

DEVELOPMENT OF NUREG-0700, REV 3

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The U.S. Nuclear Regulatory Commission (NRC) evaluates the human factors engineering (HFE) of nuclear power plant design and operations to protect public health and safety. The HFE safety reviews encompass both the design process and its products. Detailed guidance for these reviews is provided in two key documents: the *HFE Program Review Model* (NUREG-0711) and the *Human-System Interface Design Review Guidelines* (NUREG-0700). The NRC is committed to the periodic update and improvement of the guidance to ensure that they remain state-of-the-art design evaluation tools. In this paper, we will describe the updates made to NUREG-0700 that resulted in Revision 3 of the guidance.

Key Words: control rooms, human factors, regulatory review

1 INTRODUCTION

Human factors engineering (HFE) standards and guidelines (S&Gs) documents play an important role in the design and evaluation of complex systems [1]. Both consensus and government S&Gs are periodically updated. This paper describes the update of guidance used by the U.S. Nuclear Regulatory Commission (NRC) to perform safety reviews of the HFE aspects of nuclear power plant (NPP) designs.

The NRC's HFE staff evaluate the HFE programs of applicants for construction permits, operating licenses, standard design certifications, combined licenses, and amendments to licenses. The safety reviews help to ensure public health and safety. HFE is an important aspect of the review and helps to ensure that personnel performance and reliability are appropriately supported. The reviews encompass both the design process, such as the use of task analysis, and its products, such as the design of the main control room. High-level review guidance is described in the Standard Review Plan, specifically Chapter 18, Human Factors Engineering [2]. Detailed review criteria are contained in the *HFE Program Review Model* (NUREG-0711; [3]) and the *Human System Interface Design Review Guidelines* (NUREG-0700; [4]), addressing process and product respectively.

As new plants are designed, new human performance challenges and issues arise. Further, human system interface (HSI) technology continues to evolve, as do the methods and tools HFE practitioners use to analyze, test, and evaluate their designs. Thus, it is essential that the NRC periodically update its HFE review guidance to keep pace with industry advances and to ensure its guidance remains consistent with the state-of-the art. At the *9th International Conference on Nuclear Plant Instrumentation, Control & Human-Machine Interface Technologies* meeting in 2015, we described the objectives of the update program, the guidance development methodology, and an overview of the topics being addressed [5]. In this paper, we will describe the updates made to NUREG-0700 that have been completed and resulted in Revision 3 of the guidance [6].

2 NUREG-0700 DESCRIPTION

NUREG-0700 is used to review the detailed design of the main control room and other HSIs in the plant. The evaluation is performed to verify that the HSIs are designed to accommodate human capabilities and limitations as reflected in HFE guidelines. The review criteria address the physical and functional characteristics of the HSIs. The topics currently addressed in Revision 2 are shown in Figure 1. Also shown is the organizational structure for Revision 3. The updated sections are highlighted.

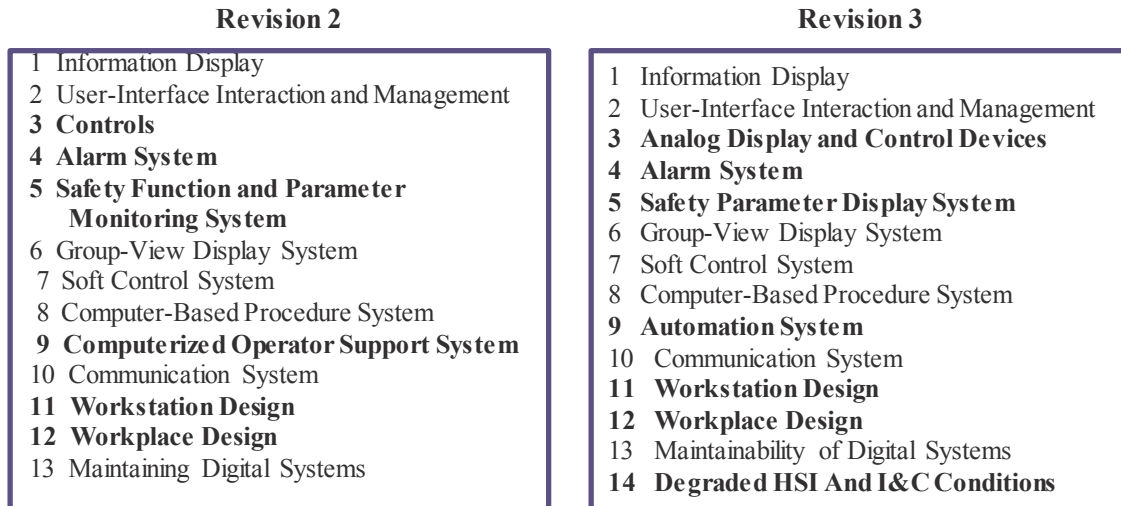


Figure 1. NUREG-0700, Revisions 2 and 3 organizational structures

Each section has a topic characterization and review guidance. The characterization describes the key functions and characteristics of the aspect of the HSI being described. Characterizations are developed by examining existing and emerging systems, as well as the research on the effects of the system on human performance. For example, the characterization of alarm systems includes:

- High-Level Alarm Functions
- Information Display, User-System Interaction and Controls
- Reliability, Test, Maintenance, and Failure Indication
- Alarm Response Procedures
- Control-Display Integration and Layout
- Integration with Other HSI Elements

The review guidelines in each section are presented in a standard format (see Figure 2) that includes:

- *Guideline Number* - Within sections, individual guidelines are numbered consecutively from 1 to n.
- *Guideline Title* - Each guideline has a brief unique title.
- *Review Criterion* - Each guideline contains a concise statement of the characteristic/function the HSI should embody.
- *Additional Information* - The additional information provides clarifications, examples, exceptions, details regarding measurement, figures, or tables. This information supports the reviewer's interpretation or application of the guideline.
- *Source* - A numerical reference to the technical basis document is provided at the end of each guideline. In Figure 2, the reference "67653" is to the technical report providing the guideline [7].

8.1.2-1 Overall Representation of an Automation System

The HSI should accurately represent automation, related instrumentation and controls, and the plant equipment being controlled (e.g., pumps and valves).

Additional Information: Providing a representation of the automation and the aspects of the plant with which it interfaces helps operators to understand automation's effects. For example, if automation is maintaining a level in a tank that has a leak, so long as automation can pump water in, the level is achieved and operators may not know there is a problem. When the level can no longer be maintained, operators need to quickly determine whether the failure is in the automation or the controlled system. Offering an overall representation of both automation and its plant interfaces helps operators assess this situation. 67653

Figure 2. Example of a NUREG-0700 review guideline.

3 REVIEW GUIDANCE UPDATES

NUREG-0700 hasn't been updated since 2002, so most of its sections are being revised. The updates are being conducted in a phased approach using the NRC's general HFE guidance development methodology [8]. To technically guide the update, we developed a revision plan [9]. Revision 3 is the result of the first phase of the update, which addressed the highlighted sections in Figure 1. The other sections of NUREG-0700 will be updated in a future revision. The updates to Rev. 3 are summarized below.

3.1 Section 3 - Controls

This section now contains the review guidance for all analog HSIs. The guidance for analog HSI from other sections into Section 3 has been moved to this section. Guidance pertaining to computer-based HSIs that was in Section 3 was relocated to other sections. The section was renamed "Analog Control and Display Devices" to better reflect its content.

3.2 Section 4 - Alarm System

This section was updated to address new alarm system capabilities, such as:

- alarms integrated into non-alarm displays, such as mimic diagrams, computer-based procedures, and soft control displays
- routing alarms to the appropriate personnel to help reduce the number of alarms that operators must deal with, e.g., digital instrumentation and control (I&C) systems can significantly increase the number of alarms; however, not all of these alarms should be sent to control room operators, such as those used by maintenance personnel

3.3 Section 5 – Safety Function and Parameter Monitoring System

We changed the Section title to "Safety Parameter Display System" (SPDS) since this is the name used in the regulations, thus applicants still use this term. The main focus of the update to this section was (1) to integrate all available HFE review information contained in various NRC documents to ensure consistency, and (2) to accommodate non-light water reactor (LWR) plant designs. Regarding the latter, modifications were made to ensure that all the guidance is technology neutral. LWR-specific information is only used as examples. We also added a table (Table 5.1) to provide examples of safety functions and associated parameters for high-temperature, gas-cooled reactors and liquid metal reactors in addition to LWRs. The table is intended to provide examples that illustrate the safety functions and parameters for the designs identified.

3.4 Section 9 – Computerized Operator Support System

Computerized operator support systems (COSSs) are operator aids that support situation analysis and decision making. COSSs are "knowledge-based" aids that provide assessments of plant conditions and typically do not involve controls. This section has undergone a major update to extend its application beyond COSSs to human-automation interaction in general. The new section includes COSSs, but also

provides review guidance for other aspects of human-automation interaction such as monitoring displays, automation modes, levels of automation, adaptive automation, and interaction with automation. The guidance included in this section is the result of an NRC research on human-automation interaction [7, 10]. The expansion of this section from COSSs to automation systems in general led to a change in the section title to “Automation Systems.”

In addition to design review guidance, the research also identified a number of design process implications. These are included in NUREG-0700, Appendix B, Design Process Guidelines (see the description below).

3.5 Section 11 – Workstation Design

Significant updating of this section was needed to address computer-based workstations. New NPP control rooms have primarily computer-based workstations that operators sit at to perform their tasks. The workstations often contain selected analog HSIs for controlling emergency safety functions and to back up other key functions. NUREG-0700 was updated to provide guidance for these types of workstations. This resulted in an extensive revision and reorganization of Section 11. Several key documents were used to support the update [11, 12, 13, 14, 15]. A summary of the key changes to the workstation design review guidance is provided below.

Section 11.1, General Workstation Guidelines - This is a new section addressing configuration, posture support, and user safety.

Section 11.2, Workstations Containing Primarily Analog HSIs - This section has been significantly updated and reorganized to address *Sections 11.1, Workstation Configuration; 11.2, Control and Display Device Layout; and 11.4, Panel Layout.*

Section 11.3, Workstations Containing Primarily Computer-Based HSIs - This section is new and addresses workstations that contain computer-based HSIs, such as keyboards, mice, and flat screen monitors. Typically operators sit at computer-based workstations. While Section 11.2 on analog workstations addressed HSI grouping and layout, as control-display relationships, this section does not. The review guidance for the design of the information content of visual display devices is contained in Section 1 of NUREG-0700. The present section is divided into five subsections: visual display devices, computer input devices, hand-held devices, desktops and work surfaces, and workstation support devices.

Section 11.3.1, Visual Display Devices - This new section replaces Section 1.6.1, Video Display Units, from Rev. 2. and addresses visual display device considerations such as the number of monitors included at a workstation, the relationship between users and the devices (e.g., viewing angles and distances), the lighting environment (e.g., reflections and glare), and the parameters used to measure display screen performance (e.g., screen spatial properties, temporal properties, luminance, and colors).

Section 11.3.2, Computer Input Devices - This section replaces Section 3.2, Input Devices (Computer input devices), from Rev. 2. Computer input devices are the means by which operators enter information into a computer system. They can include keyboards as well as pointing devices such as a mouse, trackball, and touchscreen. This section provides guidelines for the review of the design of these devices. General input device review guidelines are presented first and address characteristics such as device stability for use, handedness, and feedback for user inputs to the device. Then guidance for the review of keyboard design is presented. These guidelines address characteristics such as keyboard layout, dimensions, and orientation with respect to the user. The guidance also addresses keyboard key characteristics. Finally, guidance for the review of pointing devices is provided. An important consideration for these devices is ensuring the appropriate device is used based on task demands.

Section 11.3.3, Hand-Held Devices - This section is new and addresses the usability and task appropriateness of such devices, as well as, the accommodations that need to be made when information and controls are provided on such small display screens and devices.

Section 11.3.4, Desktops and Work Surfaces - This section is an update of Rev 2 Section 11.1.5, Desk Dimensions. Many of the guidelines have been updated and new guidance added.

Section 11.3.5, Workstation Support Devices - This section is new and provides review guidance for devices used at workstations to support displays, input devices, and documents. Depending on the device being supported, the characteristics differ slightly, but often include adjustability, surface height, and tilt angle. Guidance is also provided for the review of the support of the user's wrist, palm and forearm.

Section 11.5, Chairs and Footrests - All guidelines in the Rev 2 Section 11.1.6, Chairs, were deleted and replaced with the new guidelines.

In addition to the updates summarized above, many of the workstation measurements were updated to reflect changes in population anthropometrics.

3.6 Section 12 - Workplace Design

Similar to the workstation guidance, the workplace guidance needed significant updating to address computer-based control rooms. Modern control rooms consist of one or more computer-based workstations and large group-view displays that can be seen by the entire crew. We updated the review guidance to address the design and layout of this type of control room. In addition, we updated the guidance on lighting and environmental factors. Several key documents were used to support the update [16, 17, 18, 19]. A summary of the key changes to the workplace design review guidance is provided below.

Section 12.1, Control Rooms

Section 12.1.1.1, Architectural Features - This is a new section that addresses architectural features of the control room including its shape, entrances and exits, and windows.

Section 12.1.1.3, Group-View Display (GVD) Devices - This section consists of guidelines from Section 6.3, Group-View Display Devices, and Section 1.6.2, Projectors. Some new guidelines have been added.

Section 12.1.1.5, Emergency Equipment – This section has been divided into three subsections to clarify the context of individual guidelines: *12.1.1.5.1, Personnel Protective Equipment*; *12.1.1.5.2, Radiation and Rescue Equipment*; and *12.1.1.5.3, Emergency Equipment Storage*.

Section 12.1.1.7, Visitor Viewing Areas and Security - This is a new section that addresses the protection of confidential information from being observed from visitor areas.

Section 12.1.1.9, Maintenance - This is a new section that addresses the control and accommodation of maintenance activities in the control room.

Section 12.1.2, Control Room Environment - Guidance in this section has been updated and expanded with new guidance addressing temperature and humidity, ventilation and air quality, illumination, emergency lighting, and the auditory environment.

Section 12.2, Local Control Stations

Section 12.2.1.2, Information Display:

- *Sections 12.2.1.2.1, Gauges/Meters*, and *12.2.1.2.2, CRT Displays* were deleted because they repeat guidance contained elsewhere.
- The guidance in *Section 12.2.1.2.3, Valve Position Indication*, was moved to Section 3.

Section 12.2.1.3, Controls – Guidance in this section was either deleted because it repeats guidance already available elsewhere, was integrated with guidance in Section 3 or was moved to Section 3.

Sections 12.2.2.4, Auditory Environment, *12.2.2.5, Accessibility*, and *12.2.2.6, Vibration* were updated and expanded with new guidance.

Seventeen review guidelines were removed from Rev 3 because they did not address HSI design. Instead, they address topics now reviewed in NUREG-0711, such as task analysis, or they pertain to operational considerations, such as administrative procedures and operator training.

3.7 New Section 14 – Degraded HSI and I&C Conditions

Integrated digital I&C systems in new reactors will support operators in monitoring and controlling the plants. Even though digital systems typically are highly reliable, they can degrade or fail, which can significantly affect the operators' performance and plant safety. We included a new section containing guidance for reviewing the operator's ability to detect and manage degraded HSI and digital I&C conditions, such as the degradation of sensors that can complicate the operators' interpretation of displays by misleading them into thinking that a process disturbance has occurred. The guidance is organized into sections addressing: HSIs for monitoring I&C system conditions, HSI response to I&C system changes, information source and quality, and backup of HSI and I&C failures. The guidance included in this section is the result of an NRC research project on the effects of degraded digital instrumentation and control systems on human-system interfaces and operator performance [20, 21].

Most of the existing NUREG-0700 guidance on this topic that was contained in other sections was integrated into the new section. This was done to enhance the visibility of this important topic and to help ensure that it is addressed in all aspects of HSI review. In addition to design review guidance, the research also identified a number of design process implications. These are included in NUREG-0700, Appendix B, Design Process Guidelines (see the description below).

3.8 Appendix B - Design Process Guidelines

Appendix B of NUREG-0700 contains guidance for selected HSI topics that address important considerations in the design of those topics. The guidelines in the main sections of NUREG-0700 address the physical and functional characteristics of HSIs and not the unique design process considerations that may be important. However, in the development of guidelines, we often identify aspects of the design process or training that may be important to consider. Since such considerations are not within the scope of the main design review guidelines, they are contained in Appendix B. We note that while NUREG-0711 addresses an applicant's HFE program and their design process, the review is at a more programmatic level and does not address design considerations for specific HSI technologies. Thus, NUREG-0700, Appendix B fills this gap by identifying important design process considerations that are specific to particular HSI technologies. The considerations contained in Appendix B can be addressed by NRC reviewers on a case-by-case basis during specific reviews.

Two new sections were added to Appendix B. *Section B.4, Review Guidelines for the Automation System Design Process*, is organized according to design process topics such as operating experience review and function allocation, similar to NUREG-0711. Within these topics, considerations address the high-level goals of automation design, automation design characteristics, HSI design, training for automation use and degradation, and test and evaluation.

Section B.5, Review Guidance for Degraded HSI and I&C Conditions Design Process, is similarly organized using NUREG-0711 topics. Within these topics, considerations are presented pertaining to understanding the systems failure modes and their effects on human performance, task requirements for managing HFE-significant HSI and I&C degradations, and identifying which degradations impact important human actions.

4 DISCUSSION

The updated review guidance in NUREG-0700, Rev 3 will help keep it current with recent research on human performance, advances in HFE methods and tools, and new technology being employed in NPP designs.

In Phase 2, we plan to address the following guidance needs through revisions of existing sections:

- *Alarm Systems* – While some updates to the alarm review guidance were accomplished in Phase 1, a larger research issue pertains to the avalanche of alarms that comes from a major process disturbance which can easily overwhelm operators making the alarm system less effective. This issue will be addressed in Phase 2.
- *Group View Displays* – These are large displays in a control room that can be viewed by the entire crew. We plan to address the *functionality* of these displays, e.g., how they should be used and what types of information should be displayed.
- *Soft Controls* – These are screen-based controls, e.g., controls integrated into process displays or computer-based procedures. Guidance on the range of ways that soft control functions can be implemented will be addressed in Phase 2.
- *Computer-Based Procedure Systems* – These systems have added functionality, such as increased automation, that is not addressed in the existing guidance in NUREG-0700. This increased capability and the integration of procedures with other plant alarm and information systems will be addressed in Phase 2.

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