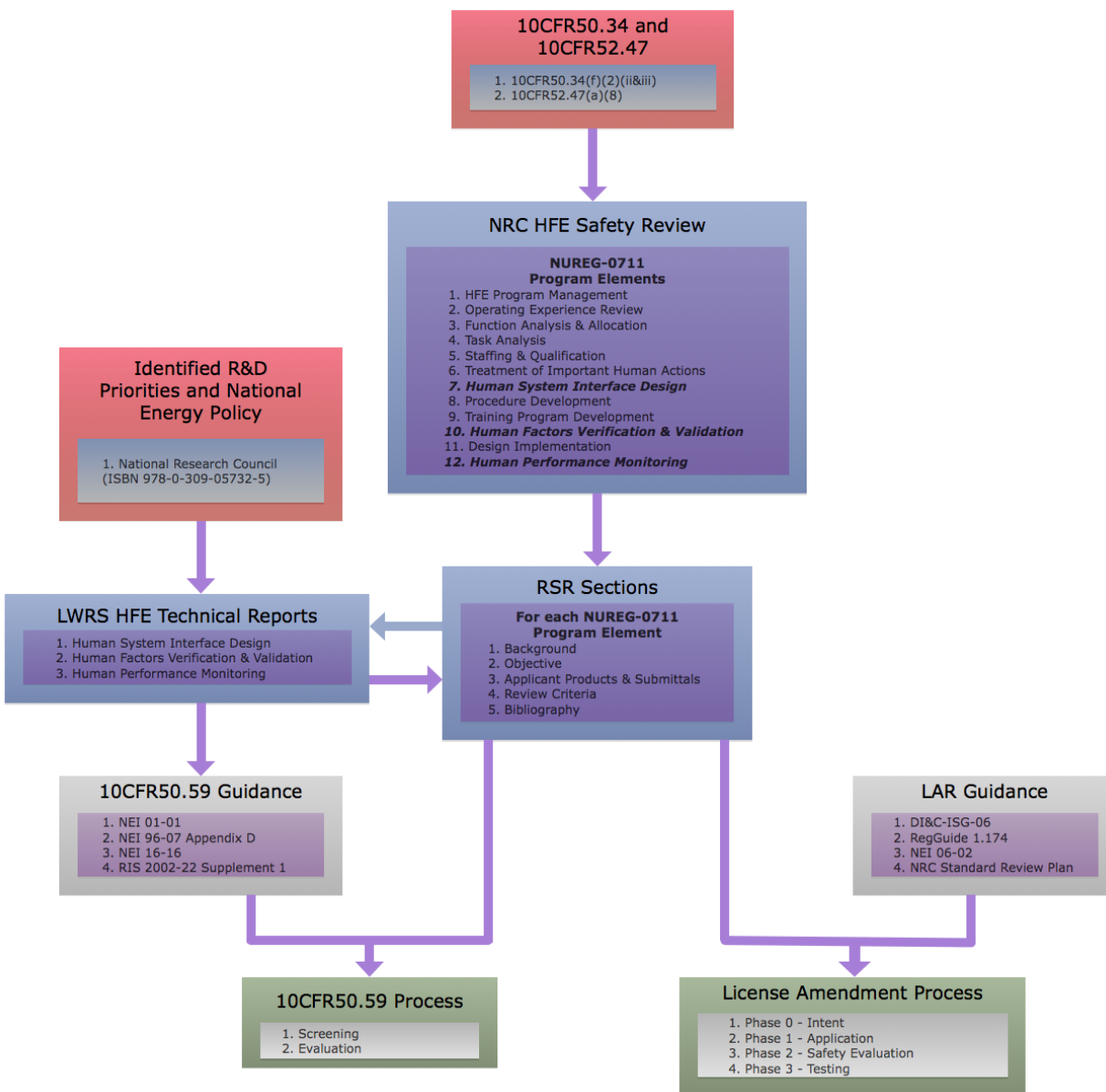


Figure 5. The connections between LWRS HFE R&D, NUREG-0711 elements, and modification activities in nuclear power plants.

All LWRS technical reports are intended to lead to the plant's success in completing its modernization or modification. The intent is to make the modernization or modification process less burdensome to utility staff, as well as provide credible source documents to justify design features. Utility

staff and LWRs HFE staff work together to integrate the HFE technical reports into the documentation process and to ensure that duplicate effort is avoided.

LWRs HFE assistance may start as early as the creation of specifications for modifications. The LWRs HFE staff services usually supplement on-site HFE activities if the utility already has HFE subject matter experts. A goal of the LWRs HFE staff is to show value added with minimum interruption while identifying and filling any HFE design needs.

By entering into agreements or partnerships with the DOE LWRs program, utilities are able to receive HFE services and documentation that are unavailable elsewhere. It is particularly attractive that the utility makes no payments directly to DOE or INL; the only utility costs are those incurred supporting the LWRs HFE staff during their assistance activities.

As a result of NRC familiarity with HFE involvement in the modification process and with associated successes, NRC staff is expected to anticipate HFE considerations in future modifications. By adding rigor to areas previously glossed over, utilities will be able to enjoy adequate assurance and confidence that HFE was addressed sufficiently and that any NRC inspector would find a solid technical basis should an HFE topic require review.

3. LWRS HFE EXAMPLES

In the interest of sustaining the operation of existing nuclear power plants, LWRS program staff are conducting research on implementation of digital I&C technology in nuclear power plants. LWRS HFE services are used by utilities to assist in modernizing their systems within NRC guidelines and regulations.

3.1 LWRS Fleet-based Control Room Modernization Project

LWRS program researchers are collaborating with Exelon to support control room upgrades at their Braidwood and Byron plants. Exelon is replacing the Westinghouse non-safety-related 7300 process I&C systems with the Westinghouse Ovation digital control system (DCS) for the nuclear steam supply systems and balance of plant. The Ovation DCS is designed to be significantly more reliable and fault tolerant than the Westinghouse 7300 DCS system.

Early in the modification process, LWRS program experts worked with Exelon to perform independent HFE reviews and evaluations to verify and validate the design and operation of the upgraded Ovation system. In a collaborative effort between Exelon and the LWRS program using a reconfigurable full scope control room simulator at INL, researchers conducted studies of the modified control room human machine interface (HMI). Together, they conducted a one-week operator-in-the-loop workshop comprising a series of simulated runs through a representative set of control room procedures related to the upgrades. These scenarios identified potential HEDs and determined whether control board arrangements satisfied HFE guidelines and supported improved operator efficiency. The LWRS program issued INL/LTD-16-40705, *Preliminary Human Factors Evaluation of Control System Upgrades for the Byron and Braidwood Nuclear Power Stations*, Rev. 1.

With an LWRS HFE team monitoring, Exelon staff completed a factory acceptance test (FAT), software- and hardware-functionality testing, and the delivery of the software and hardware to the site. Exelon included the HFE team when validating the new system by running through scenarios, validating revised procedures, and evaluating the upgraded system response at the Byron and Braidwood sites. Completion of the Exelon operator training process was done with INL coordinated scenarios in the simulators to ensure that the operators demonstrated proficiency with the upgraded controls and HMI before they operated these in the plants. The results of this workshop (INL/LTD-18-44781, *Workshop Report: Braidwood Operator-in-the-Loop Evaluation of the N Upgrades*) document that completion times, operator workload, situational awareness, and equipment usability were observed to be at an acceptable level across the various scenarios.

The Exelon 7300 project brought the LWRS HFE team in to address three of the elements of NUREG-0711. The team used nine of the available HFE activities over several months to confirm conformance to the guideline. Figure 6 illustrates the one-to-many relationships of elements to activities.

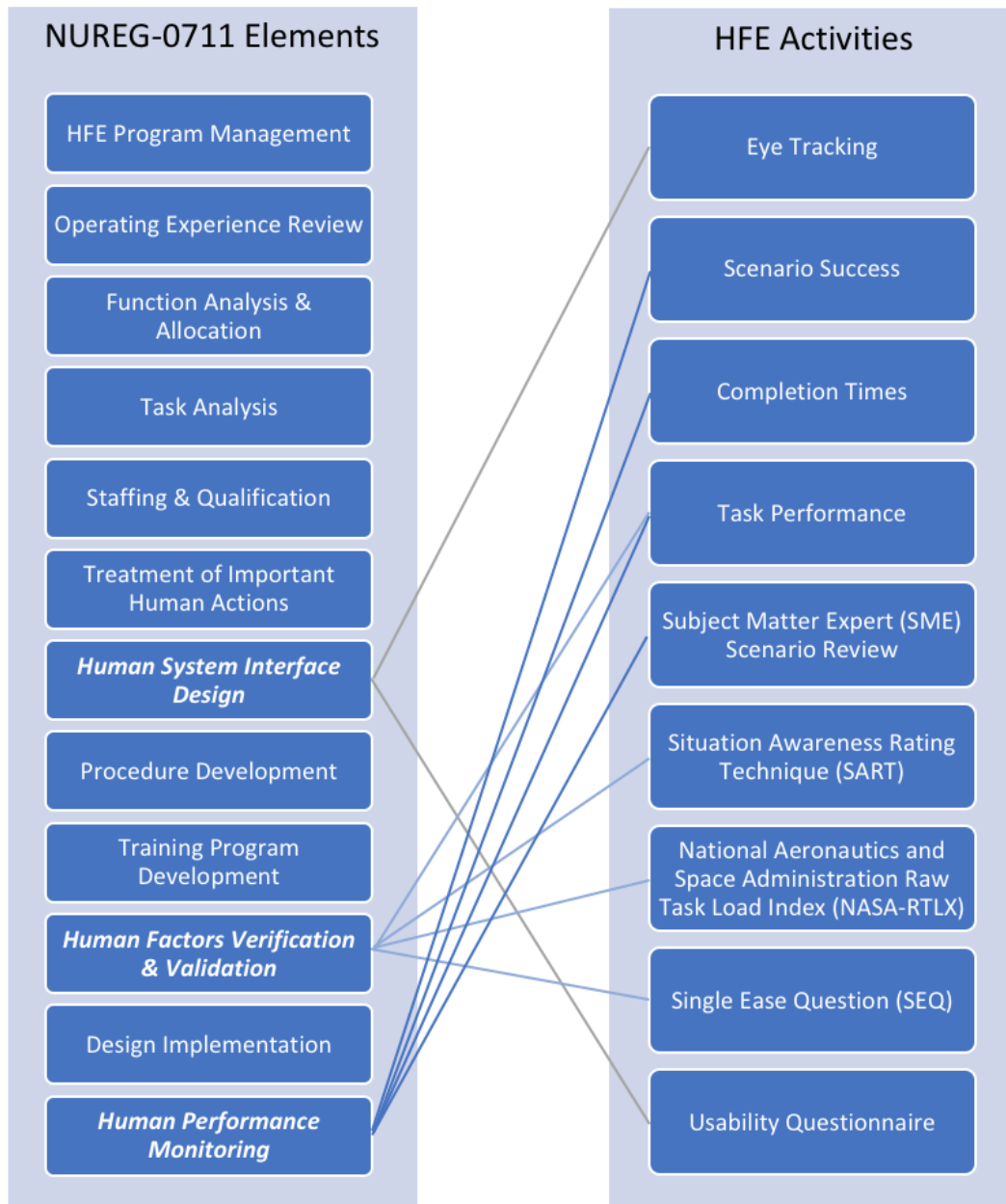


Figure 6. A specific crosswalk between NUREG-0711 elements and some HFE activities performed with Exelon.

Using the 10 CFR 50.59 process, the Exelon 7300 I&C system modernization was determined to be a non-safety modification and not to require a LAR. The LWRS HFE team contributed to the 10 CFR 50.59 documentation in both the screening and evaluation phases. LWRS HFE documents, reports, and formal contributions are referenced in the Exelon material supporting the decision to proceed with the modification under 10 CFR 50.59 process.

3.2 LWRs Palo Verde Control Room Modernization Project

One on-going LWRs HFE collaboration is with Palo Verde Nuclear Generating Station to develop a strategic plan to achieve a desirable end state using a phased modernization approach. The HFE research team provided valuable input to Palo Verde's end state main control room layout, its alarm system design, and the HSI design for the upgraded control systems. This collaboration demonstrates that an approach that fully considers human factors from the start of upgrade planning can result in more consistent, appealing, and efficient control room design than would a series of like-for-like replacement of components.

The research team showed that incorporating advanced technologies, in the areas of HSI designs, alarms, and computer based procedures can enhance operations elsewhere in the plant, such as in a liquid radiological-waste control room. This HFE assistance in plant modifications serves as a proof-of-concept for HFE processes, which allows confidence in a successful upgrade for control rooms in accordance with industry and NRC guidance.

While working with Arizona Public Service, the HFE research team evaluated the use of overview displays to support plant and system level operations with implementations of advanced visualizations for the turbine control system and the chemical and volume control system. Palo Verde provided extensive operations and training support which allowed LWRs program researchers to evaluate and validate the design concepts with a sizeable sample of operators. This involvement resulted in many HFE design recommendations which were based upon applying the applicable regulations and standards.

This collaboration and planned modernization venture provides an example that other utilities can follow in their control room modernization projects. The LWRs HFE activities at Palo Verde show that HFE input into plant modification processes can help reduce the regulatory uncertainty by providing solid basis for the HFE aspects of 10 CFR 50.59 documentation. Likewise, combining resources helps utilities both achieve a reduction in the costs and risks associated with implementing operationally beneficial, cost saving digital technologies and retain economic viability in competitive energy markets.

3.3 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 (TCS) at their Brunswick, Robinson, and Harris plants. This TSC 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. In helping to guide the development of the underlying control logic for the I&C system, the experts ensured that there would be consistency in DCS functionality and behavior from one subsystem (e.g., TCS) to another within the plant process computer.

LWRs researchers developed a framework to help map their Duke HFE activities to NUREG-0711 in 2015. It serves as a means of helping explain and catalog the value of different types and phases of human performance data collection. In Table 2, each box represents a different piece of evidence for establishing the quality of the design.

Table 2. HFE methods and measures mapped to GONUKE (rows) and NUREG-0711 (columns).

	Planning and Analysis	Design	Verification and Validation	Implementation and Operation
Verification	<i>Verification incorporates use of various human factors standards and guidelines as opposed to data collection methods from plant personnel.</i>			
Validation	<u>Baseline Evaluation</u> <ul style="list-style-type: none"> • Eye Tracking (Heat Maps) • Usability Questionnaires • Usability/performance Metrics • Procedure Logs • Simulator Logs • Eye Tracking (Metrics) • SAGAT • SEQ • SART • NASA-RTLX 	<u>Usability Testing</u> <ul style="list-style-type: none"> • Eye Tracking (Heat Maps) • Usability Questionnaires • Usability/performance Metrics • Procedure Logs • Simulator Logs • Eye Tracking (Metrics) • SAGAT • SEQ • SART • NASA-RTLX 	<u>Integrated System Validation (i.e., ISV)</u> <ul style="list-style-type: none"> • Usability/performance Metrics • Procedure Logs • Simulator Logs • Eye Tracking (Metrics) • SAGAT • SEQ • SART • NASA-RTLX 	<u>Operator Training</u> <ul style="list-style-type: none"> • Procedure Logs • Simulator Logs • SART • NASA-RTLX
Knowledge Elicitation	<u>Cognitive Walkthrough</u> <ul style="list-style-type: none"> • Observation (General) • Walk/talk-throughs • Interviews (General) • Usability Questionnaires 	<u>Operator Feedback on Design</u> <ul style="list-style-type: none"> • Walk/talk-throughs • Focus Groups • Display Reviews • Interviews (General) • Usability Questionnaires 	<u>Operator Feedback on Performance</u> <ul style="list-style-type: none"> • Focus Groups • Interviews (General) 	<u>Operator Experience Reviews</u> <ul style="list-style-type: none"> • Observation (General) • Focus Groups • Interviews (General)

Table 2 shows how LWRs researchers address key HFE activities for each of the four phases of NUREG-0711 (columns in figure). The researchers applied a greater emphasis on HFE involvement in the earlier phases to ensure success at later phases. The rows in the figure describe three types of evaluation:

- Expert review (verification)
- User testing (validation)
- Knowledge elicitation (obtain tangible representation of knowledge).

The last two involve data collection methods with plant personnel while the first involves HFE subject matter experts using standards like NUREG-0700 in analyses.

The work with Duke Energy demonstrates the value of a harmonized HSI design that can be used across vendor platforms. Additionally, the Duke Energy collaboration demonstrates a fleetwide HFE solution whereby a common upgrade process and platform may be deployed efficiently.

3.4 LWRs Southern Nuclear Company Control Room Upgrade

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. 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.

4. NON-OBSERVABLE HFE INPUT

One of the benefits of a plant's modification program with integrated HFE is that a thorough human factors assessment of a potential design can be accomplished early in the modification process. Thus, any HFE shortcomings or gaps can be addressed properly before false starts are initiated. Such involvement also assists in efficiency of design, as well as giving confidence that HFE was not glossed over as a purely administrative step in the modification process, which could lead to NRC findings or operational failures. No findings are associated with safe operations.

By providing HFE technical reports, HFE subject matter experts provide the licensing staff at a utility the foundational engineering documents that are used as references in answering 10 CFR 50.59 questions in the screening and evaluation processes. A thread may never be pulled by an auditor or NRC inspector to the detailed level of such an HFE technical report, but the utility can have confidence that well documented supporting material is available if a root cause analysis is conducted. HFE experts recognize that their input to a successful design is an important contribution although there is usually no frontline visibility in the finished product. After working with digital displays and controls in so many applications, operators generally do not recognize the HFE effort involved in producing an excellent design that meets regulatory requirements and guidance criteria.

Since there has been very little construction or modification in the nuclear power industry, the number of practicing human factors engineers and the associated knowledge base has diminished. This, coupled with staff reductions at nuclear utilities mean that HFE skilled employees are frequently stretched to their limits. The LWRS program offers HFE services that strengthen a utility's ability to ensure continued safe control of a nuclear plant and that support the NRC's safety mission of protecting people and the environment.

5. CONCLUSION

Modernization and modification of nuclear power plants are a high priority for Congress, NRC commissioners, and utility management. The LWRS program HFE staff's current and most recent LWRS program activities assist plants in modernizing or modifying I&C systems in an efficient, effective manner.

LWRS HFE R&D activities result in technical reports that are linked to NUREG-0711 RSRs. These technical reports are shared with U.S. nuclear power plants to identify potential HEDs with planned upgrades. This information gives utilities confidence that their upgraded HMIs, operating procedures, conduct of operations, and training with the upgraded systems will ensure their continued safe control of the nuclear plant.

LWRS program HFE staff supports HFE related utility modernization and modification activities whenever requested. HFE activities thereby support NRC's safety mission of protecting people and the environment.

6. ANNOTATED BIBLIOGRAPHY

NUREG-0711, *Human Factors Engineering Program Review Model*

This document describes NRC expectations for a plant's human factors program and appropriate HFE design and evaluation processes. It addresses both new plant designs and modifications.

- <http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0711>

NUREG-0700, *Human System Interface Design Review Guidelines*

As part of the NRC's review process, interfaces between plant personnel and plant's systems and components are evaluated for conformance with HFE guidelines. The NUREG-0700 guidelines address human factors aspects of physical and functional characteristics of HSIs. In addition to the review of actual HSIs, NRC can use NUREG-0700 guidelines to evaluate a design specific HFE guideline document or style guide.

- <https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0700>

NUREG-0800, *Standard Review Plan*

The standard review plan provides guidance to NRC reviewers; it also provides a source of guidance and understanding of NRC expectations related to I&C and HSI upgrades. Of special importance to control room modernization is Chapter 7, which covers I&C systems, and Chapter 18, which covers human factors and the HSI.

- <https://www.nrc.gov/docs/ML1612/ML16125A114.pdf>

NEI 01-01 / EPRI TR-102348, *Guideline on Licensing Digital Upgrades*

This industry guideline on design and licensing of digital I&C systems was endorsed by the NRC. It covers the overall I&C upgrade design process, dealing with digital systems issues such as software common cause failure, diversity, and defense in depth. It specifically addresses digital issues in the context of 10 CFR 50.59 evaluations and how to determine the need for license amendments when making changes to the I&C systems and HSIs.

INL/LTD-16-40705, *Preliminary Human Factors Evaluation of Control System Upgrades for the Byron and Braidwood Nuclear Power Stations*, Rev. 1

This report summarizes the work INL performed, including one prerequisite modeling task and three evaluations that correspond to the Design phase of NUREG-0711. The findings and recommendations from this report are intended to help facilitate the control room modernization by minimizing the potential for human engineering discrepancies and by confirming that no new failure modes are introduced with the installation of the new digital I&C. Simulator scenarios were also identified during the static baseline workshop in order to prepare for future workshops where a dynamic version of the simulator will be available.

INL/LTD-18-44781, *Workshop Report: Braidwood Operator-in-the-Loop Evaluation of the N Upgrades*

This report documents the results from two operator-in-the-loop workshop studies that evaluated the effects of instrumentation and control system upgrades on human system performance for the Braidwood and Byron nuclear generating stations.