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ADVANCED HUMAN-SYSTEM INTERFACE DESIGN REVIEW GUIDELINES

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ABSTRACT

Advanced, computer-based, human-system interface designs are emerging in nuclear power plant (NPP) control rooms. These developments may have significant implications for plant safety in that they will greatly affect the ways in which operators interact with systems. At present, however, the only guidance available to the U.S. Nuclear Regulatory Commission (NRC) for the review of control room-operator interfaces, NUREG-0700, was written prior to these technological changes and is thus not designed to address them. The objective of the project reported in this paper is to develop an Advanced Control Room Design Review Guideline for use in performing human factors reviews of advanced operator interfaces. This guideline will be implemented, in part, as a portable, computer-based, interactive document for field use. The paper describes the overall guideline development methodology, the present status of the document, and the plans for further guideline testing and development.

BACKGROUND

Advanced, computer-based, human-system interface (HSI) designs are emerging in NPP control rooms as a result of several factors. These include: (1) incorporation of new systems such as safety parameter display systems, (2) backfitting of current control rooms with new control and display technologies when existing hardware is no longer supported by equipment vendors; and (3) development of advanced control room concepts as part of new reactor designs. Control rooms of the future will be developed almost exclusively with advanced instrumentation and controls based upon digital technology. In addition, the operator will be interfacing with more "intelligent" systems which will be capable of providing information processing support for his tasks. These developments may have significant implications for plant safety in that they will affect the operator's role in the system as well as the ways in which he interacts with it.

The introduction of advanced instrumentation and control (I&C) technology holds great promise to improve the safe operation of NPPs. The potential advantages of advanced technology over conventional control room technologies are compelling:

- Rapid, highly reliable validated data transfer,
- Highly accurate and precise digital data displays,

- Large amounts of data at the operator's fingertips,
- Data integration providing the operator with high-level information such as overall system status,
- Parameter trending displays,
- Color graphic displays to facilitate the operator's assimilation of important information,
- Increased opportunities for decision aids and automation, and
- Information presentation in a compact workstation.

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 (i.e., Coblentz, 1988; Rasmussen, Duncan, and Leplat, 1987; and Weiner and Nagel, 1989). However, since the contributors to unreliability in an advanced control room are different from those which are familiar contributors to human error in conventional control rooms, they are less obvious and generally less well understood (see O'Hara and Hall, 1990, for a more detailed discussion of this topic). Among those factors most frequently associated with potentially negative influences on human performance in advanced computer-based systems are:

- Shift from physical to high cognitive workload leading to impaired monitoring and inability to process all relevant data,
- Increase in the cognitive workload associated with managing the interface (e.g., opening, positioning, scaling windows),
- Loss of operator vigilance in automated systems resulting in reduced ability to detect off-normal situations,
- Loss of "situation awareness" making it difficult for the operator to assume direct control when required,
- Loss of skill proficiency for the occasional performance of those functions which are typically automated,
- Loss of the ability to utilize well-learned, rapid eye scanning patterns and pattern recognition from spatially fixed parameter displays (a particular problem with highly flexible interfaces), and
- Difficulty navigating through information presented in a computer-based workspace (i.e., information that is in the computer system and must be accessed rather than always present in fixed position indicators).

To help assure that advanced technology is incorporated in new and existing control rooms in a way that maximizes the potential safety benefits of the technology and minimizes the potential negative effects on performance and plant safety, the NRC reviews the design and implementation of significant changes to control rooms and the human engineering aspects of new control room designs. At present, however, the only guidance available to the NRC for the review of control room-operator interfaces is NUREG-0700. It is a document which was written prior to these technological changes and is, therefore, tailored to the technologies used in "traditional" control rooms. Thus, the present guidance needs to be updated since it is not adequate to serve as the basis for NRC staff review of such advanced or hybrid control room designs.

While there is indeed much still to be learned about the effects of advanced technology interfaces on human performance, there have been many government, industry, and professional groups (e.g., NASA, DOD, Human Factors Society), in addition to those efforts within the nuclear industry, which have initiated development of guidelines and evaluation methodologies for the incorporation of advanced technology at the human-system interface. Several of these efforts have involved multi-year studies with extensive peer review and revision. While it is recognized that the human-system interface in NPP control rooms is, in many ways, unique, a critical review and incorporation of relevant portions of prior (and ongoing) efforts in other fields would maximize the speed and minimize the cost of NRC's needed guidelines development effort. Such an approach will enable the available resources to be specifically directed toward resolving those issues which are either unique to NPPs or which have not been adequately addressed by available guidelines. Further, there are many similarities between advanced control rooms and other advanced workstation applications such as telecommunications network control rooms, space-based workstations, advanced aircraft cockpits, and "command, control, communications and intelligence" (C3I) workstations. This trend toward increasing similarity of command and control complexes for diverse applications has been referred to as "convergent evolution" (Weiner, 1988) and is, in part, being brought about by digital technology. Thus, while there will remain many unique aspects to NPP operations, modern approaches to control room design share much in common with design of other types of control complexes, thus providing a further benefit to and effort which reviews and incorporates previous work from other fields.

The objective of the project reported in this paper is to develop a first draft of an NRC Advanced Control Room Design Review (ACRDR) Guideline suitable for use in performing human factors reviews of advanced operator interfaces in NPPs. This phase of the project is principally directed toward the review and integration of the advanced human factors technology guidelines efforts available from both within and outside the nuclear industry into an ACRDR Guideline. This guideline will take the form of a portable, interactive, computer-based document that may be conveniently used by an inspector in the field, as well as a text-based document. However, because many of the advanced technologies are new and/or rapidly changing, and firm guidelines about their implementation in complex control rooms have not yet emerged, it is intended that the Guideline be a "living document," one that may be readily updated as further advances are made in the state of the art of control room design.

The remaining sections will describe the overall guideline development methodology, the present status of the document, and the plans for further guideline testing and development.

ACRDR GUIDELINES DEVELOPMENT METHODOLOGY

The guideline development effort is illustrated in Figure 1. The program is basically divided into three sets of related activities. First, an initial set of guidelines is developed which is based upon an analysis of the general requirements of advanced control room review and a review and analysis of existing human factors guidelines. Second, the guideline document is defined, developed, and tested. Third, since technology transfer will serve as the basis for document development in this phase of the project, the areas where additional guidance is required will be identified and the guidelines to support reviews in these areas will begin to be developed.

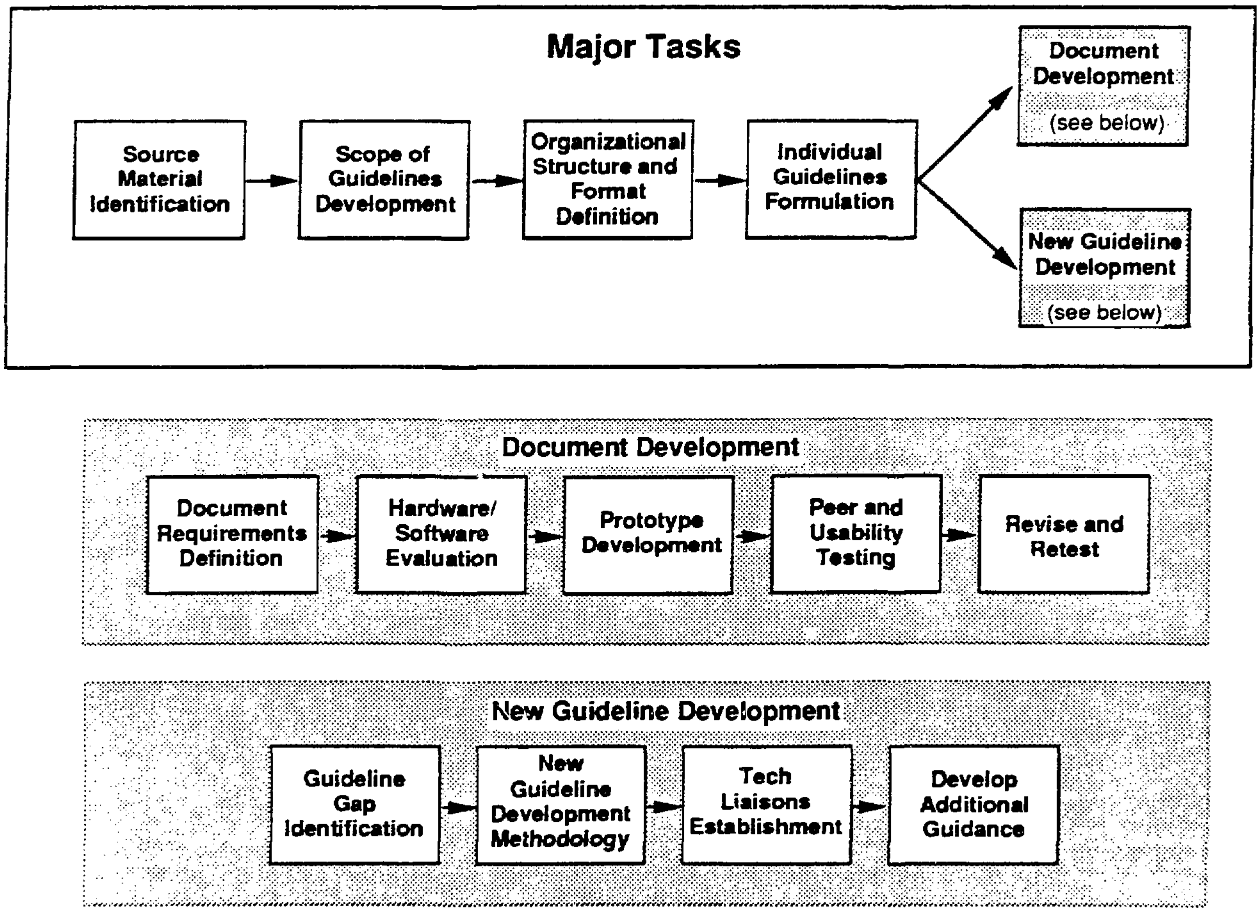

Figure 1. ACRDR guidelines program

At the present time, we are in the document development stage. The initial set of guidelines has been compiled, and prototyping of the electronic document interfaces and functionality has been accomplished. The first test, evaluation, and revision cycle is about to begin.

Source Material Identification and Selection

The objective of this task was to identify human factors guidelines for advanced HSI technology and selection of those guidelines which would serve as the basis of the ACRDR Guideline. The search process was composed of: (1) a search of the human factors literature including journal articles, conference papers, special interest group newsletters, and announcements of recent publications for books, manuals, etc.; and (2) direct contact with organizations which sponsor such research as well as individuals in the field of advanced human factors technology.

Three general criteria were used to facilitate the identification of guidelines projects for consideration in this project. First, no effort was made to identify documents developed before 1980 since HSI and computer technology have so dramatically changed in the last decade that many of the guidelines published in the 1970s are not applicable to today's technology, and those that were appropriate were absorbed in guidelines documents developed in the 1980s, including NUREG-0700. Second, for this stage of the project, very specialized documents were not included because they are typically based on guidelines drawn from more well-known guidelines, and where they presented new guidelines, their validity could not be evaluated. Documents in this category include guidelines such as those prepared in support of a specific piece of equipment or a specific system. Third, a "finer net" was used to evaluate applicable documents in the nuclear industry. That is, almost any nuclear industry document suggesting recommendations or guidelines for advanced HSI technology was sought, while such a fine resolution search was not performed to identify such guidelines from other applications. For example, NUREG/CR-3987 (Rankin et al., 1985) on computerized annunciator systems contains general guidelines for such systems and was identified in the search process. Similar documents outside of the nuclear industry would not have been captured in the search process at this stage of the project.

Information on each effort was entered into a computerized database containing information such as: contact person, document title, document number, publication date, performing organization, sponsoring organization, status (completed, draft report, or work-in-progress), availability (available or not available for release), and a synopsis of the document's contents. The available documents for all projects were solicited and obtained where available.

Over 50 guideline efforts were identified. The great emphasis of the documents is on human-computer interaction (HCI) with the more recent emphasis on the human-software interface. Many of the hardware aspects of HCI were elaborated in earlier guidelines, although there are some exceptions to this as well (such as for computer input devices like the mouse and touch screen). It was also observed that there has been a great increase in the number of books that have been published recently on general HCI guidelines and on user interfaces with intelligent systems, such as expert systems. These texts, however, are generally limited in terms of the research justification provided for individual guidelines (i.e., individual guidelines are not linked with references validating their use).

Once ongoing guideline development 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 ACRDR document. In the selection of primary source documents and subsequently the selection of individual guidelines, a high priority was given to establishing the validity of the guidelines, i.e., assuring that the guidelines were based upon empirical research and/or accepted human engineering practice. Validity was defined in terms of two aspects of potential source document development which loosely correspond to the empirical research support and conformance with accepted human engineering practice. "Internal" validity was evaluated by the degree to which the individual guidelines within a document were based upon empirical research and an audit trail maintained in the documentation from each guideline back to the research upon which it was based. "External" validity was evaluated as a function of the degree to which the guidelines were subjected to outside peer review. A document which had undergone extensive peer review prior to publication was considered to have external validity. Such a review process was considered a good method of screening guidelines for conformance to accepted human engineering practices. Internal and external validity were evaluated at the document level and not at the level of individual guidelines.

In general, documents which had both good internal and external validity were considered primary source documents. Documents which had either good internal or external validity (but not both) were classified as secondary sources. Finally, documents which had neither internal or external validity were considered tertiary sources. This classification was used to specify the use of the documents in the guidelines compilation process. The primary source documents were used as a basis for the first draft of the ACRDR guideline document and the guidelines coming from these sources were considered "firm." Where the primary sources were lacking needed guidance, the secondary sources will be consulted. However, guidelines from the secondary source documents will be considered "tentative." The tertiary documents are not expected to be used since neither their internal or external validity is established. If such a source is used for any reason, the resulting guideline would be classified as "weak" in validation.

Based upon this classification scheme, the documents rated as primary sources of guidelines were (the full citations to these documents are provided in the "References" section of this paper):

- Department of Defense Human Engineering Design Criteria (MIL-STD-1472D)

- Department of Defense Management Information Systems Guidelines Handbook (DOD-HDBK-761A)

- National Atmospheric and Space Administration Man-Systems Integration Standards (NASA-STD-3000)

- National Atmospheric and Space Administration Human Computer Interface Guidelines (NASA-USE-1000,V2.1)

- Smith and Mosier's User-System Interface Software Guidelines (ESD-TR86-278)

- American National Standards Institute Video Display Terminal Workstations Standard (ANSI/HFS 100-1988)

- Gilmore et al., User-Computer Interface for Process Control Guidelines (1989; based on NUREG/CR-4227)

While internal validity (research basis) and external validity (peer review) are important factors, there are additional factors which affect a document's priority within a class. Thus, a more fine-grained prioritization procedure was developed that included three additional factors:

- *Authorship:* A document was considered higher priority than another if it was developed by a panel of experts under the auspices of a recognized institution (such as the Human Factors Society) than if it was developed by a small group of authors.

- *Recency:* A document was considered higher priority than another if it was developed recently (1985-present) than if it was developed prior to that (1980-1984).

- *Industry:* A document was considered higher priority than another if it was developed for the nuclear industry than if it was developed for another industry.

When these three factors are combined with the first two factors, a 32-level prioritization system results. Each of the documents in the database was rated by priority and that information was coded in the database. The priority rating was used to guide the order of document utilization and to facilitate the resolution of conflicting guidance that may appear between documents.

Scope and Structure of the ACRDR Guidelines

The main purpose of this task was to identify the scope of technology that needs to be addressed in the ACRDR Guideline. It was based upon a review of: (1) the types of advanced technologies utilized in control room design; (2) new and emerging approaches to information display and management; (3) the types of advanced I&C systems that are under development; and (4) the human factors issues that have been associated with these emerging technologies. Several sources of information were reviewed, including:

- Nuclear industry related research reports and articles from the past several years on advances in control room technology,

- Information available on several advanced control room designs,

- General guidance developed in the nuclear industry for the design of advanced control rooms, e.g., EPRI (1989) and IEC (1989),

- Reports of nuclear industry surveys on the use and intended applications of advanced instrumentation and controls both internationally (e.g., Kennedy, 1988) and in North America (e.g., Carter & Uhrig, 1989), and

- Existing advanced-technology, human-factors guidelines.

Two important themes emerged from the review of the information. First, there is a trend toward the development of compact, computer-based workstations as the locus of control room operations. Typically, these workstations include elements such as centralized and integrated controls and displays, color graphics, high levels of data integration, display devices such as CRTs and flat panels, new input devices such as the mouse and touch screen, multifunction ("soft") controls, workstation flexibility, and an emphasis on information management and software-interface issues. These characteristics are often discussed as representing advances in the control room.

The second trend was the development of intelligent operator aids based on expert systems and other artificial intelligence-based technologies. These applications include aids for alarm processing, diagnostics, accident management, plant monitoring, and procedure tracking. In fact, many of the recently published articles on advances in NPP control room technology specifically address intelligent operator aids.

These trends are consistent with general trends in advanced monitoring and control workstations for a diversity of complex systems throughout the human factors community.

Organizational Structure and Format Definition

Before developing an organizational structure for the ACRDR Guideline, we examined the approaches used in other documents that provide advanced human factors guidelines. The structure needs to remain fairly flexible at this point to allow for the diversity of technology implementations, the growth of emerging technology, and to provide for an expansion of document scope to other types of interfaces.

The organizational structure of the primary source documents was examined. Typically these documents used a generic function-based approach, that is, the guidelines are organized by high-level functions the operator performs with the system, such as data entry, data display, dialogue, communication, and data protection. In addition, a section on integration of these functional elements is usually provided. Several of these documents address the human interface issues peculiar to computer systems. The more general documents, such as MIL-STD-1472D and NASA-STD-3000 also include guidelines for the hardware required to perform computer functions (e.g., keyboards, CRTs). NUREG-0700 follows a similar approach.

The first draft of the ACRDR Guidelines Document will follow the organizational structure of similar guidelines documents that focus heavily on the human-computer interface. However, the organizational structure was influenced by the results of the scoping task which indicated major trends in the use of intelligent operator aids and relatively "compact" computer-based workstations. Thus, the proposed structure represents a blend of current guideline approaches and the anticipated needs of the NRC inspector or reviewer. The seven major sections of the draft document include:

1. Information Display

    A. Screen Organization and Layout
    B. Information Format
    C. Coding

2. Operator Input

    A. Entering Information
    B. Operator Dialogue

3. Control-Display Integration

    A. System Response Time
    B. Input from the User
    C. Information Manipulation
    D. Display Control

4. Operator Aids

    A. Prompts, Alarms and Messages
    B. Operator Guidance
    C. Decision Aids
    D. Supervised Automation

5. Inter-Operator Communication

    A. Preparing and Sending Messages
    B. Monitoring and Receiving Messages

6. Information Protection

    A. Error Prevention and Correction
    B. Security

7. Workstation Design

    A. Display Devices
    B. Control Devices
    C. Workstation Configuration

Each of these is broken into several subsections. Of the seven sections, the first six tend to be human-software/human-information oriented. The last section provides the majority of the guidelines pertaining to hardware and workplace layout. Note that no effort is being made in this project to incorporate guidelines for "traditional" technology (e.g., rotating knobs or sound-powered phones) already addressed by NUREG-0700, although the NRC has plans to do so in the future.

Each individual guideline within the document will contain data in several fields, as illustrated in Figure 2.

Individual Guideline Formulation

The next step was to determine which guidelines in the primary source documents fell into the various sections of the ACRDR guideline document's organizational structure. This process is not straightforward since the documents were all organized differently, used dissimilar terminology to address the same topics, were syntactically different, and were developed to provide design guidance and not review guidance.

There was considerable overlap in the guidelines recommended across the primary source documents. Thus, the guidelines were edited to combine similar guidelines into a single guideline and to transform the material into a standardized format (as per the data fields in Figure 2). Where compound guidelines were encountered (several guidelines in a single statement), an effort was made to break the compound guideline into several logical units and represent the units as separate guidelines on the ACRDR Guideline. This would make each individual guideline clear and distinct, and thus easier for an inspector to use. Information as to the primary source document from which each guideline was derived was recorded. Occasionally primary source documents differed as to the guidance recommended. Conflict resolution was handled case by case. Typically, the document prioritization system was used to resolve any conflicts which existed between guidelines. In those instances where conflicts existed between guidelines of the same priority, then the more conservative guideline was taken.

At present, there are approximately 2000 individual guidelines included in the seven sections defined above.

Electronic Document Development

The main form of presentation of the guidelines will be as an electronic document to serve as an in-field inspection aid. Thus, the packaging of the guidelines in a portable computer in a format that facilitates the inspection process was an important consideration. An analysis of the inspection task and the variety of ways the document would be used was performed to identify the

Number Field: A unique number for each guideline
Title Field: A short descriptor fo each guideline
Guideline Field: Narrative criteria for each guideline
Comment Field: A further expalanation, rationale, or examples - where appropriate
Assessment Method Field: Describes the data collection procedure: Measurement - Instruments and or devices Observations - Visual and/or auditory observations Interview - Structured interview or questionnaire Documentation Review - Specifies the review of applicable documentation including manufactures specifications, manuals, etc. Operational Review - A licenced reactor operator assessment
Source Field: The sources from which the guidelines were obtained
Classification Field: Based upon validity criteria as firm, tentative, or weak

Figure 2. Guideline data fields

guideline requirements, organized into four categories: general usability requirements, inspection task requirements, electronic document functionality requirements, and general hardware requirements to support prototype development of the system.

The general usability requirements included electronic document characteristics such as that it should be easy to learn, provide on-line help, minimize user errors, and minimize requirements for the user to memorize commands, modes, key sequences or other actions not inherent in the inspection process. The inspection task requirements included factors such as the requirement to support all phases of inspection including planning/preparation, on-site evaluation, and report writing. In addition, the electronic document must support a variety of document usage modes such as guidelines review, control room inspection, and guideline editing. Electronic document functional requirements included functions which were deemed highly desirable based upon a consideration of the ways in which the document will be used. The factors identified included the capability to display high resolution graphic images (e.g., figures, illustrations), rapid search initiation, and independent "scrollable" windows to allow access to various parts of the document at one time or for various functions, such as evaluation and notetaking. Finally, hardware requirements were derived. One of the most important characteristics of the electronic version of the ACRDR Guideline is that it be portable. This feature is necessary to support on-site use of the guidelines by NRC personnel. The principal attributes of the machine which contribute to its portability are capacity requirements, weight, size, design and battery life (i.e., operating time between recharges). In addition, the human factors characteristics of screen design and input devices were considered.

This initial pass at requirements analysis allowed us to select an environment for guideline prototyping. However, before a final decision on hardware and software is made, the document will be tested to better define the basic requirements. For the near-term purposes of mocking-up a prototype of the electronic guidelines and testing its screen design, guidelines format, functionality, etc., we have decided to use a portable Apple MacIntosh computer and implement the document in HyperCard software. The portable MacIntosh meets most of the hardware characteristics required in terms of speed and capacity. Two very desirable features were its battery life and screen design. According to specifications, the portable MacIntosh can operate for 6 to 10 hours under normal use, including hard disk access, before battery recharging is necessary. With respect to screen design the portable MacIntosh uses an active matrix LCD, consisting of individual transistors for each screen pixel. This technology results in contrast that is up to five times greater than what can be found on conventional and supertwist LCD displays. This high resolution is necessary to display the graphic images that are envisioned to support the final version of the ACRDR Guideline. The MacIintosh display also has a wider viewing angle than most portables and can be easily read when positioned at oblique angles to the user. Since the display is reflective instead of backlit, its legibility becomes greater as the ambient light level becomes brighter. Although a minimum amount of ambient light is required to read the display, the amount is fairly low, and the display can still be read in a dimly lit room.

HyperCard satisfies the functional requirements of the ACRDR Guideline very well. It has the capability to display text in multiple, scrolling fields which can be simultaneously displayed on the screen. This allows users the greatest control over the display of information. HyperCard also has the facility to implement such features as "bookmarks" and an embedded notebook. It supports note links, whereby the user can access notes pertaining to a specific topic or field. Graphics support is included whereby nontextual, bit-mapped images can be displayed in association with the text. In addition, HyperCard offers a powerful help facility, allowing users to seek context sensitive help such as clarification on a document navigation problem, or more detailed information pertaining to a specific area or field of the ACRDR Guideline.

Among the program's most positive features are adaptability and extendibility. HyperCard contains its own object-oriented programming language, HyperTalk, which permits the developer to have essentially total control over the "look and feel" of the user interface and the ability to rapidly prototype user interfaces. This capability allows developers to design and demonstrate user interface concepts, present the concepts to potential users and then incorporate user comments into the final design. This will permit us to work with users during the development of the document to ensure that the final design is acceptable.

An example of one of the guidelines depicted in a prototype screen format is provided in Figure 3. The main screen provides information on document mode (e.g., inspection versus edit mode), location in the document, guideline content and comments. The shaded areas represent "control buttons" which allow the inspector to access document/system functions such as help and index or windows for data functions, such as guideline evaluation and note taking.

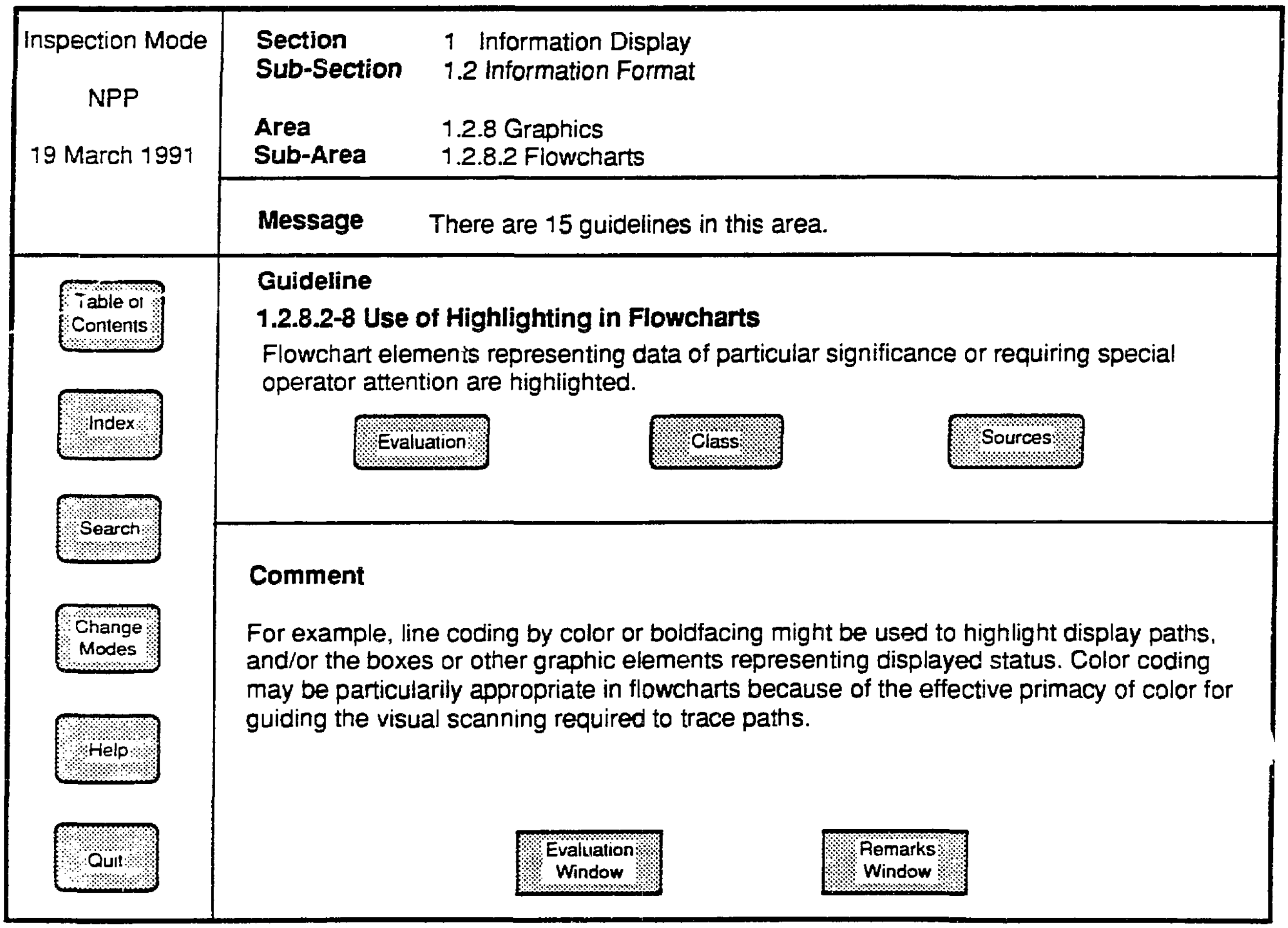

Figure 3. Sample guideline

New Guideline Development

We have just begun looking at the development of new guidelines. In part, the identification of areas where new guidelines are needed is accomplished by finding a mismatch between the scope of the ACRDR document and the guidelines obtained from the primary sources. That is, new guidelines are indicated by gaps in the document where the scoping effort identified an area where guidance was needed, but where the guidelines compiled from existing documents were lacking. This process results in a preliminary list of required guidelines pending more thorough analysis. A more comprehensive list of new guidelines required will be developed following evaluation and testing of the ACRDR guidelines document through actual application in a NPP. However, the preliminary identification of areas needing further guideline development includes:

User Interface Requirements for Supervised Automation

Advanced reactors are planning to make greater use of operator-controlled automation, a form of "shared control." An operator monitors the automated process and at certain way points (predefined operator check points in the automated process), the automated process stops to get operator authorization to proceed. Thus, the automated process is being directly supervised by the operator, who is playing a more active "monitoring" role than is traditionally the case with automated processes. Guidelines for this type of human-system interaction are not available and need to be developed.

User Interface Requirements for Intelligent Operator Aids

Operators in new control rooms will be faced with many different types of intelligent aids. Human factors guidelines for these systems are sparse and experience with their use in real systems (as opposed to laboratory studies) is very limited. These types of systems need to be classified (since the guidelines for an interface to an expert system for fault diagnosis during a transient may be different than one which is used to assist maintenance operations), and appropriate guidance developed where possible.

Visual Display Hardware Guidelines

Human factors guidelines were found to be lacking for many of the variables which impact the readability and legibility of video display terminals (VDTs). Specific areas where further research is needed include (see Snyder and Bogle (1989) for a detailed discussion of these areas):

- The measurement of raster modulation for color displays,
- Determination of maximum character and background contrast ratio,
- Determination of polarity recommendations,
- The measurement of display resolution for color CRT and flat panel screens,

- A requirement for luminance uniformity (acceptable variation in luminance),
- Selection and specification of suitable color coding metrics and color spaces,
- Character, Line, and Word Spacing for emissive displays, and
- Flicker sensitivity.

Flat Panel Displays

Flat panel displays have been identified as a potential display technology for use in advanced NPP control rooms. Among these flat panel displays are light emitting diodes (LEDs), both AC and DC plasma displays, thin film electroluminescence (TFEL), electrochromics, electorophoretics, and liquid crystals (LC). According to manufacturer specifications, flat panel technology appears to be quite compatible with requirements of the human visual system (at least in terms of contrast and viewing angles). However, little human factors guidance exists on these technologies within the primary documents surveyed.

Stereoscopic and Virtual Image Displays

Three-dimensional (stereoscopic) and virtual image display technology has come a long way in recent years and shows considerable promise for commercial applications. However, before these display technologies can be implemented with confidence, methods need to be developed to measure the image quality of such displays. Psychophysical concepts, measurement techniques, and subjective evaluation data for virtual image three-dimensional displays are nonexistent, and are in need of human factors research.

Screen Design

There exists a vast number of graphic display techniques for representing numerical data (e.g., pattern charts, simulated meters, surface charts, segmented column histograms) that are presently found on VDTs, yet the "science" behind these screen design techniques is not always well understood. In order to make the most effective use of these screen design techniques, more research is needed on understanding the effects these graphic techniques have on users. Specific areas where more research is needed includes (see Tullis (1988) for a detailed discussion of these areas):

- Effects of highlighting,
- Effects of spatial relationships,
- Effects of graphics,
- Effects of animation,

- Effects of user characteristics, and

- Effects of task characteristics.

User Input Device Guidelines

While many guidelines exist for the more traditional methods for interacting with VDTs (i.e., displacement keyboards), guidance for some of the more recently accepted input mediums is sparse. For example, very little human factors guidance was found for membrane keyboards, track balls, head movement controllers, glove controllers, and handcontrollers. While more guidance was found for other devices (e.g., mice, light pens, touch input devices), the guidance available is not as complete as that which exists for displacement keyboards. Since keyboards are the primary input devices for computers, this is not surprising. However, with the recent advances made in display technology and the corresponding drop in VDT prices, graphic displays are becoming more accessible. With the benefits associated with graphic direct manipulation user interfaces (Shneiderman, 1987), new methods for interacting with these displays are being explored.

Guidelines Specific to Nuclear Operations

Despite convergent evolution there remains many unique aspects to the implementation of advanced technology for nuclear operations. Some human factors guidelines specific to the nuclear industry have been identified and included in the document via Gilmore et al. (1989). However, many more are needed.

CONCLUSION

At the present time, the first draft of the ACRDR guidelines has been developed. The guidelines were the result of the integration of several significant human factors guidelines documents from both within and outside the nuclear industry. The guidelines have been packaged into an electronic document whose primary purpose will be to serve as an aid to the NRC inspector/reviewer conducting human factors audits of advanced control room technology. The prototype document contains much of the functionality requirements identified in the analysis although not all could be developed within this phase of the project.

The project is now proceeding along two pathways. First, the electronic form of the guidelines will be tested by conducting peer review evaluations and usability tests. Through this process the guidelines format, functionality requirements, and the user interfaces to the inspection aid can be better defined and developed. This review and testing process will also help us to better define where review guidance is weak.

The second pathway will involve the development of new guidelines in those areas where the present document is found to be lacking. A variety of methods are available to accomplish this goal including: (1) review of secondary and tertiary documents already in the guidelines efforts database; (2) ongoing liaison with colleagues both within and outside the nuclear industry who are working on similar issues; (3) review of the basic and applied literature in the areas where guidelines are needed; and (4) development and conduct of the research needed to serve as a foundation for guideline development. Each of these approaches has to be reviewed with respect to the need for guidelines to determine the most appropriate strategy for each.

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

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