

IEEE Guide for the Application of Human Factors Engineering in the Design of Computer-Based Monitoring and Control Displays for Nuclear Power Generating Stations

Sponsor

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Abstract: System design considerations, information display and control techniques for use with computer-based displays, and human factors engineering guidance for the use of these techniques in nuclear power generating stations are provided.

Keywords: displays, human factors engineering, nuclear power generating stations

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Introduction

(This introduction is not part of IEEE Std 1289-1998, IEEE Guide for the Application of Human Factors Engineering in the Design of Computer-Based Monitoring and Control Displays for Nuclear Power Generating Stations.)

When the majority of the presently operating nuclear power plants were first designed, the operator interface design philosophy reflected the availability of, and experience with, single sensor/single parameter displays, such as meters or trend recorders. During the control room design reviews of the 1980's, it was realized that this type of display often led to poor functional performance. The user frequently needed displays that could integrate information rather than just present data. In other cases, traditional instrumentation performed poorly or unreliably. A trend has developed slowly over the past decade in which, while replacing control room instrumentation, utilities have found that the instruments have become obsolete, are no longer available, and are not supported by vendors. This has led nuclear power generating stations to upgrade instrumentation utilizing computer-based display/control devices.

Working Group 7.1 (WG 7.1) reviewed existing standards that address the use of computer-based displays in the nuclear power industry. It found that, while there were top-level human factors standards (such as IEEE Std 1023-1988) and specific standards to address visual display hardware parameters, there was no available industry guidance to address computer-based display formats appropriate for nuclear power plant monitoring and control. The working group also investigated efforts throughout the industry to develop computer-based monitoring and control displays, and found significant efforts at many utilities, instrumentation and control vendors, and government laboratories that attempted to provide guidance. Based on the identified need for guidance in this area and the developing industry base, the development of this guide was initiated.

The intent of this guide is to provide human factors engineering principles as guidance to management personnel and engineers who must develop or select computer-based displays, either in the replacement, modification, or design of instrumentation and control systems. A process for determining display needs, which are related to those of IEEE Std 1023-1988, and descriptions of a wide variety of display formats are provided.

Guidance is provided for using user tasks to determine information needs, which in turn define display characteristics. Information is provided that relates to a wide range of display formats, describing what they are, when they are useful, and when they are not useful to display the information needed by the user. This design criteria guide provides more specific guidance under the top-level guide, IEEE Std 1023-1988.

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IEEE Guide for the Application of Human Factors Engineering in the Design of Computer-Based Monitoring and Control Displays for Nuclear Power Generating Stations

1. Scope

This guide provides system design considerations, identifies information display and control techniques for use with computer-based displays, and provides human factors engineering guidance for the use of these techniques in nuclear power generating stations.

2. References

This guide should be used in conjunction with the following IEEE standards. When the following standards are superseded by an approved revision, the revision shall apply:

IEEE Std 1023-1988, IEEE Guide for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations.¹

IEEE Std 610-1990, IEEE Standard Computer Dictionary, Compilation of IEEE Standard Computer Glossaries.

NOTE—See Clause 9 for a bibliography of publications and other documents that provide additional information or amplify this guide.

3. Definitions

3.1 command language: A type of dialog in which a user composes entries to evoke a system response.

3.2 data validation: The process of checking data-entry items for correct content or format.

3.3 direct manipulation: User manipulation of symbols in the display by direct interaction with the symbol. It is generally performed through the use of a display structure, such as a pointer, and a cursor control device, such as a mouse.

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3.4 display: Visual depiction of a single, integrated, organized set of information. A display may be an integration of several display formats (such as a system mimic that includes bar charts, trend graphs, and data fields).

3.5 display device: The hardware used to provide the display to users. An example is a video display unit. *See also:* **display**.

3.6 display elements: The individual components of a display, such as labels, abbreviations, acronyms, icons, symbols, numbers, color, graph lines, coding, highlighting, and background. *See also:* **display**.

3.7 display format: Method of data presentation, such as a trend plot, bar chart, graph, table, or cross-plot. *See also:* **display**.

3.8 field: An area of the display screen that is reserved for the display of data or for user entry of a data item. In a database, it is a specified area used for a particular category of data (e.g., equipment operational status). *See also:* **display**.

3.9 hierarchical branching: A tree-like menu structure that allows selection among alternatives without requiring the opening and closing of a series of menus. The alternatives are contained in one menu.

3.10 legibility: The quality of a display that allows groups of characters and symbols to be easily discriminated and recognized. *See also:* **display**.

3.11 luminance: The luminous intensity per unit projected area of a given surface as viewed from a given direction. Measured in candelas per square meter or footlamberts.

3.12 luminance contrast: The ratio of the luminance of the features of the object being viewed, in particular of the feature to be discriminated, to the luminance of the background. *See also:* **luminance**.

3.13 page: a) A fixed-length block of data, especially that which fits into a single printed sheet. b) To summon a particular page or the next logical page. *See also:* **paging**.

3.14 paging: A method of viewing and moving through data in which a user conceives of data as being grouped into pages and moves through it by discrete steps. *See also:* **page**.

3.15 pop-up menu: A menu that is brought into view as a result of a selection action other than choosing a menu-bar label. *Contrast:* **pull-down menu**.

3.16 pull-down menu: A menu that is brought into view by selecting a menu-bar label. *Contrast:* **pop-up menu**.

3.17 readability: The ease with which words and text can be read. Refers specifically to the functional relationships that exist between the properties of words and text and the observer's accuracy and speed of understanding words or text.

3.18 screen: The portion of a display that is visible on the display device. A screen may show part of a page, an entire page, or several pages. *See also:* **display device**.

3.19 scrolling: A method of viewing and moving the data displayed in which the data rolls continuously behind a fixed display frame.

3.20 stroke width: The thickness of the lines that make up a character, usually expressed as a proportion of the character's height.

4. Systems considerations

Displays should be developed in accordance with the design procedures described in IEEE Std 1023-1988.² This guide provides details for the implementation of that process when developing computer-based monitoring and control displays.

4.1 Display development methodology

4.1.1 Determining display requirements

The purpose of any display is to provide the user with the information needed to accomplish tasks. Display development should begin with a determination of the user information and control requirements of the control/display system. This determination should not be limited by consideration of what signals or hardware capabilities are currently available.

As used in IEEE Std 1023-1988, task analysis is the process of identifying user information or other user cognitive needs. There are many techniques of task analysis. The method used should be tailored to develop the information needed for the specific system. Some of the factors that may be considered in task analysis that are relevant to display selection are

- a) Type of user (e.g., operator, maintenance personal, engineer, etc.)
- b) Information required by user, including cues for task initiation
- c) The nature of the decision to be reached and the user's evaluation process
- d) Action to be taken by the user (following each decision)
- e) Feedback informing the user of the adequacy of the actions taken
- f) Job aids or references required

The display requirements identified in the task analysis should be used in determining the selection and placement of displays. Placement may be physical, as in a standard nuclear power plant panel, or it may be relational, as in location and accessibility within a computer-based control system.

Task analysis may also be used to analyze user workload and to identify situations in which information or work overload may occur. In the case in which analysis indicates a potential overload, system and task design should be reevaluated to determine if options exist that allow the reallocation of functions or the redistribution of tasks.

4.1.2 Display presentation considerations

Once the information requirements for displays are identified, the display design (i.e., decisions about the presentation of displays), which also includes display selection, should be based upon criteria that reflect the perceptual and cognitive abilities of the intended user. Perceptual factors such as vision, hearing, and other sensory capabilities, along with cognitive considerations such as decision making ability, impact on training requirements, time considerations, and the number and skills of personnel, should be considered when selecting how the information needs identified are presented to the user. Much of this knowledge has been refined, and human factors engineering design-criteria standards and handbooks are available to assist in the selection. When the handbooks fail to provide adequate guidance, the human factors research literature usually provides relevant cognitive and perceptual studies. A short experimental comparison study of alternatives could be done. Techniques such as link analysis (as described in IEEE Std 1023-1988) may be useful for combining information and task sequence data to reach an acceptable display layout. Ultimately, specific displays and display layouts should be subject to adequate verification and validation for the human-machine interface, as described in IEEE Std 1023-1988.

²Information on references can be found in Clause 2.

4.2 System design considerations

The following aspects of the system interaction design and display format determine the ability of the system to perform its functions under all expected conditions by all expected users.

4.2.1 General user-system interaction guidance

The level of expertise and training of the expected users should be taken into consideration in the design of the displays. In order to minimize the amount of training that will be needed, system hardware, navigation between displays, and display configuration should be understood easily by the intended user. The amount of additional training that will be needed should be a display design consideration.

Interpretation of displayed data and navigation between displays should not overload the user during the most demanding operational situations.

The displays should be easy to interpret for trained users under expected environmental conditions. No critical loss of information should be experienced under conditions of emergency lighting.

4.2.1.1 Consistency

The manner in which the display system functions and appears to the user should be consistent with the rest of the system interfaces, procedures, and training. Nomenclature, labeling, coding, abbreviations, acronyms, and graphic symbols should be consistent across and within all displays and systems documentation. The wording and required format of information or command entry functions should be reflected consistently in the wording of user guides, including all labels, messages, and instructional material.

Procedures for entering commands or information should be consistent in both form and consequences.

4.2.1.2 User expectations

System design specifics (e.g., formats, terminology, sequencing, grouping, and user decision aids) should be consistent with the user's expectations, training, procedures, experience, and established conventions (e.g., menu-selection techniques, user-input procedures, editing, and error-correction procedures).

It should be easy for users to recognize their location in the display structure and to rapidly access data that is not currently visible.

Information entry sequences should reflect the user's expectations and should provide required control options. When the completion of a control entry is indicated by a special function key, that key should be labeled ENTER (or some functionally equivalent word), and should result in a computer acknowledgment of the entry.

4.2.1.3 User memory requirements

The system should minimize the burden on the user's memory. A dictionary of all abbreviations, symbols, icons, codes, display design conventions, commands, etc., should be readily available to the user. Users should be provided with a list of the control options. Only control options that are actually available for the current transaction should be provided. All abbreviations and terminology should be consistent with those used (approved) in the plant.

Information or command entry should not require the memorization of special codes or sequences, translations, or conversions. User entries should be in the same units as those that are used in control-room displays and procedures. Command names should describe specifically the functions being implemented.

4.2.1.4 Explicit organization and structure of display elements

The organization of all aspects of the display system should be based on user requirements and should reflect the general principles of organization by importance, frequency, and order of use. Critical safety function information should be available to the entire operating crew in dedicated locations.

User entry features should have distinctive positions and/or formats. If the consequences of an entry differ depending upon mode, then continuous indication of the current mode should be provided. Mode status indication should be distinctive in location and format, and should be displayed consistently from one transaction to the next. If PAUSE or SUSPEND options are provided, some indication of the status should be displayed whenever such an option is selected. The action that will permit resumption of an interrupted transaction should be indicated.

Feedback from commands or data entries should be distinguishable from displayed text.

Optional vs. required data entries within fields on input forms should be distinct.

Annotations added by users to displayed text should be distinguishable from the text itself.

4.2.1.5 Workload reduction

Only the information necessary to accomplish a specific entry (e.g., labels, annotations, prompts, or options lists) should be available to the user when that transaction action is appropriate.

User-input actions should be simple, particularly for real-time tasks that require a fast user response. The user interface should permit completion of a task with a minimal number of actions. This guidance does not apply to redundant actions that are required for security or to potentially destructive functions.

A user should not be required to reenter information that is already available to the system.

At the start of an input transaction, currently defined default values should be displayed in their appropriate data fields. Default values may be marked to distinguish them from data entries. Confirmation of the acceptance of a displayed default value should be provided. Users should not be permitted to define, change, or remove default values for any input field without adequate cross-checking.

Input transactions and associated displays should minimize shifts between input modes or hardware, such as shifts from the mouse to the keyboard. User-composed control entries should not distinguish between upper and lower-case letters.

Automatic justification of input should be provided as follows:

- a) Left justification for alpha input
- b) Right justification for numeric input of integer data
- c) Decimal point justification for numeric input of decimal data

A user should not have to enter blanks or other extraneous formatting characters to achieve proper justification.

4.2.1.6 User feedback

The system should provide useful information on the system status, permissible operations, errors and error-recovery options, potentially destructive operations, and the validity of data. The computer should acknowledge every entry immediately. The absence of a computer response is not an acceptable means of indicating that an entry is being processed.

When system functioning requires the user to stand by, feedback should be provided to indicate normal system operation. If a user is currently involved in some new transaction, then the completion of processing for a prior transaction should be indicated by the nondisruptive display of an appropriate advisory message. If the outcome of a completed transaction implies the need for further action, that action should be indicated.

If entries must be delayed pending computer processing of prior entries, then the delay should be indicated to the user.

In some applications, it may be desirable to ensure that the keyboard and other control devices are automatically locked until the user may begin a new transaction. Processing delays resulting in control lockout should be indicated visually and should be accompanied by an audible signal. Following control lockout, computer readiness to accept further entries should be indicated to the user.

4.2.1.7 Flexibility

The system should provide multiple means for carrying out actions (and verifying automatic actions) and should permit displays to be formatted in the configuration that is most convenient for the task. Flexibility should be limited to situations in which it offers advantages in task performance, such as to accommodate different levels of user experience.

Dialog structure should vary and should be compatible with user skills. It should permit both simple, step-by-step actions by beginners and more complex entries by experienced users. The user should be able to go forward or backward when scanning a multi-page display.

A user should be able to interrupt or terminate processing in progress. A single user action should not modify or remove stored or entered data.

4.2.1.8 User guidance

Transactions should never leave the user without further available action. Transactions should provide next steps or alternatives. The system should provide an effective “help” function with relevant guidance provided both on-line and off-line.

4.2.2 Legibility and readability

Legibility refers to the rapid identification of single characters that may be presented in a noncontextual format. *Readability* is the quality of text that allows groups of characters to be easily discriminated and recognized as words or to have meaning and understanding attached to the characters. The following guidelines are designed to optimize both legibility and readability.

4.2.2.1 Contrast

There should be high contrast between the luminance of objects and the luminance of the background on the displays.

The recommended luminance contrast range is 10:1 to 18:1.

4.2.2.2 Brightness

Brightness or luminance control should cover a range of 17–172 cd/m² (5–50 ftL).

Legibility improves as luminance increases from 0.03–34 cd/m² (0.009–10 ftL). Low luminance, in the range of 0.1–1.0 cd/m² (0.03–0.3 ftL), requires a contrast ratio of at least 5:1 and a symbol size of 20 min of visual arc.

4.2.2.3 Viewing distance

The design of displays should be based upon the normal viewing distance of the users. Qualitative data that is intended to draw attention should always be large enough to read at a distance. Most quantitative data, however, may be smaller, assuming that users are within reach distance of the associated controls, which is usually 40–70 cm (16–28 in).

4.2.2.4 Character size

Character size specifications are traditionally given in terms of visual angles or visual arcs measured in minutes of arc. Character size is the measure of the vertical angle, as measured at the viewer's eye, between the top and bottom of the character at a given distance.

The character size for above 34 cd/m² (10 ftL) should be

Height:

Minimum:	16 min of visual arc
Preferred:	20–22 min of visual arc
Maximum:	24 min of visual arc for tasks in which readability is important
Height to width ratio:	1:0.7 to 1:0.9
Stroke width to height ratio:	1:12 to 1:5
Between character spacing:	10–50% of character height
Between word spacing:	1 character “N” width
Between line spacing:	A minimum of two stroke widths or 15% of character height (50% of character height preferred)

4.2.3 Visual environment

Display legibility is highly dependent upon the ambient lighting environment in which the display is located. The display should always be tested under all illumination environments (normal and emergency) in which it is intended to be used. For example, the effects of glare, backscatter, and background light spectrum should be considered.

4.2.4 Visual coding

Visual coding (such as color, shape, blink, etc.) may be used to convey status information (e.g., changing the color of parameters that exceed their setpoints to red) or to facilitate locating particular items. Whenever possible, redundant coding should be used.

Since all codes must be learned, only a few simple meanings should be assigned to each type of coding (e.g., shape, size, or color). In addition, the code should be consistent with that meaning rather than contrary to that meaning (e.g., minimum flow bypass lines should not be drawn thicker than main lines).

4.2.4.1 Color coding

Color provides an effective coding device; however, it should always be redundant to some other type of coding, since it is extremely vulnerable to hardware and perceptual problems that may eliminate its effectiveness and is less effective under poor lighting.

Displays should first be designed in a monochromatic format. Color may then be used to enhance the display by differentiating between different types of display elements.

The same colors may be employed for several primary uses (e.g., equipment status, alarm category, parameter range, and equipment group) because the user can readily distinguish the intent. Color coding within a primary use should be consistent throughout the facility.

Many colors are readily discriminated when compared, but may be easily confused if the similar color is not available for comparison. Colors used for coding should be identifiable under a variety of lighting conditions.

The requirement for reliable recognition limits the set of colors that may be assigned different meanings to approximately six or fewer, depending on the display systems and the viewing environment.

Color codes should take advantage of population stereotypes regarding the meaning usually associated with colors. Alphanumeric and graphic displays may have different color-coding schemes; however, with either type of display, the meaning of colors should be consistent.

4.2.4.2 Size coding

Size may be used to code differences in importance or magnitude. A common use of size coding is the use of different line weights (thicknesses) to convey different capacities of electrical or fluid lines or to differentiate between normal and backup flow paths. To ensure reliability in recognizing the different levels of the code, no more than three levels should be used, with each level differing from the next lower level by at least 50%.

4.2.4.3 Intensity coding

Intensity coding (brightness) may be used to call attention to an object and to highlight information. Only two levels of brightness should be used for coding. Levels approximating 33% and 100% of the display luminance should be used. Both levels should be present simultaneously to ensure reliable recognition.

4.2.4.4 Blinking

Blinking should be reserved for conditions requiring the immediate attention of the user. No more than two blink rates should be used for coding.

The differences between the two blink rates should be at least 2 Hz. The slow blink rate should be not less than 0.8 Hz, and the fast blink rate should not be more than 5 Hz. The percentage of time that the image is “on” should be greater than or equal to the time that it is “off.”

4.2.4.5 Shape coding

Although the number of readily differentiable shapes is large, it is best to use a small number of shapes that have an easily recognizable association with their assigned meanings. The shapes used for coding should be tested to ensure that they are easy to differentiate.

Symbols should be drawn large enough so that they are readily discernible. A minimum size of 20 min of visual arc at the intended viewing distance is recommended. The symbol selected should be as simple as possible, and unnecessary detail should be avoided.

Symbols should be tested with the intended users to ensure that they are clearly discriminable and that their meanings are easily learned and remembered.

The computer system should have a dictionary of all symbols that appear on its displays and keyboards.

4.2.4.6 Icons

Icons are a special class of symbol that may serve as shorthand pictographic labels for functions or data sets available on the computer. Icons should be constructed to have a distinctive appearance that identifies them as icons, such as a special shape or border. An icon should look like what it means. A supplemental label to identify the icon's function should be available.

4.2.4.7 Location coding

Standard information fields (such as the title, message area, location of labels for hard-wired multi-function keys, etc.) that are repeated on a set of displays should be placed in the same location on all of the displays.

4.2.4.8 Multiple coding

Coding dimensions may be combined when multiple meanings are appropriate. For example, a red object combined with blinking may combine the meanings "exceeds setpoint" and "attention urgently required."

4.2.5 Information density

Information density refers to how much information is presented on a single display screen. Low information density favors quicker search and retrieval of the data. This must be balanced against time spent navigating through multiple screens.

Problems related to high density may often be offset by a logical organization that is consistent from display to display, the efficient use of coding techniques that may facilitate location and identification tasks, and the presentation of some detailed information only on demand.

4.2.5.1 Alphanumeric displays

For alphanumeric displays, the ratio of the number of characters displayed to the number of character spaces available should be less than 25%.

Tables and lists tend to have high information density. Densities in excess of 25% may be acceptable if the table or list is organized in a manner that facilitates searching and accurate scanning, such as the insertion of a space after every third or fourth line.

4.2.5.2 Graphic displays

The volume of graphics should not interfere with the ability of the user to identify individual display elements or to understand the display.

4.2.6 Dialog structure

The dialog structure may use menus, maps, pointing, paging, dedicated functions keys, etc.

The dialog structure should be based on the task requirements, should be logical and consistent, and should reflect the vocabulary and syntax of the expected user population.

- a) Individual input words that must be typed should not exceed seven characters.
- b) The system should allow the user to abort or undo an input.
- c) The computer system should retain a sequential file of user inputs that can be displayed upon request.
- d) The computer system should check each input and provide meaningful feedback or an error message to indicate when a command is not valid or is out of range.