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THE DEVELOPMENT AND EVALUATION OF HUMAN FACTORS GUIDELINES FOR THE REVIEW OF ADVANCED HUMAN-SYSTEM INTERFACES*

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Abstract

Advanced control rooms for future nuclear power plants are being designed utilizing computer-based technologies. The U.S. Nuclear Regulatory Commission reviews the human engineering aspects of such control rooms to ensure that they are designed to good human factors engineering principles and that operator performance and reliability are appropriately supported in order to protect public health and safety. This paper describes the rationale, general approach, and initial development of an NRC Advanced Control Room Design Review Guideline.

Introduction

Advanced control room (ACR) concepts are being developed in the commercial nuclear industry as part of future reactor designs. The ACRs will utilize advanced human-system interface (HSI) technologies that may have significant implications for plant safety in that they will affect the operator's overall role (function) in the system, the method of information presentation, the ways in which the operator interacts with the system, and the requirements on the operator to understand and supervise an increasingly complex system. The U.S. Nuclear Regulatory Commission (NRC) reviews the HSI aspects of control rooms to ensure that they are designed to good human factors engineering principles and that operator performance and reliability are appropriately supported in order to protect public health and safety. The principal guidance available to the NRC (NUREG-0700)[1], however, was developed more than ten years ago, well prior to these technological changes. Accordingly, the human factors guidance needs to be updated to serve as the basis for NRC review of these advanced designs. The purpose of this paper is to discuss the development of an NRC Advanced Control Room Design Review Guideline, hereafter referred to as the "Guideline." The term "Guideline" (with a capitol "G") refers to the entire document, while the term "guideline" refers to the individual guidelines within the document.

Evaluation Issues

In order to develop an approach to the evaluation of ACRs, it is necessary to consider: (1) standardization of design, (2) the trends in advanced nuclear power plants (NPPs), (3) the human factors issues that are associated with advanced technology, and (4) the state-of-the-art of human factors guidelines for advanced HSIs.

Standardized Designs

Over the past several decades commercial NPP design and construction in the US has resulted in considerably different plant, system, and control room (CR) designs across the industry. Likewise NRC reviews of existing control rooms have been directed toward the existing, as built, plant-specific equipment. Recently both the NRC and the utility industry have embarked upon an effort to standardize future NPP design. Toward this end the NRC has issued 10 CFR 52 in order to encourage standardization and to streamline the licensing process. Nuclear plant designers or vendors have begun the design of advanced standard plants, which are now being submitted to the NRC for review and certification under Part 52. If all were to proceed according to plan, then these standard plants, including the control rooms, would be approved and a utility could apply to build such a plant and merely reference the already approved standard design. This would result in control rooms which were essentially identical in NPPs in all future plants.

An early issue to arise from the review of the first standardized NPP control room submittal was the lack of a control room design sufficiently complete to allow a safety and human factors engineering design review by the NRC. Thus in order to proceed with the review and certification, the NRC had devised a process through which it would review the preliminary control room design material and also define a design implementation process whereby the control room detailed design would be completed by the utility that is building the standard NPP, in accordance with the approved design implementation process. The review of such a design implementation process was unprecedented, and evaluation criteria for such a review were not addressed by current regulations and guidance documents. Hence, these criteria needed to be developed.[21]

Thus, human factors engineering (HFE) reviews of advanced reactor control rooms must be capable of supporting both fully designed control rooms and through a specified design process plan, control rooms that are only in the conceptual design stage.

Trends in Advanced NPPs

Diversity in Advanced Reactor Technology: The current generation of commercial nuclear power plants (NPPs) operating in the U.S. numbers more than 100; all of those are based upon light water reactor technology. Although the next generation of plants will reflect advances on this technology base, the industry has also developed designs based on different technologies, including heavy water reactors, liquid metal reactors, and gas-cooled reactors. Some of these are proposed to be multiple units of smaller, modular reactors at a single site. One important design initiative to improve safety and reliability has been the move from active safety features (based upon active components such as pumps) toward more "passive" safety features (based upon natural physical processes such as convection flow, radiation cooling, and gravity). This plant diversity and the new passive features introduce new and different systems for operators to control, test, and monitor. There are questions as to how the reliable functioning of these passive systems can be verified (by the operators) during operation. Also, the role of the operator during transients and accidents changes considerably with these new passive systems. Important questions include: (1) How operators

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verify that these systems are ready during normal operation; (2) How proper operation can be confirmed when the systems are called upon; (3) What parameters should be monitored; and (4) What the proper operator response is when the passive systems do not function properly. Advanced NPPs will result in different operator roles and tasks, different CRs, and different operator-control interfaces. One implication of this diversity is that a narrow view and therefore a prescriptive approach to interface design based upon known operator tasks is not possible in an NRC guideline which must be capable of enabling reviews of all possible designs and a great diversity of operator functional roles in the system.

Control Room Evolution: There are several important trends emerging in advanced HSI design concepts in the nuclear industry, including: (1) greater use of automation and a corresponding shift of the operator's role in the system as monitor, supervisor, and back-up to automated systems; (2) greater centralization of controls and displays into "compact" digital work stations; (3) use of large display panels that can be seen from anywhere in the control room to present high-level information and critical parameters; (4) a primary operator interface with a data management system (DMS) with little interaction directly with components; (5) use of data integration and graphic displays; and (6) information processing and decision-support aids. As these trends are implemented, they will result in a further diversification of CR types from conventional to hybrid to advanced to "intelligent" CRs. Related to CR evolution is the wide range of technological approaches to HSIs in computer-based CRs. In part, this is due to the tremendous flexibility offered by software-driven interfaces to provide for alternative data processing, display and control. The NRC will need guidance to review new CRs and modifications to existing CRs which represent these industry trends.

Advanced Technology and Human Performance

While the use of advanced technology is generally considered to enhance system performance, computer-based operator interfaces also have the potential to negatively impact human performance, spawn new types of human errors, and reduce human reliability.[2,3,4,5] However, since the contributors to unreliability in an advanced control room are likely to be different from those which are present in conventional CRs, they are less obvious and generally less well understood.[6] Some of the factors contributing to the problems of integrating human operators and advanced systems are reviewed below.

General state of Knowledge: Despite the rapidly increasing utilization of advanced HSI technology in complex, high-reliability systems such as NPPs and civilian aircraft, there is broad consensus that the knowledge-base for understanding the effects of this technology on human performance and system safety is in need of further research.[7,8] The operating environment associated with advanced systems is very different from that of a conventional control room. Cognitive and human information processing issues are emerging as more significant than the physical and ergonomic considerations which dominated the design of conventional HSIs. While these issues have been recognized for a long time, their full implications for human performance and system safety have only recently begun to be addressed in research, and there is not a long history of operational experience upon which to draw. The National Academy of Sciences, for example, has identified areas such as automation, supervisory control, and human-computer interface as high priority research areas for the human factors community in general and for the commercial nuclear industry in particular.[7,8]

Allocation of Function and Automation: Many human factors problems originate early in the design process. Historically, functions were allocated to automated systems based largely on the capability of available technology to reliably and safely execute the function, rather than on the human operator's ability to perform as part of the overall system. This was true even though the human factors problems associated with automation had been known for some time[9] and the emergence of new types of human and system errors had been identified.[10] Increases in automation have been associated with a shift from physical to cognitive workload, with a loss of operator vigilance and a concomitant increase in vigilance-associated human errors,[11] with difficulty maintaining adequate "situation awareness,"[12] and with loss of skills to perform the task in the event of automated system failure. In part, many of these issues may be the result of a shift in the operator's role from that of an active, in-the-loop controller to an out-of-the-loop supervisor and monitor, together with a failure on the part of the HSI and system designers to adequately account for this shift.[13,14,15]

Advanced HSI Design: Computer-based HSI design requires, to a far greater extent than traditional control room designs, the specification of cognitive requirements and processing resources that the operator must utilize in task performance; i.e., cognitive task analysis. That information is needed for proper evaluation of the interface. Four aspects of HSI are primarily responsible for this requirement. First, information is typically presented in "predigested" form; i.e., raw data parameters are processed and integrated into a higher level of information, thus potentially obscuring their meaning. Second, the operator typically has much more information available which, if not properly organized and presented, can be overwhelming. Third, information is typically resident in a "virtual" work station, rather than in dedicated spatial locations spread out across control stations. Information is located somewhere in a computer system which provides only a glimpse of its contents (through a display device) at any one time. A poorly designed interface can make location of information and navigation through data difficult. Fourth, the flexibility of software-driven interfaces can increase the workload associated with managing the interface itself.

System Complexity and Operator Skills: NPP operations have always demanded a high level of skill and readiness on the part of the operating staff. These demands may increase, however, because of the need for operators to understand and evaluate the performance of advanced systems, to know their limitations, and to be ready to assume manual control when appropriate. There is a somewhat paradoxical relationship between these requirements and the day-to-day tasks that operators must perform, which in a highly-automated plant are predominantly monitoring functions. Thus, there is a risk that these carefully selected and highly trained operators may be required to perform a routinely boring and monotonous job.

Advanced HSI Guidelines Issues

Hardware vs. Software Guidelines: In an ACR, the physical layout of the display devices and computer input devices may be less important than the design of the human-software interface; i.e., the information management system and the methods with which information is displayed to the operator. This information can be displayed in a complex network of thousands of computer displays and flexible, operator-defined display formats. The difficulty of developing guidelines for human-software interfaces when compared with human-hardware interfaces has been elaborated by Smith.[16] Perhaps most significant to the evaluation of human-software interfaces is that the most important design features are often hidden to the reviewer and transparent to the operator, while important hardware design features are usually readily observable. For example, the observable display may be an end product of data integration providing higher-level, more abstract displays in contrast to the "single sensor/single display" characteristic of conventional CRs. As a result, while hardware guidelines tend to be relatively clear and specific, software guidelines tend to be stated in more general language.

Status of Guidelines for Advanced Technology: ACRs are based upon relatively new technology which is rapidly changing. Relative to the guidelines available for traditional hardware interfaces, the guidelines available for computer-based, software interfaces have a considerably weaker research base, and have not been as well tested and validated through many years of design application. Thus, the human factors guidelines available for the review of advanced CR technology are less firm and, as indicated above, typically stated in more general terms. Further, the cognitive task requirements, critical to human software interface design, are typically less familiar to designers and reviewers.[17,5] These characteristics of advanced technology guidelines can make the reviewers' job more difficult.[18]

Suitability of Guidelines for Evaluation: Another issue related to the maturity of advanced technology guidelines is whether evaluations based only on conformance to HFE guidelines provide a sufficient basis for review. Gould has indicated that, due to the nature of advanced human-system interfaces (as discussed above), a good system cannot be designed by guidelines alone.[19] A similar conclusion resulted from an effort to evaluate a computer-based system using only guidelines.[20] Evaluations need to be broader and, in terms of final design must include dynamic, real-time testing under simulated or actual operating conditions.

Proposed HFE Program Review Model

The issues discussed above have implications for the development of an approach to the safety review of the HFE aspects of advanced reactor designs. These implications are summarized below.

1. The Guideline should provide guidance for reviews to be performed throughout the design life cycle, i.e., proposed/conceptual design to final designs and periodic modifications during the life of such designs.

2. Reviews of the final HSIs should extend beyond checklist-based evaluations and should include validations of the fully integrated system under realistic, dynamic conditions using experienced operators performing the types of tasks the HSI has been designed for (including various types of failures and transient conditions).

3. The Guideline will have to provide for the review of a broad range of CR "types" and a diversity of approaches to advanced HSI technology. The Guideline should focus on human-software interface since this is where some of the most significant human performance issues reside.

4. Violations of human-software guidelines have been found to be more difficult to detect than violations of hardware guidelines. This places a greater burden on the judgement of the reviewer and the reviewer's ability to adapt and interpret the guidelines in the context of a particular review.

These factors have led to the development of a top-down approach to the review of ACRs. A generic HFE Program Review Model was developed based largely on applied general systems theory. Guidelines should be developed in four broad areas: HFE program planning, design analysis, HFE review, and dynamic evaluation. When used in total, the review process should permit the tracking of the design from initial conception through final design implementation. HFE Program planning refers to elements such as the organization of the human factors team and its role in the design process, the human factors program plan, and the specification of high level design goals and objectives. Design Analysis refers to elements such as the system analysis, function analysis, task analysis, technology assessments, allocation of function, specification of performance requirements, trade-off studies, development of design-specific guidelines, and tests/evaluations at the system/function or part-task level, including the use of human factors design and evaluation tools. HFE review of the HSI refers to the evaluation of control room interfaces according to currently accepted human factors design guidelines. Dynamic evaluation involves the use of full-mission, dynamic, real-time, system performance evaluation to ensure that the final design actually meets all design performance goals as an integrated operational whole. Guidelines are needed for this aspect of the review to assure that an assessment of human performance-related design goals and objectives using human performance variables is clearly incorporated into the test design and that the test plan is adequate from a human factors perspective.

Detailed guidance and acceptance criteria for the entire model have not yet been developed. The guidelines described below represent the detailed development of the HFE review guidelines.

Guideline Development Methodology

The Guideline development effort is composed of a primary "Guideline development" task and three related support tasks: electronic document development, test and evaluation, and new guidance development. Each is briefly described below.

A set of General Design Principles that depict the generic HSI characteristics necessary to support operator performance was identified. The General Design Principles are referred to as "Meta Guidelines," and include: effective screen organization, logical sequencing and grouping, consistency, meaningfulness, task compatibility, minimize memory load, minimize action, flexibility, feedback, and effective error handling. Since these principles are generic and stated at a fairly general level, they must be made more technology dependent and developed to a level of detail sufficient to support HSI review and evaluations. The general HSI principles were translated into terms that can be applied to specific applications by developing guidelines for the review of the specific types of technology (e.g., graphic displays, touch screens, and expert systems).

The effort to develop detailed guidelines began with an identification of human factors guidance documents for advanced HSIs. Through a review of the human factors literature and contact with organizations which sponsor such research, approximately 50 guideline efforts were identified. The next step was to select those documents that would serve as the "primary sources" for the initial set of guidelines to be incorporated in the NRC Guideline. A high priority was given to establishing the validity of the guidelines; i.e., assuring that they were based upon empirical research and/or accepted human engineering practice. Validity was defined in terms of two aspects of document development. "Internal" validity was evaluated by the degree to which the individual guidelines within a document were based upon empirical research and an audit trail to the research maintained. "External" validity was evaluated as a function of the degree to which the guidelines were subjected to independent peer review. The peer review process was considered a good method of screening guidelines for conformance to accepted human engineering practices. In general, documents which had strong validity were considered primary source documents to serve as a basis for the Guideline.

The Guideline is organized according to a structure similar to that of documents that focus heavily on HCI, but modified to accommodate HSI trends in advanced control rooms. The individual guidelines in the primary source documents were sorted into the various sections of the organizational structure. The guidelines were edited to combine similar guidelines and to transform the material into a standardized format. Where compound guidelines were encountered (several guidelines in a single statement) an effort was made to break them into logical units and represent the units as separate guidelines. Conflict resolution between guidelines was handled on a case-by-case basis. The seven major sections of the draft document include:

- **Information Display** - This section deals primarily with the formatting of visual displays, both text-based and graphicsbased. Guidance is provided in top-down fashion beginning with overall organization and layout, then the selection of type of display, display elements, and coding.

• **Operator Input and Control** - This section addresses information entry, operator dialogue, display control, information manipulation, and system response time. Considerations of display-control integration are also included here.

• **Alarms** - While this section contains several guidelines, it is essentially a place holder for the results of another NRC project. (The NRC has identified annunciators as a generic issue and initiated research to develop review guidance in the area of advanced alarm systems.)

• **Operator Aids** - Areas covered by guidelines in this section are prompts (including routine messages), operator guidance (feedback and on-line help), and decision aids (i.e., expert systems).

• **Inter-Personnel Communication** - This section contains guidelines for activities related to computer-mediated communication among the plant personnel, e.g., preparing, addressing, transmitting and receiving messages.

• **Information Protection** - This section contains guidelines pertaining to methods for ensuring the integrity of data accessed through the user interface . Guidance covers prevention of inadvertent change or deletion of data, minimization of data loss due to computer failure, and protection of data such as setpoints from unauthorized access.

• ***Workstation Design*** - This section is hardware-oriented and organized in bottom-up fashion beginning with guidelines on individual display and control devices, then continuing with the organization of those devices within an individual workstation, then finally treating the overall organization of the entire CR.

Within each section of the Guideline, individual guidelines are arranged into three tiers. Tiering was accomplished to aid reviewers in performing more efficient, less time consuming evaluations. The first tier contains guidelines that address the appropriate use (or contraindication) of a particular technology, equipment, methodology, or approach. These are called the "appropriate use guidelines." Not every section in the Guideline contains Tier 1 guidelines. The remainder of the guidelines were divided in two tiers of importance with respect to design safety review. Tier 2, called "leading indicator guidelines," contains guidelines that are more general, directly observable to a reviewer (without special equipment), and considered more significant in terms of their potential effect on operating crew performance than the Tier 3 guidelines. Tier 2 contains guidelines that (1) represent technology specific applications of the meta guidelines or (2) were not clearly tied to a meta guideline but were judged by the project staff as important. Tier 3 guidelines, called "detailed guidelines," were considered slightly less important than the Tier 2 guidelines and of ten represented finer levels of detail of more general Tier 2 guidelines.

The logic of using the tiers as part of a design review is as follows. Essentially the reviewer first evaluates the design feature for to its acceptability with respect to Tier 1 - Appropriate Use. If the reviewer concludes that the design represents an inappropriate use of the design feature, then the evaluation of that particular feature is terminated. The rationale is that if a design feature is inappropriately applied, there is no purpose to evaluating the further specifics of the design. If the display is acceptable at Tier 1, then the reviewer evaluates the design feature for Tier 2 guidelines. If the feature "passes" the Tier 2 guidelines, then the evaluation of the specific feature is terminated with an acceptable evaluation. Since Tier 2 are the more important guidelines, no further review at Tier 3 would be made. By similar logic, if the design feature "fails" the Tier 2 guidelines, no further evaluation need be made at Tier 3 unless the reviewer wishes to more specifically pinpoint the deficiencies. If the results at Tier 2 are equivocal, then the Tier 3 guidelines would be used to determine the ultimate acceptability of the design feature. The current tiering is considered preliminary and will be subject to further evaluation.

The Guideline is being developed in an interactive, computer-based as well as hardcopy form to facilitate guideline access and review, editing, compilation of individual guidelines for a specific review, and incorporation of new guidelines as they become available. Availability of the Guideline on a portable computer will also facilitate in-the-field reviews. In order to identify the Guideline requirements, an analysis was performed of the inspection task and the variety of ways the document might be used. These requirements were organized into four categories: general usability requirements; inspection task requirements; interactive, computer-based document functionality requirements; and general hardware requirements to support prototype development of the system. Based on the initial pass at requirements analysis, an Apple Macintosh™ computer and Hypercard™ software were selected for prototyping and testing.

Each guideline in the database is represented by several primary fields: guideline number, title, statement of the guideline, comment, assessment methods, source (link to primary source document), and classification (primary or secondary). Other user assistance fields are also available, e.g., to provide location (in the document) information and a note pad for users to append comments related to specific guidelines. The prototype user interface (see Figure 1) provides for many document functions such as instant table of contents (ToC) access, context index, glossary, and placemarkers. Users can automatically go to desired sections by clicking on the ToC or index entry. Guideline evaluation, evaluation summary and reporting functions are also available.

Guideline Evaluation

The Guideline is being evaluated with respect to its scope and technical content (i.e., its adequacy for the review of advanced control room technology), and usability (i.e., Guideline presentation, interactive document functionality, and user interfaces). Not all these evaluation objectives can be accomplished in one test. They will be accomplished across three evaluations, each using a different methodology. The first evaluation, the Development Test has been completed and is described below. The other evaluations are a User Test and peer-review workshop. They are not yet completed but their purposes are briefly described below.

Development Test

The Development Test provided a preliminary evaluation of the prototype Guideline and an opportunity to correct interface problems prior to subsequent testing. The purpose of the test was to assess the Guideline's technical content, user interface design, document functionality, and usability as a review aid evaluation.

The Development Test consisted of three types of evaluations: a function implementation evaluation, an HFE review, and a limited field test. The function implementation evaluation was designed to test the ease with which novice users understand the interface and could use the document's many functions. For the HFE review, the project staff evaluated the user interface design of the interactive document using the guidelines contained in the Guideline itself. The field test was designed so that the project team could evaluate the Guideline's technical content and interface for conducting an evaluation in a control room environment. A variety of data were collected during and following the evaluations, including rating scales, questionnaires, and both user and test conductor comments. The major findings are discussed below. It should be noted that the Development Test was not a formal experiment and that the results are based on a relatively small number of participants who were mainly project personnel. All results should be considered with this limitation in mind.

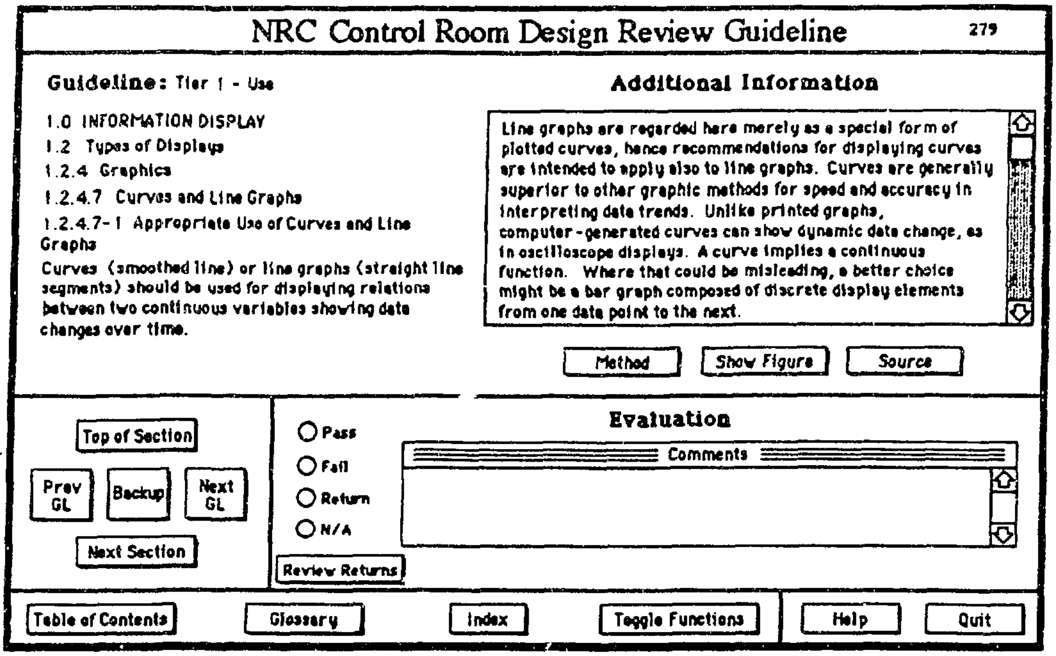

Figure 1. Prototype NRC Guideline User Interface

General Guideline usability was found to be quite good. Most interface characteristics thought to be indicative of usability (such as visual clarity, consistency, explicitness, ease of use, ease of learning and remembering, response time, etc.) were rated highly. Some difficulties were encountered, mainly in the areas of input devices, reporting and help functions. Thus, good progress has been made toward the design objective of developing a straightforward and intuitive interface for reviewers who are not already familiar with the host computer system.

While users indicated that improvements in screen design and organization could be achieved, the Guideline was judged to be easy to use and readable. Some inconsistencies in appearance and functioning across different display screens were noted. Most of the functions and controls were evaluated as highly useful and easy to use. The exception to the highly useful category was the glossary function. Since the glossary was not tailored to the Guideline, many terms for which definitions were needed were not present. In addition, several controls/functions were evaluated as not being easy to use. These included the evaluation function, information input functions, and the reporting function. The evaluation function was hindered by the lack of adequate guideline selection support. In addition, users indicated a need for a method of identifying applicable guidelines for which they were unable to make an immediate pass/fail determination, i.e., it was considered important to be able to distinguish "pending" evaluations from guidelines that were judged "not applicable" or those that the reviewer had not yet accessed. The exclusive reliance on the mouse/trackball for evaluation and navigation functions was considered time consuming and tedious. Most users indicated a desire for using command (keyboard) inputs for these functions. Finally, the reporting function did not always work properly and was very time consuming.

The technical content of many guidelines was sufficiently abstract as to create difficulty when used for evaluation purposes. This problem reflects a generally recognized limitation of guidelines in the area of advanced technology human-system interface and of human-computer interface guidelines in particular. The reasons for this problem are many and include limitations in the technical basis for guidance development due to deficiencies in both scientific knowledge and industry experience with advanced technology. Inconsistent wording also contributed to the users' difficulty with some guidelines. In addition, the guidelines were judged to be too detailed in some areas and to contain some redundancy. While an effort to correct these problems had been made prior to the Development Test, there were over 1900 guidelines and the complete elimination of all redundancy and the clarification of all terminology had not been fully accomplished in advance of the test.

Based upon these results, modifications were made to the technical content of the guidelines. In addition, the inspection/review screen design and the interactive document's functionality was improved. The Guideline was also reviewed technically in order to eliminate redundancy and revise technical terminology to ensure consistency throughout the document, and to organize the guidelines into tiers (as described in Section 3).

These modifications resulted in the present version of the Guideline (Revision 2).

<u>User Test</u>

The User Test is presently underway and is a field test of the Guideline in an environment of greater fidelity to an advanced control room. It encompasses a greater diversity of advanced control room technologies than the Development Test. The User Test also utilizes representative advanced control room reviewers to conduct the evaluation rather than the project staff. Therefore, the User Test is a simulation of the actual Guideline utilization. Both technical content and Guideline implementation objectives are being assessed. With respect to technical content, the objectives of Guideline scope and Guideline content are being evaluated. Since the test participants are novice with respect to use of the interactive, computer-based document, the User Test is well suited for evaluation of the Guideline implementation objectives. The results of the User Test will be used to develop recommendations for Guideline modification.

<u>Peer-Review Workshop</u>

The third evaluation is a Peer-Review Workshop. The individuals will be selected based upon their expertise in at least one of the following: (1) human factors evaluations for advanced systems, (2) inspections of NPP CRs, (3) NRC regulatory reviews and issues, and (4) advanced nuclear power plant control room technology. Thus the Guideline will be evaluated by independent experts. The workshop will provide a different type of evaluation than the two testing tasks and will address the broader aspects of the Guideline, such as the general approach to advanced control room review and the Guideline value in meeting the NRC's need to evaluate advanced HSI. The workshop will assess objectives which cannot be adequately addressed in the other T&E tasks, i.e., the validity and technical basis for the Guideline.

Results from the User Test and workshop will be used to modify the Guideline into Revision 3. At that time, the first complete draft of the Guideline will be completed.

New Guideline Development

In part, the identification of areas where new guidelines are needed is accomplished by finding a mismatch between the scope requirements of the Guideline and the individual guidelines obtained from the primary sources. The preliminary identification of areas needing further guideline development includes user interface requirements for: supervised automation, intelligent operator aids, interface management and navigation, virtual image displays, visual display hardware such as flat panel displays, screen design for graphic presentation of information, new input devices, and selected nuclear-specific applications.

Future Development

The approaches established to review, develop, and integrate additional information into the Guideline will be an ongoing task in order to ensure that the document always has the most up-to-date and valid human factors review guidance. Since the technology is rapidly changing and the nuclear industry's experience (as well as that of other application areas) will be increasing, the Guideline will need to remain a living document in order to meet NRC needs.

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