Designation: F 1166 – 95a (Reapproved 2006)

An American National Standard

Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities[1]

This standard is issued under the fixed designation F 1166; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice establishes general human engineering design criteria for marine vessels, and systems, subsystems, and equipment contained therein. It provides a useful tool for the designer to incorporate human capabilities into a design.

1.2 The purpose of this practice is to present human engineering design criteria, principles, and practices to achieve mission success through integration of the human into the vessel system, subsystem, and equipment with the goals of effectiveness, simplicity, efficiency, reliability, and safety for operation, training, and maintenance.

1.3 This practice applies to the design of vessels, systems, subsystems, and equipment. Nothing in this practice shall be construed as limiting the selection of hardware, materials, or processes to the specific items described herein. Unless otherwise stated in specific provisions, this practice is applicable to design of vessel systems, subsystems, and equipment for use by both men and women.

1.4 Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.

1.5 This practice is not intended to be a criterion for limiting use of material already in the field in areas such as lift repetition or temperature exposure time.

1.6 *Force Limits*—If it is known that an item is to be used by an already established occupational specialty, for which physical qualification requirements for entry into that specialty are also established, any discrepancy between the force criteria of this practice and the physical qualification requirements shall be resolved in favor of the latter. In this event, the least stringent physical qualification requirement of all specialties which may operate, maintain, transport, supply, move, lift, or otherwise manipulate the item, in the manner being considered, is selected as a maximum design force limit.

1.7 *Manufacturing Tolerances*—When manufacturing tolerances are not perceptible to the user, this practice shall not be construed as preventing the use of components whose dimensions are within a normal manufacturing upper or lower limit tolerance of the dimensions specified herein.

1.8 This practice is divided into the following sections:

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[1] This specification is under the jurisdiction of ASTM Committee F25 on Ships and Marine Technology and is the direct responsibility of Subcommittee F25.07 on General Requirements.

Current edition approved June 1, 2006. Published June 2006. Originally approved in 1988. Last previous edition approved in 2000 as F 1166 – 95a (2000).

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2.1 *ASTM Standards:* [2]

IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System

2.2 *Military Specifications:*

MIL-C-25050, Colors, Aeronautical Lights and Lighting Equipment, General Requirements for[3]

2.3 *Federal Standard:*

FED-STD-595 Color[3]

2.4 *Military Standards:*

MIL-STD-12, Abbreviation for Use on Drawings, Specifications, Standards, and in Technical Documents[3]

MIL-STD-740, Airborne and Structureborne Noise Measurements and Acceptance Criteria of Shipboard Equipment[3]

2.5 *Military Handbook:*

DOD-HDBK-743, Anthropometry of US Military Personnel[3]

2.6 *Federal Regulations:*

29 CFR 1910, Occupational Safety and Health Standards[4]

46 CFR 113.25-9, U.S. Coast Guard Regulation[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *abort*—a capability that cancels all user entries in a defined transaction sequence.

3.1.2 *accessible*—unless otherwise specified herein or where specific design values are given, an item is considered accessible only where it can be operated, manipulated, removed, or replaced by the suitably clothed and equipped user with applicable fifth and ninety-fifth percentile body dimensions. Applicable body dimensions are those dimensions that are design critical to the operation, manipulation, removal, or replacement task. For example, an adjustment control behind an access opening should be located sufficiently close to the aperture to enable a suitably clothed and equipped user with a fifth percentile depth of reach to grasp and manipulate the adjustment control, while the opening should be sufficiently large to enable passage of a similarly clothed and equipped ninety-fifth percentile hand and arm.

3.1.3 *advisory signal*—a signal that indicates safe or normal configuration, condition of performance, operation of essential equipment, or that attracts attention and imparts information for routine action purposes.

3.1.4 *angle of incidence*—the angle between the line of direction of anything (such as a ray of light or line of sight) striking a surface and a line perpendicular to that surface drawn to the point of contact as shown in Fig. 1.

3.1.5 *backup*—a capability that returns a user to the last previous display in a defined transaction sequence. Also refers to the practice of preserving a second copy of files for data protection purposes.

3.1.6 *brightness*—the amount of emitted or reflected light visible to the eye.

3.1.7 *cancel*—a capability that regenerates or reinitializes the current display without processing or retaining any changes made by the user.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

[4] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

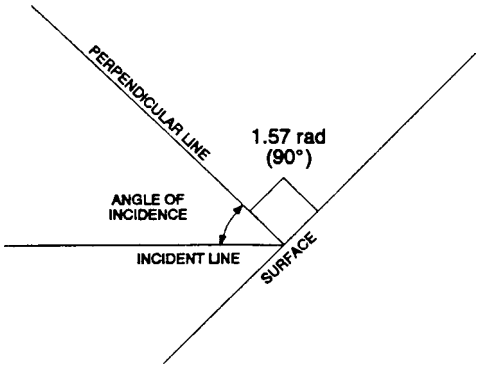

FIG. 1 Angle of Incidence

3.1.8 *caution signal*—a signal that alerts the operator to an impending hazardous condition requiring attention, but not necessarily immediate action.

3.1.9 *command and control system equipment*—the main mission element equipment and related ground equipment used in collecting, transmitting, processing, and displaying information for command and control.

3.1.10 *command language*—a type of dialogue in which a user composes control entries with minimal prompting by the computer.

3.1.11 *common hand tools*—items of tools found in common usage or applicable to a variety of operations or to a single operation on a variety of material. Screwdrivers, hammers, and wrenches are examples of common hand tools.

3.1.12 *control entry*—user input for sequence control, such as function key actuation, menu selection, command entry, and so forth.

3.1.13 *data*—the raw materials from which a user extracts information. Data may include numbers, words, pictures, and so forth.

3.1.14 *data display*—output of data from a computer to its users. Generally, the phrase denotes visual output, but it may be qualified to indicate a different modality, such as "auditory display."

3.1.15 *data entry*—user input of data for computer processing and computer responses to such inputs.

3.1.16 *data field*—an area of the display screen reserved for user entry of a data item.

3.1.17 *data item*—a set of characters of fixed or variable length that forms a single unit of data. Examples of a data item might be a person's name or a zip code. Data items may be entered by a user or may be supplied by the computer.

3.1.18 *data protection*—functional capabilities that guard against unauthorized data access and tampering, user errors, and computer failure.

3.1.19 *4a decibel (dB)*—sound level, measured between acoustic signals, equal to ten times the common logarithm of the ratio of the two levels.

3.1.20 *4a dB (A)*—the sound level measured through the A-weighing network of a sound level meter.

3.1.21 *de-emphasis*—the inverse of preemphasis, used for the purpose of restoring original vowel-consonant amplitude relationships in preemphasized speech; primarily useful in maintaining the "natural" sound quality. (See 3.1.56)

3.1.22 *default value*—a predetermined, frequently used value for a data field or control entry, intended to reduce required user entry actions.

3.1.23 *dialogue*—a structured series of interchanges between a user and a computer terminal. Dialogues can be computer initiated, for example, question and answer, or user initiated, for example, command languages.

3.1.24 *dichotic*—the condition in which the sound stimulus presented at one ear differs from the sound stimulus presented at the other ear. The stimulus may differ in sound pressure, frequency, phase, time, duration, or bandwidth.

3.1.25 *display format*—the organization of different types of data in a display, including information about the data such as labels, and other user guidance such as prompts, error messages, and so forth.

3.1.26 *effective temperature (ET)*—a single value combining the effect of temperature, humidity, and air movement on the sensation of warmth or cold felt by the human body. The numerical value is that of the temperature of still, saturated air, that would induce an identical sensation.

3.1.27 *emergency*—a condition of danger that requires immediate action.

3.1.28 *emergency alarm*—an alarm that indicates that danger exists and that immediate action must be taken. They include the general emergency alarm, fire alarms, those alarms giving warning of personnel hazard; including fire-extinguishing medium alarm, power-operated sliding watertight door closure alarm, and fire detection alarm.

3.1.29 *enter*—an explicit user action that effects computer processing of user entries. For example, after typing a series of numbers, a user might press an ENTER key that will add them to a database, subject to data validation.

3.1.30 *equipment*—general term designating any item or group of items.

3.1.31 *equipment failure*—the cessation of the ability to meet the minimum performance requirements of the equipment specifications. Further, equipment failure shall imply that the minimum specified performance cannot be restored through permissible readjustment of operator controls.

3.1.32 *facilities*—a physical plant, such as real estate and improvements thereto, including building and equipment, which provides the means for assisting or making easier the performance of a system function. The facilities to which this practice apply are those in which personnel perform system operational or maintenance duties.

3.1.33 *fail-safe design*—a design that, upon failure or malfunction of a component, subsystem, or system, automatically reverts to a predetermined design state of least critical consequence.

3.1.34 *field*—see 3.1.16.

3.1.35 *file*—a collection of data, treated as a single unit, that is stored in a computer.

3.1.36 *function key*—a key whose actuation will effect a control entry.

3.1.37 *help*—a capability that displays information upon user request for on-line guidance. HELP may inform a user generally about system capabilities or may provide more specific guidance in information-handling transactions.

3.1.38 *highlighting*—emphasizing displayed data or format features in some way, for example, through the use of underlining, bolding, or inverse video.

3.1.39 *human engineering design criteria*—the summation of available knowledge that defines the nature and limits of human capabilities as they relate to the checkout, operation, maintenance, or control of systems or equipment, to achieve optimum compatibility between equipment and human performance.

3.1.40 *information*—organized data that users need to perform their tasks successfully. Information serves as an answer to a user's questions about data. It is used here to refer to the effective assimilation of data by a user.

3.1.41 *interrupt*—stopping an ongoing transaction to redirect the course of the processing. Examples of interrupt options are ABORT, BACKUP, CANCEL, and RESTART.

3.1.42 *legibility*—the ability to see and identify the alphanumeric characters, symbols, or other visual information on a display.

3.1.43 *luminance contrast*—the contrast between background and a figure equals the absolute difference between the higher luminance, L_1, and the lower luminance, L_2, divided by the higher luminance; that is, $C = (L_1 - L_2)/L_1$. Conversions to the other contrast formulae are as follows:

L_1 (brighter)	L_2 (dimmer)	L_1-L_2/L_2	L_1-L_2/L_1	L_1-L_2/L_1+L_2	L_1/L_2
100	150	1.0	0.50 (50 %)	0.33	2.0
100	25	3.0	0.75 (75 %)	0.60	4.0
100	10	9.0	0.90 (90 %)	0.82	10.0

3.1.44 *luminance ratio (LR)*—the difference in luminance between the target subject and the surrounding field or background. For projection systems, the luminance ratio is equal to the light output of a projector (measured with no film in the projector) reflected off the screen (image luminance) divided by all the light falling on the screen (measured from the greatest viewing angle) other than that actually forming the image (non-image or background); as follows:

$$LR = L/L_n \quad (1)$$

where:

L = image or subject luminance and

L_n = non-image or background luminance.

3.1.45 *macro*—the capability to allow the user to assign a single name or function key to a defined series of commands for use with subsequent command entry. Sometimes called "smartkey." Examples of use are storage of addresses or signature blocks that are frequently used.

3.1.46 *maintainability design*—design considerations directed toward achieving those combined characteristics of the equipment and human beings that will enable the accomplishment of necessary maintenance quickly, safely, accurately, and effectively with minimum requirements for personnel, skills, special tools, and cost.

3.1.47 *master caution (warning) signal*—a signal that indicates that one or more caution (warning) lights has been actuated.

3.1.48 *menu selection*—a type of dialogue in which the user selects one item out of a list of displayed alternatives, whether the selection is by pointing, by entry of an associated option code, or by actuation of an assigned function key.

3.1.49 *metric equivalents, abbreviations, and prefixes*—Table 1 has been used herein to reflect the International System of Units (SI).

3.1.50 *noise-cancelling (microphone)*—a feature that reduces the masking effect of ambient noise upon speech impressed on a microphone, usually by providing equal access of the ambient noise to both surfaces of a diaphragm to achieve approximate equilibrium, effectively causing the noise to cancel itself out. Since the talker's own voice output impinges on only one side of the microphone diaphragm, the talker's signals are not subject to this cancellation, and are transmitted more favorably than if both ambient noise and speech fell simultaneously upon one face of the diaphragm.

3.1.51 *nuclear, biological, chemical (NBC), and other contaminated environment survivability*—NBC survivability includes both the instantaneous, cumulative, and residual effects of NBC weapons or environmental contamination upon a system, including its personnel. NBC or other environmental survivability describes the capability of a system to withstand the NBC environment, including decontamination, without losing the ability to accomplish its mission. For any system to be considered survivable in a contaminated environment, it must have at least three essential characteristics: decontaminability, hardness, and compatibility.

TABLE 1 Metric Equivalents, Abbreviations, and Prefixes

NOTE—Each conversion factor is presented as a number, between one and ten, to six decimal places. The letter E (for exponent), a plus or minus sign and two digits following the number, represent the power of 10 by which the number is to be multiplied.

For example: 3.048 000 E – 01 = 3.048 000 × 10^{-1} = 0.304 800 0
or: 1.076 391 E + 01 = 1.076 391 × 10^{1} = 10.763 91

Examples of use of tables:

To convert 2 ft^3 to m^3 multiply 2 by 2.831 685 E – 02
(2 x 0.028 316 85 = 0.056 634 m^3

To convert 22 m^3 to ft^3 divide 2 by 2.831 685 E – 02
(2/0.028 316 85 = 70.629 325 ft^3

A more complete listing and discussion may be found in IEEE/ASTM

To convert from:	To:	multiply by:
Degree (angle) (deg)	radian (rad)	1.745 329 E – 02
Foot (ft)	metre (m)	3.048 000 E – 01
Foot^2 (ft^2)	metre^2 (m^2)	9.290 304 E – 02
Foot^3 (ft^3)	metre^3 (m^3)	2.831 685 E – 02
Footcandle (ft·C)	lux (lx)	1.076 391 E + 01
Footlambert (ft·L)	candela per metre^2 (cd/m^2)	3.426 259 E + 00
Inch (in.)	metre	2.540 000 E – 02
Inch^2 ($in.^2$)	metre^2 (m^2)	6.451 600 E – 04
Inch^3 ($in.^3$)	metre^3 (m^3)	1.638 706 E – 05
Minute (angle) (min)	radian (rad)	2.908 882 E – 04
Ounce—force (ozf)	Newton (N)	2.780 139 E – 01
Ounce—inch (ozf in)	Newton metre (N·m)	7.061 552 E – 03
Pound (lb) avoirdupois	kilogram (kg)	4.535 924 E – 01
Pound—force (lbf)	Newton (N)	4.448 222 E + 00
Pound—inch (lbf·in)	Newton metre (N·m)	1.129 848 E – 01
Second (angle) (sec)	radian (rad)	4.848 137 E – 06

Prefixes						Temperature Conversion
nano	n	10^{-9}	centi	c	10^{-2}	$°C = \frac{5}{9}(°F - 32)$
micro	μ	10^{-6}	kilo	k	10^{3}	
milli	m	10^{-3}	mega	M	10^{6}	$°F = \frac{9}{5}°C + 32$

decontaminability—the ability of a system to be rapidly decontaminated to reduce the hazard to personnel operating, maintaining, and resupplying it.
hardness—the ability of a system to withstand the material damaging effects of NBC contamination and any decontamination agents and procedures required to remove it.
compatibility—the ability of a system to be effectively operated, maintained, and resupplied by persons wearing the full NBC or other protective ensemble.

3.1.52 *page*—for this standard, the data appearing at one time on a single display screen.

3.1.53 *panel*—the front face of an assembly, normally used for mounting controls and displays.

3.1.54 *panning*—an orientation for display framing in which a user conceives of the display as moving over a fixed array of data. The opposite of scrolling.

3.1.55 *peak-clipping (of speech signals)*—a technique for controlling amplitude relationships in speech by limiting the instantaneous peak amplitudes to improve intelligibility of speech, usually followed by amplification of the signal to increase the amplitude of the clipped peaks to their original level, with proportional increase of the weaker speech sounds.

3.1.56 *preemphasis*—systematic distortion of the speech spectrum to improve intelligibility of speech sound by attenuating the low-frequency components of vowels (relatively unimportant for intelligibility) and proportionately increasing the amplitude of high-frequency vowel components and consonants (highly important for intelligible speech transmission).

3.1.57 *primary alarm (essential alarm)*—an alarm that indicates a condition that requires prompt attention to prevent an emergency condition. They include machinery alarms, control fault alarms, alarms indicating faults in emergency or primary (essential) alarm(s) or detection systems or failure of their normal power supplies, steering gear alarms, bilge alarms, engineer's alarms, and personnel alarms.

3.1.58 *prompt*—an indicator provided by the computer that alerts the user that the computer is ready, data should be entered, and so forth.

3.1.59 *query language*—a language that allows users to compose control entries for displaying specified data from a database.

3.1.60 *question and answer*—a type of dialogue in which the computer displays questions, one at a time, for a user to answer.

3.1.61 *readability*—the ability to understand the message imparted by printed material, characters, numbers, or other visual information from a visual display.

3.1.62 *remote-handling system*—the equipment (for example, manipulators, viewing devices, and other aids) that permits personnel to extend their capabilities into remote environments.

3.1.63 *scrolling*—an orientation for display framing in which the user conceives of data as moving behind a fixed display frame. The opposite of panning.

3.1.64 *seat reference point (SRP)*—the point at which the center line of the seat back surface (depressed) and seat bottom surface (depressed) intersect. When the seat is positioned at the midpoint of the adjustment range(s), this intersection point is called the neutral seat reference point.

3.1.65 *signals*—a secondary, nonessential, advisory, or call indication. (Call is a request for contact, assistance, or action from one location to another.)

3.1.66 *sound pressure level (SPL)*—the pressure of an acoustic wave; usually expressed in decibels (dB), equal to 20 times the logarithm to the base 10 of the ratio of the effective root-mean-square (rms) pressure of this sound to the reference pressure, as follows:

$$SPL = 20 \log_{10} \frac{P}{20\ \mu Pa} \quad (2)$$

where:

P = the effective (rms) sound pressure in micropascals (μPa) or micronewtons per square metre ($\mu N/M^2$). (20 μPa = 20 $\mu N/M^2$ = 0.0002 microbar = 0.0002 dynes/cm^2.

3.1.67 *source documents*—user's documents, which are a source of data eventually processed by the computer program, such as target lists, supply codes, parts lists, maintenance forms, bills of lading, and so forth.

3.1.68 *spatial relationship*—the placement of controls, displays, and their related equipment so that it is visually obvious to an operator or maintainer that all components of a particular system are related. Further, when controls and displays are used for identical equipments or systems located in different parts of the same compartment, or in different compartments, the controls and displays shall be placed in the same location in respect to the equipments or systems at each installation. Consoles and overall work stations shall be designed and placed so the individual controls and displays on the consoles or work stations are arranged, as viewed by the operator facing the console or work station, in the same spatial arrangement as is the actual equipment being controlled or monitored at the console or work station.

3.1.69 *special tools*—tools not listed in the Federal Supply Catalog or meet the requirements of 3.1.75.

3.1.70 *speech intelligibility*—a measure of the percent of words, phrases, or sentences correctly understood over a given speech communication system in a given noise situation. It may be measured, when complying with this practice, by using either the phonetically balanced Monosyllabic Word Intelligibility Test or the Modified Rhyme Test (MRT), or may be calculated by the Articulation Index (AI).

3.1.71 *speech interference level (SIL)*—a measure of the effectiveness of noise in masking speech, defined as the arithmetic average of the same pressure levels of the interfering noise (in decibels re 20 μPa) in the four-octave bands centered on the frequencies 500, 1000, 2000, and 4000 Hz, respectively. The unit of speech interference is the decibel.

3.1.72 *speech signal processing*—the modification of the electrical signal representing speech to enhance the capability of a speech communications channel. Some examples are simple analog processing, Automatic Gain Control (AGC), frequency shaping, peak clipping, and syllabic compression.

3.1.73 *speech spectrum*—a segment of the range of audible frequencies containing the sounds of speech; defined as approximately the range from 80 to 8000 Hz.

3.1.74 *speech-to-noise ratio (peak speech to rms noise)*—the ratio between the arithmetic mean of peak amplitudes of speech and the root-mean-square (rms) amplitude of background noise.

3.1.75 *standard tools*—standard tools (normally hand tools) used for the assembly, disassembly, inspection, servicing, repair, and maintenance of the equipment, and which are manufactured by two or more recognized tool manufacturing companies and are listed in those companies' catalogs.

3.1.76 *string*—in the user's context, a word, phrase, or number (string of characters) in the text or file. Normally used in the context of causing the computer to search for, find, or replace a desired "string."

3.1.77 *text entry*—initial entry and subsequent editing of textual material, typified by messages.

3.1.78 *transaction*—an action by a user followed by a response from the computer. The term is used here to represent the smallest functional "molecule" of user-computer interaction.

3.1.79 *transillumination*—light passed through, rather than reflected off, an element to be viewed, for example, illumination used on console panels or indicators using edge or backlighting techniques on clear, translucent, fluorescent, or sandwich-type plastic materials.

3.1.80 *visibility*—the ability to see a visual display from its surrounding background.

3.1.81 *warning signal*—a signal that alerts the operator to a dangerous condition requiring immediate action.

3.1.82 *wet bulb globe temperature (WBGT)*—an index of the stress incorporating, as a major element, the evaporative cooling available to a natural wet bulb thermometer and calculated as follows:

$$WBGT = 0.7TWB_{np} + 0.2T_g + 0.1T_a \quad (3)$$

where:

TWB_{np} = nonpsychometric (np) wet-bulb (*WB*) temperature,

T_g = temperature at interior center of a 15.2-cm (6-in.) black globe, and

T_a = nonpsychometric, but shaded, dry bulb (air) temperature.

—In the absence of a radiant heat source (solar, engine, furnace, and so forth), a modified wet-dry (*WD*85) index shall be used where:

$$WD85 = 0.85TWB_{np} + 0.15T_a \quad (4)$$

4. Significance and Use

4.1 *Objectives*—Vessels, systems, and equipment shall provide work environments that foster effective procedures, work patterns, and personnel safety and health, and that minimize factors which degrade human performance or increase error. Design shall be such that operator workload, accuracy, time constraint, mental processing, and communication requirements do not exceed the operator's physical or mental capacities. Design shall also minimize personnel and training requirements within the limits of time, cost, and performance tradeoffs.

4.2 *Standardization*—Controls, displays, marking, coding, labeling, and arrangement schemes (equipment and panel layout) shall be uniform for common functions of all equipment. One criterion for selecting off-the-shelf commercial or government equipment shall be the degree to which the equipment conforms to this practice. Where off-the-shelf equipment requires modification to interface with other equipment, the modification shall be designed to comply with the criteria herein. Redesign of off-the-shelf equipment shall have the approval of the procuring activity.

4.3 *Function Allocation*—The design shall reflect allocation of functions to personnel, equipment, and personnel-equipment combinations to achieve the following:

4.3.1 Required sensitivity, precision, time, and safety.

4.3.2 Required reliability of system performance.

4.3.3 Minimum number and level of skills of personnel required to operate and maintain the system.

4.3.4 Required performance in a cost-effective manner.

4.4 *Human Engineering Design*—The design of vessels, systems, and equipment shall include the human engineering, life support, and biomedical design criteria, when applicable, contained in this practice to provide the following:

4.4.1 Satisfactory atmospheric conditions including composition, pressure, temperature, and humidity, and also safeguards against uncontrolled variability beyond the limits contained herein.

4.4.2 Acceptable limits of acoustic noise, vibration, acceleration, shock, blast, impact forces, and safeguards against uncontrolled variability beyond the safe limits defined in this practice.

4.4.3 Protection from thermal, toxicological, radiological, mechanical, electrical, electromagnetic, pyrotechnic, visual, and other hazards.

4.4.4 Space for personnel, their equipment, and free volume for the movements and activities they are required to perform during operation and maintenance tasks under both normal and emergency conditions.

4.4.5 Physical, visual, auditory, and other communication links between personnel, and between personnel and their equipment, under both normal and emergency conditions.

4.4.6 Efficient arrangement of operation and maintenance workplaces, equipment, controls, and displays.

4.4.7 Natural or artificial illumination for the performance of operation, control, training, and maintenance.

4.4.8 Safe and adequate passageways, hatches, ladders, stairways, platforms, inclines, and other provisions for ingress, egress, and passage under normal, adverse, and emergency conditions.

4.4.9 Provision of acceptable personnel accommodations including body support and restraint, seating, rest, and sustenance, that is, food, water, and waste management.

4.4.10 Provision of nonrestrictive personal life support and protective equipment and clothing.

4.4.11 Provisions for minimizing psychophysiological stress effects of mission duration and fatigue.

4.4.12 Design features to ensure rapidity, safety, ease, and economy of operation and maintenance in normal, adverse, and emergency maintenance environments.

4.4.13 Satisfactory remote handling provisions and tools.

4.4.14 Emergency systems for contingency management, escape, survival, and rescue.

4.4.15 Compatibility of the design, location, and layout of controls, displays, workspaces, maintenance accesses, stowage provisions, and passenger compartments with the clothing and personal equipment (C/PE) to be worn by personnel operating, riding in, or maintaining all systems or equipment. Task allocation and control movements shall be compatible with restrictions imposed on human performance by C/PE.

4.4.16 Compatibility of control/display interfaces and procedures with human information processing capability, decision-making effectiveness, and the limits of short-term memory, long-term memory, and computation skill.

4.4.17 Immediate, accurate, and pertinent feedback to the operator of equipment or system performance after each control movement or other action taken by the operator.

4.5 *Fail-Safe Design*—A fail-safe design shall be provided in those areas in which failure can disable a vital system or cause catastrophe through damage to equipment, injury to personnel, or inadvertent operation of critical equipment.

4.6 *Simplicity of Design*—The equipment shall represent the simplest design consistent with functional requirements and expected service conditions. Where practical, it shall be capable of operation, maintenance, and repair in its operational environment by personnel with a minimum of training.

4.7 *Interaction*—The design of the system shall reflect the interaction requirements of crew-served equipment.

4.8 *Safety*—Design shall reflect applicable system and personnel safety factors, including minimization of potential human error in the operation and maintenance of the system, particularly under the conditions of stress.

4.9 *Ruggedness*—Systems and equipment shall be sufficiently rugged to withstand handling during operation, maintenance, supply, and transport within the environmental limits specified for those conditions in the applicable hardware or system specification.

4.10 *Design for NBC and Other Contaminated Environment Survivability*—As applicable, equipment design shall be compatible with NBC and other contaminated environment protection and shall permit performance of mission-essential operations, communications, maintenance, resupply, and decontamination tasks by suitably clothed, trained, and acclimatized personnel for the survival periods and NBC or other environments required by the system. Equipment design shall also facilitate contaminated environment hardness surveillance and shall minimize susceptibility to reduction of inherent contaminated environment hardness as a result of errors or damage induced by maintenance or operator personnel.

4.10.1 NBC or other contaminated environments hardness shall be easily verifiable by maintenance personnel before and after maintenance actions (hardness surveillance).

4.10.2 NBC or other contaminated environments hardness shall not be degraded when routine (scheduled) and corrective (unscheduled) maintenance are performed.

4.10.3 Maintenance of the equipment's inherent NBC or other contaminated environments hardness shall not be dependent on maintenance personnel expertise and critical alignments/maintenance actions.

4.11 *Design for Electromagnetic Pulse (EMP) Hardening*—As applicable, equipment design shall be compatible with EMP-hardening requirements, including personal accommodations such as EMP-hardened electrical power outlets and antenna lead-ins within EMP-hardened facilities or spaces. Access shall be provided to EMP-hardened facilities or spaces without the need to open doors or hatches which form part of an electromagnetic barrier protecting the space. Items such as surge arrestors, terminal protection devices, and filters, which form part of an electromagnetic barrier for protection against EMP effects, shall be accessible.

5. Control/Display Integration

5.1 *Control/Display Relationship*—The relationships of a control to its associated display and the display to the control shall be immediately apparent and unambiguous to the operator. Controls shall be located adjacent to (normally under or to the right of) their associated displays and positioned so that neither the control nor the hand normally used for setting the control will obscure the display.

5.2 *Control/Display/Equipment Relationships*—Where controls and displays (such as a motor controller and gage board) are associated with a specific piece of equipment (for example, a pump, filter, heater, and so forth) and the controls or displays are located for local operation of the equipment, they shall be located above, or immediately adjacent to, the equipment so that it is visually obvious that all of the components are functionally related. Where other design considerations or where a deliberate choice is made to place the controls and displays remote from the equipment which precludes this preferred location, the controls and displays shall be mounted in such a manner that the relationship of location of the controls and displays matches the arrangement of the equipment to which they belong. Controls and displays used on identical systems located in different locations in the same compartment, or in different compartments, shall be located in the same spatial relationship to the equipment in each compartment. Figs. 2-5 illustrate these principles.

5.3 *Design*—Control-display relationships shall be apparent through proximity, similarity of groupings, coding, framing, labeling, and similar techniques.

5.4 *Complexity and Precision*—The complexity and precision required of control manipulation and display monitoring shall be consistent with the precision required of the system.

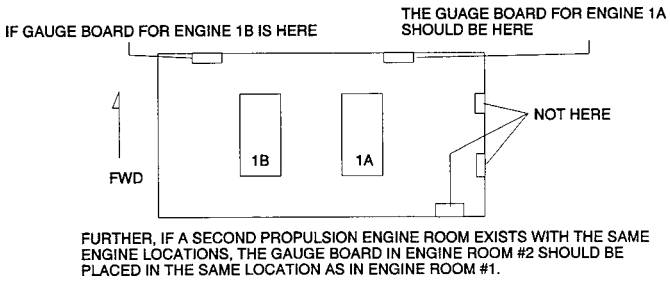

FIG. 2 Example of Display/Equipment Relationship in Main Propulsion Engine Room with Two Medium-Speed Diesel Engines

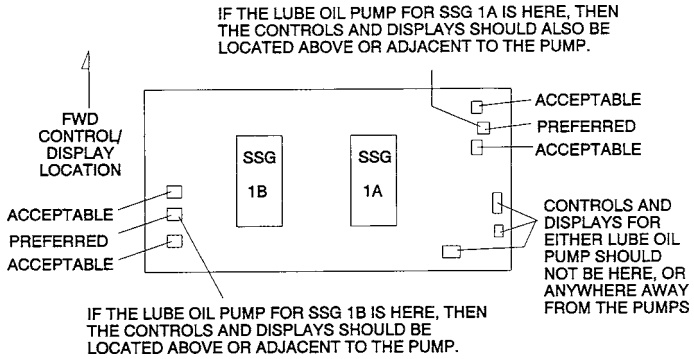

FIG. 3 Example of Control/Display/Equipment Relationship in Auxiliary Machinery Space with Two-Ship Service Generators

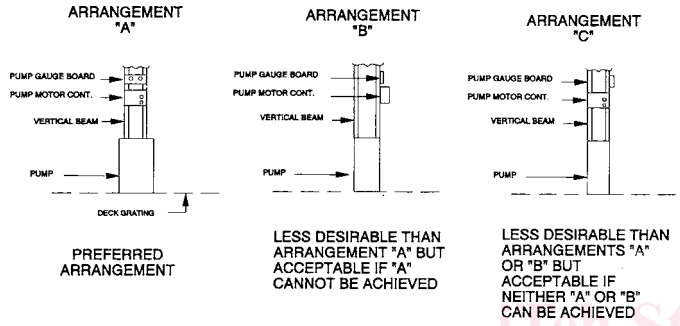

FIG. 4 Example of Control/Display/Equipment Relationship in Machinery Space with Pump, Motor Controller, and Gage Board Located at Vertical Beam

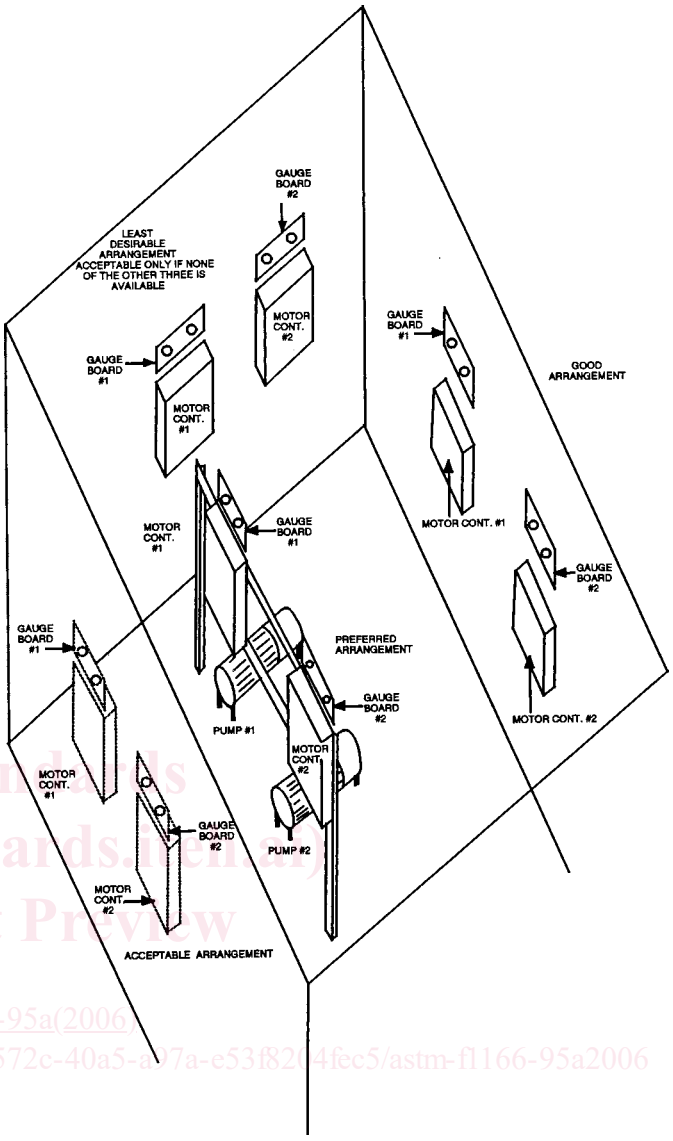

FIG. 5 CHT Pump Room with Various Options for Locating the Two Motor Controllers and Their Corresponding Gage Boards Given the Location of the Two Pumps

Control/display complexity and precision shall not exceed the capability of the operator (in terms of discrimination of display detail) or exceed the operator's manipulative capability under the dynamic conditions and environment (in terms of manual dexterity, coordination, or reaction time) in which human performance is expected to occur.

5.5 *Feedback*—Feedback on control response adequacy shall be provided as rapidly as possible. For keyboards, feedback shall be provided to the operator before entry to ensure that the keyed entry is, in fact, errorless and the one that the operator desires to enter.

5.6 *Illumination*—Adjustable illumination shall be provided for visual displays, including display, control, and panel labels and critical markings, that must be read at night or under darkened conditions.

5.7 *Simultaneous Access*—If more than one crew member must have simultaneous access to a particular group of controls or displays to ensure proper functioning of a system or subsystem, the operator assigned to control and monitor a particular function or group of related functions shall have physical and visual access to all controls, displays, and communication capability necessary to perform assigned tasks adequately.

5.8 *Position Relationships*:

5.8.1 *Functional Grouping*—Functionally related controls and displays shall be located in proximity to one another and arranged in functional groups, for example, power, status, test.

5.8.2 *Functional Group Arrangement*:

5.8.2.1 *Sequence*—Functional groups of controls and displays shall be located to provide for left-to-right (preferred) or top-to-bottom order of use, or both.

5.8.2.2 *Access*—Providing that the integrity of grouping by function and sequence is not compromised, the more frequently used groups and the most important groups shall be located in areas of easiest access. Control-display groups required solely for maintenance purposes may be located in positions providing a lesser degree of access relative to operating groups.

5.8.2.3 *Functional Group Marking*—Functional groups may be set apart by outlining with contrasting lines that completely encompass the groups. Color numbers in this paragraph are in accordance with FED-STD-595. Where such coding is specified by the procuring activity, and where gray panels are used, noncritical functional groups (those not associated with emergency operations) shall be outlined with a

1.5-mm (1⁄16-in.) black border (27038), and those involving emergency or extremely critical operations shall be outlined with a 5-mm (3⁄16-in.) red border (21136). As an alternate method, contrasting color pads or patches may be used to designate both critical and noncritical functional areas, subject to prior approval by the procuring activity. When red compartment lighting is used, an orange-yellow (23538) and black (27038) striped border shall be used to outline functional groups involving emergency (hazardous or potentially hazardous conditions requiring immediate attention) or extremely critical operations.

5.8.2.4 *Consistency*—Location of recurring functional groups and individual items shall be similar from panel to panel. Mirror image arrangements shall be used only with the approval of the procuring activity.

5.8.3 *Location and Arrangement*—Whenever an operator must use a large number of controls and displays, their location and arrangement shall be designed to aid in determining which controls are used with which displays, which equipment component each control affects, and which equipment component each display describes.

5.8.4 *Arrangement Within Groups*—Controls and displays within functional groups shall be located according to operational sequence or function, or both.

5.8.4.1 *Left-to-Right Arrangement*—If there is more than one row of displays, and their corresponding controls cannot be located under each display, or placed in the same row arrangement under the displays as the displays are arranged, then the controls shall be located as shown in Fig. 6.

5.8.4.2 *Vertical and Horizontal Arrays*—If a horizontal row of displays must be associated with a vertical column of controls or vice versa, the farthest left item in the horizontal array shall correspond to the top item in the vertical array, and so forth. However, this type of arrangement shall be avoided whenever possible.

5.8.4.3 *Simultaneous Use*—A visual display that must be monitored concurrently with manipulation of a related control shall be located so that the operator is not required to observe the display from an extreme visual angle and thus introduce the possibility of parallax error.

5.8.4.4 *Multiple Displays*—When the manipulation of one control requires the reading of several displays, the control shall be placed as near as possible to the related displays and preferably beneath the middle of the displays, but not to obscure displays when manipulating the control.

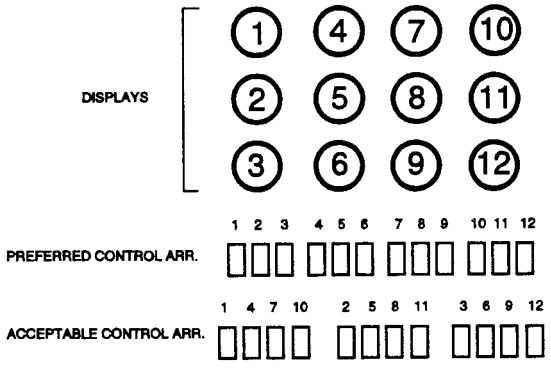

FIG. 6 Preferred and Acceptable Alternatives for Multiple Row/ Column Display and Control Arrangement

5.8.4.5 *Combined Control*—When separate displays are affected by a combined control (for example, concentrically ganged knobs), the display shall be arranged from left to right with the combined control underneath the center of the displays, but not to obscure displays when manipulating controls.

5.8.4.6 *Separate Panels*—When related controls and displays must be located on separate panels and both panels are mounted at approximately the same angle relative to the operator, the control positions on one panel shall correspond to the associated display positions on the other panel. The two panels shall not be mounted facing each other.

5.8.4.7 *Component Groups*—When a group of equipment components has the same function, the related control and display positions shall be oriented to correspond to those of the controlled and monitored components. (For example, the position of propulsion engine controls shall be oriented as if the operator faces the normal direction of vessel movement.)

5.8.4.8 *Emergency Use*—Emergency displays and controls are those associated with a hazardous or potentially hazardous condition that requires immediate action to prevent injury to the crew or damage to the ship. They shall be located where they can be seen and reached with minimum delay (for example, warning lights within a 30° cone about the operator's normal line of sight; emergency control close to its related warning display or the nearest available hand in its nominal operating position).

5.9 *Movement Relationships*:

5.9.1 *Lack of Ambiguity*—Display indicators shall clearly and unambiguously direct and guide the appropriate control response. The response of a display to control movements shall be consistent, predictable, and compatible with the operator's expectations.

5.9.2 *Time Lag*—The time lag between the response of a system to a control input and the display presentation of the response shall be minimized, consistent with safe and efficient system operation.

5.9.3 *Moving Pointer Circular Scales*—Clockwise movement of a rotary control or movement of a linear control forward, up, or to the right shall produce a clockwise movement of circular scale pointers and an increase in the magnitude of the reading.

5.9.4 *Moving Pointer Linear Scales*—Clockwise movement of a rotary control or movement of a linear control forward, up, or to the right shall produce a movement up or to the right for horizontal and vertical scale pointers and an increase in the magnitude of the reading.

5.9.5 *Fixed Pointer Circular Scale*—Displays with moving scales and fixed pointers or cursers shall be avoided. When circular fixed-pointer, moving-scale indicators are necessary, clockwise movement of a rotary control or movement of a linear control forward, up, or to the right shall normally produce a counterclockwise movement of the scale and an increase in the magnitude of the reading.

5.9.6 *Fixed Pointer Linear Scale*—When use of vertical or horizontal fixed pointer, moving-scale indicators is necessary, clockwise movement of an associated rotary control or movement of a linear control forward, up, or to the right shall normally produce a movement of the scale down or to the left and an increase in the magnitude of the reading.

5.9.7 *Direct Linkage*—When there is a direct linkage between control and display (for example, radio frequency selector and station pointer), a rotary control shall be used if the indicator moves through an arc of more than 180°. If the indicator moves through an arc of less than 180° a linear control may be used, provided that the path of control movement parallels the average path of the indicator movement and that the indicator and control move in the same relative direction.

5.9.8 *Common Plane*—Controls shall be selected so that the direction of movement of the control will be consistent with the related movement of an associated display, equipment component, or vessel.

5.9.9 *Parallel Movement*—Direction-of-movement relationships shall be adhered to when control and display are parallel in line of movement.

5.9.10 *Labeling*—When control-display relationships specified herein cannot be adhered to, controls shall be clearly labeled (in accordance with Section 27) to indicate the direction of control movement required.

5.9.11 *Movement Direction*—When a rotary control and a linear display are in the same plane, the part of the control adjacent to the display shall move in the same direction as the moving part of the display.

5.10 *Control Display Movement Ratio*:

5.10.1 *Minimization of Time*—Control display ratios for continuous adjustment controls shall minimize the total time required to make the desired control movement (slowing time plus fine adjusting time), consistent with display size, tolerance requirements, viewing distance, and time delays.

5.10.2 *Range of Display Movement*—When a wide range of display element movement is required, small movement of the control shall yield a large movement of the display element. When a small range of display movement is required, a large movement of the control shall result in small movement of the display, consistent with final accuracy required.

5.10.3 *Knob, Coarse Setting*—When a knob is provided for making coarse display element settings on linear scales (0.4- to 2.5-mm (0.016- to 0.100-in.) tolerance), an approximately 150-mm (6-in.) display element movement shall be provided for one complete turn of the knob.

5.10.4 *Knob, Fine Setting*—For fine setting on linear scales (0.2- to 0.4-mm (0.008- to 0.016-in.) tolerance), a 25 to 50 mm (1 to 2 in.) of display element movement shall be provided for one complete turn of the knob.

5.10.5 *Bracketing*—When bracketing is used to locate a maximum or minimum rather than a specific value (for example, as in tuning a transmitter), the control knob shall swing through an arc of not less than 175 mrad (10°) nor more than 525 mrad (30°) either side of the target value to make the peak or dip associated with that value clearly noticeable.

5.10.6 *Lever, Coarse Setting*—When a lever is provided for coarse settings (0.4- to 2.5-mm (0.016- to 0.100-in.) tolerance), one unit of display element movement shall be used to three units of lever movement.

5.10.7 *Lever, Two-Dimensional Setting*— When a lever is provided to make settings in two dimensions to coarse tolerances (2.5 mm (0.100 in.)), one unit of display element movement shall be used to two and one-half units of lever movement.

5.10.8 *Counters*—When counters are provided, the control-display ratio shall be such that one revolution of the knob produces approximately 50 counts (that is, the right hand drum rotates 5 times).

6. Visual Displays, General Information

6.1 *General*—Visual displays shall be used to provide the operator with a clear indication of equipment or system conditions for operation under any eventuality commensurate with the operational and maintenance philosophy of the system under design.

6.2 *Alerting/Warning*—An alerting/warning display shall provide the operator with a greater probability of detecting the triggering condition than normal observation would provide in the absence of the display.

6.3 *Display Illumination and Light Distribution*:

6.3.1 *Display Illumination*:

6.3.1.1 *Normal*—When maximum dark adaptation is not required, low-brightness white light (preferably integral and adjustable as appropriate) shall be used; however, when complete dark adaptation is required, low-level illumination shall be accomplished by use of gray filter sleeves over the lamps. The white light transmittance through the sleeves shall be either 5.0, 2.5, or 1.0 %.

6.3.1.2 *Night Vision Device Compatibility*— When night vision devices will be worn or used by the operator(s), display illumination color shall be low-density blue-green light (incandescent filament through a high-pass filter with a 600-nm cutoff). The color selected shall provide the operator(s) with the capability to obtain required display information rapidly and accurately with unaided eye vision or via viewing with the night vision device. The color selected shall also provide the operator(s) with the ability to obtain required display information rapidly and accurately during any daylight condition. The lighting shall be continuously variable to the full OFF position. In the OFF position, no current shall flow through the lamps.

6.3.1.3 *Field Use Panel Dimming*—When control or annunciator panels will be viewed by personnel out of doors at night, maximum panel illumination shall be provided when a dimming rotary control is at its extreme clockwise rotation. Maximum illumination is that in accordance with 32.9. No current shall be provided to luminaries at extreme counterclockwise rotation of a dimming control. Panel light levels shall be continuously variable from 0.1 cd/m^2 (0.03 fL) near OFF to 3.5 cd/m^3 (1 fL) at 50 % of clockwise rotation.

6.3.2 *Light Distribution*—Where multiple displays are grouped together, lighting shall be balanced across the instrument panel such that the mean indicator luminances of any two instruments shall not differ by more than 33 % across the range of full ON to full OFF. Light distribution shall be sufficiently

uniform within an integrally illuminated instrument such that the ratio of standard deviation of indicator element luminances to mean indicator luminance shall not be more than 0.25, using eight or more equally spaced test measurements.

6.3.3 *Contrast*—Sufficient contrast shall be provided between all displayed information and the display background to ensure that the required information can be perceived by the operator under all expected lighting conditions.

6.4 *Information*:

6.4.1 *Content*—The information displayed to an operator shall allow the operator to perform the intended mission, but shall be limited to that which is necessary to perform specific actions or to make decisions.

6.4.2 *Precision*—Information shall be displayed only within the limits and precision required for specified operator actions or decisions.

6.4.3 *Format*—Information shall be presented to the operator in a directly usable form. Requirements for transposing, computing, interpolating, or mentally translating into other units shall be prohibited.

6.4.4 *Redundancy*—Redundancy in the display of information to a single operator shall be avoided unless it is required to achieve specified reliability.

6.4.5 *Combining Operator/Maintainer Information*—Operator and maintainer information shall not be combined in a single display unless the information content and format are well suited to, and time is compatible for, both users.

6.4.6 *Display Failure Clarity*—A method shall be provided to determine if a display or circuit has failed.

6.4.7 *Display Circuit Failure*—Failure of the display circuit shall not cause a failure in the equipment associated with the display.

6.4.8 *Unrelated Markings*—Trademarks and company names or other similar markings not related to the panel function shall not be displayed on the panel face or on the displays.

6.4.9 *Duration*—For signals or displays that frequently or consistently change their outputs, the information displayed shall have durations of sufficient length to be reliably detected under expected operator workload and operational environment.

6.4.10 *Timeliness*—Displays, such as cathode ray tube displays, requiring refreshed information shall be updated in a synchronous manner, and be refreshed to a degree of timeliness required by personnel in the normal operating or servicing mode.

6.4.11 *Advisory and Alerting*—Displays such as multifunction displays, cathode ray tube displays, and other visual display devices displaying simultaneous and integrated information shall advise or alert operating personnel to information that becomes critical within the display.

6.4.12 *NBC Contamination*—As applicable, display characteristics (for example, clarity, legibility) shall be compatible with viewing while wearing an NBC or other protective mask. Displays or indicators that show the presence of NBC or other environmental contamination agents shall also show when such agent concentrations decrease to safe levels.

6.4.13 *Numeric Digital Displays*—Numeric digital displays shall not be used as the only display of information when trends in display change or perception of a display pattern is required of the operator. Numeric digital displays shall not be used when rapid or slow digital display rates inhibit perception of the display.

7. Location and Arrangement of Visual Displays

7.1 *Location*—Displays, including sight fill tubes on tanks, shall be located and designed so that they may be read to the degree of accuracy required by personnel in the normal operating or servicing positions without requiring the operator to assume an uncomfortable, awkward, or unsafe position. Dual gages providing an IN and OUT reading (that is, suction and discharge, voltage in and out, and so forth) shall be arranged so that the gage with the IN reading is on the left (preferred) or top, and the gage with the OUT reading is on the right (preferred) or bottom, unless the IN and OUT displays are a part of a system mimic that does not permit this arrangement.

7.2 *Access*—Visual displays shall be visually accessible from the normal work position without requiring the operator to stand on equipment components, handrails, wireways or wireway supports, or nearby pipes (especially if they are insulated). Flashlights or other special equipment shall not be required to read the display. No display shall require the removal of a cover (that is, sheathing, deck plate, and so forth) or any other component to be visible, unless the display is noncritical and a clearly marked quick access door is provided. Where possible, the access door shall be of transparent material. Light-emitting diodes (LEDs) used on PC boards inside consoles for calibration or troubleshooting shall be visible from the maintainer's normal work position once the console doors or maintenance access openings are open.

7.3 *Orientation*—Displays, such as thermometers, pressure gages, and so forth, that are attached directly to a pipe shall be mounted so they are read upright, or turned no more than 90°, from the upright position. Displays located immediately adjacent to walkways shall not be located lower than 460 mm (18 in.) above the deck to prevent them from being kicked and broken, unless the display face is protected by a nonbreakable transparent material. Armored sight gages shall be oriented so the sight gage is directly visible from the normal work position.

7.4 *Reflection*—Displays shall be constructed, arranged, and mounted to prevent reduction of information transfer as a result of the reflection of the ambient illumination from the display cover. Reflection of instruments and consoles in windows and other reflective enclosures shall be avoided. If necessary, techniques (such as shields and filters) shall be used to ensure that the system performance will not be degraded. Sight gages that contain clear liquid shall have a color backing so as to provide a color contrast between the liquid and the color backing to make the liquid more visible in the gage.

7.5 *Vibration*—Vibration of visual display shall not degrade user performance below the level required for mission accomplishment (see 32.13).

7.6 *Grouping*—All displays necessary to support an operator activity or sequence of activities shall be grouped together.

7.7 *Function and Sequence*—Displays shall be arranged in relation to one another according to their sequence of use or the

functional relations of the components they represent. They shall be arranged in sequence within functional groups, whenever possible, to provide a viewing flow from left to right or top to bottom.

7.8 *Frequency of Use*—Displays used most frequently shall be grouped together and placed in the primary visual zone in accordance with Fig. 7 and Fig. 8.

7.9 *Importance*—Important or critical displays shall be located in the primary visual zone or otherwise highlighted.

7.10 *Consistency*—The arrangement of displays within a system shall be consistent from application to application.

7.11 *Maximum Viewing Distance*—The viewing distance from the eye reference point of the seated operator to displays located close to their associated controls shall not exceed 635

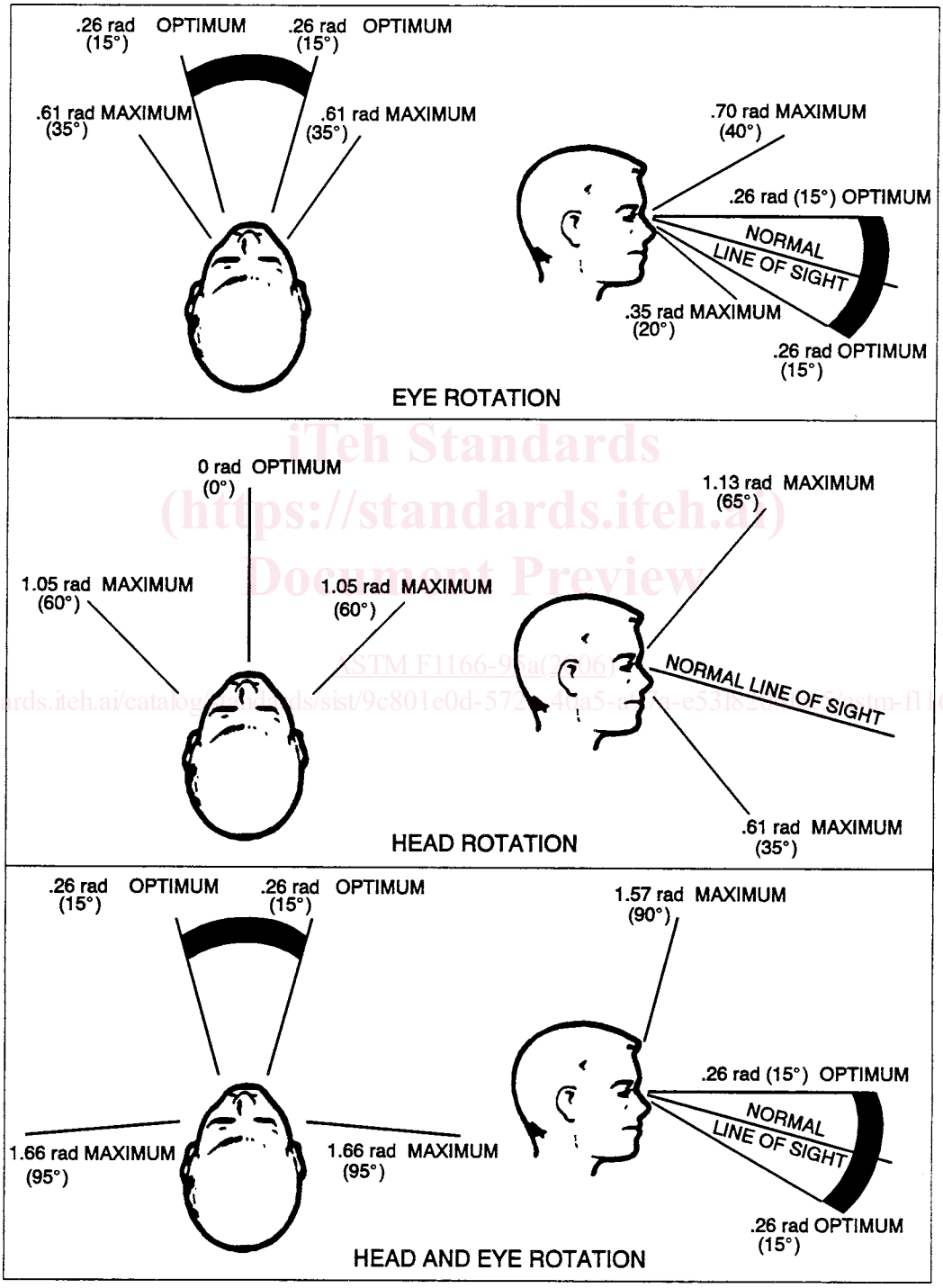

FIG. 7 Vertical and Horizontal Visual Field

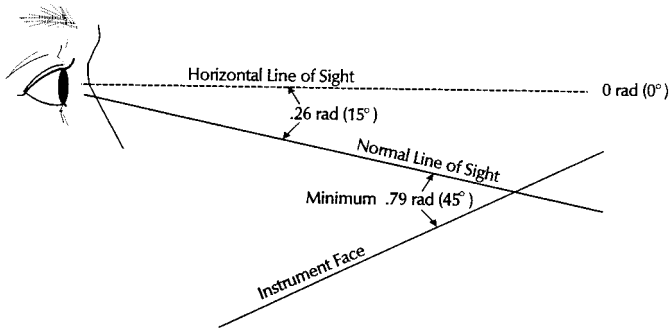

FIG. 8 Lines of Sight

mm (25 in.). Otherwise, there is no maximum limit other than that imposed by legibility limitations, which shall be compensated for by proper design.

7.12 *Minimum Viewing Distance*—The viewing distance from the operator's eye to the face of the displays, with the exception of cathode ray tube displays and collimated displays, shall never be less than 330 mm (13 in.) and preferably not less than 510 mm (20 in.).

8. Coding of Visual Displays

8.1 *Objectives*—Coding techniques shall be used to facilitate discrimination between individual displays, identification of functionally related displays, indication of relationship between displays, and identification of critical information within a display.

8.2 *Techniques*—Displays shall be coded by color, size, location, shape, or flash coding, as applicable.

8.3 *Standardization*—All coding within the system shall be uniform and shall be established by agreement with the procuring activity.

9. Transilluminated Displays

9.1 Three general types of transilluminated displays that may be used include the following: single- and multiple-legend lights, which present information in the form of meaningful words, numbers, symbols, and abbreviations; simple indicator lights; and, transilluminated panel assemblies, which present qualitative status or system readiness information.

9.2 *Use*—Transilluminated indicators shall be used to display qualitative information to the operator requiring either an immediate reaction by the operator or to draw attention to an important system status. Such indicators may also be used occasionally for maintenance and adjustment function.

9.3 *Equipment Response*—Lights, including those used in illuminated push buttons, shall display equipment response and not control position (that is, a lighted ON push button for a pump means that the pump is running, not that the control has been pushed).

9.4 *Information*—Lights and related indicators shall be used sparingly and shall display only that information necessary for effective system operation.

9.5 *Positive Feedback*—Changes in display status shall signify changes in functional status rather than simply indicate that a control has been activated (for example, a lighted VALVE CLOSED indicator shall signify that the valve is actually closed, not that the VALVE CLOSED control has been activated). The absence or extinguishment of a signal or visual indication shall not be exclusively used to denote a malfunction, no go, or out-of-tolerance condition; however, the absence of a power on signal or visual indication shall be acceptable to indicate a power-off condition for operational displays only—not for maintenance displays. The absence or extinguishment of a signal or visual indication shall not be used to indicate a ready or in tolerance condition, unless the status or caution light filament and its associated circuitry can be easily tested by the operator and operator perception of such events is not time critical.

9.6 *Grouping*—Master caution, master warning, master advisory, and summation lights used to indicate the condition of an entire subsystem shall be discriminable from the lights which show the status of the subsystem components, except as required under 9.9.

9.7 *Location*—When a transilluminated indicator is associated with control, the indicator light shall be so located that it can be associated with the control without error and shall be visible to the operator during control operation. When a transilluminated indicator is used in conjunction with a meter or readout as an indication of an out-of-tolerance condition (such as, a LOW PRESSURE lighted annunciator associated with a pressure meter), it shall be placed directly above the meter. Other arrangements are permissible with the approval of the procuring activity.

9.8 *Location, Critical Functions*—For critical functions, indicators shall be located within 265 mrad (15°) of the operator's normal line of sight (as shown in Fig. 8). Warning lights shall be an integral part of, or located adjacent to, the lever, switch, or other control device by which the operator is to take action, or placed as defined in 9.7.

9.9 *Maintenance Displays*—Indicator lights used solely for maintenance and adjustment shall be covered or nonvisible during normal equipment operation, but shall be readily accessible when required.

9.10 *Luminance*—The luminance of transilluminated displays shall be compatible with the expected ambient illuminance level, and shall be at least 10 % greater than the surrounding luminance. Where glare must be reduced, the luminance of transilluminated displays shall not exceed 300 % of the surrounding luminance.

9.11 *Luminance Control*—When displays will be used under varied ambient illuminance, a dimming control shall be provided. The range of the control shall permit the displays to be legible under all expected ambient illuminance. The control shall be capable of providing multiple-step or continuously variable illumination. Dimming to full OFF may be provided in noncritical operations, but shall not be used if inadvertent