EPRI

Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms: Scoping and Planning Study

Technical Report

Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms: Scoping and Planning Study

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REPORT SUMMARY

This report contains results of a scoping and planning study to determine the need for and characteristics of a *Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms* document. The study was initiated because of the perceived need to have human factors guidance available to aid in specifying and designing modern digital instrumentation and control (I&C) components and systems. Equally important was to aid utilities and vendors in incorporating these components and systems into nuclear power plant control rooms.

Background

Nuclear power plant control rooms are being upgraded and modernized with digital I&C components and systems, due in part to the unavailability of replacements for failed and obsolete analog units. More widespread use of digital technology is expected as plants age and as additional plants receive license renewals. The U.S. Nuclear Regulatory Commission (NRC) staff and others have identified human-system interface (HSI) problems caused by digital upgrades that have already been installed in control rooms. No one set of existing guidance documents, including government-sponsored and international standards, was found to completely satisfy utility needs for human factors guidance. Although useful guidance may be found, it is necessary to search and evaluate many different sources. These include research reports; NRC NUREGs and NUREG/CRs; guidelines and standards created by EPRI, U.S. Department of Defense (DoD), and international and U.S. standards organizations; and, software company display design guidelines. Applying human factors guidance to digital I&C system design and integrating them into control rooms can reduce human errors and inefficiencies, resulting in improved plant safety, availability, reliability, and efficiency.

Objectives

To perform a scoping and planning study regarding the need for—and content, organization, format, and development of—a *Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms* document; to identify sources of information and examples of entries for possible incorporation into the document; and, to prepare a plan to develop a guidance document.

Approach

The project researcher reviewed relevant documents, including existing human factors standards and guidelines. He collected information during visits to three nuclear power plants and one I&C system vendor and from a second vendor by telephone. Discussions were held with (1) a National Laboratory manager responsible for many human factors projects that resulted in NUREG/CRs, (2) NRC and EPRI personnel involved in I&C activities, (3) DoD personnel and consultants involved in military human factors standards and guidance documents, and (4) Halden Reactor Project (HRP) personnel regarding applicable research efforts. Based on the

reviews and discussions, the researcher made an assessment of the need for a *Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms* document. A plan was then created to develop such a guidance document. To support document development, the researcher prepared sources of information, content, organization, format, and examples of guideline entries.

Results

Study results indicate that a need exists for developing a document providing human factors guidance for specifying and designing digital I&C components and systems and for incorporating them into hybrid control rooms. Utilities and vendors will apply the guidance. This guidance will facilitate installation, operations, maintenance, training, and procedure activities with upgrades and modernized control rooms based on modern digital technology. Development of the guidance document will occur under a future project. Three development tasks are recommended: (1) refine the need for and description of the guidance document, (2) develop, test, and publish the guidance document, and (3) develop supporting materials (for example, training programs for the document and plans for document maintenance and updating).

EPRI Perspective

Digital I&C technology provides the opportunity to make available information not possible with analog systems as well as to address equipment obsolescence concerns. Data processing techniques and the flexibility of computer-based information presentation offer the ability to present information in ways that are much better suited to personnel tasks and information processing needs. It is important that consideration be given to current human factors knowledge and guidance if the power and potential of digital technology is to be realized. Careful design of HSIs using digital technology and their integration into control rooms can provide I&C capabilities permitting personnel to accomplish their roles effectively in such tasks as process and equipment monitoring, fault detection and diagnosis, situation assessment, response planning, and response execution. Results can be reduced human errors and inefficiencies and, thus, enhanced plant safety, availability, reliability, and efficiency. The study recognized that a need exists to develop human factors guidance to aid in specifying and designing I&C components and systems and also to aid in incorporating these components and systems into control rooms. Rather than immediately launching a project to develop such guidelines, it was decided to first perform a study to define the scope of and develop a plan for developing a guidance document. The results of this study are presented in this report.

Keywords

Instrumentation and control systems
Digital systems
Human factors
Hybrid control room
Human performance
Control rooms

ABSTRACT

This report contains the results of a scoping and planning study to determine the need for and characteristics of a *Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms* document. It is concluded that a need exists to develop a document to provide Human Factors guidance for specifying and designing digital I&C components and systems, and their incorporation into hybrid control rooms. A plan is presented to develop such a guidance document. Sources of information, content, organization, format, and examples of guideline entries are provided to support document development.

CONTENTS

ACRONYMS

BNL	Brookhaven National Laboratory
DoD	Department of Defense
DOE	Department of Energy
GDC	General Design Criteria
GUI	Graphical User Interface
HCI	Human-Computer Interface
HRA	Human Reliability Analysis
HRP	Halden Reactor Project
HF	Human Factors
HFE	Human Factors Engineering
HSI	Human-System Interface
IAG	Industry Advisory Group
I&C	Instrumentation and Control
ISO	International Standards Organization
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
NUMARC	Nuclear Management and Resources Council
SER	Safety Evaluation Report
SC	Steering Committee
SRP	Standard Review Plan
USQ	Unresolved Safety Question
V&V	Verification and Validation

1
INTRODUCTION

Nuclear power plants rely on instrumentation and control (I&C) systems for control, monitoring, and protection. Many I&C systems are of analog design, and contain components that are or soon will be obsolete. In many instances, analog replacements are no longer available. Nuclear power plants are finding it necessary to procure digital-based designs as a result. In fact, many plants already have retrofitted some components with modern digital designs, ranging from one-for-one replacements (e.g., displays and recorders) to some large-scale, microprocessor-based systems (e.g., reactor protection systems). Control room modernization involving the move from analog to digital technology is expected to accelerate as plants age and as more plants receive license renewals. The term *hybrid* is used to describe control rooms containing mixed analog and digital technology.

It is important that consideration be given to current human factors (HF) knowledge and guidance in the design, use, and maintenance of digital I&C systems if the power and potential of this technology is to be realized. Careful design of human-system interfaces (HSIs) utilizing digital technology, and integration of these interfaces into control rooms, can provide I&C capabilities permitting personnel to accomplish their roles effectively in such tasks as process and equipment monitoring, fault detection and diagnosis, situation assessment, response planning, and response execution. The results can be reduced human errors and inefficiencies, and thus enhanced plant safety, availability, reliability, and efficiency. Conversely, ignoring or inappropriate application of state-of-the-art HF guidance may result in higher levels of human errors and inefficiencies.

Digital I&C technology provides the opportunity to make available information not possible with analog systems. Improved instrumentation and signal validation techniques can ensure that information is more accurate, precise, and reliable. Data processing techniques and the flexibility of computer-based information presentation offer designers with the ability to present information in ways that are much better suited to personnel tasks and information processing needs. Thus, the problem of operator “data overload” may be reduced in situations in which the plant state is changing rapidly. Data overload may impose a high mental (information processing) requirement to find and acquire the relevant data, interpret these data correctly, and decide on the appropriate course of action. HF guidance is needed to support design and use of the data processing and display systems to minimize the data overload problem. The result may be that the crew is able to respond more quickly and in a correct manner to prevent or minimize the consequences of the undesirable condition.

Digital technology offers the opportunity to automate some of the tasks currently performed by operators and maintainers. The operator’s role for selected tasks changes from a manual controller to a monitor, supervising one or more computer-based systems. Supervisory control is a term used to describe the operator’s role with automation. Increased use of automation can

eliminate opportunities for the operating crew and others to make errors; they are no longer permitted to take actions. Unless the system is so automated that no human intervention is possible, HF guidance is needed to support design and use of the automation, displays to monitor the automated systems, and control to take actions when required. Without proper HF guidance, the potential exists for the operators and others to develop automation complacency, which may involve loss of familiarity with system status, and loss of situation awareness. Design of the automation system based on "good" HF practices will reduce crew mental workload while still providing awareness of the status and situation, thus freeing the crew to attend to other activities going on within the plant.

An issue related to automation is the role of the operator and operating crew. The newer German and Japanese advanced plant designs tend to provide more automation than earlier designs. In contrast, newer French plant designs typically use computer-based displays to guide plant operators as they move through procedures. The availability of computer-based procedure displays and the capability provided by digital technology to increase the use of automation make definition of the crew role very important. The role definition will have a significant impact on digital upgrade designs, operator tasks, procedures, and training. HF guidance is needed to support decisions regarding operator role.

A major challenge faces utility and vendor I&C system and component designers and engineers, and others attempting to apply current HF knowledge and guidance. Although numerous HF guidelines have been published, the specific guidance needed both to satisfy safety requirements and to achieve high levels of availability, reliability, and efficiency is not readily available. The U.S. Nuclear Regulatory Commission (NRC) has published the best known HF guidance documents in the nuclear power generation industry. These documents are intended for use by NRC regulators in reviewing proposed HSIs and control room upgrades regarding safety issues. These documents, even though very useful, do not provide the additional guidance needed to design and provide cost-effective, integrated HSIs to achieve high levels of availability, reliability, and efficiency. The issues discussed above–role of the operator, increased use of automation, use of data processing to create HSIs that provide information in a form not previously possible—are not handled well by the existing guidance documents. Information is available, however, from which applicable HF guidance can be prepared. It is this kind of guidance that has the potential to improve worker performance by reducing errors and inefficient performance. Such guidance goes well beyond the application of HF guidance to satisfy NRC licensing requirements.

EPRI has recognized the need to develop HF guidance to aid in specifying and designing I&C components and systems, and to aid in incorporating these units into control rooms. Rather than immediately launching a project to develop such guidelines, EPRI has decided to first perform a study to define the scope of and develop a plan for developing a HF guidance document. The results of this study are presented in this report.

Section 2 describes the study objective, basis, and approach. The need for a HF guidance document is reviewed in Section 3. A description of the guidance document is provided in Section 4. Section 5 contains a plan to develop this document. Conclusions are presented in Section 6. Section 7 contains a list of references.

2
STUDY OBJECTIVE, BASIS, AND APPROACH

2.1 Study Objective

The major objective of this effort is to perform a scoping and planning study regarding the need for; and content, format, and development of a *Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms* document.

The following activities were completed to satisfy the objective.

- Determine if a need exists for a HF guidance document.
- Identify guidance document content, organization, and format.
- Identify sources of information for possible incorporation into the document.
- Prepare examples and samples of entries for the guidance document.
- Prepare plan to develop a HF guidance document.

2.2 Study Basis

The EPRI I&C Steering Committee (SC) has noted that several utilities are upgrading and modernizing plant control rooms by incorporating modern digital technology. This process is expected to grow rapidly over the next several years as additional utilities face the need to replace analog with modern digital equipment.

The I&C SC also noted that I&C upgrades and control room modernization efforts offer the opportunity to improve plant efficiency, reliability, and availability through improved human performance, including reduced errors and inefficiencies. Achievement of these improvements requires that state-of-the-art HF knowledge and guidance be applied during I&C system design and control room upgrades. The SC observed, however, that adequate HF guidance is not readily available.

The EPRI Human Performance Technology SC also considered the need for HF guidance in support of I&C upgrades and control room modernization efforts. This SC agreed with the conclusion of the I&C SC that guidance is needed and should be developed.

The I&C SC considered authorizing a project to develop a HF guidance document that would satisfy the industry need. After careful deliberation, the SC decided to proceed with the scoping and planning study described in this report. It was believed that better definition of the guidance document is needed before the full development effort is initiated.

2.3 Study Approach

The study involved collecting information from a variety of sources, reviewing and analyzing the information, and preparing this report containing the results. Information was collected through visits, telephone contacts, and review of relevant literature. Some of the discussions in which information was collected involved:

- I&C engineers and others at three nuclear plants currently involved in control room modifications and upgrades (visits were made to the three plants).
- I&C technical manager and a consultant representing two major vendors of digital I&C systems to nuclear power plants (visit made with one vendor).
- NRC staff member involved in reviewing HF sections of I&C submittals.
- EPRI personnel responsible for I&C activities.
- Manager at a National Laboratory responsible for developing many NRC NUREGs and NUREG/CRs applicable to this study.
- DoD personnel and consultants involved in developing and maintaining military HF standards.
- Department of Energy (DOE) person serving as liaison to an international group developing an ISO ergonomics design of control centers standard.
- Halden Reactor Project (HRP) personnel regarding applicable research efforts.

An extensive amount of literature was obtained and reviewed. The relevant standards, reports, and other material are identified later in this report and listed in the References section. The information that was collected was reviewed and analyzed. The results were used in the preparation of this report.

3
NEED FOR A HF GUIDANCE DOCUMENT

This section of the report discusses the need for developing a HF guidance document for use by utilities and I&C system vendors. The need determination is based primarily on review of experiences with digital upgrades, discussions with plant and vendor personnel, review of NRC requirements, and assessment of available HF guidance, standards and other material.

3.1 Experience with Digital Upgrades

There have been very few published studies in which human performance in nuclear power plant hybrid control rooms has been assessed. Three reports that were found are described below. In addition, it is important to note that other safety-critical industries already make extensive use of digital technology.

NRC Staff Study

The NRC staff conducted a study of five operating reactor events in which digital technology was involved. The following human performance weaknesses were noted in the report (1)[1]:

- Over-reliance on digital instrumentation over other information sources.
- Lack of operator understanding of plant conditions.
- Deficiencies in the HSI design.
- Lack of operator training in all aspects of system operations.
- Deficiencies in normal and abnormal operating procedures.

Lessons Learned by Observing Operators

A limited study of integrating digital HSIs into a conventional nuclear power plant control room has been described (2). An overseas utility is replacing a plant computer system, and in the process decided to upgrade its control room. The advanced HSIs being incorporated into the control room include a graphic-based plant information display system, an advanced alarm system, and a computer-based procedure system. Information on crew performance was obtained by observing crews during full-scope training simulations of plant disturbances. In addition, interviews were conducted with operators and other utility and vendor personnel. It should be noted that data were collected during initial operator training. It is expected that performance and

[1] Numbers in parentheses identify references in list found in Section 7.

interview responses would change somewhat as the crews became more familiar with the hybrid control room.

The general findings were that the new HSIs provided positive support for crew performance, reduced workload, and were well accepted by the crews. The following excerpt from a paragraph on overall impact contained in the Discussion section of the study report summarizes some of the results (2, page 44).

The results show that the computerized HSIs expanded the range of data available to the operators and provided increased power and flexibility. They reduced the workload associated with gathering and integrating plant parameter information needed to work through the emergency response procedures, freeing attentional resources to more broadly monitor plant state. The operators were uniformly positive about the new HSIs and would not want to revert back to the conventional control board, alarm system, and paper-based procedures…. While the general results were positive, the study identified HSI design issues that warrant consideration in the design and evaluation of new HSIs.

European Experiences

A report was published in 1993 (3) describing the results of a questionnaire in which respondents at electric utility power stations and transmission/distribution centers provided information regarding their experiences in introducing new systems to support the HSI (in this study, the term Human-Machine Interface was used rather than HSI). Responses were collected from nine facilities, one in each of nine European countries. The questionnaire collected information about the effectiveness of the new HSI systems with respect to operator and system performance. The study conclusions included the following:

- In control rooms where conventional HSI equipment is still available, operators tend to return to these information sources because of the overview provided and direct access to needed information. More difficulty was reported with hierarchical system-based displays.
- System-based displays sometimes do not provide the information needed during non-routine situations, where there is insufficient time to search for information and controls within a hierarchy of displays and controls.
- Operators need to be aware of the status of automatic sequences at all times, whatever the level of automation. (Although not part of this study, it is important to note that awareness of plant state is also important.)
- Training is required for rapid familiarization with new HSI systems.
- Structured user participation in all phases of the HSI project was shown to be very effective and led to improved user performance and acceptance of HSI systems.

Other Industries

The studies described above identify both good features and problems with digital I&C systems installed in power plants. It is important to recognize that other safety-critical industries already make extensive use of digital technology for operator displays, aids, and control automation (4).

Examples include fossil-fuel power generating plants, process control plants, aerospace and aviation industries, and air traffic control systems. It is generally perceived that digital technology has had a positive benefit to overall system safety and effectiveness (4, pages 62-63). Commercial aircraft are often cited as an example of systems in which incorporation of digital technology in the cockpit is widely believed to have improved safety and system efficiency (5).

3.2 Needs Expressed by Utility and Vendor Personnel

Discussions were held with 22 corporate and nuclear power plant personnel at three utilities, and two representatives from two of the major companies providing digital I&C systems. The responsibilities of those interviewed at utilities and the number of personnel in each category are presented below.

- I&C design and related activities-8
- Systems, electrical and control systems-4
- Human factors-3
- Information technology and software-2
- Maintenance-2
- Procurement-2
- Operations-1

The vendor personnel were both engineers responsible for designing I&C systems and working with potential and current utility customers helping define needs and designs, among many responsibilities.

The comments provided by those interviewed are summarized below. It should be emphasized that the comments may not be representative of the views held by personnel at other utilities or I&C system vendors. The number of utilities visited numbered only three, and only two vendors participated.

Driving Forces for Digital Upgrades and Control Room Modernization

The primary driving force responsible for upgrade and modernization efforts is analog system obsolescence. Several other driving forces were mentioned also.

- Obsolescence: Plants are finding it impossible to obtain analog replacement parts or entire devices from suppliers for certain control room I&C systems. It is necessary for them to make or have made the needed replacements (usually very expensive and time-consuming) or upgrade by purchasing replacements based on digital technology. It is expected that the obsolescence problem will become much more severe as plants age. In addition, as more plants request and receive license renewals, it is expected that the movement to digital technology in control rooms will increase dramatically.

- Improved plant efficiency and availability: Although not a major driving force at this time, several comments were received about the improvement in plant performance expected because of better operator performance attributable to digital technology. It was believed that single unit digital replacements of analog recorders, displays, or controls would not have much impact. It was suggested, however, that this force should become more significant as large parts of the control room are modernized.
- Regulatory pressure: No one suggested that regulators would directly cause plants to upgrade to digital systems. Some suggested that if a plant has problems that regulators believe are caused by aging analog I&C systems, then pressure may be applied to replace those units at fault. The only reasonable replacement may be of digital design.
- Operator and other personnel requests: One person interviewed remarked that control room operators are beginning to request control room upgrades. They see more modern designs in fossil and overseas nuclear power plant control rooms. They ask, "why can't our control rooms be similar?" This force is not significant now, but may become more of an issue as U.S. plants begin to upgrade. It is likely that such upgrades will receive visibility in the industry. It may be somewhat easier for plants with modern control rooms to hire operators, engineers, and software specialists than plants maintaining conventional technology.

Long-Range Upgrade Plan

There was general agreement that a utility needs to develop a long-range HF upgrade and modernization plan very early in the upgrade process. It is unlikely that plants will have the resources or be willing to shut down long enough to perform a complete control room modernization effort at one time. Rather, the process will most likely occur in steps over a five-or-ten year time span. The HF plan should include consideration of the capabilities of the modern digital technology, which capabilities should be selected for application, and how the capabilities will be implemented. Early in an upgrade effort, when an analog device is going to be replaced by a digital device, the unit to be replaced is usually analyzed to determine the features needed in the new unit. Little consideration may be given to additional capabilities possible with the replacement, or the intrinsic differences introduced by the new technology. It should be recognized that even after a major control room modernization effort, a hybrid environment may still exist. A good plan, however, would permit design decisions regarding replaced units to be based on the role of the units in the eventual upgraded control room.

Existing Guidelines

It was reported that the current NRC HF NUREGs (see section 3.3 of this report) are important and useful. The NUREGs are extremely important because they contain guidelines for review of control room designs to determine if safety requirements have been satisfied. The NUREGs, however, do not provide guidance on how to achieve designs that maximize human performance regarding plant efficiency and availability, while also meeting safety requirements. Such design guidance is needed.

Some plants have developed their own HF guidelines. These guidelines were reported to handle present control room designs, but may not be current regarding guidance needed for design of digital I&C systems and hybrid control rooms.

It was reported that many other HF guidelines exist, e.g., DoD and ISO (see section 3.4 of this report). It is difficult for utility people to know which guidance documents are applicable, the quality of each document, etc. Also, the applicability may be difficult to determine since most of these guidance documents were developed and validated (if at all) for non-nuclear applications.

Vendor Involvement

Vendors are currently very much involved with utilities in the control room upgrade process. It is generally believed that vendors should facilitate HF I&C design efforts. Some of the suggestions made by utility personnel include the following:

- Vendors should be encouraged to prepare topical reports on safety-related digital I&C system upgrades and submit them to the NRC for review and issuance of a Safety Evaluation Report (SER). The topical reports would include applicable HF information to satisfy NRC reviewers. The utility would then find it relatively simple to obtain NRC approval for installation of the I&C system. The utility would need only to describe any changes made to the system and the specific installation aspects.
- Utilities should include in procurement documents the requirement for the vendor to have applied appropriate HF guidance during I&C system design and development, and to deliver documentation of this process and the results.
- Vendors should provide information regarding control room operator and maintenance training requirements for the I&C system.
- Vendors should provide information regarding procedure requirements for the I&C system.

Guidance Needed

There was extensive discussion of the HF guidance needed. Some of the issues discussed are listed below.

- A major concern is with replacing an analog device that provides display of certain information (or control capability) in a fixed position and always available with a design in which the information or control capability is not always available immediately. As an example, it was mentioned that there may be a need for some critical alarms to be displayed in a fixed space if the operator is expected to respond quickly. The digital technology will permit a selectable display of information (or soft control on a touch screen) to be made available automatically when the plant is in a certain mode or selected by the operator. Guidance is needed regarding how to make the design decisions regarding replacement functions: are they fixed or selectable?
- Adequate guidance is available in most cases for design of one-for-one digital replacements for analog units, when the replacements have basically the same functionality as the original unit. Use of color, font size, etc., are examples of guidance that is required. In addition, the

guidance available to design Human-Computer Interfaces (HCIs) appears adequate. Applicable guidance may include menu styles, dialog types, windows management, use of graphics, etc.

- Inadequate guidance is available regarding the design of information systems in which the operator must locate the needed information in a reasonably short period of time. One HF specialist participating in the discussions mentioned the "overhead" time required to operate controls to obtain the needed information if it was not already displayed, and the problem of "getting lost in information space."
- Inadequate guidance is available regarding the use of automation, and the design of supervisory displays, controls, training and procedures.
- Some utilities have a task team, including operators, design certain displays. HF guidance needs to be available regarding methods such teams should apply. Also, guidance is needed regarding permitting operators to develop custom displays for their own use as opposed to requiring all operators to use the same displays.
- Guidance is needed regarding the HF process and methods applicable during the design effort. For relatively simple designs, e.g., a one-for-one replacement of an analog unit with a digital unit, what parts of the HF process are applicable? For complex designs in which major sections of the control board are being replaced by digital technology, what parts of the HF process are applicable? The verification and validation (V&V) process was mentioned as another example of where guidance is needed.
- Guidance is needed regarding design, or in some cases, evaluation of digital systems that can have significant impact on human performance. An example is alarm processing designs that help reduce the number of alarms during process disturbances so that operators can attend to those that are most significant. The alarm information can be integrated with other plant information to make the meaning of the alarm more obvious. Another example is computerized procedures that replace hard-copy procedures.
- Several cultural issues were mentioned. It would be useful for guidance to be provided to facilitate operating crew acceptance of control room and procedure changes. In this regard, there may be changes in crew structure, roles of crew members, and their interactions.
- Training and procedure modifications were mentioned as important concerns. Guidance is needed to develop the appropriate training so that operators, and maintenance engineers and technicians can effectively use and maintain the new digital I&C systems. Guidance is also needed to ensure that the procedures have been upgraded properly for the new digital systems, including taking into account the different characteristics as compared with analog systems.
- An assessment needs to be made to determine if the introduction of the new digital technology imposes any new skill requirements at the plant. Of course, training of existing personnel may be adequate in most cases.
- The issue of recertification and requalification of control room operators was discussed. Guidance is needed regarding what changes in the control room will create the need for operator recertification, or if this is a non-issue.

- The HF guidance document should be applicable for acquisition, design and development, test and evaluation, and implementation. It should be designed for utility and vendor use. The expected users include design and systems engineers, HF specialists, and task teams participating in the design effort.
- The guidelines document should be available in several formats. It was suggested that the document should be available in hard copy, on a CD-ROM, in electronic form providing interactive capability, and web-based on the Internet. The guidelines should be updated periodically. Several people mentioned that it would be useful for users to be able to share experiences. Lessons-learned might be made available as plants apply the document.
- A training course was suggested to facilitate use and application of the guidance document.

3.3 NRC Requirements

This section contains a discussion of the process NRC applies to review and license I&C systems, and to review HF and HSI material included in I&C system submittals. The discussion is rather extensive because NRC can play a very important role in digital upgrades and control room modifications.

NRC Licensing of I&C Systems

The National Research Council performed a study at the request of the NRC to examine the use of digital I&C systems in nuclear power plants. The results are presented in a 1997 National Research Council report (4). A section of the report entitled, “Licensing of Instrumentation and Control Systems” (pages 17-18), provides a brief summary of the licensing process. Relevant parts of this section, updated with recent developments, are summarized below.

Licensing of any system for use in a nuclear power plant is governed by formal, documented criteria stated in the General Design Criteria (GDC), Title 10 CFR Part 50, Appendix A (6). The GDC are written for I&C systems at a very general level. Therefore, the NRC provides extensive supplemental guidance. Much of this guidance is summarized in a revised version of Chapter 7 of NUREG-0800, the Standard Review Plan (SRP) (7).

The updated SRP Chapter 7 does not, by itself, establish any new or revised requirements. It incorporates lessons learned from the completed reviews of I&C systems in the advanced light water reactor designs and digital I&C system retrofits of operating reactors. The NRC staff in evaluating future submittals by applicants will use review guidance described in the updated SRP Chapter 7. The SRP guidance may also be applied in the review of topical reports submitted to NRC for safety evaluation, especially reports requesting generic acceptance of systems or components that may be used in I&C systems. For example, systems, components, or operational practices that are being considered for use in multiple plants may be submitted for generic review.

An important aspect of any I&C modifications and replacement of existing equipment is 10 CFR 50.59 (8). The purpose of this regulation is to define the circumstances under which the licensees may, without prior NRC approval, make changes. Since virtually all U.S. nuclear plants

have original analog equipment, 10 CFR 50.59 is of particular interest if the licensee is considering a digital modification or upgrade. If the criteria in 10 CFR 50.59 for making a change without prior regulatory approval are not satisfied, a formal change of the license is needed. In this situation, 10 CFR 50.90 (9) applies. The process to change the license under 10 CFR 50.90 is a more difficult and costly procedure, and requires a longer schedule. Basically, if there is a change in technical specifications, the licensee must seek prior NRC approval via 10 CFR 50.90. If the licensee's analysis shows the presence of an "unreviewed safety question (USQ)" per 10 CFR 50.59, the licensee must seek prior NRC approval via 10 CFR 50.90. If there are no changes in the technical specifications and no USQ is uncovered, the licensee can make the change or upgrade without prior NRC approval via 10 CFR 50.59.

The nuclear power industry has been active in addressing the introduction of digital I&C technology into nuclear power plants. A joint committee of the Nuclear Management and Resources Council (NUMARC) and EPRI has developed guidelines for streamlining licensing of I&C upgrades (10). The NRC has issued a Generic Letter (11) in which it is stated on page 1 that this NUMARC/EPRI Guideline is "…acceptable guidance for determining when an analog-to-digital replacement can be performed without prior NRC approval under the requirements of Section 50.59…."

The NUMARC/EPRI Guideline (10) discussed above contains a diagram showing a typical digital upgrade design, specification, and implementation process. The HF involvement shown in the figure includes the following:

- HSI including all interfaces between the digital system and plant personnel, involving:
  - Operators—alarms, status displays, control interfaces, etc.
  - Maintenance technicians—test and calibration interfaces, diagnostic information displays, data entry terminals for setpoints, etc.
  - Engineering personnel—configuration workstations or terminals, etc.
- Procedures for use by plant personnel, including changes required to existing procedures and any new procedures required to support configuration, operation, and maintenance of the upgraded equipment, including software maintenance and configuration control of software programs and data (e.g., setpoints).
- Training of plant personnel, including the operators, maintainers, and engineers involved in interactions with the digital upgrades.

NRC Review of HF and HSI

It is expected that a submittal to the NRC for approval of a digital upgrade will follow the guidance provided in Chapter 7 of NUREG-0800 (7). It is also expected that this submittal will include appropriate HF information following the guidance in Chapters 13 *Conduct of Operations* (12) and 18 *Human Factors Engineering* (13) of NUREG-0800. The NRC recipient would transmit the submittal to the responsible NRC Branches, with the Chapters 13 and 18 material assigned for review and comment to the Branch responsible for Human Performance.

According to the Technical Rationale section in Chapter 18 of the SRP (13), the NRC regulatory bases for Human Factors Engineering (HFE) review are established in 10 CFR 50.34(g), "Conformance with the Standard Review Plan (SRP)" (14), and 10 CFR 50.34(f), "Additional TMI-Related Requirements" (14). HFE aspects of the HSI are reviewed to verify that it reflects "state-of-the-art human factors principles" as required by 10 CFR 50.34(f)(2)(iii) and that personnel performance is appropriately supported. According to Chapter 18, meeting the requirements presented in the 10 CFR sections cited above provides assurance "…that plant safety will not be compromised by human error or deficiencies in human interfaces with hardware and software" (13, page 18.0-17).

Chapter 18 of the SRP (13) is applicable to both review of existing control room upgrades and new control room designs. The purpose of these reviews is to improve safety by verifying that accepted HFE practices and guidelines are incorporated into the program design. Chapter 18 describes a process for evaluating designs, the design processes, and design reviews submitted by applicants. The Chapter identifies the following 10 areas of review, although all may not be applicable to reviewing an applicant's submittal:

- HFE Program Management
- Operating Experience Review
- Functional Requirements Analysis and Function Allocation
- Task Analysis
- Staffing
- Human Reliability Analysis (HRA)
- Procedure Development
- Training Program Development
- HSI Design
- HF Verification and Validation (V&V)

The Chapter 18 review is coordinated with reviews performed in accordance with several other SRP Chapters:

- Chapter 7— I&C (7).
- Sections of Chapter 13 (12) pertaining to Operating Organization (concerned with specific staffing requirements), Training, and Plant Procedures.
- Chapter 15—Accident Analysis (15), which addresses anticipated operational occurrences and postulated accidents. Information from analyses should be incorporated as input to the HFE design process, including the development of HSI design and test requirements.
- The Chapter 18 HRA should be coordinated with the NRC Branch responsible for Probabilistic Risk Assessment reviews.

In addition to Chapter 18 of the SRP, the NRC has two documents to support the HF review process and to provide criteria for evaluation: NUREG-0700, Revision 1 (16), and NUREG-0711 (17).

NRC HFE review guidance and methodology is provided in NUREG-0700, Revision 1 (16). This NUREG provides guidance to the NRC staff for review of HSI design review submittals. It consists of two major parts. Part 1 describes those aspects of the design review that are important in identifying and resolving human engineering discrepancies. Part 2 provides detailed HFE guidelines that describe the specific review criteria for the assessment of the HSI design implementation. Revision 2 of this NUREG is scheduled for release in 2001.

NUREG-0711 (17) addresses the integration of HFE in the design process. This NUREG provides a HFE Program Review Model as a basis for performing design certification reviews that include design process evaluations. The NRC in its reviews of re-designs and upgrades of current control rooms will use applicable portions of NUREG-0711.

3.4 Existing Human Factors Guidelines

There are many documents available providing HF guidance. Information may be contained in standards, design guides, design criteria, handbooks, guidelines, style guides, books and articles, reports, etc. A few of the recent documents viewed as more relevant to this study are identified and discussed in this section of the report.

NRC Documents

The three NRC NUREGs (Chapters 13 and 18 of NUREG-0800, NUREG-0711, and NUREG-0700, Rev. 1) discussed above are applicable when considering safety issues and NRC reviews. The initial version of NUREG-0700 was applied during reviews of conventional control rooms containing spatially fixed arrangements of displays, controls, alarms, etc. The NRC found it necessary to revise NUREG-0700 and NUREG-0711 as it began to review advanced standardized nuclear power plants under 10 CFR Part 52. The submittals included designs in which computer-based systems were providing selectable displays, displays and controls were being integrated and placed in compact work stations, etc. Adequate HF review guidance was not available.

During the upgrade effort resulting in NUREG-0700, Revision 1, the NRC recognized that “gaps” existed in the guidance that could be included (18). Technical basis information upon which guidelines could be based was not available. Therefore, the NRC is revising this document and plans to issue NUREG-0700 Rev. 2, probably in 2001. This revision is expected to contain new guidance applicable to modern digital technology that is becoming part of control room upgrade and modernization designs submitted for review. The NRC has published five NUREG/CR reports and plans to publish an additional three to provide the basis for revising NUREG-0700, Revision 1. These eight reports address the following topics:

- Advanced Information Systems (18)
- Computer-Based Procedure Systems (19)

- Soft Controls (20)
- Maintainability of Digital Systems (21)
- Human-System Interface and Plant Modernization Process (22)
- Advanced Alarm Systems (23)
- Control Room and Work Place Environment (24)
- Group-View Displays (25)

The eight reports contain review guidance that will probably be included in the NUREG-0700 revision. In addition, important information for designers is contained in the technical basis section of each report.

The Brookhaven National Laboratory (BNL) has been responsible for developing the first drafts of many of the recent NRC HF NUREGs and NUREG/CRs. Obviously, the NRC reviewed, modified, and approved the documents before publication. The BNL human factors manager leading the development of drafts for most of these recent documents has described differences between regulatory review guidance (contained in the NRC NUREGs) and the HF guidance needed by utilities to support digital system upgrades and integration of these systems into hybrid control rooms (26). The following paragraphs summarize his comments.

The NRC guidance consists of HF guidelines and procedures for their use. With respect to guidelines, regulatory documents are checklist-oriented and specified in general terms. The guidelines depict HF principles in discrete units to identify design features that could lead to performance problems. In NUREG-0700, the guidelines are often expressed in easily observable terms, with greater detail provided in supplemental information. The reason is that the guideline serves as a "red flag" to enable a review to be performed quickly to determine if further investigation is warranted. If such a review could be accomplished "at a glance" where a detailed measurement could be taken specifically to determine a characteristic, the "at a glance" version was preferred.

Another issue is that the guidelines are often expressed as envelopes (the range within which some HSI characteristic should be designed) or limits (a minimum or maximum value). For example, a general guideline may state that font size should be at least 18 minutes of arc. This type of generality is necessary for two reasons. First, the guidance needs to be standardized for use across a wide range of design options, e.g., different control room designs by different vendors. Second, the actual size of characters depends on tradeoffs with several other factors, such as the distance users are expected to be from the information and how much information the designer wants on a given screen. If such guidance were to be used without modification, it would be difficult to apply and would not result in the standardization and consistency of a well-engineered design.

Designers, on the other hand, need to use such general guidance to develop more of a detailed level of specification for their specific design. In the design guide, tradeoffs are resolved for a specific design. Using the example above, a design guide might state that the display font is a specific font and size. Guidance in this more concrete form can be more readily used by the design team or to specify the design requirements to an HSI design contractor. To make the

guidance more useful in preparing a design guide, the guidance should be more narrative and integrated than regulatory guidelines to better illustrate the application of the principles and the relevant design considerations.

Another consideration is that the NRC documents are focused on safety. While utilities are also focused on safety, interface design must support efficiency and productivity as well.

With respect to procedures for guideline use, regulatory guidance differs from that needed by designers in two important ways. First, the procedures in NUREGs-0711 and 0700 are design-review oriented. While designers are interested in design evaluation, they are also interested in procedures for the use of the guidelines for design purposes. This aspect of the existing guidance needs to be revised to accommodate the broader scope of procedures for use of guidance in design as well as design evaluation.

Another difference is that the regulatory guidance looks at the design process in an input-output framework. For example, the review criteria for task analysis focus on inputs to the analysis and the types of information that should result from the analysis. The specific methods for performing the analysis are not addressed. In the regulatory review, the selection of methods is left to the designer. Designers, however, need to be provided information about methods so they can make informed choices among methods, based on their relative strengths and weaknesses.

In summary, the BNL manager (26) notes that prior NRC/BNL research on hybrid HSIs provides an excellent technical basis, but the resulting guidance (HFE guidelines and procedures) needs to be modified for use by designers.

Other Guidance Documents

HF guidance documents relevant to digital upgrade designs have been published by many organizations other than the NRC. Some of the better known guidance documents released since 1995 include:

- MIL-STD 1472 F Human Engineering, August 1999 (27). This standard establishes general human engineering criteria for military systems, subsystems, equipment, and facilities.
- MIL-HDBK-46855A Human Engineering Program Process and Procedures, May 1999 (28). This handbook provides human engineering (a) program tasks, (b) procedures and preferred practices, and (c) methods for application to system acquisition. The handbook contains application guidance for tailoring to identify only those tasks, procedures, and practices required to achieve essential human performance requirements consistent with avoiding unnecessary program costs.
- MIL-HDBK-759C9C(2) Human Engineering Design Guidelines, March 1998 (29). This handbook provides human engineering design guidelines and reference data for design of military systems, equipment, and facilities. This document is intended to serve as a companion document to MIL-STD 1472 F.
- Technical Architecture Framework for Information Management, Volume 8: DoD Human Computer Interface Style Guide, April 1996 (30). This style guide provides recommendations for good interface design, and addresses functional requirements and

operations that are intended by DoD to be consistent across the entire interface design. According to the Compliance section of the document, the interface developer is expected to follow the commercial Graphical User Interface (GUI) style guide, this Style Guide, and the appropriate domain-level style guide along with human factors specialists to create the HCI.

- NASA-STD-3000 Man-Systems Integration Standards, Revision B, July 1995 (31). This document provides man-system integration design considerations, design requirements, and example design solutions for development of manned space stations.
- DOT/FAA/CT-96/1 Human Factors Design Guide, January 1996 (32). This guide provides a compilation of HF principles integral to the procurement, design, development, and testing of FAA systems, facilities, and equipment. It covers a broad range of HF topics that pertain to automation, maintenance, human interfaces, workplace design, documentation, system security, safety, the environment, and anthropometry. The guide is available in electronic format on CD-ROM and the Internet.
- The FAA Human Factors Job Aid, March 1999 (33). This aid provides a reference for HF integration during system acquisition, and describes functions required for a successful HF program.
- U. S. Army MANPRINT Guidebook for Systems' Design and Assessment, September 1998 (34).
- ISO/DIS 11064 Ergonomic Design of Control Centres, draft under development (35). This document is intended to establish ergonomic principles, recommendations, and requirements to be applied in the design of control centers, control center expansion, refurbishment, and technology-based upgrades. The eight Parts of the standard are listed below.
  - Part 1 Principles for the design of control centres
  - Part 2 Principles of control suite arrangement
  - Part 3 Control room layout
  - Part 4 Workstations layout and dimensions
  - Part 5 Displays, controls, interactions
  - Part 6 Environmental requirements
  - Part 7 Principles for the evaluation of control centres
  - Part 8 Ergonomics requirements for specific applications

The discussion in the NRC documents section above identifies numerous problems expected if utilities attempt to use NUREGs for design purposes. This is not a surprise, however, since the NUREGs are intended for use by NRC staff for review, and not design, purposes. The HF guidance documents listed immediately above are intended for use for design and other purposes (e.g., to support acquisition). Do these documents satisfy the need of electric utilities for HF design and related guidance? An answer to this question is contained in the summary paragraph at the conclusion of this section.

Review of these documents suggests that some valuable guidance information is now available. For example, the DoD Human Computer Interface Guide (30) contains extensive HCI design guidance. Some of the topics for which guidance is provided include:

- Interface style
- Input devices and special (flat panel, liquid crystal, gas plasma, electoluminescence, stereoscopic/3D, touch interactive, and large-screen) displays
- Screen design
- Windows, menu, text, and query designs
- Graphics and multimedia
- Direct manipulation
- Decision aids
- Embedded training

MIL-HDBK-46855A (28) provides extensive information about HF methods and tools for analysis, and test and evaluation. Another report prepared by the HRP (36) also provides useful information about human performance assessment methods and measures. MIL-HDBK-46855A (28) provides useful application guidance regarding tailoring of the human factors efforts required to be consistent with the phase of the project (e.g., acquisition versus design), and the nature of the effort (e.g., major versus minor design).

The FAA Human Factors Design Guide (32) contains useful information on maintenance automation and designing equipment for maintenance.

Several of the documents provide guidance for acquisition of devices and systems in which HF must be considered. The FAA Human Factors Job Aid (33), U. S. Army MANPRINT Guidebook for Systems' Design and Assessment (34), and MIL-HDBK-46855A (28) are three such documents.

The ISO Ergonomic Design of Control Centres draft standard under development (35) is intended to be applicable to all types of control centers, including those for the process industry, transportation/logistic control systems, and people deployment and dispatching systems in emergency services. Although this standard is still under development and review, it appears that it is general in orientation. This should not be surprising since it is intended for broad application.

The discussion above is not intended to be complete or comprehensive. Rather, it is intended to identify examples of available information that may be relevant in developing a *Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms* document. Also, it must be mentioned that the quality and applicability to nuclear power plants of the guidance provided in the referenced documents were not determined. Such determination is beyond the scope of the present study. Quality and applicability would need to be established when a project is initiated to develop a guidance document, and information from these documents was considered for inclusion.

A problem facing utilities attempting to apply the various documents listed above, and others, is the amount of time to find and interpret the guidance needed. A challenge is to locate relevant guidance scattered among many documents, and interpret essentially the same guidance presented in different forms since it was developed for different applications (e.g., aircraft, spacecraft, tanks, air traffic control centers, emergency services dispatching centers). A reason is that the documents were prepared by different groups attempting to satisfy the requirements of the organization (e.g., DoD, FAA, NASA, and Army) sponsoring guidelines development.

Although only a cursory review was made of the guidance contained in the referenced documents, it appears that some topics for which guidance would prove useful are not addressed adequately for nuclear power plant applications. For example, specific design guidance was not found regarding minimizing distractions and human resources (e.g., time and cognitive processing) required to decide what information is needed and to operate one or more control(s) to obtain this information if it is not already displayed. Guidance, of course, is available on methods that might be followed to decide how to design, and then how to evaluate the design.

In summary, it is important to note that each of the major organizations cited in this report (DoD, NASA, FAA, and U. S. Army) developed their own guidance documents. The current versions of these documents all were published since 1995. Thus, the organizations responsible for these guidance documents have recently determined that material produced by others does not meet their needs. Some of the problems mentioned above may explain in part the basis for this decision. The U.S. nuclear industry is closely regulated and must demonstrate that systems are safe to operate. Therefore, HF guidance must satisfy safety requirements imposed by the NRC, and also provide for high levels of reliability, availability, and efficiency. Thus, it is concluded that the available guidance documents produced by others (e.g., government, international, and other groups) are not adequate to meet the utility industry need for HF guidance to support design of digital I&C systems and to incorporate these systems into control rooms. It is expected, however, that these guidance documents will be very useful as resources for developing a nuclear power plant-specific guidance document.

3.5 Other Information Sources

The 1997 National Research Council report referenced earlier (4, page 63) observed that "…for the foreseeable future, ensuring effective design with respect to human factors of digital I&C applications cannot rest on guidelines." The report continues that guidelines are frequently well meaning but vague, sometimes obsolete, and usually provide only limited guidance on more serious HF problems. Problem examples included information and cognitive workload, mode error, and the key-hole effect.

Research and other reports have been published addressing some of the guidance "gaps" identified in the National Research Council report. It is outside of the scope of this study to identify or review this material. The best source for a review of such publications is the Guidance Development and Technical Basis Part of each of the five published NUREG/CRs (18-22) and the three draft NUREG/CRs (23-25) (see NRC Documents section of this report). This Part of each document contains reviews of applicable research studies, HF processes, and guidance pertaining to the report topic. The guidelines for possible inclusion in Revision 2 of NUREG-0700 are based on information contained in the Technical Basis Part of the Reports.

The published and draft NUREG/CRs reports are comprehensive and current. They provide the best source of information to consider when developing guidance for "gaps" in published guidelines. In addition, these NUREG/CRs provide important information needed to create HF guidance for achieving high levels of system availability, reliability, and efficiency.

3.6 Conclusion Regarding Need for a Human Factors Guidance Document

It is concluded that a need exists to develop a *Human Factors Guidance for Digital I&C Systems and Hybrid Control Rooms* document for use by utilities and vendors. The guidance is needed to ensure that in addition to meeting NRC safety requirements, a plant will realize significant reduced human errors and inefficiencies, resulting in improved plant safety, availability, reliability, and efficiency.

The basis for this conclusion is based on the following:

- Most of the utility and vendor personnel interviewed during this study reported that HF guidance is needed, and that available guidance does not satisfy some of their important needs as the move to hybrid control rooms accelerates.
- No existing guidance documents, including NRC NUREGs, government-sponsored documents, or international standards were found that satisfy utility needs for information to support design. The NUREGs provide useful HF guidelines and procedures but are general in nature, focussed on safety, and structured to facilitate review of whatever designs are submitted.
- Although government-sponsored documents (e.g., DoD, FAA, NASA, and the Army) provide some useful design guidance, they were prepared for the specific application (e.g., aircraft cockpit, spacecraft, air traffic center, and tank) of concern to the sponsoring organization.
- Guidance is not provided in the referenced documents to eliminate some of the HCI and HSI problems encountered since digital upgrades have been installed in nuclear power plant control rooms (1-4). Recently published (18-22) and draft NUREG/CRs (23-25) provide comprehensive review and evaluation of information available to fill many of the "gaps" in available guidance documents. A need exists to review and evaluate the information available from these and other sources, select the relevant material, and present it in one document applicable specifically to the nuclear power plant control room application.

4
DESCRIPTION OF HF GUIDANCE DOCUMENT

This section of the report presents a description of the HF guidance document. Topics include assumptions regarding the digital upgrade and control room modernization process; long range HF plan; sources of information; and document description regarding content, organization, format, and expected users.

4.1 Assumptions

The description of the HF guidance document is based on certain assumptions about the digital upgrade and control room modernization process. Some of the more significant assumptions are presented below.

- It is expected that many utilities will develop a long range control room I&C upgrade and modernization plan. It is outside of the scope of the study described in this report to recommend whether such a plan should be developed or to suggest contents. It is expected, however, that if a plan is developed it will include identification of which I&C components and systems will be replaced and the expected time frame for replacement. In addition, it is likely that to the extent possible upgrades will be identified that meet 10 CFR 50.59 criteria and thus not require prior regulatory approval.
- It will be necessary for a utility to prepare a HF program plan if upgrades must be submitted to the NRC under 10 CFR 50.90 (13, page 18.0-4). Since no NRC submittal is required for upgrades satisfying 10 CFR 50.59 criteria, no HF plan is required. It should be emphasized, however, that the NRC staff investigates various types of events at nuclear power plants. Section 1.3.1 of NUREG-0700, Revision 1 (16, page 9) states that, "NRC inspectors could use the guidance in this document to support their work." It appears prudent, therefore, for a utility to have prepared and implemented a HF program plan for both 50.59 and 50.50 upgrades. This observation is supported by comments made by personnel at one of the nuclear power plants visited during this study. This utility plans to develop and apply a HF plan for all control room upgrades.
- Utilities want to ensure that in addition to meeting NRC safety requirements, digital upgrades and control room modernization will result in an improved control room, resulting in significant reduced human errors and inefficiencies, and thus improved plant safety, availability, reliability, and efficiency. Application of the HF guidance document is viewed as necessary to achieve this objective (see section 3.6 above).
- Major I&C system vendors have prepared and submitted to the NRC generic Topical Reports on I&C systems and potential applications, consistent with Advanced Light Water Reactor licensing practices and generic safety system specifications. These Topical Reports typically

included HF information specified in NUREGs-0800, 0711, and 0700 Revision 1 to satisfy NRC review requirements. It is expected that utilities will credit the generic SERs in applying for site-specific license amendments.

- Discussions with vendor and utility personnel reveal that it is likely that in the future vendors will continue the process described in the paragraph above. It is expected that vendors will work closely with individual utilities, several utilities that have banded together to develop common requirements and specifications, NSSS owners groups, EPRI, and others to develop designs acceptable to all concerned. The vendor would then prepare and submit to the NRC generic Topical Reports including required HF documentation. The generic SERs would be used by utilities in applying for site-specific license amendments.

4.2 Long Range Human Factors Program Plan

This HF guidance document should provide guidance regarding the process to use in preparing a HF program plan.

NUREG-0711 (17, page 2-1) identifies the purpose of the NRC HF program review. This purpose statement and consideration of the importance of improved human performance for economic reasons provide guidance regarding the objectives that the HF program plan should satisfy. The plan should demonstrate that:

- HF has been integrated into I&C component and system design, development, and evaluation.
- HF products (e.g., HSIs, procedures, and training) make possible safe, reliable, and efficient performance of operation, maintenance, test, inspection, and surveillance tasks.
- The HF program and its products reflect “state-of-the-art HF principles.”

The content of the HF program plan may include the following:

- Program goals and scope
- HF team and composition
- Process and procedures
- Issues tracking
- Technical activities, including:
  - Operating experience review
  - Task analysis
  - Staffing
  - Human reliability analysis
  - HSI design
  - Procedure development
  - Training development

– HF verification and validation

The HF program plan should provide guidance regarding tailoring HF participation and activities to the specific upgrade or modification planned. It will not be necessary to apply all of the HF design processes or technical activities to many of the upgrades and modifications (see section 4.6 below).

A very important goal of the HF program plan is to ensure that the overall hybrid control room HSIs, procedures, training, and maintenance provisions existing at the completion of the modernization effort reflect successful application of "state-of-the-art HF principles." It is possible that without a long range HF program plan, HF efforts will be performed in support of individual upgrade efforts. Although such an approach may result in acceptable design of individual components and systems, the overall result may not be acceptable. For example, the opportunity to juxtaposition and integrate information from (formerly) separated displays may facilitate operator cognitive processing resulting in improved diagnosis and problem-solving. This information juxtaposition and integration may not occur unless the overall upgrade plan is considered. Another example of a potential problem that could develop if a HF program plan is not prepared or followed involves operating procedures. The control room upgrade process is expected to extend over several years. Frequent changes may occur during and between planned refueling outages. A challenge exists to ensure that correct procedures are available for the current control board configuration.

4.3 Sources of Information for the Document

The guidance provided in the HF guidance document will be developed from existing information. No original research is planned. Of course, during the course of developing the document, specific guidance that is not available may be identified. Such guidance needs should be identified and documented.

Most of the sources from which guidance will be extracted for the HF guidance document are identified in this report and contained in the References list (section 7). Some of the more relevant material is cited in section 4.4. In addition, experiences and lessons learned from fossil plant control room upgrades needs to be collected and evaluated.

It is important during HF guidance document development that newly available information, possibly related to document content, be evaluated and included, if appropriate.

4.4 Document Description and Content

The HF guidance document is envisioned to contain the general HF guidance needed by utilities and vendors to meet NRC safety requirements, and also to achieve high levels of plant availability, reliability, and efficiency. The document will incorporate relevant material from many sources (see section 4.3 above) into one reference source. This should facilitate application as compared to obtaining, reviewing, and selecting guidance information from multiple sources (e.g., the NRC 0800, 0711, and 0700 Revision 1 NUREGs and NUREG/CRs; DoD, NASA,

FAA, international and national technical society standards and other guidance documents; and research reports and technical books).

It is expected that some utilities, or groups of utilities with similar control room designs, will decide to develop a HF design style guide (or standard) based on the HF guidance document. A HF design style guide (standard) will provide plant-specific guidance that could be applicable at one or several plants within a given utility, or be applicable to plants at different utilities sharing a common control room design.

The HF guidance document must provide guidance at a somewhat general level since several vendors and many utilities with a variety of I&C system and control room designs may use the document. The general guidance provides a basis to develop the more detailed level of specification for a specific design. For example, the HF guidance document may provide a general guideline stating that character size (height) should be at least 16 minutes of arc for black and white displays and 21 minutes for color displays. The preferred angles are 20 and 30 minutes of arc, respectively (32, guideline 7.2.4.6, page 7-26). In comparison, NRC NUREG 0700 Revision 1, Volume 2 (16, checklist item 1.3.1-4, page 1-44) states that the character size (height) should be at least 16 minutes of arc, with a maximum height of 24 minutes of arc. This type of generality is necessary for two reasons. First, the guidance needs to be standardized for use across a wide range of design options, e.g., different I&C system and control room designs at different plants. Second, the actual size of characters depends on trade-offs with several other factors, such as the distance users are expected to be from the information and how much information the designer wants on a given screen. If general guidance were to be used without modification by designers, it would be difficult to apply and would not necessarily result in a desirable design from a HF perspective.

The HF guidance document will need to be revised and upgraded. One reason is that it is expected to contain the guidance needed by utilities and vendors to prepare applications submitted to the NRC. Obviously, the document will need updating whenever changes occur in applicable NRC NUREGs or other NRC or industry (e.g., EPRI) documents. Other reasons to upgrade include availability of experiences (lessons learned) of those using the document, and availability of technical information about advances in HSI technology incorporated in upgrades.

The major topics to include in the HF guidance document are presented in the paragraphs that follow.

General Guidance

This section of the HF guidance document should provide guidance and information at a general level. Examples of topics that should be addressed include the following:

- Scope, objectives, role in satisfying NRC requirements, limitations, and expected benefits of use.
- Description of how to use the document.

- Applicability to vendors and utilities for use in planning, analysis, specification development, HSI design, procedure development, training development, and verification and validation (V&V).
- Use of document during I&C component and system acquisition process, e.g., to develop contractual requirements for vendors to perform selected HF activities during design and development, and to provide documentation including information relevant to any special skills needs, performing maintenance, and updating procedures and training.
- General design considerations and guidance involving issues such as:
  - Deciding if displayed information (or control capability) should be in a fixed position and always available on the control board, or be organized in a hierarchical fashion and selectable when needed or desired.
  - Designing information and display systems to minimize difficulties caused by the "keyhole effect," and "getting lost in information space." Also, designing to minimize the need to devote large amounts of time and attention to operating controls simply to access information or "soft" controls (sometimes described as a secondary task as contrasted with a primary task involving plant and process control).
  - Designing information and display systems to take advantage of human cognitive processing capabilities (e.g., designing to facilitate situation awareness, monitoring and detection, response planning, and response implementation).
  - Evaluating impacts on human performance of advanced and more complex systems under consideration (e.g., computer-based procedures, computerized operator support systems, advanced alarm systems, more automated systems, systems in which displays of process and alarm information and controls are integrated).
  - Cultural issues, such as creating crew acceptance and "ownership" of the upgraded hybrid control room and modified procedures, and changes in operating crew responsibilities and interactions.
  - Deciding how to handle the transition over a five-to-ten year time period from the current control room to the one existing at the completion of the upgrade and modernization process.

An example of general HF design guidance is shown below. This example was copied from the FAA Human Factors Design Guide (32).

Human-Computer Interaction

Design requirements for human-computer interaction shall be evaluated in advance of software coding (via appropriate analyses, rapid prototyping, or simulation). Human performance shall be evaluated at appropriate points in the system development and test processes, as approved by the acquisition program office.

Design Process Guidance

The purpose of this section of the HF guidance document is to present the general design and development process within which the HF guidelines may be effectively used. The guidance should also identify and describe the methods applicable to each step in the design and development process.

NUREG-0711 (17) provides a basis for developing this guidance. Design process activities may be categorized as follows:

- Program planning
- Analyses
  - Operating experience
  - Functional requirements
  - Task and reliability
  - Staffing and personnel
- HSI design
  - HSI design methodology (e.g., requirements development, HSI concept design, and HSI detailed design and integration)
  - Tests and evaluations (e.g., trade-off evaluations, subjective evaluation, performance-based tests)
  - HSI design documentation
- Procedure design/modification
- Training program design/modification
- HF verification and validation
  - HSI task support verification
  - HF design verification
  - Integrated system validation
  - Final design verification

NUREG-0711 (17), MIL-HDBK-46855A (28), the NRC NUREG/CRs and other documents will provide the initial material for developing the design process guidance. This material requires modification to better meet the needs of designers, especially to ensure that proper attention is given to reducing human errors and inefficiencies influencing plant availability and efficiency.

It is important to note that this section of the HF guidance document must provide process guidance applicable not only to HSI design, but also to procedure and training design and modification.

The HF design process guidance needs to be tailored to the specific upgrade or modification planned. It will not be necessary to apply all of the HF design processes to many of the upgrades and modifications. The HF program plan should provide the guidance needed by vendor and utility personnel to determine the specific HF design process effort required (see section 4.6 below).

Detailed HF Design Guidance

The purpose of this section of the HF guidance document is to provide detailed HF guidance regarding design of individual I&C components (e.g., digital recorders), larger systems (e.g., Post Accident Monitoring Systems, computer-based procedures systems), and the overall hybrid control room. Part 2 of NUREG-0700, Revision 1 (16) entitled, "Guidelines for Human Factors Reviews," provides somewhat similar information, but is intended for review rather than design purposes. It is reported that the equivalent section in NUREG-0700, Revision 2 will be entitled "Human Factors Engineering Guidelines" (26). The equivalent section in MIL-STD-1472F is called "Detailed Requirements" (27).

NUREG-0700, Revision 1 (16) and Revision 2 (when it becomes available), MIL-STD-1472F (27), and other documents will provide the initial material for developing the detailed HF design guidance. As with the design process guidance, this material needs to be modified to better meet the requirements of designers, especially to ensure that proper attention is given to reducing human errors and inefficiencies influencing plant availability and efficiency.

The NRC NUREG/CRs (18-25) identified in section 3.4 will be very important sources for design guidance. These reports became available very recently, and provide current information. The reports contain extensive reviews of the literature, and provide the technical bases for NRC development of the new design review guidelines contained in NUREG-0700, Revision 2 (26).

The organization and content of this section of the HF guidance document needs to be determined. It is beyond the scope of the study described in this report to provide specific recommendations regarding organization and content. Such decisions will be made during development of the document. The contents of sections of three documents, however, are presented below to provide insight into what may be expected in the HF guidance document.

The organization and content being considered for NUREG-0700, Revision 2 (26) is as follows:

- Part I Basic HSI elements
  - Information display
  - User-system interaction
  - Controls
- Part II HSI systems
  - Alarm system
  - Safety function monitoring (SPDS function)
  - Group-view display system

  - Soft control system
  - Computer-based procedure systems
  - Computerized operator systems
  - Automation
  - Communication system
- Part III Workstation and workplace design
  - Workstation design
  - Workplace design
- Part IV HSI support
  - Digital systems maintenance
  - Configuration management

Recently revised MIL-STD-1472F (27), which is applicable to design of military systems, includes the following organization for presenting detailed HF requirements:

- Control/display integration
- Visual displays
- Audio displays
- Controls
- Labeling
- Physical accommodation
- Workspace design
- Environment
- Design for maintainer
- User-computer interface
- Visual display terminals

Detailed design guidance that is provided in the DoD HCI Style Guide (30) is of interest since many control room upgrades are expected to involve HCIs. The major section headings in this report include:

- Interface style
- Hardware (input devices and procedures, special displays, alternate input/output devices)
- Screen design
- Windows
- Menu design

- Direct manipulation(e.g., metaphors, icons)
- Common features (e.g., on-line help, interactive control, function keys)
- Text
- Graphics
- Decision aids
- Query
- Embedded training
- Emerging technology (personal layer, multimedia)

An example of detailed HF design guidance is shown below. This example was copied from the DoD HCI Style Guide (30).

Character Design. Use capital letters for typographic coding, headlines, and where special emphasis is required, such as some captions and labels. However, it is usually best to capitalize only the first letter, for example, in a horizontal series such as button labels.

Do not use all capital letters in running text or tables, as this impairs word recognition, reduces readability, and limits space between text lines.

Ensure spacing between characters (both fixed and proportional width) at 20 to 50 percent of character height. Spacing between lines should be equal to character height.

Ensure that the minimum height of displayed characters is 1/200 of viewing distance (approximately 17 minutes of visual angle). Therefore, a viewing distance of 36 inches requires 0.18-inch character height on the display screen. Character width should be 50 to 100 percent of character height. Character stroke width minimum is 10 to 12.5 percent of character height. Maximum text size should not exceed 10 percent of the available vertical display area on a full-size screen.

Ensure that characters contain a minimum 7 x 9 dot matrix construction for better readability.

Some applications require over-the-shoulder reading of characters on the screen and should be legible to a person standing behind the user (e.g., operations in a tactical environment). Ensure that the screen viewing distance referred to in Paragraph 4.2.3.4d reflects the anticipated maximum viewing distance. Large fonts with broad stroke widths are recommended to improve readability. Selections of background color and contrasting foreground (text) color should ensure sufficient contrast for good readability.

The usual font size designation is given in points. Display of text fonts on screens is proportional to point size, but the actual size of displayed text is related to screen size and application software. Font point size only controls the actual size of printed output. It is recommended that screen text size be reviewed and adjusted in relation to the objective hardware system.

This section of the HF guidance document must provide detailed HF guidance applicable to HSI design, and to procedure and training design and modification.

It should be obvious that the detailed HF guidance needs to be tailored to the specific upgrade or modification planned. Many of the guidance items will not apply to a given upgrade or modification. The HF program plan should provide the guidance needed by vendor and utility personnel to determine applicable HF guidance (see section 4.6 below).

HF Methods and Tools

This section of the HF guidance document will provide guidance and information regarding HF methods and tools to support the design process and application of detailed design guidance.

There are many sources providing information about methods and tools. One example is MIL-HDBK-46855A (28) that contains a major section describing HF methods and tools. Another source is a HRP draft report (36) providing a description of some of the more effective methods used in the extensive Halden HF program. NUREG/CR-6637 (22) provides an especially relevant section (section 5 entitled, "Technical Basis Development: Design Process Considerations for Hybrid HSI").

An example of the contents of the HF methods and tools section of the HF guidance document is shown below. This example was copied from MIL-HDBK-46855A (28).

Mockup

A mockup is a large-scale, proportioned model of the final equipment, subsystem, or system used for validation of layout. Mockups are extremely valuable for depicting three-dimensional relationships that would otherwise be difficult to represent before the system goes into manufacture.

Description

Mockups can contribute significantly to the development of the human-machine system. They should be considered as tools for evaluating the system design before the actual manufacture of system hardware. There are three basic types of physical mockup, which are described in the following paragraphs. In addition, virtual mockups can now be generated directly from CAD environments.

Class I

A class I mockup is used primarily for determining basic shape, allotting space, proving concepts to familiarize personnel with the basic design of the system or equipment, or presenting new ideas. Such a mockup is usually made of inexpensive materials (e.g., heavy cardboard, cardboard with a foam core, fiberboard, plywood).

Class II

A class II mockup is used primarily to assist in the development of the system/equipment detail design and as a demonstrator for customer evaluation. It is constructed from a good grade of wood, metal, or plastic. Overall dimensions and sizes of parts, features, etc., are as close to drawing tolerance as practical. The more complex mockups differ little from simulators.

Class III

A class III mockup is primarily an engineering/manufacturing/simulation vehicle or facility.

Procedure

Mockups should be made initially with the easiest to use and cheapest material possible. They can be constructed quite easily from various thicknesses of foam-core cardboard sheets using a matte knife and a hot glue gun. Console panel layout drawings may be simply glued to the foam-core cardboard to simulate displays and controls. Test participants or evaluators may simulate display reading or control actuation by simply touching the drawing and performing the appropriate hand (foot) motion. As the system design progresses and mockup tolerances become more critical, plywood material should be used. Plywood mockups may be converted from a static to a dynamic representation of the system. Console panel drawings that were glued to the plywood may be replaced by the actual displays and controls.

Use

Mockups can be used in the design so that three-dimensional problems can be visualized. Operator and maintainer reach, handling, and manipulation distances, as well as clearance spaces, access openings, and visual envelopes, can be determined from mockups and the results compared with system design requirements. Photographs, videotapes, or motion pictures may be made using the mockups to provide coordination aids and maintain records. It is cheaper to develop a static mockup or even a functional mockup than it is to build prototype hardware. A functional mockup makes it possible to study the performance of personnel in simulated operational situations. The HF practitioner can thus evaluate the operational characteristics of equipment in terms of human performance. More realistic lighting and sound measurements can be taken. Procedures can be verified. Test participants can be observed and interviewed with much greater confidence in the validity of their responses. In addition to all the above, mockups—along with photographs, video tapes, or movies—serve as an aid in designing presentation reviews and, later, in training system development.

It is mentioned in the example above that technology now permits virtual mockups to be created. The HRP has successfully applied virtual reality tools to obtain early user participation in and evaluation of control room designs (37).

It is mentioned in the design process guidance and detailed HF guidance paragraphs above that guidance needs to be tailored to the specific upgrade or modification planned. The same

comment is applicable to this paragraph. Many of the methods and tools will not apply to a given upgrade or modification. The HF program plan should provide the guidance needed by vendor and utility personnel to determine applicable methods and tools (see section 4.6 below).

Display and Control Design Examples

The HF guidance document should contain display and control design examples. These examples are not intended as models to be followed, but rather are expected to provide the design team with ideas and concepts, and to help clarify the guidance. The examples should be selected from existing displays and controls that have been designed following the guidance contained in the HF guidance document. An EPRI handbook (38) provides display examples (called "prototypes" in the handbook) developed following guidance presented in another part of the document.

4.5 Organization, Format, and Guideline Tracking

This section provides initial suggestions for the overall organization of the HF guidance document, format for individual guidance items and the entire document, and a method to track individual guidelines. It is expected that an Industry Advisory Group (IAG) will be formed to provide direction to the document development activity (see section 5). This group will provide specific recommendations about the guidance document, including its organization, format, and guideline tracking.

Organization

The material presented in section 4 of this report provides the basis for the suggested organization of the HF guidance document. The proposed organization is as follows:

- Scope
- Applicability
  - Utilities and vendors
  - Use in planning, analysis, specification development, HSI design for operators and maintainers, updating procedures and training, determining need for special skills, and verification and validation
- Objectives and need for document
- Expected benefits and limitations
- Expected document users
- Role in satisfying NRC requirements
- Role in reducing human errors and inefficiencies resulting in improved plant availability, reliability, and efficiency
- Description of how to use the document

- General guidance
- Design process guidance
- Detailed HF guidance
- HF methods and tools
- Display and control design examples
- Document tailoring (see section 4.6)

Guidelines Format

A format for guidelines will be determined during HF guidance document development. It is beyond the scope of this study to develop a specific format recommendation.

The format used in NUREG-0700, Revision 1 (16) is an example of one possible format. The example and discussion presented below were provided by Dr. John O'Hara (26).

10.1.1 Correspondence Mapping

There should be an explicit mapping between the characteristics and functions of the system to be represented and the features of the display representation, i.e., changes in the appearance of the display form, should have a one-to-one relation with the plant states it represents. These changes should result from explicit rules relating the physical form of the display and its meaning with respect to the plant state represented.

ADDITIONAL INFORMATION: Correspondence mapping addresses how well the display communicates meaningful information about the plant to operators. The physical form and functions of the display should be explicitly tied to its meaning with respect to the plant's functions and states. The meaning of the display must consider the instrumentation and the data processing that drives the display format. If a single display can lead to more than one interpretation, the display is ambiguous and can be more easily misunderstood. Changes in the graphic display should be unambiguously related to the plant's state. The same graphic change should not be associated with more than one interpretation.

Source: NUREG/CR-6633

Each of the guidelines is composed of the following components:

Guideline Number

Within each section, individual guidelines are numbered consecutively. Each guideline has a number that reflects its section and subsection location, followed by a dash, and then its unique number.

Guideline Title

Each guideline has a brief, unique, descriptive title.

Review Criterion

Each guideline contains a statement of a HSI characteristic so that the reviewer may judge the HSI's acceptability. The criterion is not a requirement, and discrepant characteristics may be judged acceptable based on the procedures in the review process.

Additional Information

For many guidelines, there is additional information that may address clarifications, examples, exceptions, and details on measurements, figures, or tables. This information is intended to support the reviewer's interpretation or application of the guideline.

Source

The source field identifies the NUREG or NUREG/CR (or other document) containing the technical basis and development methodology for the guideline.

This NUREG-0700, Revision 1 format may not be ideally suited for use by designers. For example, the technical basis on which the guideline was developed is documented in the NUREG/CR referenced by the source document. It may be desirable to provide this technical basis information to enable designers to evaluate tradeoffs between guidelines, and to evaluate decisions to develop design features that are inconsistent with the guidance. The technical bases will also provide the information that may be needed to respond to regulatory concerns.

Document Format

The document format was discussed during this study with utility and vendor personnel. It was generally agreed that the HF guidance document should be available in several forms. The suggested formats were as follows:

- Hard-copy
- Electronic version available on CD-ROM
- Electronic version available at an Internet web site.

It should be noted that the NRC NUREG-0700, Revision 1 (16) is available in hard copy format and on CD-ROMs. The DoD and NASA documents cited in this report (27-30) are available in hard copy formats and on Internet web sites.

A real advantage exists in having the HF guidance document available in an interactive electronic format. This would facilitate accessing only the relevant and applicable design

process, detailed HF guidance, and HF methods and tools during document tailoring (see section 4.6 below).

An advantage of providing an electronic version on an Internet web site is ease of updating. The document could be updated in a timely manner. It would not be necessary to prepare and distribute new hard copies and CD-ROMs. A decision regarding document format will be made during HF guidance document development.

Guideline Tracking

It will be necessary to develop an individual guideline tracking system. Guidelines will need to be added, eliminated, and modified over time. Making and keeping track of these changes could prove difficult unless a system is established to manage the process. In addition, it will be desirable to provide a link from the guideline to its source, and to provide other relevant information. It is expected that this supporting material will not be included with the guideline.

Dr. John O'Hara (26) has suggested that the need described above can be handled by a Guidelines Tracking and Modification Database similar to the one developed for NUREG-0700, Revision 1. The guideline tracking and modification database serves to document any changes. This database greatly enhances the ability to track from NUREG-0700 to its source documents and to understand how and why a guideline may be different from its source. Such a database was established for tracking guidelines between NUREG-0700, Revision 0 and Revision 1. This database was expanded to include all guidance and sources currently being used for NUREG-0700, Revision 2. Further study is required, but it appears that a similar database should be developed for the guidelines contained in the HF guidance document.

4.6 Tailoring of Document

It was mentioned in section 4.2 and several paragraphs of sections 4.4 that guidance regarding HF participation and activities needs to be tailored to the specific upgrade or modification planned. It will not be necessary, and in fact undesirable due to cost and time, to try to apply the entire set of HF design processes and technical activities to many of the upgrades and modifications. For example, a one-for-one replacement of an analog with a digital recorder in the same location on the control board may involve minimum HF effort. The HF activity may consist of ensuring that detailed information display criteria are applied during design (if a commercial off-the-shelf recorder is not selected), and/or verifying that the criteria have been satisfied by the proposed replacement recorder. Application of HF processes, guidance, and methods would be much more extensive for upgrades involving a larger portion of the control board, e.g., replacement of the Post Accident Monitoring System.

The DoD has recognized the need to limit HF program tasks to the minimum essential needs. MIL-HDBK-46855A (28) contains an Application and Tailoring Appendix describing tailoring of HF program task guidelines to apply only those that are deemed necessary.

One approach is to develop a tailoring matrix. For example, the specific I&C component or system could be listed in the row headings of the matrix. The individual general guidelines, design process guidelines, detailed HF design guidelines, the HF methods and tools, and the display and control design examples could be listed in the column headings of the matrix. Applicable items to apply to a given I&C component or system could be flagged. Review of the matrix would show which items should be considered during the design activity.

It must be recognized that a hard copy of the matrix proposed above would be unwieldy to use. There would be a very large number of columns and rows making it difficult to access the required information. A more practical approach would be to store the matrix in an interactive computer database. The user could enter the I&C component or system to be upgraded, and page through the applicable guidelines on the computer display. Modifying and updating the database would be relatively simple as compared to updating a hard copy of the matrix.

The tailoring process using the matrix concept presented above is also applicable to developing and upgrading procedures and training required by the digital upgrades and modifications. In this application, the column headings would contain the guidelines pertaining to procedure and training design and development.

4.7 Expected Document Users

It is expected that utility and vendor personnel will apply the HF guidance document. Some of the users are expected to include:

- Individuals preparing upgrade and modification specifications and plans
- Individuals preparing NUREG-0800 Chapter 7 (I&C) and 18 (Human Factors) submittals to the NRC
- System and design engineers
- I&C engineers
- Maintenance engineers
- HF specialists
- Software engineers and specialists
- Task team members involved in design and evaluation efforts
- Procurement specialists specifying HF requirements in procurement documents
- Procedure writers
- Training specialists

5
PLAN TO DEVELOP HF GUIDANCE DOCUMENT

This section of the report presents a plan to develop the HF guidance document. This document will provide guidance for specifying and designing digital I&C components and systems, and their incorporation into analog and mixed analog/digital (hybrid) control rooms. The guidance is intended for application by utilities and vendors. The guidance will facilitate implementation, operations, maintenance, training, and procedure activities with the new digital upgrades.

The scoping and planning study results presented in this report need to be reviewed by EPRI staff and its utility advisors. A decision is required regarding HF guidance document development. If the decision is to proceed, then available financial resources and duration of the development activity must be determined. A statement of work could then be prepared defining project scope and duration. An organization would be selected to perform the project work, and the development effort would begin.

It is expected that this plan and the HF guidance document contents, format, etc., will be modified during the development effort. This is to be expected, and in fact encouraged, as additional input is received from utility and vendor users and experts from the organization responsible for creating the document.

It is likely that the project described in this section of the report will require about two years for completion. Useful guidance for some of the important areas in which guidance is needed in the near-term could be developed and made available in less time. But the overall effort will require time for the development and evaluation processes to be accomplished.

Document development should involve the three major tasks described below.

5.1 Task 1: Refine Need for and Description of Guidance Document

This scoping and planning study report provides the starting point for performing Task 1. The study involved discussions with a limited number of utility and vendor personnel, and review of a limited set of HF guidance documents. Additional discussions need to be held with utility, vendor, and NRC personnel regarding the specific needs that the HF guidance document must satisfy. For example, do users agree with a conclusion of this study that the HF guidance document should be self-contained and provide the guidance required for preparing material for submittal to the NRC?

Although many relevant HF guidance documents were obtained and reviewed during the current study, the search needs to be widened to ensure that all relevant sources are identified and evaluated. For example, the draft of NUREG-0700, Revision 2 was not available, and the

ISO control center design document (35), currently under development and revision, should be issued in the near future.

The experiences and lessons learned by fossil generating stations that have modernized control rooms need to be evaluated. This information could prove valuable in finalizing content of the HF guidance document.

An Industry Advisory Group (IAG) should be formed consisting of interested utility, vendor, and possibly NRC, personnel. This IAG will provide the knowledge and information required to precisely define the guidance document need, intended users, content, format, presentation methods, and description of guidance (general, design process, detailed HF design, and use of HF methods and tools).

5.2 Task 2: Develop, Test, and Publish the Guidance Document

The results from Task 1 will determine the content and organization the HF guidance document. Sections 4.4 (Document Description and Content), 4.5 (Organization, Format, and Guideline Tracking), and 4.6 (Tailoring of Document) contained in this report provide recommendations based on the scoping and planning study.

The development and testing efforts will be concerned with HSI HF guidance for I&C components and systems involving operations and maintenance personnel, and for guidance in preparing new and/or modified procedures and training materials.

The information sources identified during performance of Task 1 will be reviewed and evaluated, the relevant material extracted and modified, as necessary, and the results incorporated into a draft guidance document. The IAG will review progress and provide direction at appropriate times. The draft document will be implemented and evaluated at several sites, and revised as necessary.

The revised HF guidance document will be published and made available at the conclusion of the project.

5.3 Task 3: Develop Supporting Materials

Supporting material will be developed to facilitate document use, and to upgrade and maintain the document, as required.

A training program will be created and tested for users of the HF guidance document. Although the document will be designed to be usable without special training, effective application of some of the methods could benefit from a training program. For example, training may be of benefit to a design team that wants to achieve a high level of situation awareness in a control room in which multiple digital displays are being designed for integration with existing analog instruments.

The guidance document will require updating periodically. Therefore, a plan will be prepared for maintaining and updating the document. There are several reasons for updates. A major reason is that the NRC may change requirements for HF information. The guidance document must provide the current guidance needed to prepare the HF submittals to the NRC (assuming that this document is the primary source of guidance for preparing these submittals).

Another important reason for updates is the rapid change in modern digital technology. During the time that control rooms are being upgraded over the next several years, the digital I&C capabilities will be enhanced considerably. Existing guidance may not be applicable to or even available for the new technology.

Nuclear power plants will be gaining experience with digital upgrades and hybrid control rooms over the next several years. Lessons will be learned and analyses performed on the human performance problems that are experienced. It is important that guidance in the document be updated to reflect this new information.

6
CONCLUSIONS

It is concluded that a need exists for the nuclear electric power generation industry to develop a HF guidance document. This document will provide guidance for specifying and designing digital I&C components and systems, and their incorporation into hybrid control rooms. The guidance is intended for application by utilities and vendors, and will facilitate operations, maintenance, training, and procedure activities with the new digital upgrades. Additional conclusions based on the study described in this report are presented below.

- Many I&C systems are of analog design, and contain components that are obsolete. Analog replacements may not be available. It is necessary to replace analog with digital-based designs. This move will accelerate as plants age.
- Careful digital I&C system design and integration into control rooms can reduce human errors and inefficiencies, resulting in improved plant safety, availability, reliability, and efficiency.
- NRC staff and others have identified HSI problems caused by digital upgrades.
- No one set of existing guidance documents, including NRC NUREGs, government-sponsored documents, or other standards were found that completely satisfy utility needs for HF information to support design.
- The NRC staff that evaluates HF submittals relies on NUREG-0800, NUREG-0711, and NUREG-0700, Revision 1. These NUREGs are important, but are only intended to guide NRC review to ensure safety requirements are met. They do not provide guidance needed to achieve the improved human performance possible by utilizing the power and potential of modern digital technology.
- Although government-sponsored documents (e.g., DoD, FAA, NASA) provide useful design guidance, they were prepared for the specific application (e.g., aircraft cockpit) of concern to the sponsoring organization.
- The HF guidance document will incorporate existing guidance from many sources. This will facilitate application by utility and vendor personnel, versus obtaining, reviewing, and selecting information from many sources (e.g., NRC NUREGs and NUREG/CRs; DoD, NASA, FAA, technical society standards; and research reports and technical books).
- Four categories of HF guidance will be provided in the document: general, design process, detailed design, and use of methods and tools.
- Document guidance needs to be tailored to the specific upgrade or modification being planned to minimize the amount of effort that has to be applied.
- The HF guidance document should be available in three formats: hard copy, CD-ROM, and at an Internet web site.

- The guidance document may need to be revised when significant changes occur in applicable NRC or industry documents, lessons learned become available from document users, and new information becomes available about HSI technology.
- Actual development of the HF guidance document is dependent on EPRI and utility advisor approval and funding availability. It is expected that document contents, format, etc., as described in this report, will be modified during the development effort. This is expected as additional input is received from utility and vendor users, and experts from the organization responsible for creating the document.

7
REFERENCES

1. Galletti, G.S. 1996. *Human Factors Issues in Digital System Design and Implementation*. In Proceedings of the 1996 American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies. LaGrange Park, IL: American Nuclear Society.

2. Roth, E., and O'Hara, J. 1998. *Integrating Digital and Conventional Human System Interfaces: Lessons Learned from a Control Room Modernization Program.* BNL Letter Report J6012-3-4-7/98. Upton, NY: Brookhaven National Laboratory.

3. Heslinga, G., and Herbert, M. (Eds.) 1993. *Experiences with the Introduction of New Systems for Human-Machine Interaction from a Human Factors Perspective–Summary Report.* The Netherlands: KEMA. (Report of a study group established by the Coordination of Research Study Committee of the International Union of Producers and Distributors of Electrical Energy.)

4. National Research Council. 1997. *Digital Instrumentation and Control Systems in Nuclear Power Plants: Safety and Reliability Issues, Final Report.* Washington, D.C.: National Academy Press.

5. FAA. 1996. *The Interfaces Between Flightcrews and Modern Flight Deck Systems.* Washington, D.C.: FAA.

6. U.S. Code of Federal Regulations, Appendix A of Title 10 CFR Part 50 *General Design Criteria for Nuclear Power Plants.* Federal Register, December 1999. Washington, D.C.: U.S. Government Printing Office.

7. USNRC (U.S. Nuclear Regulatory Commission). 1981 *USNRC Standard Review Plan (SRP), NUREG-0800, Chapter 7* (Revised in 1997) *Instrumentation and Controls*. Washington, D.C.: USNRC.

8. U.S. Code of Federal Regulations, Section 50.59 of Title 10 (10 CFR 50.59). Federal Register Notice published October 4, 1999, effective 90 days after applicable regulatory guidance available. *Changes, tests and experiments.* Washington, D.C.: U.S. Government Printing Office.

9. U.S. Code of Federal Regulations, Section 50.90 of Title 10 (10 CFR 50.90). Federal Register Notice published October 4, 1999, effective 90 days after applicable regulatory guidance available. *Application for amendment of license or construction permit.* Washington, D.C.: U.S. Government Printing Office.

10. Nuclear Management and Resources Council/EPRI. 1993. *Guideline on Licensing Digital Upgrades,* EPRI TR-102348. Palo Alto, CA: EPRI.

11. USNRC. 1995. *NRC Generic Letter 95-02: Use of NUMARC/EPRI Report TR-102348, "Guideline on Licensing Digital Upgrades," in Determining the Acceptability of Performing Analog-to-Digital Replacements under 10 CFR 50.59.* Washington, D.C.: USNRC.

12. USNRC (U.S. Nuclear Regulatory Commission). 1981. *USNRC Standard Review Plan (SRP), NUREG-0800, Chapter 13* (Revised in 1999) Conduct of Operations. Washington, D.C.: USNRC.

13. USNRC. 1981. *USNRC Standard Review Plan (SRP), NUREG-0800, Chapter 18* (Draft report for comment issued in 1996) *Human Factors Engineering.* Washington, D.C.: USNRC.

14. U.S. Code of Federal Regulations, Section 50.34 of Title 10 (10 CFR 50.34). *Contents of Applications; Technical Specifications.* December 1999. Federal Register, Washington, D.C.: U.S. Government Printing Office.

15. USNRC. 1981. *USNRC Standard Review Plan (SRP), NUREG-0800, Chapter 15* (Draft report for comment issued in 1996) *Accident Analysis*. Washington, D.C.: USNRC.

16. USNRC. 1996. *Human-system interface design review guideline. NUREG-0700, Revision 1*. Washington, D.C.: USNRC.

17. USNRC. 1994. *Human factors engineering review model, NUREG-0711*. Washington, D.C.: USNRC.

18. USNRC. 1999. *Advanced Information Systems: Technical Basis and Human Factors Review Guidance, NUREG/CR-6633*. Washington, D.C.: USNRC.

19. USNRC. 1999. *Computer-Based Procedure Systems: Technical Basis and Human Factors Review Guidance, NUREG/CR-6634*. Washington, D.C.: USNRC.

20. USNRC. 1999. *Soft Controls: Technical Basis and Human Factors Review Guidance, NUREG/CR-6635*. Washington, D.C.: USNRC.

21. USNRC. 1999. *Maintainability of Digital Systems: Technical Basis and Human Factors Review Guidance, NUREG/CR-6636*. Washington, D.C.: USNRC.

22. USNRC. 1999. *Human-System Interface and Plant Modernization Process: Technical Basis and Human Factors Review Guidance, NUREG/CR-6637*. Washington, D.C.: USNRC.

23. USNRC. 2000. *Advanced Alarm Systems: Revision of Guidance and Its Technical Basis. NUREG/CR-*. Washington, D.C.: USNRC.

24. Brown, W. S. 2000. *Update of NUREG-0700 Control Room and Work Place Environment Review Guidance (Draft).* BNL Technical Report W6835-T5-1-11/98. Upton, NY: Brookhaven National Laboratory.

25. Stubler, W. F., and O'Hara, J. M. 1996. *Group-View Displays. Functional Characteristics and Review Criteria (Draft).* BNL Technical Report E2090-T4-4-12/94. Upton, NY: Brookhaven National Laboratory.

26. *Personal communication*. July 2000. John O'Hara, Brookhaven National Laboratory.

27. DoD. 1999. MIL-STD 1472 F *Human Engineering.* Philadelphia: Defense Automation and Production Service.

28. DoD. 1999. MIL-HDBK-46855A *Human Engineering Program Process and Procedures*. Philadelphia: Defense Automation and Production Service.

29. DoD. 1998. MIL-HDBK-759C9C(2) *Human Engineering Design Guidelines*. Philadelphia: Defense Automation and Production Service.

30. DoD. 1996. Technical Architecture Framework for Information Management, *Volume 8: DoD Human Computer Interface Style Guide.* Washington, D.C.: Defense Information Systems Agency.

31. NASA. 1995. NASA-STD-3000 *Man-Systems Integration Standards, Revision B.* Houston: NASA Lyndon B. Johnson Space Center.

32. FAA. 1996. DOT/FAA/CT-96/1 *Human Factors Design Guide.* Springfield, VA: National Technical Information Service.

33. FAA. 1999. *The FAA Human Factors Job Aid*. Springfield, VA: National Technical Information Service.

34. U. S. Army. 1998. *MANPRINT Guidebook for Systems' Design and Assessment.* Washington, D.C.: U. S. Army.

35. ISO ISO/DIS 11064 *Ergonomic Design of Control Centres*, draft under development. Geneva, Switzerland: ISO.

36. Andresen, G., and Droivoldsmo. (March 2000). *Human Performance Assessment: Methods and Measures (Final Draft)*. Halden, Norway: OECD Halden Reactor Project.

37. *Personal communication*. May 2000. Fridtjov Owre. OECD Halden Reactor Project.

38. EPRI. 1987. *Display Design for Dispatch Control Centers in Electric Utilities: Handbook.* EPRI EL-4960. Palo Alto: EPRI.

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