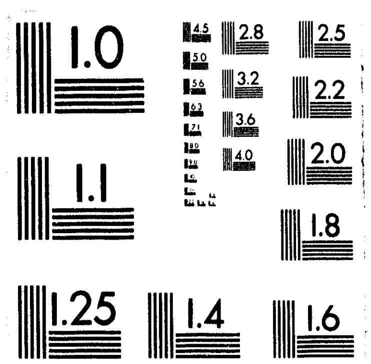

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THE IMPORTANCE OF SIMULATION FACILITIES FOR THE DEVELOPMENT OF REVIEW CRITERIA FOR ADVANCED HUMAN SYSTEM INTERFACES*

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ABSTRACT

Advanced control room (ACR) concepts are being developed in the commercial nuclear industry as part of future reactor designs. The ACRs will use 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 to protect public health and safety. The NRC is developing guidelines to support their review of these advanced designs. As part of this effort, a methodology for guidance development was established, and topics in need of further research were identified. Simulators of various kinds are likely to play important roles in the development of review guidelines and in the evaluation of ACRs. This paper describes a general approach to review criteria development, and discusses the role of simulators in addressing research needs.

INTRODUCTION

Advanced control room (ACR) concepts are being developed by the major nuclear steam supply system (NSSS) vendors as part of future reactor designs. Although each vendor's proposed ACR approach is different, all will use 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 a complex control 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 principles and that operator performance and reliability are appropriately supported in order to protect public health and safety. The HSI should be designed to support the operator's primary task of monitoring and controlling the process without imposing excessive secondary task workload demands associated with managing the interface itself; tasks such as window manipulation, display selection, and navigation. The HSI should also support recognition and tolerance of human error, and recovery from such errors when they do occur. The NRC Advanced HSI Design Review Guideline (DRG) (O'Hara and Brown, in preparation) was developed to provide criteria, in support of the NRC's review of advanced designs, for determining whether these design goals have been achieved. The DRG has been developed, to date, by selecting and/or adapting, wherever possible, proven guidelines previously developed for use in other applications. During the DRG development effort, however, it became clear that existing guidance in certain technological areas was either inadequate or unavailable, and that a methodology was therefore required to develop new review guidance in these areas. This paper describes the approach taken in the development of review criteria in general, and discusses the important role of simulation facility support for the development and validation of new HSI review guidance.

THE APPROACH TO GUIDELINES DEVELOPMENT

The methodology that was developed to prepare HSI review guidance had, as its goals, cost-effective development and the assurance of the validity of the resulting criteria. To achieve these objectives, relevant

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portions of acceptable existing guidelines were utilized whenever possible.

First, available guidance documents in the public domain were identified. From this list, an appropriate subset was chosen to serve as the basis for an initial set of guidelines. This subset was selected based upon an evaluation of the internal and external validity of all available documents.**

From their internal and external validity rankings, documents were sorted into primary, secondary, and tertiary categories. In general, those documents with high internal and external validity were considered primary; those that had either internal or external validity, but not both, were considered secondary; and those that had neither internal or external validity were considered tertiary sources.

This rigorous selection process ensured that only those existing review guidelines with strong validity could serve as a basis for the DRG. The disadvantage of this approach, however, was that many existing guidelines did not meet our criteria; thus the breadth and depth of the resulting review guidance was restricted in many HSI areas, particularly those which had experienced recent and dramatic technological advances. This led to an approach for the development of new review guidance in areas not yet addressed by validated guidelines. Development of such new guidance was complicated, however, by the fact that internal and external validity would have to be established as part of the guidance development process itself; such validity could not be "inherited" as was the case in the first phase of the effort, i.e. when the principal sources were the primary guideline documents. Table 1 contains a list of technical areas in which existing guidance is either inadequate or nonexistent.

The process for new guideline development in areas that cannot benefit from existing primary source documents is rather labor-intensive. This process is depicted in Figure 1. First, appropriate guidance is sought in secondary or tertiary sources. If this search proves unsuccessful, results from basic literature (articles from refereed technical journals, reports from research organizations, and papers from technical conferences, for example) can be analyzed to serve as a technical basis for guidance development. Industry experience is another potentially valuable source for identifying human performance issues and tested design solutions that may be relevant. This information may be obtained from sources such as published case studies and surveys/interviews with knowledgeable domain experts. Although this information may lack a rigorous experimental basis (and thus a measure of validity) it does have the benefits of relevance and face validity.

Table 1. Technical Areas for Which Current Guidelines are Inadequate

Alarm systems
Graphical presentation of NPP information
Computer-based procedures
Automation interface monitoring and control methodologies
Interface management and navigational strategies
Large screen displays
Knowledge-based systems and intelligent operator aids
Flat panel display characteristics
VDU hardware characteristics
Soft switches and multifunction displays/controls
Computer-based workstation integration
Computer-based control room layout and environment
Test and maintenance of digital systems

Finally, if sufficient data does not exist in the sources described above, or when additional experimentation is needed to provide supporting evidence, it may be necessary to conduct original research. Although labor intensive, such research has the advantage of being focused on specific issues of interest. Thus, interpretation of the results can be more direct. Original research, therefore, has both high relevance and a sound experimental basis from which to establish validity.

Regardless of which method (or combination of methods) is used to develop new guidelines, once the draft set of guidelines has been developed, they must be evaluated for validity. In order to support such validation studies, each draft guideline should contain the specific

**"Internal" validity was defined as the degree to which individual guidelines were based upon empirical research or data. The presence of an audit trail to the supporting data, so that a guideline's technical basis could be assessed, provided additional assurance of internal validity. "External" validity was defined as the degree to which the guidelines had been subjected to independent peer review. The peer review process was considered a good method of screening guidelines for conformance to accepted human factors practices.

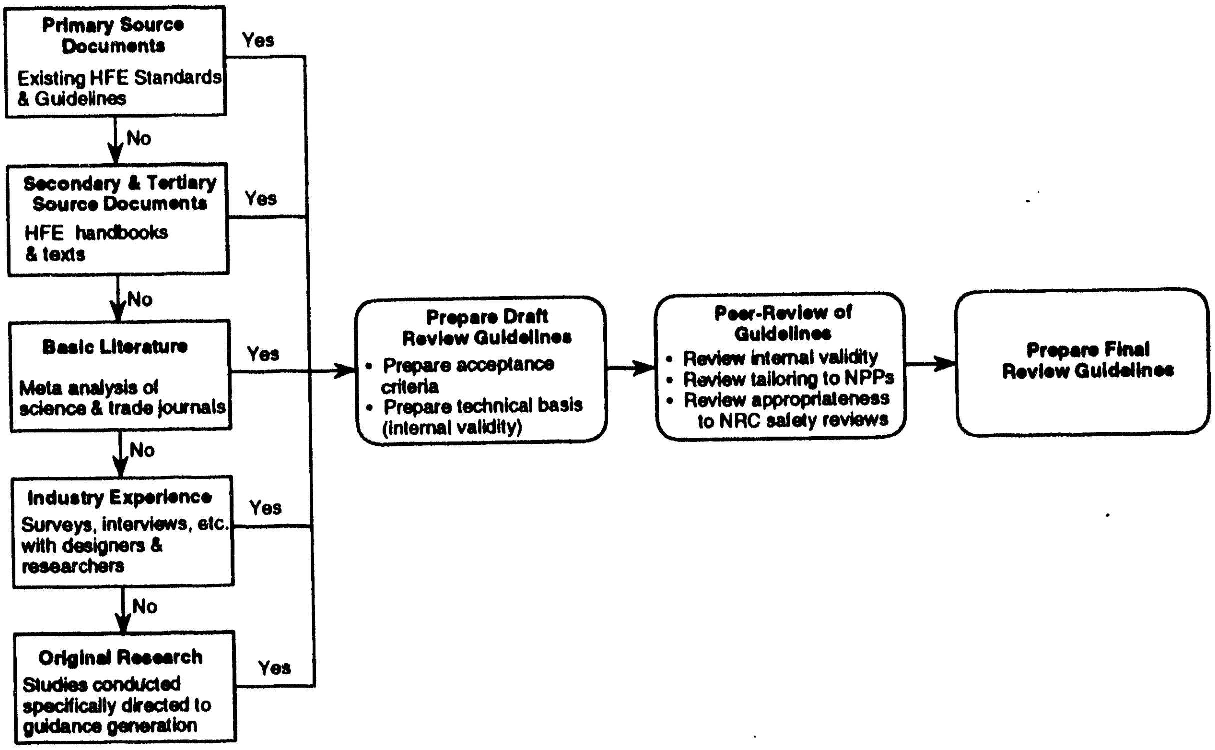

Figure 1. Review guidance development methodology

acceptance criteria that would be used by an NRC reviewer, and each should clearly identify the technical basis upon which it was formulated. This will provide the basis for evaluation of the guideline's internal validity. The guideline's technical basis will vary depending on the source material upon which it was based. A peer-review panel of subject matter experts should evaluate: (1) the internal validity or technical basis of the guidance, (2) the tailoring of the guideline to nuclear power plants (NPPs), and (3) the appropriateness of the guideline to NRC safety reviews. This peer-review constitutes the external validation of the guidelines.

ALARM SYSTEM GUIDANCE DEVELOPMENT: A CASE STUDY

As stated above, the first phase of development of the DRG was based mainly on primary source documents which were tailored to the nuclear industry, field tested, and subjected to peer-review. In contrast, the development of guidance for the review of advanced alarm systems is more complicated. The brief case study presented below provides an example of how the complete methodology, as outlined in Figure 1, would be employed in the development of guidelines where current guidance is inadequate.

Traditional nuclear power plant annunciator systems employ a "single sensor - single alarm" framework. The human factors weaknesses of such systems have been well documented over the years (e.g, MPR 1985; Seminara 1988), and include problems such as alarm overload during plant upsets, redundant alarms and nuisance alarms. Advances in digital instrumentation and control have provided the opportunity to overcome the human factors weaknesses of traditional annunciator systems by permitting the development of advanced alarm systems in which alarm data are processed in some way before they are presented to the control room crew. The processing can be simple, such as the filtering of plant mode-dependent alarms, or complex, such as dynamically prioritizing alarms based upon unfolding events. The defining feature of an advanced alarm system, however, is its capacity to assist the operator by processing alarm data prior to its presentation. This technology has the capability to correct many known alarm system deficiencies, and may be used in new plants as well as in backfits to existing plants. Thus, while it is clear that guidance for the review of advanced alarm system design is needed, there is general agreement in the literature that there is an "international lack of guidance and requirements for alarm systems" (Kennedy 1989).

In support of NRC guidance development, a review of the literature on alarm system design features and their effects on operator performance was conducted (O'Hara, Brown, and Kim 1991). The results indicated that there are many HFE issues associated with advanced alarm systems. Issues were defined as topics for which: (1) specific problems were identified, (2) conflicting findings were found in the literature, or (3) there was a lack of data addressing the issue. Primary, secondary, and tertiary documents were evaluated for their technical merit and applicability. Where guidance could not be obtained from these sources, the results of basic literature were reviewed and evaluated. In addition, available information about industry experience was obtained from published surveys and interviews. The results of this effort were compiled into an alarm system review guideline (O'Hara, Brown, and Higgins, in preparation).

A comparison of the previously identified human performance issues with the guidance available in the alarm system review guideline indicated, however, that, despite this comprehensive approach to guidance development, not all of the performance issues had been adequately addressed. Therefore it was concluded that the safety impact of significant aspects of advanced alarm system design on operating crew performance was unknown.

These remaining human factors issues were prioritized to determine the most significant (Brown and O'Hara 1992). Following an approach to prioritization similar to that used by the National Academy of Sciences in its review of human factors research needs in the nuclear industry (Moray and Huey 1988), prioritization of alarm system issues was based on two dimensions: potential impact on operator performance, and need for issue resolution to support near-term NRC reviews. Based on this analysis, the issues associated with visual display of alarm information and simple alarm processing prioritization/filtering methods were rated as the highest priority, and a research project was designed to study them (O'Hara 1993).

The overall purpose of this research is to evaluate the impact of alarm system design characteristics on plant/system and operator performance, to better understand the potential safety issues involved, and to provide data to support the development of design review guidelines in these areas. Three alarm system design factors will be evaluated: (1) display type, (2) processing methods (alarm reduction and generation methods), and (3) availability of processing results.

Display type refers to the mode by which alarm information is presented to the operator, e.g., spatially dedicated/permanent displays or some combination of these with alternative VDU-based presentations such as alarm lists and integrated alarm-process display presentations. Alarm processing refers to the alarm analysis that is conducted by the system prior to presentation of data to operators; processing impacts the degree of alarm reduction achieved since some processing methods reduce the overall number of alarms that occur during an off-normal situation while others generate alarms which may actually increase the overall number. In this study we will evaluate a variety of methods which focus on likely near-term implementation, and, therefore, near-term regulatory review considerations. Finally, the availability of alarm processing results will be examined, i.e., the differential effects of several key processing techniques such as dynamic prioritization, suppression, and filtering.

THE IMPORTANCE OF SIMULATION FACILITIES IN GUIDANCE DEVELOPMENT

At the time of this writing, several facilities have been considered for the alarm system study, but none have yet been selected. The human performance issues to be addressed, together with the complexity and dynamic nature of the process in which that performance must realistically be measured, are not unique to this project. They are similar to human factors issues that increasingly arise as more attention is paid to the performance of operators in advanced nuclear power plants. These issues include: information overload, development and maintenance of situation awareness, and pattern recognition. Measurement of the effects of alarm system design on human performance must account for time constants (e.g., rapid search for detectable patterns), system complexity, and the operators' expertise. Therefore, high-fidelity (although not necessarily full-scope) simulation, and representative test subjects (e.g., control room operators) are needed in this project.

With specific regard to the forthcoming alarm system study, the required support facility characteristics include:

- *Process Model* - An HSI driven by a model representing a complex process that can simulate a representative range of operating modes from normal operations to complex transients and accident situations.

- *Alarm System* - The capability to simulate the different alarm conditions being studied is needed. Since these will vary across experimental conditions, configuration flexibility (including rapid reconfiguration) in alarm system presentation is required - both for display and availability characteristics. A relatively high fidelity of simulated alarm system characteristics is needed.

- *Participants* - Professional nuclear power plant operators (or equivalent surrogates) who are experts in the process modeled are required to serve as test subjects.

- *Control Room/HSI* - A control room is required to present non-alarm HSIs such as process displays, parameter indications, and controls. The control room should be sufficiently functional to allow operators to view plant parameters that confirm alarm conditions or which show that plant parameters are trending toward alarm conditions. In addition, some means of controlling the process is necessary. (A "high-fidelity" control room, i.e., equipment and layout similar to an actual plant, would be valuable but is not a requirement for this research project).

- *Data Collection* - To support the evaluation, extensive data must be collected including: plant, system and operator performance parameters; operator cognitive behavior, including measures of situation awareness and workload; and subjective evaluations. The data collection package must include the ability to record: selected process parameters; operator performance measures at the workstation; direct and videotaped observations, and participant responses to questionnaires/interviews.

- *Briefing/Debriefing Facilities* - Quiet, confidential facilities will be needed to brief study participants on the alarm system characteristics being simulated and, after their participation in the study, to debrief them to obtain their evaluations of their experience.

- *Experimenter's Station* - Space will be needed to allow the test conductors to unobtrusively observe the participants during testing sessions.

The specific requirements as stated above are unique to this project, and the choice of facilities and personnel has not yet been made. The facility, personnel, and support system requirements will vary depending on the research questions asked and the context in which performance must be assessed. For example, a research need addressing more basic human capabilities, limitations, or performance, would require lower fidelity in system modeling than in the present case. For final "proof of concept" testing, however, or where highly integrated systems must be evaluated, high-fidelity plant models, HSI, and test scenarios will potentially be required, as will actual operators.

CONCLUSIONS

Development of the NRC advanced control room design review guideline has been underway since 1989, and the first phase of the DRG will be published shortly. For the reasons discussed earlier in this paper, this DRG will not include guidelines for the review of advanced technologies for which no existing, validated guidelines have been found that are relevant to the nuclear power plant environment. Some of these guidelines will have to be developed, and once developed, will have to be validated before they can be incorporated into the DRG. The availability of suitable facilities and personnel to support this work will be important.

ACKNOWLEDGEMENTS

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