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Human Factors Engineering Program Review Model (NUREG-0711) Revision 3: Update Methodology and Key Revisions

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) reviews the human factors engineering (HFE) programs of applicants for nuclear power plant construction permits, operating licenses, standard design certifications, and combined operating licenses. The purpose of these safety reviews is to help ensure that personnel performance and reliability are appropriately supported. Detailed design review procedures and guidance for the evaluations is provided in three key documents: the Standard Review Plan (NUREG-0800), the *HFE Program Review Model* (NUREG-0711), and the *Human-System Interface Design Review Guidelines* (NUREG-0700). These documents were last revised in 2007, 2004 and 2002, respectively. The NRC is committed to the periodic update and improvement of the guidance to ensure that it remains a state-of-the-art design evaluation tool. To this end, the NRC is updating its guidance to stay current with recent research on human performance, advances in HFE methods and tools, and new technology being employed in plant and control room design. NUREG-0711 is the first document to be addressed. We present the methodology used to update NUREG-0711 and summarize the main changes made. Finally, we discuss the current status of the update program and the future plans.

Key Words: human factors engineering, guidelines, nuclear power plants, control rooms, safety reviews

1 INTRODUCTION

Human factors engineering (HFE) standards and guidelines (S&Gs) documents play an important role in the design and evaluation of complex systems (Karwowski, 2006). S&Gs provide users with principles to help ensure that the physiological, cognitive, and social characteristics of personnel are accommodated in system development. They also support standardization and consistency of human-system interface (HSI) characteristics and functionality.

Many HFE S&Gs are developed by professional organizations such as the Human Factors and Ergonomics Society (HFES) and the Institute of Electrical and Electronics Engineers (IEEE) using a consensus process. In fact, Dul et al. (2004) identified 174 international HFE standards from the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) alone. Consensus S&Gs are periodically updated to keep current with new research and technological developments. Government organizations also develop HFE S&Gs. The Department of Defense's HFE Technical Advisory Group (DoD, 2004) listed over 30 U.S. government HFE standards. Like consensus documents, government S&Gs are periodically updated. Ahlstrom et al. (2010) discussed the status of three key government standards that are being updated: DoD's *Design Criteria Standard: Human Engineering* (MIL-STD-1472), the Federal Aviation Administration's (FAA) - *Human Factors*

Design Standard, and National Aeronautics and Space Administration's (NASA) *Space Flight Human System Standard* (NASA-STD-3001, formerly 3000).

The purpose of this paper is to describe the update of government guidelines used by the U.S. Nuclear Regulatory Commission (NRC) to perform safety reviews of the HFE aspects of both new and operating nuclear power plant (NPP) designs. With the U.S. planning for the construction of the next generation of plants and the existing plants modernizing their control rooms, it is essential that the NRC have review guidance that is up-to-date with state-of-the art HFE methods and HSI technology.

Our focus in this paper is on the *HFE Program Review Model* (NUREG-0711). We will first describe the role of HFE guidelines in the safety review process focusing mainly on NUREG-0711 (O'Hara et al. 2004). Then we present the methodology used to update NUREG-0711 and summarize the main changes made. Finally, we discuss the current status of the update program and the future plans. This paper updates prior papers describing the update of NRC HFE guidance (Fleger & O'Hara, 2010; O'Hara, Higgins & Fleger, 2011).

2 NRC HFE REVIEWS AND NUREG-0711

The NRC staff reviews the HFE programs of applicants for NPP construction permits, operating licenses, standard design certifications, and combined operating licenses. The purpose of these safety reviews is to help ensure that personnel performance and reliability are appropriately supported. The review methodology is based on a systems engineering approach (e.g., IEEE, 2005) and embodies two key principles to addressing the human factors aspects of design: a "top-down" methodology and "life-cycle" considerations. "Top-down" refers to an approach to HFE that starts at the "top," i.e., with the plant's high-level mission and goals. These are divided into the functions necessary to achieve the goals which are then allocated to human and system resources. Functions are broken down into tasks and analyzed to identify the HSIs (e.g., alarms, displays, and controls) that will be needed to support operator performance. Tasks are arranged into work activities to be performed by individual crewmembers and teams. The detailed design of the HSI, procedures, and training represents the "bottom" of the top-down process. HFE should be addressed over the plant life-cycle, e.g., concept planning through operations.

The NRC's safety review was developed to track the design process with these key principles in mind. The methodology examines the applicant's HFE design development process as well as its products, e.g., the main control room. Three primary guidance documents are used. Chapter 18, Human Factors Engineering, of the *Standard Review Plan* (NUREG-0800) provides high-level guidance for the conduct of HFE reviews (NRC, 2007a). Detailed review criteria for evaluating an HFE program are contained in the *HFE Program Review Model* (NUREG-0711). NUREG-0711 contains the detailed review criteria for evaluating an applicant's HFE program and consists of twelve review elements. Each element is divided into five sections: Background, Objective, Applicant Submittals, Review Criteria, and Bibliography.

Using the HFE guidance, the reviewer makes a safety determination of the design's acceptability. The regulator and the public have the greatest confidence in a design that: (1) was developed by a qualified HFE design team with the requisite skills required, using an acceptable HFE program plan; (2) resulted from appropriate HFE studies and analyses that provide accurate and complete inputs to the design process; (3) designed using proven technology based on human performance and task requirements incorporating accepted HFE standards and guidelines; and (4) was evaluated using thorough verification and validation (V&V) tests.

The HFE guidance has, and continues to be used, for the review of applicant submittals. Over time, however, new technologies evolve and new methods are developed and utilized to analyze, test, and evaluate the new control room designs. The NRC is committed to keeping its HFE review guidance up-to-date. NUREGs-0800, -0711, and -0700 were last updated in 2007, 2004 and 2002, respectively. Since

the last revisions, the NRC has conducted research in many areas of HFE in order to provide a technical basis on which to update the review guidance. NUREG-0711 is a key HFE review document and is the first to be updated.

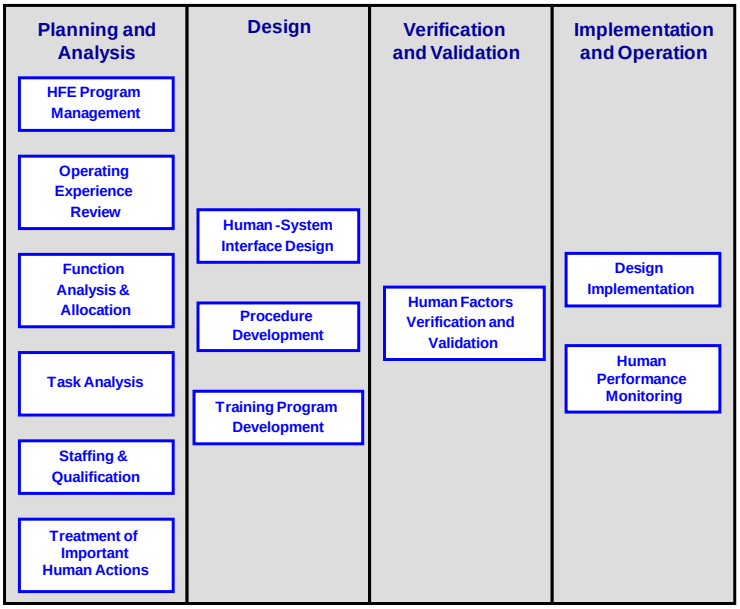

Figure 1. NUREG-0711, Revision 2 HFE review elements

A brief description of each element follows.

HFE Program Management - The review objective is to verify that the applicant has an HFE design team with the responsibility, authority, placement within the organization, and composition to provide reasonable assurance that the design commitment to HFE is met. Also, the team should be guided by a plan to verify that the HFE program is properly developed, executed, overseen, and documented.

Operating Experience Review - The review objective is to verify that the applicant has identified and analyzed HFE-related problems and issues in previous designs that are similar to the current design under review. In this way, negative features associated with predecessor designs may be avoided in the current one while retaining positive features.

Functional Requirements Analysis and Function Allocation - The review objective is to verify that the applicant has defined the plant's safety functional requirements and that the function allocations take advantage of human strengths and avoid allocating functions that would be negatively affected by human limitations. This defines the operator's role and the levels of automation.

Task Analysis - The review objective is to verify that the applicant's analysis identifies task requirements.

Staffing and Qualifications - The review objective is to verify that the applicant has systematically analyzed the requirements for the number and their qualifications.

Human Reliability Analysis - The review objective is to verify that (1) the applicant has addressed human-error mechanisms in the design of the HFE aspects of the plant to minimize the likelihood of personnel error, and verify that errors are detected and recovered from; and (2) the HRA is integrated with the HFE program.

Human-System Interface Design - The review objective is to evaluate the process by which HSI design requirements are developed and HSI designs are identified and refined. The review should verify that the applicant has appropriately translated functional and task requirements to the detailed design of alarms, displays, controls, and other HSI aspects.

Procedure Development - The review objective is to verify that HFE guidance is applied, with all other design requirements, to develop procedures that are technically accurate, comprehensive, explicit, easy to use, and validated.

Training Program Development - The review objective is to verify that the applicant's approach to personnel training incorporates the elements of a systems approach that (1) evaluates the knowledge and skill-requirements of personnel, (2) coordinates the development of the training program with the other elements of the HFE design process, and (3) implements the training effectively in a manner consistent with human factors principles and practices.

Human Factors Verification and Validation (V&V) - This aspect of the review involves three evaluations, the review objectives are to verify that the applicant has performed:

- HSI Task Support Verification - an evaluation to verify the availability of the HSIs that are needed to support personnel task requirements as defined by task analyses.
- HFE Design Verification - an evaluation to verify the suitability of the HSI design to accommodate human capabilities and limitations as reflected in HFE guidelines such as those provided in NUREG-0700 (described below).
- Integrated System Validation (ISV) - an evaluation using performance-based tests to determine whether an integrated system design (i.e., hardware, software, and personnel elements) meets performance requirements and acceptably supports safe operation of the plant.

Design Implementation - The review objective is to verify that the as-built design conforms to the verified and validated design that resulted from the HFE design process.

Human Performance Monitoring - The review objective is to verify that the applicant has prepared a human performance monitoring strategy for ensuring that no safety degradations occur over time.

3 GUIDANCE DEVELOPMENT METHODOLOGY

The HFE documents are being updated using the NRC's general methodology for guidance development (see O'Hara et al., 2008). The updates to NUREG-0711, Revision 3 are based primarily on two sources of information: user needs/comments and NRC technical basis documents published after NUREG-0711, Revision 2 was completed. A fourth revision is planned and is discussed in Section 5 of this paper.

3.1 User Comments

NUREG-0711 users include the NRC staff responsible for conducting HFE reviews in the Office of New Reactors (NRO) and the Office of Nuclear Regulatory Regulation (NRR). The users also include NRC contractors, such as the authors, who support the NRC staff to conduct HFE reviews.

NRC user needs and comments were obtained through a variety of means. The first was a NUREG-0711 question and comment table maintained by NRC HFE reviewers. This table was given to the project staff for disposition. Second, a meeting was held with NRC users to discuss their needs and expectations for modifications to NUREG-0711. As part of that meeting, general categories of revisions were discussed and prioritized. The users were asked to rate each category as: high (rating of 3), medium (rating of 2), or low priority (rating of 1). The results are shown in Table I. The prioritization effort

yielded additional comments. We used the results of the prioritization to focus our efforts on the areas more important to NRC users.

Table I. NRC User Ratings of NUREG-0711 Improvement Categories

Category	NRO Rating	NRR Rating
Priority Categories		
Technical Information Updates	2.76	3.00
Element Revisions	2.65	3.00
Cross-checks with Other Documents and Info	2.25	2.50
Clarifications and Corrections	2.10	3.00
Expansion Updates	2.00	2.50
Low-Priority Categories		
Potential New Considerations	1.67	1.00
Potential Supporting Info	1.17	3.00
Background Update	1.00	2.00

Ranking: 3 = High Priority; 2 = Medium Priority; 1 = Low Priority
Priority categories are those receiving both NRO and NRR ratings above 2.

With respect to non-NRC users, comments related to needed changes and clarifications were maintained since NUREG-0711, Revision 2 was first published in 2004. These comments addressed lessons learned while conducting reviews of new reactor designs in support of the NRC staff.

3.2 NRC Technical Basis Documents

The NRC documents identified are those published after NUREG-0711, Revision 2 and include: the standard review plan (SRP) sections, regulatory guides (RGs), interim guidance documents (ISGs), NUREGs, NUREG/CRs, and technical reports (TRs) prepared for the NRC by contractors. Table II (see top of next page) lists the documents in each category. These documents were reviewed to determine if their content should result in a modification of 0711.

4 RESULTS

Based on the user comments and our analysis of the technical basis documents, NUREG-0711 was revised. Some of the key technical revisions included in Revision 3 include:

- The Function Analysis and Allocation element has been revised to better address more modern implementations of automation.
- Task Analysis has been revised to more precisely define the scope of the analyses as well as to more clearly identify the aspects of human performance to be addressed in the task analysis.
- The Human Reliability Analysis element was expanded to address important human actions that are deterministically identified, as well as those that have been identified using risk analysis. Deterministic engineering analyses typically are completed as part of the suite of analyses in the FSAR/DCD in Chapters 7, Instrumentation & Control, and 15, Accident Analyses. These deterministic analyses often credit human actions. In light of this expanded scope, the element was renamed “Treatment of Important Human Actions.”

Table II. Technical Basis Documents Potentially Impacting NUREG-0711

Type	Title
SRP	Human Factors Engineering – SRP Ch 18 (NRC, 2007a)
	Guidance for Evaluating Minimum Inventory of Alarm, Controls, and Displays for New Light-Water Reactor Plant Designs – SRP Ch. 18, BTP 18-1 (NRC, 2009a)
	Crediting Manual Operator Actions in Diversity and Defense-In-Depth (D3) Analyses - SRP, Ch. 18, Appendix 18-A (NRC, 2009b)
	Guidance for Evaluation Of Diversity and Defense-In-Depth in Digital Computer-Based I&C Systems (Branch Technical Position 7-19, Rev. 5) (NRC, 2007b)
RGs	Combined License Applications for Nuclear Power Plants - RG 1.206, Rev 0 (NRC, 2007c)
	Criteria for Accident Monitoring Instrumentation For NPPs - RG 1.97, Rev 4 - (NRC, 2006)
	Manual Initiation of Protective Actions - Regulatory Guide 1.62, Rev 1 (NRC, 2010)
ISG	Highly-Integrated Control Rooms: Communications Issues - DI&C-ISG-04, Rev 1 - (NRC, 2009c)
	Highly-Integrated Control Rooms: Human Factors Issues - DI&C-ISG-05 Rev1 - (NRC, 2008)
NUREG	Guidance for Assessing Exemption Requests from the NPP Licensed Operator Staffing Requirements Specified in 10 CFR 50.54 - NUREG-1791 (Persensky, et. al, 2005)
	Guidance for the Review of Changes to Human Actions - NUREG-1764 (Higgins et al. (2007)
NUREG/ CRs and TRs	The Effects of Degraded Digital I&C Systems on HSIs and Operator Performance - BNL Tech Report No. 91047-2010 (O'Hara et al., 2010)
	Human-System Interfaces to Automatic Systems: Review Guidance and Technical Basis - BNL Technical Report 91017-2010 (O'Hara & Higgins, 2010)
	Applying Human Performance Models to Designing and Evaluating NPPs: Review Guidance and Technical Basis - BNL Technical Report BNL-90676-2009 (O'Hara, 2009)
	Technical Basis For Regulatory Guidance For Assessing Exemption Requests From NPP Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m) - NUREG/CR-6838 (Plott et al., 2004).

- The Human-System Interface element has been revised to include specific guidance for the review of the detailed design and integration of the main control room, technical support center, emergency operations facility, remote shutdown facility, and local control stations.
- The Verification and Validation element was revised to simplify and streamline the guidance on scenario development, performance measurement, and human engineering discrepancy evaluation.
- The OER predecessor system review guidance and the critical safety function criteria were updated to address small modular reactors (SMRs).

We made other changes to facilitate the use of the guidelines by reviewers, including:

- providing additional information to explain some of the criteria and more clearly separating explanatory information from the review criteria
- providing more precise information on applicant products and submittals
- rewriting the document for compliance to "Plain Language" principles

In Revision 2, some of the review criteria included information that was intended to provide explanations related to the criteria. However, this was sometimes confusing because that information was not meant to be part of the criterion itself. This information was removed from the criterion and placed in "Additional Information" sections below the criterion. As part of the revision, additional information was added where the guidance needed further explanation or to give examples to support the reviewers' understanding of the guideline's meaning.

NUREG-0711 reviews typically focus on applicant submittals in the form of implementation plans and results summary reports. These two types of reports are more precisely defined in Revision 3 and the

"Applicant Products and Submittals" section of each review element were expanded to include the expected contents of the results summary reports that are the product of the applicant's activities.

In addition, the document was revised in accordance with the NRC's guidance on the use of "Plain Language" in its publications (NRC, 2009b). Some of the principles of Plain Language are to use reader-oriented writing that is based on natural expression, e.g., to write as you speak using common words. Thus, for example, active rather that passive voice is used. The NRC has adopted Plain Language principles as part of the overall U.S. Government initiative to foster its use and make government communications easier to understand.[1]

5 DISCUSSION

Like other consensus and government S&Gs, the NRC is updating its HFE review guidance. The update will enable the guidance to stay current with recent research on human performance, advances in HFE methods and tools, and new technology being employed in plant modernization efforts and in new control room designs. In addition, the updates will reflect user needs and lessons learned from guidance usage.

NUREG-0711, Revision 3 is the first step in the HFE guidance update process. As noted earlier, the full update of NUREG-0711 is occurring in two phases. The next revision, tentatively scheduled for 2013, will incorporate the results from current, ongoing research. Revision 4 will be based on a broader spectrum of technical information. While our plans for Revision 4 are not yet firm, some of the topics we are currently planning to address include:

- *Small Modular Reactors* - Recent research on the HFE aspects has identified several unique human performance issues that need to be addressed in safety reviews (O'Hara et al., 2012). This research will support the development of Revision 4. As noted above, some changes were made in Revision 3 based on this SMR research. Revision 4 will address unique SMR issues more completely.
- *Integrated System Validation* - Evaluating the integrated HSI to ensure it meets performance requirements is important to determining the safety of the design. Methods for performance-based evaluation and ISV are available in NUREG-0711, Revision 3. However, additional guidance is needed to improve those methods. Some selected specific questions are:
    - Are there alternative ISV models (e.g. stepwise or equivalence models)?
    - How should representative samples of operators be obtained?
    - How should performance and productivity measures be prioritized?
    - What is the relationship of performance measures to safety?
    - How should SME observations be incorporated into the analysis?
    - How should acceptance criteria be established and used?
    - Can PRA and HRA be used to a greater extent to inform acceptance criteria?

  ISV is especially important for advanced reactors, since these designs may involve more complex monitoring demands on operators that include: multiple reactors, more extensive automation, intelligent agents, software-based support systems, etc. In short, computer-based HSIs will incorporate more capabilities and functions than conventional designs. Further, evaluations based on measured performance criteria are an important component in achieving design review methods that

[1] Current information about the U.S. Government's Plain Language initiative can be found at: http://www.plainlanguage.gov; retrieved January 12, 2012.

are neutral with respect to specific technologies. Guidance is needed to establish NRC review procedures for independently assessing performance-based evaluations and ISV.

- *Cognitive Task Analysis* - Digital technology has changed plant I&C systems to provide much more information processing and automation than was previously possible. The operator's role is increasingly moving to that of a supervisory controller who oversees plant automation, intelligent agents and operator support systems. This shift has led to an increased emphasis on analyzing cognitive tasks such as detection, situation assessment and decision making. As a result a new suite of cognitive task analysis and cognitive engineering methodologies has emerged. However, there is no clear guidance to reviewers for determining what specific methods are appropriate for the analysis of particular NPP personnel tasks. Additional guidance will be developed for Revision 4.
- *Degraded I&C* - HFE-significant I&C degradations are defined as the failure modes and degraded conditions of the I&C system that potentially might affect HSIs used by personnel in carrying out risk-important tasks. Several methods have been developed for identifying such degradations, including human reliability analysis (HRA), failure mode and effects analysis (FMEA), confusion matrix analysis and misdiagnosis tree analysis. Guidance is needed to evaluate these methodologies and to undertake comparisons to highlight the strengths and weakness of each approach in the context of NPP design.
- *Human Performance Modeling* - Human performance models (HPMs) are simulations of human behavior with which we can predict human performance. They are (1) mathematical, programmable, and executable; and (2) applied in the engineering design and evaluation of complex systems. Designers use them to support their HFE programs for a wide range of complex systems, including commercial nuclear power plants. The NRC needs to assure that HPMs are verified and validated, and their usage is consistent with their intended purpose. Using HPMs improperly may generate misleading or incorrect information, entailing safety concerns. In earlier research, we developed preliminary review guidance to evaluate an applicant's use of HPMs (O'Hara, 2009). This guidance needs to be further evaluated and incorporated into NUREG-0711.
- *Treatment of Important Manual Actions* - Important manual actions are currently addressed in three documents (RG 1.62, BTP 7-19, and this Appendix 18-A of the SRP), but there are inconsistencies between them. While we think that the modification made to NUREG-0711, Section 7, Treatment of Important Human Actions will help minimize these inconsistencies, additional work will help to ensure that one consistent approach to important manual actions is used by the NRC.

In addition to updating the content of NRC guidance, the usability of the documents will also be improved. The usability of HFE S&Gs has frequently been questioned (e.g., Ahlstrom, 2008), thus usability improvements are identified for the DoD, FAA, and NASA standards updates mentioned earlier. The same is true for our guidance. Usability improvements will be approached in two ways. First, we will develop a "primer' or handbook to provide guidance rationale, regulatory bases, technical bases, tutorial information, and examples, principally for the criteria referenced in NUREG-0711. Second, we will develop electronic tools to help users identify applicable guidance that's needed to conduct reviews and prepare safety evaluation reports. The electronic tools also will provide ready access to the technical basis reports.

In addition to the updates of NUREG-0711, other NRC HFE review guidance will be updated as well. NUREG-0700 (O'Hara et al., 2004) will be updated to incorporate the HSI considerations contained in the automation and degraded conditions documents cited above. We will also be updating old guidance and annexing or removing guidelines that are dated and no longer applicable. This further update is scheduled to be completed in 2013.

Chapter 18 of NUREG-0800 will be updated to make it consistent with changes to the other documents and to address advances in the NRC's licensing procedures. The revision to Chapter 18 of the Standard Review Plan is presently scheduled for publication toward the end of 2013.

The updated guidance will facilitate the NRC's safety review of the HFE aspects of NPPs to ensure that they reflect state-of-the-art principles in order to meet the challenges of new and modernized plants. We acknowledge that, even with up-to-date guidance, there are sometimes HFE methods or HSI technologies that are not specifically addressed by the guidance. The NRC's safety review methodology accommodates such innovations using a diversity of evaluation approaches (O'Hara & Higgins, 2004).

Our new guidance documents should also contribute to the broader community of HFE S&G users. In the past, criteria within our guidance documents have been incorporated into national NPP standards (e.g., IEEE, 1998), international control room design standards (e.g., ISO, 2000), as well as other government standards (e.g., FAA, 2003). We believe the new updates will similarly provide guidelines for topics of interest to HFE practitioners, such as HSIs for automation, computer-based procedure systems, and soft controls. While there are some unique aspects to NPP HFE guidance, most of the guidelines are generally applicable, or easily adapted, to other industrial systems.

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