HUMAN FACTORS ENGINEERING

STANDARDS, GUIDELINES, AND BASES

FOR NUPLEX 80+™

Report NPX80-IC-DR-791-02

Combustion Engineering, Inc.

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PART A: STANDARDS AND GUIDELINES

1.0 INTRODUCTION

ALWR program requirements include mandates for equipment standardization and usability, enhanced operator support from the Man-Machine Interface (MMI), and the general integration of human factors in design. The Human Factors Engineering Standards and Guidelines Document (herein referred to as the HFE Standards) is a key part of the System 80+ approach to improving the MMI, thereby contributing to the assurance of safety through improved defense in depth.

1.1 Scope

The HFE Standards are part of the Human Factors Program Plan for System 80+. The program ensures a consistent and usable MMI for the System 80+ design. In addition, it affords mechanisms for documenting human factors design bases, and provides accountability for HFE in the design process.

The scope of the HFE Standards includes the design of the Nuplex 80+ Control Complex facilities, and the certified System 80+ NSSS and BOP facilities, equipment, and systems. In addition, portions of the HFE Standards may be found applicable to site specific facilities, procured items, and programmatic issues. However, these are not presently within the scope of the HFE Standards (or the larger Human Factors Program.) See the Human Factors Program Plan for System 80+ for more detail on the program.

1.2 Applicability

The contents of the HFE Standards and Guidelines Document apply, as appropriate, to all System 80+ system and equipment designs built by ABB Combustion Engineering and its subcontractors for use by operations and maintenance personnel (see subject of Conformance Criteria under Section 1.4.b).

In general all System 80+ Man-Machine Interfaces (MMIs) should follow the methodologies and conventions established for the main control complex to the extent practical. These methodologies and conventions adhere to the guidance provided in this document and are defined in the Nuplex 80+ Control Complex design documentation. Where deviations from these conventions are warranted, the guidance in this document shall be applied and the deviations must be evaluated from a human factors perspective relative to the consistency of the overall System 80+ MMI.

1.3 Approach

The HFE Standards have been created in keeping with the following philosophy approach.

a) Limitations of Generic Guidance - A growing number of generic human factors guidance documents are available to provide designers with rules for design format in various domains. The application of such guidance tends to enhance the usability of the designer's products (e.g., usability of software, maintainability of equipment, readability of printed matter, etc.) While they are a useful resource for many designers, their utility is often limited (particularly in large, complex design projects) for the following reasons:

- Substantial redundancy exists between documents
- Unresolved conflicts exist within documents
- Guidance is generic, and does not adequately constrain, direct, or standardize the design
- Guidance is usually in a form that does not facilitate testing or evaluation of design products

Thus, this guidance was treated as source material from which to generate a more useful design guide specifically for the System 80+ project.

b) Develop Specific Standards from Generic Guidance - The HFE Standards for System 80+ have been based on a selection of well-established, generic guidance documents available from the NRC, EPRI, DOE, the military, and other recognized authorities. This generic guidance ("should") has been used as a point of departure to develop, wherever possible, more specific standards ("shall") within bounds of the original guidance. These more restrictive constraints will contribute to standardizing and directing the efforts of designers.

c) Minimize Redundancy and Maximize Cross-Reference - A design decision for the document was to minimize the use of redundant entries, and instead, to maximize the use of cross-reference. This was done with the goal of minimizing the size and number of conflicts in the document, in the hope that it would therefore be easier to learn. It does presume that designers who will be using the HFE Standards, become familiar with its contents.

d) Provide Bases for Explanation and Review - Bases in the form of references and explanations for individual items will be provided for the HFE Standards in a companion basis document. This material is intended to provide reviewers with a justification for specific guidance items. It is also intended to support informed departures from the Standards if non-conformance appears to be warranted.

If there are any questions on the content, basis, or need for conformance to the material contained in the HFE Standards & Guidelines, or the associated Basis Document, contact the Supervisor of Control Complex Engineering for System 80+.

Comments on the form, content, and overall usability of this document are important and appreciated, and should also be directed to the Supervisor of Control Complex Engineering for System 80+.

1.4 Evaluative Criteria

Two general types of evaluative criteria are identified as potentially applicable to the products of HFE design activities: performance and conformance criteria. Their general applicability to evaluating HFE in the products of the System 80+ design, and their specific applicability to evaluating implementation of the HFE Standards, are explained as follows.

a) Performance Criteria - In general, the application of the HFE Standards, as well as other applications of HFE in the System 80+ design, contribute to the assurance [illegible] safety, reliability, availability, maintainability, and inspectability goals will be met. This implies the belief that application of HFE contributes, in general, to an increase in performance on such theoretically objective measures as speed and accuracy, while reducing workload, training requirements, and the likelihood of errors (or costly consequences). At the present time, however, the System 80+ design is expected, by analysis, to meet the such goals without taking particular credit for human performance being specified. Thus, no effort will be made to use objective measures to analyze or quantify contribution of the HFE Standards to achieving overall System 80+ goals.

The general HFE goal, beyond meeting specific System 80+ program requirements, is to improve the usability of the System 80+ design. Operability and maintainability are two ad hoc "types" of usability, distinguishing two relatively distinct job performance contexts for any given item. Evaluation of operability and maintainability will be conducted in the form of various validation activities at to-be-determined points in the design process. Validation testing will demonstrate that the usability of the design aspect in question is sufficient to permit specific criterion tasks to be successfully accomplished.

b) Conformance Criteria - In terms of interpretations of specific guidance, use of the term "shall" denotes a testable standard, while use of the term "should" denotes suggested (i.e., nontestable) guidance. Conformance to specified standards shall be verified for all System 80+ design activities Nonconformance to individual standards must be documented in all areas, and either be corrected or justified in terms of the basis for the violated HFE standard. The HFE Program Plan will incorporate the actual requirements and mechanisms for implementing this scheme.

1.5 Document Definitions

The following definitions apply for use within the present document. They are presented to clarify concepts used to explain the goals and tasks that System 80+ design engineers need to perform as part of the Human Factors program. While the terms may be useful in other contexts, they are not presented with the intention that they will be placed in wider use. However, it is intended that these definitions be applied consistently throughout the Human Factors Program.

The list of terms follows.

Alarm - A prioritized status annunciator in the Nuplex 80+ Information System. Non-alarm annunciators (operator aids) are also used to alert the operator to certain status changes, but they have no priority and do not reflect undesirable or abnormal conditions.

Annunciator - An alerting display mechanism denoting a defined status transition on a monitored variable in the Nuplex 80+ Information System.

Caution - An equipment or operational hazard.

Contrast Ratio - The ratio between the luminance of a target and its background. Various different formulations exist; a simple one is $(L_{max} \div L_{min})$.

Controls - Devices, particularly remote devices, used to adjust, manipulate, tune, change (etc.) the discrete status of a component or system, or the continuously distributed value of a component or system parameter.

Danger - A direct or immediate personnel safety hazard.

Descriptor - A descriptor is the software-based equivalent of an equipment label displayed on a VDU screen (and assigned in a database).

Designator - A designator is the unique, alphanumerically encoded "tag number" that identifies each component, parameter, system object, etc. in the design. In a designator, logical uniqueness and data compactness take precedence over obvious meaning (Compare with "Name").

HFE Guideline - A generic, non-testable HFE design recommendation ("should") based on subjective HFE principals that is intended to provide designers with useful input in making MMI design decisions.

HFE Standard - A specific, testable HFE design requirement ("shall") based on objective HFE principals. Nonconformance to an HFE Standard requires a documented justification to be filed with the HFE Group.

Illuminance - The amount of light falling on a surface from ambient and local sources, measured in *lux* or *footcandles*.

Label - A label is a semi-permanent physical attachment to an object that bears one of several types of key information (i.e., its name, component designator, specific instructions, warnings, etc.

Laydown Space - Workspace required to accommodate material and activities (tools, parts, etc.) for staging expected maintenance operations.

Luminance - The photometric correlate of the psychological sensation of brightness, related to the amount of light emitted in a given direction by a luminous source; measured in *candelas per square meter* or *footlamberts*.

Maintainability - The degree to which any system, equipment, component, etc. enables maintenance tasks to be quickly, easily, and correctly performed by virtue of its design or installation.

Maintenance Task - A task performed to enable or ensure that a component, equipment, system, etc. will adequately perform its design function when operated. Maintenance tasks are construed broadly to include such tasks as formal inspection, surveillance, preventive maintenance, alignment, testing, troubleshooting, repair, replacement, or required modification, and their associated routine activities.

Name - A name (i.e., for a system, equipment, etc.) is a unique and directly meaningful identifier that facilitates verbal exchange and reference. In a name, obvious meaning takes precedence over logical uniqueness or data compactness (Compare with "Designator").

O&M - The complete set of operations and maintenance activities for which HFE should provide development support so that systems and equipment are designed and built to enable satisfactory performance by the human component of those activities.

Operability - The degree to which any system, equipment, component, etc. enables operations tasks to be quickly, easily, and correctly performed by virtue of its design or installation.

Operations Tasks - Tasks performed to a component, equipment, system, etc. in the course of serving its design function in the overall system. Operations tasks are construed broadly to include such tasks as startup, shutdown, and other changes in mode, status, or configuration; also regulation, control, and planned responses to anticipated abnormal operating conditions, and their associated routine activities.

Operator Aids - Non-alarm annunciators on certain status variable information.

Parameter (Variable) - A continuously distributed variable with a range of possible values. Compare with Status.

Pull Space - The location and dimension of a spatial envelope that can accommodate the removal of a component from its installed position in the plant. The pull space dimension must accommodate necessary personnel and equipment, and its location must enable use of necessary lifting and rigging features. Prior to equipment installation in the plant (or its analysis by CAD), an equipment pull space dimension (i.e., independent of location) can be specified by the equipment designer.

Reading/Working Distance - The maximum distance of the operator from a piece of equipment, at which at task can be correctly performed, by design. Determining this distance typically must consider physical reach envelopes, and/or text size on particular displays.

Scaling - The division of the operating range of an indicating or control interface device into numbered, proportioned units.

Status (Variable) - A discretely distributed variable with a set of possible states and transitions. Compare with Parameter.

Tag - A tag is a temporary attachment applied to equipment by O&M personnel to indicate and/or manage certain temporary status conditions (e.g., danger, caution, calibration status, etc.) It is defined here to render it distinct from hardware labels and software descriptors.

Usability - The degree of ease with which an operator, or user, can use the system to achieve the design intended goal of that system. Use of the system is defined as having two components: operability and maintainability. Design for usability must incorporate human performance characteristics and limitations in order to minimize the likelihood of costly human error while performing either of these components. Also, when assessing the design with respect to usability one must consider how well the performance of the user is facilitated by the design, evaluating performance on these two components.

Virtual Devices - User-interface mechanisms that have functional characteristics that mimic physical devices (e.g., switches, pushbuttons, etc.), but are primarily implemented through software on VDU screens.

2.0 INFORMATION FORMAT CONVENTIONS

Section 2 contains material that applies to the format and presentation of visual information. The term "format" is used to indicate that the subject is the form and appearance of general types of information; the subject of specific information content has been intentionally avoided. The term "visual" is used to indicate that this includes text, labels, signs, symbols, scales, etc. but excludes auditory information and communications. Unless specified, the guidance and standards given here are to be applied to any visual information presentation medium. Section 2 has five subsections:

- 2.1 General Principals of Information Format
- 2.2 Print & Text Format Conventions
- 2.3 Graphics & Non-Text Format Conventions
- 2.4 Numerical Scaling
- 2.5 Equipment Labeling

The development of procedures, manuals, and other programmatically managed documents are beyond the scope of the HFE Standards. Thus, while the contents of this or other sections may be helpful in developing such guidance, it has not been developed or offered for this purpose.

2.1 General Principles of Information Format

This section presents eight general principles of information display format. They combine to form a useful set of goals which should help to guide the implementation of the more specific HFE Standards and Guidelines on information format.

a) Simple - Content considerations aside, a simpler format tends to be easier to use. Thus, uninformative complexities in a format should be eliminated. These might be unnecessary dividing lines on a page, superfluous data on a screen, or uninformative words in a title. Such items add "visual noise" to a presentation (rather than useful information or "visual signal") and create unnecessary competition for the attention of the operator.

b) Meaningful - A presentation should be inherently meaningful to the reader. This surpasses the concept that an item simply bears information, implying also that the information can be readily understood. For example, the two telephone numbers 1(800)433-4357 and 1(800)HFE-HELP can be said to provide the same information, but only one is inherently meaningful. From the standpoint of dialing information, the first, purely numeric encoding is adequate. However, in the second alphanumeric version, meaningful organization simplifies the reader's learning and memory tasks, and makes errors easier to detect as well. Note that to provide a meaningful organization, it is necessary to know and/or assume something about the reader's knowledge level (e.g., before reading this document, readers might not have recognized "HFE" as "Human Factors Engineering".) It is also necessary to have a certain degree of flexibility in choosing your terms. This is not always

c) Unambiguous - An item is ambiguous if its intended meaning is uncertain or obscured. This occurs if there is insufficient information in a presentation, e.g., combining "high water temperature" and "low oil pressure" into a single "engine trouble" light on an automobile's dashboard. Note that to be confident that a reference is made without ambiguity requires the designer to know or assume something about how an information element will be used, i.e., what the operator needs to do with it, or as a result of receiving it. An engine trouble light might be appropriate if the driver's response is intended to be "stop the motor & have the car taken to your mechanic" rather than "stop the motor, let the motor cool off, check the fluid level, check belts and pump..." etc.

d) Consistent - Meanings and relationships should be consistent among similarly elements in similar contexts. When relationships between such elements vary, users must learn and remember each separate case, and keep them organized by the distinctive features of otherwise similar contexts or situations. This is laborious and error-prone.

e) Compatible - Where relationships cannot be entirely consistent between contexts, they still should be compatible (i.e., should not conflict) with one another. For example, CRT screens may use the color red to denote active components, while red may also be applied to the color coding of equipment danger tags and placards. Because the two contexts of use are thoroughly separate, no conflict is identified. Compatibility between the motion of a control and associated display is a particularly important topic; the design of these two components and their relationships can tolerate some inconsistency, but they must never be incompatible.

f) Readable - Information presented in any form needs to be readable. This requires that the style and presentation of individual characters, symbols, etc. be legible (i.e., discriminable and unambiguous), and that the conventions for combining the symbols into words, codes, abbreviations, etc. produce material that can be easily read and processed.

g) Salient - Salience is attention-getting capacity. In general, it is important that a displayed item's salience be matched to its purpose and position. Thus, an item must be relatively noticeable, i.e., available and able to effectively compete for the attention of the operator with its surroundings, such that there is a high probability that it will be noticed as necessary to serve its purpose. For example, an alarm must be intrusive to perform its function, while a component label needs only to be noticeably located and readably sized. Since excess salience can produce distraction and possibly stress, it is no more desirable for an item than inadequate salience. Note that determination of appropriate salience for an item requires some knowledge and/or assumptions about the item's environment.

h) Cognizance of Users, Tasks, & Working Environment - This last item is implied throughout the other principles. From a human factors standpoint, good design of any engineered item must include the usability of its features. This requires consideration of various users (e.g., both operators and maintainers, in terms of their knowledge and abilities), their tasks (goals, problems, procedures, equipment), and the working environment (normal and emergency conditions, other external constraints, etc.) Designers should attempt to consider all these aspects in their own design efforts.

2.2 Print & Text Format Conventions

2.2.1 Names & Designators

The importance of clear and consistent use of terminology in the design cannot be overstressed. Yet, the development of names and numbering schemes begins early in the design process, and is difficult to coordinate and integrate the many participating activities. These problems ultimately impact on the operability and maintainability of the finished plant, where labeling, communications, and procedures will build upon the designers' initial use of terminology.

This section distinguishes several basic types of terminologies, and provides guidance for their consistent development and use.

An important basic distinction is made between equipment names and designators. Both names and designators provide a means to unambiguously identify and refer to objects (e.g., equipment, components, signals, etc.) in written materials and verbal communications. However, while similar, their roles are distinct.

2.2.1.1 Names

In a name, the emphasis is on verbal exchange and reference. Names should be both meaningful and unique; however, <u>in a name, obvious meaning takes precedence over logical uniqueness or data compactness.</u> Names are therefore less complete and unambiguous than are designators (see 2.2.1.2), but more convenient and "robust" in terms of human communications.

a) Names should be chosen to be brief but meaningful. Each word should be specific and necessary. For example, the "Control Rod Drive Mechanism Control" loses little if changed to "Rod Drive Control".

b) Names should clarify the unique function of the item, and minimize confusion and maintain compatibility with other existing names. Thus the "Circulating Water System" might be better named the "Tertiary Cooling System", (i.e., the third cooling loop accepts heat from the Secondary Cooling System.)

c) Names of systems and key components should be chosen to provide a unique acronym or abbreviation. This is facilitated by using relatively specific, rather than generic, terms to form the name. (See 2.2.2, Abbreviations and Acronyms.)

2.2.1.2 Designators

In a designator (i.e., a uniquely coded alphanumeric string used for numbering of system objects) the emphasis is on uniqueness. In addition, designators can carry several pieces of distinct information in a relatively compact coding. In a designator, logical uniqueness and data compactness take precedence over obvious meaning. Thus, designators have computational advantages, but they are harder to refer to and less "robust" in terms of human communication.

2.2.2 Abbreviations & Acronyms for O&M Terminology

It is often desirable to shorten frequently used terminology to make labels smaller, communications shorter, or documentation more compact. Abbreviations and acronyms are methods of shortening terms and collections of terms, respectively, so that the information carried in the full word version can be carried by a small fraction of the original letters.

Both processes attempt to discard from the full term its least informative letters, while retaining a few of its most informative letters. In a good shortened term, the result is unique (so it will not be confused with other similar abbreviations) and memorable (it recalls to mind the original full term).

Several methods exist to generate short forms of terminology. They do not always apply equally well to a given term; sometimes none of them apply very well. In addition, when a large number of terms are being shortened and combined into a set, additional problems are encountered. It may be desirable for related or similar items show their relations in the shortened term. On the other hand, terms with unrelated meanings may end up with abbreviations that look similar. Certain characters will tend to be used more than others, eventually becoming overused (e.g., "c": control, console, component, cooling, circulating, chill, etc.) The larger the list grows, the more these problems will tend to occur, even if the development of names for the system is carefully controlled and developed. However, often names will not be carefully developed, using too many terms, each with too little genuine information.

If these problems are not actively managed, the results tend to be too many shortened terms, redundant terms for single items, multiple items with the same abbreviation, shortened terms that vary widely in length, and worst of all, cryptic terms that are unique but indecipherable, and do not serve as a memory aid.

The remainder of this Section provides guidance to support the generation of abbreviations and acronyms.

2.2.2.1 Algorithms

The guidance for generating abbreviations and acronyms is presented as an algorithm in Figures 2.2.2.1a and 2.2.2.1b.

2.2.2.2 Approved Abbreviations List

Acronyms and abbreviations shall be combined and maintained on a single list known as the Approved Abbreviations List. This list will be provided in two versions: alphabetically by short form, and alphabetically by full form.

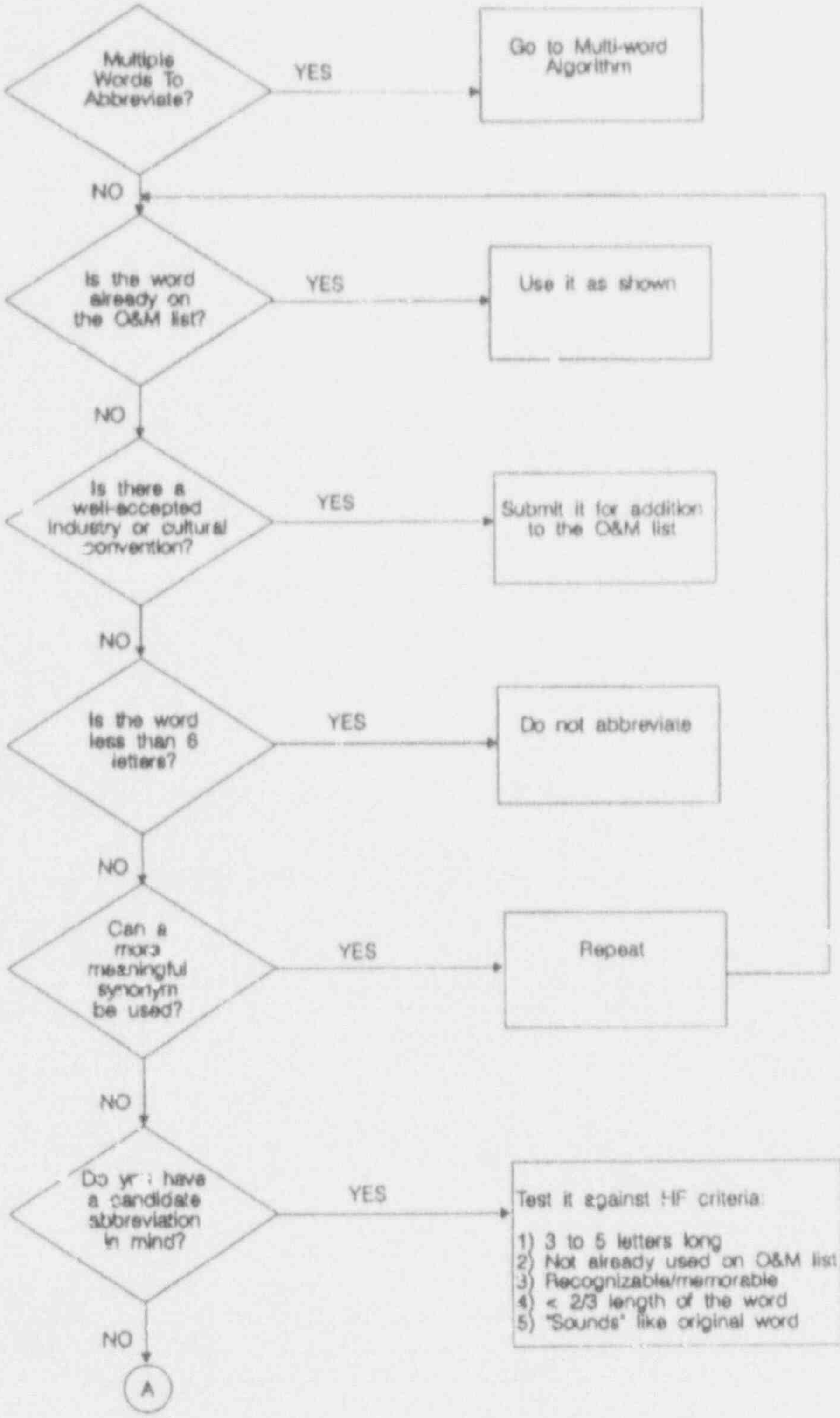
2.2.2.3 Management of the Approved Abbreviations List

The Approved Abbreviations List shall support consistent development of meaningful materials for use by operators, maintainers, designers, engineers, technicians, and other O&M technical staff. The list will be controlled and updated as necessary to incorporate new terms. This list of abbreviated O&M terms should not incorporate organizational or administrative terms unless these will be used in labeling, procedures, tech specs, etc.

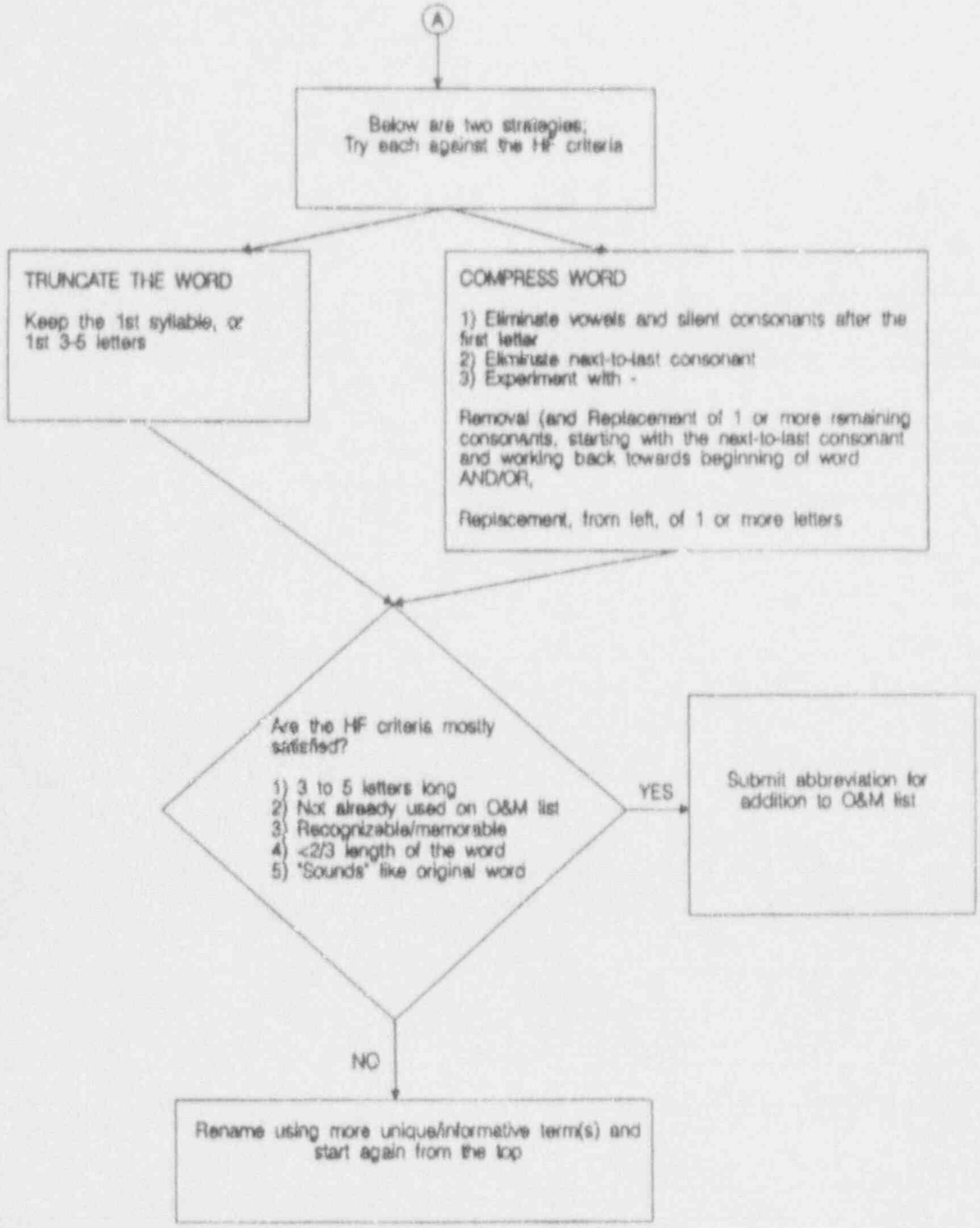
2.2.3 Alphanumeric Characters for Labels & Text

Alphanumeric characters obviously have wide-ranging applications in a large engineering facility. Inadequate implementations of characters and text conflict directly with the general principle to provide readable information (Item f, Section 2.1).

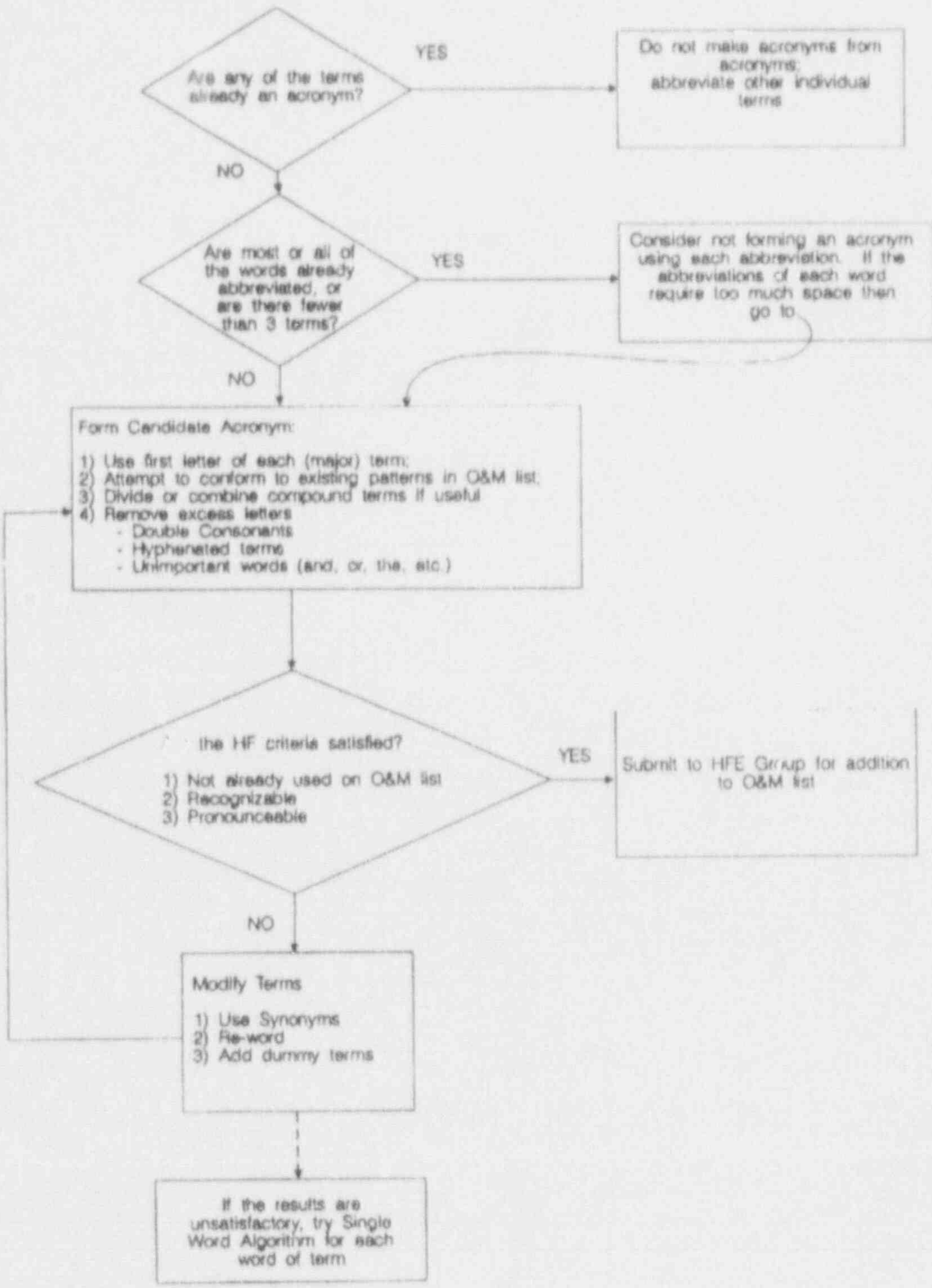
Many issues impact significantly on the selection of adequate characters, including ambient lighting, print and background colors, display medium characteristics, and conditions of degraded usability (e.g., off-normal viewing angles or distances, emergency lighting, facemasks, foreign matter, physical wear or damage to the character medium, etc.) This section does not address these matters individually, but provides broadly



ABBREVIATION ALGORITHM (single words)
Figure 2.2.2.1.a (1 of 2)



ABBREVIATION ALGORITHM (single words)
Figure 2.2.2.1.a (2 of 2)



ACRONYM ALGORITHM (Multiple Words)
Figure 2.2.2.1b

applicable guidance on the basic issues governing font selection, namely, character form and size. Additional cross-references are provided to other topics where applicable.

2.2.3.1 Style

a) Plain Block Fonts - Plain block "sans serif" style fonts (i.e., character sets) shall be used in all applications. Examples of block sans-serif include Lincoln/Mitre, Leroy, Amel, Helvetica, Swiss Roman, Gothic ... (etc.)

Figure 2.2.3.1 Examples of Font Types

b) Descenders, Super/Subscripts - The font shall allow for true descenders, superscripts and subscripts (See 2.2.3.2f, Vertical Spacing, and 2.2.3.2g, Descender Length).

c) Confusable Characters - Fonts used shall enable positive absolute discrimination (i.e., discrimination without relative comparisons) of similar characters such as:

I and 1	O and 0	S and 5	U and V
I and L	O and Q	T and Y	X and K

d) Upper Case - Upper case characters should be used where text is presented as singular isolated terms (emphasis on visibility), such as equipment labels, screen titles, or low resolution dot matrix displays.

e) Mixed Case - Mixed case lettering should be used for written instructions, software messages, and other cases where text is presented as word strings, phrases or sentences (emphasis on readability). Mixed case shall be used for abbreviations and units of measurement as is common practice (see Webster's New Collegiate Dictionary or equivalent.)

2.2.3.2 Dimensions

Character size is an important component of readability. Apparent size is determined by the physical size of the character, and the distance from which it is viewed. Thus, the first step in choosing character size for an application is to determine the reading/working distance from which the characters must be read. Character height is the usually the principle dimension to which the remaining dimensions of the character are referenced.

a) Reading/Working Distance - The intended user's reading/working distance and its basis (i.e., statement of type of tasks supported) shall be specified in the equipment design documentation for applications that require text or print to be displayed. Reading distances shall not be assumed to be less than 20 inches.

b) Character Height - Since size of text interacts with other variables to determine legibility and readability the following standards are provided. Apparent character height shall subtend at least 12 minutes of arc, and should subtend between 18 and 28 minutes of visual arc, at the specified design basis reading/working distance. To calculate the minimum character height needed to meet this standard for a given viewing distance, the formula is:

$$0.003491 \times \text{Reading Distance} = \text{Minimum Character (12 min) Height}$$

This guidance assumes that the VDU screens, on which characters might be displayed are of "high resolution" i.e image quality of the text is at least 12 lines of vertical resolution (i.e., a 7 x 9 character matrix) per character, that lighting meets the Standards specified in 7.1, Illumination, and that text will not be read from more than 30 degrees off-axis. If it is necessary to violate these assumptions, larger characters should be used.

Table 2.2.3.2 offers character heights based on the design basis viewing distances at the Main Control Console in the control room.

Max Viewing Distance	Min Character Height (12 min)
"at the Panel"= 36 in	0.125 in
"Adjacent Panel"= 50 in	0.175 in
"Across the MCC"= 151 in	0.527 in

Table 2.2.3.2 Character Heights for Ranges of Viewing Distances

c) Character Width - Width of characters within a character set is predetermined by the selection of font style and height. In general, a typical character's width should be about 60% of its height, although individual characters will vary from this value.

d) Stroke Width - Stroke width shall be 1/7 to 1/9 of character height for standard applications of text and print.

e) Horizontal Spacing - Minimum spacing between characters shall be one pixel, one stroke width, or 20% of median character width (whichever is greater). Between words minimum spacing shall be one character width. Multiple or variable spacing between words in text (such as occurs when text is full justified) should not be used.

f) Vertical Spacing - Spacing between the baseline of one line of text and the top of the next line of text shall be at least 50% of the character height. Spacing between lines of continuous text shall not exceed 150% of character height. Spacing between the lines shall be sufficient to visibly separate adjacent leaders and descenders (i.e., by at least one blank pixel for VDUs, or by 10% of the character height for printed and engraved text).

g) Descender Length - Descenders shall descend below the line by a minimum distance of 25% of the uppercase character height. See Figure 2.2.3.2.

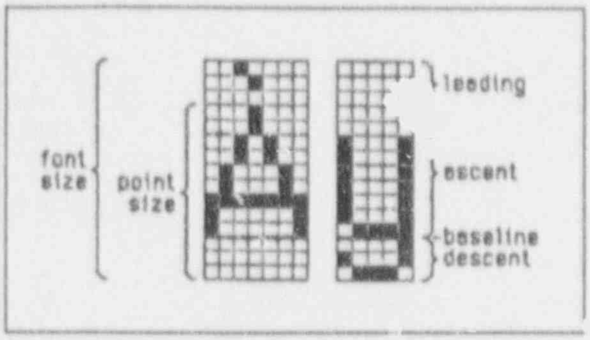


Figure 2.2.3.2 Character Dimensions

2.2.3.3 Other Concerns

a) Equipment Labels. For embossing, engraving and other design requirements of the physical label itself, see 2.5, Equipment Labels.

b) Warning Labels. Titles on warning labels (e.g. Caution Warning, radioactivity, etc.) shall be 3 times the minimum specification for legible character size at the specified reading distance. Text beneath the title should use the standard size for characters based on the viewing distance. Additional information on warning labels is contained in 2.5.10.

c) VDU Resolution. The minimum font matrix size shall be 7 by 9 dots or pixels per character (12 raster lines per text line).

2.3 Graphics & Non-Textual Format Conventions

2.3.1 General Conventions

The General Principles of Information Format of 2.1 shall be applied to graphics and non-textual formats.

2.3.1.1 Accessibility of Information

Displays and indications should be organized so that information that is most frequently needed or is most critical to guide actions and make operating decisions can be easily acquired.

2.3.1.2 Actual Equipment Responses

Indicating devices for remotely instrumented equipment shall present actual equipment responses, and shall not substitute indication of ordered action or control power indication.

2.3.1.3 Positive Indications

The absence or loss of a signal or visual indication shall not be used to inform or alert the operator of a condition. The absence of a signal or visual indication may be used to indicate a "power off" condition for operational displays, but not for maintenance displays.

2.3.1.4 Display Failure Indications

Displays should be designed so that failure of the display or display circuitry is readily distinguished from the range of possible readings for the parameter.

2.3.2 Color

Color coding is employed to differentiate between classes of displayed information and supports visual search in complex, dense, or critical displays. Color applications shall not conflict or be incompatible (e.g., opposite meanings using the same color, different colors for the same meaning, etc.) with color associations specified. Color associations specified shall be used consistently in specified systems, and should be used consistently throughout the plant. The use of assigned colors for other purposes in other separate contexts may be permitted if necessary and contexts are clearly separate. Such continued development of the

System 80+ color coding conventions shall be reported to the Supervisor of Control Complex Engineering for review and incorporation in these guidelines.

2.3.2.1 Number of Colors

No more than 9 colors, including white and black, should be used in a coding system supporting time-critical decision behavior. The selected colors should be maximally discriminable.

2.3.2.2 Redundant Coding Dimensions

Color coding shall not be the only method or dimension used to encode and display a set of distinctions. Shape, fill, intensity, or other redundant code dimension shall be used.

2.3.2.3 Color Assignments

The following color conventions have been established for and shall be used in the System 80+ design. They have been selected to be compatible with common usage and existing industry conventions. Color assignments are presented within specified contexts. Some colors have distinct meanings in different contexts. This is permissible if conflicts and incompatibilities among the assignments are avoided.

a) Control Panels & Associated Displays - Component states shall be coded only in terms of their objective physical status (see 2.3.1.2, Actual Equipment Response). Component status symbols will not be coded to show normality/abnormality. Mode-sensitive alerting mechanisms (alarm tiles, operator aids, and associated messages) will direct the operator/maintainer's attention to this type of information; within this context, operators will then be responsible for evaluating the acceptability or normality of the indicated conditions.

The following color set will be used where color is applied in the context of control panels, for both control and indicating devices:

Black	-	Background color, text for control panel labels on white background
Blue	-	Component Control Status: Auto permissive/ on-line

Green	-	Flow Status (of remotely indicated or controlled components): Off/Inactive/De-energized/Flow Preventive (e.g., Valve Closed, Breaker Open, Pump Off, etc.)
Yellow	-	Alarm annunciators
Orange	-	Component Control Status: Manual; Non-alarm annunciator
Red	-	Flow Status (of remotely indicated or controlled components): On/Active/Energized/Flow Permissive (e.g., Valve Open, Breaker Shut, Pump On, etc.)
Grey	-	Static data (i.e. data that is not changing dynamically) such as menu options, dividing lines, piping, non-controllable components and non-instrumented valves, graph grids, and default graphical items without other assigned color conventions
Cyan	-	Descriptors of dynamic process parameter values
White	-	Dynamic data i.e process parameter values and system's response to operator touch, e.g., menu selection until appropriate system response occurs, background for labels, color of text on the momentary actuation switch lens.
Tan	-	Control Panel Surfaces
Light Brown	-	Control Panel demarcations
Dark Brown	-	Control Panel Mimic Flowpaths
Purple	-	Background for white-lettered discrete indicator control panel labels containing post accident monitoring parameters

b) Personnel Safety & Physical Hazards. The following specifications are general. They are consistent with applicable OSHA standards in 10 CFR 1910 Sections 144, "Safety Color Code for Marking Physical Hazards" and are not incompatible with the color assignments in 2.3.2.3

Green	-	Safe; Go
Yellow & Orange	-	Caution; Attention
Red	-	Danger; Stop; Fire Hazard, Fire Safety
Magenta	-	Radiation Hazard

c) Labels. See 2.5.6, Label Colors.

2.3.3 Emphasis Coding (Brightness & Flash)

Emphasis coding or highlighting should be used to direct and prioritize the operator's attention to plant, system, and equipment status changes based their importance to operator evaluation, decision-making, and action requirements. Salience (i.e., attention-getting capacity) between levels of a coding dimension should ordered by priority or importance, so that more important categories have more salient coding assignments.

2.3.3.1 Consistency

Emphasis methods used to encode specific information (i.e., beyond their call for attention) shall have the same meaning in similar applications.

2.3.3.2 Brightness Coding

When brightness coding (i.e., contrast enhancement, or increased difference between figure and background intensity) is used for highlighting, the number of brightness levels used should be limited to two and shall be limited to three distinct levels. Levels shall differ by a ratio of at least 2:1 or more. (Note: situations may occur where some minor adjustment of intensity between different, but similarly coded, shape or size symbols in a may be necessary to make them look subjectively similar; this is a display implementation issue and not a coding distinction.)

2.3.3.3 Flash Coding

Flashing of a symbol or message (e.g. on-off or alternating high-low brightness) shall be reserved for alerts and (re)directions of operator attention to status changes.

a) Number of Flash Rates. No more than 2 flash rates shall be used, with the faster rate denoting higher priority.

b) Single Flash rate. When a single flash rate is used, the rate shall be between 3 and 5 Hz, with a minimum of 50 msec of signal "on" time between flashes of the signal "off".

c) More than one flash rate. When more a second flash rate is used, the lower priority flash shall be between 1 and 2 Hz.

d) Duty Cycle. When 2 flash rates are used the "on-off" cycle times should be in a ratio from 1:1 (50% duty cycle) to 1:3 (25% duty cycle). Higher priority information shall have the duty cycle closest to 50%.

e) Synchronization. Simultaneously active flashing devices of the same rates shall be synchronized.

2.3.4 Shapes/Symbols

Shape or pictorial symbol coding should be used to provide visually direct representation. Symbols should be easily recognized pictorial analogs or symbols of the component, system, or action, and should be based on established standards and conventions (e.g. P&IDs).

2.3.4.1 Size

a) Perceived Absolute Size. The smallest attribute of the symbol that is required for its unambiguous interpretation shall subtend 12 minutes of visual arc at the design basis reading/working distance. Overall symbols dimensions should exceed 20 minutes of arc across the width of the smallest rectangle that can enclose the symbol.

b) Relative Size. Size coding of information on indications (other than proportional numeric scales) is not recommended. When the size difference of symbols is to be used as the means of discrimination, there shall be at least a 150% difference in size, with a maximum of three levels of size difference permitted.

2.3.4.2 Number of Symbols

The number of different symbolic codes that are used on a single MMI display snould be reasonably minimized, and shall not exceed 20. The total number of symbols should be limited but subject to the requirements of the task analysis, i.e. if a new symbol is necessary for operations and information display it should not be disallowed based on the standards portrayed here.

2.3.4.3 Fill Coding (Symbol Modifiers)

Coding dimensions may be added to a symbol, to indicate changes in the status of a symbol's referent. In System 80+, the flow status of valves, pumps, and breaker components shall be indicated by filled (i.e., flow-preventive) and unfilled (i.e., flow-permissive) component symbols.

2.3.4.4 Meaning of Symbols

The symbols used in System 80+ are presented in Figure 2.3.4.4.

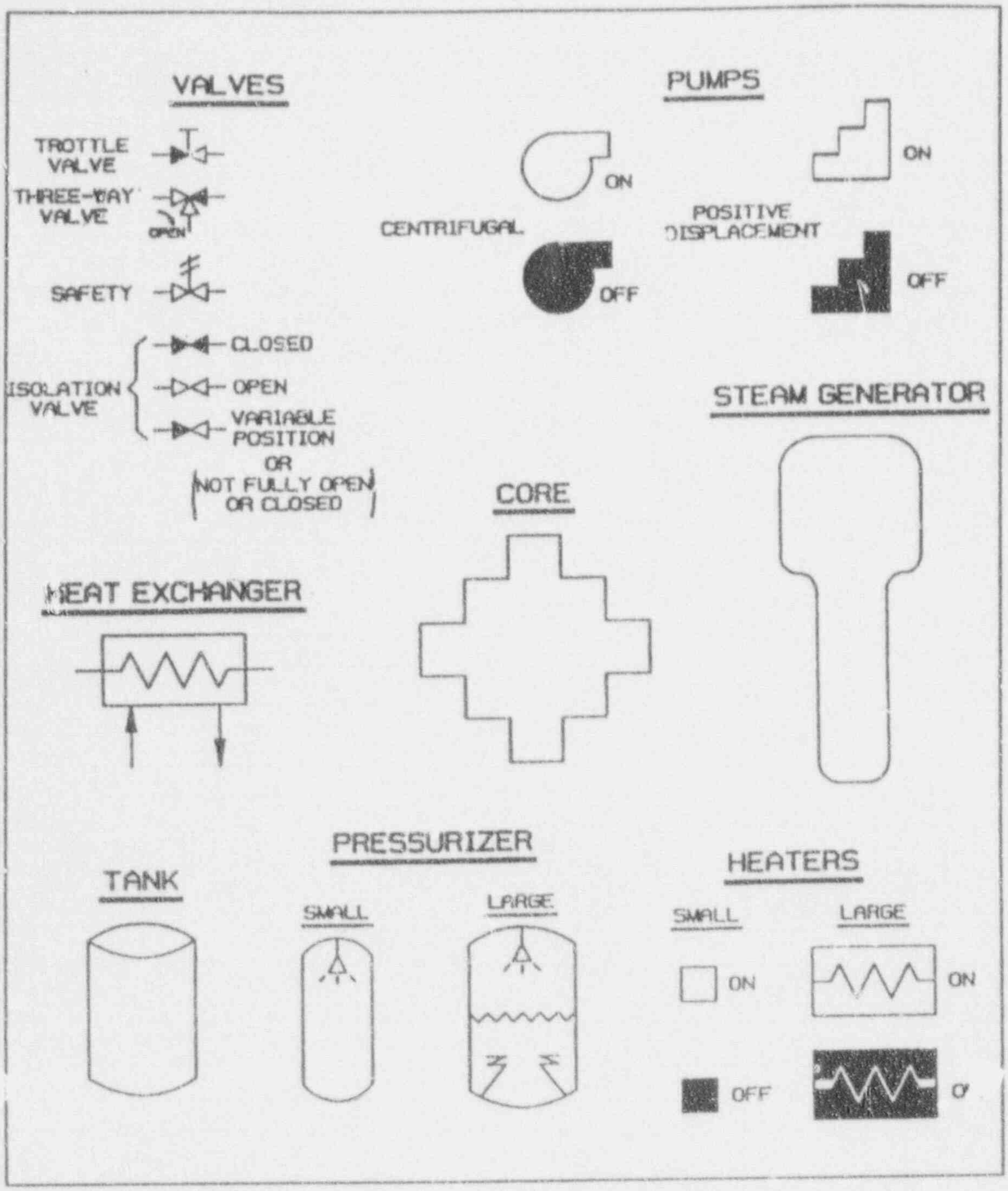


Figure 2.3.4.4 System 80+ Symbols (page 1 of 2)

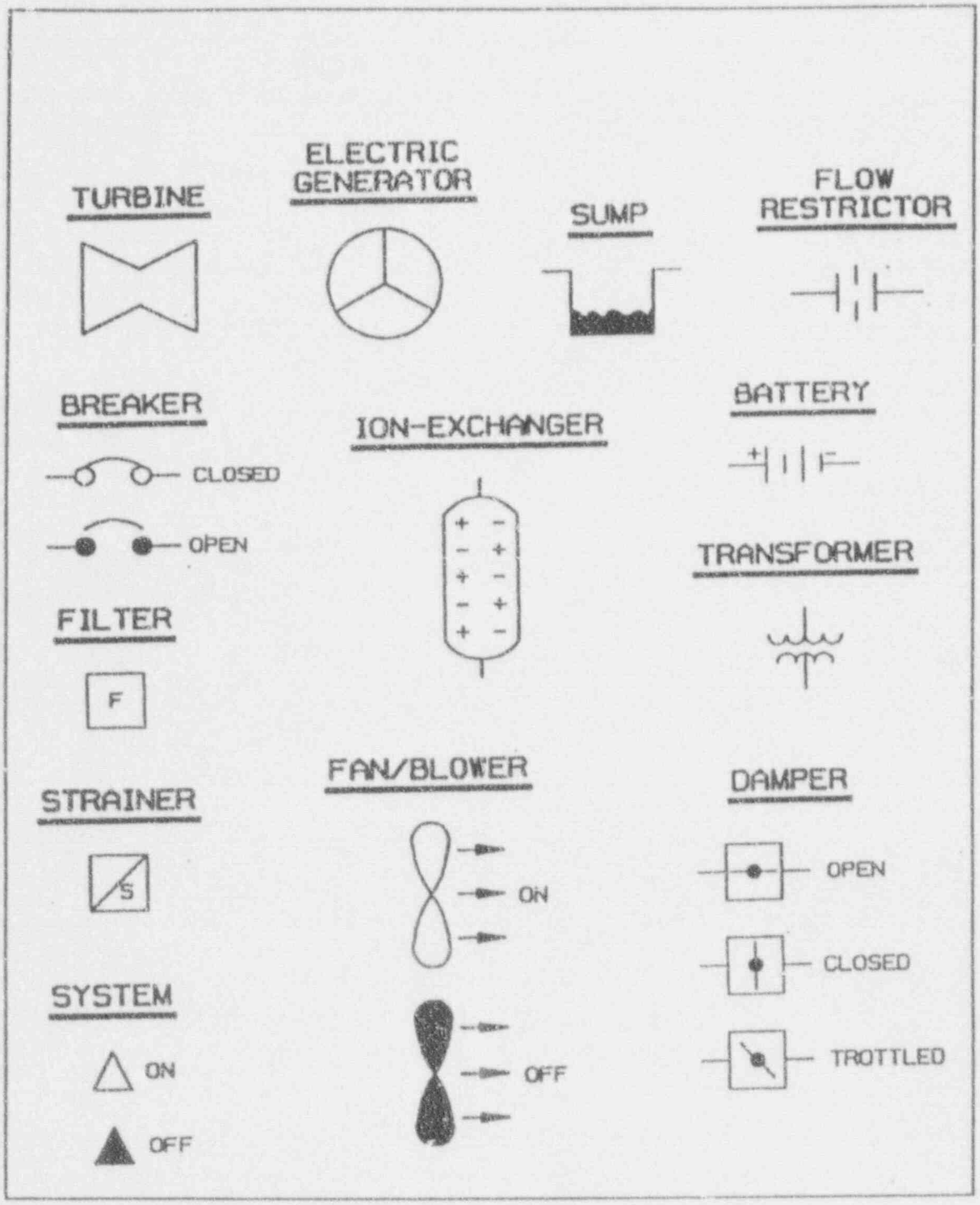


Figure 2.3.4.4 System 80+ Symbols (page 2 of 2)

2.3.5 Graphs and Graphics

Graphic displays should be used to display data showing relations or changes in space or time; when operators must quickly scan and compare related sets of data, or when operators must monitor slowly changing data for trends.

2.3.5.1 Consistent Scaling

When operators must compare graphic data across a series of charts or graphs, the same scale shall be used for each chart (see Figure 2.3.5.1.).

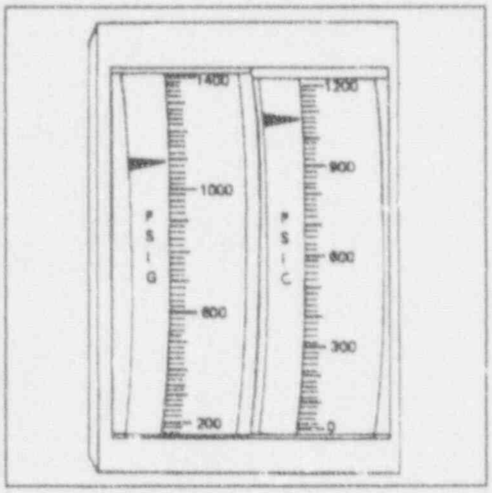


Figure 2.3.5.1 Example of Incompatible Adjacent Scales

2.3.5.2 Direct Display of Comparisons

When operators must routinely determine difference readings between two sets of data, or the quantitative margin between a parameter and a limit, then the difference or margin value should be displayed directly as a curve in its own right. See 4.1.2, Direct Usability of Data.

2.3.5.3 Grid Lines

If the operator must use the graph to precisely extract point values then scale graduation on axes shall be extended to form a grid in a two-dimensional graph. Grid lines shall be unobtrusive (low intensity) and shall not obscure data elements. Grid lines should be displayed or suppressed at the option of the operator

2.3.5.4 Scales

See 2.4, Numerical Scaling on page 30.

2.3.5.5 Labelling of Axes

The horizontal (x-axis) should be used to plot time or the postulated cause and the vertical (y-axis) should be used to plot the monitored parameter. See also sections 2.5 Equipment Labelling and 2.2.2 Abbreviations and Acronyms.

2.3.5.6 Values

When graphed data represents only positive numbers, the graph should be displayed with the origin at the lower left. When the data include negative values and the axes extend in both directions from a zero point, the origin should be displayed in the center of the graph. Time history displays shall have the origin in the lower right hand corner of the display (e.g., 30 minutes ago equals -30 minutes).

2.3.5.7 Scale Range Descriptors

Graphics with multiple scale ranges or resolutions shall display a unique descriptor for each scale. When a graphic display changes range in response to parameter input (e.g., autoranging narrow to wide range), a non-alarm annunciation of the scale descriptor (e.g., flashing, required acknowledgment) shall direct the operator's attention to the change in scale (See also 2.4, Numerical Scaling). The display of current values on the indicator shall not be prevented by a failure to acknowledge the scale change annunciation.

2.3.5.8 Bar Graphs

Bar graphs should be used for comparing a single measure across a set of several entities or a variable sampled at discrete intervals. Where bars are to be compared, the bars should be arranged in parallel and spaced closely enough, normally not more than one bar width, so that a direct visual comparison can be made without eye movement.

2.3.5.9 Panel Mimic Layouts

Process flow lines (mimic lines) shall be included in all layouts of controls and dedicated indicators where the relationship of actual plant components is not apparent from the layout and labeling of controls and indicators alone.

Labels shall be provided in process mimics such that all flow lines lead to or from a specified component, a source label (e.g., "from makeup"), or a destination label (e.g., "to letdown").

Demarcation lines and mimic flow lines on control panels shall be 3/16" wide.

2.4 Numerical Scaling

Scaling is the division of the operating range of an indicating or control device into numbered, proportioned units.

Other sections that should be applied to the development of scaled displays include 2.2, Print and Text Format Conventions; 2.3.2, Color; and 3.1.1, Display-Control Compatibility.

Sections to which this guidance should be applied includes 3.5, Instrument Meters and Gauges; and 4.0, Software.

2.4.1 Scale Range

a) Sufficiency - Interface hardware devices shall have sufficient scale range to accommodate all anticipated normal and abnormal operating conditions.

b) Nominal Readings - Interface hardware devices shall provide scale range such that nominal readings or settings fall between 20% and 90% of full scale during normal operations.

c) Multiple Ranges - The high end range of the device shall be sufficient to prevent over-ranging during anticipated conditions. If sufficient high end range causes normal operations to occur below 20% of scale, then multiple ranges should be considered. (See 2.3.5.7, Scale Range Descriptors, and 2.4.6., Nonlinear Scaling.)

2.4.2 Scale Demarcation and Numbering

Demarcation refers to the techniques used to portray an analog scale range as a series of measured divisions separated by graduation marks. See also 2.4.7, Units of Measure.

a) Graduation Size - Major (numbered) and minor (unnumbered) graduations shall have different sizes. Different lengths may be more legible for quantitative point readings; different widths may be more visible (though less accurate) if only qualitative check readings are required. Graduations shall be proportioned as shown in Figure 2.4.2.a. Intermediate graduations (either numbered or unnumbered) are unnecessary if minor, unnumbered graduations number four or less.

b) Graduation Intervals - Scales shall be graduated (and numbered) in intervals of one, two, or five units, or multiples thereof by powers of ten, as shown in Figure 2.4.2.b. (Multiplying a scale by a power of ten may be denoted as part of the overall scale label, rather than at each numbered graduation.)

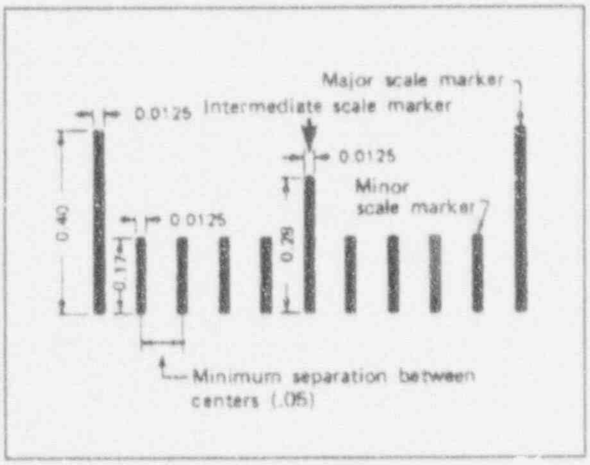


Figure 2.4.2.a Graduation Dimensions in inches for Viewing Distance of 3 feet

GOOD					FAIR				
1	2	3	4	5	2	4	6	8	10
5	10	15	20	25	20	40	60	80	100
10	20	30	40	50					

Figure 2.4.2.b Graduation Intervals

c) Numbered & Unnumbered Graduations - Between the numbered graduations, unnumbered graduations should not exceed four and shall not exceed nine in number.

d) Percentage Scaling - Percentages shall not be used unless they have been identified as the standard for a specific parameter. Where percentages are used, 0% of scale will correspond to the low end of the parameter range (e.g., minimum level, flow, power, capacity, etc.); similarly, 100% of scale shall correspond to the high end of the parameter range.

2.4.3 Scale Precision

Precision refers to the finest level of significant graduated data on the device scale.

a) Analog Scale Precision - Interface Hardware devices with analog scale ranges shall provide scale demarcation not less than one-half the minimum precision required by the user's tasks. For example, if a task requires reading pressure to within 10 pounds of accuracy, then the minimum required scale precision would be 20 pound graduations (25 pound graduations would be too coarse, while 10 pound graduations would be acceptable, but finer than required.)

b) Digital Scale Precision - Interface hardware devices with digital scale ranges shall provide scale resolution (i.e., number of decimal places) greater than or equal the minimum precision required by the user's tasks. For example, if a task requires reading temperature to within half a degree of accuracy, then the minimum required scale precision would be a single decimal place following the zero (no places following the decimal point would be too coarse, while two decimal places would be acceptable, but finer than required.)

c) Excessive Precision - Scale precision shall not exceed the accuracy of the detector-instrument ensemble. Unnecessary scale precision (e.g., more than one decimal place or scale division beyond that required by the task) should be avoided, or be suppressible by the user.

2.4.4 Scale Labeling

Scale labelling shall adhere to the conventions specified under 2.2, Print and Text Format Conventions; and 2.5, Equipment Labels.

2.4.5 Scale Zone Banding

Zone banding with color or graphical highlights to denote normal, abnormal, or other categorical operating ranges of a parameter should, if applied, be conspicuous, distinct, and not interfere with the quantitative reading of the display. Zone banding should not be used unless the implementation is one where parameter zones can be reliably and usefully defined, and where the implementation can account for relevant mode dependencies in the interpretation and display of the parameter.

2.4.6 Nonlinear Scaling

Logarithmic or other nonlinear scaling shall be reserved for devices that require at least three orders of magnitude of precise range, and for which nonlinear scaling is deemed conventional or appropriate (e.g., source range reactor power).

2.4.7 Engineering Units

The use of engineering units shall conform to the standards of [TBD].

2.5 Equipment Labels

2.5.1 Applicability

a) Identification Labels - Identification labels (names and designators) shall be provided on all specific equipment, components, structural features, etc., where personnel must identify and perform O&M-related actions, or where personnel need to be directed to avoid equipment or personnel safety hazards.

b) Other Labels - Other specific types of labels (e.g., Warnings, Instructions) should be applied as specified in this section.

c) VDUs - Names and designators identifying equipment status and plant parameter items on VDU screens are descriptors, not labels, and are covered elsewhere (see 4.0, Software.)

2.5.2 Terminology

Terminology on equipment labels shall utilize controlled names and nomenclature, approved acronyms and abbreviations, and equipment designators, to help assure that labels are informative, unambiguous, and consistent (see 2.1, General Principles of Information Format; 2.2.1, Names and Designators; and 2.2.2, Abbreviation and Acronyms.)

2.5.3 Scan Codes

Installed equipment items with unique designators shall incorporate some form of scan code system [TBD] into their labels that will provide access to O&M databases.

2.5.4 Size

a) Label Text - Equipment labels shall use upper case characters (unless providing lengthy instructions), be sized to be legible from the normal working position of the operator, and otherwise conform to the contents of 2.2.3, Alphanumeric Characters for Labels and Text. Subject to these constraints, character size may be further determined by hierarchical labeling requirements (see 2.5.11d). However, if there is a conflict between the hierarchical labeling requirements and the viewing distance character size requirements, the viewing distance requirements are to be followed.

b) Label Width - The width of the label base shall provide at least one blank character at the start and end of the longest line of text.

c) Label Height - The height of the label base shall provide an unoccupied margin of at least 50% of character height preceding the first and following the last line of text.

2.5.5 Layout of Identification Labels

Generic equipment identification labels shall have the following layout:

a) Name - The item's name will occupy one or more horizontal lines on the tag as appropriate to the application (e.g., space available, label technology, etc.)

b) Designator - The item's designator shall follow the item's name. The designator should appear on a single line of the label. If this is a problem, then 1) get a wider label base, or 2) break the designator at an existing hyphenation. Designators shall not be broken at any point other than where they are already hyphenated by their standard format.

c) Scan Code - The item's scan code shall be [TBD].

2.5.6 Label Colors

a) The standard color for identification and other generic information labels shall be black letters on white background.

b) The standard color for danger labels (i.e., personnel safety warnings) shall be white letters on red background.

c) The standard color for caution labels (i.e., equipment protection or availability warnings) shall be black letters on yellow background.

d) The standard color for radiation hazard labels shall be magenta letters on yellow background.

e) The color of the text and/or background on a label shall not be used to identify systems or trains (e.g., safety train A, loop B, etc.)

2.5.7 Cor ·ction & Materials

Choice of appropriate label material and construction depends on the specific application. Thus:

a) System Descriptions should specify conditions of the ambient environment that labeling must tolerate (e.g., temperature, humidity, chemistry, vibration, etc.)

b) Detailed system procurement documentation should include specification of the selected labeling technology, and verification of its durability under the applicable plant ambient conditions.

c) Informal or improvised labels such as dymo tape, handwritten paper and tape, etc., shall not be used.

2.5.8 Position & Mounting

a) Labels on plant equipment should be placed in an obvious and well-lit position that affords a horizontal viewing orientation to the operator or maintainer.

b) Labels shall be mounted in a way that is semi-permanent (i.e., can be removed, but remains affixed under daily wear and tear), is appropriate to the item, and will not damage the metal of the item.

c) Screw-mounted and similar hardware-mounted labels cause damage to the labelled item, and shall not be used. Screw-mounted labels also tend to warp, are harder to read, and require otherwise unnecessary space for the screws.

2.5.9 Data & Instruction Labels

a) It may be useful to provide a label with key data or brief instructions at the point of use or entry.

b) Instruction labels should be near to but operationally "preceding" the point of operation. This will generally be above, to the left of, or in front of the point in question.

c) Instructions should be presented as a series of itemized steps, rather than in narrative or paragraph form.

2.5.10 Warning Labels

Warning labels should be provided near to but operationally "preceding" the point of hazard, entry, or operation (i.e., where the hazard can be avoided, and accidents prevented, outside of appropriate guards and/or barriers.) Warning labels shall identify the nature and/or extent of the hazard, and tell what to do to minimize the specified hazard.

a) General Warnings - General warnings (not annunciators; see 5.0) have been defined to be of two types: Danger (immediate personnel safety hazard) and Caution (equipment or personnel operations hazard). Both have distinctive color schemes, and are illustrated in Figure 2.5.10.

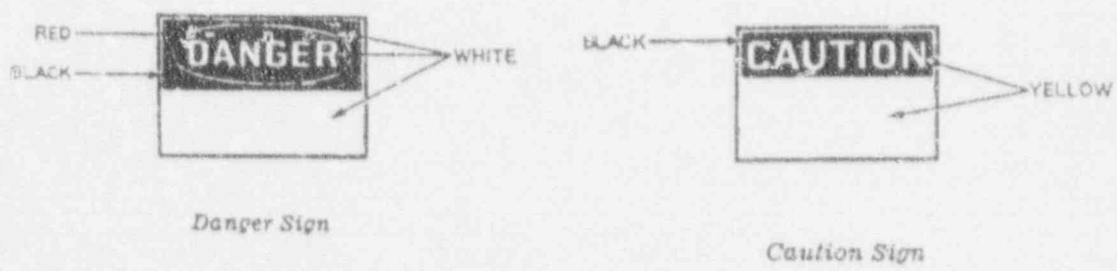


Figure 2.5.10 Examples of Warning Labels (from 29 CFR Subpart G Section 1926.200)

b) Radiation Hazards - Radiation hazards shall be denoted using current industry conventions and standard ALARA practices. Posting of "High Radiation Areas", "RWP" areas, etc., shall be via standard yellow and magenta signs. Lettering on signs shall use Bold Boston font (see 2.2.3.1, Style) for key headings. Yellow and magenta ropes shall be employed as appropriate.

2.5.11 Panel Labels

a) Materials - Labels shall be engraved from a layered (sandwich) material where the inner color is the lettering color which is engraved down to the material. Label material shall be rigid, low-glare, durable, and heat resistant to 140°F. A typical label material such as Gravoply II or Setonply is acceptable with the understanding that they scratch easily; more durable materials such as Gravoply I should be substituted in harsh local environments.

b) Positioning - Labels on panels shall be placed in a horizontal orientation, flat on the panel, and above the pertinent component.

c) Mounting - Panel labels shall be mounted on clean surfaces with double sided tape or properly cured glue, such that firm, continuous adhesion occurs over the entire rear surface of the label. Labels shall be no thicker than 3/16" so that they do not present an unacceptable protuberance.

d) Hierarchical Labeling - The height of the characters on control panels can be used to portray the hierarchical structure of the system and its components. The letter heights shown in Table 2.5.11 should be used as a sample framework for panel labeling. Each different level is at least 33% larger than the previous level to ensure that different levels are discriminable. It is not necessary to use all the levels, but the application of levels for a given set of panels (i.e., in a single control room) shall be consistent.

2.5.12 Tanks, Filters, Heat Exchangers, & Pipes

These items, in addition to identification, shall be labelled to indicate contents, rated pressure, and direction of flow. Piping shall be so labelled every [TBD] feet.

2.5.13 Structural Features

Structural members such as frames, penetrations, padeyes shall be labelled for identification and any appropriate ratings (e.g., load, clearance, etc.)

2.5.14 Geographical Locations

A you-are-here map should be provided as a navigation aid at all building, equipment room, and workspace entrances. These should explicitly indicate present location, major features on the same level, and emergency egress routes.

The maps shall be aligned with the terrain, with the assumption that the upward direction on a vertical map is equivalent to the forward direction on a horizontal map.

Type	Character Height	Example
Full Panel Label	1"	Reactor Panel
Whole System Label	3/4"	CVCS
Subsystem Label in Major Component Group	1/2"	Shutdown Cooling
Warning Header	3/8"	"Caution"
Subgroup Meter Scale Numbers	1/4"	Reactor Coolant Pumps
Individual Components	3/16"	RCP 1A
Warning Text	3/16"	"Do not operate when..."
Mimic Source/Destination Label	1/8"	"Note: later lock between..."
Component Meter Label	1/8"	"To SDC HX"/"RC-HS-105"
Test Point Label	1/10"	"Jumper between contacts 1 xd ..."

Table 2.5.11 Relative Size of Characters in Panel Labelling Hierarchy

3.0 DISPLAY AND CONTROL HARDWARE

The physical devices discussed in this section are associated with indicating (i.e., display) and control interfaces between an operator and plant systems. They have been collected here under the term "interface hardware". In some cases (i.e., touch screens, Section 3.4.8) an interface hardware device is provided to serve as both display and control functions simultaneously. Thus, it was decided that a high-level division into hardware and software might be more clearcut than an attempt to separate the contents into categories of indications and controls.

Section 3.0 begins with general design principles (Section 3.1) that apply broadly to many types of interface hardware. Remaining parts of Section 3.0 present guidance that is more device-specific in nature.

Since the purpose of this document is to guide the implementation of the System 80+ design and the Nuplex 80+ control complex, the guidance provided is limited to that which is applicable to System 80+ devices, design features, etc. If, as an designer, implementer, or procurer, you encounter a need for devices (and guidance) not specified in this document, contact the Supervisor of Control Complex Engineering for assistance.

All hardware that is electrically powered shall be designed with respect to the safety standards as set forth in OSHA requirements specified in 29 CFR Subpart S Section 1910.301-1910.308.

3.1 Design Principles

Design Principles are a collection of HFE standards and guidance that apply generally to the physical selection and implementation of many types of display and/or control devices (as opposed to their information formats, in Sections 2.2 and 2.3). These principles have been collected here to minimize the redundant presentation of similar material throughout the document. However, it is important to consider how each piece of guidance applies to a particular design problem. Generic guidance cannot be implemented without thoughtful interpretation.

The following principles of interface hardware design will be covered in Section 3.1:

3.1.1 - Display-Control Compatibility
3.1.2 - Feedback
3.1.3 - Failure Indications
3.1.4 - Emergency Control Provisions
3.1.5 - Prevention of Accidental Actuation
3.1.6 - Redundancy
3.1.7 - Durability
3.1.8 - Maintainability

3.1.1 Display-Control Compatibility

To minimize operator workload and error, control device movements and display response shall conform to the population stereotypes provided in Table 3.1.1 and Figure 3.1.1.

Function	Control Action
On, Start Run	Up, right, forward, clockwise, pull
Off, Stop	Down, left, backward, counterclockwise, push
Right	Clockwise, right
Left	Counterclockwise, left
Raise	Up
Lower	Down
Increase	Forward, up, right, clockwise
Decrease	Backward, down, left, counterclockwise

Table 3.1.1 User Population Stereotypes

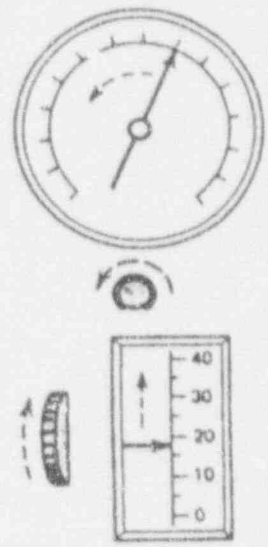


Figure 3.1.1 Control Actions

3.1.2 Feedback

Control devices shall be located near or integrated with a display or other indicating device that will provide prompt reporting of the actual results of control actions on systems or components (see 2.3.1.2, Actual Equipment Response). Each control device shall have a corresponding feedback indication on which users can verify proper operation of the controlled equipment.

3.1.3 Failure Indications

a) <u>Interface Devices</u> - When an interface device fails or becomes inoperative it should be apparent to, and readily verifiable by the operator (see also 2.3.1.4, Display Failure Indications).

b) <u>Positive Indications</u> - Failure of necessary or critical functions, systems, or equipment, or the activation of backup equipment on the loss of main equipment function, shall result in a positive indication such as a failure light, warning annunciator, etc., rather than a loss of similar "run" indications (i.e., a negative indication; see 2.3.1.3, Positive Indications).

3.1.4 Emergency Control Provisions

a) Emergency Garb - Interface hardware shall be operable by personnel wearing required emergency garb, in all locations where the anticipated need exists in the system design basis.

b) Backup Controls - If emergency or backup interface hardware is required, its configuration shall be the same as its counterpart for normal operation.

3.1.5 Prevention of Accidental Actuation

Interface hardware should be designed and located so that accidental activation is unlikely, particularly for devices whose accidental activation may cause equipment damage, personnel injury, or degraded system readiness or performance.

3.1.5.1 Noninterference

Protective mechanisms should not interfere with the normal operation of the control, adjacent controls and associated displays. In addition, any protective cover should not obscure position indication.

3.1.5.2 Protective Methods

Seven methods are provided to inhibit the inadvertent activation of a control. Methods a, b, and c (Location, Resistance, and Dead-Man Controls) are good general control device approaches and should be generally implemented if appropriate. Methods d, e, f, and g (Recess, Cover Guards, Mechanical Interlocks, and Delay Locks) are not as broadly applicable as the other methods, but may be useful if none of the first three methods can be applied and accidental activation is a concern.

a) Location - Instrumentation and interface devices should be located so that personnel are not likely to strike them accidentally while conducting other normal movements or activities in the vicinity. Sensing, control, or display devices that are fragile, critical, or periodically require alignment should not be located near high-traffic paths. If a concern exists that a device may be accidentally struck or actuated, then use one or more of the following protective methods to prevent inadvertent actuation.

b) Resistance - Control devices should be provided with sufficient resistance (e.g., spring-loading, viscous damping, etc.) so that a definite or sustained effort is required for activation. This force should not be excessive, as it will hinder intended operation. An acceptable required force would be 10 to 1[illegible] Newtons and shall not exceed 30 Newtons. Section 3.2 provides specific ranges for various individual control types.

c) Dead-man Controls - Where appropriate, control devices should be configured to return the system to a conservative, unchanging, or otherwise stable state when operating force is removed from the control, so that operator inattention will be less likely to result in an undesired system condition.

d) Recess - Controls may be recessed by physical barriers. The control shall be entirely contained in the envelop described by the recess or barrier. See Figure 3.1.5.2.d.

e) Cover Guard - A hinged or removable cover may be placed over a control. Do not use safety or lock wire as they interfere with the proper use of the device. See Figure 3.1.5.2.e.

f) Mechanical Interlock - A control device may be provided with a mechanical interlock that requires an additional prior movement or operation on the device before it can be actuated.

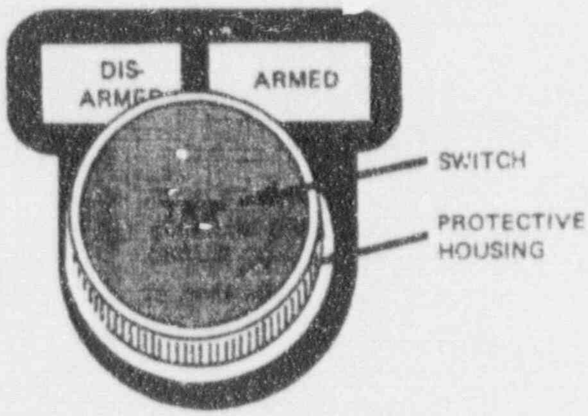


Figure 3.1.5.2.d Recessed Button With Barrier

g) Delay Lock - A control device may incorporate a time delay lock on the actuating mechanism. When actuation is attempted, the delay is initiated; the control device will not accept the input until after the delay interval has elapsed.

24" wide. If space is not provided on the panel for writing, a desk or other writing surface shall be provided in the immediate work area.

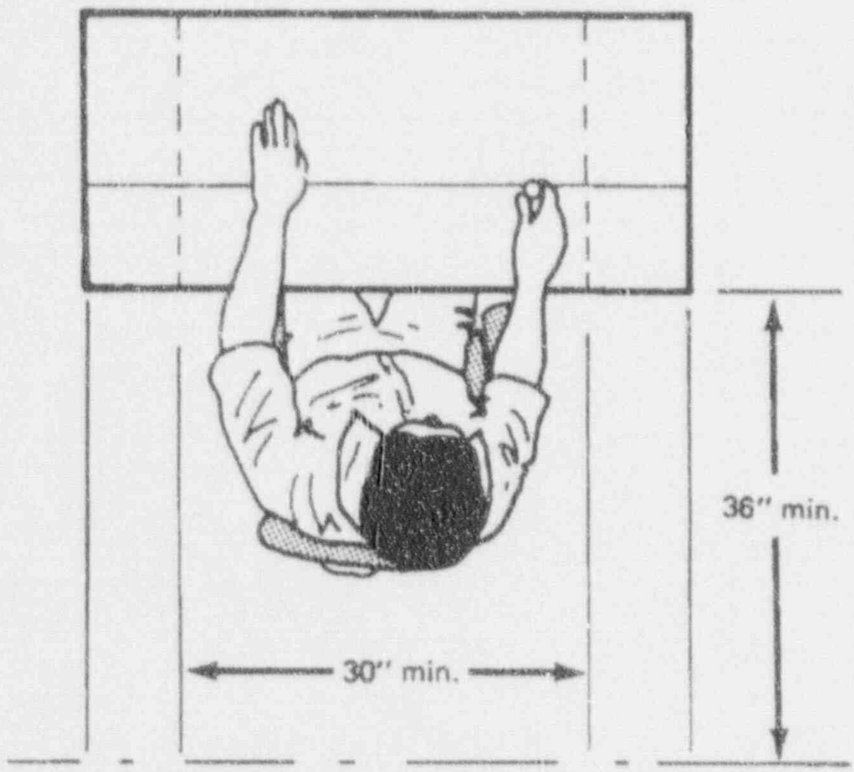


Figure 7.6.2.3.a Seated Operator

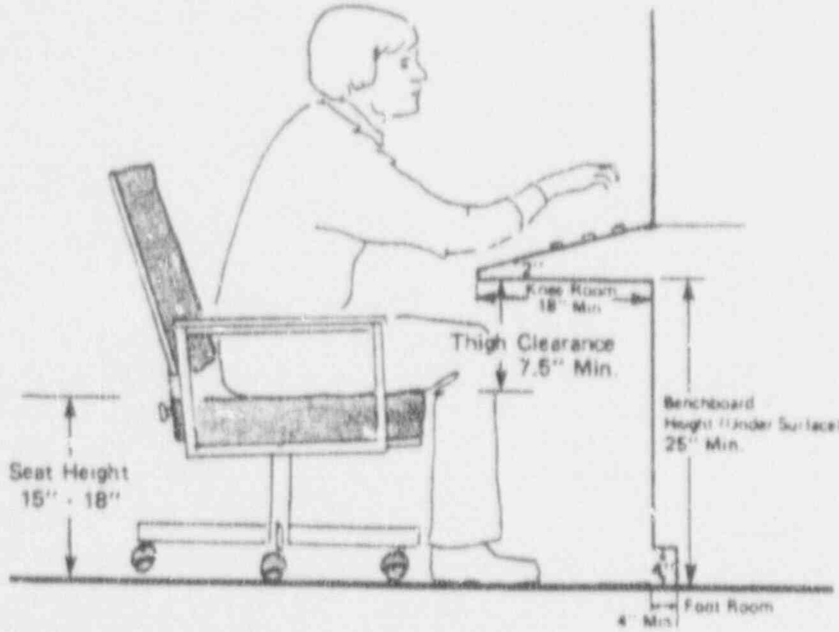


Figure 7.6.2.3.b Legroom & Kick Space

7.6.3 Workstation Layout

The procedure for panel layout is given in the Panel Layout Guidelines Document, NPX80-IC-DP-791-01. Some additional guidance on panel layout is provided here.

7.6.3.1 Group Spacing

Separate groups of components should be spaced apart sufficiently so that the group boundary is obvious. Spacing between groups should be greater than the width of a typical control or display in the group, and at least twice size of spacing between components within the group.

7.6.3.2 Demarcation

Demarcation should also be used to make group boundaries obvious, particularly where ample space between groups of components is not available. Lines of moderate contrast with the panel surface shall be used (see Section 2.3.2.3, Color

Assignments). Demarcation lines should be easily removed and replaced, for maintenance. See Figure 7.6.3.5 for an example of demarcation.

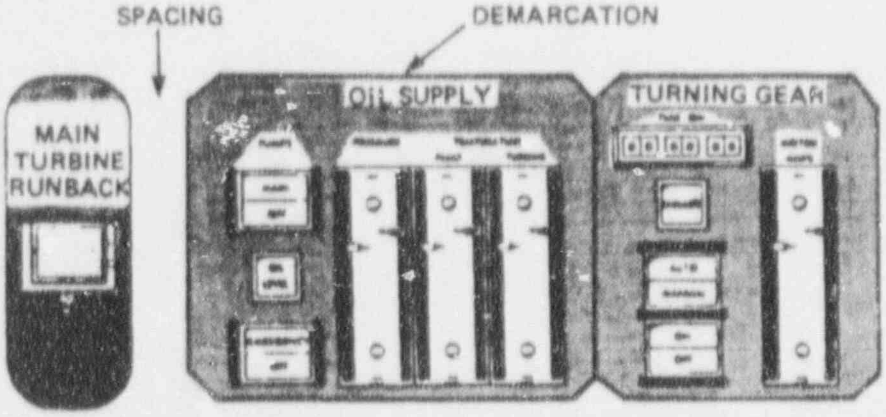


Figure 7.6.3.2 Demarcation of Component Groups (example)

7.6.3.3 Component Spacing

This section gives guidance for the spacing of adjacent components. Separation between control devices should be sufficient such that access to one device cannot be impeded by adjacent devices, and that erroneous activation of components can be reasonably avoided. The components themselves are discussed in some detail in Section 3.2, Switches and Pushbuttons. See also Section 3.1.5, Accidental Activation.

a) Legend Switches - Legend switch assemblies or modules should be separated by 2 inches at their edge from adjacent modules. However, legend switch modules that meet the requirements of Section 3.2 may, if necessary, be mounted as closely as other engineering considerations permit. See also Section 3.2.1.1, Pushbutton Dimensions.

b) Simultaneous Actuation - Where simultaneous actuation of devices is necessary, the devices should not be separated by more than 40 inches.

7.6.3.4 Arrangement of Physically Similar Components

a) Consistent Layout - The layout of similar control and display sets shall be consistent at all locations.

b) Orientation - Horizontal rows rather than vertical columns should be used.

c) Parsing Rows of Components - No more than 5 similar components shall be laid in an unbroken row or column. If more than 5 similar components must be laid out together, the row must be broken or parsed into groups or segments with additional spacing. Ideally these would be meaningful subgroups, however, if there is no meaningful organization evident, arbitrary parsing is better than none.

d) Mirror Images - Plant relationships may show bilateral (i.e., left-right) symmetry, and this may be an effective organizing framework for displays and controls. However, arbitrary reversal of component layout relationships (mirror-imaging) that does not denote a meaningful attribute of the system can contribute to errors, and should be avoided.

7.6.3.5 Large Matrices

Matrices of similar components should have labeled coordinate axes for identification of any single component within the grid. The left and top sides of the matrix should be used for labeling. Large (more than 5 by 5 element) matrices shall be broken up using physical spacing or demarcation discussed in Sections 7.6.3.1 and 7.6.3.2.

7.6.3.6 Paired Controls & Displays

Controls and related displays shall be closely placed so that the two items are readily associated and can be used conveniently with one another. The control shall be placed so that the display is not obscured by the operator during control operation. It is preferred that the display be above the control for that reason as shown in Figure 7.6.3.9. See also Section 3.1.1, Display-Control Compatibility.

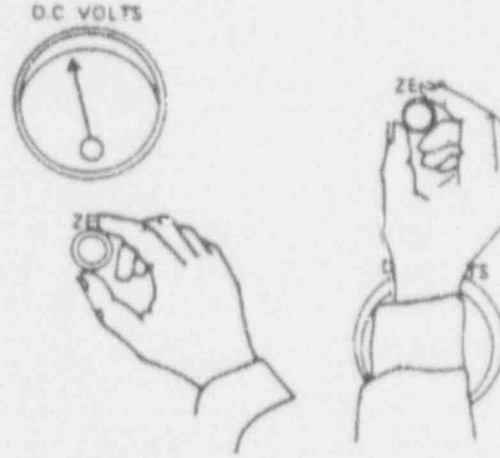


Figure 7.6.3.9 Control and Display Pairs

7.6.4 Display Position

The principle concerns in display positioning (besides display size, covered in Section 2.2.3.2, Text Dimensions) are the vertical and horizontal displacement (angle) from the operator's straight-ahead line of sight, and the angular (non-perpendicular) orientation of the display surface with regard to the operator. The values given in the following guidance are based on the limits of the normal visual field; particular hardware may result in additional limitations. In addition, evaluation of working position, eye height, display location, and resulting viewing angles must be performed (e.g., Figure 7.6.4.1.a) in order to apply these criteria; they cannot be further simplified outside the context of specific design questions.

7.6.4.1 Display Position - Vertical Displacement

a) <u>Seated Operator</u> - Displays shall not be placed at a height that requires the 5%ile female to look more than 70° above the horizontal, or the 5%ile male to look more than 90° below the horizontal. Frequently used displays should not be placed at a height that requires the 5%ile female to look more than 20° above the horizontal, or the 5%ile male to look more than 40° below the horizontal. See Figure 7.6.4.1.a and 7.6.4.1.b.

b) <u>Standing Operator</u> - Displays shall not be placed at a height that requires the 5%ile female to look more than 85° above the horizontal, or the 5%ile male to look more than 90° below the horizontal. Frequently used displays should not be placed at a height that requires the 5%ile female to look more than 35° above the horizontal, or the 5%ile male to look more than 25° below the horizontal. See Figure 7.6.4.1.a and 7.6.4.1.b.

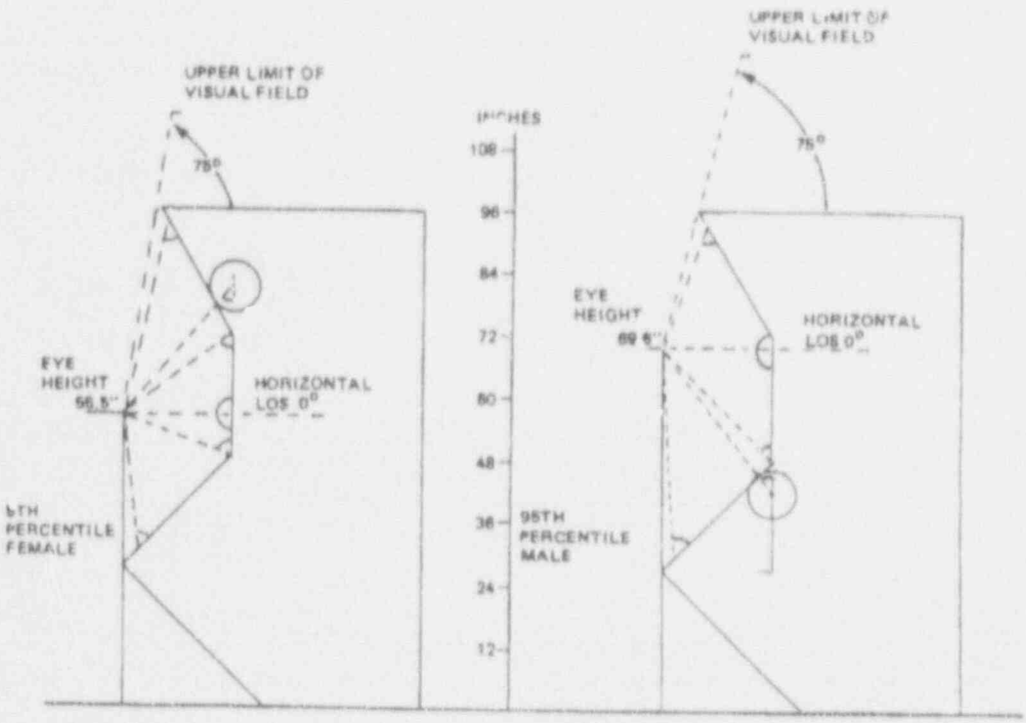


Figure 7.6.4.1.a Analysis of Vertical Viewing Angles (example)

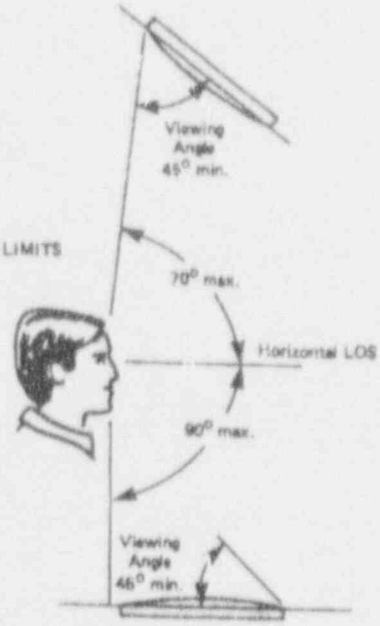


Figure 7.6.4.1.b Vertical Displacement & Surface Orientation

7.6.4.2 Display Orientation - Horizontal Displacement

Displays shall not be placed farther than 95° to the left or right of center (i.e., of straight-ahead line of sight). Frequently used displays should not be placed more than 35° off-center. See Figure 7.6.4.2.

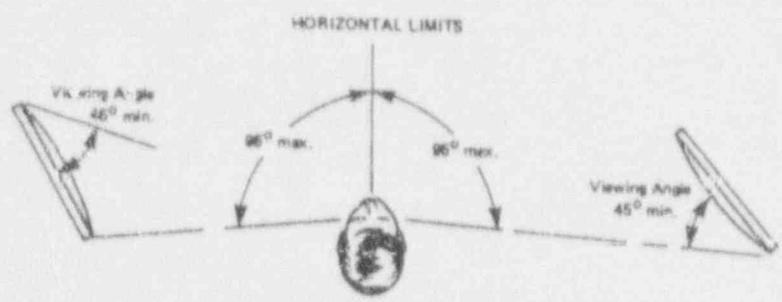


Figure 7.6.4.2 Horizontal Display Limits

7.6.4.3 Display Surface Angle

Ideally (ignoring glare concerns, curved screens, etc.) display surfaces would be perpendicular (i.e., 90°) to the operator's line of sight; departures from 90° degrade readability. Display surfaces should be designed to be read at angles between 90° and 60°, and shall not be designed to be read at angles of less than 45°. Note that this angular value is not constant for any display (other than an idealized "point" display) and should be evaluated, relative to the operator's expected position, from the furthest off-angle active point on the display surface.

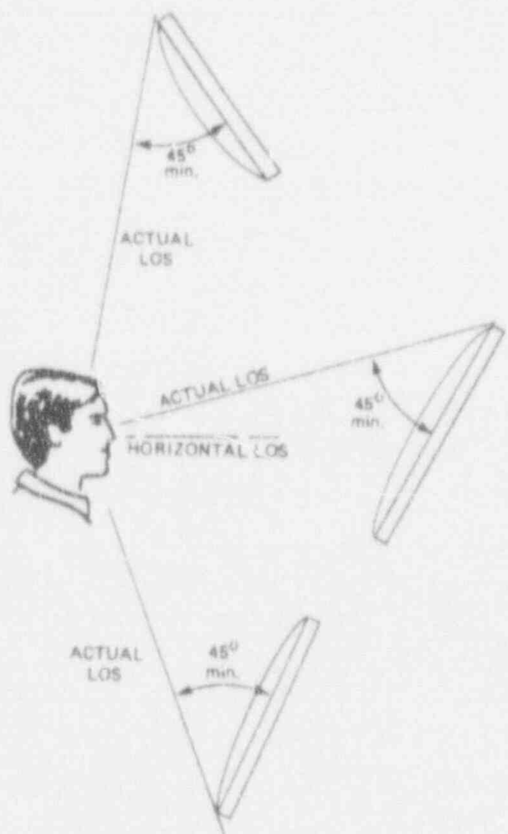


Figure 7.6.4.3 Display Surface Angle

7.6.4.4 Display Distance

Displays shall not be designed for use at less than 18 inches from the operator.

7.6.5 Desks

Desks should conform to the dimensions in Figure 7.6.5.

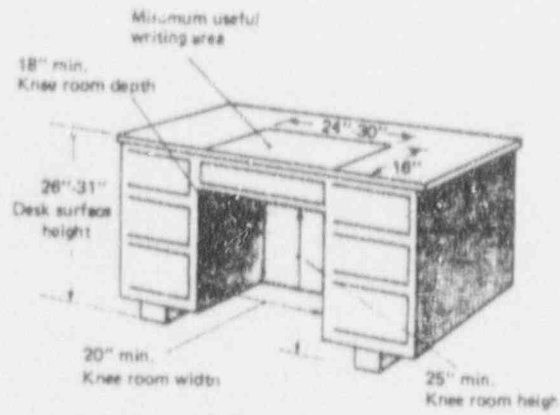


Figure 7.6.5 Desk Dimensions

7.6.6 Chairs

Chairs used at desks and seated workstations should conform to the following guidance.

a) Backrests - Workstation chairs shall have supportive back rests, including support for the lower lumbar region. A 100° angle between the back and the seat should be used for office tasks (i.e., keyboard tasks).

b) Armrests - Workstation chairs shall have armrests.

c) Cushioning - Workstation chairs should be well cushioned, with remaining resilience when the seat is occupied.

d) Covering - Workstation chairs shall be covered in breathable cloth material.

e) Seat Height - Normal workstation chairs shall be adjustable from at least 15 to 18 inches. For sit-stand stations the range should cover 26 to 32 inches.

f) Footrests - Footrests shall be used where seat heights are greater than the normal 15 to 18 inch range. If footrests are necessary, they shall be located so that the seat height can be adjusted in the range of 15 to 18 inches above the footrest, and cover the full circular motion of the chair.

g) Rotation & Recline - Workstation chairs shall provide 360° rotation and an adjustable spring-loaded recline of approximately 30°, so that operators can easily adjust their position at the console.

h) Mobility - Workstation seating should permit operators to easily and safely adjust their location at the console. Thus, workstation chairs shall have five legs with casters as shown in Figure 7.6.6. Casters should be large (at least 2"), and high quality.

Figure 7.6.6 Chair Dimensions

8.0 MAINTAINABILITY

8.1 Introduction

Maintenance tasks are defined in Section 1.4 as the subset of O&M activities that is performed to enable or ensure that components, equipment, systems, etc. will adequately perform their design function when they are required for operations.

As described below, three categories of treatment for maintainability guidance have been identified.

a) Overlap with General Issues - There is much overlap between the general design issues presented in this guide, and those in the area of design-for-maintainability. Thus, the contents of this document should be examined and applied both from the standpoint of maintainability as well as that of operability. Preceding topics with maintenance-related implications include:

Anthropometry
Color Coding
Doors, Hatches, & Hallways
Equipment Guards
Labelling
Lighting
Names & Designators
Noise
Scaffolds & Railings
Stairways & Ladders
Storage
Work Platforms

These aspects of System 80+ equipment and systems must accommodate the needs of maintainers as well as operators.

b) Specialized Problems and Data - A number of issues would require an extensive amount of specialized data with narrow applicability, merely to generate generic maintainability guidance. Such issues are beyond the scope of this document. For example:

Comprehensive OSHA Standards
Selection of Protective Garb
Occupancy Limits for Hazardous Environments

Note that all OSHA standards apply throughout the design. The HFE Standards should in no case conflict with OSHA standards. However, adherence to the HFE Standards is not adequate assurance that OSHA standards have been met. Reference to applicable OSHA standards is therefore always a necessity.

Contact the Supervisor, Control Complex Engineering, if HFE assistance in these areas is needed.

c) Maintainability Standards and Guidelines - The remainder of Section 8 contains a collection of standards and guidance material that applies broadly, but uniquely, to maintainability (and associated personnel safety) issues.

8.2 Design of Equipment for Maintainability

8.2.1 Facilitate Frequent and Expected Activities

a) Apply General HFE Principles - The contents of Sections 1.0 through 8.0 of the HFE Standards shall be applied to all aspects of equipment maintainability (e.g., labelling, lighting, etc.)

b) Analyze Expected Tasks - Analyze the likely and expected tasks of the maintainer as the design progresses. What is the sequence of use of features? What are the possible and likely errors, and are the consequences potentially significant? What could be easier, better organized, require less memory, or less training and experience? These are all opportunities to improve the design.

c) Utilize Standard Material - Use of standard equipment, hardware, and tools should be maximized within the constraints of performance requirements. Special tools should be considered only in cases where the operator is afforded a substantial advantage over the use of more standard tools.

d) Afford Easy Removal & Replacement - The number of fasteners and connectors used should be limited to that required by the integrity of the equipment. The number of turns or actions required to secure the fasteners and connections should be minimized. Use locking hinges on one side of equipment covers where acceptable. Utilize quick disconnects or aggregate connectors (i.e., multi-lead/single plug) on appropriate modular items. See also 8.2.3, In-situ Maintenance.

e) Implement Fool-Proof Features - See Section 8.2.2 below.

f) Design for In-Situ Maintenance - See Section 8.2.3 below.

8.2.2 Fool-proof Features

To the extent practical, equipment should be designed to be fool-proof in connection, operation, inspection, surveillance, etc. That is, it should incorporate "forcing functions" on the operator's actions that prevent human errors from resulting in actual improper equipment operation or operational status, reductions in plant availability or safety readiness, damage to equipment, or harm to personnel. Forcing functions are most suitable in situations where one correct way can be specified for the action(s) in question to be performed, and having flexibility to deviate from this way is undesirable.

a) Incorporate Alignment Aids - Electrical and mechanical connectors, assemblies, linkages, and cases should be designed with keys, seats, alignment pins, asymmetric bolt patterns, etc. that will prevent improper connection or assembly, thereby avoiding equipment damage. Correct alignments should be marked, labeled, or otherwise clearly visible to the technician during actual in-service assembly.

b) Provide Interlocks for Personnel Safety - Interlocks shall be used to secure high voltage to electrical cabinets, breaker enclosures, etc. when the door is opened or the cover is removed. Such interlocks should be defeatable to permit work on energized equipment, where necessary.

c) Ensure Deliberate Test Switch Status - Test switches shall provide detentes or other means to prevent intermediate or uncertain positioning of the switch. (See also Section 3.1.5 on use of switch guards to prevent unintended actuation.)

d) Avoid Temporary Connections - Temporary connections of test leads, jumper wires, test connections, etc. shall be permitted only where it is directly necessary to install test equipment that would not typically be part of its own features. Jumpered test connections should be hard-wired through test switch positions. Where temporary connections are necessary they shall be readily accessible, clearly labeled or coded, and keyed to prevent equipment damage.

e) Utilize Captive Hardware - Equipment inspection covers, component modules, and other frequently removed assemblies shall, utilize captive hardware to prevent loss or equipment damage (e.g., on rotating equipment, instrument cabinets, etc.)

f) Utilize Guides and Stops - Guides, tracks, and stops shall be implemented on equipment racks, drawers, and subassemblies, to facilitate their proper and deliberate manipulation, and to prevent equipment damage or personnel injury.

Examples of these principles are found in Figure 8.2.2

8.2.3 In-Situ Maintenance

Equipment should be designed and installed to facilitate on-line and in-situ inspection, service, and repair to the maximum extent possible.

a) Make Service-Prone Items Accessible - Service access for frequently serviced or easy-access items should be from 2.5 - 4 feet above floor level. Equipment installations and component layouts should minimize the need to remove outer, working items before the inner, to-be-serviced item can be reached. Items requiring more frequent inspection, service, or replacement should be the most readily accessible (i.e., located towards the periphery) on the equipment or installation.

b) Make Maintenance Transaction Points Accessible - Component lubrication points, fill-and/or-drain points, isolation points, adjustment points, test points, etc. should be easy to see, reach, and use, and shall be labeled with their name and specifications or requirements (e.g., oil grade and sump capacity), if any.

c) Make Service Commodities Available - Connections for various air, water, waste drain, and electrical power services should be readily accessible in several locations of every workspace. Inlets/outlets for all of these services should be immediately adjacent to each row or island of equipment.

d) Utilize Modular Construction - I&C and electrical equipments should be of modular construction wherever possible to simplify replacement in the event of component failure. Testing features must be organized to enable easy isolation of the faulty module for replacement.

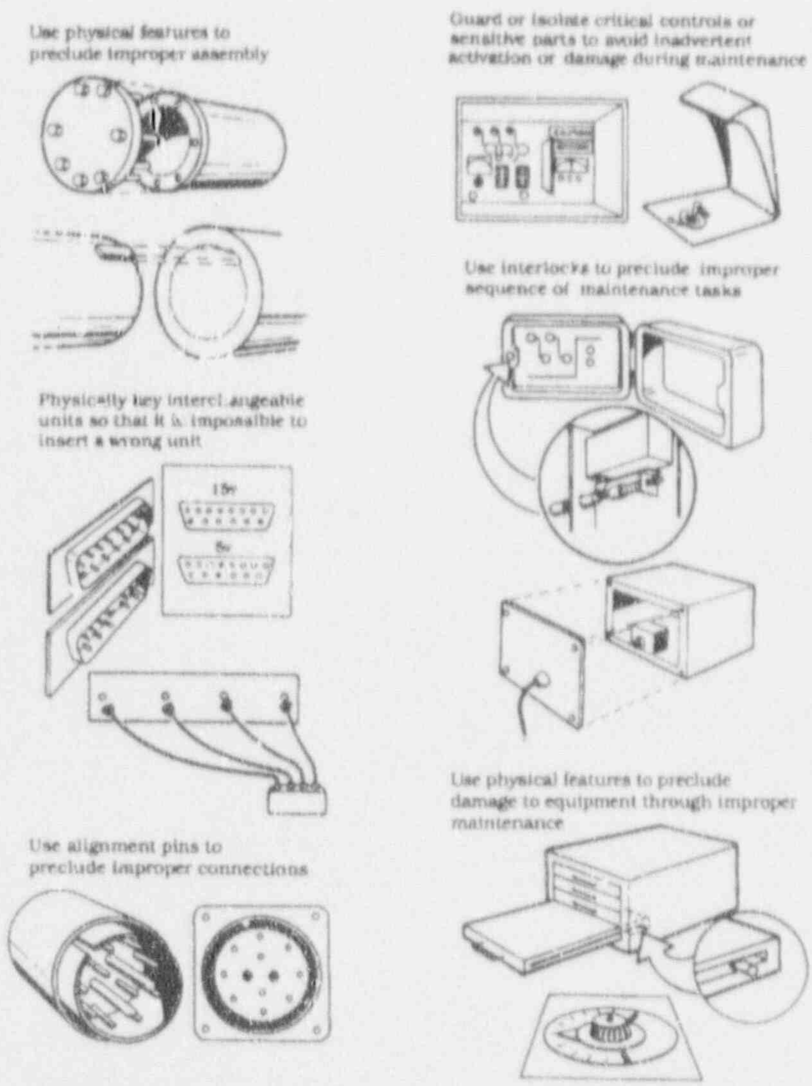


Figure 8.2.2 Fool Proof Design

e) Electronic Labels - Equipment items that are entered in the planned maintenance system shall be labelled to incorporate a selected scanning technology [TBD] to provide a direct interface to the planned maintenance system database through portable laptop-type computers. This will make checks and updates of the database easier and more reliable (see Section 2.5, Equipment Labelling).

f) Enhance Work Area Visibility - Design of equipment for planned maintenance should enhance visibility of the related components. Cabinet enclosures shall be painted non-glare white on the inside. Enclosures subject to frequent access (once a month or greater) shall provide effective, permanently installed lighting.

g) Provide Data & Instructions as Labels - For frequently used data or instructions that will change infrequently, if ever, provide the information as a permanently installed label at the point of use (see Section 2.5, Labeling.)

h) Enable Control Device Repair with Controlled Device On-line - Devices should be removable without changing the status of the controlled function, or precluding use of the panel. Equipment indicating lamps should be replaceable without risk of equipment actuation.

i) Provide Personnel Safety Features - Personnel should be reasonably protected against all specific hazards and equipment (e.g., cutting, rotating, or other moving parts, electrical voltage, hydraulic or gas pressure, extreme temperatures, toxic or caustic chemicals, radiation or contamination levels.) Design the system to be free of, resistant to, or interlocked to avoid unnecessary hazards (see Section 8.2.2, Fool-Proof Design). If the presence of the hazard cannot be avoided, provide guards against exposure to remaining hazards. Always provide attention-getting, informative warnings outside the hazard envelope at its entry and/or initiation points.

8.3 Facility Arrangements & Installations

8.3.1 Access, Pull, & Laydown Space

a) Nominal Component Clearances - Major components and large piping (2 feet or more in diameter including insulation) should have a nominal clearance for maintenance purposes of not less than 50 inches and shall have nominal clearance of not less than 36 inches from structural features and other components. (The standard value accommodates only the need for personnel access, and does not account for additional pull and laydown space that a particular equipment may require.)

b) Dual Components - Parallel components or other redundant component trains should not be arranged in an inboard-outboard or other manner that restricts access to one of the components. Such systems should be staggered, stacked, or otherwise arranged in a fashion that allows acceptable access to, or removal of, either unit.

c) Component Heights - Components that are large, or that may require frequent inspection or maintenance should be placed 3 to 5 feet above floor or walkway level. Items considered for overhead placement should be relatively small (e.g., valves not greater than 1 foot in diameter), infrequently or remotely operated, and require infrequent inspection or maintenance.

d) Pull Space Specifications - Pull spaces for all major components (> 50 pounds) shall be specified in detailed plant design layouts using the CAD system. The pull space specifications shall incorporate pull space dimensions from the system design documents, and ensure that necessary padeyes and lifting or pulling devices are available to the component.

e) Cabinet Entry - If physical entry of a cabinet space is anticipated, and the cabinet must be less than 78 inches tall, an easily removable top, or installed "pop-up" top arrangement, should be considered.

f) Accessibility of Local Indicators and Controls - All local indications and controls shall be properly lit and safely accessible without the aid of stools, ladders, crawling under pipes, etc. Indicators and controls shall conform to the same guidelines for visibility and operability as in the main control room. The use of flashlights, mirrors and similar aids to see sight glasses, bordon-tube indicators and other on-component data presentations shall not be necessary.

g) Spare Parts and Tools - Spare parts and tools for use in routine maintenance shall be placed or stored in locations around the plant from which they may not accidentally or casually be removed. However, storage space access shall not be blocked or delayed by the use of keys and/or combination locks.

Spare parts of infrequent use or high value shall have a warehouse control mechanism. However, frequently used items such as light bulbs, screws, etc. shall be readily accessible around the plant.

8.3.2 Cranes, Hoists, & Lifting

TBD

8.3.3 Scaffolds, Stands, & Miscellaneous Facilities

TBD

8.4 Special Requirements for Contaminated Systems

a) Access Control Points - Potentially contaminated workspaces should be designed with a specified access control point area. This requires space for clean and contaminated waste containers, step-off pads, boundary markers or mounts, a frisking and air sampling station, status postings, anti-contamination garb and other supplies, paperwork, a writing area, appropriate lighting, and probably a computer terminal. Remote viewing facilities, either temporary or permanent, may also be desirable.

b) Component Access - Consistent with ALARA principles, extra design effort should be made to avoid unnecessary placement of noncontaminated system components inside potentially contaminated workspaces. Similarly, extra effort should be made to provide adequate access, pull space, etc. for all components inside such workspaces. Dual trains of systems whose operation results in high rad levels (e.g., purification) should be separated such that operation of one does not raise dose levels near the other (so that one can be maintained while the other is operated).

c) Temporary Shielding - Equipment trains of radioactive systems should be separated by sufficient space to accommodate temporary shielding and still provide adequate personnel and equipment clearance (see Section 8.3.1, Access, Pull, & Laydown Space.)

d) Drains - Workspace drains should be arranged to minimize the potential for spread of contamination. Floor drainage should be away from aisles, traffic paths, and open areas. Equipment drain lines should drain directly to floor drain connections.

e) Insulation & Lagging - Insulation and lagging in and near potentially contaminated systems should be designed for easy removal with little or no creation of hazardous dust particles.

f) Hot Tools - Separate storage arrangements shall be provided for tools and equipment used for hot (i.e., contaminated) maintenance activities. Such tools must be clearly and permanently marked as contaminated.

g) Terminal Boards - Physically oversized terminal boards and connecting hardware for electrical and I&C components should be specified for use in potentially contaminated equipment workspaces, to facilitate handling by technicians wearing rubber gloves.

h) Ladders - Ladders into contaminated spaces shall be a minimum of 18 inches in width to accommodate anti-C booted feet.

8.5 Equipment Design Documentation of Maintenance Task Data & Requirements

a) Planned Maintenance Requirements - Equipment design documentation shall identify the expected maintenance and repair activities required to maintain the equipment in a state of operational readiness. For each maintenance activity, this should include specification of necessary tools, test devices, skills, manpower, system modes, performance time and frequency requirements, and the additional system activities necessary to return the unit to service.

b) Installation Requirements - Equipment design documentation shall identify the requirements for arrangement, installation, and removal of the equipment in plant systems. This shall include specification of O&M personnel access requirements, pull space dimensions, expected laydown space requirements, lifting and support requirements, and special fixtures, if necessary.

c) Failure Modes - Equipment design documentation shall identify equipment failure modes, diagnostic symptoms, and consequent effects, as a basis for planning, troubleshooting, and training.

d) Visual Aids - Equipment design documentation shall include a complete set of visual aids to support maintenance and repair of the equipment.

e) Parts List - Equipment design documentation shall include a complete parts list.

8.6 Software Maintainability

As "virtual equipment", software code must be maintainable by programming staff in the sense that it occasionally needs to be debugged or modified. The following guidance applies to the design of software code that supports these subsequent maintenance activities.

a) Provide Clear & Complete Comments - Verbal explanation of the code is invaluable to maintainers who must figure out exactly how it works. Similarly, meaningful variable names can also be helpful.

b) Use Modular Tools - Program code is more comprehensible if generic or macro "tools" are built as subroutines, and the main program consists primarily of calls to these subroutines.

c) Apply Format Conventions - Stating and using of a set of format conventions can make code structure easier to identify and read. Thus, programming language keywords might be upper-cased, and variable names mix-cased; logical structures could be made more evident by allocating a new line to each keyword and its arguments, etc.

d) Use Sequential Flow of Control - Sequential flow of control in the style of structured programming is easier to understand and trace.

e) Avoid Tricks & Kluges - The use of convenient but confusing or inelegant programming tricks (i.e., a "kluge") to solve problems should be avoided.

HUMAN FACTORS ENGINEERING

STANDARDS, GUIDELINES, AND BASES

FOR NUPLEX 80+™

Report NPX80-IC-DR-791-02

PART B: BASES

1.0 INTRODUCTION

1.1 Purpose

Part B provides the underlying bases for the material presented in the Human Factors Engineering (HFE) Standards and Guidelines (SAG) for the System 80+ design. The purpose of the SAG Basis is to provide references, records, explanations, and controls on the HFE SAG. It is thus controlled as part of the System 80+ design documentation.

The compilation and maintenance of the SAG Basis supports many activities and personnel, both during design and throughout first-of-a-kind engineering. It formally retains valuable HFE products of literature review and interdisciplinary design development. It reduces and avoids effort spent on revisiting issues that have already been resolved. It minimizes the amount of generally extraneous material that users encounter in the actual SAG document. It provides an efficient mechanism for justifying design selections to auditors and reviewers. Most importantly, it enables designers to make informed tradeoffs and resolutions where better understanding of pertinent HFE criteria is required.

The SAG and the SAG Basis were developed primarily by HFE Specialists working as part of the System 80+ design team. While the availability of this material should reduce the volume of HFE questions that must be individually addressed, the SAG and its basis do not substitute for the continued involvement of HFE specialists in the System 80+ design process.

1.2 Approach

The SAG Basis material draws on diverse sources to provide what is felt to be the best practical guidance that can be afforded to the design. As a part of the design, it may therefore incorporate tradeoffs and constraints that originate with the equipment or task environment, rather than just isolated HFE material.

SAG Basis information may take one of two forms:

1) Reference - Where existing guidance has been accepted as sufficient, direct reference to its source is provided.

2) Rationale - In some cases, an unequivocal or definitive HFE basis may not exist in the general literature. This may reflect an intractable evaluation problem, a relatively new technology, or the case that generic guidance is too vague to serve as a criterion for the specific System 80+ design. In such cases, design decisions may be predominated by larger concepts, consistency issues, qualitative evaluation, and tradeoffs. In these cases, a rationale is provided to explain the reasons and justification for the decision. References may be identified in a Rationale, but by definition may not always be available.

Some SAG document subheadings are simply introductory or other general explanatory material. Where a subheading does not itself present design standards or guidance immediately below, the statement "*No SAG entries*" will appear below in its corresponding SAG Basis entry. References provided in a higher level heading apply to SAG entries at lower levels unless more specific basis material is provided.

The SAG Basis begins with Chapter 2 of the SAG, since Chapter 1 was introductory material.

2.0 INFORMATION FORMAT CONVENTIONS

No SAG entries

2.1 General Principles of Information Format

Rationale: Problems in information perception are a fundamental source of human error. Such error-likely situations can often be mitigated by improving the format of the information. The eight general formatting principles provided here are self-evident, and thus by definition provide their own basis. Their purpose here is to clarify the goals and philosophy of the Chapter's approach, to guide designer's in their subsequent interpretation and use of more specific standards and guidelines.

2.2 Print & Text Format Conventions

No SAG entries

2.2.1 Names, Designators, & Controlled Nomenclature

Rationale: Distinguishing between names and designators allows a[illegible] encourages their separate development, to guide improvement of what remains an awkward area. It permits either or both types of reference, when appropriate, useful, and acceptable; acceptable usage will vary with and must be defined and controlled within specific contexts (e.g., procedures, phone communications, equipment labeling, etc.). Use of both references has the notably important advantage of redundancy, whic[illegible] is the information theoretic parameter correlate of message secu[illegible]. Use of diverse but redundant terms (name and designation) thus constitute a message with a built-in check, and has training value as well.

2.2.1.1 Names

References: MIL-STD-1472D - 5.5.3.1, 5.5.4.1, 5.5.4.2
NUREG-0700 - 6.6.3.1.a, 6.6.3.2.d

2.2.1.2 Designators

Rationale: The SAG entry is simply high level guidance that is itself a first principle of any logically rigorous coding scheme.

2.2.1.3 Controlled Nomenclature

References: MIL-STD-1472D - 5.5.4.2
NUREG-0700 - 6.6.3.2, 6.6.3.3.a

2.2.2 Abbreviations & Acronyms for O&M Terminology

No SAG entries

2.2.2.1 Abbreviation & Acronym Algorithms

References: Human Factors, 27, 2 (Ehrenreich, 1985)
Human Performance Engineering (Bailey, 1982)

2.2.2.2 Approved O&M Abbreviations List

References: NUREG-0700 - 6.6.3.3.a

2.2.3 Alphanumeric Characters for Labels & Text

Rationale: The complexity of interactions among variables and performance measures make perception and processing of text a challenging area in which to perform generalizable research. Each situation tends to create a unique opportunity for study. Thus, the present approach seeks to provide simple but robust results that will safely enable the vast majority of designers to address their particular design tasks and problems.

2.2.3.1 Style

No SAG entries

2.2.3.1.a Plain Block Fonts

References: NUREG-0700 - 6.6.4.2.a.2, 6.7.2.2.g.1

Rationale: A variety of concerns and diverse issues are behind this selection. One clear prohibition is against elaborate or highly stylized text (e.g., old english) which never enhances readability. Next is possibly a concern for lower resolution electronic displays (less than 12 lines of vertical resolution per character), on which serifs tend increasingly to degrade rather than enhance perception. Also, plain block letters are the most manageable for fabricating cut and stamped panel and equipment labels. Some studies do suggest that serifs improve readability of high resolution text (e.g., good quality printed copy) particularly at smaller sizes or under other degraded conditions. However, informal comparisons seem to indicate that plain fonts (e.g., Swiss Roman) are subjectively preferred to those with serifs (e.g., Times Roman) in "cleanliness" of structured text copy. In any case, this latter effect is comparatively small. The guidance in NUREG-0700 for "plain block fonts" was thus retained as robust and acceptable for the widest variety of applications.

2.2.3.1.b Descenders, Super/subscripts

References: NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.3.9.i.2.b

2.2.3.1.c Confusable Characters

References: MIL-STD-1472D - 5.2.4.10

2.2.3.1.d Upper Case

References: MIL-STD-1472D - 5.2.6.6.4.1, 5.2.6.8.5, 5.5.5.4.1
NUREG-0700 - 6.6.4.2.a.1
NASA-STD-3000/Vol 1/Rev A - 9.5.3.1.14.3.b

Rationale: Use of upper case characters are generally specified for labels, isolated words (e.g., presentation overheads), and low resolution displays (e.g., dot matrix with less than 12 vertical lines of resolution per character.) The issue in labelling is primarily to maximize size, and thus visibility and legibility at distance (contrast these with readability, for which conventional mixed case is superior; see 2.2.3.1.e.) Dot matrix displays, with already low resolution, are similarly restricted to upper case characters, to preclude display of characters using only part of the available (but already undesirably low) resolution. Since such displays tend to be brief (isolated characters or terms), legibility takes priority over readability.

2.2.3.1.e Mixed Case

References: MIL-STD-1472D - 5.2.6.6.4.1
NASA-STD-3000/Vol 1/Rev A - 9.5.3.1.14.3.b
User-computer Interface in Process Control, p. 73
(Gilmore, Gertman, and Blackman, 1989)

Rationale: Use of mixed case characters is generally specified for text of message length or greater, for readability. In reading, beyond adequate legibility, the need is for smooth continuous uptake of information. Given adequate legibility word perception takes advantage of information inherent in the combination of word shapes and message context. Use of all upper case text slows reading significantly, because word shapes, an important source of reading information, are significantly degraded. (Note: Tasks that require readability should utilize reasonably high resolution displays; i.e., with a minimum of 12 vertical lines of resolution per character.) In the case of abbreviations, units of measure, etc., mixed case is specified to avoid confusion by remaining consistent with cultural conventions.

2.2.3.2 Dimensions

No SAG entries

2.2.3.2.a Reading/Working Distance

Rationale: Since perceived letter height is really determined by reading distance, it is more valuable to evaluate this variable first, then to determine letter height. The approach has the benefit of focussing designers' attention on the most important consideration (what is the user doing?) and requires them to document the decision.

2.2.3.2.b Character Height

References: NUREG-0700 - 6.5.1.3.a, 6.6.4.1.a.1, 6.7.2.2
MIL-STD-1472D - 5.2.6.6.4.2, 5.2.6.8.4, 5.2.6.9.2
ANSI/HFS 100-198 - 6.14

NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.3.2.d.6, 9.4.2.3.3.9.i.3.a
USE 1000 Ver 2.1 - 3.1.1.1.1.a
Handbook of Human Factors - 5.1.8
Ergonomic Design for People at Work - III.B.4.a(1)
User-Computer Interface in Process Control - Character Size and Proportion (p. 71-73)
Engineering Data Compendium - 11.109, 11.111, 11.112, 11.118

Rationale: The formula relating visual angle, reading distance, and character height is:

$$\text{Visual Angle (minutes-of-arc)} = 3438 \frac{\text{Char. Height (inches)}}{\text{Reading Distance (inches)}}$$

Numerous studies have examined text legibility as a function of character size and reading distance, and the added impact on legibility of such variables as screen resolution, contrast, color, ambient lighting levels, viewing angle, font, stroke width, etc. In addition, familiarity with the displayed text can have a powerful impact on performance. In general, the literature suggests the following generalizations for individuals with 20/20 vision, viewing unfamiliar text, under good reading conditions:

1) The threshold (i.e., > 50% correct) for legibility (i.e., identification of random letters) is around 5 or 6 minutes-of-arc.

2) Relatively fast (i.e., nominally within 3 times simple reaction time) and accurate (i.e., > 95% correct) legibility is possible above 8 to 9 minutes-of-arc with the full effort of the reader. (That is, the crossover from data-limited to resource-limited perceptual performance appears to occur at about 1.5 times the legibility threshold.) This is the most important lower limit on text size, performance quickly degrades below this point. Furthermore, some margin needs to be provided to this limit in order to account for routine degradation of actual reading conditions due to poor light, off-angle viewing, etc.

3) Reading effort (i.e., for sequential text) declines with larger text size over a relatively wide range of values. 20 minutes-of-arc is perhaps an ideal point value, and many guidelines quote values from 15 to 22 minutes-of-arc as preferred. Such values provide acceptable readability for a range of +/- 50% of the expected reading distance (note that, for a variety of reasons, readers routinely tolerate self-imposed inoptimal reading distances).

4) Reading effort begins to increase again as 30 minutes-of-arc is approached and exceeded. This occurs because the larger text begins to interfere with the smooth flow of saccadic eye movements, which is due to the limited range of sharp foveal vision.

5) Note that in the literature, there is sufficient variability of professional opinion for the range of preferred values to overlap with limiting values at either end of the scale. These values could vary further as more of the interacting variables are considered.

6) As a point of reference in common experience, Wordperfect provides approximately .125 inch lowercase letters and .188 inch uppercase letters on a 13 inch screen with a VGA adapter; this translates to a range of 12 to 18 minutes-of-arc at a 36 inch reading distance. (Note that workstation guidelines anticipate reading distances ranging well below half this value; reading from a distance of 16 inches, the uppercase letters subtend over 40 minutes-of-arc.)

Tradeoffs for Nuplex 80+ were resolved bearing in mind that while larger text might be desirable from the standpoint of reading isolated words, the drawback would be a large increase in panel and screen areas to accommodate the larger text. This had obvious drawbacks in terms of human performance. As a result, the approach taken was to define the working distances imposed by tasks, then ensure that the characters provided for use from these distances were of adequate size (12 minutes-of-arc was selected as a robust standard minimum, per the above analysis).

Note that no credit was taken for familiarity of the reader with the displayed material; but this is held to be an important generally beneficial effect that can reasonably be assumed to exist for trained operators viewing familiar panels, labels, and so on. Furthermore, the data with the greatest uncertainty appears primarily on DPS screens; since these are afforded at every panel, operators have maximum flexibility to "optimize" proximal (i.e., perceived) text size as necessary, by adjusting their own reading distance.

2.2.3.2.c Character Width

References: NUREG-0700 - 6.6.4.2.b
Human Factors in Engineering & Design (Sanders & McCormick, 1987) - p. 87

Rationale: The common availability of proportional fonts, and desirability of their use, makes inflexible standardization of width-to-height ratio (the generally used parameter) undesirable for general text. A good general value of width-to-height ratio is 3:5 (equivalent to the 60% value stated in the SAG); ratios approaching 1:1 may be appropriate for engraved or transilluminated characters.

2.2.3.2.d Stroke Width

References: NUREG-0700 - 6.6.4.2.c
Human Factors in Engineering & Design (Sanders & McCormick, 1987) - p. 86

Rationale: Stroke width varies with, and is determined as a part of, the selection of font style (unless the further step of building a custom font from scratch is possible, which depends on hardware and software, and is a nontrivial design task in itself). Thus, it is not simply a matter of adjusting this parameter to a desired value. Appropriate stroke width also depends on text and background color contrast effects. As a result of these constraints and interactions, stroke width is more practically treated as one of the elements that must be considered in the tradeoffs and selection of a text font. Text font selection/development should thus ensure that character stroke width is appropriate for the demands of its particular application.

Assuming good contrast, stroke widths of white-on-black letters typically are best from 1/8 to 1/10, while stroke widths of black-on-white letters typically are best from 1/6 to 1/8 (Note: white letters on black background appear thicker than their black-on-white counterparts due to a perceptual effect called "irradiation".) Under low light, with poor contrast between text and background, or for black letters on highly luminous background, bolder print (e.g., stroke widths 1/5 of character height) is appropriate. On the other hand, highly luminous letters on dark background may warrant finer print (e.g., stroke width 1/12 of character height). A robust value of stroke width for general application is 1/8 the height of the character.

2.2.3.2.e Horizontal Spacing

References: NUREG-0700 - 6.6.4.2.d
User-computer Interface in Process Control, p. 73
(Gilmore, Gertman, and Blackman, 1989)

2.2.3.2.f Vertical Spacing

References: NUREG-0700 - 6.6.4.2.
User-computer Interface in Process Control, p. 73
(Gilmore, Gertman, and Blackman, 1989)

2.2.3.2.g Descender Length

Rationale: Full or true descenders form larger and more distinct characters. The only potential drawback of such characters is that with insufficient line spacing, descenders may overlap with the largest letters on the line below. However, since the vertical text spacing requirements were determined to permit the use of full descenders, this is not a problem in the present context.

2.2.3.3 Other Concerns

References: NUREG-0700 - 6.7.2.2.g.2
NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.3.9.i.1

2.3 Graphics & Non-Textual Format Conventions

2.3.1 General Conventions

2.3.1.1 Accessibility of Information

Rationale: This is held to be a self-evident first principle, and is really more philosophy than guidance.

2.3.1.2 Actual Equipment Response

References: NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.2.b
MIL-STD-1472D - 5.2.2.1.2
NUREG-0700 - 6.5.1.1.e

2.3.1.3 Positive Indications

References: NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.2.c
MIL-STD-1472D - 5.2.2.1.4

2.3.1.4 Display Failure Indications

References: NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.2.g.1
MIL-STD-1472D - 5.2.1.3.6
NUREG-0700 - 6.5.1.1.f

2.3.2 Color

No SAG entries

2.3.2.1 Number of Colors

References: NASA-STD-3000/Vol 1/Rev A - 9.5.3.2.i.2
NUREG-0700 - 6.5.1.6.b.2

2.3.2.2 Redundancy of Color

References: NUREG-0700 - 6.5.1.6.a

2.3.2.3 Color Assignments

References: NUREG-0700 - 6.5.1.6, 6.6.4.1.b, 6.6.6.3, 6.6.6.4.a, 6.7.2.7.k-m
NASA-STD-3000/Vol 1/Rev A - 9.5.3.2.i

OSHA 10 CFR 29 - Part 1910.144

Rationale: The use of color coding is a well understood problem in theory, but remains awkward from a practical standpoint. The number of items that designers find useful to color code far exceeds the number that can be effectively encompassed (from a human memory and absolute judgement standpoint) by a single system. In addition, arbitrary constraints due to pre-existing coding conventions, characteristics of human color perception, and technological limitations impose further limits on color coding schemes. It is not possible to satisfy all of these requirements simultaneously and continue to make good use of the benefits that color coding affords.

Within these limitations, System 80+ applies the following philosophy and approach to color coding:

1) Maintain compatibility with and standardize the application of existing industry conventions.

2) Identify well-defined and separate contexts which are mutually distinct, within which separate, unconflicting color codes can be developed and applied.

3) Individual codes should be fully compatible and consistent within the contexts to which they apply.

4) Color coding is always applied redundantly with some other unambiguous coding scheme.

5) The preceding goals notwithstanding, applicable coding standards, guidelines, and good practice shall continue to be applied within appropriate contexts.

Individual contexts, and the rationale for their color assignments, are identified below.

2.3.2.3.a (Color coding for) Control Panels and Associated Displays

Rationale: Given the general basis position of Section 2.3.2.3, the Nuplex 80+ system applies color as follows.

Black - Background DPS CRT color. Also character color for white background lamacoid panel labels. [A standard selection for CRT devices. Has high contrast and legibility with the widest selection of other colors. The standard alternatives, white and blue, offered some benefit for glare reduction but at the cost of reduced flexibility for use of color coding.]

Red - Component Flow Status = Active/on/energized/flow permissive, etc. [Generalized industry standard; see Appendix A, this section. Consistency is established across multiple application contexts by coding flow states of component. Complements use of green. Red/Green distinction applied only to remotely indicated/controlled components; remaining components are grey, denoting static data.]

Green - Component Flow Status = Inactive/off/deenergized/flow preventive, etc. [Generalized industry standard for fluid systems; see Appendix A, this section. Consistency is established across multiple application contexts by coding flow states of component. Complements use of red. Red/Green distinction applied only to remotely indicated/controlled components; remaining components are grey, denoting static data.]

Yellow - Alarm annunciators. [Highly visible and salient color; use is consistent with general cultural and industrial conventions for cautionary alerts and indications.]

Orange - Non-alarm annunciators; Component Control System Status = Manual. [Visible and salient color, but with less emphasis/priority than yellow; still consistent with general cultural and industrial conventions for cautionary alerts and indications. Non-alarm annunciator application and control status = manual application are mutually consistent and compatible; both warrant attention. Complements use of blue to denote automatic control status.]

Blue - Component Control System Status = Automatic permissive/on-line. [Non-alerting color is often applied, generally, as normal or operating indication. Complements use of orange (alerting) to denote manual control status. Auto "on-line" (blue), is not the same as "running" (red); these are separate, orthogonal dimensions. It is also not the same as cyan; however, it is compatible (i.e., evaluation indicates no likely errors) with all applications of cyan.]

Cyan - Descriptors on dynamic process parameter values. [Cyan is salient but non-alerting. Given the assumption that indicator labels are generally used not so much to be read as to guide operators to the time-varying information, cyan was applied to the descriptors to provide visual landmarks to the data (shown in white). Cyan was not applied to the data itself because its blue content slightly degrades legibility; for perceptual reasons, blue always is a bit fuzzy.]

White - DPS CRT dynamic data/text; also system response to touch. Background for black characters on lamacoid panel labels. [White (on black) is the color of maximum contrast and legibility. Legibility is maximally important for changing data and message text, since these must be fully evaluated on a frequent basis (in contrast to their labels). Identifies otherwise uncategorized dynamic (high-information) data/text and thus complements the use of grey for static (low-information) data/text. This application is perhaps more easily recognized as appropriate when it is viewed as intensity or brightness coding for emphasis (usually covered as a highlighting technique) rather than color coding. The secondary use of white as indication touch response does not conflict with the live data application, and is effective for the diverse color range of touch targets.]

Grey - Static (non-dynamic) data/text, menu options, non-controllable and non-instrumented components, dividing lines, graph grids, static piping, etc. [Applied to maintain adequate legibility while distinguishing and highlighting the dynamic data and graphical items in white and other status colors. Low salience reduces "visual noise" by deemphasizing the less informative elements comprising the relatively familiar framework for the real objects of interest (the dynamic, driven data).]

Tan - Control panel surfaces. [Selected for low reflectance and aesthetic/environmental considerations (e.g., neutral, low salience) to apply as panel paint color. Used within DPS system to apply a spatial/functional metaphor to the organization of certain menus:

functions (screen pages) are organized as selections within panels (menu). The panel organization corresponds to that in the actual control room. In its limited role as menu framework, it is not an information-bearing "code".]

Light Brown - Control panel demarcation. [A neutral, low-salience color used to provide additional organization of sub-function relations on panel layout. Contrasts but is aesthetically consistent with tan panels and dark brown mimic flowpaths.]

Dark Brown - Panel mimic flowpaths. [A neutral, low-salience color chosen to dominate the light brown panel demarcation; used to convey essential component relations on panel layouts. Contrasts but is aesthetically consistent with tan panels and light brown functional demarcation.]

Purple - Labels for discrete indicators containing post accident monitoring (PAMI) parameters. [Allows unambiguous discrimination of PAMI indicators. Low to intermediate salience consistent with fairly static information content. Acceptable background contrast for white letters.]

Discussion: Application of Red & Green to Component Status Indication

(Note: This seemingly elemental issue is a good example of the practical obstacles that exist to the "correct" or optimal application of human factors guidance.)

Most adults are familiar with green=go and red=stop from early in childhood, and many industrial workers are also familiar machine shop safety conventions that use large red "off" switches for powerful equipment motors (these are most easily found if an accident occurs.) These are population stereotypes. If you assume that "go" and "flow" are similar, then by extension, an open valves is green, and shut valves red. These functional conventions apply in Naval reactor plants, which is a training ground for many future commercial reactor operators.

These Naval reactors conventions are the exact opposite of those used in most commercial nuclear plants. Commercial nuclear conventions are consistent with those used in fossil power plants, where the use of red to indicate active states perhaps stems from the "fire in the boiler" metaphor. Additional conflicts and constraints on commercial color conventions come from a multitude of sources: regulatory guidance (assign red/green to danger/safe; NUREG-0700), lighting technology (LEDs are not available in blue or white, thus limiting the alternatives without degrading reliability), and degrees of red/green and blue/yellow color blindness (particularly among males). The following

As evidenced by their use in traffic lights, color blindness is not a genuine barrier to the use of red and green, in large part because redundant position (or other) coding can be easily applied.

Furthermore, either the existing Naval reactors scheme (with active=green and inactive=red) or the opposite commercial power plant convention can be used to achieve a large amount of internal consistency, if the common dimension of flow (rather than the names of component states) is emphasized in design, training, and procedures.

Control devices should thus be consistently and redundantly coded by both position and color along the flow dimension. For example, using commercial conventions, the red, flow-producing selection (i.e., pump running, valve open, breaker closed) would always be the right-hand or uppermost switch selection in a pair of red/green pushbuttons.

Although the existing difference between the Naval and the opposite commercial plant color conventions is undesirable, it is at this point beyond remediation. Changing either would be a costly and foolish recommendation, due to the burdensome and error-likely impact of expected negative transfer of training (i.e., interference from previously learned material on the performance of more recently learned material.) Since a permanent change from one set of conventions to another (e.g., from military to civilian life) poses the least problem, it is more important to avoid new conflicts, and to ensure continued uniformity and consistency for similar contexts (e.g., when personnel routinely move between facilities as part of their jobs or activities).

The safe/normal vs. unsafe/abnormal use of green and red could still be applied in distinct contexts that would not be confused with component states, such as zones on parameter displays, if this was highly desirable. However, coding component status (off, on) for its normality should be avoided, since the normality of component state usually varies with plant conditions. To indicate unanticipated or abnormal component conditions, yellow was selected as an alarm color that is consistent with generally accepted warning conventions, does not conflict with equipment status, and keep the issues of equipment status and normality distinct. Changing to yet an entirely new set of conventions, though not a favored alternative, had little in its favor due to the present unavailability of some of the most likely alternatives (i.e., blue & white) as LEDs. The technological alternative (use of incandescent lightbulbs) dramatically increases heat level, failure rate, and maintenance frequency of the indicating device.

2.3.2.3.b (Color coding for) Personnel Hazards & Physical Safety Hazards

References: <u>OSHA 10 CFR 29</u> - Part 1910.144

2.3.3 Emphasis Coding (Brightness & Flash)

References: <u>NUREG-0700</u> - 6.7.2.7.a
<u>MIL-STD-1472D</u> - 5.15.3.3, 5.15.3.6.20

Rationale: Highlighting refers to techniques of visual emphasis that result in one item having significantly higher salience (i.e., attention-getting capacity) than otherwise similar items within the same context. All Nuplex 80+ coding schemes have been developed to consider the appropriate allocation of salience to the indication's priority, informativeness, and relative importance in the overall operating scheme. Unsystematic or ad hoc highlighting of individual items is thus discouraged, as this leads to inconsistent, visually noisy displays (non-information overload). Instead, various systematic codes and categories are employed to unambiguously denote abnormal conditions, questionable data, etc. This approach represents one of many possible solutions to this collection of problems, and is consistent with the overall intent of the cited references.

2.3.3.1 Consistency

Reference: NUREG-0700 - 6.7.2.7.b

2.3.3.2 Brightness Coding

References: NUREG-0700 - 6.7.2.7.c
MIL-STD-1472D - 5.15.3.3.3
NASA-STD-3000/Vol 1/Rev A - 9.5.3.2.b.2

2.3.3.3 Flash Coding

References: NUREG-0700 - 6.7.2.7.d, 6.7.2.7.e
MIL-STD-1472D - 5.15.3.3.2
NASA-STD-3000/Vol 1/Rev A - 9.5.3.2.h

Rationale: Implementation of flash rate guidance is context and hardware dependent. Flashing is used in the Nuplex 80+ system as a visual code directing attention to changes in alarm or annunciator status. Flash rates are applied as part of a larger coding approach that makes it possible for the four alarm states (new, existing, cleared, and reset) to be shown unambiguously under a single tile heading.

Different on/off duty cycles (50/50 for new alarms, 25/75 for cleared) are used to code the visual annunciation of the two alarm transition states (new and cleared). Guidance in the literature was vague as to what or why a 50/50 duty cycle is preferable, although departing from that balance in either direction makes it difficult to see the target, depending on flash rate, display persistence, and visual sampling behavior. Still, for the range of values specified, no problems were anticipated, and mockup studies indicated that they were quite adequate. In fact, use of the multiple duty cycles made it possible to superimpose both new or cleared alarms on existing alarms (i.e., within a single tile) without ambiguity or loss of any information. (Note, however, that the intensity coding of the alarm color and the size of the different priority tile shapes also contribute to making this a viable scheme, from a usability standpoint. For a description of the entire system, see Rev 1 of the System Description for Control Complex Information System for Nuplex 80+, NPX80-IC-SD791-01.

However, to really understand and see that it works, the dynamic Nuplex 80+ demo is recommended.)

2.3.4 Shapes/Symbols

Rationale: Use of shapes in Nuplex 80+ conforms to Piping & Instrumentation Drawing (P&ID) conventions, as extended to a consistent scheme of color applications on both white- and black-backgrounded VDU devices. This is to help avoid confusion when operators are comparing VDUs and drawings. (Shape coding of control handles has yet to be identified as necessary, simply because the design has no handled switches at this time.) Graphics serve as pictorial aids on labels (in static displays), or as icons, with certain dynamic indicating functions (on software VDUs). In both cases, the symbols look like something readily associated with what they represent, rather than arbitrary shapes or characters, and are redundantly coded with some other aspect of the display (e.g., a name and/or designator).

2.3.4.1 Size

References: NUREG-0700 - 6.7.2.2.a
NASA-STD-3000/Vol 1/Rev A - 9.5.3.2.c.1

2.3.4.2 Number of Symbols

References: NUREG-0700 - 6.7.2.7.j

2.3.4.3 Fill Coding (Symbol Modifiers)

References: NUREG-0700 - 6.7.2.7.j

Rationale: In general, the direct modification of icons with coding attributes is limited to denoting the flow state of component (e.g., open/shut). This utilizes, for instrumented components, redundant red/green and hollow/filled codes on the icon itself (uninstrumented components appear gray, though the empty/fill convention will still be applied to denote the component state.) Other coded conditions, like alarms, are presented in a way that allows them to be clearly associated with, yet separate from, the icon itself.

The coding of component status conditions using fill (hollow = active, and filled = inactive) conforms to and generalizes the standard P&ID valve symbol convention in which an "open" valve is hollow against its background (black outline over white), while a "closed" valve is solid black. While this conflicts somewhat with the general perception that active symbols should be more salient than inactive ones, it is judged to be a more consistent (and thus, reliably trained) outcome within the defined context than would be that of applying mismatched conventions between P&IDs and VDUs, or applying different conventions for different types of components.

2.3.4.4 Meaning of Symbols

Rationale: Nuplex 80+ symbols are based on System 80+ P&ID conventions.

2.3.5 Graphs and Graphics

References: The Visual Display of Quantitative Information, E. R. Tufte, 1983.

2.3.5.1 Consistent Scaling

References: MIL-STD-1472D - 5.15.3.6.26

2.3.5.2 Direct Display of Comparisons

References: MIL-STD-1472D - 5.15.3.6.29

2.3.5.3 Grid Lines

References: MIL-STD-1472D - 5.15.3.6.28

2.3.5.4 Scales

No SAG Entries (see Section 2.4)

2.3.5.5 Labeling of Axes

References: MIL-HDBK-761A - 5.3.8.3 1.1

2.3.5.6 Values

Rationale: This is a standard Cartesian Coordinate convention.

2.3.5.7 Scale Range Descriptors

References: MIL-STD-1472D - 5.15.3.6.25

Rationale: A scale range descriptor is not universally required because some dedicated displays without multiple ranges could utilize the device label without ambiguity.

2.3.5.8 Bar Graphs

References: MIL-STD-1472D - 5.15.3.6.30, 5.15.3.6.30.1

2.3.5.9 Panel Mimic Layouts

References: NUREG-0700 - 6.6.6.4

2.4 Numerical Scaling

No SAG entries

2.4 1 Scale Range

Rationale: The guidance here is largely self-evident and not held to require justification. The one exception is Item b, the standard specified on the scale range in which nominal readings should occur. The general principal is that the measurement/indication should match the magnitude of the measured parameter fairly closely. For example, if a meter under normal conditions routinely indicates 10% of full scale (not by any means an unheard of situation), then the meter's resolution was mismatched to the functional requirements of the system by nearly an order of magnitude. On the other hand, indicating devices should have some headroom even when operating at 100% of expected levels since 100% is also a nominal value and may vary up or down. A larger margin was specified at the bottom of the range (0-20%) than at the top (90-100%) to reflect the loss of resolution as explained previously; also, it is a more normal (and accurate) situation for a device to be run at or near a full load, level, etc. rating.

2.4.2 Scale Demarcation and Numbering

References: NUREG-0700 - 6.5.1.5
NASA-STD-3000/Vol 1/Rev A - 9.5.3.1.4

Rationale: The guidance found in the references has been developed primarily to demarcate analog meter faces. In generalizing the guidance additional issues are noted.

Under Item a, Graduation Size, it is observed that the relative lengths (as shown in Figure 2.4.2.a) are best for meter reading of quantitative point values, i.e., legibility. However, for an indicating device that is designed as a qualitative indication, i.e., for check reading of parameters within bands, the issue is not legibility so much as visibility. Graduations in such displays tend to be fewer and more widely spaced, which is acceptable if they are not used for detailed counting. Still, they must be readily visible at a glance, perhaps at distance, which implies that the graduation's minimum dimensions may be the more important of the two. Thus, varying the width of demarcations for a given length was found, in certain cases, to be more appropriate and effective.

Design of the Discrete Indicator devices forced development of these issues. A standard Nuplex 80+ application for Discrete Indicators is to display time history plots; these are provided along with a digital point value display. Thus the time history plot is not intended to be a source of accurate point value data. Since using standard demarcation guidance produced crowded and ineffective demarcation, different techniques were explored.

Under Item b, Graduation Intervals, it is noted that quarters are a cognitively easy fraction (familiar from monetary transactions, within short term memory limits), and although they can be awkward in decimal form (more so than power-of-ten-multiples of 1, 2, or 5), they are still easily counted as whole numbers. Thus, graduating a scale in "whole" quarters (e.g., 25, 50, 75, 100, etc.) is not necessarily a poor choice, human factors-wise, if it is for some other reason particularly desirable.

Under Item d, Units of Measure, it is held that this is a programmatic matter in that these standards may vary between customers for cultural or other reasons; thus, this issue is referred to a different source of standardization.

Under Item f, Percentage Scaling, this position reflects that although use of percentages represents a reduction of parametric information being carried by the data, it is nonetheless a useful (i.e., operator workload-reducing) simplification that will be desirable in specific cases.

2.4.3 Scale Precision

References: NASA-STD-3000/Vol 1/Rev A - 9.5.3.1.4.a

2.4.4 Scale Labeling

No SAG entries (Cross-references only)

2.4.5 Scale Zone Banding

References: MIL-STD-1472D - 5.2.3.1.10
NUREG-0700 - 6.5.2.3

2.4.6 Nonlinear Scaling

References: NUREG-0700 - 6.5.1.5.e

2.5 Equipment Labels

No SAG entries

2.5.1 Applicability

References: MIL-STD-1472D - 5.5.6.1.1
OSHA 10 CFR 29 - Part 1910.145

2.5.2 Terminology

References: NUREG-0700 - 6.6.3.3

2.5.3 Scan Codes

Rationale: Various forms of electronic scanning are proven technologies that have obvious potential utility for numerous O&M tasks. Even if the specific tasks and technology are not yet defined, this is presently considered to be a standard usability feature.

2.5.4 Size

References: NUREG-0700 - 6.6.4.1.a.2

Rationale: Item a, Label Characters, is primarily a cross-reference to other parts of the SAG document. However, it does establish the rule for resolving conflicts between standards for character size based on viewing distance versus those based on hierarchical labeling. In such case, size requirements for viewing distance (i.e., readability) take precedence, because readability is a fundamental necessity for performance, while the hierarchical relationships are only a performance aid.

Items b and c, Label Width and Label Height, are extensions of text spacing requirements.

2.5.5 Layout of Identification Labels

Rationale: This simply establishes a standard for the general configuration of equipment labels.

2.5.6 Label Colors

Rationale: See bases under 2.3.2.3

2.5.7 Construction & Materials

Rationale: It is more manageable for individual systems to select label construction materials and technology according to their own needs; from the usability standpoint, reasonable quality and longevity (rather than standardization of the results) is the concern.

2.5.8 Position & Mounting

Rationale: These entries are self-evident and have no additional justification.

2.5.9 Data & Instruction Labels

Rationale: This material is judged to be self-evident. Items a and b are based on the idea that affording information as it becomes required during an item's natural sequence of use can often be helpful. This approach is exemplified by such obvious instructions as "In case of fire, break glass" as well as the guided instructions found on modern Xerox-type machines (though this latter example correctly implies that all applications need not be equally successful).

Item c is a standard improvement afforded by structured procedures that break material into more manageable and easily identified steps.

2.5.10 Warning Labels

References: OSHA 10 CFR 29 - Part 1910.145
NUREG 0899 - 5.5.3

Rationale: Terms like Danger, Caution, and Warning are extremely valuable and necessary, but it is difficult to assure their consistent and unconflicting use. OSHA 10 CFR 29 defines danger as meaning "immediate hazard," and caution as meaning "potential hazard or unsafe practice." NUREG 0899 observes that, in power plant emergency procedures, warnings and cautions are assumed to be synonymous, addressing "conditions, practices, or procedures which must be observed to avoid personal injury, loss of life, a long-term health hazard, or damage to equipment." US Navy conventions apply danger tags to denote that operation is prohibited under ANY conditions (other than clearing the tagout), while caution tags denote that if the accompanying cautionary conditions are observed, operation is permissible. Obviously, these definitions are not entirely consistent with one another. To attempt to preserve the distinctions the above references have found useful, the term danger has been applied to immediate personnel safety hazards, and the term caution to potential equipment or personnel operations hazards.

2.5.11 Panel Labels

References: NUREG-0700 - 6.6.2.1, 6.6.2.3, 6.6.2.2, 6.6.1.2
NASA-STD-3000/Vol 1/Rev A - 9.5.3.2.c.1

2.5.12 Tanks, Filters, Heat Exchangers, & Pipes

Rationale: This was evaluated to be a good standard practice.

2.5.13 Structural Features

Rationale: This was evaluated to be a good standard practice.

2.5.14 Geographical Locations

Rationale: This was evaluated to be a good standard practice.

3.0 DISPLAY AND CONTROL HARDWARE

No SAG entries (introductory material)

3.1 Design Principles

No SAG entries (introductory material)

3.1.1 Display-Control Compatibility

References: NUREG-0700 - 6.4.2.1, 6.9.3.1

3.1.2 Feedback

References: NUREG-0700 - 6.5.1.1.e
MIL-STD-1472D - 5.1.1.4, 5.2.2.1.4, 5.15.4.1.13

3.1.3 Failure Indications

References: See bases under 2.3.1.3 and 2.3.1.4

3.1.4 Emergency Control Provisions

References: NUREG-0700 - 6.4.1.1.c.2, 6.4.1.1.d

3.1.5 Prevention of Accidental Actuation

Rationale NASA-STD-3000/Vol 1/Rev A - 9.3.3.2
NUREG-0700 - 6.4.1.2

3.1.5.1 Noninterference

Rationale NASA-STD-3000/Vol 1/Rev A - 9.3.3.2.c, 9.3.3.2.i
NUREG-0700 - 6.4.1.2

3.1.5.2 Protective Methods

References: NASA-STD-3000/Vol 1/Rev A - 9.3.3.2
NUREG-0700 - 6.4.1.2

3.1.6 Redundancy

References: NUREG-0700 - 6.5.1.1.d

Rationale: In highly computerized control rooms, more data will be available and presented in a more diverse number of formats than in older, hardwired control rooms. The prior concern for excessive redundancy was really a concern for overloading operators with an excessive volume of raw data that contained little or no added information. While this remains a concern, the phrasing of the source guidance should not be misunderstood to imply that redundancy is inherently bad, or that it has to reduce physical operator movement before it is necessarily justified. Virtual movement within software systems should also be minimized to a practical extent. At the same time, one of the advantages of software-based displays is their flexibility for organizing and presenting data in a diversity of useful contexts. An alternative perspective on reducing unnecessary redundancy might therefore be to "ensure usefulness within specific contexts."

3.1.7 Durability

References: NUREG-0700 - 6.4.1.1.e

3.1.8 Maintainability

No SAG entries (cross reference only)

3.2 Switch Devices

No SAG entries (introductory material)

3.2.1 Pushbuttons

No SAG entries (introductory material)

3.2.1.1 Dimensions

References: MIL-STD-1472D - 5.4.3.1.5
NASA-STD-3000/Vol 1/Rev A - 9.3.3.3.15.a
NUREG-0700 - Exhibit 6.8-2

3.2.1.2 Activation Feedback

References: MIL-STD-1472D - 5.4.3.1.1.3
NASA-STD-3000/Vol 1/Rev A - 9.3.3.3.8.a.1, 9.3.3.3.15.c.1

3.2.1.3 Operating Force

References: MIL-STD-1472D - 5.4.3.1.5
NASA-STD-3000/Vol 1/Rev A - 9.3.3.3.8.b
9.3.3.3.15.a
NUREG-0700 - Exhibit 6.8-2

3.2.1.4 Legend

References: NASA-STD-3000/Vol 1/Rev A - 9.3.3.3.15.c.2, 9.3.3.3.15.c.5

3.2.1.5 Barriers

References: See basis for 3.1.5, Prevention of Accidental Activation.

3.3 Keyboards

No SAG entries

3.3.1 Numeric Keypads

References: NUREG-0700 - 6.7.1.4.b
Engineering Data Compendium - 12.406

3.3.2 Alphanumeric Keyboards

References: NASA-STD-3000/Vol 1/Rev A - 9.3.3.4.1.1.a

3.3.2.1 Destructive Key Functions

References: NASA-STD-3000/Vol 1/Rev A - 9.3.3.4.1.1.d.2

3.3.3 Dedicated Function Keypads

References: NASA-STD-3000/Vol 1/Rev A - 9.3.3.4.1.1.b

3.3.4 Cursor Movement Keys

References: NASA-STD-3000/Vol 1/Rev A - 9.3.3.4.1.1.d.1.b

3.4 Video Display Units

No SAG entries (Introductory material)

3.4.1 Resolution

References: Handbook of Human Factors - 5.1.8
MIL-STD-1472D - 5.2.6.8.3
Engineering Data Compendium - 11.117, 11.109, 11.111

3.4.2 Refresh Rate

References: NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.3.9.f
Engineering Data Compendium - 11.122

3.4.3 Phosphor Persistence

References: Video Display Terminals - Preliminary Guidelines for Selection, Installation and Use - 3.3.1

3.4.4 Luminance

References: NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.3.9.b
NUREG-0700 - 6.2.7.1.d

3.4.5 Contrast

References: NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.3.9.c
NUREG-0700 - 6.2.7.1.c
Engineering Data Compendium - 1.601

3.4.6 Effect of Ambient Illumination on Screen Luminance

References: MIL-STD-1472D - Table IV, 5.2.6.6.4.3.1
Human Engineering Guide to Equipment Design - 3.9.2, 3.9.3
NUREG-0700 - 6.7.2.1.c.1
Handbook of Human Factors - 5.1.6, 5.1.7
NASA-STD-3000/Vol 1/Rev A - 9.4.2.3.3.2.e

Rationale: There appears to be some confusion on the meaning and interpretation of the literature as it has been quoted and reiterated by successive generations of guidance documents. Van Cott and Kinkade (Human Engineering Guide to Equipment Design) appear closest to the source, which appears to have been the IES Lighting Handbook (1966) and Kodak Pamphlet No. S-3. In Section 3.9.2 they observe that the contribution of ambient illumination to total screen luminance (lets call this the ambient-to-total-screen luminance ratio) should be minimized, and less than 20% for even the most well-defined images (black-and-white line drawings, alphanumerics, etc.) Images with greater range of intensity or hue should have a relatively smaller ambient contribution; less than 1% is suggested for photographic materials. This data is summarized in the last line of Table 3-12, which shows the 20% limit as a decimal (.2), under "Acceptable Limits".

The reiteration of this data in MIL-STD-1472D shows the same table as Table IV, with the small change that the "Acceptable Limit" is now shown as .1 (i.e., a 10% contribution of ambient illumination to total screen luminance) and the .2 value is footnoted with the original qualifications (it applies to black-and-white line drawings, etc.) Under 5.2.6.6.4.3.1, what appears to be similar data is presented in ratio format (e.g., 5:1); however, it is referred to as and explained, perhaps erroneously, as a Luminance Ratio (i.e., the contrast ratio between the projected character and background intensities). If this is the same data it is not being presented as it was originally, in Van Cott and Kinkade. In turn, this MIL-STD-1472D passage been quoted directly by other authoritative sources (e.g., NASA 3000/Vol 1/Rev A Section 9.4.2.3.3.2.e). Due to the difficulty of further verifying the source or correctness of this guidance, it is simply observed that the range of unitless values provided for the tabled, ambient-to-total-screen luminance ratio are more or less consistent with values of generally acceptable screen luminance ratios; in either case, the preferred values will be pragmatically irrelevant for the control room workspace (which not a darkened projection theater) and the IPSO backprojection technology.

3.4.7 Electroluminescent Displays

References: MIL-STD-1472D - 5.2.6.9

3.4.8 Large Screen Displays

References: MIL-STD-1472D - 5.2.6.6.1

3.4.9 Touch Screens

References: Handbook of Human Factors - 11.4.2.2

Rationale: Touch screens were selected for their simplicity and general adequacy for the tasks allocated to VDU interfaces in Nuplex 80+. Through use of touch screens, training requirements were minimized (no command languages to learn); they provide adequate precision for operator tasks (no drawing tasks or other fine work have yet been identified); and they simplify workstation design and qualification (no additional components to accommodate such as a mouse or lightpen). Problems in the general area of parallax and touch resolution are being managed through development of improved touch screen technologies, and are not anticipated to pose a problem in the final design. One task that is expected to require a different interface is detailed data entry and manipulation; physical keyboards will perhaps be desirable, but they are not presently identified as an availability requirement for the controlling workspace.

3.4.9.1 Touch Screen Targets or buttons

References: MIL-STD-1472D - Figure 14, 5.4.6.4
NUREG-0700 - 6.8.3.1, Exhibit 6.8-2
Engineering Data Compendium - 14.401
Effects of Key Layout, Visual Feedback, and Encoding Algorithm on Menu Selection with LED-

based Touch Panels. Weiman, N., Beaton, R. J., Knox, S. T., and Glasser, P. C. (1985). Tech Report No. HFL-604-02. Tektronix Human Factors Research Laboratory, Beaverton, OR.

Rationale: Available guidance on touch target sizes in the human factors literature is taken from studies on similar legend switches (MIL-STD-1472D). The legend switches are shown as minimum of .75 inches on a side, and .875 inches between centers. This guidance accommodates the use of protective switch barriers and displacements, and apparently 1) enables a large fingertip (.75 inches x .75 inches), or possibly a gloved finger, to fit entirely within the boundaries of the switch area, 2) guards against inadvertent actuation of the switches, and 3) provides a larger area for inscription. However, while it may be conservatively adequate, it constrains display space (i.e., it requires large buttons).

Another fairly well validated choice for button size can be found on commercial typewriter/QWERTY keyboards (approximately .5 inches on a side, .75 inches between centers). Though the keyboard is designed for touch typing (a task performed without view of the keys), it seems to be widely used as a "pushbutton" (hunt-and-peck) interface without particular problem (considering the large number of choices, the speed-accuracy tradeoff, etc.) Note that, this is not dissimilar to the NUREG 0700 Exhibit 6.8-2 Footnote 1 value for "pushbuttons within an array, 0.75 inches center-to-center." Also, like the legend switch, the keyboard dimensions accommodate the "limiting" .75 inch x .75 inch fingertip.

Touch targets are yet different from either of these mechanical pushbuttons, however, and they present a different set of task characteristics to the user.

The Nuplex 80+ design uses a "make-on-break" touch convention. Thus, feedback of activation (i.e., which target is being touched) can precede its final selection, which is made on proper touch release (i.e., breaking screen contact while the target remains touch activated.) Unlike the case with mechanical switches, the user's finger does not need to be contained entirely within a touch target border (nor be entirely separated from the adjacent target) for proper activation. Spatial overlap is not a problem because the computer can discriminate and provide prompt visual feedback as to which target is being sensed and activated. Although actual touch screen resolution depends on the technology used as well as certain details of the hardware and software implementation, accurate selection can be provided in response to inaccurate touch, and striking multiple keys simultaneously can be prevented.

Such software functions offer the potential to cut the limiting effects of fingertip anthropometry (as must be accommodated by the QWERTY example) nearly in half, if otherwise desired, since the limiting fingertip can now be accommodated within the desired target and its adjoining targets. Enough room must remain so that the touch screen implementation can reliably identify the "most" activated target while providing sufficient margin to the edge of the activated target in which the user can view the activation feedback (a visual angle of 12 min at the panel = .125 inch margin). This discussion simply serves to point out that touch targets can be implemented to eliminate some of the constraints of physical keys and pushbuttons. Nuplex 80+ touch target dimensions nonetheless remain primarily within the conservative envelope of validated physical pushbutton data.

A final point concerns touch target spacing. Pushbutton data can be found to indicate that, particularly when display space is tight, separation is perhaps more important to maintain than size in maintaining speed and accuracy. Thus, more restrictive spacing standards are stated for component-controlling touch targets, where the concern for avoiding (rather than correcting) errors is substantially greater. The larger area devoted on the screen to such devices is not dissimilar to the common convention that larger devices are more important.

3.4.9.2 Touch Target Text

Rationale: This treats the margin between text and target borders as requiring as much space as do separate words or lines of text.

3.4.9.3 Touch Target Standardization

Rationale: The purpose of this guidance is to generally encourage orderly aesthetics in display design. This guidance can be violated for virtually any good reason, and it is probably beneficial to do so, to some extent, to help ensure that individual display screens each have certain unique visual elements.

3.5 Instrument Meters and Gages

References: NUREG-0700 - 6.5.2.5

3.5.1 Direction of Scale Increase

References: NUREG-0700 - 6.5.2.1
MIL-STD-1472D - 5.2.3.2.1

3.5.2 Pointer Characteristics

References: NUREG-0700 - 6.5.2.2.a, 6.5.2.2.b, 6.5.2.2.c

3.5.3 Numeral Orientation

References: NUREG-0700 - 6.5.2.4.a
MIL-STD-1472D - 5.2.3.2.2

3.5.4 Orientation on Circular Scales

References: NUREG-0700 - 6.5.2.4.b, 6.5.2.4.c
MIL-STD-1472D - 5.2.3.2.3.2, 5.2.3.2.3.3

3.6 Printers [TBD]

4.0 SOFTWARE

No SAG entries (Introductory material and cross references)

4.1 Principals of Organization

No SAG entries (Cross references)

4.1.1 Information Density

References: NUREG-0700 - 6.7.2.5.m
User Computer Interface in Process Control - p. 80-83 (Display Density)
MIL-STD-1472D - 5.15.3.2.2.1
The Role of Hierarchical Knowledge Representation in Decisionmaking and System Management. Rasmussen, J. (1985).

Rationale: Guidance in this area varies widely, which in part reflects the difficulty of quantifying a meaningful information density metric. Is it the percentage of total characters that are in use? Of total pixels? Is it impacted by the degree of organization of the data? Do demarcation lines count? And so forth.

A wide range of guidance has been provided that is consistent with the range of uncertainty in the literature. This affords flexibility needed to organize information so that conflicting human engineering goals can be pursued (e.g., reduced information burden, and increased access to detail). The Nuplex 80+ system employs a structured hierarchy of information in the DPS:

1) High level screens have lowest data density, most aggregate information, support (generally skill-based) operator monitoring tasks. Support observation of broad normal status, alerting departure-from-normal status, and directing monitor to locus of greater detail.

2) Mid level screens have intermediate data density and aggregation, support (generally rule-based) operator control tasks, procedural execution and direct observation of automatic system performance.

3) Low level screens have maximum density and minimum aggregation of data, to support (generally knowledge-based) operator diagnostic tasks. These are expected to be used infrequently and in potentially unexpected ways; flexibility is stressed over ease of use.

4.1.2 Direct Usability of Data

References: MIL-STD-1472D - 5.15.3.1.3
NUREG-0700 - 6.7.2.4.a

4.1.3 Meaningful Grouping and Organization of Data

References: NUREG-0700 - 6.7.2.5.a
MIL-STD-1472D - 5.15.3.1.4, 5.15.3.5
NASA-STD-3000/Vol 1/Rev A - 9.6.2.4.3.2

4.1.4 Recurring Data Fields

References: MIL-STD-1472D - 5.15.3.1.6

4.1.5 Descriptors

References: MIL-STD-1472D - 5.15.3.1.9, 5.15.3.1.10
NUREG-0700 - 6.7.2.4.m

4.1.6 Prompts and Messages

References: MIL-STD-1472D - 5.15.3.1.9.2

4.2 Menus

No SAG entries (Cross reference to touch screens)

4.2.1 Menu Item Selection

References: NASA-STD-3000/Vol 1/Rev A - 9.6.3.1.6.2.a.1, 9.6.3.1.6.2.h.2
The Depth/breadth trade-off in the design of menu-driven user interfaces. Kiger, J. I. (1984)

Rationale: The nominal two-touch input for making screen transitions through the menu hierarchy provides an economical and consistent approach to the user. It also provides the necessary capacity for total system choices while keeping the number of choices within categories to a cognitively manageable level (i.e., less-than-10 choices per menu/category, within accepted working memory limits.) A high level menu provides access to one of seven (again, less than ten), high level menu categories; each of these provides the screen choices available within that high level category. The menu of screen choices is typically organized at one further level: subfunctions (e.g., using panel function categories) are used to organize groups of screens into what is the equivalent of multiple submenus on a single screen page. This achieves a broad, shallow hierarchy of the type that research has shown to be most efficient in terms of overall human performance (i.e., speed/accuracy).

4.2.2 Organization of Menu Items

References: <u>NASA-STD-3000/Vol 1/Rev A</u> - 9.6.3.1.6.2.c

4.2.3 Menu Consistency

References: <u>NASA-STD-3000/Vol 1/Rev A</u> - 9.6.3.1.6.2.f
<u>The Case Against User Interface Consistency</u>, Ledgard, H. P., (1989)

Rationale: Our interpretation of this very general consistency guideline takes into account that consistency is important to maintain between similar tasks and contexts, but that different purposes for a menu may warrant different formats. Such menus would be likely to have different organization and/or contents precisely because they correspond to different tasks. Forcing superficial similarity in such cases is not an improvement but a degradation of the interface. Within similar formats and applications, however, conventions should be applied consistently.

4.2.4 Navigational Cues

References: <u>NASA-STD-3000/Vol 1/Rev A</u> - 9.6.3.1.6.2.h.3

Rationale: Due to the flatness of the Nuplex 80+ menu structure, their would be little location information provided by displaying the path structure to your present position in the screen hierarchy. However, present location is still an important piece of information; this is afforded through a screen title descriptor.

4.3 Moving Through Data

No SAG entries (Introductory material)

4.3.1 Scrolling

References: NASA-STD-3000/Vol 1/Rev A - 9.6.3.2.2

4.3.2 Paging

References: NASA-STD-3000/Vol 1/Rev A - 9.6.3.2.3

4.4 Windows

References: NASA-STD-3000/Vol 1/Rev A - 9.6.2.7
Handbook of Human-Computer Interaction - Ch. 19

Rationale: Definition and preferred use of the virtual devices called windows is not agreed upon or well-established. The contents of this section were primarily presented to prohibit certain design features such as 1) enabling operators to make uncontrolled modifications in the screens provided by the certified system, or 2) causing or enabling important information to be obscured.

4.5 Timing Issues

4.5.1 Update Rate of Dynamic data

References: MIL-STD-1472D - 5.15.3.4.1

4.5.2 Display Heartbeat

Rationale: Steady state plant conditions can result in indications that are indistinguishable from those provided by a locked-up computer processor. To prevent such situations from going unnoticed, an unobtrusive (i.e., text character-sized), visually active, frequently updated (i.e., at least every .1 seconds) symbol called a display heartbeat has been specified as an element of each VDU screen.

4.5.3 System Response Time

References: MIL-STD-1472D - 5.15.4.1.1.2
NASA-STD-3000/Vol 1/Rev A - 9.6.2.9.1.b, 9.6.2.9.1.d, 9.6.2.9.1.e

5.0 ANNUNCIATOR SYSTEMS

No SAG entries

5.1 General System Characteristics

References: NUREG-0700 - 6.3.1.1

5.1.1 Selection of Annunciator Status Variables

References: NUREG-0700 - 6.3.1.2

5.1.2 Alarm Prioritization

References: NUREG-0700 - 6.3.1.4

5.1.3 Annunciator States

No SAG entries (Definitional)

5.2 Auditory Alert Subsystem

No SAG entries

5.2.1 Audible Intensity

References: NUREG-0700 - 6.2.2.6, 6.3.2.1
Human Eng. Guide to Equipment Design - Fig 4.3

5.2.2 Auditory Coding

References: NUREG-0700 - 6.3.2.2, 6.3.1.5.a

Rationale: It is noted here that auditory location coding is not a highly valuable auditory subsystem feature in Nuplex 80+, since any alarm can be acknowledged at any workstation. Thus, considering alarm system operation from the standpoint of cognitive function, the directing-of-attention function that follows the alerting function has essentially been shifted from the alerting phase to the acknowledgement phase of operation. This is considered to be an improvement since 1) auditory coding mechanisms should minimize their diversity, and are limited in their range of directing ability, and 2) acknowledgement, which was in older systems rather an undirected operator activity (just press the button) that had to be accompanied by active search, is now a very concise operation; acknowledgement is equivalent to a system query that results in delivery of alarm message(s) to the operator at his present location.

5.3 Visual Indicating Subsystem

References: NUREG-0700 - 6.3.3.2.e, 6.3.3.2.f

5.3.1 Annunciator Tile Matrices

References. NUREG-0700 - 6.3.3.1.a, 6.3.3.1.b, 6.3.3.3.a, 6.3.3.3.b

Rationale: It is noted that support for pattern recognition (detection of an overall condition that is perceptually driven, by seeing that a particular set of alarms is present), which is often cited as a benefit of hardwired individual alarm tiles, will be somewhat diminished by the aggregate tiles of Nuplex 80+. This is an unavoidable tradeoff with the goal of reducing information overload. Other devices, such as the IPSO overview, the CFMS and success path monitoring, as well as the various alarm system features that afford various information handling functions (e.g., listings, group acknowledgement, mode dependency, and sensor validation), are expected to more than make up for this particular tradeoff. This is one example of how software-based implementation and VDU presentation of alarms has an impact on their management and use.

5.3.2 Tile Legends

References: NUREG-0700 - 6.3.3.4

Rationale: On hard tiles, the label must serve as the annunciated message and therefore there should be one tile for each annunciator. On software tiles, messages can be linked by category names on the tile label. Thus, the alerting, directing, and informing functions of an annunciator are now performed by distinct, more specialized mechanisms. Specific messages can be afforded readily through the computer system, thereby satisfying the requirement that each alarm have a unique designator through the alarm message, rather than the tile itself.

5.4 Operator Response Subsystem

No SAG entries

5.4.1 Controls

References: NUREG-0700 - 6.3.4.1
System Description for Control Complex Information System for Nuplex 80+, Rev 01 - 8.2

Rationale: The enhanced flash suppression and reminder features of Nuplex 80+ is part of an integrated solution to respond to specific problems experienced with conventional control room designs for the management of incoming alarms. These problems included information overload (too many alarms), heightened stress (insufficient time and support), and lost information (global acknowledgment) associated with older designs.

5.4.2 Annunciator Response Procedures

References: NUREG-0700 - 6.3.4.3

6.0 COMMUNICATION SYSTEMS

No SAG entries

6.1 General Requirements

No SAG entries

6.1.1 Speech Transmission and Reproduction

References: NUREG-0700 - 6.2.1, 6.1.5.5
MIL-STD-1472D - 5.3.7, 5.3.8, 5.3.10, 5.3.11
EPRI NP-4350 - III-F 2.2.1, 2.3

6.1.2 Equipment Configuration

References: MIL-STD-1472D - 5.3.9
NUREG-0700 - 6.2.1.2.b, 6.2.1.3.b
EPRI NP-4350 - III-F 2.2.1

6.1.3 Equipment Controls

References: MIL-STD-1472D - 5.3.10
NUREG-0700 - 6.2.1.5.b

6.1.4 Emergency Communications

References: NUREG-0700 - 6.2.1.1.c, 6.2.1.8

6.1.5 Noise Testing

References: MIL-STD-1472D - 5.3.12
NUREG-0700 - 6.2.1.1.b
Human Eng. Guide to Equipment Design - Section 5.3.5

6.2 Telephone

No SAG entries

6.2.1 Keyboard

No SAG entries (Cross reference to Numeric Keypads, Section 3.3.1)

6.2.2 Function Keys

Rationale: These practices are deemed to be self-evident, if not they are not already general practice.

6.2.3 Hot Lines

Rationale: These practices are deemed to be self-evident, if not they are not already general practice.

6.3 Radio Transceivers

No SAG entries

6.3.1 Radio Frequency Interference

References: NUREG-0700 - 6.2.1.4, 6.2.1.5

6.3.2 Portability

References: NUREG-0700 - 6.2.1.4

6.3.3 Sound Controls

References: EPRI NP-4350 - III-F 2.2.1, 2.3, 4.1.1

6.3.4 Durability

Rationale: This is simply to avoid procuring fragile units.

6.4 Paging Systems

No SAG entries

6.4.1 Channel Characteristics

References: NUREG-0700 - 6.2.1.6.1
EPRI NP-4350 - III-F 3.1.1

6.4.2 Station Characteristics

References: EPRI NP-4350 - III-F 2.2.1, 3.2

6.4.3 Loudspeakers

References: NUREG-0700 - 6.2.1.6.a.2, 6.2.1.6.c
EPRI NP-4350 - III-F 2.1.3, 2.3.1

6.5 Sound-Powered Phones

References: NUREG-0700 - 6.2.1.3
EPRI NP-4350 - III-F 3.1.2

7.0 WORK SPACE ENVIRONMENT

No SAG entries

7.1 Illumination

No SAG entries (Introductory material)

7.1.1 Task Lighting

References: NUREG-0700 - 6.1.5.3.a
MIL-STD-1472D - 5.8.2

7.1.2 Emergency Lighting

References: NUREG-0700 - 6.1.5.4

7.1.3 Task Area Luminance Ratios

References: NUREG-0700 - 6.1.5.3
Handbook of Human Factors - 6.3.4.4
ANSI/HFS 100-1988 - 5.3

Rationale: Guidance (e.g. NUREG-0700) on task area luminance ratios (the variation in luminous power emitted by sequentially fixated visual areas) are apparently based on old studies whose validity has been severely criticized, of late. What constitutes either ideal or unacceptable values of this parameter (or even how it should best be measured) remains unclear. While extreme ratios (much greater than 100:1) can be said to be a possible source of discomfort or degraded performance and should be avoided, "strict recommendations of luminance ratios of [the frequently cited range between] 3:1 and 10:1 between the task and any other source of luminance in the visual field cannot be justified" (ANSI/HFS 100-1988). Thus, the HFESAG merely suggests that light (dark) task areas should be somewhat brighter (darker) than their surrounds, and that steps should generally be taken to mitigate situations unintentionally produce extreme ratios (unshaded brilliance, strong shadows, etc.) in a work area.

7.1.4 Reducing Glare and Reflectance

References: NUREG-0700 - 6.1.5.3.f, 6.1.5.3.g
Handbook of Human Factors - Ch. 5.1, Table 5.1.5

7.2 Noise

No SAG entries (Cross-reference to Communications Systems)

7.2.1 Operations Centers and Workspaces

References: NUREG-0700 - 6.1.5.5
MIL-STD-1472D - 5.8.3

Rationale: These limits are based primarily on ease, effectiveness, and reliability of verbal communication and auditory signalling.

7.2.2 Equipment Spaces

References: 10 CFR 29 (OSHA) - 1910.95
Human Eng. Guide to Equipment Design - Ch. 4

Rationale: OSHA limits are default standards, and are based on the long-term health and safety of employees, specifically to protect their hearing abilities. Guidelines provided for System 80+ are conservative with respect to OSHA standards. Standards are not provided since excessive noise from large power plant equipment must be managed by personnel, through stay time and use of ear protection, which are not system design issues.

7.3 Air Quality and Temperature

No SAG entries

7.3.1 Temperature and Humidity

References: NUREG-0700 - 6.1.5.1

7.3.2 Ventilation

References: NUREG-0700 - 6.1.5.2
10 CFR 29 (OSHA) - 1910.94

7.4 Vibration

References: MIL-STD-1472D - 5.8.4

7.5 Architectural Features

No SAG entries

7.5.1 Operator Comfort

References: NUREG-0700 - 6.1.4.3, 6.1.5.6, 6.1.5.7

7.5.2 Doors

References: EPRI NP-4350 - IIIA 2.1.3
10 CFR 29 (OSHA) - Subpart E (Means of Egress)
MIL-STD-1472D - 5.7.8 (Ingress and Egress), 5.13.4.2 (Emergency Doors and Exits)

7.5.3 Bathrooms, Kitchens and Other Facilities

No SAG entries

7.5.3.1 Bathrooms

References: NUREG-0700 - 6.1.5.7.b.1

7.5.3.2 Kitchen

References: NUREG-0700 - 6.1.5.7.b.1

7.5.3.3 Other Facilities

References: NUREG-0700 - 6.1.5.7

7.5.4 Flooring

References: EPRI CS-3745 - 3.2.11
EPRI NP-2411
10 CFR 29 (OSHA) - Subpart D (Walking & Working Surfaces)

7.5.5 Wall Covering

References: EPRI CS-3745 - 3.2.11
EPRI NP-2411

7.5.6 Supervisor's Office

References: NUREG-0700 - 6.1.1.6

Rationale: The requirements of this SAG are already incorporated in the Nuplex 80+ design basis and the resulting control complex design; see CESSAR-DC Section 18.6.5.4, and 18.6.5.6.1.4.

7.5.7 Nonessential Personnel Access

References: NUREG-0700 - 6.1.1.7

Rationale: Nuplex 80+ has a variety of features that limit the intrusiveness of access-authorized but nonessential personnel to control room operations. The Technical Support Center provides authorized visitors a full view of the control room without entering. Furthermore, offices inside the control room have visual and verbal contact with the controlling workspace, while maintaining isolated workspace for collateral operations duties and activities. Finally, the control panels themselves form a natural exclusion boundary around the controlling workspace, while permitting convenient access to all areas of the control room

7.5.8 Installed Platforms, Workstands, Stairs and Ladders

References: MIL-STD-1472D - 5.7.7 (Stairs, Ladders, Ramps, Platforms), 5.9.11.1 (Work Stands), 5.13 (Hazards and Safety)
10 CFR 29 1910 (OSHA) - Subpart D (Walking & Working Surfaces)
EPRI NP-4350 - 7.2 (Stairs), 7.3 (Ladders)

7.5.9 Storage

No SAG entries

7.5.9.1 Document Storage

References: NUREG-0700 - 6.1.1.4

7.5.9.2 Personal Storage Space

References: NUREG-0700 - 6.1.5.6

7.5.9.3 Emergency Equipment Storage

References: NUREG-0700 - 6.1.4.3

7.6 Workstations & Panels

No SAG entries (Introductory)

7.6.1 General Arrangements

References: NUREG-0700 - 6.1.1.1, 6.1.1.3.a, 6.1.1.3.b, 6.1.1.3.c, 6.1.1.3.d, 6.1.2.2.e

Rationale: Availability of necessary indications and controls is a fundamental requirement and design basis for nuclear power plant main control rooms. Beyond minimum availability, the Nuplex 80+ Controlling Workspace concept and design has sought to minimize operator problems with access, visibility, communication, mobility, and intrusion. See Nuplex 80+ Design Basis Document NPX80-IC-DP790-01.

. .6.2 Panel Dimensions

No SAG entries (Introductory)

7.6.2.1 General Dimensions

References: NUREG-0700 - 6.1.1.3, 6.1.2.1, 6.1.2.2, 6.1.2.3
MIL-STD-1472D - 5.6, 5.13.5.4

Rationale: The subset of anthropometry data provided in NUREG-0700 is taken from MIL-STD-1472B. The same section from MIL-STD-1472D is included in Appendix A in its entirety, for the use of designers; the data is unchanged. Note that NUREG-0700 averaged the ground troop and aviator data to get a more representative 95%ile male estimate. Also note that the value of 5%ile female fingertip height in NUREG-0700 (24.2") is footnoted as 5%ile male aviator data. Using the related values of 95%ile male fingertip height and extended functional reach, and assuming proportionality with the 5%ile female fingertip height and extended functional reach relationships, a value of 20.7" for 5%ile female fingertip height is the result. Finally, NUREG-0700 has some additional values that were taken from an EPRI source; these data showed that the distance from the central axis of the body to the panel leading edge had a range from 5" (5%ile female) to 5.3" (95%ile male), and that the eye distance forward of the central axis of the body had a range from 3" (5%ile female) to 3.4" (95%ile male).

The range of heights on workstations for physically manipulated indicating or control devices for use by operators (not maintainers) is based on the limiting upper reach of the standing 5th% female operator (74.6 inches), and limiting lower reach of the standing 95th% male operator (26.8 inches). These values are based on data for shoulder height (plus 1 inch for shoe height) and functional reach. Actual reach envelopes, however, are unique to each panel (given its benchboard depth and slope) and must be evaluated individually.

7.6.2.2 Stand-up Panels

References: NUREG-0700 - 6.1.2.2

Rationale: Much of the relevant information for stand-up panel dimensions is contained in the previous section. Residual stand-up panel basis material is provided here.

True stand-up panels (e.g., the ACSC panels) are not designed to permit viewing over the top; as well as affording more panel area, this serves an exclusionary function for foot traffic outside the Controlling Workspace. In addition, tall cabinets (e.g., 78" = 95%ile male stature + 4.5" margin) permit easy entry for maintenance. Cabinets of such height, if used, would afford display space that is out-of-reach to 5%ile females, even assuming a vertical panel with no benchboard. This is not a human factors problem as long as the excess-height panel "real estate" remains off-limits for placement of controls and touch screen devices. This is assured by the standards on height of control placement (see Section 7.6.1.3). If the shorter panel is deemed desirable, one alternative is to implement a "pop-top" arrangement on the panel with a spring and damper arrangement. Note also that the ACSC panel shown in CESSAR-DC Figure 18.6.5-12, Amendment E, Sheet 3 has already been redesigned with a steeper, shallower skirt, so that the 5%ile female reach envelope extends to the top of the panel.

7.6.2.3 Sit-down Panels

References: <u>NUREG-0700</u> - 6.1.2.3, 6.1.2.7.d
<u>MIL-STD-1472D</u> - 5.6.2

Rationale: Much of the relevant information for sit-down panel dimensions is contained in the General Dimensions section. Residual sit-down panel basis material is provided here.

Nuplex 80+ sit-down panels at the MCC are designed for use in both the sitting and standing positions. Standards driven by task action (i.e., reach requirements) assume standing operators; standards driven by monitoring (i.e., visibility) requirements assume seated operators.

Although the MCC panels meet the visibility-over-the-panel specification in NUREG-0700 for standing operators (not greater than 58"), this particular task is not required of operators in Nuplex 80+ (there is nothing for operators to observe below the MCC "horizon"; since the wall-mounted IPSO is above this horizon, this guidance is distinct from that which delimits the IPSO viewing window when seated, or from elsewhere in the control room. See Section 7.6.5 on Display Positioning.) The 42 in. over view guideline is based on 5%ile female eye height (27 inches) plus seat height (15 inches).

Note also that the 5%ile female operator is also required to stand when touching interface hardware on the uppermost portion of the sit-down panel's vertical section (see the MCC panel shown in

CESSAR-DC Figure 18.6.5-11, Amendment E, Sheet 3). This is consistent with the design basis assumption that task actions are being taken by standing operators. While as much as a further 7" reduction in panel height may be possible (while still accommodating the specified VDU hardware), the reduction is not necessary to accommodate the operator, and it could be considered also as a potential degradation of the maintainer's task, which requires unimpeded access to the panel.

7.6.3 Workstation Layout

References: NUREG-0700 - 6.8.2.1

Rationale: The procedure for panel layout is given in the Panel Layout Guidelines Document, NPX80-IC-DP-791-01. A discussion of some related issues is still provided here.

The Nuplex 80+ design basis segments control device hardware from other indicating devices. Control devices are placed on the baseboard section, while other indicating devices are placed on the vertical section.

Within the vertical section, various VDU devices are arranged in a fairly standard fashion, although their plasticity affords variety in application. The point is, there is relatively little functional grouping taking place on the vertical section. The DPS VDU is in the center; the alarm tile VDU is in the upper right-hand corner; remaining real estate is allocated to various discrete indicators (both dedicated and non-dedicated parameters.) Layout will correspond primarily to the larger organization of panel functions (more frequently used towards center of MCC, etc.; see CESSAR-DC Section 18.6.5); then to correspond to and be compatible with the layout of control devices on the benchboard (see Sections 7.6.3.2 and 7.6.3.3).

Application of guidelines for grouping are difficult to convert to standards. In general, grouping and layout in terms of functions, systems, and components will be the most frequently implemented approach (as is true, in Nuplex 80+, of the organization of panels within consoles based on the Task Analysis). Layout by operational sequence should then be considered next. Finally, within a panel/function, layout by importance and/or frequency may be useful, with the most frequently used items in the most central or accessible location (though some important but infrequently used items, such as manual safety injection switches, should be readily accessible but not too convenient to actuate--inadvertently). This is a generic order, and design requirements or evaluation may implicate another order as preferable in any particular case.

This accommodation-by-aspects layout strategy is not unlike a correlation equation that seeks out the largest variance sources (i.e., the most powerful explanations) first. In both cases, this is held to be parsimonious; thus the approach conforms to one of the fundamental principals of good science (given that more precise causal and interactive relationships cannot presently be determined among the variables.)

7.6.3.1 Group Spacing

References: NUREG-0700 - 6.8.1.3.a

7.6.3.2 Demarcation

References: NUREG-0700 - 6.8.1.3.b

7.6.3.3 Component Spacing

References: NUREG-0700 - Exhibit 6.8-2, Footnote 2.
MIL-STD-1472D - 5.6.2

Rationale: The guidance for separation of simultaneously actuated components is based on 5%ile female anthropometry: shoulder breadth (15.0 inches) plus twice the shoulder-to-elbow (2 x 12.1 = 24.2 inches) length, yielding 39.2 inches as a conservative approximation of working (broad) reach.

7.6.3.4 Arrangement of Physically Similar Components

References: NUREG-0700 - 6.8.3.2

7.6.3.5 Large Matrices

References: NUREG-0700 - 6.8.3.2.d

7.6.3.6 Paired Controls & Displays

References: NUREG-0700 - 6.9.1.1

7.6.4 Display Positioning

No SAG entries

7.6.4.1 Display Position - Vertical Displacement

References: NUREG-0700 - 6.1.2.2.e.1.a, 6.1.2.3.e.1, 6.7.2.3.c.1.b, 6.7.2.3.c.2.b, 6.7.2.3.d.1.b, 6.7.2.3.d.2.b

7.6.4.2 Display Position - Horizontal Displacement

References: NUREG-0700 - 6.7.2.3.c.1.a, 6.7.2.3.c.2.a

7.6.4.3 Display Plane Angle

References: NUREG-0700 - 6.7.2.3.b
Engineering Data Compendium - 11.109. CRT Symbol Size, Viewing Angle, and Vertical Resolution: Effects on Identification Accuracy.

Rationale: Results in 11.109 indicate that for "larger (8.1 and 14.3 min arc) characters" off-angle viewing was relatively unaffected up to 30° (equivalent, in our guidance, to a display surface angle of 60°); screens in the study were high resolution (>= 15 scan lines per character height), character stimuli were random.

7.6.4.4 Display Distance

References: NUREG-0700 - 6.7.2.3.a

7.6.5 Desks

References: NUREG-0700 - 6.1.2.7.d

7.6.6 Chairs

References: NUREG-0700 - 6.1.2.8

8.0 MAINTAINABILITY

No SAG entries

8.1 Introduction

No SAG entries (defines approach)

8.2 Design of Equipment for Maintainability

No SAG entries

8.2.1 Facilitate Frequent and Expected Activities

References: EPRI NP-4350 - IV-A 2.2, 2.3, 2.5, 2.6,
UCRL-15673 - 1.1, 1.5, 1.9, 1.11
NUREG/CR-3517 - 8.5

8.2.2 Fool-proof Features

References: NUREG/CR-3517 - 2.3, 8.3.1

8.2.3 In-Situ Maintenance

References: EPRI NP-4350 - IV-A 2.1, 2.3, 2.4, 2.8
UCRL-15673 - 1.1, 1.2, 1.4, 1.7, 1.9, 1.10, 1.12
NUREG/CR-3517 - 3.3, 3.7, 3.8, 3.9, 3.10, 6.5
MIL-STD-1472D - 5.6.2

Rationale: The guidance given in 8.2.3.a on height above floor level for frequently serviced or easy-access items (2.5 - 4 feet) is based on MIL-STD-1472D anthropometric data for standing 5%ile female shoulder height (48 inches) and seated 95% male elbow height (31 inches).

8.3 Facility Arrangements & Installations

No SAG entries

8.3.1 Access, Pull, & Laydown Space

References: EPRI NP-4350 - III-A 3.2.2; III-E 4.0, 5.0; IV-A 2.1
UCRL-15673 - 1.4, 2.1
NUREG/CR-3517 - 3.3, 3.4, 3.5.6, 6.5.1, 8.4
MIL-STD-1472D - 5.6.2

Rationale: The guidance given in 8.3.1.e on cabinet height for anticipated entry (78 inches) is based on MIL-STD-1472D anthropometric data for standing 95%ile male shoulder stature (74 inches) plus 4 inches for maneuvering.

8.3.2 Cranes, Hoists, & Lifting

References: 10 CFR 29 1910 (OSHA) - 1910.179
EPRI NP-4350 - III-E 3.0, 4.0
NUREG/CR-3517 - 7.5

8.3.3 Scaffolds, Stands, & Miscellaneous Facilities

References: 10 CFR 29 1910 (OSHA) - Subparts D (Walking-Working Surfaces), E (Means of Egress), F (Powered Platforms, Manlifts, etc.), N (Materials Handling & Storage), O (Machinery & Machine Guarding).

8.4 Special Requirements for Contaminated Systems

References: EPRI NP-4350 - III-A 2.3.2, 2.4
NUREG/CR-3517 - 4.7
10 CFR 29 (OSHA) - 1910.96

8.5 Equipment Design Documentation of Maintenance Task Data & Requirements

Rationale: This is standard good design practice.

8.6 Software Maintainability

Rationale: Legislation of software engineering practices is beyond the scope of this document. However, these tips are fairly well-established good general practices, and are thus encouraged.

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3) MIL-STD-1472D - Human Engineering Design Criteria for Military Systems, Equipment, and Facilities. Washington, DC: Department of Defense (1981).

4) NASA-STD-3000 - Man-Systems Integration Standards. Houston, TX: National Aeronautics and Space Administration (1989).

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APPENDIX A

MIL-STD-1472D Section 5.6 - Anthropometry (pp. 129-143, 148-152).

5.6 Anthropometry.

5.6.1 General. Design and sizing shall insure accommodation, compatibility, operability, and maintainability by the user population. Generally, design limits shall be based upon a range from the 5th percentile female to the 95th percentile male values for critical body dimensions, as appropriate, except for Naval aviator special populations (see 5.6.4). For any body dimension, the 5th percentile value indicates that five percent of the population will be equal to or smaller than that value, and 95 percent will be larger; conversely, the 95th percentile values indicates that 95 percent of the population will be equal to or smaller than that value and five percent will be larger. Therefore, use of a design range from the 5th to 95th percentile values will theoretically provide coverage for 90 percent of the user population for that dimension. Where two or more dimensions are used simultaneously as design parameters, appropriate multivariate data and techniques should be utilized. (See Appendix for representative references.) The limited anthropometric data presented in this section in Figures 23 through 28 and Tables XIII through XVIII are intended to provide general design guidance. DOD-HDBK-743 should be consulted for more extensive data. Use of these data shall take the following into consideration:

a. The nature, frequency, safety, and difficulty of the related tasks to be performed by the operator or wearer of the equipment.

b. The position of the body during performance of these tasks.

c. Mobility or flexibility requirements imposed by these tasks.

d. Increments in the design-critical dimensions imposed by the need to compensate for obstacles, projections, etc.

e. Increments in the design-critical dimensions imposed by protective clothing or equipment, packages, lines, padding, etc.

5.6.2 Anthropometric data. The anthropometric data presented in Tables XIII through XVIII are nude body measurements; data in centimeters are given in the upper half of each table, and data in inches are shown in the lower half of each table. (Note: The anthropometric data shown in these tables have been compiled and collated from several sources. The data on Ground Troops consist of measurements on a series of 6682 U.S. Army men and a series of 2008 U.S. Marines, both measured in 1966, as well as of 287 U.S. Army men measured in 1977. The data on Aviators represent 1482 U.S. Army aviation personnel, measured in 1970; 1549 U.S. Navy pilots, measured in 1964; and 2420 U.S. Air Force flying personnel, measured in 1967. The data on military women consist of measurements of 1300 U.S. Army WAC personnel and Army nurses, measured in 1977; and 1905 U.S. Air Force WAF personnel and Air Force nurses, measured in 1968.) Blanks in the tables indicate that data are not available for those dimensions. Technical reports (see appendix) should be consulted for definitions of specified measurements, methods of data collection and

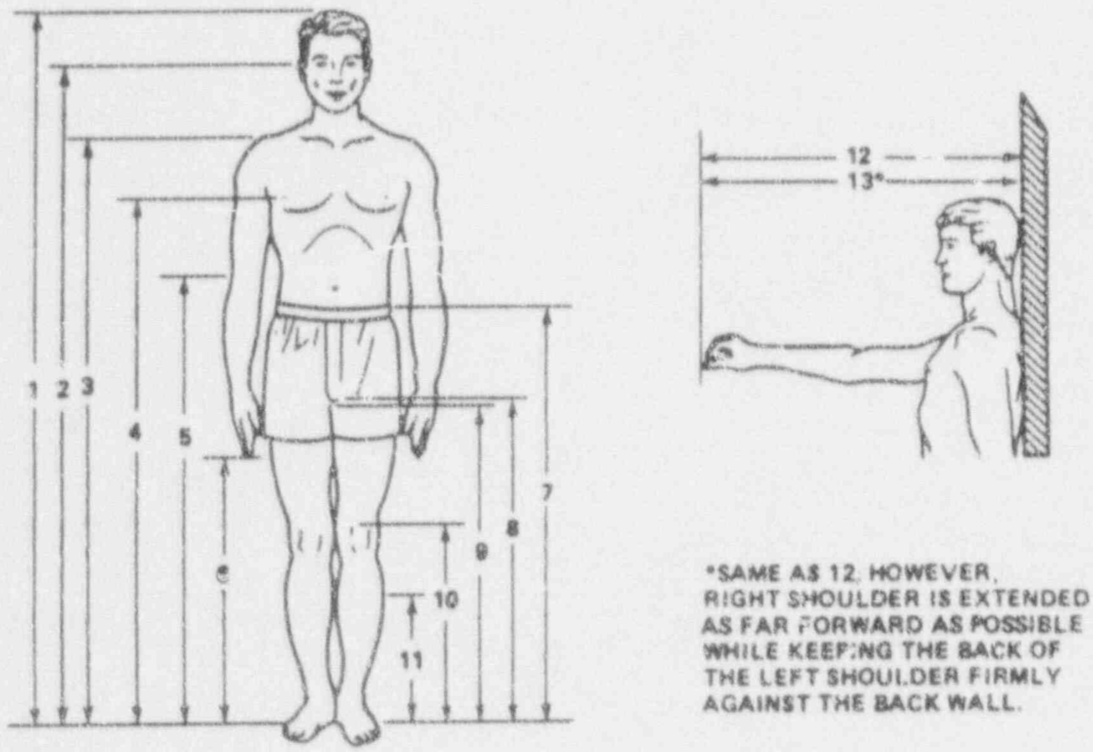


FIGURE 23. STANDING BODY DIMENSIONS

TABLE XIII. STANDING BODY DIMENSIONS

	PERCENTILE VALUES IN CENTIMETERS					
	5th PERCENTILE			95th PERCENTILE		
	GROUND TROOPS	AVIATORS	WOMEN	GROUND TROOPS	AVIATORS	WOMEN
WEIGHT (kg)	55.5	60.4	46.4	91.6	96.0	74.5
STANDING BODY DIMENSIONS						
1 STATURE	162.8	164.2	152.4	185.6	187.7	174.1
2 EYE HEIGHT (STANDING)	151.1	152.1	140.9	173.3	175.2	162.2
3 SHOULDER (ACROMIALE) HEIGHT	133.6	133.3	123.0	154.2	154.8	143.7
4 CHEST (NIPPLE) HEIGHT *	117.9	120.8	109.3	136.5	138.5	127.8
5 ELBOW (RADIALE) HEIGHT	101.0	104.8	94.9	117.8	120.0	110.7
6 FINGERTIP (DACTYLION) HEIGHT		61.5			73.2	
7 WAIST HEIGHT	96.6	97.6	93.1	115.2	115.1	110.3
8 CROTCH HEIGHT	76.3	74.7	68.1	91.8	92.0	83.9
9 GLUTEAL FURROW HEIGHT	73.3	74.6	66.4	87.7	88.1	81.0
10 KNEECAP HEIGHT	47.5	46.8	43.8	58.6	57.8	52.5
11 CALF HEIGHT	31.1	30.9	29.0	40.6	39.3	36.6
12 FUNCTIONAL REACH	72.6	73.1	64.0	90.9	87.0	80.4
13 FUNCTIONAL REACH, EXTENDED	84.2	82.3	73.5	101.2	97.3	92.7
	PERCENTILE VALUES IN INCHES					
WEIGHT (lb)	122.4	133.1	102.3	201.9	211.6	164.3
STANDING BODY DIMENSIONS						
1 STATURE	64.1	64.6	60.0	73.1	73.9	68.5
2 EYE HEIGHT (STANDING)	59.5	59.9	[illegible]	68.2	69.0	63.9
3 SHOULDER (ACROMIALE) HEIGHT	52.6	52.5	48.4	60.7	60.9	56.6
4 CHEST (NIPPLE) HEIGHT *	46.4	47.5	43.0	53.7	54.5	50.3
5 ELBOW (RADIALE) HEIGHT	39.8	41.3	37.4	46.4	47.2	43.6
6 FINGERTIP (DACTYLION) HEIGHT		24.2	20.7		28.8	
7 WAIST HEIGHT	38.0	38.4	36.6	45.3	45.3	43.4
8 CROTCH HEIGHT	30.0	29.4	26.8	36.1	36.2	33.0
9 GLUTEAL FURROW HEIGHT	28.8	29.4	26.2	34.5	34.7	31.9
10 KNEECAP HEIGHT	18.7	18.4	17.2	23.1	22.8	20.7
11 CALF HEIGHT	12.2	12.2	11.4	16.0	15.5	14.4
12 FUNCTIONAL REACH	28.6	28.8	[illegible]	35.8	[illegible]	31.7
13 FUNCTIONAL REACH, EXTENDED	33.2	32.4	28.9	39.8	38.3	36.5

*BUSTPOINT HEIGHT FOR WOMEN

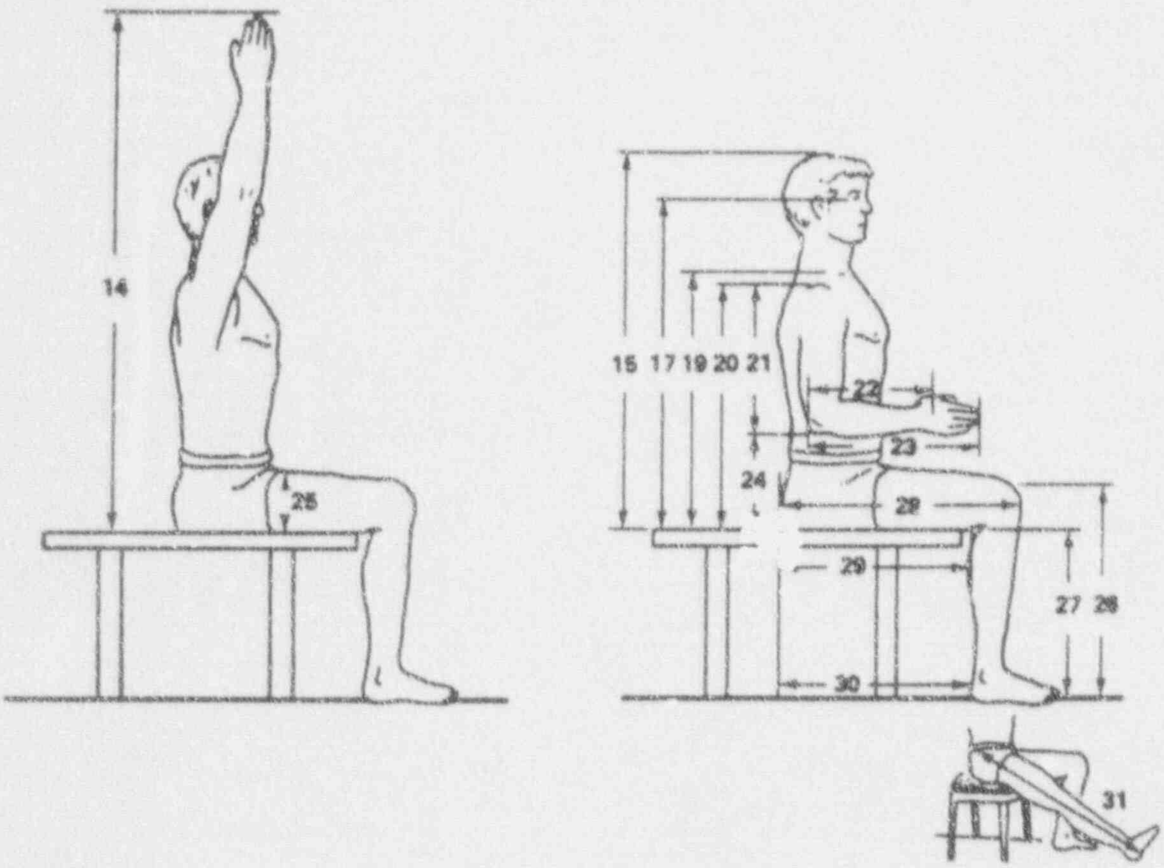


FIGURE 24. SEATED BODY DIMENSIONS

TABLE XIV. SEATED BODY DIMENSIONS

	PERCENTILE VALUES IN CENTIMETERS					
	5th PERCENTILE			95th PERCENTILE		
	GROUND TROOPS	AVIATORS	WOMEN	GROUND TROOPS	AVIATORS	WOMEN
SEATED BODY DIMENSIONS						
14 VERTICAL ARM REACH, SITTING	128.6	134.0	117.4	147.8	153.2	139.4
15 SITTING HEIGHT, ERECT	83.5	85.7	79.0	96.9	98.6	90.9
16 SITTING HEIGHT, RELAXED	81.5	83.6	77.5	94.8	96.5	89.7
17 EYE HEIGHT, SITTING ERECT	72.0	73.6	67.7	84.6	86.1	79.1
18 EYE HEIGHT, SITTING RELAXED	70.0	71.6	66.2	82.5	84.0	77.9
19 MID-SHOULDER HEIGHT	56.6	58.3	53.7	67.7	69.2	62.5
20 SHOULDER HEIGHT, SITTING	54.2	54.6	49.9	65.4	65.9	60.3
21 SHOULDER-ELBOW LENGTH	33.3	33.2	30.8	40.2	39.7	36.6
22 ELBOW-GRIP LENGTH	31.7	32.6	29.6	38.3	37.9	35.4
23 ELBOW-FINGERTIP LENGTH	43.8	44.7	40.0	52.0	51.7	47.5
24 ELBOW REST HEIGHT	17.5	18.7	16.1	28.0	29.5	26.9
25 THIGH CLEARANCE HEIGHT		12.4	10.4		18.8	17.5
26 KNEE HEIGHT, SITTING	49.7	48.9	46.9	60.2	59.9	55.5
27 POPLITEAL HEIGHT	39.7	38.4	38.0	50.0	47.7	45.7
28 BUTTOCK-KNEE LENGTH	54.9	55.9	53.1	65.8	65.5	63.2
29 BUTTOCK-POPLITEAL LENGTH	45.8	44.9	43.4	54.5	54.6	52.6
30 BUTTOCK-HEEL LENGTH		46.7			56.4	
31 FUNCTIONAL LEG LENGTH	110.6	103.9	99.6	127.7	120.4	118.6
	PERCENTILE VALUES IN INCHES					
SEATED BODY DIMENSIONS						
14 VERTICAL ARM REACH, SITTING	50.6	52.8	46.2	58.2	60.3	54.9
15 SITTING HEIGHT, ERECT	32.9	33.7	31.1	38.2	38.8	35.8
16 SITTING HEIGHT, RELAXED	32.1	32.9	30.5	37.3	38.0	35.3
17 EYE HEIGHT, SITTING ERECT	28.3	30.0	26.6	33.3	33.9	31.2
18 EYE HEIGHT, SITTING RELAXED	27.6	28.2	26.1	32.5	33.1	30.7
19 MID-SHOULDER HEIGHT	22.3	23.0	21.2	26.7	27.3	24.6
20 SHOULDER HEIGHT, SITTING	21.3	21.5	19.6	25.7	25.9	23.7
21 SHOULDER-ELBOW LENGTH	13.1	13.1	12.1	15.8	15.6	14.4
22 ELBOW-GRIP LENGTH	12.5	12.8	11.6	15.1	14.9	14.0
23 ELBOW-FINGERTIP LENGTH	17.3	17.6	15.7	20.5	20.4	18.7
24 ELBOW REST HEIGHT	6.9	7.4	6.4	11.0	11.6	10.6
25 THIGH CLEARANCE HEIGHT		4.9	4.1		7.4	6.9
26 KNEE HEIGHT, SITTING	19.6	19.3	18.5	23.7	23.6	21.8
27 POPLITEAL HEIGHT	15.6	15.1	15.0	19.7	18.8	18.0
28 BUTTOCK-KNEE LENGTH	21.6	22.0	20.9	25.9	25.8	24.9
29 BUTTOCK-POPLITEAL LENGTH	17.9	17.7	17.1	21.5	21.5	20.7
30 BUTTOCK-HEEL LENGTH		18.4			22.2	
31 FUNCTIONAL LEG LENGTH	43.5	40.9	39.2	50.3	47.4	46.7

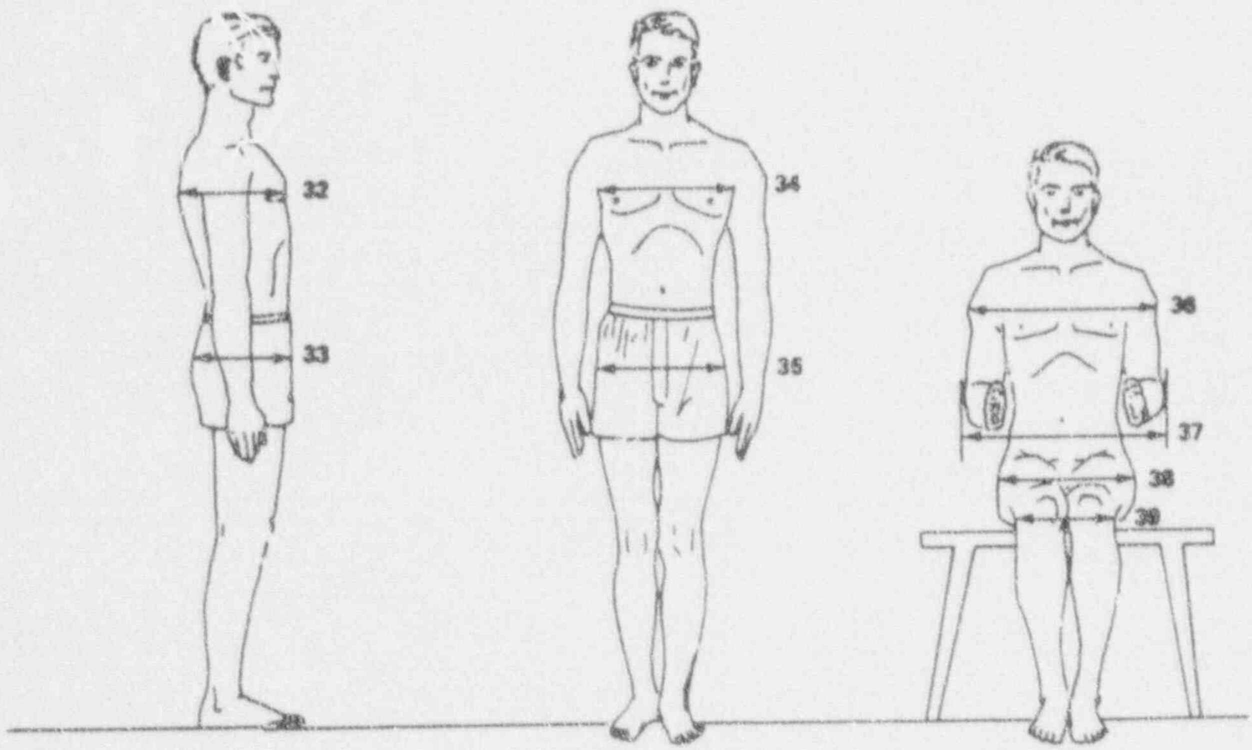


FIGURE 25. DEPTH AND BREADTH DIMENSIONS

TABLE XV. DEPTH AND BREADTH DIMENSIONS

		PERCENTILE VALUES IN CENTIMETERS					
		5th PERCENTILE			95th PERCENTILE		
		GROUND TROOPS	AVIATORS	WOMEN	GROUND TROOPS	AVIATORS	WOMEN
DEPTH AND BREADTH DIMENSIONS							
32	CHEST DEPTH*	18.9	20.4	19.6	26.7	27.8	27.2
33	BUTTOCK DEPTH		20.7	18.4		27.4	24.3
34	CHEST BREADTH	27.3	29.5	25.1	34.4	38.5	31.4
35	HIP BREADTH, STANDING	30.2	31.7	31.5	36.7	38.8	39.5
36	SHOULDER (BIDELTOID) BREADTH	41.5	43.2	38.2	49.8	52.6	45.8
37	FOREARM–FOREARM BREADTH	39.8	43.2	33.0	53.6	60.7	44.9
38	HIP BREADTH, SITTING	30.7	33.3	33.0	38.4	42.4	43.9
39	KNEE–TO–KNEE BREADTH		19.1			25.5	
		PERCENTILE VALUES IN INCHES					
DEPTH AND BREADTH DIMENSIONS							
32	CHEST DEPTH*	7.5	8.0	7.7	10.5	11.0	10.7
33	BUTTOCK DEPTH		8.2	7.2		10.8	9.6
34	CHEST BREADTH	10.8	11.6	9.9	13.5	15.1	12.4
35	HIP BREADTH, STANDING	11.9	12.5	12.4	14.5	15.3	15.6
36	SHOULDER (BIDELTOID) BREADTH	16.3	17.0	15.0	19.6	20.7	18.0
37	FOREARM–FOREARM BREADTH	15.7	17.0	13.0	21.1	23.9	17.7
38	HIP BREADTH, SITTING	12.1	13.1	13.0	15.1	16.7	17.3
39	KNEE–TO–KNEE BREADTH		7.5			10.0	

*BUST DEPTH FOR WOMEN

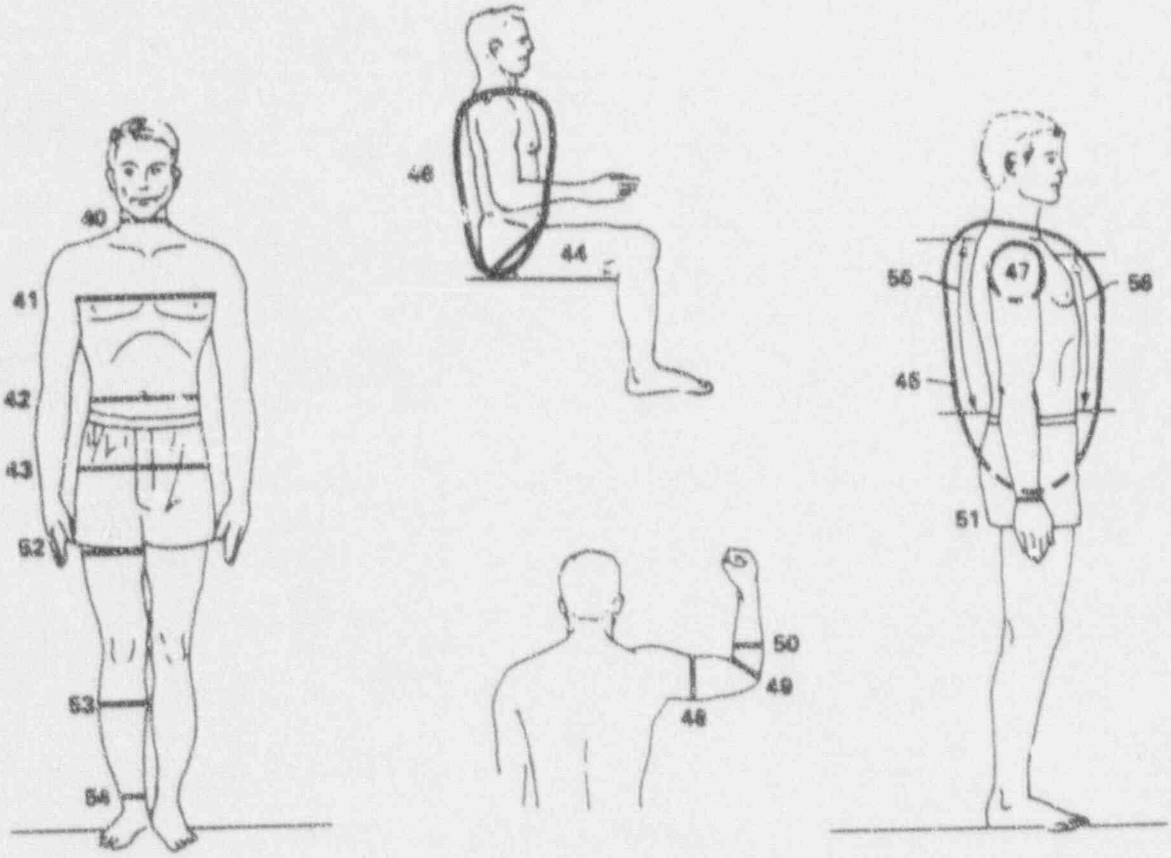


FIGURE 26. CIRCUMFERENCES AND SURFACE DIMENSIONS

TABLE XVI. CIRCUMFERENCES AND SURFACE DIMENSIONS

	PERCENTILE VALUES IN CENTIMETERS					
	5th PERCENTILE			95th PERCENTILE		
	GROUND TROOPS	AVIATORS	WOMEN	GROUND TROOPS	AVIATORS	WOMEN
CIRCUMFERENCES						
40 NECK CIRCUMFERENCE	34.2	34.6	29.9	41.0	41.6	36.7
41 CHEST CIRCUMFERENCE*	83.8	87.5	78.4	105.9	109.9	100.2
42 WAIST CIRCUMFERENCE	68.4	73.5	58.5	95.9	101.7	83.5
43 HIP CIRCUMFERENCE	85.1	87.1	85.5	106.9	108.4	106.1
44 HIP CIRCUMFERENCE, SITTING		97.0	87.7		119.3	110.8
45 VERTICAL TRUNK CIRCUMFERENCE, STANDING	150.6	156.3	142.2	178.6	181.9	166.3
46 VERTICAL TRUNK CIRCUMFERENCE, SITTING		150.4	134.8		175.0	161.0
47 ARM SCYE CIRCUMFERENCE	39.6	39.9	33.6	50.3	53.0	41.7
48 BICEPS CIRCUMFERENCE, FLEXED	27.0	27.8	23.2	37.0	36.9	30.8
49 ELBOW CIRCUMFERENCE, FLEXED		28.5	23.5		34.2	30.0
50 FOREARM CIRCUMFERENCE, FLEXED	26.1	26.3	22.2	33.1	33.1	27.5
51 WRIST CIRCUMFERENCE	15.7	15.3	13.6	18.6	19.2	16.2
52 UPPER THIGH CIRCUMFERENCE	48.1	49.6	48.7	63.9	66.9	64.5
53 CALF CIRCUMFERENCE	31.6	33.3	30.6	41.2	41.3	39.2
54 ANKLE CIRCUMFERENCE	19.3	20.0	18.7	25.2	24.8	23.3
55 WAIST BACK LENGTH	39.2	42.4	36.7	50.8	50.9	45.4
56 WAIST FRONT LENGTH	36.1	35.7	30.5	46.2	44.2	41.4
	PERCENTILE VALUES IN INCHES					
CIRCUMFERENCES						
40 NECK CIRCUMFERENCE	13.5	13.6	11.8	16.1	16.4	14.4
41 CHEST CIRCUMFERENCE*	33.0	34.4	30.8	41.7	43.3	39.5
42 WAIST CIRCUMFERENCE	26.9	28.9	23.4	37.8	40.0	32.9
43 HIP CIRCUMFERENCE	33.5	34.3	33.7	42.1	42.7	41.8
44 HIP CIRCUMFERENCE, SITTING		38.2	34.6		47.0	43.6
45 VERTICAL TRUNK CIRCUMFERENCE, STANDING	59.3	61.6	56.0	70.3	71.6	65.5
46 VERTICAL TRUNK CIRCUMFERENCE, SITTING		59.2	53.1		68.9	63.4
47 ARM SCYE CIRCUMFERENCE	15.6	15.7	13.2	19.8	20.9	16.4
48 BICEPS CIRCUMFERENCE, FLEXED	10.6	11.0	9.1	14.6	14.5	12.1
49 ELBOW CIRCUMFERENCE, FLEXED		11.2	9.2		13.5	11.8
50 FOREARM CIRCUMFERENCE, FLEXED	10.3	10.4	8.7	13.0	13.0	10.8
51 WRIST CIRCUMFERENCE	6.2	6.0	5.4	7.3	7.8	6.4
52 UPPER THIGH CIRCUMFERENCE	18.9	19.5	19.2	25.1	26.3	25.4
53 CALF CIRCUMFERENCE	12.4	13.1	12.0	16.2	16.3	15.4
54 ANKLE CIRCUMFERENCE	7.6	7.9	7.4	9.9	9.7	9.2
55 WAIST BACK LENGTH	15.4	16.7	14.4	20.0	20.0	17.9
56 WAIST FRONT LENGTH	14.2	14.1	12.0	18.2	17.4	16.3

*BUST CIRCUMFERENCE FOR WOMEN

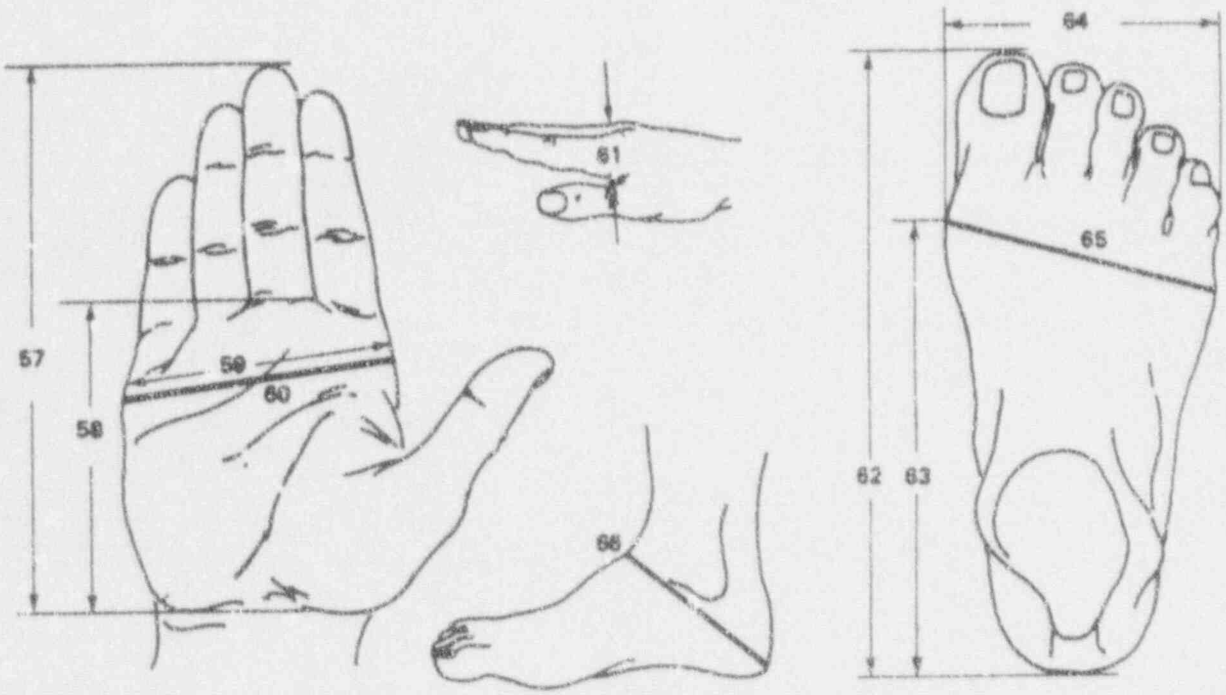


FIGURE 27. HAND AND FOOT DIMENSIONS

TABLE XVII. HAND AND FOOT DIMENSIONS

	PERCENTILE VALUES IN CENTIMETERS					
	5th PERCENTILE			95th PERCENTILE		
	GROUND TROOPS	AVIATORS	WOMEN	GROUND TROOPS	AVIATORS	WOMEN
HAND DIMENSIONS						
57 HAND LENGTH	17.4	17.7	16.1	20.7	20.7	20.0
58 PALM LENGTH	9.6	10.0	9.0	11.7	11.9	10.8
59 HAND BREADTH	8.1	8.2	6.9	9.7	9.7	8.5
60 HAND CIRCUMFERFNCE	19.5	19.6	16.8	23.6	23.1	19.9
61 HAND THICKNESS		2.4			3.5	
FOOT DIMENSIONS						
62 FOOT LENGTH	24.5	24.4	22.2	29.0	29.0	26.5
63 INSTEP LENGTH	17.7	17.5	16.3	21.7	21.4	19.6
64 FOOT BREADTH	9.0	9.0	8.0	10.9	11.6	9.8
65 FOOT CIRCUMFERENCE	22.5	22.6	20.8	27.4	27.0	24.5
66 HEEL–ANKLE CIRCUMFERENCE	31.3	30.7	28.5	37.0	36.3	33.3
	PERCENTILE VALUES IN INCHES					
HAND DIMENSIONS						
57 HAND LENGTH	6.85	6.98	6.32	8.13	8.14	7.89
58 PALM LENGTH	3.77	3.92	3.56	4.61	4.69	4.24
59 HAND BREADTH	3.20	3.22	2.72	3.83	3.80	3.33
60 HAND CIRCUMFERENCE	7.68	7.71	6.62	9.28	9.11	7.82
61 HAND THICKNESS		0.95			1.37	
FOOT DIMENSIONS						
62 FOOT LENGTH	9.65	9.62	8.74	11.41	11.42	10.42
63 INSTEP LENGTH	6.97	6.88	6.41	8.54	8.42	7.70
64 FOOT BREADTH	3.53	3.54	3.16	4.29	4.58	3.84
65 FOOT CIRCUMFERENCE	8.86	8.91	8.17	10.79	10.62	9.65
66 HEEL–ANGLE CIRCUMFERENCE	12.32	12.08	11.21	14.57	14.30	13.11

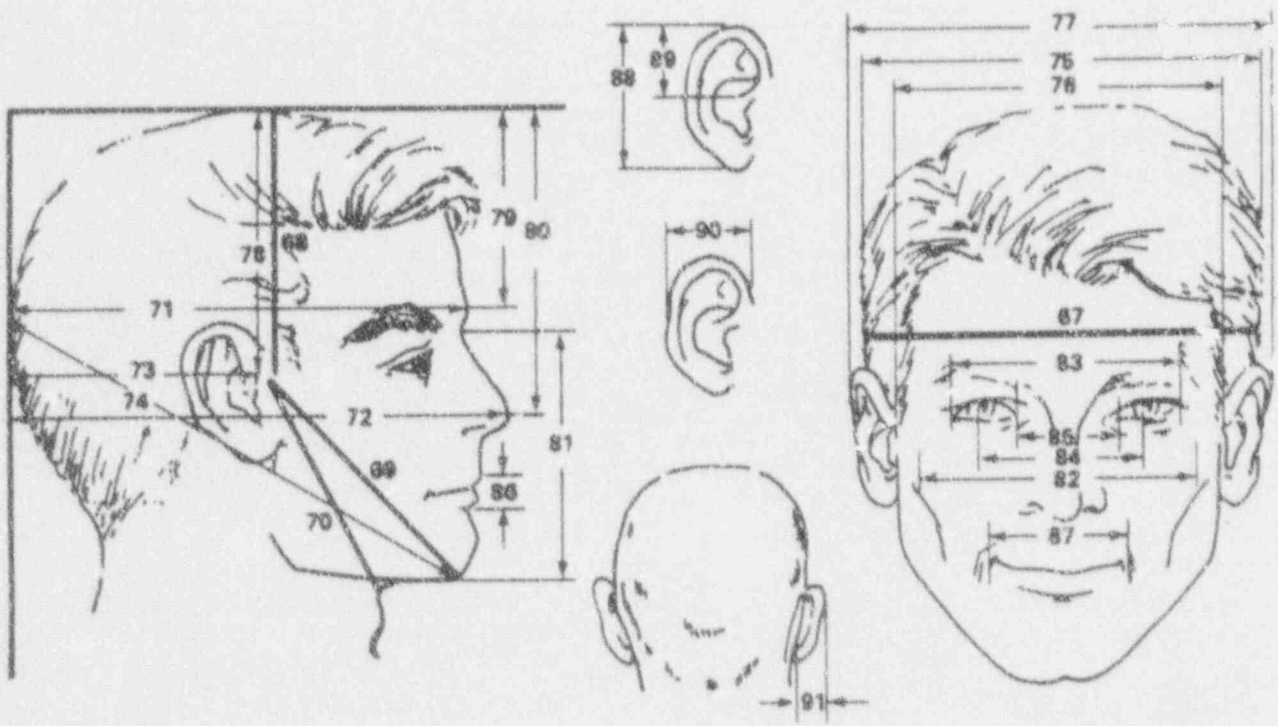


FIGURE 28. HEAD AND FACE DIMENSIONS

TABLE XVIII. HEAD AND FACE DIMENSIONS

	PERCENTILE VALUES IN CENTIMETERS					
	5th PERCENTILE			95th PERCENTILE		
	GROUND TROOPS	AVIATORS	WOMEN	GROUND TROOPS	AVIATORS	WOMEN
HEAD AND FACE DIMENSIONS						
67 HEAD CIRCUMFERENCE	53.2	53.8	52.2	58.8	59.9	57.7
68 BITRAGION-CORONAL CURVATURE	31.9	33.4	31.3	36.1	37.8	36.3
69 BITRAGION-MENTON CURVATURE	29.0	30.1	27.3	33.1	34.7	31.6
70 BITRAGION-SUBMANDIBULAR CURVATURE	26.7	28.4	24.5	30.7	33.6	28.9
71 HEAD LENGTH	18.2	18.6	17.3	20.7	21.0	19.8
72 PRONASALE TO WALL	20.8	21.4	19.7	23.5	24.1	23.2
73 TRAGION TO WALL	8.5	9.2	8.8	12.6	12.1	11.8
74 HEAD DIAGONAL (MENTON-OCCIPUT)		24.4			28.9	
75 HEAD BREADTH	14.2	14.4	13.5	16.3	16.5	15.6
76 BITRAGION BREADTH	12.5	13.1	12.1	14.5	15.2	13.8
77 BIAURICULAR BREADTH	16.5	17.5	14.2	19.4	20.2	17.4
78 HEAD HEIGHT (TRAG.-TOP OF HEAD)	11.9	12.0	11.6	14.5	14.4	14.3
79 GLABELLA TO TOP OF HEAD	6.5	7.2	7.1	9.4	10.9	9.9
80 PRONASALE TO TOP OF HEAD	11.6	13.0	11.9	15.1	16.6	16.8
81 FACE LENGTH (MENTON-SELLION)	10.6	10.2	9.6	13.1	13.0	11.8
82 FACE (BIZYGOMATIC) BREADTH	12.6	12.4	11.9	14.9	15.1	14.0
83 BIOCULAR BREADTH	9.3	8.4	8.8	10.5		10.5
84 INTERPUPILLARY BREADTH	5.1	5.3	5.1	6.8	[illegible]	6.5
85 INTEROCULAR BREADTH		2.7	2.7		3.8	3.7
86 LIP TO LIP LENGTH		1.1			2.3	
87 LIP-LENGTH (MOUTH BREADTH)		4.5	3.7		5.9	5.1
88 EAR LENGTH	5.5	5.9	4.5	6.9	7.3	6.0
89 EAR LENGTH ABOVE TRAGION		2.5			3.1	
90 EAR BREADTH	3.8	3.0	2.4	5.0	4.3	3.5
91 EAR PROTRUSION		1.6			2.8	

(Continued)

TABLE XVIII. HEAD AND FACE DIMENSIONS (CONCLUDED)

	PERCENTILE VALUES IN INCHES					
	5th PERCENTILE			95th PERCENTILE		
	GROUND TROOPS	AVIATORS	WOMEN	GROUND TROOPS	AVIATORS	WOMEN
HEAD AND FACE DIMENSIONS						
67 HEAD CIRCUMFERENCE	20.94	21.18	20.57	23.16	23.59	22.73
68 BITRAGION-CORONAL CURVATURE	12.56	13.14	12.31	14.21	14.90	14.29
69 BITRAGION-MENTON CURVATURE	11.42	11.86	10.74	13.03	13.68	12.45
70 BITRAGION-SUBMANDIBULAR CURVATURE	10.51	11.18	9.63	12.09	13.23	11.37
71 HEAD LENGTH	7.19	7.32	6.80	8.14	8.27	7.80
72 PRONASALE TO WALL	8.18	8.42	7.88	9.27	9.50	9.15
73 TRAGION TO WALL	3.33	3.62	3.47	4.95	4.77	4.64
74 HEAD DIAGONAL (MENTON-OCCIPUT)		9.60			10.59	
75 HEAD BREADTH	5.59	5.67	5.33	6.40	6.50	6.12
76 BITRAGION BREADTH	4.92	5.17	4.76	5.71	5.98	5.45
77 BIAURICULAR BREADTH	6.50	6.89	5.61	7.64	7.95	6.84
78 HEAD HEIGHT (TRAG.-TOP OF HEAD)	4.69	4.74	4.55	5.72	5.69	5.62
79 GLABELLA TO TOP OF HEAD	2.56	2.81	2.79	3.70	4.30	3.88
80 PRONASALE TO TOP OF HEAD	4.57	5.12	4.70	5.94	6.54	6.61
81 FACE LENGTH (MENTON-SELLION)	4.17	4.04	3.79	5.17	5.13	4.63
82 FACE (BIZYGOMATIC) BREADTH	5.04	4.87	4.39	5.88	5.94	5.53
83 BIOCULAR BREADTH	3.66	3.31	3.47	4.29	3.99	4.14
84 INTERPUPILLARY BREADTH	2.01	2.10	2.00	2.67	2.75	2.57
85 INTEROCULAR BREADTH		1.08	1.05		1.50	1.45
86 LIP TO LIP LENGTH		0.41			0.92	
87 LIP LENGTH (MOUTH BREADTH)		1.76	1.46		2.30	2.01
88 EAR LENGTH	2.17	2.31	1.77	2.72	2.88	2.34
89 EAR LENGTH ABOVE TRAGION		0.97			1.36	
90 EAR BREADTH	1.50	1.19	0.95	1.97	1.70	1.38
91 EAR PROTRUSION		0.65			1.09	

more detailed anthropometric data; definitive or more specific data should be obtained from the service agency responsible for anthropometry.

5.6.3 Use of data.

5.6.3.1 Data limitations. Because the anthropometric data presented here represent nude body measurements, suitable allowances shall be made for light or heavy clothing, flying suits, helmets, boots, body armor, load-carrying equipment, protective equipment, and other worn or carried items, when utilizing these data for design criteria.

5.6.3.2 Clearance dimensions. Clearance dimensions (e.g., for passageways and accesses), which must accommodate or allow passage of the body or parts of the body, shall be based upon the 95th percentile values for applicable body dimensions.

5.6.3.3 Limiting dimensions. Limiting dimensions (reaching distance, control movement, displays, test points, handrails, etc.) which restrict or are limited by extensions of the body shall be based upon the 5th percentile values for applicable body dimensions.

5.6.3.4 Adjustable dimensions. Seats, restraint systems, safety harnesses, belts, controls or any equipment that must be adjusted for the comfort or performance of the individual user shall be adjustable over the range of the 5th to 95th percentile values for the applicable body member(s).

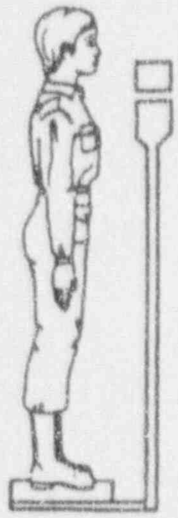
5.6.3.5 Clothing and personal equipment. Clothing and personal equipment (including protective or specialized equipment worn or carried by the individual) shall be designed and sized to accommodate at least the 5th through the 95th percentile values of body dimensions. Pertinent dimensions of essential or critical equipment (e.g., aviators' helmets) shall be based on the 1st and 99th percentile values. Where two or more dimensions are used simultaneously as design parameters, appropriate multivariate data and techniques shall be utilized. (See appendix for representative references.)

5.6.4 Special populations. Where equipment will be used, inclusively or exclusively, by selected or specialized segments of the military population (e.g., Army tank crews, Navy divers, etc.) or population ranges other than the 5 - 95th percentiles (e.g., disproportionate anthropometric accommodation test cases), appropriate available anthropometric data on these specialized populations, contained in DOD-HDBK-743, shall be utilized for design and sizing criteria. Where equipment is intended for use by foreign military personnel, appropriate anthropometric data on such populations shall be utilized for design and sizing criteria. (See appendix for representative references.)

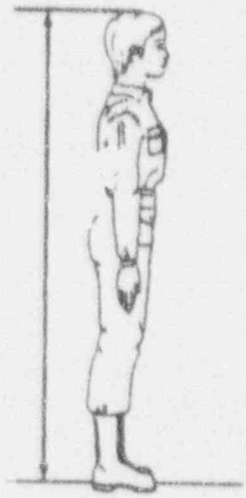
TABLE XIX. ANTHROPOMETRIC DATA FOR COMMON WORKING POSITIONS

*	PERCENTILE VALUES IN CENTIMETERS			
	5th PERCENTILE		95th PERCENTILE	
	MEN	WOMEN	MEN	WOMEN
1. WEIGHT – CLOTHED (KILOGRAMS)	58.6	48.8	90.2	74.6
2. STATURE – CLOTHED	168.5	156.8	189.0	178.7
3. FUNCTIONAL REACH	72.6	64.0	86.4	79.0
4. FUNCTIONAL REACH, EXTENDED	84.2	73.5	101.2	92.7
5. OVERHEAD REACH HEIGHT	200.4	185.3	230.5	215.1
6. OVERHEAD REACH BREADTH	35.2	31.5	41.9	37.9
7. BENT TORSO HEIGHT	125.6	112.7	149.8	138.6
8. BENT TORSO BREADTH	40.9	36.8	48.3	43.5
9. OVERHEAD REACH, SITTING	127.9	117.4	146.9	139.4
10. FUNCTIONAL LEG LENGTH	110.6	99.6	127.7	118.6
11. KNEELING HEIGHT	121.9	114.5	136.9	130.3
12. KNEELING LEG LENGTH	63.9	59.2	75.5	70.5
13. BENT KNEE HEIGHT, SUPINE	44.7	41.3	53.5	49.6
14. HORIZONTAL LENGTH, KNEES BENT	150.8	140.3	173.0	163.8
	PERCENTILE VALUES IN INCHES			
1. WEIGHT – CLOTHED (POUNDS)	129.1	107.6	198.8	164.5
2. STATURE – CLOTHED	66.4	61.8	74.4	70.3
3. FUNCTIONAL REACH	28.6	25.2	34.0	31.1
4. FUNCTIONAL REACH, EXTENDED	33.2	28.9	39.8	36.5
5. OVERHEAD REACH HEIGHT	78.9	73.0	90.8	84.7
6. OVERHEAD REACH BREADTH	13.9	12.4	16.5	14.9
7. BENT TORSO HEIGHT	49.4	44.4	59.0	54.6
8. BENT TORSO BREADTH	16.1	14.5	19.0	17.1
9. OVERHEAD REACH, SITTING	50.3	46.2	57.9	54.9
10. FUNCTIONAL LEG LENGTH	43.5	39.2	50.3	46.7
11. KNEELING HEIGHT	48.0	45.1	53.9	51.3
12. KNEELING LEG LENGTH	25.2	23.3	29.7	27.8
13. BENT KNEE HEIGHT SUPINE	17.6	16.3	21.1	19.5
14. HORIZONTAL LENGTH, KNEES BENT	59.4	55.2	68.1	64.5

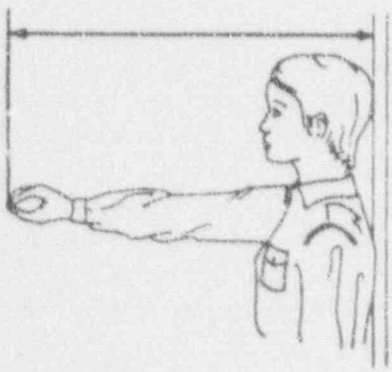
*See Figure 28 for illustration of each measurement.



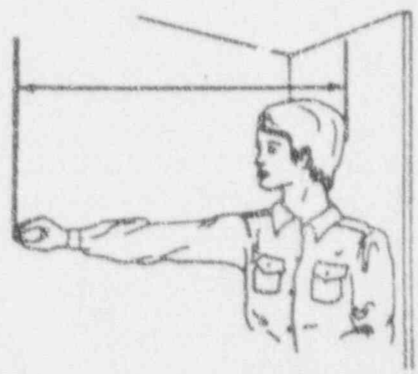
(1) WEIGHT (CLOTHED) WEARING FATIGUES & COMBAT BOOTS; STANDING IN CENTER OF SCALE



(2) STATURE (CLOTHED) STANDING ERECT; HEELS TOGETHER; WEIGHT DISTRIBUTED EQUALLY ON BOTH FEET. MEASURED FROM STANDING SURFACE TO TOP OF HEAD.

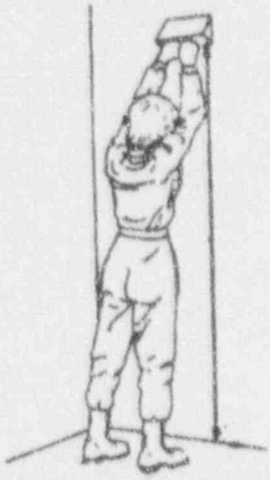


(3) FUNCTIONAL REACH – STANDING ERECT; LOOKING STRAIGHT AHEAD; BOTH SHOULDERS AGAINST WALL; RIGHT ARM HORIZONTAL. MEASURED FROM WALL TO TIP OF INDEX FINGER

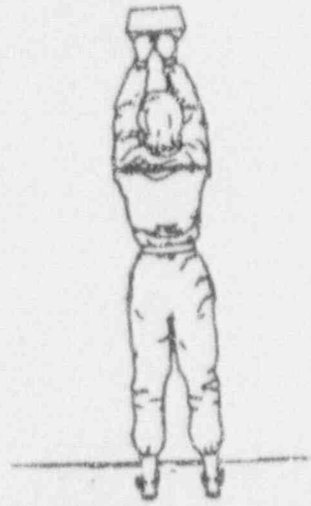


(4) FUNCTIONAL REACH, EXTENDED– STANDING ERECT; LOOKING STRAIGHT AHEAD; RIGHT SHOULDER EXTENDED AS FAR FORWARD AS POSSIBLE WHILE BACK OF LEFT SHOULDER FIRMLY AGAINST WALL; ARM HORIZONTAL. MEASURED FROM WALL TO TIP OF INDEX FINGER.

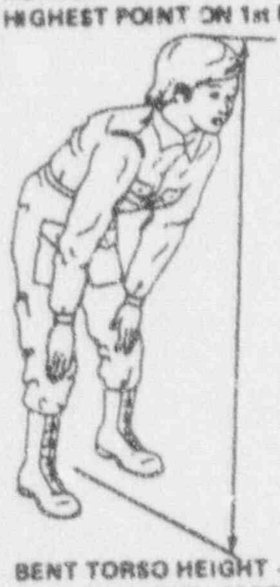
FIGURE 29. ANTHROPOMETRIC DATA FOR WORKSPACES



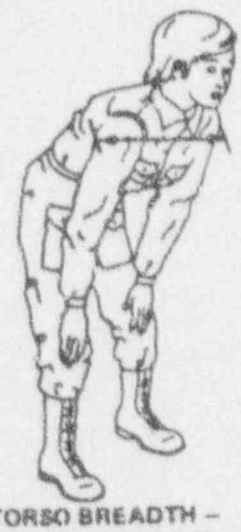
(5) OVERHEAD REACH HEIGHT – STANDING WITH HEELS 23 cm APART AND TOES 15 cm FROM WALL; ARMS EXTENDED OVERHEAD WITH FISTS TOUCHING AND AGAINST WALL; 1st PHALANGES HORIZONTAL. MEASURED FROM FLOOR TO HIGHEST POINT ON 1st PHALANGES



(6) OVERHEAD REACH BREADTH – STANDING WITH HEELS 23 cm APART AND TOES 15 cm FROM WALL; ARMS EXTENDED OVERHEAD WITH FISTS TOUCHING AND AGAINST WALL; 1st PHALANGES HORIZONTAL. MEASURED HORIZONTALLY ACROSS ARMS OR SHOULDERS, WHICHEVER IS WIDER.

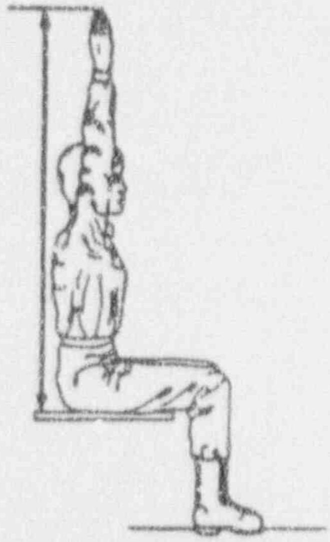


(7) BENT TORSO HEIGHT – STANDING WITH FEET 30 cm APART; BENDING OVER AND PLACING PALMS OF THE HANDS ON KNEECAPS; ELBOWS AND KNEES LOCKED; LOOKING FORWARD; HEAD TILTED AS FAR BACK AS POSSIBLE. MEASURED FROM FLOOR TO TOP OF HEAD.

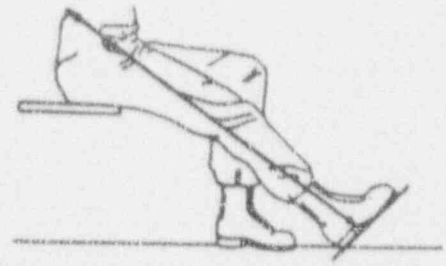


(8) BENT TORSO BREADTH – STANDING WITH FEET 30 cm APART; BENDING OVER AND PLACING THE PALMS OF THE HANDS ON KNEECAPS; ELBOWS AND KNEES LOCKED; LOOKING FORWARD; HEAD TILTED AS FAR BACK AS POSSIBLE. MEASURED AS MAXIMUM HORIZONTAL DISTANCE ACROSS SHOULDERS.

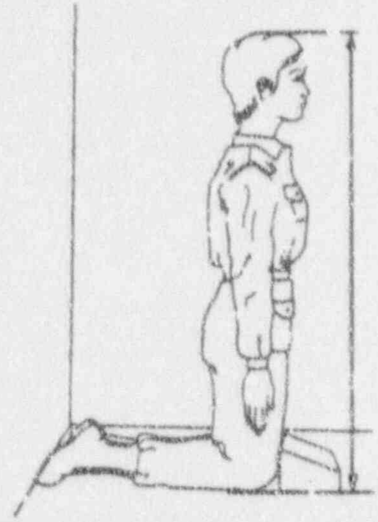
FIGURE 29. ANTHROPOMETRIC DATA FOR WORKSPACES (CONTINUED)



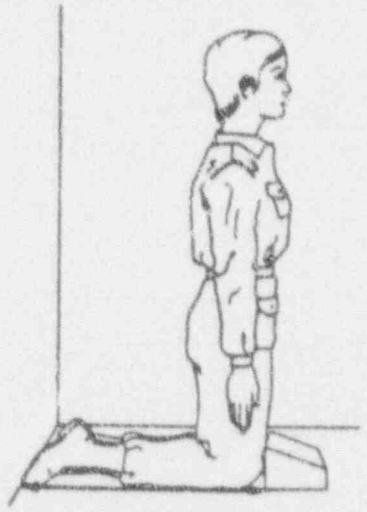
(9) OVERHEAD REACH, SITTING –
SITTING ERECT; RIGHT SIDE AGAINST WALL; RIGHT ARM EXTENDED UPWARD WITH PALM FLAT AGAINST WALL AND FINGERS EXTENDED. MEASURED FROM SITTING SURFACE TO TIP OF MIDDLE FINGER.



(10) FUNCTIONAL LEG LENGTH –
SITTING ERECT ON EDGE OF CHAIR; RIGHT LEG EXTENDED FORWARD WITH KNEE STRAIGHTENED. MEASURED FROM HEEL ALONG AXIS OF LEG TO POSTERIOR WAIST.

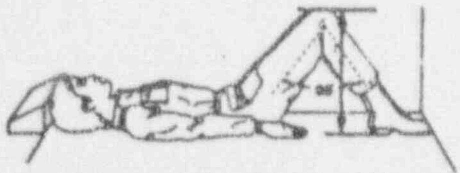


(11) KNEELING HEIGHT –
KNEELING WITH TOES EXTENDED AND LIGHTLY TOUCHING REAR WALL; TORSO ERECT WITH ARMS HANGING LOOSELY AT SIDES. MEASURED FROM FLOOR TO TOP OF HEAD.

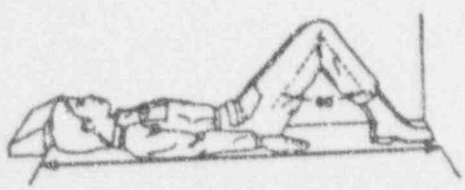


(12) KNEELING LEG LENGTH –
KNEELING WITH TOES EXTENDED AND LIGHTLY TOUCHING REAR WALL; TORSO ERECT WITH ARMS HANGING LOOSELY AT SIDES. MEASURED FROM WALL TO ANTERIOR PORTION OF BOTH KNEES.

FIGURE 29. ANTHROPOMETRIC DATA FOR WORKSPACES (CONTINUED)



(13) BENT KNEE HEIGHT, SUPINE –
LYING SUPINE; KNEES RAISED UNTIL ANGLE BETWEEN UPPER AND LOWER LEGS APPROXIMATES 90°; TOES LIGHTLY TOUCHING WALL. MEASURED FROM FLOOR TO HIGHEST POINT ON KNEES.



(14) HORIZONTAL LENGTH, KNEES BENT –
LYING SUPINE; KNEES RAISED UNTIL ANGLE BETWEEN UPPER AND LOWER LEGS APPROXIMATES 90°; TOES LIGHTLY TOUCHING WALL. MEASURED FROM WALL TO TOP OF HEAD.

FIGURE 29. ANTHROPOMETRIC DATA FOR WORKSPACES (CONCLUDED)