NUREG/CR-1580

Human Engineering Guide to Control Room Evaluation

Draft Report

I - Control Room Evaluation Process
II - Human Engineering Guidelines

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Prepared by
K. Mallory, S. Fleger, J. Johnson, L. Avery, R. Walker, C. Baker, T. Malone

The Essex Corporation
333 N. Fairfax Street
Alexandria, VA 22314

Prepared for
Division of Human Factors Safety
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

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PREFACE

Task I.D, Control Room Design, of NUREG-0660, the NRC Action Plan Developed as a Result of the TMI-2 Accident, specifies that the Commission's Office of Nuclear Reactor Regulation will require that operating reactor licensees and applicants for operating licenses perform a detailed control room design review to identify and correct design deficiencies. This review will include an assessment of control room layout, the adequacy of the information provided, the arrangement and identification of important controls and instrumentation displays, the usefulness of the audio and visual alarm systems, the information recording and recall capability, lighting, and other considerations of human factors that have an impact on operating effectiveness. Prior to the initiation of the detailed reviews, NRR will formulate design review guidelines to be used by each licensee and applicant to assist in the identification of design weaknesses. A contract was awarded to the Essex Corporation to develop the review guidelines.

The following two-part report prepared by the Essex Corporation is a draft version of the guidelines to be used in the detailed control room reviews. The guidelines and procedures of this report were based on human factors evaluations of nine nuclear power plant control rooms. As implied by the title, the report is a suggested set of guidelines and procedures for control room evaluation, and as such does not directly address all of the design review factors specified in Task I.D of NUREG-0660. The report is issued at this time for public review and comment, and these comments plus results of an internal NRC review will be used to prepare the Commission's final design review guidelines. These final guidelines will be issued as NUREG-0700.

Some material not applicable to control room design review (e.g. guidelines for procedure content, operator training) has been omitted from the Essex report as submitted to the NRC. This material will be used in other NRC reports and guidelines dealing with human factors issues not related to control room design. Other modifications and revisions planned at this time include the addition of material addressing the remainder of the Task I.d issues, such as guidelines to support task analyses to determine if the control room provides adequate plant status information to the operator. We also expect that the format will be revised to simplify application of the guidelines and procedures to a control room design review.

Comments on these draft guidelines are requested from the following:

- Federal Agencies with expertise in human factors analysis
- Electric Utilities
- Architect/Engineer Organizations
- Nuclear Industry Service Organizations
- Human Factors Analysts
- Interested members of the public

All comments will be considered in developing the final control room design review guidelines.

Single copies of these draft guidelines may be obtained by writing the:

Director, Division of Technical Information and
Document Control
Office of Administration
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Mr. Richard Froelich is the NRC Task Manager for these guidelines. Should there be specific questions regarding the guidelines or their content, Mr. Froelich may be contacted by calling (301) 492-8442 or by writing to the following address:

Division of Human Factors Safety
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555
ATTN: R.W. Froelich

V. A. Moore

V. A. Moore, Acting Deputy Director
Division of Human Factors Safety
Office of Nuclear Reactor Regulation

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FOREWORD

This document contains guidelines for a human engineering evaluation of nuclear power plant control rooms. These guidelines are intended to help in identifying potential human engineering problem areas in control room design, documentation, and operations and should not be construed to be NRC standards, criteria or regulations.

Part I suggests a procedure for applying the guidelines (Part II) to uncover potential human engineering problems, and for identifying critical problems by estimating the impact of the potential problems on safe control room operations. This procedure is suggested and should not be considered as an NRC requirement.

It should be recognized from the outset that hardware or procedures that fail to meet one or more of the guidelines are not necessarily in violation of NRC criteria or regulations. Only where operator performance of a safety-related task could be jeopardized should the hardware or procedure problem be considered serious.

Many of the guidelines in Part II can be applied to control room design. However, many human engineering guidelines addressing design issues, and not evaluation, have been intentionally omitted from this document.

Finally, these guidelines and evaluation procedures were validated on nuclear power plants that were operating or ready for licensing prior to May, 1980. Thus, these guidelines and procedures may not be completely appropriate or sufficient for plants of a later vintage.

The Essex Corporation
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I

CONTROL ROOM EVALUATION PROCESS

1.0 INTRODUCTION

1.1 General

From the point of view of control room evaluation, human engineering seeks to locate and remove causes for operator error. While this definition depicts only a small part of the general discipline of human engineering, it focuses on the primary thrust of the information presented in the two volumes of this Guide — namely, to provide a means to locate and remove causes for operator error in nuclear power plant control rooms.

Many studies have been performed which attempt to quantify the effect of human error on nuclear power systems' safety and reliability. Results show that 15 to 66 percent of plant safety failures are attributable to human failure. For example, IEEE Spectrum (1) reports some of these findings to be: a) "Between 1/2 and 2/3 of hypothesized reactor accidents are caused by human error," b) "20 to 50 percent of all LER failures are due to human error;" c) "About half of the accidents that lead to any release of radiation are caused by human error;" and d) "In about one percent of the LERs (examined by the investigators), or about 35 a year, there are indications that a safety feature has been severely compromised or made unavailable by human error." Further, a report issued by the Aerospace Corporation (2) states that "personnel errors constitute 15 to 20 percent of all reportable occurrences in a nuclear power plant." Lastly, according to a report based on WASH 1400 (3), human errors in nuclear power plants present one of the most significant potential risks to public health.

Research has also been performed on the effects of human error on power plant outages. Results of these studies are in general agreement that upwards of 20 percent of plant outages are caused or contributed to by operator error (4). Representative statements include: "The single most important cause of the July 13, 1977, power failure was the failure of the system operator to take the necessary action," (5) and "A study of major power system disturbances found that human factors problems either initiated or compounded about 20 percent of the events" (6).

Reviews of nuclear power plants have repeatedly demonstrated that most of the control rooms designed prior to the TMI-2 accident were not in compliance with human engineering standards and principles (2, 7, 8, 9). Based on extensive military and aerospace experience with complex systems, operator error will be reduced if control panels and procedures are brought into agreement with human engineering practices. The procedures (Volume I) and guidelines (Volume II) that make up this Guide will assist the user in determining which components, labels, procedures, etc. are at variance with *established* guidelines and provide a means to determine whether or not this variance is likely to result in a significant operator error.

As part of developing this Guide, nine control rooms were examined for compliance with a large sample of human engineering guidelines and to test the control room and evaluation process covered in Volume I. Since no human engineering standards had been developed specifically for the nuclear power plant control room applications, military and aerospace guidelines were used. In most cases, these guidelines appeared to be valid since they are applied quite successfully to systems containing the same types of operational requirements, components, personnel and procedures.

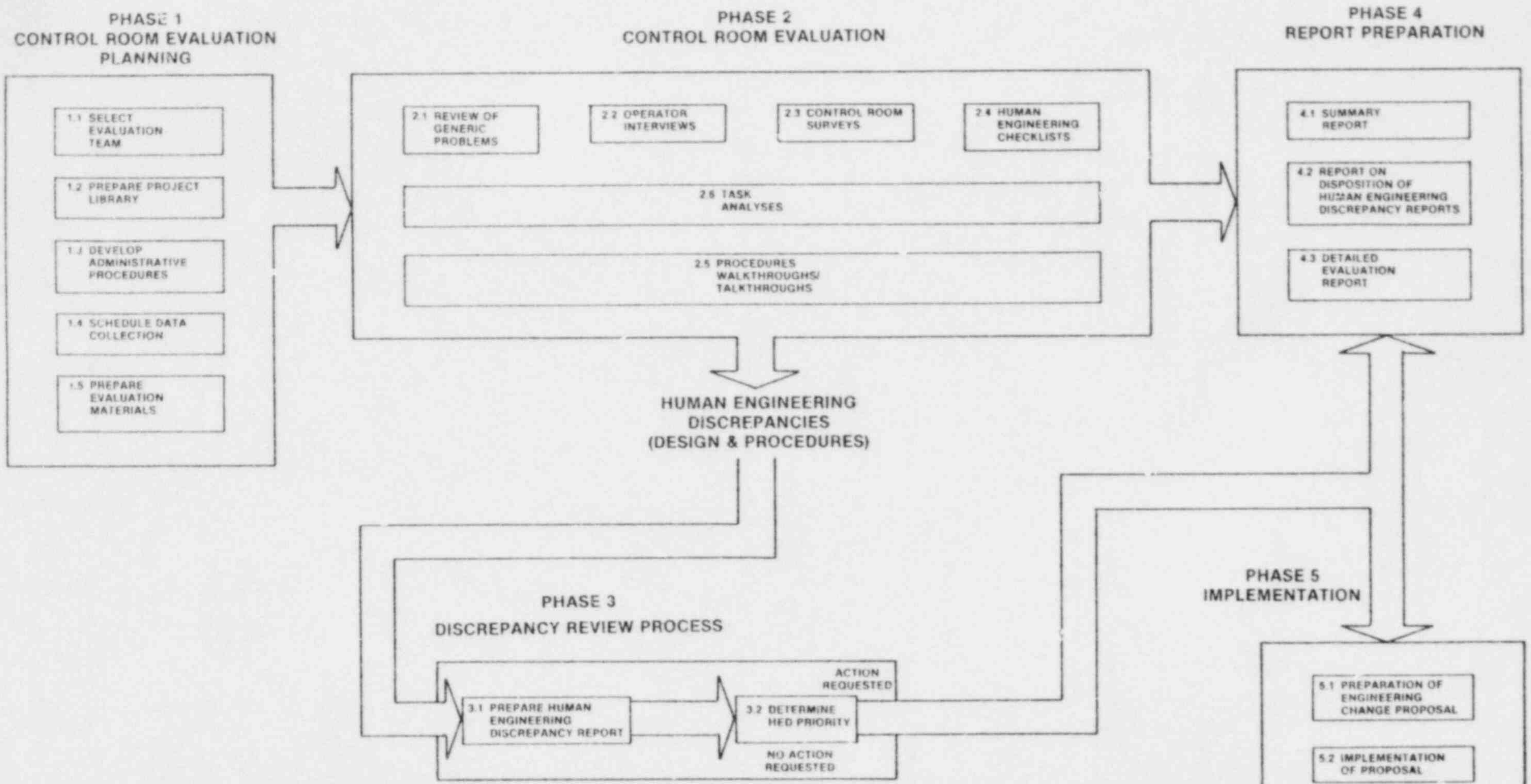
The control room evaluation process *suggested* in these volumes can be characterized in five steps (Figure I-1).

1. Plan the evaluation.
2. Locate *all* instances where the control room differs from the Human Engineering Guidelines.
3. Evaluate the impact of each instance on safety and reliability.
4. Prepare Evaluation Reports.
5. Develop means (engineering, procedures, etc.) to correct the high priority discrepancies.

The general objectives of each Phase are summarized below.

- Phase I
    - to gather all of the resources needed to complete the evaluation
    - to develop data collection and evaluation checklists, surveys, etc.
    - to schedule all subsequent activities and prepare management plans.
- Phase II
    - to locate and record all control room interfaces (e.g., controls, displays, labels) where design or operation do not meet human engineering guidelines
    - to suggest potential backfits.
- Phase III
    - to determine which of the interfaces cited in human engineering discrepancies have an impact on plant safety or reliability
    - to select most cost-effective backfits.

FIGURE 1-1. PROCESS FOR HUMAN ENGINEERING REVIEW OF NUCLEAR POWER PLANT CONTROL ROOMS



* TIMES ARE NOMINAL. CAN BE CHANGED TO FIT LICENSING, CR UTILIZATION OR OTHER SCHEDULE CONSTRAINTS.

- Phase IV
  - to prepare reports documenting the scope, methods, objectives and results of the review.
- Phase V
  - to implement control room backfits that correct high priority human engineering discrepancies.

As pointed out by an EPRI study (7), backfits for human engineering discrepancies do not necessarily involve hardware modifications. Demarcation lines, special emphasis markings, relabeling, special training, etc. are often satisfactory in lieu of moving components. This being the case, each guideline in Volume II contains a range of backfits that *might* be satisfactory, depending on the specific circumstances. In fact, each guideline in Volume II gives:

- The evaluation guideline itself
- The type of operator error that can result from violation of the guidelines (e.g., inadvertent switch actuation)
- The source for the guideline (e.g., MIL STD-1472B)
- Backfits that may be suitable for correcting discrepancies (e.g., Switch guarding)

When this Guide is applied throughout the nuclear power industry needs for revised or new guidelines or evaluation procedures will be discovered. Such needs should be referred to the Division of Human Factors Safety, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

1.2 Human Error as a Function of Control Room Design

During the development of these guidelines Essex conducted a human factors engineering evaluation at nine plants. These were:

Crystal River - Unit 3
Zion - Unit 1
Dresden - Unit 1
Dresden - Unit 2
Indian Point - Unit 2
Diablo Canyon - Unit 2
Sequoyah - Unit 1
Salem - Unit 2
North Anna - Unit 2

A number of design discrepancies were identified during these surveys. These discrepancies were categorized by the types of errors that they could be expected to cause or contribute to. The taxonomy of errors is based on the following general categories:

- Control errors — errors in activating controls
- Display errors — errors in reading displays
- Annunciator errors — errors in reading annunciators
- Labeling errors — errors in reading labels
- Procedural errors — errors in reading or following procedures.

The control room design features associated with general types of error are listed in Appendix I-c.

2.0 CONTROL ROOM EVALUATION PLANNING

Timely completion of a thorough human engineering control room evaluation can be aided by conscientious planning prior to actual data collection. Evaluation team members should be selected for the decisionmaking and judgmental skills as well as the technical knowledge and management status needed to identify, qualify, and correct human engineering discrepancies. A project library as well as data collection instruments (e.g., checklists) and instrumentation (e.g., video systems) tailored to the control room under review will be quite useful to the evaluation team. Finally, well-coordinated data collection schedules and administrative procedures for reviewing Human Engineering Discrepancy Reports (HEDs) prepared during data collection will help to assure that every man-system interface in the control room receives sufficient attention.

2.1 Select Evaluation Team

The first step in the CR evaluation process is to organize a team of technical specialists and managers. This team must be capable of performing a thorough job in the control room review and of making technically acceptable decisions with respect to prioritizing human engineering problem areas and developing acceptable backfits. The operator, through use of controls, displays and communications, interacts with virtually every plant system and organization; therefore, the evaluation team must be multidisciplinary. While human engineers can identify CR problem areas, engineering and operations personnel should participate in determining the priority of problems and in reviewing the technical and operational acceptability of backfits suggested by human engineers.

2.1.1 Objectives

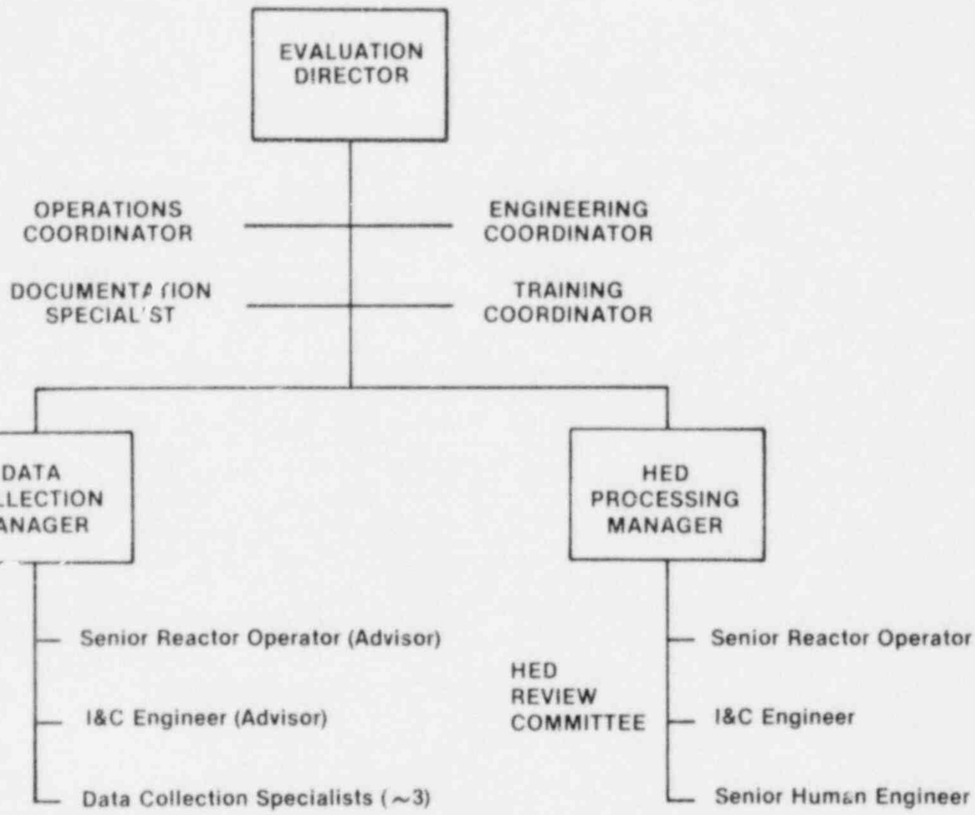
The objective of this first step in the evaluation process is to organize a multidisciplinary team capable of performing the control room human engineering evaluation.

2.1.2 Method

Before team members can be selected, the organization of the team must be specified along with the responsibilities (or functions) of each position in the organization.

Then, the qualifications for team members can be determined for each position. Figure 2-1 gives a typical organization with a sample of some position descriptions. A complete listing of descriptions for the positions named in Figure 2-1 can be found in Appendix I-a.

FIGURE 2—1
TYPICAL CONTROL ROOM EVALUATION MANAGEMENT PLAN



2.2 Prepare Project Library

Easy access to a variety of information sources will expedite the CR evaluation process, minimize dependence on memory and improve the quality of results with respect to plant safety.

2.2.1 Objectives

The result of this task will be a centralized project library suitable for use throughout all phases of the project by the entire project team.

2.2.2 Methods

The first step is to identify sources of information that might prove useful in identifying human engineering problems, prioritizing these problems, and evaluating backfits. Such a list might include:

- Licensee Event Reports
- System Descriptions
- Piping and Instrumentation Diagrams
- Procedures (emergency, operating, etc.)
- Software Descriptions
- Operator Comments on Panel Design
- Operator Training Materials and Aids.
- Final Safety Analysis Report
- Outage Analysis Reports
- Panel Layout Drawings
- Control Room Floor Plans
- Lists of Acronyms and Abbreviations
- Samples of Computer Printouts
- Annunciator Response Procedures
- Fault Trees and Failure Modes and Effects Analyses
- Photographs of Panel

2.3 Prepare Management Procedures

In many respects, the process and management organization presented in this Guide is only a framework or perhaps a point of departure for developing a specific organization and method for conducting the evaluation. Defining detailed data collection and HED review procedures at all levels of management will help to assure that each operator-control room interface is given adequate attention during evaluation, prioritization and backfit selection. Also, defining management procedures will help to clearly delineate the roles and responsibilities of each team member.

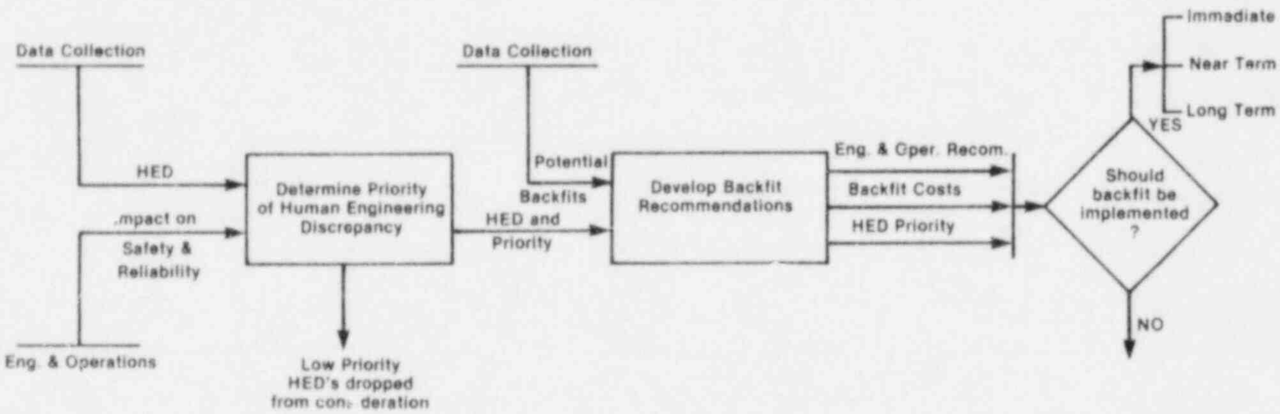
2.3.1 Objective

This step will produce a detailed flow chart of the entire human engineering review of the control room. Each function in the chart will be assigned to one position in the team organization (Figure 2-1).

2.3.2 Method

A time-based process for data collection and HED review should be designed for implementation by the evaluation team. This process identifies data collection; HED processing and reporting functions, decisions, the inputs to each function, the outputs from each function and the information needed to make each type of decision (Figure 2-2). The positions responsible for performing each function and decision will be identified.

FIGURE 2—2
EXAMPLE OF FUNCTIONS IN PLANNING PROCESS FLOW



2.4 Schedule Data Collection and Reporting Activities

Dovetailing evaluation activities with simulator and control room schedules will help to assure that all evaluation data are collected, processed and reported in a timely manner.

2.4.1 Objective

The goal of this task is to develop realistic schedules for all data collection, HED evaluation and reporting tasks to be performed throughout the evaluation.

2.4.2 Method

The flow chart prepared as a result of developing management procedures (2.3 above) provides the basis for the sequence of tasks to be scheduled. The time required to complete each task will depend on several factors, including:

- Number of man-system interfaces considered in the evaluation
- Number of personnel involved in data collection
- Human engineering guidelines considered to be applicable
- Numbers and types of situations and casualties considered in establishing HED priorities
- Amount of applied research performed in support of evaluation
- Breadth of procedural evaluations (e.g., emergency, abnormal, operational) as well as range of contingencies considered within each procedure.

The sequence and duration of tasks should be used in light of constraints to compile an end-to-end project schedule complete with milestones and specific responsibilities. Of course, scheduling constraints should be determined with respect to:

- Simulator availability
- Team commitments to other projects
- Control room scheduled and unscheduled activities.

Prior to revising the evaluation materials, a complete listing of all operator-control room evaluations should be made. One copy of the Human Engineering Evaluation Report (Appendix I-b) should be filed, by panel or procedures, for each interface. The surveys, checklists and walk-throughs contained in Appendix IV, V and VII respectively should be reviewed for applicability to the interface and recorded on the HEER as appropriate. Interfaces could be:

- Individual components
- Environmental characteristics
- Groups of components operated together
- Systems or subsystems
- Features of the control room layout, etc.

2.5 Preparation of Evaluation Materials

Prior to performing the control room data collection, certain steps should be taken to streamline the data collection process by tailoring the general methodology to the specific control room under review:

- Examine generic problems and operator interviews for applicability to control room
- Develop human engineering surveys and checklists matched to the systems, layout and components of the control room

- Prepare for walk-throughs of plant-specific procedures
- Select and acquire necessary instrumentation
- Initiate task analyses.

2.5.1 Development of Generic Problem Reviews and Operator Interviews

The first two steps in control room evaluation were selected to provide an immediate look at what could be some of the serious or more apparent human engineering problems. By comparing the control room design and operations to problem areas (called generic problems) characterizing a number of existing plants (Appendix II), some problems can be identified quickly for immediate action by the HED review committee (Section 2.1).

Operator opinion has been used widely as a design aid, and to identify engineering and procedure problems during operation. A rather extensive operator interview, included as Appendix III, assures that shortcomings known to the operators will be considered for backfit early in the process.

2.5.1.1 Objectives — The results of this task will be a list of generic problems and operator interviews directly related to the design and operation of the plant under review.

2.5.1.2 Methods — The list of generic problems (Appendix II) and the standard operator interview (Appendex III) should be reviewed by Instrumentation and Control Engineering and Operations Speciclists. During this review generic problems not related to the plant (if any) would be purged from the list, and inappropriate questionnaire items (if any) would be dropped or modified.

Generic problems and operator interviews should be revised, together with their instructions for use, for application during Data Collection.

2.5.2 Development of Surveys

The surveys combined in Appendix IV cover aspects of the control room not well suited to checklist evaluation. For example, noise, illumination, and use of design conventions throughout the control room.

Since surveys can be performed quickly to identify human engineering discrepancies, they are scheduled for early in the data collection phase.

2.5.2.1 Objectives — The objective of this task is to tailor the survey items to the specific configuration of the control room review.

2.5.2.2 Methods — While the sample surveys included in Appendix IV have been designed based on reviews of several plants, there may be some items that are inappropraite for a particular control room. Instrumentation and Control Engineers and Operations Specialists should recommend survey changes to the Data Collection Manager (Section 2.1). In turn, the Data Collection Manager should review, discuss and, where appropriate, implement these changes.

In some cases, the Data Collection Manager may be required to develop specific survey items (Figure 2-3) from the guidelines (Volume II).

2.5.3 Development of Checklists

Checklists are probably the most widely used tool for human engineering evaluation. When properly designed and systematically and thoroughly applied throughout the control room, checklists will enable the evaluator to pinpoint specific operator-control room interfaces that do not agree with the human engineering guidelines (Volume II). In turn, these discrepancies become candidates for backfits.

2.5.3.1 Objectives — The results of this task will be several checklists which, when applied collectively, thoroughly compare the control room to the guidelines in Volume II.

2.5.3.2 Methods — The checklist samples given in Appendix V will often serve "as is" for control room evaluations. However, to identify any inappropriate items, Instrumentation and Control Engineers and Operations Specialists should review all checklist items with respect to control room design and operator procedures. Figure 2-4 illustrates how to develop a checklist item from a guideline.

Some characteristics of a control panel component need be examined for only one component and then the results can be assumed for all components of the same type. For instance: handle dimensions, size of legend pushbuttons, size of lettering on switch position labels. For these parameters, one measurement on a typical component will suffice for the entire control room. Other measurements, such as the push force on a "Pull-to-Defeat" J-handle switch, may require several measurements of components to determine both the means and variance of the force across switches. Finally, many checklist items must be applied to every component of the type indicated. For instance, the distance between controls and related displays may change remarkably from control to control.

FIGURE 2-3 DEVELOPMENT OF SURVEY QUESTIONS FROM GUIDELINES

GUIDELINE

A. TITLE: CODING—WARNING, CAUTION ANNUNCIATORS

B. GUIDELINES: Objectives—Coding techniques shall be used to facilitate:

1. Discrimination between individual displays.
2. Identification of functionally related displays.
3. Indication of relationship between displays.
4. Identification of critical information within a display.

Techniques—Displays shall be coded by color, size, location, shape, flash rate, alphanumerics, brightness, motion, or inclination, as applicable.

1. Only one kind of information should be coded by one method. Compound coding for only one kind of information usually is less satisfactory than single coding if the single code used is the best available.
2. If two or more kinds of information are to be coded, the same number of coding methods should be used; do not use one coding method to code two or more kinds of information.

POTENTIAL SURVEY QUESTIONS

Are annunciators prioritized in some way? If yes, please describe.

Are annunciators grouped, say by system? If yes, please show arrangement.

Are annunciators above the system they monitor?

FIGURE 2-4 DEVELOPMENT OF CHECKLIST ITEMS FROM GUIDELINES

GUIDELINE

A. TITLE: TOGGLE SWITCHES AND PREVENTION OF INADVERTENT ACTIVATION—

B. GUIDELINES: When it is critical to prevent inadvertent activation of a toggle switch, a guard should be provided. This guard may be a lift-to-unlock mechanism, a safety cover or any equivalent method. If a lift-to-unlock mechanism is used, resistance should not exceed 48 oz. If a cover guard is used, its location should not interfere with the activation of the guarded control or any adjacent controls.

C. HUMAN ERROR: Inadvertent activation of a critical control, inability to activate a control within a given time limit.

D. DOCUMENTATION: 1472B (1974); 1472C (1980); Woodson (1964)

E. TYPICAL BACKFIT: Installing an appropriate guard, replacing a guard with appropriate guard.

POTENTIAL CHECKLIST ITEMS

TOGGLE SWITCHES

Evaluation Guidelines	Check
1. Are critical toggle switches provided with guards to prevent accidental activation? 2. Does the guard interfere with the activation of the guarded control or any adjacent controls?	

It is suggested that the basic arrangement of checklist items in Appendix V be maintained even if the contents are changed somewhat. This will minimize the time and effort required to complete the checklists.

2.5.4 Preparation of Procedures for Walk-Throughs

Surveys and checklists treat the engineering aspects of the control room. The operational aspects are examined through walk-throughs of emergency, abnormal and operating procedures using normal complements of trained and licensed operators. Operational features that can induce error include:

- The time between reading a meter and taking an appropriate action
- The number of personnel reading and sequencing actions
- The nature and structure of verbal (and nonverbal) communications between operators
- The sequence of operations with respect to panel arrangement.

The purpose of conducting videotaped procedures walk-throughs is threefold. One objective is to validate the completeness of task analyses of operating procedures. Another is to gain data on the use of particular control/display components during normal and emergency operations. The frequency and criticality of use will influence and validate the importance of human engineering discrepancies identified through the application of surveys, checklists and operator interviews. The third objective is to identify/tape procedural and operational factors which may lead to human error.

2.5.4.1 Objective — The purpose of this task is to select procedures, to develop casualty scenarios for emergency procedures to be used in walk-throughs, and to select operators for walk-throughs.

2.5.4.2 Method — Procedures selected for walk-throughs should include all emergency and abnormal procedures which require CR operator response as well as sample normal operation procedures. Normal operations sampled should include startup and shutdown procedures, specific systems operation procedures, and those operating procedures identified by operators (in the operator interview portion of this evaluation) as problematic.

Once procedures have been selected, scenarios should be developed for each procedure. For emergency procedures, scenarios should be developed where the operators' responses differ. For example: for a Loss of Coolant Accident procedure, scenarios should be developed which address actions taken during a small, slow leak; those taken during a large break; and, if the operator response differs, during a leak of intermediate size. For each set of automatic actions (for example, one set would be those automatic actions which occur any time a reactor trip occurs), at least one scenario should be developed which assumes that the automatic functions fail to actuate and the operator must take corrective manual action.

A team of operators must be selected to perform the walk-throughs. A full complement of operators should be chosen to represent normal staffing levels. This team should be composed of SRO and RO licensed personnel as would normally staff the CR, and should include experienced and knowledgeable operators.

2.5.5 Instrumentation Requirements

Human engineering evaluation of just about any complex system will involve some use of specialized instrumentation. Light levels, sound pressure levels, spot brightness, force and torque are frequently measured during an evaluation, since many human engineering guidelines are written with physical measurements as a basis.

2.5.5.1 Objective — The objective of this section is to provide the evaluation planner and conductor with guidance for selecting appropriate measuring instruments for the control room human engineering evaluation.

2.5.5.2 Method — Certain evaluation procedures require the physical measurement of a parameter. The control room evaluation planner should determine in advance what instruments are required and take steps to procure them. The following table (Table 2-1), in conjunction with the instrumentation paragraph of the specific procedures (Section 3.0), should be used to select the necessary instrumentation. The instrumentation should have been calibrated, if required, within the past year.

TABLE 2-1: INSTRUMENTATION FOR HFE EVALUATIONS

	Parameter to be Measured	Instrument Type	Range/Accuracy/ Characteristics
1.	Ambient Illumination	Photometer	1 to 300 ft. Candles
2.	Luminance Contrast	Spot Brightness Meter	1 to 300 ft. Lamberts; Focus Down to 1/2°
3.	Distance, Panel/ Room Dimensions	Tape Measure - Nonmetallic	Up to 20 feet
4.	Control Size, Separation	Ruler - Nonmetallic	Up to 5 inches
5.	Control Resistance (Force Required to Activate)	Spring Gauge (Push-Pull) Torque Gauge	Up to 5 lbs
6.	Control Displacement	Ruler - Nonmetallic Protractor	Up to 5 inches Up to 180°
7.	Sound/Noise Levels	Sound Level Meters	50 to 120 dB with Flat Response, A Weighting and C Weighting

2.5.6 Prepare and Develop Task Analyses

What specific information will the operator need and what control must be provided to maintain the systems and plant in balance? How much time do the systems allow the operator to collect information and make decisions? How many mental and physical tasks must be performed simultaneously?

These questions, and others, are answered through a process called "task analysis." While all of the evaluation's Data Collection Tasks should be performed by human engineering specialists, the task analyses must be performed by (or at least managed by) human engineers experienced in task analysis on complex systems.

2.5.6.1 Objective — The objective for developing task analyses of operator activities under emergency and normal operating conditions is to create a basis for the evaluation of panel and workspace layout. With a detailed analysis of all operator tasks and clearly defined performance requirements, design problems and potential human errors can be identified.

2.5.6.2 Method — Task analyses will be conducted on all emergency procedure operations and sample normal operations (hot startup, reduction in power, etc.). Control room operator functions will be listed in sufficient detail in a format like the sample form in Figure 2-5. Analyses will focus on the following characteristics:

a. Task — task designation

b. Activity — action(s) required by the operator to complete a task

c. Time — estimated or observed time required to complete each activity

d. Frequency (f) — frequency of each activity

e. Information — information required by the operator to complete an activity (i.e., signal to initiate activity, indication that activity is progressing as required, feedback that activity has been successfully completed)

f. Control — control capabilities required by the operator to complete the activity

g. Indication/Display — feedback of system response to operator actions

h. Concurrent/Shared tasks — tasks which must be performed simultaneously to the subject task or tasks requiring assistance from one or more other operators, including field operators

i. Potential errors — errors which may occur during the conduct of the activity (e.g., reading errors, control errors, sequence errors, etc.)

j. Error impact — affect of potential error on task or system performance.

Data required to complete task analyses will be collected using four complementary methods:

a. Review of emergency and normal operating procedures

b. Interviews with experienced control room operators

c. Review of videotaped walk-throughs of procedures

d. Where possible, observation of actual task performance.

An appropriate format should be selected which will insure complete and detailed data collection. The form provided in Appendix VI, or a similar form, is recommended. Experienced and knowledgeable operators should be selected and briefed on their role as

FIGURE 2-5 EXAMPLE OF CONTROL ROOM OPERATIONS TASK ANALYSIS

CR/UNIT: Nuclear Plant - 1

ANALYSTS: J. Smith, R. Brown

PROCEDURE: Loss of Secondary Coolant, EP-4

TASK	ACTIVITY	EST. TIME (MIN.)	f	INFORMATION/ COMMUNICATION REQUIREMENTS	CONTROL	INDICATION/ DISPLAY	CONCURRENT/ SHARED TASKS	POTENTIAL ERROR	ERROR IMPACT
Diagnose Condition	Recognize Symptoms	.5	1	Annunciators:					
				LO PRZR PRESS		PRZR PRESS	Task of diagnosis shared by ROs and SRO in CR	Incorrect diagnosis	Equipment damage
				LO PRZR LVL		PRZR LVL		Failure to take proper action	Loss of core integrity
				LO-LO REACTOR T-AVE		T-AVE			Inadvertent release of radioactivity
				HI CNTMT PRESS		CNTMT PRESS			
				HI CNTMT TEMP		CNTMT PRESS			
				HI CNTMT RECIRC SUMP LVL		STEAM FLOW			
				STEAM FLOW/FW FLOW MISMATCH		FW FLOW			
				LO STEAM LINE PRESS		STEAM LINE PRESS			
				LO SG WTR LVL		SG WTR LVL			
				HI STEAM FLOW		FW PUMP DISCHARGE PRESS			
				LO FW PUMP DISCHARGE PRESS					
Verify Reactor Trip	Check Reactor Trip indication, manually initiate if not activated	.5	1		Rod position control	Rod status indicators		Failure to verify incomplete automatic action	Failure to shut-down system
						Rod bottom lights			Loss of core integrity
						Reactor Trip annunciator			Inadvertent release of radioactivity

reviewers. Operators will be expected to verify the completeness of the data listed, supplying information regarding steps or information requirements not listed in the procedures. Operators will also provide information concerning potential human error and its affect on task or system performance. Potential error and its impact must be detailed for every operator action.

2.5.7 Photographic Support

2.5.7.1 Objective — The objective of compiling a photo log is twofold. First, it will provide the evaluation team with photographs for mockup construction and verification of control, display and panel configuration without physically returning to the control room. Second, it will provide a photograph for each Human Engineering Discrepancy Report. Photographs also offer a record of panel changes and corrective measures taken.

2.5.7.2 Instrumentation — The following camera equipment and supplies will be required for completion of the photo log:

- 35mm camera
- 50 to 55mm normal lens
- 24 to 28mm wide angle lens
- Tripods, one standard sized and one small (12" to 18" range)
- Tape measure
- One (1) inch stick on dots
- Film, Plus-X-ASA125-Black and White, and ASA400 Color Slide would be suitable.

2.5.7.3 Method — The control room photography should be performed in three phases. The first phase consists of general control room and generic problem photographs. The second phase consists of a detailed mosaic of the control room panels. The final phase consists of photographing an example of each Human Engineering Discrepancy Report. The photographer should shoot a test roll of each type of film to determine camera settings necessary to compensate for lighting peculiarities in the control room. The use of a flash is not recommended due to reflected glare. All items photographed should be shot in color and black and white except the mosaic. During the evaluation, every photograph and slide taken should have a designation to insure identification later. Each designation and subject matter should be logged into a master list of photographs. A method should be devised for storing, cataloguing and retrieving all negatives and photographs.

2.5.7.3.1 General Control Room and Generic Problems — Color slides should be taken in this phase which includes the following types of photographs:

- Control room panoramas
- Procedure and document storage facilities
- System and panel shots
- Items the operators report as problematic
- A sample of each type of control, display and label
- Any generic problems identified.

The slides should be taken from as close as possible. Visual cues such as hands, rulers and coins should be included in the slides to supply a size reference. If any control and display relationships are identified as problems, operators should be used to illustrate these problems. Any alteration, addition, or retrofit change to the control room during the course of the evaluation should be photographed, documented, and stored.

Photographs should be made documenting variations existing between control room and simulator panels (assuming plant specific simulator) or between panels of similar but not identical units.

2.5.7.3.2 Mosaic — The mosaic (used to support checklisting and HED evaluation) should be shot with black and white film, a tripod and a normal lens. The camera, during photography, should be kept perpendicular to the panel surface. All panels and systems normally used by the operator should be photographed. A grid of easy on and off dots should be applied at predetermined coordinates on the panel surface numbered as reference points for each mosaic segment. These should be placed about every 20" vertically and 24" horizontally. Each of the mosaic segment rectangles should be photographed with the dots well in the viewfinder to provide overlap. Each photograph should be logged into the master file. It is very important that every label in a segment photograph be readable. Once developed, the negatives should be printed full frame on 8" x 10" paper.

2.5.7.3.3 Human Engineering Discrepancy Reports — Near the end of the data collection phase, a photograph of each Human Engineering Discrepancy Report should be taken. The photograph should provide enough detail to clearly read all labeling and easily identify the nature of the problem. Once again, each photograph, when taken, should be entered into the master log.

3.0 CONTROL ROOM EVALUATION

The following sections detail the data collection procedures necessary for the control room HFE evaluation. The order of data collection methodology should be as follows: review of generic problems, operator interviews, surveys, checklists, and procedure walk-throughs. By followng this order, the evaluator can progress from a general understanding of the control room to a detailed understanding of each system and component. Also, human engineering discrepancies will be identified throughout the data collection process, thus enabling orderly prioritization and backfit decisionmaking.

3.1 Review of CR Design Against Generic Problems

A number of human engineering design and procedural problems have been identified as common throughout the industry (Appendix II). Comparing the control room to these generic problems will enable the reviewer to determine quickly whether some important aspects of control room design and operations are in agreement with the human engineering guidelines.

3.1.1 Objective

The objective of this review is to determine if the control room manifests human engineering shortcomings characteristic of same-vintage nuclear power plants.

The objective in reviewing the issues listed as generic industry problems is to p vide the reviewer with a point of reference; a broad, general review of the control room with emphasis on identifying major issues which are highly likely to occur based on reviews of same-vintage plants. Problems identified in the generic problem review should be given further scrutiny applying relevant surveys and checklists.

3.1.2 Method

Using the list of generic discrepancies in Appendix II, conduct a panel by panel and system by system review. Note by label or description, every control, display, equipment item or CR characteristic which violates human engineering practices listed in Appendix C. Complete a Human Engineering Discrepancy Report form for each and refer to appropriate guidelines for evaluative and backfit data.

3.2 Conduct Operator Interviews

The operator interview questionnaire is designed to solicit qualitative comments from control room operators. Those who operate the plant and interface with the control room on a day-to-day basis offer the best sources of identifying systems or components where human error does occur. Operators should provide information on design and operation problems in the CR as well as recommendations for improvement.

3.2.1 Objective

The objective of the operator interviews is to provide an opportunity for anonymous input regarding CR workspace and panel design. The questionnaires will document operator reports and the frequency with which a particular problem is reported.

3.2.2 Instruments

The Operator Human Engineering Questionnaire provided in Appendix III may be utilized as presented or revised (Section 2.5.1) to reflect specific concerns for the particular CR design.

3.2.3 Method

Every licensed operator employed by the plant should be interviewed individually concerning design and procedural problems impacting effective normal and safety plant operations.

Operators should be briefed before starting the questionnaires as to their content, purpose and use. More complete and objective responses will be received if participants are assured of anonymity.

Briefings should be conducted by personnel familiar with interview techniques and control room design. All comments should be recorded in writing, with the interviewer repeating the written comment for concurrence by the operator. The operator should be given as much time as needed to report each problem.

3.2.4 Data Reduction

Problems or potential for human error reported by operators should be listed by system, component, component type or environmental feature. A count should be made of the frequency with which each problem is reported and those reported by two or more operators should receive further review. Relevant checklists and surveys should be applied. The impact of human error, noted on a Human Engineering Discrepancy Report, should be recorded.

3.3 Control Room Survey Procedures

Control room surveys are performed for two purposes: to evaluate control room environmental features against human engineering guidelines; and to provide information required to complete the human engineering checklists (Appendix IV). Environmental surveys include Ambient Illumination and Noise. Design Convention and Emergency Garment Surveys provide baseline data to the checklists.

3.3.1 Noise Survey

3.3.1.1 Objective — The objective of this survey is to measure the ambient noise levels in the control room from various operator positions and to assess its impact on the operators' ability to verbally communicate and/or discriminate audible signals.

3.3.1.2 Instrumentation — The performance of this study requires the use of an appropriate sound level meter, selected to conform to the requirements established in Section 2.5.5.2.

3.3.1.3 Method — The performance of this evaluation requires the consideration of not just normal control room noise but any factors that can add to the overall noise level. Included in this are the occassional noises of very short duration that can cause high peak levels.

a. Noise Conditions — The noise survey should start with a basal noise level. This is the ambient noise without alarms, typers, or communications equipment contributing. Once this measurement has been taken, each potential noise source should be integrated into the ambient environment. The following are potential noise sources:

- Audible alarms
- Typers and printers
- Communications equipment (ringing telephones, P.A.s, radios)
- Emergency or atypical environmental control systems (air conditioning, exhaust fans)
- Loud conversation

- Adjacent control room alarms
- Open doors leading out of the control room.

b. Survey Conduct — Noise measurements should be taken at each operator position that requires verbal communication and/or auditory discrimination of a signal. This will include, at a minimum, the Reactor Operator's desk position, the Senior Reactor Operator's desk position, a point near the center of each panel/board, and any position at back panels requiring communication. Three measurements should be taken at each position, one with the microphone directed towards the major noise source, one with the microphone directed towards the panel surface and one with the microphone directed towards the furthest operator's position that would require communications. Measurements should be taken flat (dB), in A weighting (dB"A"), and in C weighting (dB"C"). Any instances of extreme peak values should be noted and the source located. The result for each position should be recorded on a form similar to Appendix IV-a. An example of a completed form is given in Table 3-1.

3.3.1.4 Data Reduction — The collected data should be compared to the appropriate guidelines contained in Volume II. Values that exceed the established limits should be noted and a Human Engineering Discrepancy Report should be completed.

3.3.2 Lighting Survey

3.3.2.1 Objectives — The objective of this evaluation is twofold. One is to measure the ambient illumination in the control room and to assess its impact on the operator's ability to read and interpret displays, controls, labeling, and printed matter such as drawings and procedures. The second is to measure the brightness of display and calculate the luminance contrast values to determine the adequacy of display lighting.

3.3.2.2 Instrumentation — The ambient illumination should be measured using an appropriate photometer. The display illumination measurements should be taken with an appropriate spot brightness meter. Both instruments should conform to the requirements established in Section 2.5.5.

3.3.2.3 Methods — The ambient lighting survey should be conducted under normal lighting and emergency lighting. The display illumination survey should be conducted under normal lighting. The analyst conducting the test should be aware that ambient

TABLE 3-1 NOISE SURVEY

PLANT: Nuclear Power — Unit 2	DATE: April 27, 1980	TIME: 3:30 p.m.
TEST CONDUCTED BY: B. Smith		
SOUND LEVEL METER MODEL: GenRad 1933 SERIAL NUMBER: 1546	MICROPHONE MODEL: GenRad 1865 SERIAL NUMBER: 1009	CALIBRATION DATE: Jan 2, 1980
OPERATOR POSITION: Vertical Board 3		

NOISE CONDITION/SOURCE/DIRECTION OF MEASUREMENT		dB	dB(A)	dB(C)	REMARKS
1. Basal Level	Towards Panel	65	60	62	
	Towards Benchboard	64	60	61	
2. Annunciator Alarm	Towards Annunciator Alarm	80	77	75	
	Towards Panel	76	72	74	
	Towards Benchboard	72	68	70	
3. Alarm Printers and Phones Ringing	Towards Printers	75	71	73	
	Towards Panel	74	68	69	
	Towards Benchboard	71	65	67	
4. Annunciators, CR2 Alarms, All Other Noise Sources	Towards Annunciators	83	80	78	
	Towards Panel	78	76	73	
	Towards Benchboard	76	73	70	

lighting, besides being too dim, can also be too bright. Dim light makes reading difficult. Lighting which is too bright can cause eye fatigue, reflected glare and poor display luminance contrast.

a. Test Conduct - Ambient Illumination — Measurement of ambient illumination should be taken at all operator positions. These positions should include, at a minimum, the following:

- Reactor Operator's work desk
- Senior Reactor Operator's work desk
- Each panel
- Each point where reading of printed material might be required
- Any area that is perceived as a potential problem.

These measurements should be taken for all positions selected under both lighting conditions. The light meter should be held about eye height and pointed first at the panel/desk and then a second reading should be taken with the meter pointed at the ceiling. If the position requires reading a specific type of printed material, this should be in place when the measurement is taken. The data should be recorded on a form similar to Appendix IV-b. A completed form is illustrated by Table 3-2.

3.3.2.4 Test Conduct - Display Illumination — The evaluator should assess which displays appear to be dim enough to warrant a measurement. The following are display types that may require measurement:

- Indicator and legend lights
- CRT (video) characters
- Projection display and light emitting diode (LED) characters
- Mimic lines that are illuminated.

The spot brightness meter should be placed so that the light source fills the required area (reticle) in the viewfinder. A reading should be taken, and then the reticle should be positioned on the surface adjacent to the display. Another reading should then be taken. Several readings should be taken over the surface of a CRT, projection and LED characters and mimic lines to verify uniformity of illumination. In addition to specific areas that appear dim, measurements should be taken from a wide selection of displays on the boards to provide an adequate sampling of the brightness of the control room displays. The measurements should be recorded on a form similar to Appendix IV-c. Table 3-3 provides a sample of a completed display illumination survey.

TABLE 3-2 AMBIENT LIGHTING SURVEY

PLANT: Nuclear Power — Unit 2	DATE: April 26, 1980		TIME: 11:00 a.m.
TEST CONDUCTED BY: M. Jones			
PHOTOMETER MODEL: Photo Research Serial Number: SERIAL NUMBER: FC-200		CALIBRATION DATE: July 9, 1980	

OPERATOR/MEASUREMENT POSITION	LIGHTING CONDITIONS		REMARKS
	NORMAL	EMERGENCY	
1. CC1 - Towards Board	65 FC	8 FC	
- Ceiling	69 FC	10 FC	
2. Back of CC2 - Towards Board	63 FC	7 FC	Drawing on Board
- Ceiling	69 FC	10 FC	
3. VB3 - Towards Board	67 FC	8 FC	Midpoint of Board
- Ceiling	69 FC	10 FC	
4. VB1 - Towards Board	51 FC	5 FC	Shadowed Vertical Meters (Meter Names)
- Towards Ceiling	67 FC	7 FC	
5. CC2 - Small Writing Surface			
- Panel	58 FC	11 FC	
- Ceiling	62 FC	15 FC	

3.3.2.5 Data Reduction — The data from Section 3.3.2.3 should be compared to the appropriate guidelines from Volume II. The data from Section (b) of 3.3.2.4 should be substituted in the following formula to calculate luminance contrast:

$$LC = \frac{L_1 - L_2}{L_1} \quad \text{where } L_1 = \text{Bright area and } L_2 = \text{Dark area}$$

The values should be compared to the appropriate guidelines in Volume II. If there are any deviations from the guidelines, a Human Engineering Discrepancy Report should be completed.

3.3.3 Design Conventions

Design conventions are rules used to standardize the operation of functionally identical interface between the operator and the control panels. For instance:

- Valve open = red; valve closed = green
- To close valve turn counter clockwise; to open valve turn clockwise
- "PRZR" always means "Pressurizer."
- Panel background color pink is used for reactor control
- Star handle rotaries are used for steam generator controls
- Vertical Displays = "level" indication.

The advantage of a design convention, of course, is that the operator can learn a fairly simple rule rather than memorize all of the operation of each interface covered by the rule. Thus, design conventions reduce the operator memory load substantially.

3.3.3.1 Objective — This survey will yield a listing of design conventions used in the control room. This listing will be used later in checklists to identify any interfaces that violate these rules.

3.3.3.2 Instrumentation — None.

3.3.3.3 Method — Using the survey form in Appendix IV-d, locate examples of controls, displays, labels, etc., and record their designs. Where design conventions appear to be used (most or all interfaces surveyed follow the same operational rules) the convention should be noted for use with checklists.

For a particular interface design rule to qualify as a convention, it is not necessary for the rule to be applicable throughout the control room. Some rules may apply only to

TABLE 3-3 DISPLAY LIGHTING SURVEY

PLANT: Nuclear Power — Unit 2	DATE: April 11, 1980	TIME: 7:30 a.m.

TEST CONDUCTED BY: P. Turner

SPOT BRIGHTNESS METER MODEL: SPECTRA UB-1
SERIAL NUMBER: 2631
CALIBRATION DATE: Jan 5, 1980

DISPLAY TYPES	LOCATION	BRIGHT AREA (L_t) (FT. LAMBERTS)	DARK AREA (L_d) (FT. LAMBERTS)	LUMINANCE CONTRAST
1. Simple Indicator (name of indicator)	SAF	8	3	0.63
2. Valve protection display	Computer Console			
- Top of Character (7)		7	5	0.29
- Midpoint		8	4	0.50
- Bottom		7	4	0.43
3. CRT Screen	Computer Console			
- Top Left		9	2	0.78
- Middle		8	2	0.75
- Bottom Right		9	3	0.67
4. Legend Light	SB-1			
- Bright is Right				
- Dim Phase		5	3	0.40
- Bright Phase		8	3	0.63
5. Annunciator Window	Above SB-2	11	5	0.55

one major panel (e.g., switch positions on radiation monitoring equipment), some to one or more systems (e.g., valve operations on NSSS) and others to a particular type of display (e.g., color coding of annunciators). While the universal convention is quite a powerful aid to the operator, the local convention is useful (to the extent that it embraces several interfaces, i.e., controls, displays, labels, etc.) even though the operator will be using different local rules when addressing other interfaces. Therefore, the panels, systems, etc., using a particular convention should be identified and noted.

3.3.3.4 Data Analysis — A matrix of design conventions x control panels should be prepared, and the conventions applicable to each panel (or subpanel, if necessary) checked off (Table 3-4).

TABLE 3-4

Design Convention Array

Convention	Panel 1	2	3	4	5	....	N
Vlv Open = Red	X	X		X			
Vlv Open CW	X	X		X			
Auto = White		X	X		X		

3.3.4 Emergency Garments

Most nuclear power plants provide some type of emergency garments for operator use, including perhaps protective clothing and breathing apparatus. Since operators must be able to don and use these garments during emergencies, it is necessary to review the time needed to don and any operational restrictions or problems associated with their use.

3.3.4.1 Objective — This task will yield information needed to complete the human engineering checklists. In general the results will indicate any problems in performing control room operations while using the protective clothing and/or breathing apparatus.

3.3.4.2 Instrumentation — Video tape recorder and camera to record garment donning and operation sequences.

3.3.4.3 Method — The detail survey procedures and data recording forms are given in Appendix IV-e. It would be best if this survey could be conducted in a simulator where the suited operators could perform selected procedures. If no simulator is available, standard measurements described in Appendix IV-e should be taken.

3.3.4.4 Data Analysis

a. Impact on Staffing — Based on Technical Specifications requirements, estimate the total number of man-minutes that will be dedicated to donning protective equipment before all operators are fully equipped. Subtract this number from the total number of man-minutes available during this period to arrive at the man-minutes dedicated to plant operations.

b. Speed of Operations — Based on simulations, estimate the percentage difference in time to complete operations with and without protective garments.

c. Human Error Factors — List and describe factors that might reduce operator reliability, for instance:

- Visibility of breathing apparatus face mask
- Tactile discrimination through gloves
- Speech impairment through face plate
- Hearing impairment (noise of breathing apparatus)
- Size of gloved hand (inadvertent actuation).

3.4 Checklist Procedures

The checklists described in Section 2.5.3 are the primary means for comparing panel design to established human engineering practices. The checklists contained in Appendix V incorporate the guidelines in Volume II appropriate to the subject (e.g., annunciators, rotary switches, process controllers, etc.).

3.4.1 Objective

The objective of completing the checklist is to compare the details of the control room design to the Human Factors Guidelines in Volume II. The detailed items contained in the checkists allow for a comprehensive evaluation from the system, panel and generic component level.

3.4.2 Instrumentation

Certain checklist items require that physical measurements be performed. Appropriate instrumentation should be selected from Table 2-1.

3.4.3 Methods

The completion of the checklists requires access to the control room, a basic familiarity with the control room and the systems being evaluated, and the assistance of a qualified operator. Certain checklists are more appropriate for the control room as a whole, others more appropriate on a panel or system level. The sample checklists from Appendix B that lend themselves to general control room evaluation are 1 through 6. Checklist 12 can be appropriate for both the general control room and specific panels or systems. The remainder of the checklist samples are appropriate for a panel system or component level evaluation.

Once the appropriate checklists have been selected, a packet of checklists should be made up for each panel or system to be evaluated. The checklists should then be completed in the following manner. The panel or system name, if appropriate, should be placed on each checklist. Then each checklist item should be considered. If the item does not apply, an "N/A" should be placed in the check column. If the item is complied with, a "yes" should be placed in the check column. If the item is not complied with, a "no" should be placed in the check column and the discrepancy should be described in detail in the notes column. The notes column should be used for any and all comments felt necessary or appropriate. Table 3-5 illustrates a completed checklist.

TABLE 3-5
SAMPLE CHECKLIST

HUMAN ENGINEERING CHECKLIST
— TYPICAL COMPONENT —

Vertical Indicators

Panel ______________ Date ______________

System ______________ Reviewer ______________

EVALUATION GUIDELINE	CHECK	REF.*	NOTES
1. Pointer extends to, but does not obscure, index marks			
2. Pointer mounted close to display surface			
3. Display readable without stooping, stretching			
4. Parallax avoided			
5. When off, pointer is off scale (not at zero)			
6. Displays labeled			
7. Displays readable from normal operating position			
8. Display covers do not produce excessive glare			
9. Scales indexed consistent with system requirements			
10. Are used to indicate levels			

* Guideline (Volume II) Page Number

The operator should be queried to elicit full information on the checklist items to determine whether there is compliance. For example, on item 9 above:

Human Factors Engineer: "Does the index on this scale provide you with information that is as accurate as you need?"

Operator: "Well, yes and no."

Human Factors Engineer: "What do you mean?"

Operator: "The nominal position for the pointer on this scale is 120 volts. This position actually means that the system is operating at 480 volts."

Human Factors Engineer: "This means that you must interpret the index?"

Operator: "That is correct."

If a checklist item is found to be inappropriate, this should be noted on the checklist and the checklist should be included in the completed data package. This will preclude later confusion. Every component, system, panel and operational grouping of components in the control room should be examined and compared to all relevant checklist items. This is an arduous process but it assures that most potential human factors engineering problems will be revealed.

3.4.4 Data Reduction

The checklists should be reviewed for discrepancies (items marked "no") and each of these should be compared to the relevant guidelines in Volume II. A Human Engineering Discrepancy Report should be completed for each item that does not comply with the guidelines.

3.5 Conduct Procedures Walk-Throughs

While all controls and displays in the control room are sufficiently important to be on the panels, some gain extra importance since they are used, perhaps frequently, in emergency operations. Operators are trained to know all of the displays and controls involved in performing procedures, but rarely do the written procedures contain a complete complement of all equipment used.

3.5.1 Objectives

Videotaped walk-throughs are to be conducted in order to document operator actions as they interface with the control room panel and layout during normal and emergency operations. The videotape will be used to identify and validate human engineering discrepancies in workspace and procedure design.

3.5.2 Instrumentation

For an authentic simulation of procedures, a plant-specific simulator presents the ideal situation. If a plant-specific simulator is not available, the walk-throughs should be performed in the control room.

As the walk-throughs are being performed they should be filmed or videotaped utilizing equipment which allows voice recording in sync with action. The camera used should be capable of close-up shots, enabling identification of specific controls and displays, and should be mobile enough to follow the operators' actions throughout the CR.

3.5.3 Method

The walk-throughs/simulation will be accomplished in three phases.

1. Prior to taping, have the control room operator describe the event to be simulated, indicating which systems will be involved and generally where action will take place on the panel. This will allow the camera operator and analysts to anticipate operator actions during the walk-throughs.
2. For the first taped walk-through, allow a full complement of operators to perform the procedural actions in as close to a real-time mode as possible. Be sure that one operator narrates the action, describing all controls/displays involved. Each control or display should be pointed out.
3. The second taped walk-through should be performed by one operator, step-by-step, describing all actions performed as part of the procedure. Each control or display should be pointed out, identified by label name and its use described (i.e., switch to the off position to the left; a rise in level indicated by an increase on the meter; valve closed, green indicator light on). Camera operator should interrupt to clarify which control/display is involved. Analysts should interrupt with questions on procedural actions, controls/displays, system response, etc.

To facilitate recordkeeping, on the outside of each tape, affix labels with identifying information (plant unit number, date of taping and sequential tape number). A form, such as the Procedures Walk-Through Log form in Appendix VII, may be used to log in procedure name and number, first or second taped walk-through, tape number and footage.

In taping, be sure to have the control room operator announce on tape which procedure is being performed prior to taping. Allow several feet of leader tape between walk-throughs.

3.5.4 Data Reduction

Videotapes will be reviewed against the results of the task analyses and any operator actions not identified in a procedures task analysis should be recorded, insuring completeness of the task analysis.

Human engineering discrepancies should be validated against the walk-throughs. For any component identified as discrepant, a count should be made for the number of times it is used in emergency operations, during immediate actions, supplementary actions and during normal operations procedures. Those used frequently and during immediate actions under emergency conditions will be more critical in evaluating human reliability.

A third review of procedures walk-through videotapes will yield identification of procedural and operational factors which may lead to human error. The following lists such factors:

- Vital communications — sent or received
- Accessibility of controls/displays
- Traffic pattern/panel operability
- Fidelity of procedure to CRO actions
- Steps performed at high speed
- Steps performed with timing requirements
- Comparison of two or more displays in rapid fashion
- Decisions based on multiple source inputs
- Displays monitored over prolonged periods
- Controls/displays being discriminated from among similar components
- Displays to be discriminated which change rapidly
- Actions taken with inadequate visual or verbal feedback specified
- Actions where error-resolution interrupts task performance.

Where such factors occur in the procedures, the controls/displays, and other equipment or components being operated are more likely to be involved in human error in operation. They should therefore receive further scrutiny via applicable surveys and checklists.

3.6 Conduct Task Analyses

The tasks that the Operators are required to perform when compared to their physical and cognitive capabilities, will define the displays and controls needed to maintain the plant in balance and to respond to emergency conditions. "Task analysts" can yield baseline requirements on:

- Staffing (number, type, team structure)
- Information display (type, rates)
- Control
- Task timing
- Training
- Procedures.

3.6.1 Objective

The purpose of developing a detailed task analysis for each emergency procedure and sample normal operations is to provide detailed documentation of all operator actions, information requirements, controls and displays used under these conditions. Through the task analysis, critical controls and displays, those used during emergency operations will be identified along with their sequence of operation and impact of potential operational error.

3.6.2 Instrumentation

The sample form illustrated in Section 2.5.6.2 and included in Appendix VI may be used to collect task analysis data. An alternative format may be used as long as it provides space for recording all the pertinent data.

3.6.3 Method

Data for the task analyses will be collected and recorded in the appropriate row or column.

a. Procedure — Procedure name and referencing/identifying number should be filled in completely.

b. CR and Unit — List plant name and unit number for complete recordkeeping.

c. Analyst — Analyst's name(s) should be noted.

d. Task — This column is used to identify the specific task to be accomplished. Entries in this column are to be ordered sequentially to enable the analyst to identify operational sequence.

e. Activity — Actual behavior/action performed by the operator is listed in this column. The analyst here describes what the operator must do to complete the task. The description should contain an action verb which adequately describes the operator's response (examples: monitors; actuates; verifies).

f. Est. Time (Min.) — Under this heading, the analyst records the estimated amount of time required for the operator to complete each activity. These data are useful in evaluating the ability of the system to operate within established time constraints.

g. f (Frequency) — In this column, the analyst records the number of times an activity is performed for each specific task.

h. Information/Communication Requirements — Under this heading, the analyst describes the information or communications needed to perform the task cueing the operator to take action. The stimulus may be annunciator alarms or other out-of-tolerance display indications, a signal from another operator, or any input indicating a need for control room operator response.

i. Control — In this column, the analyst enters the name or description of the control used for the activity. Precise labeling text should be used for clarity.

j. Indication/Display — Under this heading, the analyst describes the source of feedback available to the operator which indicates that the necessary system response has occurred. Again, precise labeling text should be used in listing displays.

k. Concurrent/Shared Tasks — Tasks that require more than one operator or are initiated by the control room operator but performed by field operators are described under this heading.

l. Potential Error — In this column, the analyst lists probable sources of error based on the type of response required of the operator and characteristics of the equipment used. Probable sources of error are referenced in the guidelines for each equipment type.

m. Error Impact — Under this heading, the analyst describes the effect of possible errors on the system or task performance.

Task analysis data collection will be conducted and validated in four phases, entering information on the form as described above.

1. For each emergency and sample normal operations proced re, record information in the appropriate colu on the data form. From the procedures, list tasks and operator actions. As they are provided by procedures, list also controls, displays and other information requirements for each task.

2. Experienced control room operators, as systems and subject experts, will be needed to fill in much of the remaining data, such as estimated time to perform a task; frequency of each activity; tasks performed concurrently or shared; potential errors; and error impact. Potential errors, as suggested by operators, should be checked against those listed in the guidelines for each component type involved. Operators will also provide information concerning tasks not included in procedures documents but performed by operators in the execution of the procedures.

3. A review of the videotaped walk-throughs should be used to validate steps listed as well as controls, displays and information requirement involved. The real-time simulation should substantiate estimated time requirements; if not, further evaluation is required.

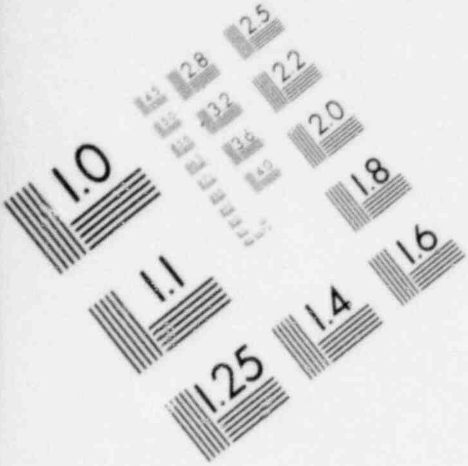
4. Where possible, observation of actual task performance is useful in validating information listed on the forms. This should be easily accomplished with normal operations such as startup or power reduction, but unlikely with operations generally contained in emergency procedures.

3.6.4 Data Reduction

Data generated by the task analysis will identify critical information and communication links (source and content) required by the operator. Control and display data will aid in the determination of the sufficiency of equipment provided the operator. The sequential ordering of the tasks and frequency of each activity will aid in determining the efficiency of workstation design and panel configuration. Those components utilized sequentially or simultaneously, frequently, or within constrained time periods, will be identified in the task analyses. If such components are not functionally grouped, the impact of potential error should be evaluated. If such error is likely and impact affects safety, a backfit to enhance human reliability is required. A Human Engineering Discrepancy Report should be completed for problematic control/display arrangements identified.

IMAGE EVALUATION
TEST TARGET (MT-3)

6"



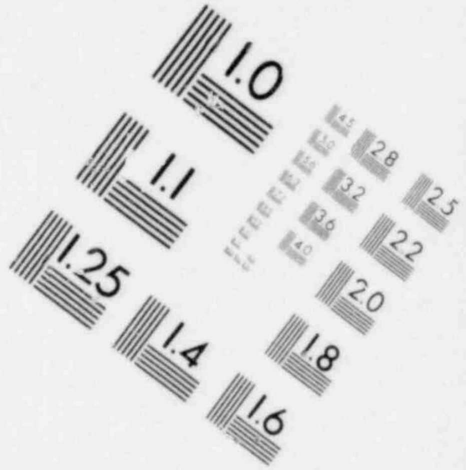
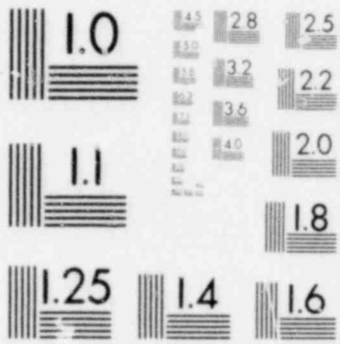
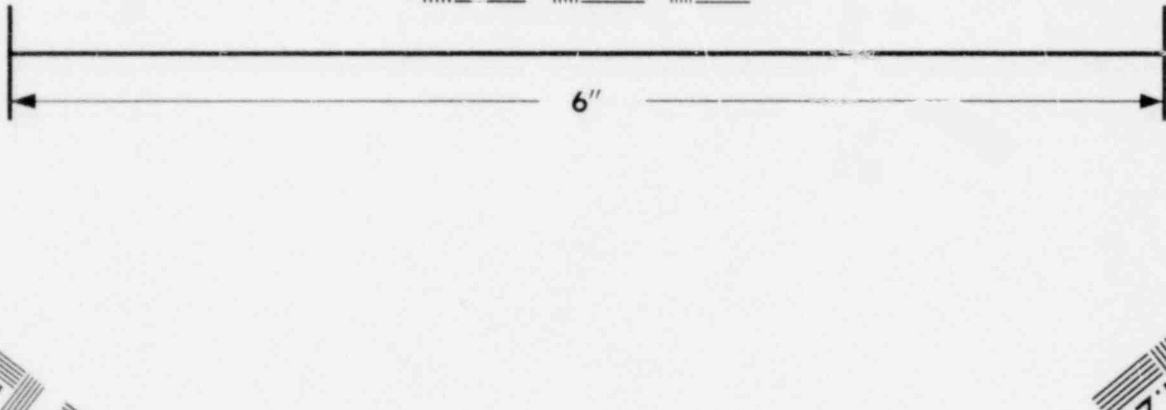
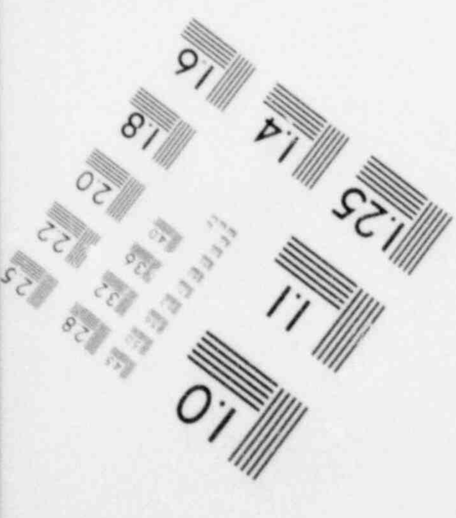
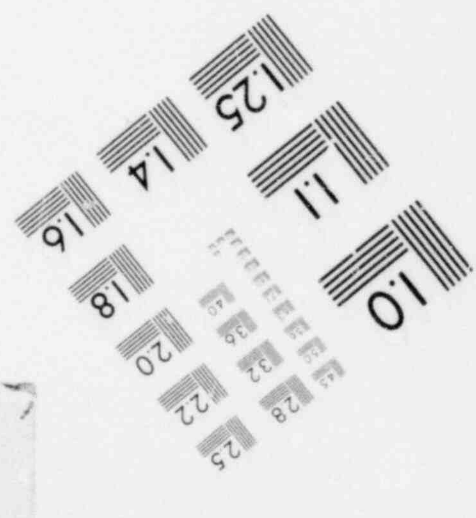


IMAGE EVALUATION TEST TARGET (MT-3)









4.0 EVALUATION OF HUMAN ENGINEERING DISCREPANCIES

As each of the several human engineering reviews progresses, some of the operator-control room interfaces reviewed will not meet the guidelines quoted in Volume II. Each of these discrepancies should be documented and reviewed with respect to its importance in plant safety (and, perhaps, reliability), and then, if of sufficient importance, backfit alternatives should be investigated.

4.1 Prepare Human Engineering Discrepancy Reports

Personnel involved in the Data Collection task (3.0) should be instructed to complete a Human Engineering Discrepancy (HED) form for each and every incidence where the control room design does not comply with human engineering guidelines. No attempt should be made during actual data collection to determine whether or not a particular discrepancy is sufficiently important to report.

HEDs should be completed for all discrepancies including environmental, layout, instrumentation, job design, procedures, etc.

4.1.1 Objective

The objective of this task is to provide complete and accurate documentation of all human engineering discrepancies in the control room; to anticipate the specific human errors that might result from the discrepancy; and to record the likely response of the plant systems to this error.

4.1.2 Method

As the control room is reviewed, data collection personnel will uncover a number of operator-control room interfaces that do not meet the human engineering guidelines. These discrepancies should be recorded on a form similar to Appendix VIII, Human Engineering Discrepancy Report form, and should include:

a. A short title for the discrepancy

b. Hardware or procedures items, nomenclature (label) and panel locations

c. Human engineering guidelines which were violated

d. Operator error(s) that might result from the discrepancy

e. Procedures or operations that use the items listed in b.

f. Plant and system level consequences of these errors.

An HED report should be prepared for each and every discrepancy and a photograph or photocopy of the equipment or procedure, respectively, should be kept (where appropriate) to document specific discrepancies.

Where there are a number of interfaces with the same discrepancy, the same procedures involved, and the same consequences of operator error, one "generic" HED might suffice. More likely there will be discrepancies where some of the information is identical from HED to HED. In this case photocopies can be used to reduce the paperwork.

The final step in HED preparation is the identification of suitable backfits (Part (g) of Appendix VIII). Most discrepancies can be corrected by any of several backfits with different potentials for reducing operator error likelihood and different costs. For instance:

- Change of instrumentation type or location
- Addition of repeating displays to improve control/display relationship
- Demarcation lines to improve operator localization of controls and/or displays
- Use of switch guards to reduce the likelihood of inadvertent or accidental operation
- Use of alarms or warnings to advise of a potential error
- Use of switch or display color coding to improve operator localization
- Use of display range markings (e.g., normal, emergency) to improve display discriminability at a distance
- Use of mimic lines to improve sequential control/display operations
- Use of warning labels to caution against specific actions
- Use of procedural cautions requesting a double-check of a difficult setting
- Use of shape coding on switch handles to tactually "separate" switches that are frequently interchanged in operation
- Attention given during training to difficult or error-prone control/display operations
- Use of indications with set points and out-of-tolerance alarm lights to improve discriminability at a distance.

Of course there are a number of backfits which might be possible with the addition of a graphic display; however, these backfits will not be considered here.

As HEDs are completed they should be prioritized, reviewed and logged into the appropriate Human Engineering Evaluation Report (Appendix I-b).

4.2 Prioritize Human Engineering Discrepancies

The method for prioritizing HEDs presented below is intended to capture all HEDs that impact plant safety. Since estimates of operator reliability and frequency-of-occurrence of tasks are sometimes undependable, these two factors are secondary to the safety impact if the operator commits the error(s) resulting from the discrepancy.

Errors that would significantly reduce plant reliability might be important to the utility; therefore, these errors are identified but assigned a lower priority than errors impacting safety.

4.2.1 Objective

Determine the priority for backfit of each and every Human Engineering Discrepancy. To the extent that dependable information is present, determine the priority and, perhaps, the likelihood that the discrepancy-induced error will occur.

4.2.2 Method

The procedure for assigning backfit priorities to HED is described in detail in Appendix IX. This procedure is based on four fundamental determinations made initially by the Data Collection Specialists during control room review (see Figure 2-1).

1. Does the discrepancy-induced operator error degrade or jeopardize plant safety?
2. Does the operator error degrade or jeopardize plant reliability?
3. What features of the task or equipment would increase or reduce the chance of operator error?
4. How often does the operator/system interface occur in procedures?

These four basic questions are used to divide HEDs into five major categories.

- Category 1 — Safety Related, Minimum Opportunity to Correct Error
- Category 2 — Safety Related, Some Opportunity to Correct Error
- Category 3 — Reliability Related, Minimum Opportunity to Correct Error

- Category 4 — Reliability Related, Some Opportunity to Correct Error
- Category 5 — No Impact on Safety or Reliability

Each category *may* be subdivided into six steps according to the features of the task that could reduce operator reliability (e.g., performing two tasks simultaneously). While these steps could be applied to all five categories, use with categories 1 and, perhaps, 2 might be unnecessary since prudence would suggest a backfit for every HED in these categories.

Within categories 3, 4 and 5, prioritizing of HEDs beyond the six steps can be obtained by determining the frequency of the operator-control room interface producing the error.

In terms of backfit:

Category 1 — To enhance safe operation, the control room interfaces should be backfitted to:

- Remove or mitigate discrepancy
- Provide error feedback to the operator
- Increase time to respond to error.

Category 2 — To enhance safe operation, the control room interface should be backfitted to remove or mitigate discrepancy.

Category 3 — To enhance reliable operation, the control room interface might be backfitted to:

- Remove or mitigate discrepancy
- Provide error feedback to the operator
- Increase time to respond to error.

Category 4 — To enhance reliable operation, the control room interface might be backfitted to remove or mitigate discrepancy.

Category 5 — Backfits may improve operations.

As a second phase of prioritizing, an independent panel of plant experts should examine the data used to assign priorities to HEDs to assure that all relevant facts have been considered. In Figure 2-1 the panel would be chaired by the HED Processing Manager.

4.3 Identification of Potential Backfits

As part of HED preparation, the reviewer and the Data Collection Manager suggest backfits that would reduce the likelihood of the discrepancy-induced operator error. For most HEDs there will be several potential backfits of varying degrees of effectiveness and cost (see Section 4.1.2). In this task the HED Review Committee selects, for each high-priority HED, the most cost-effective backfit for presentation to the Evaluation Director who, in turn, recommends its implementation or its further study.

4.3.1 Objective

To select a backfit for each high-priority HED that will reduce to an acceptable level the likelihood of the discrepancy-induced error.

4.3.2 Method

In most cases a simple cost-effectiveness matrix will be sufficient for selecting among backfit alternatives. This matrix should contain data on:

- Description of Backfit
- General Advantages (e.g., operator acceptance, no changes in procedures, etc.)
- General Disadvantages (e.g., retraining, requires outage to implement, etc.)
- Estimated Performance after backfit (a rank order across potential backfits would suffice)
- Estimated cost to implement.

At this point most of the less effective and more expensive alternatives will be apparent, leaving only a few from which to choose. If a more sophisticated trade-off is desired and warranted, the "Estimated Performance After Backfit" could be a quantitative estimate of error probability after backfit, which would be plotted against cost.

5.0 REPORTING

As noted in paragraph 2.4, the basic reporting requirements should be established in the Planning Phase to assure that Data Collection and HED Processing activities produce all of the information needed to prepare comprehensive evaluation reports.

5.1 Summary Report

An overview of all evaluation bases, activities, results, and findings should be prepared for NRC review.

5.1.1 Objective

The objective of this task is to prepare a report summarizing the control room evaluation in enough detail to demonstrate the thoroughness of the review, the validity of the evaluation and prioritization bases, and the action to be taken to correct significant deficiencies.

5.1.2 Method

A sample outline for a Control Room Evaluation Summary Report is shown in Figure 5-1 below.

FIGURE 5-1

AN OUTLINE FOR A "CONTROL ROOM EVALUATION SUMMARY"

1.0 INTRODUCTION

- 1.1 Evaluation Objectives
- 1.2 Evaluation Bases & Guidelines
- 1.3 Evaluation Activities
- 1.4 Management

2.0 APPROACH

- 2.1 Identification of Discrepancies
- 2.2 Prioritization of Discrepancies
- 2.3 Selection of Discrepancies for Backfit

3.0 RESULTS

- 3.1 High Priority Discrepancies and Backfits
- 3.2 Documentation Available for Review

4.0 REMEDIAL ACTIONS

- 4.1 Specifications for Changes
- 4.2 Schedule for Implementation

5.2 Summary of Discrepancies

The primary objective of this evaluation is to identify and remove the causes for operator error in nuclear power plant control room design and operations. A comprehensive list of discrepancies, priorities, and remedial actions documents that this objective will be met.

5.2.1 Objective

To prepare a listing and description of all Human Engineering Discrepancies found during the control room evaluation.

5.2.2 Method

An overall outline for the "Summary of Discrepancies" is suggested in Figure 5-2.

FIGURE 5-2

AN OUTLINE FOR THE "SUMMARY OF DISCREPANCIES"

1.0 INTRODUCTION

- 1.1 Evaluation Objectives
- 1.2 Evaluation Bases (Summary)
- 1.3 Evaluation Approach (Summary)

2.0 HUMAN ENGINEERING DISCREPANCIES

- 2.1 HED Descriptions
- 2.2 HED Priority by System
  (Sort HED numbers by priority and, within priority, by system)

The information to be presented in Section 2.1 (of Figure 5-2) on each discrepancy includes:

1. Human Engineering Discrepancy Number
2. Label (as it reads on panel) or procedure title/sector/paragraph
3. Components (or procedure steps) involved
4. Discrepancies found in components or procedures
5. Priority for backfit
6. Resolution of discrepancy
7. Estimated backfit completion date.

5.3 Supporting Information

During in-house and NRC reviews of the evaluation, it is likely that questions will arise that require details beyond the two summary reports. For instance, what specific guidelines were used to evaluate a given display? Or, perhaps, was control "X" examined?

Supporting information of this type was prepared as part of several planning and data collection activities; therefore, no new data need be collected unless the review described below locates oversights in the data set.

5.3.1 Objective

Review the component/group/system level data sheets (Appendix I-b), and identify and correct any oversights in data set.

5.3.2 Method

Each data sheet should be examined to assure that prescribed checklists, surveys, etc., have been performed; that all discrepancies have been prioritized; and that where, necessary, backfits have been developed. Also, at this point, it is prudent to review the data sheets against component titles to assure that all operator-control room interfaces have been examined.

6.0 IMPLEMENTATION

One of the most unfortunate misconceptions of human engineering evaluation is that there exists some relatively small number of backfits which, if implemented, will "cure" the human error problem. This view is patently incorrect. To substantially reduce the likelihood of human error jeopardizing safety, hundreds (rather than tens) of backfits may be implemented. This is caused by several facts:

a. Human reliability on current interfaces, while subject to improvement, is relatively high. Therefore it is unlikely that a few very poorly designed interfaces will be identified and backfitted with a resulting large improvement in system reliability.

b. There are a large number of operator-control room interfaces where operator performance would or could jeopardize safety. Therefore the opportunity for a safety-related human error is spread among large numbers of interfaces. In thinking of the number of interfaces, consider controls, displays, control-display functional groups, annunciators, and procedural steps, notes, cautions, addresses, etc. that the operator must use. Each is a potential source for error.

c. "Safety related interfaces" does not mean only interfaces in safety systems. For instance, some non-safety related actions may cause plant conditions which challenge safety systems. The layout of non-safety related systems could interfere with the performance of safety related tasks, or switch selection errors, caused by poor labeling or marking in non-safety related systems, could lead to inadvertent changes in the safety system. Thus, the number of interfaces that must be considered is so large as to embrace, perhaps, the entire control room.

All of this underscores the need for the control room evaluation to be comprehensive in the interfaces examined, in anticipating the possible human errors resulting from specific discrepancies, and in determining the consequences of errors on system safety and reliability.

REFERENCES

1. Sugarman, Robert. Nuclear Power and the Public Risk, IEEE Spectrum, 16 (11), November, 1979, 59-79.

2. Finlayson, Fred C., Hussman, T. A., Jr., Smith, Keith R., Crolius, R. L., and Willis, W. W. Human Engineering of Nuclear Power Plant Control Rooms and Its Effect on Operator Performance, The Aerospace Corporation, ATR-77 (2815)-1, February 1977.

* 3. WASH 1400 (NUREG-75/104): Reactor Safety Study - An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants, U.S. Nuclear Regulatory Commission, Washington, D.C., October 1975.

4. Finnegan, J. P., Rettig, T. W., and Rau, C. A., Jr., The Role of Personnel Errors in Power Plant Equipment Reliability. EPRI AF-1041, April 1979.

5. The Con Edison Power Failure of July 13 and 14, 1977. DOE/FERC-0012, June 1978.

6. Prestele, J. A. and Pack, R. W., "Human Factors in Utility Reliability," 1979 Reliability Conference for the Electric Power Industry, 1979.

7. Seminara, Joseph L., Gonzalez, Wayne R., and Parsons, Stuart O. Human Factors Review of Nuclear Power Plant Control Room Design, Final Report, EPRI NP-309, November 1976.

** 8. Malone, T. B., Kirkpatrick, M., Mallory, K., Eike, D., Johnson, J. H., and Walker, R. W. Human Factors Evaluation of Control Room Design and Operator Performance at Three Mile Island - 2, NUREG/CR-1270, January 1980.

9. Swain, A.D. Human Reliability Assessment in Nuclear Reactor Plants, SCR-69-1236, April 1969, Sandia National Laboratories, Albuquerque, NM.

* Available for free upon written request to the Division of Technical Information and Document Control, U. S. Nuclear Regulatory Commission, Washington, D.C. 20555.

** Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, D. C. 20555, and the National Technical Information Service, Springfield, VA 22161.

APP-I

APPENDIX I

APP-I

APPENDIX I

APPENDIX I-a

TYPICAL POSITION DESCRIPTIONS

TITLE	TYPICAL RESPONSIBILITIES	SUGGESTED QUALIFICATIONS
Control Room Evaluation Director	• Communicates between evaluation team and top management • Overall project scheduling • Approves HED review process • Final approval of HED priority and backfit selection • Provides authority to: - secure instrumentation - obtain technical and administrative support as necessary - purchasing - obtain all documentation needed • Determines project reporting and documentation requirements	• Holds upper-middle management position • Familiar with both operations and engineering departments and functions • Familiar with control room • Knows NRC regulations concerning control room design and operations • Recognizes the role of design in causing human error, and human error in causing safety and reliability problems
Engineering Coordinator (Staff to Director)	• Coordinates implementation of Engineering Backfits • Provides (secures) engineering documentation for project library • Communicates between evaluation team and engineering • Advises CR Evaluation Director on final disposition of Human Engineering Discrepancies (HEDs)	• Engineering management position (I&C engineer preferable) • Familiar with instrumentation and control of plant • Knowledgeable of NRC regulations on control rooms • Knowledgeable of all steps and costs in backfit process • Recognizes the role of design in causing human error, and human error in causing safety and reliability problems

TITLE	TYPICAL RESPONSIBILITIES	SUGGESTED QUALIFICATIONS
Operations Coordinator (Staff to Director)	• Coordinates implementation of operations backfits • Secures operations documentation for project library • Communicates between evaluation team and operations • Advises CR Evaluation Director on final disposition of Human Engineering Discrepancies	• Operation management position (operator or ex-operator preferable) • Familiar with operations in control room • Familiar with applicable NRC regulations • Recognizes role of design and procedures in causing human error, and human error in causing safety and reliability problems
Training Coordinator (Staff to Director)	• Coordinates implementation of training backfits • Secures training documentation for project library • Communicates between evaluation team and training • Advises CR Evaluation Director on final disposition of Human Engineering Discrepancies	• Training management position (manager of operator training preferable) • Familiar with applicable NRC regulations • Familiar with all aspects of operator selection and training • Recognizes role of design and procedures in causig human error, and human error in causing safety and reliability problems • Recognizes impact of design and procedural changes on Training.

TITLE	TYPICAL RESPONSIBILITIES	SUGGESTED QUALIFICATIONS
Documentation Specialist (Staff to Director)	• Prepares specifications defining the contents, formats, etc., for each team report • Coordinates report preparation by Data Collection manager and HED Processing Manager, with publications personnel • Advises CR evaluation director or publication schedules and constraints	• Publications manager • Familiar with preparing materials for NRC review • Authority to direct or coordinate all aspects of document preparation, reproduction and distribution for review
Data Collection Manager (Reports to Director)	• Data collection scheduling and planning • Develops data collection instruments • Specifies data collection instrumentation • Manages all data collection activities • Serves as human engineer on HED review committee • Approves all backfit suggestions for release to director • Provides advice to director on final disposition of HEDs • Approves HED and its priority for examination by the HED review committee	• Human factors engineer by training (senior level is preferable) • Experience in CR design or evaluation or in design or evaluation of comparable systems • Management (planning, administration, supervision) experience in interdisciplinary or systems engineering activities • Familiar with the human engineering guidelines applicable to CR design and procedures • Familiar with the validity and reliability of hardware instrumentation and data collection instruments suitable for CR evaluation • Understands role of operator in plant systems safety and reliability

TITLE	TYPICAL RESPONSIBILITIES	SUGGESTED QUALIFICATIONS
Data Collection Staff		
• Operator	• Provides advice and information to Data Collection Manager	• Senior reactor operator level • Fully knowledgeable of plant and CR design/operations • Advocate of improved CR design • Candidate for management might be preferable
• I&C Engineer	• Provides advice and information to Data Collection Manager	• Senior I&C engineer • Fully knowledgeable of I&C • Interest in human engineering of control rooms • Candidate for management might be preferable
• Data Collection Specialists	• Perform CR surveys • Perform CR checklists • Conduct task analyses • Conduct procedures walk-throughs • Fill out Human Engineering Discrepancy (HED) reports • Recommend HED priority • Identify potential backfits	• Junior and intermediate level human engineers are preferable; or operators/engineers trained to conduct the data collection activities • Specific understanding of evaluation procedures, instruments and instrumentation

TITLE	TYPICAL RESPONSIBILITIES	SUGGESTED QUALIFICATIONS
HED Processing Manager	• Conducts reviews to establish HED priority • Prepares HED review process for director's approval • Chairs all meetings of HED review committee • Identifies and requests advice from technical specialists as necessary • Advises Director on final disposition	• Systems engineer or engineer thoroughly familiar with I&C and CR operations • Knowledgeable of plant management and senior-level technical staff • Experience in decision making groups • Familiar with NRC regulations concerning CR design and operations
HED Review Committee		
• Senior Reactor Operator (not advising the Data Collection Manager)	• Reviews HEDs and participates in the validation of priorities and feasibility of backfits • Votes on the disposition of HEDs	• Thoroughly familiar with plant systems and CR operations • Experience in decision making groups
• Senior I&C Engineer (not advising the Data Collection Manager)	• Reviews HEDs and participates in the validation of priorities and feasibility of backfits • Votes on disposition of HEDs	• Thoroughly familiar with the design of plant I&C systems and the I&C requirements attached to each system • Familiar with NRC regulations concerning I&C • Experience in decision making groups

TITLE	TYPICAL RESPONSIBILITIES	SUGGESTED QUALIFICATIONS
(HED Review Committee, Cont)		
• Senior Human Engineer	• Describes each HED under review, provides justification for its priority and proposes a backfit where needed • Votes on disposition of HEDs	• Data Collection Manager

APPENDIX I-b
HUMAN ENGINEERING EVALUATION REPORT

(a) INTERFACE NOMENCLATURE OR DESCRIPTION: ______________________________

____

(b) • PANEL ______
• SUB-PANEL ______
• PROCD/STEP ______
• GENERAL ______

(c) EVALUATION REQUIREMENTS:

SURVEYS	√	CHECKLISTS	√	WALKTHROUGHS	√	OTHER	√

(d) DISCREPANCIES:

HED NO.	TITLE	PRIORITY	BACKFIT

APPENDIX I-c

DESIGN FEATURES INFLUENCING HUMAN ERRORS

1.0 Control Errors

1.1 Inadvertent Actuation (Accidental Activation of a Control)

1.1.1 Control location/arrangement

1.1.1.1 Location with respect to the operator's body

1.1.1.2 Location with respect to the operator's hand while controlling other controls

1.1.1.3 Location with respect to other controls

1.1.2 Control design

1.1.2.1 No guards or barriers

1.1.2.2 Too little force required to activate the control

1.1.2.3 Type of motion required to activate makes accidental activation likely — e.g., toggle switch — up/down

1.1.3 Control visibility

1.1.3.1 Control is not easy to see and avoid

1.1.3.2 View of control is obscured by other controls or operator's hand

1.2 Substitution Errors (Selection of the Wrong Control)

1.2.1 Control location/arrangement

1.2.1.1 Control located in a string of other controls of the same shape

1.2.1.2 No consideration given to the sequence of control use

1.2.1.3 No functional arrangement of controls

1.2.2 Control design

1.2.2.1 Control shape not differentiated from adjacent controls

1.2.2.2 Control size not differentiated from adjacent controls

1.2.2.3 Control color not differentiated from adjacent controls

1.2.2.4 Control labelling/marking not readily distinguishable

1.2.2.5 Control location not differentiated from other controls

1.2.2.6 Difficult to distinguish pushbutton from legend light

1.2.3 Control visilibity

1.2.3.1 Control not readily visible

1.2.3.2 Line of sight to control is obscured

1.2.3.3 Control label not readily readable

1.2.3.4 Control label obscured by the control itself or by operator's hand

1.3 Activation Errors (Selecting Wrong Position on Right Control)

1.3.1 Location/arrangement

1.3.1.1 Control is located such that operator reach can result in mis-settings

1.3.1.2 Control is located or oriented such that selection of some positions is difficult

1.3.2 Control design

1.3.2.1 Direction of motion does not follow accepted stereotypes or conventions

1.3.2.2 Direction of motion is not consistent for similar type controls

1.3.2.3 Direction of motion is not labelled

1.3.2.4 No feedback of control activation

1.3.2.5 Control position arrangement is not consistent across different controls

1.3.2.6 Control positions are not readily distinguishable

1.3.2.7 The associated display is not located with the control

1.3.2.8 The associated display motion does not follow convention

1.3.2.9 The control permits selection of positions which are not used

1.3.2.10 Labelling of control positions is difficult to read

1.3.2.11 There is not sufficient spatial separation of different switch positions

1.3.3 Control visibility

1.3.3.1 Control position indications are obscured by the control itself or by the operator's hand

1.3.3.2 The feedback cue to control activation is obscured

1.4 Temporal Errors (Taking Too Much Time to Locate, Acquire and Activate a Control)

1.4.1 Location/arrangement of controls

1.4.1.1 Controls located out of reach of the operator

1.4.1.2 Access to the control requires excessive travel on the part of the operator

1.4.1.3 Access to the control requires special effort on the part of the operator

1.4.1.4 The control is located in an array of identical controls

1.4.2 Control design

1.4.2.1 Force required to activate the control is excessive

1.4.2.2 Required direction of control motion is unexpected or confusing

2.0 Display Errors

2.1 Reading Errors

2.1.1 Location/arrangement

2.1.1.1 Display orientation to operator's line of sight is less than 45°

2.1.1.2 Viewing distance makes reading difficult

2.1.1.3 Display located above the eye height of a 5th percentile operator

2.1.1.4 Display located such that operator's view is obscured

2.1.2 Display design

2.1.2.1 Displays difficult to read due to poor brightness contrast

2.1.2.2 Display readability impaired by glare

2.1.2.3 Scale increment size makes reading difficult

2.1.2.4 Scale graduations not standard nor consistent

2.1.2.5 Pointer parallax increased likelihood of reading errors

2.1.2.6 Strip chart pens leak

2.1.2.7 Strip charts use too porous paper

2.1.2.8 Strip chart pens do not always contact paper

2.1.2.9 Strip chart parameters require ranges different from those indicated

2.1.2.10 Pullout strip charts obscure view of other displays

2.1.2.11 Impact recorders difficult to read or to identify trends

2.1.2.12 Conspicuity of pointers too low

2.2 <u>Interpretation Errors</u>

2.2.1 Display design

2.2.1.1 Displays do not indicate in-tolerance and out-of-tolerance areas

2.2.1.2 Difficult to interpret trends

2.2.1.3 Process controllers display demand only — not actual valve

2.2.1.4 Required values not displayed on trend displays

2.2.1.5 Patterns of lights are confusing

2.3 <u>Display Substitution Errors</u>

2.3.1 Location/arrangement

2.3.1.1 Display located in a string of identical displays

2.3.1.2 Display located too close to adjacent displays

2.3.1.3 Display not located in a string by sequence

2.3.1.4 Displays not functionally grouped

2.3.1.5 Display arrangement is illogical or inconsistent

2.3.1.6 Display not located adjacent to its associated display

2.3.2 Display design

2.3.2.1 Display shape not differentiated from adjacent displays

2.3.2.2 Display size not differentiated from adjacent displays

2.3.2.3 Display color not differentiated from adjacent displays

2.3.2.4 Display labelling not readily readable

2.3.3 Display visibility

2.3.3.1 Display not adequately illuminated

2.3.3.2 Line of sight to the display is obstructed

2.4 Display Activation Errors

2.4.1 Display design

2.4.1.1 No light test capability

2.4.1.2 No indicator lights are provided

2.4.1.3 Direction of display motion not conventional or stereotypical

2.4.1.4 It is possible to transpose legend light faces

2.4.1.5 Trend recorder speed not controllable

2.4.1.6 A failure to achieve required status is indicated by an extinguished light

2.4.1.7 There is no standard procedure for checking failed lights

2.4.1.8 A meter can fail leaving the pointer at mid-range

2.4.1.9 Failure of a meter is not readily detectable

2.4.1.10 Valve travel is indicated by extinguishment of open and closed lights

2.5 Display Temporal Errors

2.5.1 Location/arrangement

2.5.1.1 Display not located within visual access from viewing position

2.5.1.2 Display is located in an array of identical displays

2.5.1.3 Display located where field of view is obstructed

2.5.2 Display design

2.5.2.1 Displays not functionally grouped

2.5.2.2 Displays not grouped by sequence of use

2.5.2.3 Displays not clearly labelled

2.5.2.4 Displays not clearly coded

3.0 Annunciator Errors

3.1 Reading Errors

3.1.1 Location/arrangement

3.1.1.1 Annunciator legend cannot be read at viewing distance

3.1.1.2 Annunciator legend cannot be read at viewing angle

3.1.2 Annunciator design

3.1.2.1 Luminance level of red annunciator too low

3.1.2.2 Annunciators have dyna-tape backfits which cannot be read when illuminated

3.1.2.3 Annunciators have different type fonts

3.1.2.4 Annunciator legends are too complex

3.2 Annunciator Activation Errors

3.2.1 Annunciator design

3.2.1.1 Annunciators not prioritized

3.2.1.2 Annunciators not functionally grouped

3.2.1.3 Annunciators not coded — as first out

3.2.1.4 High annunciator nuisance rate reduces operator readiness

3.2.1.5 Annunciator silence control is operated in a defeated mode

3.2.1.6 Different flash rates or duty cycles indicate different annunciator status - and the indications are not readily distinguishable

3.2.1.7 Auditory alarms are not coded by location

3.2.1.8 No annunciator silence with visual display retention

3.2.1.9 Until an alarm is cleared, a second alarm is inhibited

3.2.1.10 Alarms are less than 20 dB above ambient noise levels

3.2.1.11 Acknowledge control difficult to access

3.2.1.12 No clear notification of alarm cleared

4.0 <u>Label Reading Errors</u>

4.1 <u>Readability</u>

4.1.1 Location/arrangement

4.1.1.1 Labels not located consistently

4.1.1.2 No labels provided

4.1.1.3 No panel designators provided

4.1.1.4 View of labels obscured

4.1.2 Design

4.1.2.1 Label font makes labels difficult to read

4.1.2.2 Functions mislabelled

4.1.2.3 Safety tags cover labels

4.1.2.4 Labels have poor brightness contrast

4.1.2.5 Labels are cluttered

4.1.2.6 Labels have low contrast to the panel

4.1.2.7 Labels are illegible

4.1.2.8 Color not used consistently

4.1.2.9 Inconsistent use of abbreviations

4.1.2.10 Labels have small fonts

4.1.3 Use of labels

4.1.3.1 Too many operator added backfits used

4.1.3.2 Backfits not consistent

4.1.3.3 No demarcations grouping panel elements

5.0 Procedure Errors

5.1 Access Errors

5.1.1 Procedures location and arrangement

5.1.1.1 Procedures are not located to be easily accessed

5.1.1.2 Procedures are not arranged to be easily accessed

5.1.1.3 Only are set of procedures provided in the CR

5.1.2 Procedures indexing

5.1.2.1 Procedures are not indexed for ease of access

5.1.2.2 Procedures are not tabbed for easy access

5.1.3 Procedures design

5.1.3.1 Procedure titles are not sufficiently discriminable

5.1.3.2 No guidelines are provided to enable operators to establish which procedures are applicable

5.1.3.3 No cross referencing of different procedures

5.1.3.4 Cross referencing sends the operator to some ancillary document

5.2 Reading Errors

5.2.1 Procedures design

5.2.1.1 Use of ambiguous language

5.2.1.2 Procedures text not clear and concise

5.2.1.3 Instruction too long

5.2.1.4 Use of overly precise control processor settings

5.2.1.5 Phrasing of instruction is ambiguous

5.2.1.6 Excessive length of instructional steps cause operators to skim rather than read these steps

5.2.1.7 Multiple steps are nested in one instructional statement

5.2.1.8 Caution and warning notes not sufficiently highlighted

5.3 Procedures Following Errors

5.3.1 Procedures design

5.3.1.1 Procedures are not complete — steps are missing

5.3.1.2 Procedural steps are out of order

5.3.1.3 Procedures do not inform the operator when to stop using the document

5.3.1.4 Emergency procedures do not indicate the feedback for the system which should cue the operator on what to do next, or even that he is on the right procedure

5.3.1.5 Procedure nomenclature different from labels and component designations

5.3.1.6 Information on component location and function left to operator's memory

5.3.1.7 Procedural steps in emergency procedures not structured to support diagnosis of problems

5.3.1.8 Charts, graphs and schematics and diagrams are not incorporated in the text

5.3.1.9 No indications are provided on system response to operator action

5.3.1.10 Procedures are not anumerable to a checklist format allowing operator checkoff of each step as completed

5.3.1.11 Too many steps of emergency procedures must be committed to memory

5.3.1.12 Arrangement of notes is confusing — not clear to which step the note applies

5.3.1.13 Inconsistent use of acronyms and action verbs

APP-II

APPENDIX II

APPENDIX II

GENERIC HUMAN ENGINEERING DESIGN ISSUES

Annunciator Design and Operation

- Organization of windows — not above systems they monitor
- Low contrast between alarming and steady-on windows
- No prioritization of alarms to aid in diagnosis
- Font size not consistent with reading distance requirements
- Difficulty in localization (low flash rates, no auditory alarm directionality correlates)
- Lack of positive indication of alarm condition cleared
- Multi-channel annunciators which have no reflash capability and lock out subsequent alarms.

Operator/Computer Interface

- No graphic trending capability on displays
- Computer operation requires lengthy searches for data point addresses (operators often substitute memory)
- Alarm computers that are limited in the number of near-simultaneous alarms that can be managed
- No alphanumeric displays whatsoever
- Display and hardcopy alphanumeric outputs which are poorly spaced, organized, etc.
- Printers obscured by cabinet.

Violations of Conventions and Stereotypes

- Switch position conventions (within plant) established and then violated on panel
- Switch and display organization by channel, bus, etc., varies within and between systems
- Stereotypic left-to-right and top-to-bottom organization of alphabetic- or numeric-ordered controls/displays is violated
- On-off, increase-decrease movement stereotypes are not followed
- Color meaning conventions are established and then violated in indicators.

Control/Display Strings

- Vertical meters, process controllers or switches are arranged in vertical or horizontal strings of 5 or more making location of mid-string components difficult
- Positioned in string without regard to operational sequence
- Coding methods are not employed to enhance discriminability
- Confusion in locating specific control/display is induced by layout or clustering
- Discriminability is reduced by C/D similarity.

Lamp Testing

- Application does not extend past annunciators/status lights
- Alternate operational methods to test lamps include valve closures/ openings and lamp replacement
- Information omission increases operator/personnel workload
- Failure states can remain unknown.

Labeling

- Readability is reduced by small font size
- Low contrast of lettering to label decreases readability
- Nomenclature is inconsistent or misleading
- Labels are not conspicuous
- Labels are not present
- Little use of summary labeling of functionally grouped components
- Contractions, abbreviations are not uniform
- Control and display label associations are obscure
- Obscured by switch handles, or other equipment.

Operator Protective Equipment

- Masks obscure visibility
- Breathing apparatus interferes with voice communication
- Operators are not practiced enough to don equipment within an acceptable period of time
- Accessibility is poor
  - supply insufficient equipment for the number of operators required to be in CR
  - store emergency equipment in locked cabinets or in obscure locations.

Intra-CR Communications

- Ambient noise levels are very high (60-70dB)
  - interferes with communications from back panels or across the CR
- Communications impossible when wearing protective breathing apparatus
- Emergency procedures are read by one operator while another takes required actions (high fidelity voice communications are required throughout the CR).

Procedures Content and Format

- Procedures are difficult to access due to storage and indexing
- Procedures lack completeness
  - steps missing
  - steps out of order from actual sequence of performance
- Actions not included in procedures are assumed to be learned in training
- Ambiguous language is used in instructional steps
- Synonyms are frequently used
- Information on system feedback is lacking
  - no instruction on operator requirements or recourse if system fails to respond
- Offer lack diagnostic aids
- Cross-referencing to other procedures or documents occurs within immediate and subsequent operator actions
- Procedures lack clarity and conciseness of text
  - instructional steps are wordy or discussional in nature
- Instructional steps are nested in notes or cautionary statements or in other steps
- Format does not agree with modern job performance aid technology
  - font size, style (10 or 12 pitch, non-ceriphed type)
  - column width (optimum width for eye scan, 3 inches)
  - sentence structure and length (10 words or less, simple sentence structure)
  - constrained vocabulary (use words of high familiarity; eliminate synonyms)
  - supplementary information (use of diagrams or pictures)
- Information on component location and function is left to operator memory
- Long lists of immediate actions tax operator long-term memory
- Field operations (not performed by control room operator) are not clearly identified as such.

Workspace Layout

- Primary panel space is cluttered with unused/inoperative controls and displays
- Accessibility of panel is obstructed by desks, computer consoles
- Critical displays are placed below the operator's line-of-sight
- Displays are located without regard for parallax or glare.

Control/Display Relationships

- Functionally related controls and displays are not colocated
- Control/display relationships are unclear
- Mimic panels, when used, are composed of overlapping, multi-colored lines which do not clearly associate controls/displays.

Positive Indication of System or Component Status

- Indicator lights indicate switch position rather than actual valve or breaker position
- Pre-trip status indication of engineered safeguards is lacking in a concise form.

Process Controllers

- Indication is given of signal sent rather than a positive indication of valve status
- Stereotype is violated in that counterclockwise control movement and increased display value (i.e., 100%) can signify a closed valve
- Control/display relationship is inverted (e.g., increase in control value produces decrease in display value).

Trend Recorders

- Trends are smeared and unreadable
- Pen position is parallaxed, unreadable or obscured
- Scaling increments do not agree with increments on paper
- Wrong color ink in pens.

General Maintenance in Control Rooms

- Bulbs burned out in indicator lights
- Labels missing or becoming unglued
- Ladders, cables and other equipment obstructing passage between panels
- Refilling of ink in trend recorders results in spillage; wrong color ink is used.

APP-
III

APPENDIX III

APPENDIX III

HUMAN ENGINEERING OPERATOR QUESTIONNAIRE

Date: ________________ HFE Analyst — Briefing: ________________

Unit: ________________ Interview: ________________

Licensed Operator ______ How Long? __________

or

Trainee ______ How Long? __________

A. Staffing and Workload

1. Please describe Tech. Spec. requirements for CR staffing.

____

____

____

a) If actual staffing differs from Tech. Specs., please describe actual staffing.

____

____

____

2. In your opinion, under worst-case conditions, what is the maximum number of operators actually needed to effectively operate the control room during each of the following:

a) Normal operations ________

b) Startup/shutdown ________

c) Transients/emergency operations ________

3. How many units do you presently operate? ____________

a) If you operate two or more, are they: (check one)

____ identical

____ nearly identical

____ mirror images of each other

____ dissimilar

b) If you operate two or more units, have you ever experienced any difficulties in shifting from one CR to another? ____ yes ____ no

____

____

____

4. Please describe your administrative or record keeping tasks (log entries, reading of parameters, etc.).

____

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____

a) Have these responsibilities ever interfere with your operational duties, especially during off-normal conditions? ____ yes ____ no

5. Have you observed any problems associated with shift turnover?
____ yes ____ no

6. Please describe any recommendation you may have to improve shift turnover.

B. Workspace Design

1. Can the status of your plant be monitored from one central position?
____ yes ____ no

2. Are specific stations assigned to operators and watch foreman?
____ yes ____ no

3. During normal or off-normal operations, do the actions or tasks of another operator ever interfere with performance of your tasks? ____ yes ____ no

4. Have you ever experienced any difficulty in reaching a required control or seeing/reading a required display? ____ yes ____ no

5. Have you ever experienced any problems locating the correct control or display (for example, operating the wrong switch or inaccurately operating the correct switch)? ____ yes ____ no

6. Are panels arranged within your CR in a manner which is logical for normal and emergency operations? ____ yes ____ no

7. Are controls and displays pertaining to systems or subsystems grouped logically and distinctively within each panel? ____ yes ____ no

8. Does your panel lack important information, controls or displays, which would help you perform your job more effectively or safely? ____ yes ____ no

____

____

____

9. Are important data, controls or displays, inaccessible, or difficult to access, because of placement (for example, located in back panels out of operator's view)? ____ yes ____ no

____

____

____

10. Does your CR contain controls, displays or other equipment which is inoperative, not used, or unnecessary for you to do an effective job? ____ yes ____ no

____

____

____

11. Do you find mimics or graphic/pictorial panel arrangements, if used, helpful in performing your job? ____ yes ____ no ____ N/A

____

____

____

a) If "no," please describe why you feel they are not helpful and any recommendations you may have to make them more so.

____

____

____

12. Have you ever inadvertently disturbed control settings (for example, accidentally bumping a switch)? ____ yes ____ no

____

____

____

13. Have groups of controls or displays which look identical or very similar been marked or coded to permit easy discrimination between them? ____ yes ____ no

____

____

____

a) If "no," please describe areas where you feel marking or coding would enhance your ability to discriminate between components.

____

____

____

14. Please describe the administrative procedure for adding operator-recommended modifications to labeling, demarcation lines, mimics, or for adding guarding for certain controls, or otherwise modifying the panel.

____

____

____

____

____

____

15. Do you find operator-added modifications helpful? ____ yes ____ no

____

____

____

a) If "no," please describe those modifications which you find to be a hindrance.

16. Are major panels, sub-panels and panel segments clearly and consistently labeled? ____ yes ____ no

17. Is the Control Room (CR) arranged to be effectively operated by the minimum shift required?

During normal operations ____ yes ____ no

During transients/emergency operations ____ yes ____ no

C. Workspace Environment

1. Do CR features c an environmental nature, such as listed below, ever interfere with effec ive performance of your job? If "yes," please describe the nature and source of each problem and their effects on job performance.

a) Ventilation ____ yes ____ no

b) Temperature/humidity ____ yes ____ no

c) Illumination ____ yes ____ no

d) Noise levels ____ yes ____ no

e) Excessive traffic through the CR ____ yes ____ no

f) Other environmental factors ____ yes ____ no

2. Are there problems with time and distance involved in leaving CR to prepare food or use facilities? ____ yes ____ no

D. Communications

1. Are there problems with communications procedures or equipment which interfere with receiving or transmitting required information in any of the following instances? If "yes," please describe.

a) CR to field/auxiliary operators ____ yes ____ no

b) Field to CR ____ yes ____ no

c) CR to supervisor ____ yes ____ no

d) Between units ____ N/A ____ yes ____ no

e) CR to NRC ____ yes ____ no

f) CR to others (please specify) ____ yes ____ no

2. Are you aware of any instances in which intra-control room (operator-to-operator) communications have been lost or misheard due to distance or noise levels? ____ yes ____ no

3. Does the operation of communications equipment, or requirements for communications interfere with operations: (Please describe if "yes.")

a) During normal operations ____ yes ____ no

b) During off-normal operations ____ yes ____ no

c) During transients/emergencies ____ yes ____ no

____

____

4. Have you experienced any problems with using communications equipment in any of the following areas? (If "yes," please describe the problems.)

a) Location of the equipment ____ yes ____ no

____

____

b) Operation of the equipment ____ yes ____ no

____

____

c) Ability to receive or transmit messages (speech intelligibility) ____ yes ____ no

____

____

d) Number of transmitters/receivers ____ yes ____ no

____

____

e) Failed or broken equipment ____ yes ____ no

____

____

E. Annunciator/Warning System

1. Please describe your alarm annunciator system and its operation from incoming alarm to acknowledge to condition cleared.

____

____

____

2. Does the annunciator system in your CR provide you with specific information about the nature of an abnormal event? ____ yes ____ no

____

____

____

3. Do alarm annunciators provide you with information about the necessary action to be taken in response? ____ yes ____ no

4. Alarm annunciators located above the instrumentation of systems which they monitor? ____ always ____ frequently ____ infrequently

____

____

____

5. Are alarm annunciators prioritized in any way? ____ yes ____ no

____

____

____

6. Please describe any use of color coding used in the annunciator system.

____

____

____

7. Do you have any problems reading annunciator messages from any point in the CR from which these messages must be read? ____ yes ____ no

____

____

____

8. Are the auditory warning signals differentiated to provide meanings, such as priority alarms or locality of system components? ____ yes ____ no

____

____

____

9. Do "nuisance" or "false" alarms ever interfere with your performing your job effectively?

Under normal conditions ____ yes ____ no

Under emergency conditions ____ yes ____ no

a) If "yes," please identify frequent nuisance alarms and the problems they present.

____

____

____

10. Are alarm acknowledge/silence/reset controls available to the operator?

Are there sufficient number ____ yes ____ no

Are they easily accessible from all panels ____ yes ____ no

____

____

____

11. Are alarm annunciators provided with a test capability?

For visual/lamps ____ yes ____ no

For audible ____ yes ____ no

12. Do you have any recommendations which would enhance the operator usability of your annunciator system?

____

____

____

F. Operator Protective Equipment

1. Please describe the operator protective equipment available in your CR.

____

____

____

2. Please describe the quantity and location of the equipment.

____

____

____

3. Does the face mask interfere with visibility? ____ yes ____ no

4. Does your protective breathing apparatus interfere with the following:

   a) Operator-to-operator communications ____ yes ____ no

   b) Use of communications equipment ____ yes ____ no

5. Have you ever encountered difficulty in performing required tasks as a result of wearing protective equipment? ____ yes ____ no

____

____

____

6. Do you feel sufficiently practiced in donning protective equipment so that, if the need arises, you feel you could don it easily and quickly? ____ yes ____ no

7. Do you have any other comments or suggestions concerning the suitability of the available protective equipment or its use?

____

____

____

G. Computers

1. Please describe the functions performed by the computer to assist you in operating the system.

2. Do you find the computer useful and reliable? ____ yes ____ no

3. Do you feel that operators are adequately trained to use the computer? ____ yes ____ no

4. What changes or additions in computer usage would you recommend?

H. Procedures/Documentation

1. Do you find that your procedures documents are difficult to access because of labeling, indexing or storage? ____ yes ____ no

2. Are your procedures sufficiently detailed to permit effective operation of your CR during normal and emergency operations? ____ yes ____ no

___

___

___

3. Are there procedures which you find difficult to execute? ____ yes ____ no

___

___

___

4. Please list the procedures which address operation of the most difficult or critical systems.

___

___

___

I. Operations

1. Do you feel that too many functions are performed automatically by the system in controlling abnormal event? ____ yes ____ no

___

___

___

2. Can you provide examples where direct control by the operator would be preferable to automatic control? ____ yes ____ no

___

___

___

3. Can you suggest examples where automatic control would be preferable, where not currently provided? ____ yes ____ no

____

____

____

4. Please describe any additional operational problems you have experienced with the current panel design.

____

____

____

5. Please describe any recommendations you would make in design or procedure which would enhance the effectiveness of the operator's job.

____

____

____

J. Operator Work Scheduling

1. Would you prefer a different system of shift scheduling? ____ yes ____ no

   a) Do you have any comments or suggestions for improving the effects of shift scheduling on the operator?

____

____

____

2. Have you ever experienced any negative effects in changing from one shift to another, in yourself or in other operators? ____ yes ____ no

   a) If "yes," has this effected operating abilities? ____ yes ____ no

b) Any comments or recommendations?

____

____

____

3. How many overtime hours do you generally work in a month? __________

   a) Do you feel that extended shifts or overtime degrades your ability to perform your job effectively? ____ yes ____ no

   b) Have you ever experienced any problems in operating the plant as a result of working extensive overtime? ____ yes ____ no

   c) Any comments or suggestions?

____

____

____

4. Are you aware of any operators who have experienced personal problems as a result of working shifts and/or overtime? ____ yes ____ no

   a) Any comments?

____

____

____

APP-IV

APPENDIX IV

APPENDIX IV-a NOISE SURVEY

PLANT:	DATE:	TIME:
TEST CONDUCTED BY:		
SOUND LEVEL METER MODEL: SERIAL NUMBER:	MICROPHONE MODEL: SERIAL NUMBER:	CALIBRATION DATE:
OPERATOR POSITION:		

NOISE CONDITION/SOURCE/DIRECTION OF MEASUREMENT	dB	dB(A)	dB(C)	REMARKS

NOISE SURVEY INSTRUCTIONS

1. Complete information at top of form.

2. Using a control room floor plan, have two or more operators identify positions or worksites throughout the control room.

3. Using a sound level meter, take several noise samples to establish an average basal noise level.

4. Using a sound level meter, take and record three measurements at each position in dB(A); dB(C); dB(flat):

   - Measurement 1 — microphone toward primary noise source
   - Measurement 2 — microphone toward panel surface
   - Measurement 3 — microphone towards furthest operator's position with which voice communications must be maintained.

5. Compare to human engineering guidelines.

APPENDIX IV-b AMBIENT LIGHTING SURVEY

PLANT:	DATE:	TIME:	
TEST CONDUCTED BY:			
PHOTOMETER MODEL: SERIAL NUMBER:		CALIBRATION DATE:	
OPERATOR/MEASUREMENT POSITION	LIGHTING CONDITIONS		REMARKS
	NORMAL	EMERGENCY	

AMBIENT ILLUMINATION SURVEY INSTRUCTIONS

1. Complete information at top of form.

2. Using a control room floor plan, have two or more operators identify positions or worksites throughout the control room.

3. Using a light meter (photometer) held near eye level, measure and record ambient light levels:

   - Towards the control panel used from that position
   - Towards the ceiling.

4. Compare to human engineering guidelines.

APPENDIX IV-c DISPLAY LIGHTING SURVEY

PLANT:	DATE:	TIME:
TEST CONDUCTED BY:		
SPOT BRIGHTNESS METER MODEL: SERIAL NUMBER:		CALIBRATION DATE:

DISPLAY TYPES	LOCATION	BRIGHT AREA (L_1) (FT. LAMBERTS)	DARK AREA (L_2) (FT. LAMBERTS)	LUMINANCE CONTRAST

DISPLAY ILLUMINATION SURVEY INSTRUCTIONS

1. Have operators locate all displays that are difficult to read.

2. Select from these the displays that might be too dim to be easily read.

3. Conduct the display illumination survey on the dimly lit displays.

4. Place the spot brightness meter so that the display fills the reticle, and take a reading (foot-candles).

5. Then take a reading on the surface adjacent to the display.

6. For CRTs, mimics, LEDs, and projection displays several readings over the surface of the display should be taken to assure uniformity of illumination.

7. Then calculate Luminance Contrast (LC)

$$LC = \frac{L_1 - L_2}{L_1}$$ where L_1 = Bright area and L_2 = Dark area

8. Compare to human engineering guidelines.

APPENDIX IV-d DESIGN CONVENTION SURVEY

Operation: ______________________

____

____

Reviewer: ______________________

Plant/Unit: ______________________

Date: ______________________

INTERFACE DESIGN	PANEL NUMBER OR NAME														

DESIGN CONVENTION SURVEY INSTRUCTIONS

The objective of this survey is to identify the conventions (or rules) used to standardize the operation of functionally similar controls and displays. For instance, "to open valve, turn switch clockwise;" "to stop pump, turn switch counterclockwise;" etc.

1. Prepare one Design Convention Survey form for each operation performed by the operator on functionally similar systems. Some examples include:

    - Open or close valve — verify valve open or closed
    - Trip or close breaker — verify breaker tripped or closed
    - Start or stop pump — verify pump started or stopped
    - Select manual or auto mode — verify manual or auto mode
    - Determine annunciator importance
    - Determine "1st-out" system
    - Determine display (incr. or decr.) response to control motion
    - Equipment off/on — verify equipment off/on
    - Select channel or train
    - Verify operational status.

2. Review all panels for examples of each operation and record the design of interface (sketches are useful). It is not unlikely that several "local" conventions will be found.

APPENDIX IV-e

EMERGENCY GARMENTS & BREATHING APPARATUS

Have one or more trained operators don emergency garments and breathing systems (Video tape if possible)

- Where is emergency equipment stored (how far from main operating station)?
- How long does it take to obtain garments/apparatus?
- How many operators are needed to suit one operator?
- How long does it take to suit one operator?
- Can CR operators suit up simultaneously?
- How long will the air last before new tanks are needed?
- How long does it take to replace tanks?
- How many operators are needed for tank replacement?

Have two operators don emergency garments and breathing systems and try to communicate at various distances. Have one operator read a 4-digit number and repeat it first in a normal voice and then shouting. Have the second operator attempt to repeat the number after normal loudness and shouting. Move the operators closer until the number can be heard shouting then record the distance between the operators. Move the operators closer until a different number can be heard with normal speech, then record the distance between the operators. Reverse the roles of the two operators. Record results below.

Operator 1 Speaking		Hearing Distance
	Normal	
	Shouting	
Operator 2 Speaking		
	Normal	
	Shouting	

Check face mask for visual obstructions. Use the space below to describe the location and magnitude of any obstructions. Photograph mask.

Measure extent of operator's reach envelopes with and without protective garments. Photograph positions (standard) at fixed distances.

Photograph hand of operator (fingers spread and extended) with and without gloves. Have the operator close his eyes and discriminate among a number of small relatively common objects with the gloves on.

If possible, have the operators perform one emergency procedure with and without the garments/breathing apparatus on (video tape).

APP-V

APPENDIX V

The checklists are not available at this time, and will be published separately. A sample checklist is shown in Table 3-5 of Section 3.4.3.

APPENDIX VI

APPENDIX VI CONTROL ROOM OPERATIONS TASK ANALYSIS

CR/UNIT: ____________________ ANALYSTS: ____________________

PROCEDURE: ____________________

TASK	ACTIVITY	EST. TIME (MIN.)	f	INFORMATION/ COMMUNICATION REQUIREMENTS	CONTROL	INDICATION/ DISPLAY	CONCURRENT/ SHARED TASKS	POTENTIAL ERROR	ERROR IMPACT

APPENDIX VII

APP-VII

APPENDIX VII

PROCEDURES WALK-THROUGH LOG

Plant Name: ____________________ Date: ____________________

Camera Operator: ____________________ Analysts: ____________________

Procedure Name & Number	Walk-Through Number	Tape Number	Footage

APPENDIX VII

PROCEDURES WALK-THROUGH LOG

Plant Name: ____________________ Date: ________ ______________

Camera Operator: ________________ Analysts: ________ ______________

Procedure Name & Number	Walk-Through Number	Tape Number	Footage

APPENDIX VIII

APP-VIII

APPENDIX VIII
HUMAN ENGINEERING DISCREPANCY

NO: ________ PLANT-UNIT: ________________ DATE: ________________

REVIEWER NAME: ____________________________

a) HED TITLE: ____

____

____

b) ITEMS INVOLVED:

ITEM TYPE	NOMENCLATURE	LOCATION	PHOTO NO.

c) PROBLEM DESCRIPTION (GUIDELINES VIOLATED):

d) SPECIFIC OPERATOR ERROR(S) THAT COULD RESULT FROM HED:

e) LIST THE PROCEDURES OR OPERATIONS THAT USE THE LISTED ITEMS IN A MANNER TO INDUCE THE OPERATOR ERROR:

f) LIST THE CONSEQUENCES OF OPERATOR ERROR DURING ALL MODES OF OPERATION:

g) SUGGESTIONS FOR POTENTIAL BACKFITS:

	NAME	DATE
REVIEWER		
DATA COLL. MGR.		
HED PROC. MGR.		
EVAL DIR.		

APPENDIX IX

APPENDIX IX
HED PRIORITY DETERMINATION

DATE: ____________

HED NO.: ____________

INTERFACE DESCRIPTION: ____

____

____

ERROR CONSEQUENCE EVALUATION TABLE
(see back for instructions)

PROC.	STEP	SPECIFIED ERROR	CONSEQUENCE OF ERROR	QUESTION							FREQ	P
				1	2	3	4	5	6	7		

HED PRIORITY DETERMINATION QUESTIONS

A. INSTRUCTIONS

1. Every question should be answered for each Procedural Step where the "Specified Error" might occur. Steps with identical operator tasks c-n be reviewed once.
2. Results should be recorded in the "Questions" section of the "ERROR CONSEQUENCE EVALUATION" table, in the row with the Procedure and Step under review.
3. The following questions assume that the operator commits the "Specified Error" while performing the Procedure and Step under review.

B. QUESTIONS

1. If this error occurred, could plant safety be jeopardized or degraded?
   - Yes — Enter a "1" in Question 1
   - No — Enter a "0" in Question 1
2. If this error occurred, could plant reliability be reduced?
   - Yes — Enter a "1" in Question 2
   - No — Enter a "0" in Question 2
3. Would the plant's response to the error both
   a. Provide the operator sufficient time to correct it
   and
   b. Provide a positive warning (e.g., alarm) that the error had been committed?
   - Yes — Enter a "0" in Question 3
   - No — Enter a "1" in Question 3
4. To correctly perform the step under review, is the operator required to recall long sequences of actions (say 5 or more in a specific order) or several settings or check readings?
   - Yes — Enter a "1" in Question 4
   - No — Enter a "0" in Question 4
5. Does the operator ever perform this step while at the same time performing another task (e.g., timing, or awaiting a change in status of another system, etc.)?
   - Yes — Enter a "1" in Question 5
   - No — Enter a "0" in Question 5
6. Do existing procedures or training caution the operator concerning the noted Human Engineering Discrepancy?
   - Yes — Enter a "0" in Question 6
   - No — Enter a "1" in Question 6
7. Would the likelihood of the specified error be increased by the operator wearing breathing apparatus, gloves, or protective garments?
   - Yes — Enter a "1" in Question 7
   - No — Enter a "0" in Question 7

C. PRIORITIZATION OF ERRORS

1. Each of the steps reviewed and listed in the ERROR CONSEQUENCE EVALUATION table should be assigned a two-digit Error Priority number
2. Error Priorities range from 1.0 (highest priority for corrective action) through 5.6 (lowest priority).
3. Use the following tables to determine priority (X means a value can be "1" or "0").

QUESTION 1	2	3	4	5	6	7		Priority	Type
1	X	1	X	X	X	X	=	1.0	Safety Related
1	X	0	X	X	X	X	=	2.0	Safety Related
0	1	1	X	X	X	X	=	3.0	Reliability Related
0	1	0	X	X	X	X	=	4.0	Reliability Related
0	0	1	X	X	X	X	=	5.0	Performance Problem

Questions 4 through 7 are used to determine the least significant digit.

4	5	6	7		Priority
1	1	X	X	=	.1
1	0	X	X	=	.2
0	1	X	X	=	.3
0	0	1	X	=	.4
0	0	0	1	=	.5
0	0	0	0	=	.6

4. Record the E-digit priority in the "B" column of the ERROR CONSEQUENCE EVALUATION TABLE.
5. While most safety-related (Category 1.X and 2.X) HEDs should be corrected, the user may find it economical to correct HEDs that significantly reduce plant reliability (Category 3.X and 4.X). By estimating and recording, in the "Freq." column, frequency of use of each discrepant interface, the importance of each discrepancy can be assessed.

II

HUMAN ENGINEERING GUIDELINES

II

1.0 INTRODUCTION

The primary objective of the human engineering evaluation described in Volume I is to identify operator-control room interfaces that pose risks to safe operation.

1.1 Means to Identify Human Engineering Problems

Since the second world war human engineers have taken two distinctly different approaches to identifying interfaces that might cause operational problems — namely, testing and evaluation.

Testing can be conducted during actual operations or during simulations and, in most cases, human performance or human error is recorded on one or more tasks. Those tasks where errors occur repeatedly are identified for backfit. Operational testing is perhaps the most valid means to identify interface problems, but it suffers low reliability, since there are few opportunities to repeat a particular task under similar conditions and can be quite costly if non-intrusive measurements are taken. On the other hand, simulation can have reasonably high reliability, but validity is always a question since it is difficult to duplicate the psychological environment found in operations. In addition, the high cost of simulation testing is a modern legend.

One means to identify problems which received support in the nuclear power community is the use of operator opinion (see Volume I, Sections 2.0 & 3.0). While this means is fruitful and of very low cost, it is also quite limited in scope and of questionable (interoperator) reliability. First, operators rarely, if ever, perform in an emergency situation except in simulations; thus, there would be little basis in real experience to identify problems during these activities. Second, operators often do not know when they have made an observational mistake, e.g., reading the wrong meter. Third, operators like everyone else will forget some of the tasks that caused problems. Finally, some operators are reluctant to admit their errors.

This is not to say that the operator opinion should be ignored. Operators should have adminstrative channels through which design and procedural recommendations can be made and implemented. However, by limiting human engineering data to operator opinion, many and perhaps most of the interface problems will go undetected until a failure during operations, such as TMI-2.

The second method for identifying human engineering problem areas is evaluation, which is the type of method described in this guide. Evaluations involve comparing operator-control room interfaces with established standards, criteria, and/or guidelines and identifying real or potential problem areas when interfaces don't agree with the guidelines. Like the other methods, evaluation has its problems. First, validity is always questionable since the conditions under which guidelines were developed never duplicate the operational conditions of the control room. Second, the applicability of specific guidelines is often questioned, since the severity of the outcome of an error differs among systems, as does the opportunity for error (frequency of task performance).

Unlike testing, the weaknesses of evaluation can be reduced at little cost. As outlined in Volume I, guidelines are only used to identify interfaces that might benefit from backfit. Then, a variety of technical and management determinations are used to determine whether a particular backfit would improve system safety or reliability.

As an adjunct to evaluation, some testing can be performed to tailor specific guidelines to conditions in the control room. For instance, guidelines on display and label readability can be supplemented by tests yielding readability envelopes for displays and labels found in the control room. In general, testing can be used:

- To develop label readability envelopes
- To determine accessibility (reach) of controls to the 5th percentile operator
- To identify displays with parallax problems, when viewed by 5th percentile operators.

1.2 Guideline Selection

The process for selecting the guidelines contained in this document was:

1. To collect all potential human engineering guidelines as stated in recognized, authoritative sources (see References).

2. To remove guidelines that were totally irrelevant to control room operations or design (e.g., Arctic dress).

3. To synthesize similar guidelines into one and list.

4. To draft guideline statements (text).

5. To determine general types of human error that would result from a discrepancy.

6. To develop suggestions for backfits that would mitigate the effects of, or correct discrepancies from the guideline.

7. To develop guidebook organization (table of contents), as well as format, typography, and graphics guidelines.

8. To prepare and review guidelines.

As can be seen, unless a guideline is totally irrelevant to control room design operations, it was included in the guidebook. This was done to ensure completeness. Guidelines with little or no applicability to control rooms but included in the guide will not impact the evaluation or its results. However, guidelines incorrectly omitted may prevent the identification of important discrepancies.

2.0 HUMAN ENGINEERING GUIDELINES

Described below are guidelines to be applied in human engineering evaluations of nuclear power plants. Each guideline contains:

- The general category of the guidelines (controls; operator/computer interface; and dialog)
- A descriptive title
- The text of the guideline
- Human errors that might result from violating the guideline
- The source (documentation) of the guidelines
- Typical backfits that would correct the operator-control room interface design or mitigate the error consequences of violating the guidelines.

REFERENCES

Altaman, J.W. Human factors methods for equipment design. Pittsburgh: American Institute for Research, J.D. Folley (ed.), 1960.

ANSI/ANS N2.3, Illinois: American Nuclear Society, 1967.

Chapanis, A. Man-machine engineering. Monterey, Cal.: Brooks/Cole, 1965.

Damon, The human body in equipment design. Cambridge: Harvard University Press, 1966.

DeGreene, K.B. Systems Psychology. New York: McGraw-Hill, Inc., 1970.

Diffrient, N., Tilley, A.R., and Bardagjy, J.C. Humanscale 1/2/3. Massachusetts: Henry Dreyfuss Associates, 1979.

Dreyfuss, H. The Measure of Man. New York: Whitney Library of Congress, 1967.

Eike, D.R., Malone, T.B., Fleger, S.A., and Johnson, J.H. Human engineering design criteria for modern control/display components and standard parts. Unpublished manuscript, 1980. (Available from The Essex Corporation, 333 North Fairfax, St., Alexandria, Virginia 22314)

Engel, S.E., and Granda, R.E. Guidelines for man/display interfaces. (Tech. Rep. 00.2720). IBM, December, 1975.

Folley, John D. Jr., Joyce, R.P., and Mallory, W.J. Fully Proceduralized Job Performance Aids Volume II - Developer's Handbook, (AFHRL-TR-71-53). Brooks Air Force Base, Texas: Air Force Human Resources Laboratory, December 1971. (NITS No. AD-744007)

Kaufman, J.E., and Christensen, J.F., (eds.) IES Lighting Handbook (5th ed.). New York: IES, 1972.

Kubokawa, C., Woodson, W., and Selby, P. Databook for human factors engineers, Volume I: Human engineering data. Moffett Field Cal.: NASA Ames Research Center, 1969. (NTIS No. N71-25944

McCormick, E.J. Human factors in engineering an design (4th ed.). New York: McGraw-Hill, Inc., 1976.

Meister, D. Human Factors: Theory and practice. New York: John Wiley and Sons, Inc., 1971.

Meister, D. and Rabideau, G.F. Human Factors Evaluation In System Development. New York: John Wiley and Sons, 1965.

MIL-HDBK-759, Human factors engineering design for army material. March, 1975. Copies are available from U.S. Government Printing Office, Washington, D. C. 20402.

MIL-STD-1472B, Human engineering design criteria for military systems, equipment and facilities. December, 1974.

Parker J.F., and West V.R. Bioastronautics data book (2nd ed.). Washington, DC: NASA SP-3006, 1973.

Seminara, J.L., Gonzalez, W.R., and Parsons, S.O., Human factors review of nuclear power plant control room design. EPRI NP-309, November 1976.

Van Cott, H.P. and Kinkade, R.G. Human engineering guide to eqiupment design. Washington, DC: American Institute for Research, 1972. (U.S. Government Printing Office Stock No. 008-051-00050-0)

Woodson, W.E., and Conover, D.W. Human engineering guide for equipment designers. Los Angeles, Cal.: University of California Press, 1964.

CONTROL ROOM ENVIRONMENT

(CRE)

CRE

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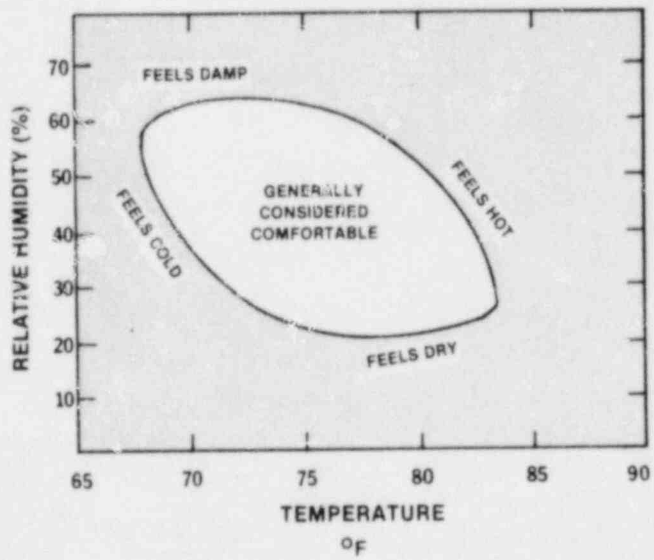
A. **TITLE:** COMFORT ZONE TEMPERATURE/HUMIDITY

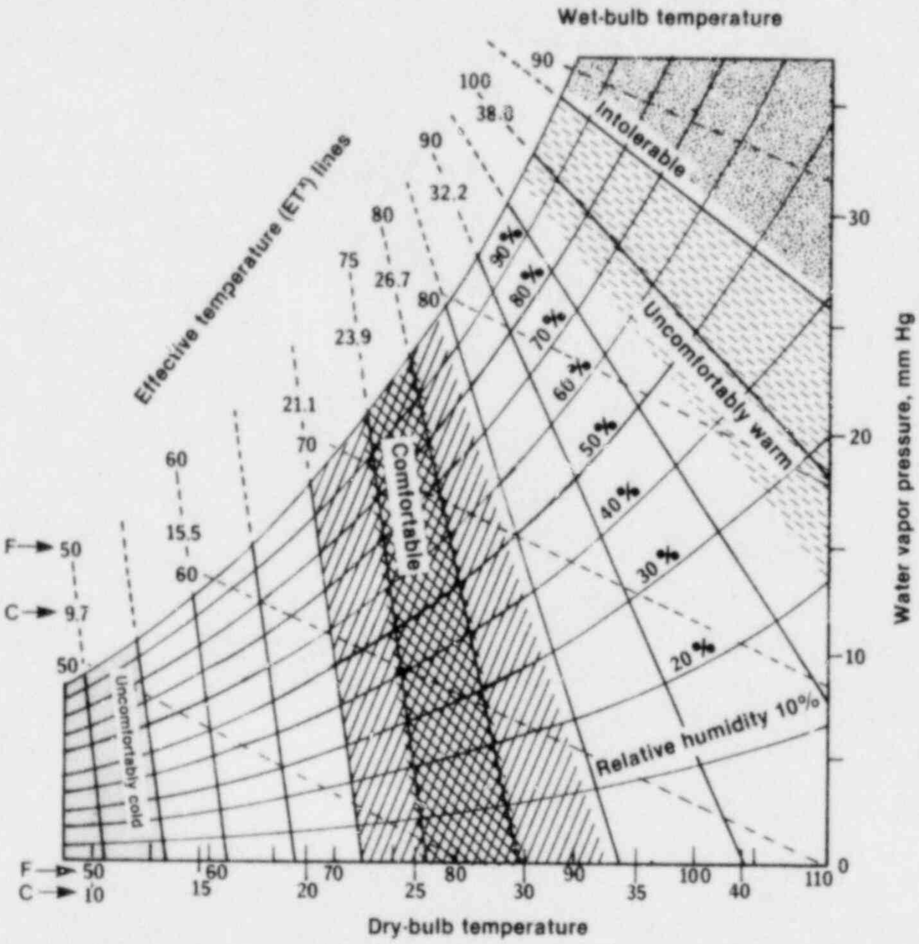
B. **GUIDELINES:** Temperature and humidity requirements shall not exceed the limits (comfort zone) given in the figure at right. Optimal thermal conditions occur when the effective temperature is between 72 and 78°F with relative humidity values between 20 and 60%. Under no conditions shall the temperature of the air at floor level and head level differ by more than 10°F.



C. **HUMAN ERROR:** Errors due to impaired judgment, reduced decision making capability.

D. **DOCUMENTATION:** Woodson and Conover (1964); Kubokawa (1969); MIL-STD-1472B (1974); McCormick (1976).

E. **TYPICAL BACKFIT:** Modify or replace air conditioning, humidifier, dehumidifier, or heating system, to meet comfort zone criteria on the following page.

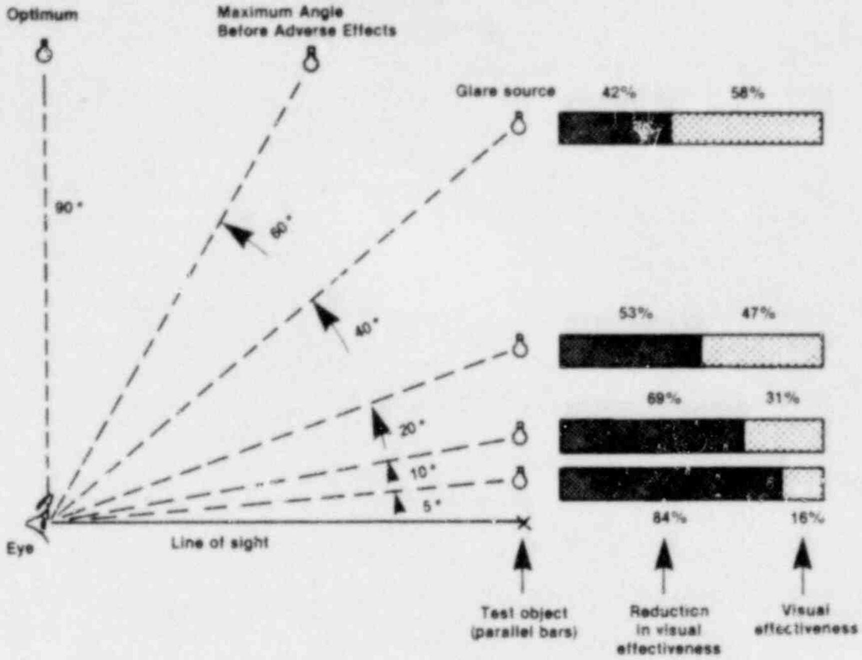


New effective temperature (ET*) scale. Each ET* line represents combinations of dry-bulb temperature and relative humidity that generally produce the same level of skin "wettedness" caused by regulatory sweating. The figure also shows areas of various thermal sensations.

A. TITLE: GLARE

B. GUIDELINES:

1. Several low intensity light sources shall be used instead of a few bright ones.
2. Light sources shall be positioned at least 60° from the viewer's line of sight.
3. Light baffles or diffuse indirect lighting shall be used.
4. Instrument consoles shall have a dull matte finish.
5. If reflection or glare is a problem, the glass covers of the instruments and displays should be sloped slightly off perpendicular to the line of sight.
6. Reflected glare from the CRT shall be minimized through one or more of the following methods.
   a. Proper placement of the CRT relative to the light source.
   b. Directional or spectrum filters.
   c. Use of a hood or shield.
   d. Optical coatings or filters over the light source.



Effects of direct glare on visual effectiveness. The effects of glare become worse as the glare source gets closer to the line of sight.

C. **HUMAN ERROR:** Failure to respond to displayed information; misreading a display.

D. **DOCUMENTATION:** Woodson and Conover (1964); Van Cott and Kinkade (1972); Bioastronautics Data Book (1973).

E. **TYPICAL BACKFIT:** Add more "less intense" luminaires; slope glass covers on the instruments and displays; paint consoles a dull matte color; use a hood or shield on CRTs; place optical filters or coatings over the light source.

A. **TITLE: SHADOW AND SURFACE COLOR**

B. **GUIDELINES:**

1. Ambient illumination shall be provided via indirect or diffuse lighting; direct lighting shall be avoided.
2. Dark shades of gray, green, blue, red, and brown shall not be used on ceilings, walls or consoles; pastels and light grays are recommended.

C. **HUMAN ERROR:** Misreading a display; misreading a label.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972)

E. **TYPICAL BACKFIT:** Install new lighting fixtures; repaint ceilings, walls, and/or consoles.

CONTROL ROOM ENVIRONMENT

A. TITLE: REFLECTANCE

B. GUIDELINES: Workplace reflectances shall conform to those recommendations listed in the table below.

Surface	Reflectances	
	Preferred	Permissible
Ceiling[1]	80%	80-90%
Upper Wall	50%	50-60%
Lower Wall	15-20%	
Instruments/Displays	80-100%	
Cabinet/Consoles	20-40%	
Floor	30%	15-30%
Furniture	35%	25-45%
Chalkboards	[2]15%	15-20%

[1] Recommended reflectances are for finish only. Over-all average reflectance of acoustic materials may be somewhat lower. The upper walls (one to two feet below the ceiling) may be painted with the same paint as is used on the ceiling.

[2] In-service "chalked" value. Reflectance of clean board should be as least 5% lower.

The table on the following page can be used in determining an approximate estimate of reflectance values for various surface colors.

Approximate Reflectance Factors for Various Surface Colors

Color	Reflectance	Color	Reflectance
White	85		
Light:		Dark:	
Cream	75	Gray	30
Gray	75	Red	13
Yellow	75	Brown	10
Buff	70	Blue	8
Green	65	Green	7
Blue	55		
Medium:		Wood Finish:	
Yellow	65	Maple	42
Buff	63	Satinwood	34
Gray	55	English Oak	17
Green	52	Walnut	16
Blue	35	Mahogany	12

C. **HUMAN ERROR:** Misreading a display; misreading a label.

D. **DOCUMENTATION:** Kubokawa (1969); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Repaint as necessary.

CONTROL ROOM ENVIRONMENT

A. TITLE: LUMINANCE RATIO

B. GUIDELINES: To insure uniform light distribution and thus legibility, the following luminance ratio shall not be exceeded.

RECOMMENDED LUMINANCE RATIOS

Areas	Recommended maximum luminance ratio
Task and adjacent darker surroundings	3:1
Task and adjacent lighter surroundings	1:3
Task and more remote darker surfaces	10:1
Task and more remote lighter surfaces	1:10
Luminaires (or windows, etc.) and surfaces adjacent to them	20:1
Anywhere within normal field of view	40:1

C. HUMAN ERROR: Misreading a display.

D. DOCUMENTATION: Van Cott and Kinkade (1972); McCormick (1976)

E. TYPICAL BACKFIT: Adjust light sources as necessary.

A. TITLE: DISPLAY LIGHTING

B. GUIDELINES: Indicator and panel lighting should conform to the recommendations outlined below:

Condition of Use	Lighting Technique	Luminance of Markings (Ft-L)	Brightness Adjustment
Indicator Reading	White Flood	1-20	Fixed or Continuous
Panel Monitoring	White Flood	10-20	Fixed or Continuous
Chart Reading	White Flood	5-20	Fixed or Continuous

C. HUMAN ERROR: Misreading labels and/or displays.

D. DOCUMENTATION: Woodson and Conover (1964); Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Modify or replace light sources as necessary.

CONTROL ROOM ENVIRONMENT

Work Area or Type of Task	Lighting (foot-candles*)	
	Recommended	Minimum
Console Surface	50	30
Dials	50	30
Gages	50	30
Meters	50	30
Panels:		
front	50	30
rear	30	10
Reading:		
handwritten reports, in pencil	70	50
large print	30	10
small type	70	50
Scales	50	30

* As measured on the task object or 30 inches above floor.

A. TITLE: ILLUMINATION LEVELS

B. GUIDELINES:

1. Portable lights shall be provided for personnel performing visual tasks in areas where fixed illumination is not provided.
2. Illumination levels shall be in accordance with the recommendations in the table to the left.

C. **HUMAN ERROR:** Misreading a display or label.

D. **DOCUMENTATION:** Chapanis (1965); Kubokawa (1969); Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Adjust luminaires as necessary.

A. **TITLE: ACOUSTICAL NOISE**

B. **GUIDELINES:** Acoustic materials with high sound-absorption coefficients should be provided as necessary in the construction of floors, walls, and ceiling to effect the required sound control. In the physical layout of rooms and work stations, excessive noise should be attenuated by such means as staggered construction of walls, staggering of doors in corridors or between rooms, and use of thick-paned or double-paned windows. Under normal operating conditions the ambient noise level shall not exceed 65 dB(A), or 58 dB PSIL.

C. **HUMAN ERROR:** Failure to respond to auditory signals.

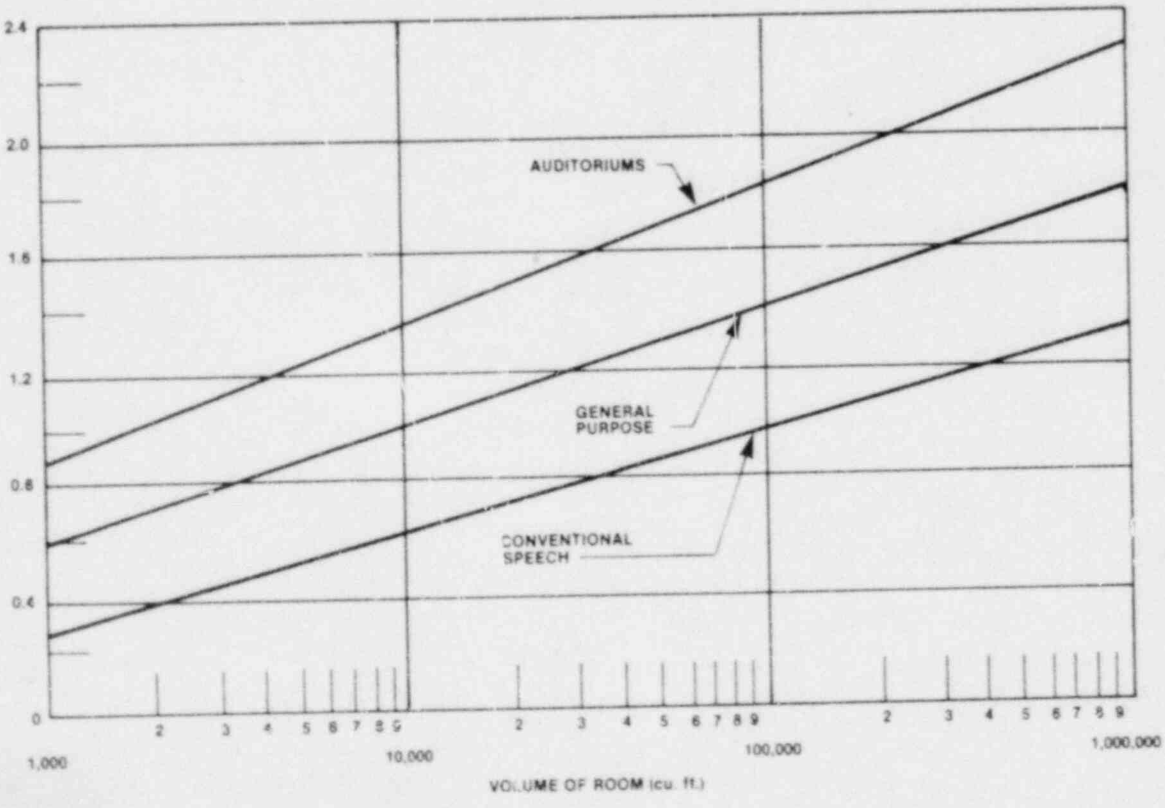
D. **DOCUMENTATION:** MIL-STD-1472B; MIL-HDBK-759 (1975); Kubokawa (1969); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Provide attenuation as necessary.

CONTROL ROOM ENVIRONMENT

A. TITLE: REVERBERATION

B. GUIDELINES: The acoustical treatment of control rooms shall be sufficient to reduce reverberation time to the applicable limits in accordance with the figure below.



RANGE OF ACCEPTABLE REVERBERATION TIME

C. **HUMAN ERROR:** Failure to respond to auditory signals.

D. **DOCUMENTATION:** MIL-STD-1472B (1974)

E. **TYPICAL BACKFIT:** Install acousti sound absorption materials.

CONTROL ROOM ENVIRONMENT

A. TITLE: SOUND CONDITIONING

B. GUIDELINES: The average room sound absorption coefficient shall be at least 0.20.

C. HUMAN ERROR: Failure to respond to auditory signals.

D. DOCUMENTATION: MIL-STD-1472B

E. TYPICAL BACKFIT: Install acoustic sound absorption materials.

A. **TITLE: VENTILATION**

B. **GUIDELINES:** Air shall be introduced into the control room at a minimum rate of 30 cubic feet per minute per man; approximately two-thirds of which should be outside air. Air shall be moved past the man at a velocity no greater than 100 feet per minute, 65 feet per minute if possible. Intakes for ventilation systems shall be so located as to preclude/prevent the introduction of contaminated air. Air shall not blow directly on operators.

C. **HUMAN ERROR:** Increased likelihood of error due to fatigue.

D. **DOCUMENTATION:** Woodson and Conover (1964); Kubokawa (1969); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify or replace system as necessary.

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A. TITLE: GENERAL WORKSPACE HAZARDS

B. GUIDELINES:

1. Handrails shall be affixed to platforms, stairs, and around floor openings, wherever personnel may fall from an elevation.
2. Emergency doors and exits shall be readily accessible and quick to open. The design should allow the door or hatch to be opened by a single motion of hand or foot. Provisons should be made for emergency exit from secure or classified areas.
3. Areas shall be specifically identified where protective clothing, tools, or equipment, such as insulated shoes, nonsparking tools, gloves, or suits, are necessary.
4. Adequate illumination shall be provided in all work and work access areas. Work areas should be illuminated by at least 20 ft.-c., access areas by at least 8 ft.-c.
5. Exposed edges shall be rounded to a minimum radius of 0.40 inch, and exposed corners to a minimum of 0.5 inch.

C. **HUMAN ERROR:** Inadvertent operation; accidental operation; personnel injury.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Provide safeguards as applicable.

A. **TITLE: FIRE EXTINGUISHERS**

B. **GUIDELINES:** Portable, hand operated fire extinguishers shall be located throughout the control room in a visible and easily accessible location.

C. **HUMAN ERROR:** Failure to locate fire extinguishers.

D. **DOCUMENTATION:** MIL-HDBK-759 (1975).

E. **TYPICAL BACKFIT:** Install fire extinguishers of the appropriate type.

CONTROL ROOM ENVIRONMENT

A. TITLE: EQUIPMENT FAILURE

B. GUIDELINES: Displays shall be designed to provide positive indication when equipment has failed or is not operating within tolerance limits.

C. HUMAN ERROR: Failure to detect equipment failure.

D. DOCUMENTATION: MIL-STD-1472B.

E. TYPICAL BACKFIT: Provide for out-of-tolerance or equipment failure feedback.

A. **TITLE: CRITICAL MALFUNCTIONS**

B. **GUIDELINES:** If equipment is not regularly monitored, an auditory alarm shall be provided to indicate critical malfunctions.

C. **HUMAN ERROR:** Failure to identify equipment malfunction.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Install alarm(s) to respective equipment.

WORKSPACE ARRANGEMENT

(WA)

WA

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A. **TITLE: DISPLAY PLACEMENT FOR STANDING OPERATORS**

B. **GUIDELINES:** Normal Displays — Visual displays mounted on vertical panels and used in normal equipment operation shall be placed in an area 41 to 70 inches above the standing surface.

Special Displays — Indicators that must be read precisely and frequently shall be placed in an area 50 to 65 inches above the standing surface.

C. **HUMAN ERROR:** Misreading the display.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relocate displays.

WORKSPACE ARRANGEMENT

A. **TITLE: DISPLAY PLACEMENT FOR SEATED OPERATORS**

B. **GUIDELINES:** Normal Displays — Visual displays mounted on vertical panels and used in normal equipment operation shall be placed in an area 6 to 46 inches above the sitting surface.

Special Displays — Indicators that must be read precisely and frequently shall be placed in an area 14 to 35 inches above the sitting surface, and no further than 21 inches laterally from the centerline.

Warning Displays — For "sit" consoles requiring horizontal vision over the top, critical visual warning displays shall be mounted at least 22.5 inches above the sitting surface.

C. **HUMAN ERROR:** Misreading the display.

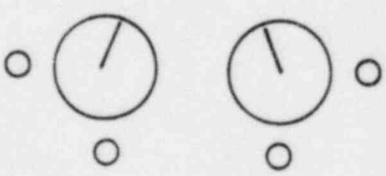
D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relocate displays.

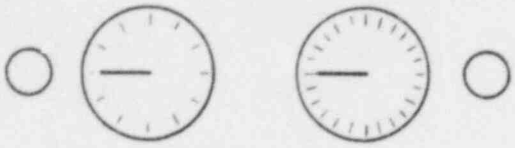
A. TITLE: CONTROL PLACEMENT FOR STANDING OPERATORS

B. GUIDELINES:

1. For precision and speed, one-handed controls are preferable to those requiring both hands.
2. Controls should be located to avoid requirements for operating from awkward or uncomfortable positions like stooping, kneeling, or crouching.
3. Controls operated with the whole hand should be located within approximately 27 inches of the back of the operator's shoulder.
4. Finger-operated controls should be located within approximately 29 inches from the same shoulder reference point.
5. Controls should be placed:
   a. Close to the displays they affect.
   b. Below or to the left for left-hand operation; below or to the right for right-hand operation.



   c. So that there is an equitable distribution of workload



between right and left hands; right-hand operation should be reserved for operations requiring the finest adjustment.

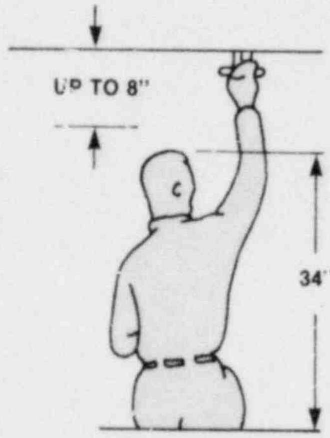
6. Controls shall be located such that simultaneous operation of two controls does not necessitate a crossing or interchanging of hands.
7. All controls mounted on a vertical surface and used in normal equipment operation shall be located in an area 34 to 74 inches above the standing surface.
8. Controls requiring precise or frequent operation and emergency controls shall be mounted 34 to 57 inches above the standing surface.
9. Controls requiring fine adjustments should be located closer to the operator's line of sight than controls requiring gross positioning.

C. **HUMAN ERROR:** Activating the wrong control; reading the wrong display; poor control adjustment; incorrect operation.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-HDBK-759 (1975); Damon (   ); Van Cott and Kinkade (1972); Woodson and Conover (1972).

E. **TYPICAL BACKFIT:** Relocate controls.

WORKSPACE ARRANGEMENT



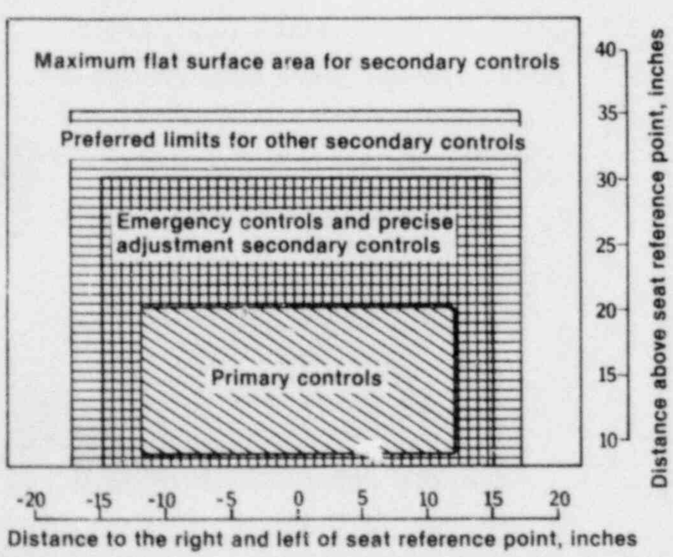
A. TITLE: CONTROL PLACEMENT FOR SEATED OPERATORS

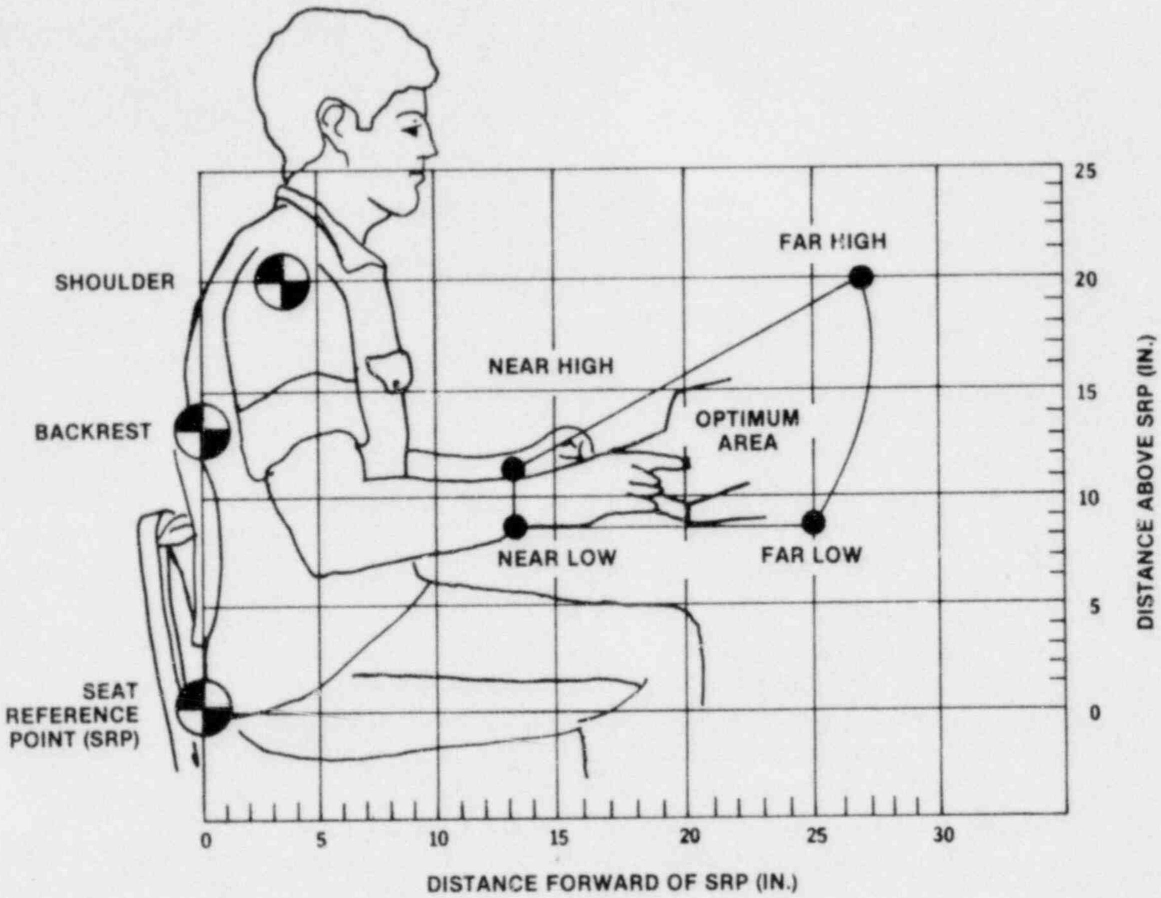
B. **GUIDELINES:** All controls mounted on a vertical surface shall be located in an area no greater than 8 inches above the head of the seated 5th percentile operator (42.3 inches above the seat) and no further than 18 inches laterally from the centerline. Primary controls (controls which must be operated frequently or are critical to operations) should be located between shoulder level and waist height (see figures at left and right).

C. **HUMAN ERROR:** Incorrect operation; activating the wrong control.

D. **DOCUMENTATION:** MIL-HDBK-759 (1977); Woodson and Conover (1964); McCormick (1976).

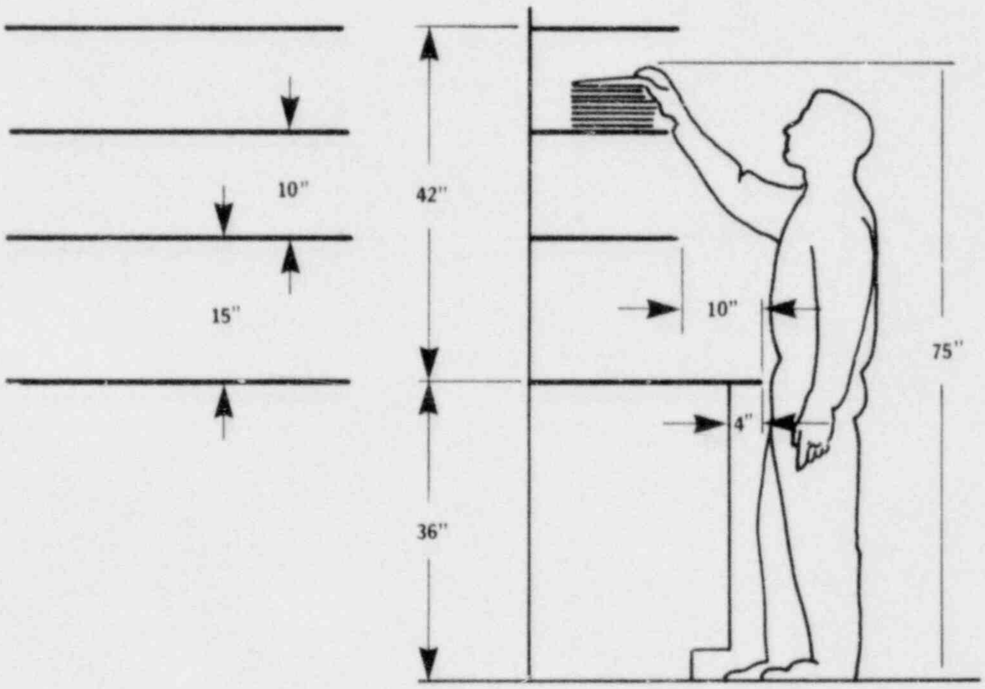
E. **TYPICAL BACKFIT:** Relocate controls.




SHOULDER
BACKREST
SEAT
REFERENCE
POINT (SRP)
FAR HIGH
NEAR HIGH
OPTIMUM
AREA
NEAR LOW
FAR LOW
25
20
15
10
5
0
DISTANCE ABOVE SRP (IN.)
0
5
10
15
20
25
30
DISTANCE FORWARD OF SRP (IN.)

A. **TITLE: SHELF DIMENSIONS**

B. **GUIDELINES:** Shelves shall be located such that their contents can be both seen and reached. Under no circumstances shall the top shelf be higher than 76 inches. Other recommended dimensions can be seen in the figure below.



C. **HUMAN ERROR:** Mistake in retrieval safety (toppling).

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Adjust, modify or replace shelves.

A. **TITLE: SPECIAL TOOLS**

B. **GUIDELINES:** Special tools required for operational adjustment shall be securely mounted in a readily accessible location.

C. **HUMAN ERROR:** Equipment damage, erroneous use of tools.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Establish accessible location for tools.

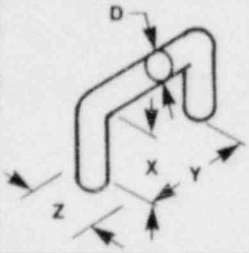
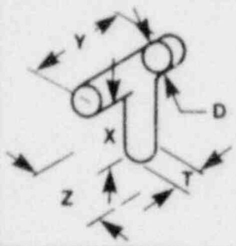
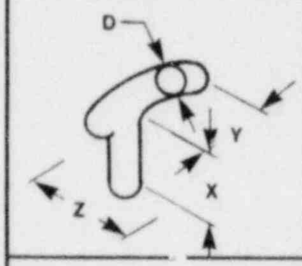
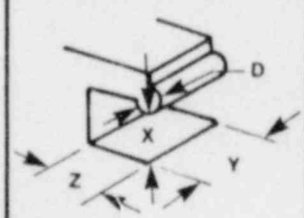
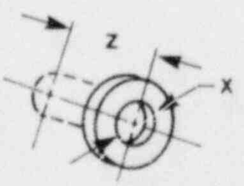
A. **TITLE: HANDLE DIMENSIONS**

B. **GUIDELINES:** Handles which are to be used with gloved or ungloved hands shall equal or exceed the minimum applicable dimensions shown in the figure on following page.

C. **HUMAN ERROR:** Dropping equipment; damage to system instrumentation.

D. **DOCUMENTATION:** MIL-STD-1472B.

E. **TYPICAL BACKFIT:** Modify handle diameters; replace with new handles.

ILLUSTRATIONS	TYPE OF HANDLE	DIMENSIONS IN INCHES (in mm)					
		(Bare Hand)			(Gloved Hand)		
		X	Y	Z	X	Y	Z
	Two-finger bar	1.25	2.5	3.0	1.5	3.0	3.0
	One-hand bar	2.0	4.5	3.0	3.5	5.25	4.0
	Two-hand bar	2.0	8.5	3.0	3.5	10.5	4.0
	T-bar	1.5	4.0	3.0	2.0	4.5	4.0
	J-bar	2.0	4.0	3.0	2.0	4.5	4.0
	Two-finger recess	1.25	2.5	2.0	1.5	3.0	2.0
	One-hand recess	2.0	4.25	3.5	3.5	5.25	4.0
	Finger-tip recess	0.75		0.5	1.0		0.75
	One-finger recess	1.25		2.0	1.5		2.0

Curvature of Handle or Edge

Weight of Item	Minimum Diameter
Up to 15 lbs	D - 1/4 in.
15 to 20 lbs	D - 1/2 in.
20 to 40 lbs	D - 3/4 in.
Over 40 lbs	D - 1 in.
T-bar Post	T - 1/2 in.

Gripping efficiency is best if finger can curl around handle or edge to any angle of 120 degrees or better.

A. **TITLE: ROLLOUT RACKS, SLIDES OR HINGES**

B. **GUIDELINES:**

1. Units which are frequently pulled out of their installed positions for checking shall be mounted on rollout tracks, slides, or hinges. Rollout racks should not shift the center of gravity to the extent that the entire rack or console falls. If this possibility exists, the console or rack shall be safely secured.
2. Limit stops shall be provided on racks and drawers which are required to be pulled out of their installed positions for checking or maintenance. The limit stop design shall permit convenient overriding of stops for unit removal.
3. Hinged units shall be provided with a brace or other means to hold units in the "out" position during checking or maintenance.

C. **HUMAN ERROR:** Failure to access components, personal injury.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Install rollout racks; limit stops and/or braces as necessary.

A. **TITLE: LATERAL WORKSPACE**

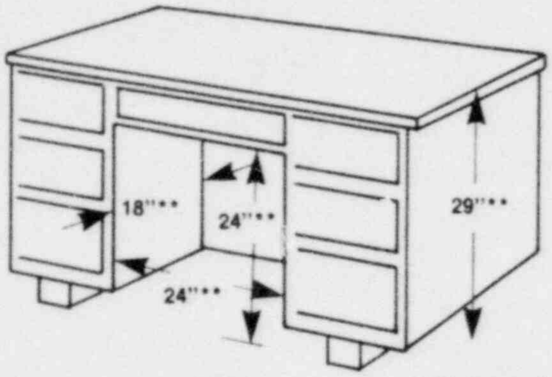
B. **GUIDELINES:** The minimum lateral workspace for racks having drawers shall be as follows (measured from drawers in the extended position):

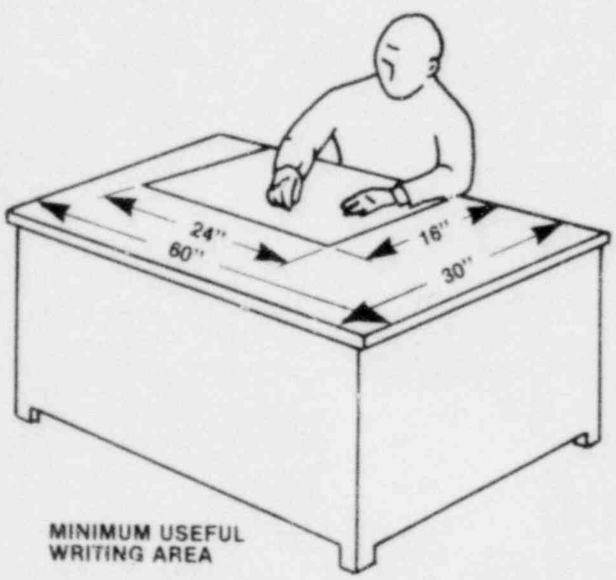
1. For racks having drawers weighing less than 45 pounds: 18 inches on one side and 4 inches on the other.
2. For racks having drawers weighing over 45 pounds: 18 inches on each side.

C. **HUMAN ERROR:** Failure to access components.

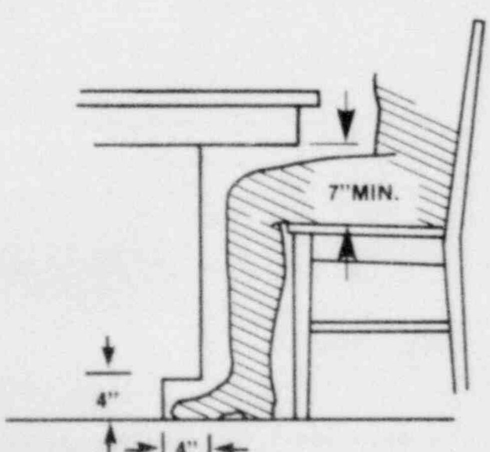
D. **DOCUMENTATION:** MIL-STD-1472B

E. **TYPICAL BACKFIT:** Relocate racks to provide adequate lateral workspace.





MINIMUM USEFUL WRITING AREA



KNEE ROOM AND KICK SPACE

A. TITLE: DESKS

B. GUIDELINES:

1. Height - Desk tops and writing tables shall be 29 to 31 inches above the floor.
2. Work Surface - When writing is required the work surface shall have a depth of at least 16 inches and a width of 24 inches. When other tasks are involved, the minimum width shall be expanded to 30 inches.
3. Knee Room Height - The minimum distance between the top of the seated surface and the bottom of the writing surface shall be 7".
4. Kick Room Height and Depth - A minimum kick space 4 inches deep by 4 inches high shall be provided.

C. HUMAN ERROR: Delay in accessing manuals, etc.

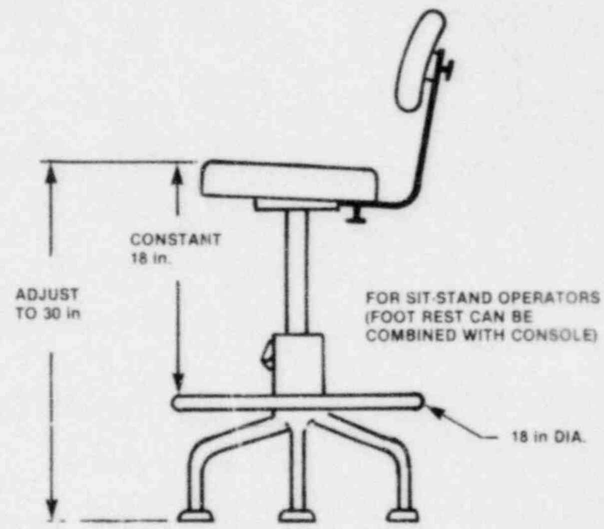
D. DOCUMENTATION: Woodson and Conover (1964); Kubokawa (1969); MIL-STD-1472B (1974); McCormick (1976).

E. TYPICAL BACKFIT: Remove equipment, books, etc. from work surface; modify or replace desks and/or tables.

A. TITLE: SEATING

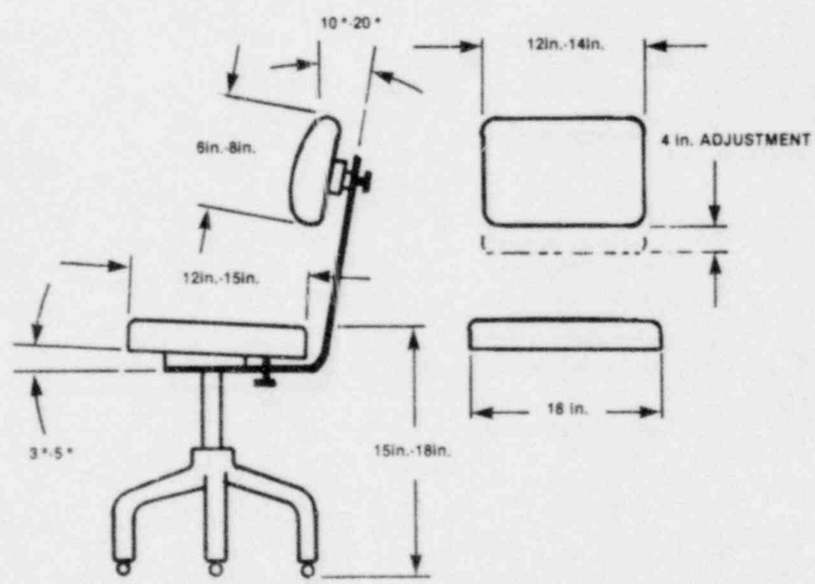
B. **GUIDELINES:** Seating criteria shall conform to the guidelines listed below.

1. Width — The seat width shall be at least 17 inches, and preferably 18 inches.

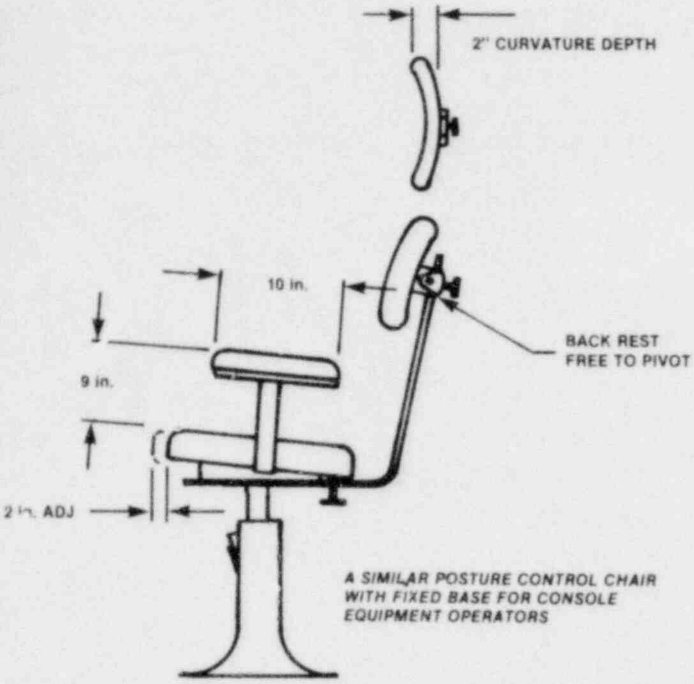


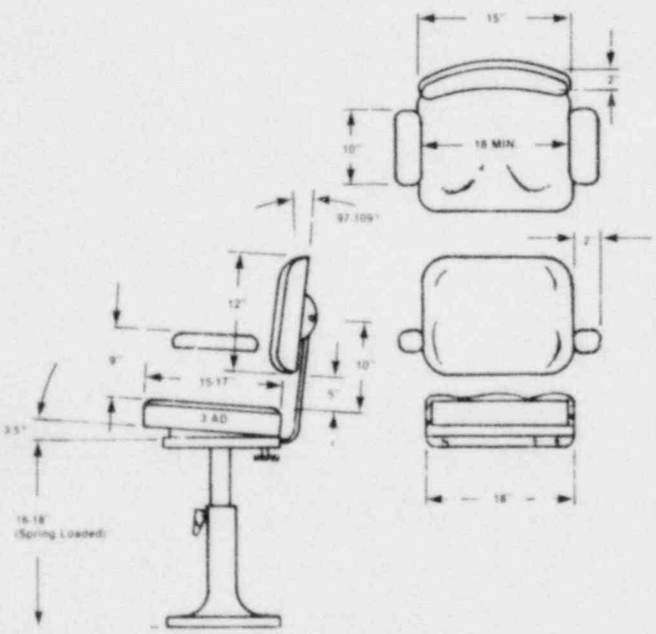
2. Backrest — A supporting backrest that reclines between 103° and 115° shall be provided with preference given towards the smaller angle. The backrest shall engage the lumbar and thoracic regions of the back, and shall support the torso in such a position that the operator's eyes can be brought to the "Eye Line" with no more than 3 inches of forward body movement.
   a. Curvature. Backrests which afford only lumbar support should not have a lateral curvature deeper than that of a circle 7.3 inches in radius. A shallower curvature is preferable.

3. Cushioning — Where applicable, both the backrest and seat shall be cushioned with at least 1 inch of compressible material and



CHAIR WITH MOBILE BASE





provided with a smooth surface. Padding shall be sufficient to prevent the subject from compressing the material to its absolute limit; there should be some resiliency remaining.

4. Adjustability —
   a. Fore-and-Aft. For fixed seating, 6 to 8 inches of adjustment, in 1-inch increments, shall be provided.
   b. Vertical. Vertical seat adjustment from 15 to 21 inches in increments of no more than 1 inch shall be provided. For sit-stand operators, vertical height shall be adjustable to 30 inches.
5. Knee Room — Knee and foot room that equals or exceeds the following minimum dimensions shall be provided beneath work surfaces:
   a. Height. 25 inches. If a footrest is provided, this dimension shall be increased accordingly.
   b. Width. 20 inches.
   c. Depth. 18 inches.

C. **HUMAN ERROR:** Operational errors resulting from fatigue or inability to reach components.

D. **DOCUMENTATION:** Woodson and Conover (1964); Van Cott and Kinkade (197_); MIL-STD-1472B (1974); McCormick (1976).

E. **TYPICAL B[illegible]IT:** Modify or replace chairs.

WORKSPACE ARRANGEMENT

A. TITLE: OPERATIONAL DIMENSIONS

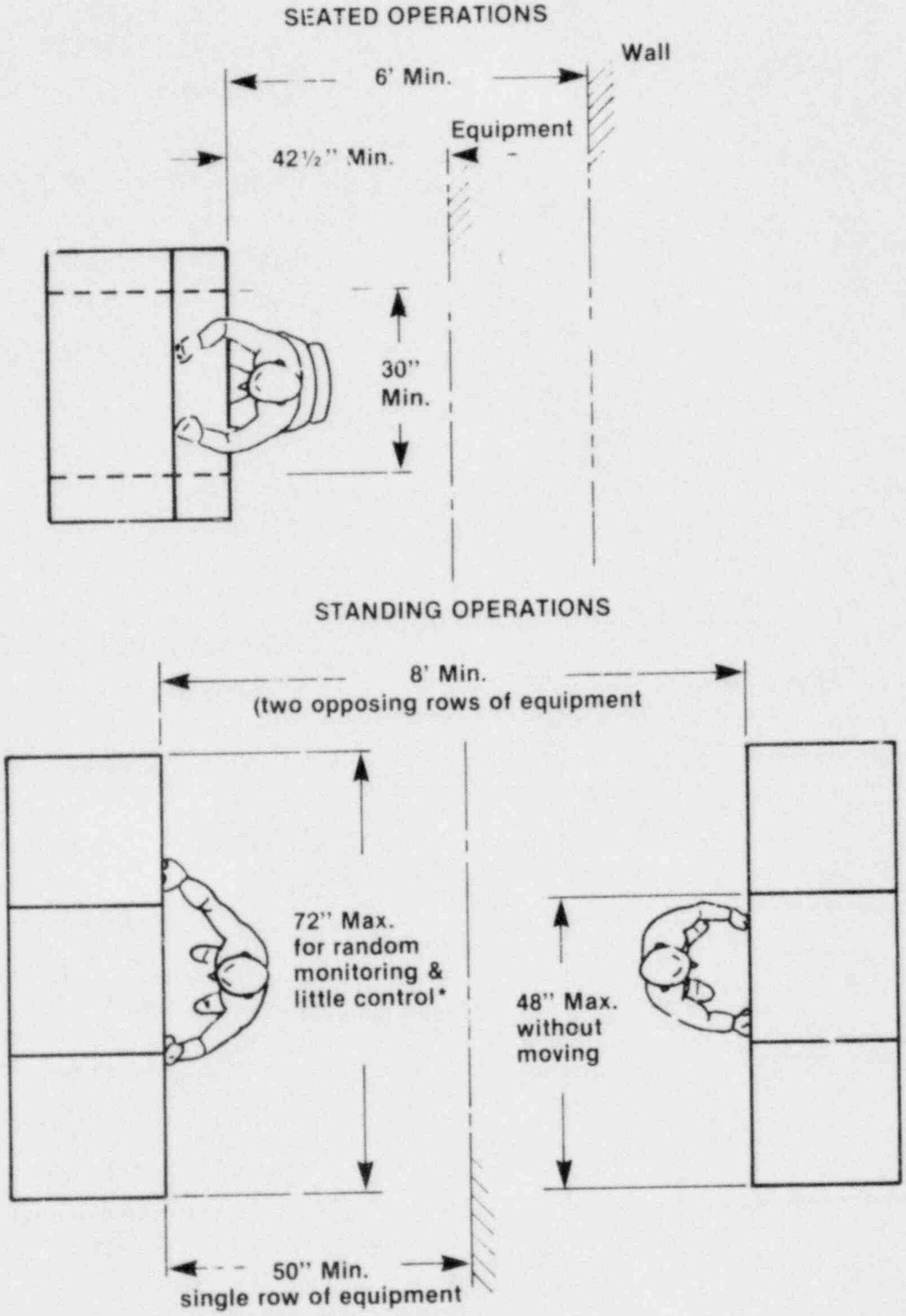
B. GUIDELINES: Operational workspace dimensions should conform to the criteria listed in the table below.

REQUIRED CLEARANCES	DIMENSION DESCRIPTION AND AREA INVOLVED	FUNCTION
Minimum 6 feet	From back of desk or console to wall (for "seeover" to wall display, and maintenance-operational functions).	operational maintenance
42½ inches	Front of console or desk (distance from leadin edge of writing shelf to back of operator equipment).	operational administration
30 inches	Per operator laterally (seated console type operation).	operational
48 inches	Per person laterally (right-handed standing operation, 30 inches to the right of the body centerline and 18 inches to the left; vice versa for the left-handed operation).	operational
50 inches	From front of equipment to opposite facing surface for momentary bending and kneeling activities, and for single row of racks - or equipment.	operational maintenance
8 feet	For two rows of equipment racks facing each other, requiring operator functions in each row and some kneeling or bending function with use of mobile test equipment.	operational maintenance

C. HUMAN ERROR: Failure to access components.

D. DOCUMENTATION: Kubokawa (1969); MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Relocate consoles.



* There is no maximum lateral dimension if equipment racks are positioned in continuous sequential order.

WORKSPACE ARRANGEMENT

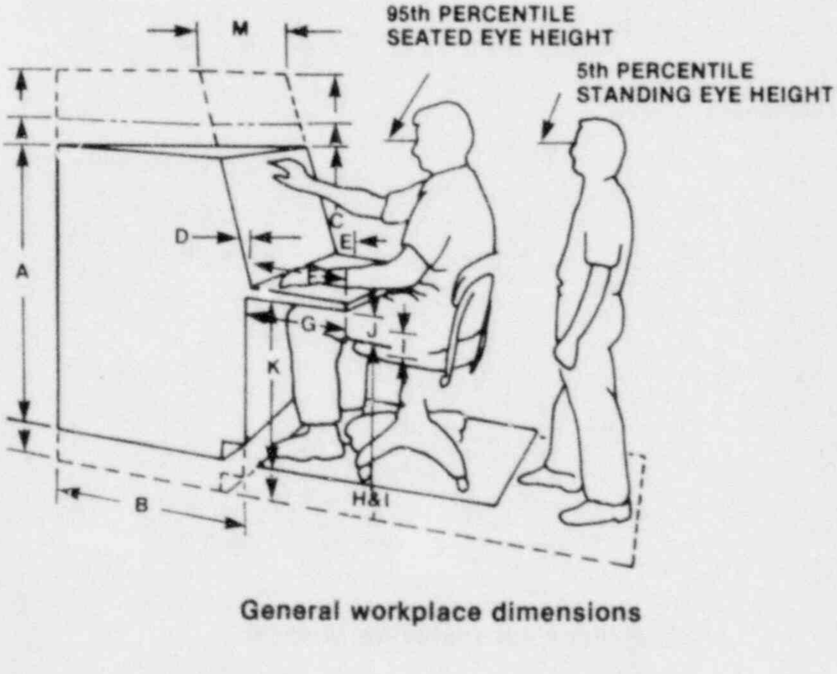
A. TITLE: STANDARD CONSOLE DIMENSIONS

B. GUIDELINES: The dimensions of instrument consoles shall conform to those guidelines listed in the figure below and the table on the following page.

C. HUMAN ERROR: Delay in control activations; delay in reading displays.

D. DOCUMENTATION: Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Design new console; modify existing consoles.



General workplace dimensions

		TYPE OF CONSOLE				
		Sit-Stand	Sit (w/vision over top)	Sit (w/o vision over top)	Stand (w/vision over top)	Stand (w/o vision over top)
A	Maximum console height from standing surface	62.0	47.5* to 58.0	51.5† to 62.0	62.0	72.0
B	Console depth at base	Opt.	Opt.	Opt.	Opt.	Opt.
C	Vertical dimension of panel, including sills	26	22	26	26	36
D	Console panel angle - from vertical	15°	15°	15°	15°	15°
E	Minimum pencil/shelf depth	4	4	4	4	4
F	Minimum writing surface depth - including pencil shelf	16	16	16	16	16
G	Minimum knee clearance	18	18	18	---	---
H	Foot support to seat‡	18	18	18	---	---
I	Seat adjustability	4	4	4	---	---
J	Minimum thigh clearance at midpoint of "I"	6.5	6.5	6.5	---	---
K	Writing surface height from standing surface	36.0	25.5 to 36.0	25.5 to 36.0	36.0	36.0
L	Seat height at midpoint of "I"	28.5	18.0 to 28.5	18.0 to 28.5	---	---
M	Maximum console panel breadth	36	36	36	---	---

*"A" must never be more than 29.5 in. greater than "L."
†"A" must never be more than 33.5 in. greater than "L."
‡When seat-to-standing surface exceeds 18 in., a heel catch should be provided.
Note: Standard values for critical dimensions used in the design of instrument consoles for the seated and/or standing operator, with and without a requirement on the operator to maintain horizontal visual contact with other display or test apparatus beyond the console.

(Refer to accompanying diagram [General workplace dimensions])

WORKSPACE ARRANGEMENT

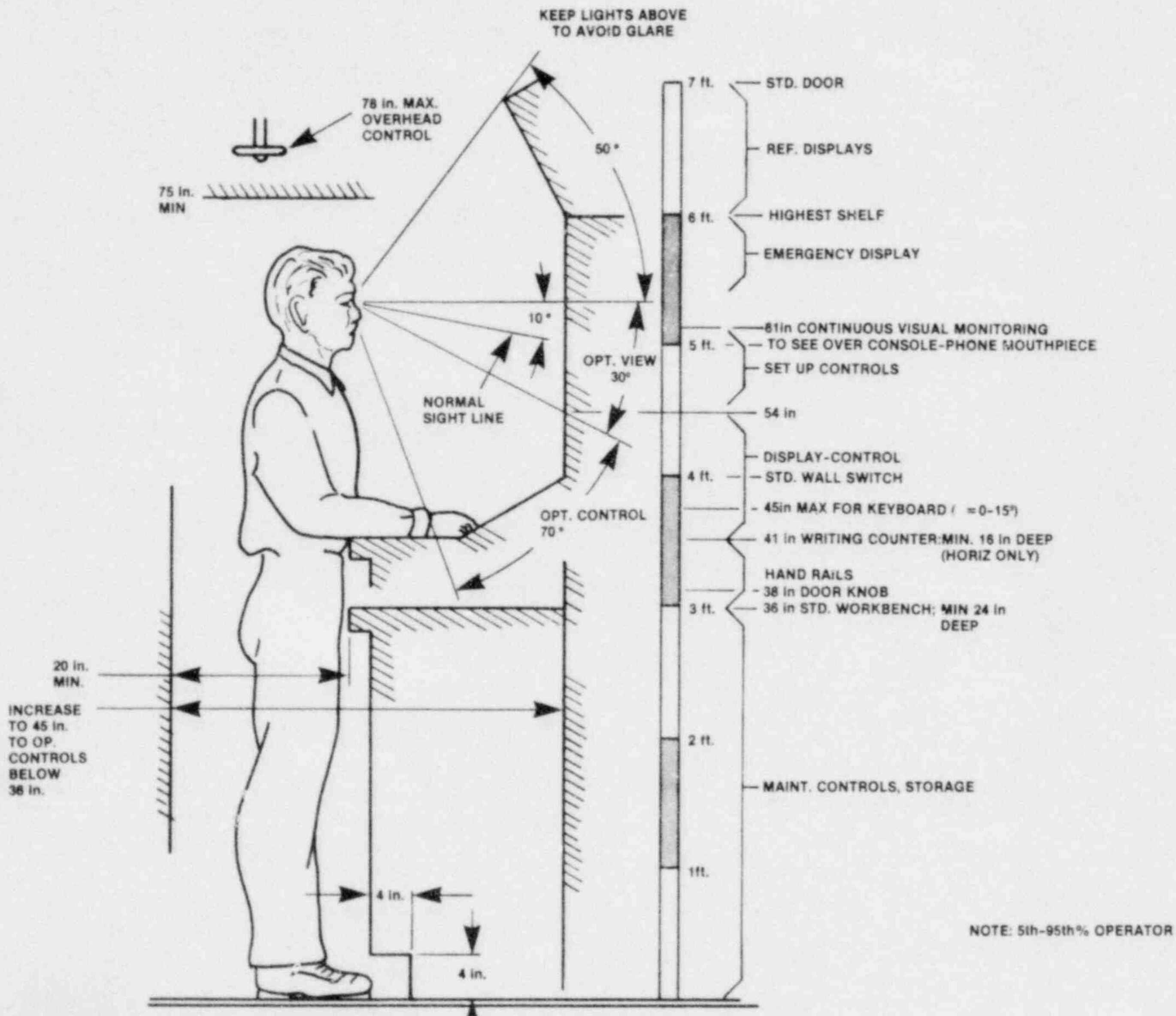
A. **TITLE: CONSOLE DIMENSIONS FOR THE STANDING OPERATOR**

B. **GUIDELINES:** Standing operator consoles shall conform to those dimensions as depicted in the figure on the following page. (See also WA-1 and WA-3)

C. **HUMAN ERROR:** Delays in activating controls or reading displays.

D. **DOCUMENTATION:** Kubokawa (1969); Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Rebuild console and rewire; replace or modify console.



STANDING OPERATOR WORKPLACE

WORKSPACE ARRANGEMENT

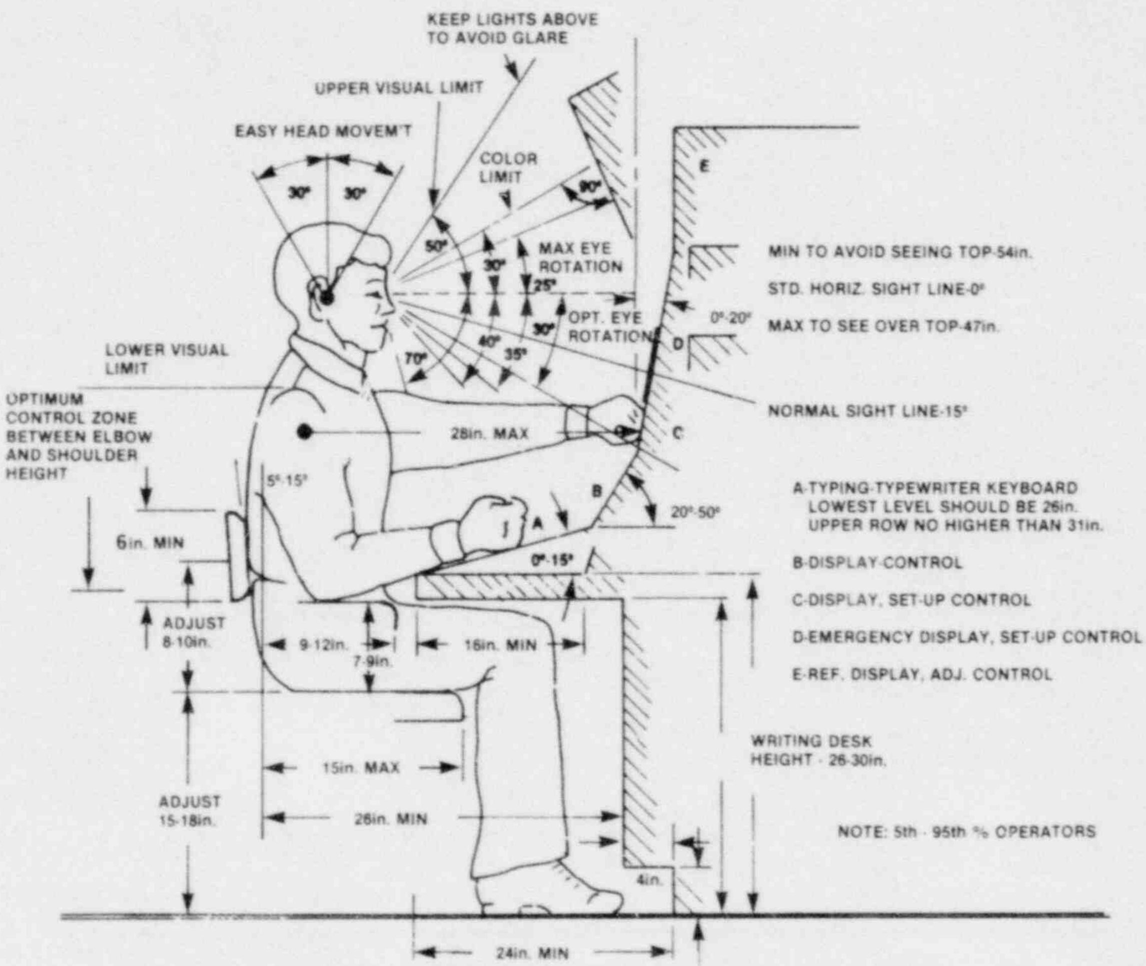
A. **TITLE: CONSOLE DIMENSIONS FOR THE SEATED OPERATOR**

B. **GUIDELINES:** Seated operator consoles shall conform to those dimensions as depicted in the figure on the following page. (See also WA-2 and WA-6)

C. **HUMAN ERROR:** Delays in activating controls or in reading displays.

D. **DOCUMENTATION:** Kubokawa (1969); Van Cott and Kinkade (1972); Bioastronautics Data Book (1973); McCormick (1976).

E. **TYPICAL BACKFIT:** Rebuild console and rewire; replace or modify console.



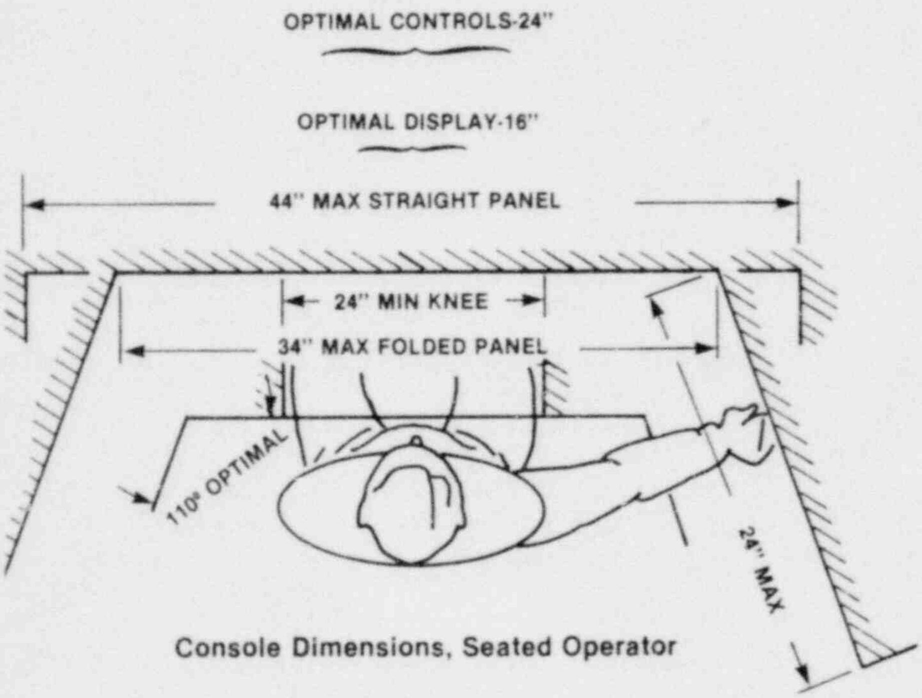
SEATED OPERATOR WORKPLACE

WORKSPACE ARRANGEMENT

A. TITLE: WRAP-AROUND CONSOLES

B. GUIDELINES:

1. Panel Width - When requirements for preferred panel space for a single seated operator exceed a panel width of 44 inches a flat-surface, segmented, wrap-around console shall be provided.
2. Panel Angle - The left and right segments shall be placed at an angle, measured from the frontal plane of the central segment, such that they can be reached by the 5th percentile stationary operator (reach = 28.6 in.). A 110° angle is recommended.
3. Dimensions (Vision Over Top) - Where vision over the top is required (thereby limiting vertical panel space), the width of the central segment shall not exceed 44 inches, and that of the left and right segments shall not exceed 24 inches.
4. Dimensions - Where vision over the top is not required, the total console height may exceed the seat height by more than 29.5 inches, the width of the central segment shall not exceed 34



Console Dimensions, Seated Operator

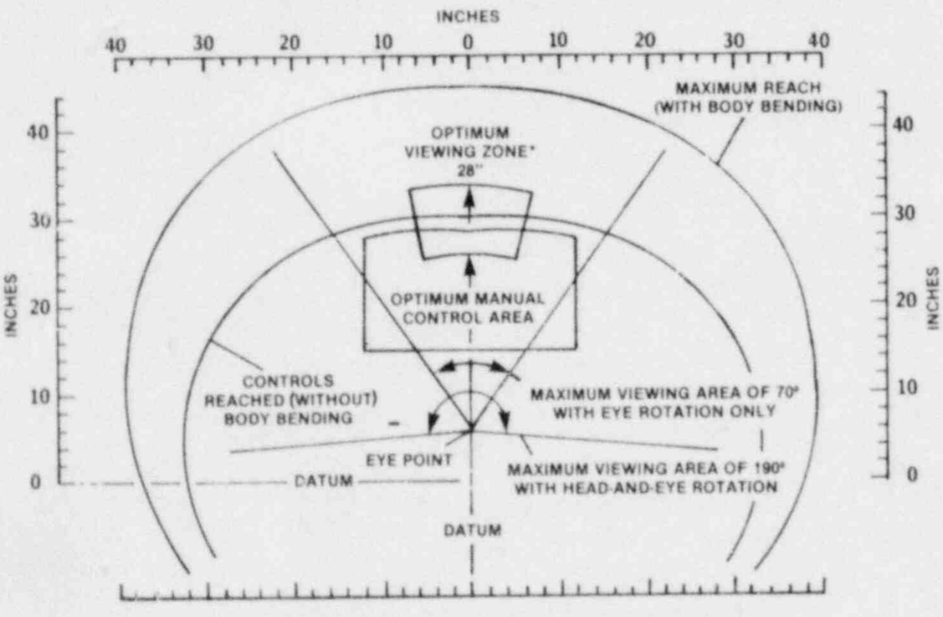
inches, and that of the left and right segments should not exceed 24 inches.

5. Viewing Angle - The total required left-to-right viewing angle shall not exceed 190°. This angle should be reduced whenever possible through appropriate control-display layout.

C. **HUMAN ERROR:** Activating the control(s) too late; failure to respond to displayed information.

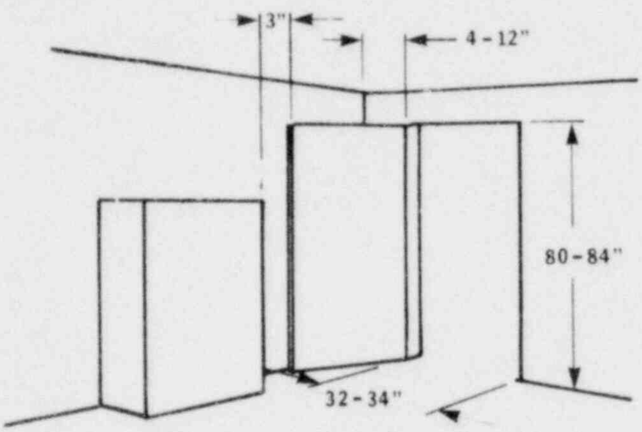
D. **DOCUMENTATION:** Kubokawa (1969); Bioastronautics Data Book (1973); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relocate, modify or replace controls, displays, or console.



*28" is maximum when viewing is limited by reach (control and display relationship). Viewing distance may be extended provided display is properly designed.

WORKSPACE ARRANGEMENT



A. TITLE: DOORS

B. GUIDELINES: Sliding doors shall never be installed as the only personnel exit from a compartment. When a sliding door is used, a separate hinged door in the sliding door should be provided for personnel use. Fixed equipment shall be at least three inches from the swept area of hinged doors.

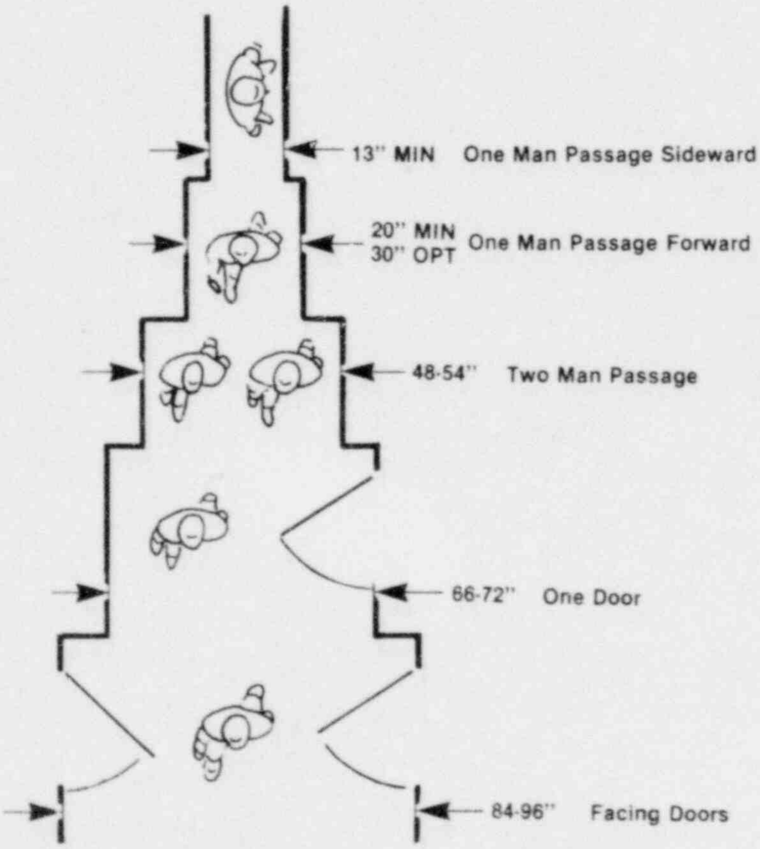
C. HUMAN ERROR: Personal injury, structural damage.

D. DOCUMENTATION: Kubokawa (1969); MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Install new door; move equipment.

A. TITLE: PASSAGEWAY DIMENSIONS

B. GUIDELINES: Corridor and aisle dimensions shall conform to those criteria as depicted in the figure below.



C. HUMAN ERROR: Personal injury, property, equipment or hardware damage.

D. **DOCUMENTATION:** Woodson and Conover (1964); Kubokawa (1969); MIL-HDBK-759.

E. **TYPICAL BACKFIT:** Widen passageways as necessary.

A. **TITLE: STORAGE SPACE**

B. **GUIDELINES:** Adequate and suitable space shall be provided on consoles or immediate work space for the storage of manuals, worksheets, and other materials that are required for use by the operational or maintenance personnel.

C. **HUMAN ERROR:** Delays in acquiring manuals, etc.

D. **DOCUMENTATION:** MIL-STD-1427B

E. **TYPICAL BACKFIT:** Provide storage space as necessary.

VISUAL DISPLAYS

(VD)

VD

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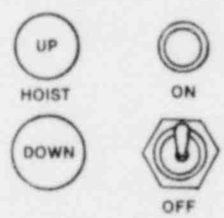
A. TITLE: GENERAL INFORMATION

B. GUIDELINES: Evaluation of Display Design and Type — Evaluation of visual displays is one of the most important problems facing the evaluator in an assessment of the effectiveness of a man-machine system. Since the human eye is the medium through which man receives the greater share of his information about the world in which he lives, effective transfer of this information is vital to his operational efficiency. The following general recommendations are presented as an aid in the assessment of the most suitable type of indicator for a given purpose.

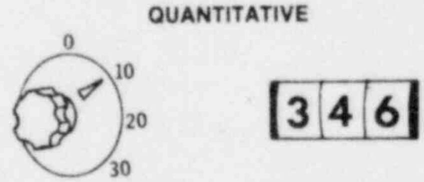
Qualitative — For a few discrete conditions, use an indicator which presents large differences in position, brightness, or color. Use of two or more variables together normally increases operator reliability — e.g., color plus position.

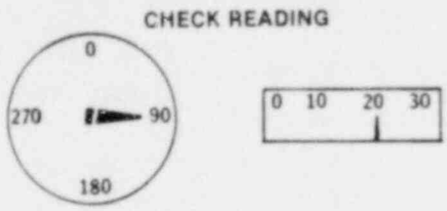
Quantitative — For precise numerical values, with no need for interpolation between numbers, or for rate or directional indication, use a digital or counter indicator. Use a scalar indicator, however, when

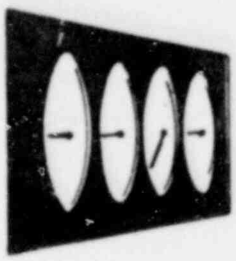
QUALITATIVE



QUANTITATIVE







values are to be set into the equipment.

Check Reading — For numerical value plus orientation in time, space, magnitude, or rate, use a scalar indicator. Avoid multiple pointers or moving scales whenever possible. A pointer plus an adjacent counter is best when scale expansion is necessary.

Pictorial — For multidimensional information, use combinations of single-value indicators or composite graphic or pictorial representations.

Orientation — For qualitative check reading, use a moving pointer against a fixed scale.

Redundancy — Displays shall be redundant to reduce the operator's requirements for moving about the control room. Otherwise redundancy should be avoided.

Display Failure Clarity — Displays shall be so designed that failure of the display or display circuit will be immediately apparent to the operator.

Combined Information — Information necessary for performing different activities (e.g., operation and troubleshooting) shall not simultaneously appear in a single display unless there are comparable functions requiring the same information.

C. **HUMAN ERROR:** Reading errors and interpretation errors.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Woodson (1964)

E. **TYPICAL BACKFIT:** Replace displays.

A. TITLE: **WARNING & CAUTION, VISUAL & AUDITORY SIGNALS**

B. **GUIDELINES:** In evaluating a warning signal for a particular application, the urgency, the other duties of the operator, and the other warning devices in the station must be considered. Unimportant warnings make operators neglect critical ones; too many of the same type are confusing.

Nuisance alarms should be avoided. Whenever an alarm goes off in a control room it should indicate to the operator that something is wrong and not merely that an instrumented component has exceeded its set point. The set points should be established to indicate real problems.

Auditory signals should be used only for a few of the most urgent warnings. Such warnings, while attention-getting and independent of visual scanning, can interfere with speech communication and may be less suitable for indicating what is wrong or what to do.

For situations in which too many displays are visually presented, or for presenting information independently of head orientation, as in duties that require body movement or head turning, auditory signals can be successfully used.

Signal lights can tell the operator what to do by their location, labeling, color or other coding, but he must be looking in their direction to notice them. Other visual signals, such as mechanical flags, have low attention value. They are practical for giving "on-off" types of information.

C. **HUMAN ERROR:** Misperceived warnings, cautions or system malfunctions.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972)

E. **TYPICAL BACKFIT:** Move; replace; or modify. Establish set points to indicate real problems.

Evaluation Guide for the Use of Auditory or Visual Form of Presentation

Use auditory presentation if:	Use visual presentation if:
1. The message is simple.	1. The message is complex.
2. The message is short.	2. The message is long.
3. The message will not be referred to later.	3. The message will be referred to later.
4. The message deals with events in time.	4. The message deals with location in the plant.
5. The message calls for immediate action.	5. The message does not call for immediate action.
6. The visual system of the person is overburdened.	6. The auditory system of the person is overburdened.
7. The receiving location is too bright.	7. The receiving location is too noisy.
8. The person's job requires him to move about continually.	8. The person's job allows him to remain in one position.

A. TITLE: INFORMATION PRESENTED

B. GUIDELINES: Content — The information displayed to an operator should be limited to that which is necessary to perform specific actions or to make decisions.

Precision — Information shall be displayed only to the degree of specificity and precision required for operator actions or decisions.

Format — Information shall be presented to the operator in a directly usable form. (Requirements for transposing, computing, interpolating, or mental translation into other units shall be avoided.)

Redundancy — Redundancy in the display of information to a single operator at one workstation shall be avoided unless it is required to achieve specified reliability or reduce movement about the control room.

Combined Information — Information necessary for performing different activities (e.g., operation and troubleshooting) shall not simultaneously appear in a single display unless the activities have comparable functions requiring the same information.

Display Failure Clarity — Displays shall be so designed that failure of the display or display circuit will be immediately apparent to the operator.

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

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

C. **HUMAN ERROR:** Inaccurate display reading.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Identify information requirements and ensure that required information is displayed.

A. TITLE: DISPLAYS FOR SYSTEM STATUS MONITORING

B. GUIDELINES: There are many system parameters having a low frequency of change; yet, the operator must be made aware of changes when they do occur. Man, being a poor monitor, reacts unreliably to low-frequency events; thus the display of such information requires special attention. In evaluating displays for system status monitoring, consider that:

1. Changes critical to safety or effectiveness require a place of high priority in the operator's central field of view. Stimuli ensuring high levels of attention should be used for these indications.
2. When different sources of information are displayed, the arrangements or combinations should be in functional or sequential groups as in a mimic. Such techniques as pointer alignment allow for rapid and accurate monitoring. Color can also be used to indicate safe and unsafe operating valves.

3. In certain applications, displays should provide information on recommended operating procedures as well as the status of the system. This is particularly applicable to shut down and start up procedures.
4. When many subsystems require monitoring, it may be necessary to use machine filtering of information to avoid overloading the operator or to save panel display space. "Auto-scanning" systems can be programmed to display only those information sources that are changing or fall outside specified tolerance thresholds.

C. **HUMAN ERROR:** Misread instruments; erroneously setting controls.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:**

1. Prioritize displays.
2. Locate important annunciators in a central position.
3. Use mimic panels to display relationships.
4. Use color coding to denote safe and unsafe operating areas.

A. TITLE: VISUAL PRESENTATION OF INFORMATION

B. GUIDELINES: General Display Considerations — Because an operator often needs more visual information than his unaided senses can gather and present to him, other sources of information such as meters, CRTs, temperature gauges, etc., have been created as adjuncts to the human senses. This section is a guide to the evaluation and use of these devices.

A good visual display must be much more than merely visible. The displayed information must be understandable so that correct decisions or control actions can be made without unacceptable delay. This means that a display must be designed to suit the particular conditions under which it will be used.

Conditions of use. To assess display effectiveness, the evaluator should consider at least the following conditions:

1. Viewing Distance. The maximum expected viewing distance will influence the size of details shown on a display. The usual reading distance for

printed materials is about 16 in. Many indicators are designed for reading at arm's length, to permit the operator to reach switches or adjust knobs on indicators. This limit is generally set at 28 inches and is used in determining the recommended dimensions for scale markings and numerals. For other reading distances, these dimensions must be adjusted up or down in direct proportion to the distances. (See page VD-23 Maximum Viewing Distance, VD-32 Viewing Distance-General, and VD-35 Viewing Distance)

2. Illumination. The size of display details should be suited to the lowest expected illumination level. The color of the illumination should also be considered. Warning signal lights, cathode-ray tubes, and other displays which emit rather than reflect light are more often hindered than helped by other lighting in the control room. When using general illumination for displays, careful design is required to minimize glare sources on the cover glass. (See CRE-3 Glare and CRE-9 Display lighting)

3. Angle of View. The preferred viewing angle is usually 90° to

the plane of the display. On large display panels, or where more than one operator views the same display, there might be a considerable deviation from the 90° angle of view. This situation can give rise to excessive parallax distortion or cause parts of the display to be hidden, unless such offset viewing has been compensated for in design.

4. Presence of Other Displays. Usually, an operator divides his attention among several displays. Inconsistencies in the manner of presentation among the displays can confuse or slow down the operator. However, displays should not look too much alike because the operator might read the wrong one. Obviously, each display must be well identified.

5. Compatibility With Related Controls. The design of a display may be affected by the controls associated with it. Ideally, displays and controls should be designed and located so that even an operator will select the correct control and operate it as expected without having to attend to his actions. That is to say, the display should imply the form of the operator's response.

<u>Method of use</u>. The way in which the operator will use the information presented to him is an important consideration in the evaluation of display configuration and arrangement. Therefore, an analysis should be made of the type of action the operator will be expected to take while receiving or after receiving information from the display.

C. **HUMAN ERROR:** Misread displays; selecting the wrong display; misinterpretation of information.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Improvement of display identification (labeling, shape or size coding, or color coding); location; and design (readability).

VISUAL DISPLAYS

A. **TITLE: REPRESENTATIONAL DISPLAYS**

B. **GUIDELINES:**

1. Graphic displays that depict trends are read better if they are formed with lines rather than bars.
2. Pursuit displays (operator sees system input and output) are usually easier for people to use than compensatory displays (operator sees only difference between system input and output).
3. Cathode-ray-tube (CRT) displays are most effective when there are seven to nine or more scan lines per mm.
4. In displays of complex configurations (such as steam routes and wiring diagrams), unnecessary detail should be avoided. Schematic representation consistent with system functions should be used.

C. **HUMAN ERROR:** Failure to note trend changes; to identify all alterations; and delay in taking action.

D. **DOCUMENTATION:** McCormick (1976)

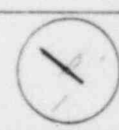
E. **TYPICAL BACKFIT:** Modify displays.

VISUAL DISPLAYS

A. TITLE: DISPLAY TYPE APPROPRIATENESS

B. GUIDELINES: Guide to Visual Display Evaluation below.

GUIDE TO VISUAL DISPLAY EVALUATION

To Display	Select	Because	Example
Go, No Go, Start, Stop On, Off	Light	Normally easy to tell if it is on or off	SERVICE WATER PUMP NO. 26
Identification	Light	Easy to see (may be coded by spacing, color, location, or flash'ng rate; may also have label for panel applications)	EXIT
Warning or Caution	Light	Attracts attention and can be seen at great distance if bright enough (may flash intermittently to increase conspicuity)	PRIMARY CONTAINMENT HIGH PRESS / RX VESSEL HIGH PRESS
Verbal instruction (operating sequence)	Annunciator light	Simple "action instruction" reduces time required for decision making	CLOSE T-I GROUP / OPEN T-I GROUP
Exact quc.ntity	Digital counter	Only one number can be seen, thus reducing chance of reading error	5 2 9 0 0
Approximate quantity	Moving pointer against fixed scale	General position of pointer gives rapid clue to the quantity plus relative rate of change	
Set-in quantity	Moving pointer against fixed scale	Natural relationship between control and display motions	

C. **HUMAN ERROR:** Inaccurate and erroneous readings; slow response times.

D. **DOCUMENTATION:** Woodson (1964)

E. **TYPICAL BACKFIT:** Remove and replace.

A. TITLE: PLACEMENT

B. GUIDELINES: Grouping — All displays necessary to support an operator activity or sequence of activities, shall be grouped together.

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.

Frequency of Use — Displays used most frequently should be grouped together and placed in the optimum visual zone (See Figure).

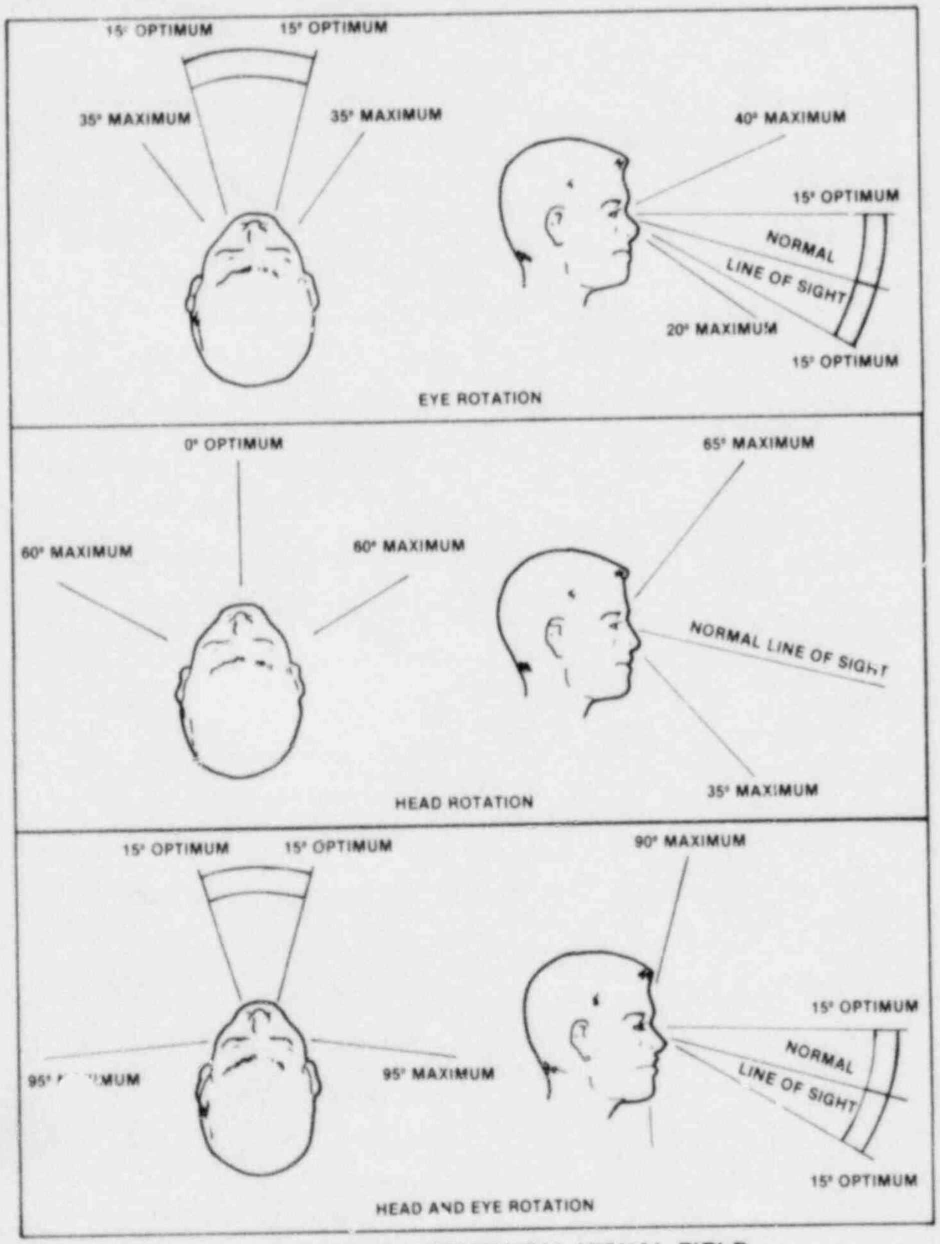
Importance — Very important or critical displays shall be placed in a privileged position in the optimum projected visual zone or otherwise highlighted.

Consistency — The arrangement of displays shall be consistent in principle from application to application, within the limits specified herein.

C. **HUMAN ERROR:** Inaccurate display reading.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Rearrange, replace, or repeat displays; or use mimic lines, demarcation or labeling.



VERTICAL AND HORIZONTAL VISUAL FIELD

A. TITLE: VISUAL DISPLAY LAYOUT

B. GUIDELINES: Preferred visual areas of control/display panels center around the operator's normal line of sight —approximately 15° down from horizontal.

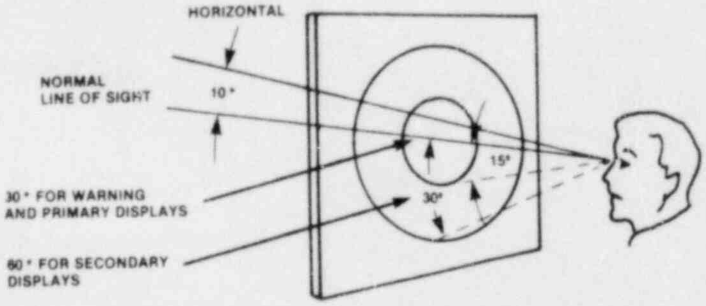
Important principles for panel visual display categories are:

1. Warning Lights and Primary Displays. (Including emergency hazard indicators, critical monitoring displays and displays where color identification is critical.) Use of these displays should not require excessive movement of the operator's head or eyes from normal line of sight.
2. Secondary Displays. (Frequently used operational displays.) Use of these displays may require eye movement from the normal line of sight, and should minimize head movement.
3. Auxiliary Displays. (Including infrequently used displays such as console power indicators and maintenance displays.) Use of

these displays may require operator head and eye movement from normal line of sight.

All warning displays (those indicating a present or potential system failure or personnel/equipment hazard) should be within 30° of normal line of sight or 45° for a sit-stand workspace.

In order to prevent interference with primary operator visual tasks, it is desirable to arrange displays and controls so that the displays are generally in the center of the panel (or upper portion) and controls are arranged in the lower section or about the periphery of the panel.



Preferred placement for visual displays.

C. **HUMAN ERROR:** Misreading the display; reading the wrong displays.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

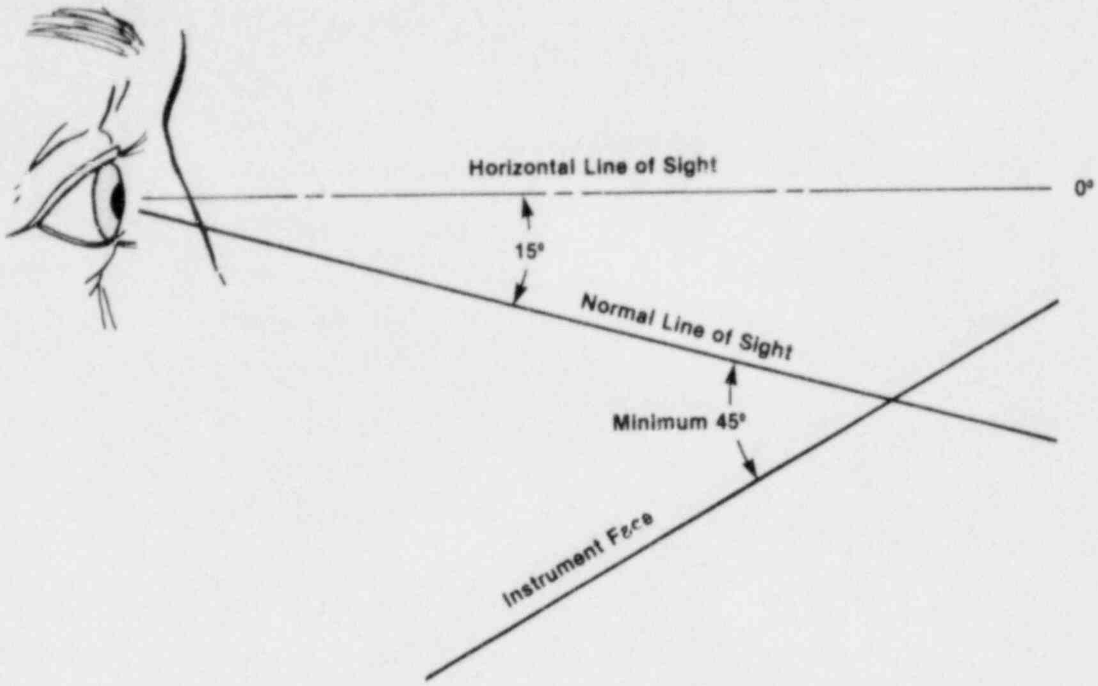
E. **TYPICAL BACKFIT:** Rearrange displays.

A. TITLE: LOCATION AND ARRANGEMENT

B. GUIDELINES: Accuracy — Displays shall be located and designed so that they may be read to the degree of accuracy required by personnel in the normal operating positions.

Access — Ladders, supplementary lighting, or other special equipment should not be required to access or read a display.

Orientation — Display faces shall be perpendicular to the operator's normal line of sight whenever feasible and shall not be less than 45° from the normal line of sight (See Figure). Parallax shall be minimized. (See Parallax on page VD-24).



LINES OF SIGHT

Reflection — Displays shall be constructed, arranged, and mounted to prevent reduction of information transfer due to the reflection of the ambient illumination from the display cover. If necessary, techniques (such as shields and filters) shall be employed to insure that system performance will not be degraded. (See CRE-6 Glare)

Maximum Viewing Distance — The viewing distance from the eye reference point to displays located close to their associated controls shall not exceed 28 inches. Otherwise, there is not a maximum limit other than that imposed by legibility for by proper design. See VD-10 Viewing Distance, VD-32 Viewing Distance General, and VD-33 Viewing Distance and Character Height)

Minimum Viewing Distance — The effective viewing distance to displays, with the exception of cathode ray tube displays, shall never be less than 13 inches and preferably not less than 20 inches. (See VD-46 for CRT Distance)

Parallax — Certain visual displays must be perpendicular to the line of sight in order to eliminate parallax and allow for accurate reading. This limits freedom in arrangement. If it is not possible to place all displays in optimum positions, tradeoffs will have to be made. Visual displays sensitive to parallax are:

1. Cathode ray tube (CRT) displays with engraved overlays which require alignment between target and engravings.
2. Scale and pointer instruments in which very precise pointer-scale alignment is required.
3. Stacked, edge-lighted digital readout displays in which a number plate at the rear of the stack may be obscured by the display case.

4. All instruments in which the instrument face is deeply inset below the instrument face cover glass (this may be true for meters, digital counters, and some types of CRTs).

Rules for arrangement of visual displays are generally quite obvious. They include placement of visual displays in front of the operator, as nearly perpendicular to his line of sight as possible, at a distance for adequate resolution of visual detail without causing fatigue, and out of direct light which causes reflection and/or glare.

C. **HUMAN ERROR:** Inaccurate display reading. If parallax is recognized by the operator, interpolation or judgment errors can occur; if not recognized, misread displays will result.

D. **DOCUMENTATION:** MIL-STD-1472B (1974) and Van Cott (1972)

E. **TYPICAL BACKFIT:** Rearrange or replace displays.

VISUAL DISPLAYS

A. TITLE: INSTRUMENT ILLUMINATION

B. GUIDELINES: Techniques, luminance and brightness adjustment for minimum adequate lighting: (See CRE-9)

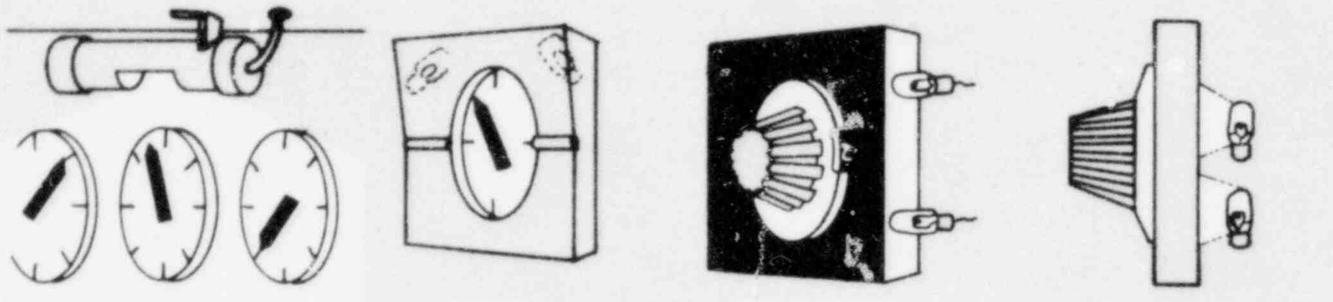
Condition of Use	Lighting Technique	Luminance of Markings (Ft-L)	Brightness Adjustment
Indicator Reading	White Flood	1-20	Fixed or Continuous
Panel Monitoring	White Flood	10-20	Fixed or Continuous
Chart Reading	White Flood	5-20	Fixed or Continuous

C. HUMAN ERROR: Failure to notice status changes, reading errors.

D. DOCUMENTATION: Chapanis (1965)

E. TYPICAL BACKFIT: In the event that indicator, panel or chart lighting is found to be inadequate, or backfits are planned for any reason, the following evaluation guidance is offered:

Lighting Methods - There are two general techniques of instrument lighting: flood lighting and integral lighting.



Flood Lighting - With this technique, light is provided by luminaires not integral to the indicator or panel. Because the light rays have a fairly large angle of incidence, the light source can be located above the indicator allowing specularly reflected light to go downward, away from the operator's eyes. The advantages of this technique are:

1. Uniform light distribution.
2. Illuminated decals, knobs, switches, and indicators.
3. Illuminated space between indicators which aids distance perception.
4. A minimum number of luminaires is required, and they can be made easily accessible for replacement of bulbs.
5. Luminaires do not obscure the edges of indicators as they may in integral lighting.

The disadvantages of flood lighting are:

1. Considerable light is scattered to other areas.
2. It is often difficult to position the luminaires without obstructing vision or otherwise cluttering workspace.
3. Shadows are cast by indicator bezels as the angle of incidence is reduced.

Integral Lighting - Integral lighting that is tailored to or built into individual instruments or panels has these advantages:

1. Minimum light scatter to other areas.
2. Lighting tailored to each indicator or panel.
3. Concealed light fixtures do not obstruct the workspace.

Among the disadvantages are:

1. The surfaces between indicators and between illuminated panel markings are not lighted, thereby causing instrument faces and panel markings to appear to be floating in space.
2. For most systems it is difficult to obtain uniform illumination on all parts of an instrument and on different indicators or markings on the same panel.

The more common types of integral lighting are the following:

1. Indirect Lighting - Light is provided around the rim of the indicator by reflection from a light shield or by transmission through plastic. Usually the light sources are at the top so that light which escapes will go downward. With this method it is difficult to get uniform light distribution and to avoid shadow areas. The fixtures are likely to occlude edges of instruments when oblique reading is necessary.
2. Rear Lighting - Light is transmitted from the rear through translucent markings in an otherwise opaque covering over transparent plastic. Difficulties arise in lighting of pointers and other moving parts and in making the lamps accessible for replacement.
3. Wedge Lighting - For lighting of small and medium sized instruments, such as those used in a small, modern, highly automated control room with a seated operator and a normal viewing distance of 28" or less, light can be applied through wedge-shaped cover glasses. The thick edge of the wedge, and the source lamps, are placed at the top, so escaping light goes downward.

Usually a reverse wedge glass is placed over the light conducting wedge, directing stray light downward.

4. Edge Lighting - Light conducted by internal reflections through flat plates of transparent plastic escapes through apertures in the otherwise black coating over the plastic. Lamps inserted through polished holes in the plastic are distributed to give fairly uniform light. As normally prepared, the markings on the plastic are white under reflected light but can be any other light color. The illumination provided by the edge lighting can also be any desired color. Although instrument dials can be illuminated with edge lighting, there is difficulty in lighting instrument pointers. This method is better suited to the lighting of legends and other markings on control panels.

5. Electroluminescent Lighting - This is a relatively new type of integral lighting in which a laminated conducting plate glows when an electrical potential is applied, a technique particularly suitable for lighting of legends on panels of all types. As further improvements are made

in this technique, it should provide an excellent solution to many control room lighting applications. Major advantages are:

a. Uniform brightness and color of panel markings.
b. Increasing variety of colors which can be useful for coding.

For some electroluminescent applications, it is desirable to use low-reflectance coatings, which appear dark under reflected light. By this method, markings can be made invisible until illuminated. Low-reflectance coatings are also beneficial for use in high ambient illumination conditions. The reduced surface reflections result in higher contrast between the illuminated markings and the background.

A. TITLE: VIEWING DISTANCE — GENERAL

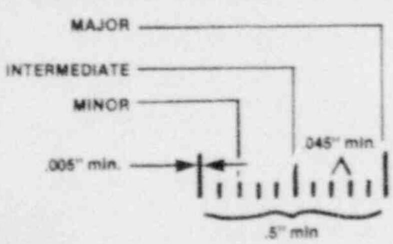
B. GUIDELINES:

IMPORTANT GENERAL CONSIDERATIONS

1. Distance of the observer from the display.
2. Position of the observer relative to the display (viewing angle).
3. Type, color, and amount of illumination available to the display.

Scale indices should be limited in number to the accuracy required. The smallest readable division should never be finer than the probable error in the metering device. Indices may be spaced as close together as 0.04 inch, although the distance should not be less than twice the stroke width of a "light" index mark on a dark background nor less than one stroke width when the index is darker than the background. A minimum of ½ inch is recommended for the distance between "major" indices. These figures are for the normal instrument-panel reading distances, 14 to 28 inches. The number of graduation marks between numbered scale points should not exceed nine.

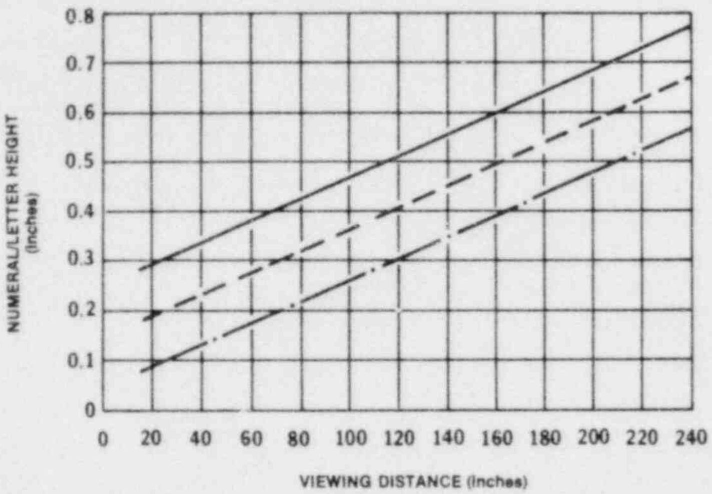
MINIMUM INDEX DIMENSIONS (28-INCH VIEWING)



VIEWING DISTANCE (feet)	INDEX HEIGHT (inches)		
	MAJOR	INTERMEDIATE	MINOR
1 1/2 or less	0.22	0.16	0.09
1 1/2 to 3	0.40	0.28	0.17
3 to 6	0.78	0.56	0.34
6 to 12	1.57	1.12	0.68
12 to 20	2.83	1.87	1.13

LETTER HEIGHT VS. VIEWING DISTANCE AND ILLUMINATION LEVEL

(MINIMUM SPACE BETWEEN CHARACTERS, 1 STROKE WIDTH; BETWEEN WORDS, 1 STROKE WIDTHS)



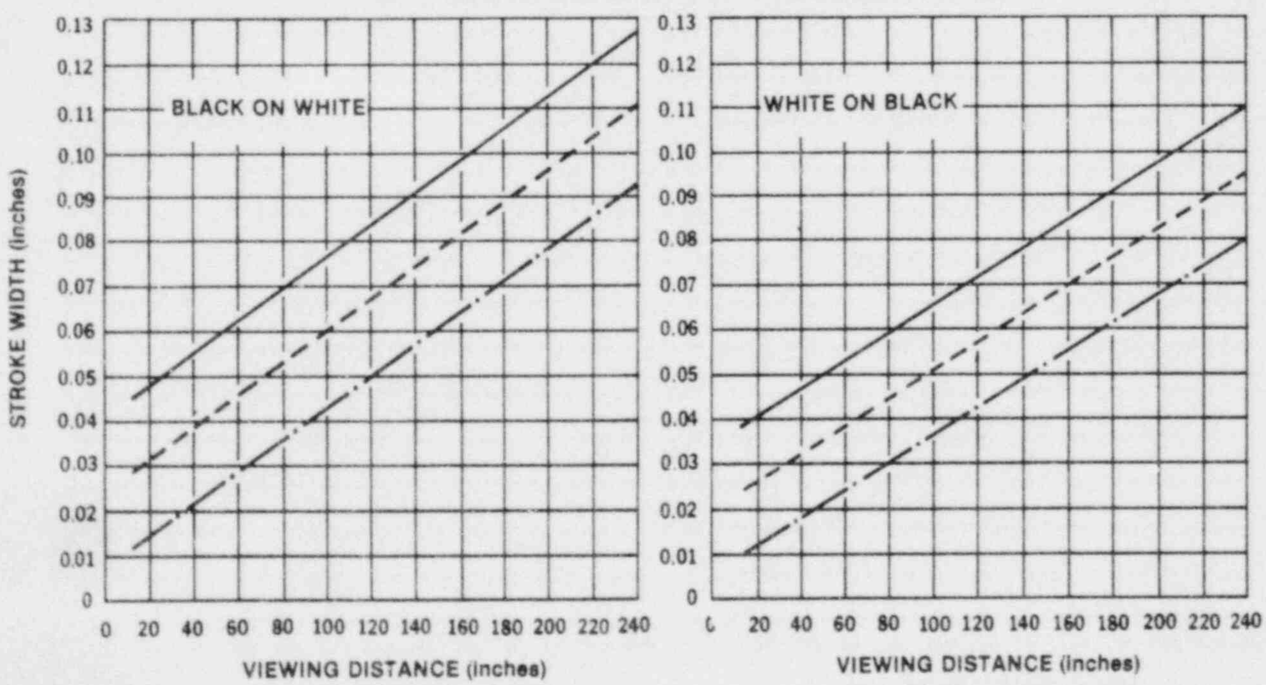
— For instruments where the position of the numerals may vary and the illumination is between 0.003 and 1.0 ft.-1.

---For instruments where the position of the numerals is fixed and the illumination is 0.3-1.0ft-1, or where position of the numerals may vary and the illumination exceeds 1.0 ft-1.

— · —For instruments where the position of the numerals is fixed and the illumination is above 1.0 ft-1.

NUMERALS, LETTERS, AND INDICES

LETTER-STROKE WIDTH VS DISTANCE VIEWED



C. **HUMAN ERROR:** Inaccurate display reading.

D. **DOCUMENTATION:** Woodson (1964).

E. **TYPICAL BACKFIT:** Replace existing instruments with appropriate size; adjust illumination; or relocate instrument panel or operator workplace.

A. TITLE: VIEWING DISTANCE AND CHARACTER HEIGHT

B. GUIDELINES: Character Height and Viewing Distance — For general dial and panel design, with the luminance normally above 1 ft-L (3.4 cd/m^2), character height should approximate the values given below for various distances: (To ensure an angular subtence of at least 15 arc minutes.)

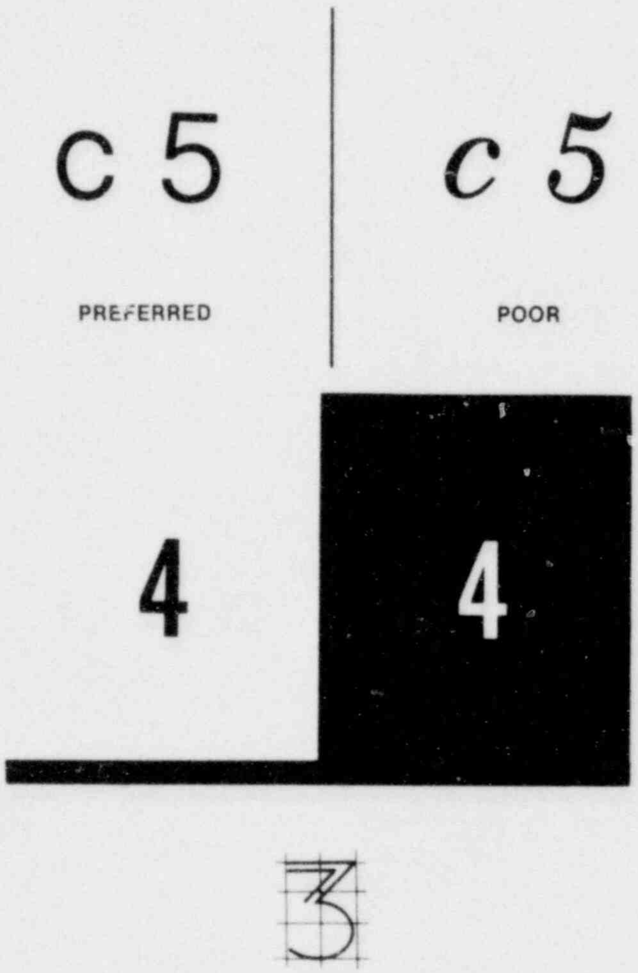
Viewing Distance	Height
20 inches or less	0.09
20 - 36 inches	0.17
36 - 72 inches	0.34
72 - 144 inches	0.68
144 - 240 inches	1.13

C. HUMAN ERROR: Misread displays.

D. DOCUMENTATION: MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Modify, replace or move displays or workplace.

A. TITLE: NUMERALS, LETTERS, AND INDICES



B. GUIDELINES: For panel use, the design of letters and numerals should be without flourishes. Such details are confusing, especially under emergency conditions. The critical details of the figures should be simple but prominent. Diagonal portions of the characters should be as near 45 degrees as possible and such characteristic features as openings and breaks should be readily apparent.

The stroke width of black characters on white background should be about one-sixth of the character height. Stroke width of white figures on black background should be about one-seventh to one-eighth of the character height; the narrower stroke is necessary since the light figure tends to spread or irradiate.

The height-to-width ratio of the normal character should be about three to two. Although there are exceptions to this rule, a close approximation to this ratio is recommended, especially for panel and scale design.

For more specific guidance, see "Numeral and Letter Style," VD-38.

C. **HUMAN ERROR:** Misread displays.

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Modify or replace.

A. TITLE: NUMERAL AND LETTER STYLE

B. GUIDELINES: Control room alphanumeric and related displays should be systematically assessed in terms of communication effectiveness. The effectiveness of communications that involve alphanumeric and symbolic characters depends upon various factors, including typography, content, selection of words, and writing style.

Definitions —

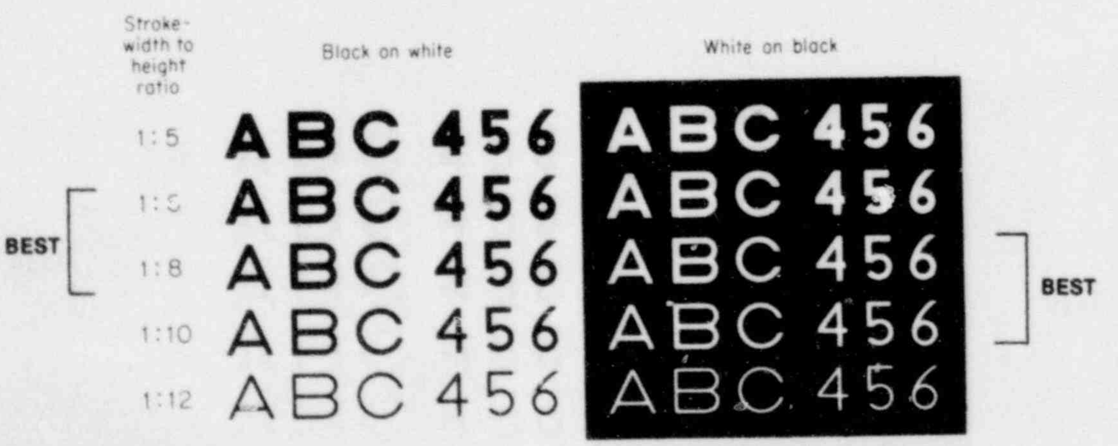
1. Visibility: The quality of a character or symbol that makes it separately visible from its surroundings.
2. Legibility: The attribute of alphanumeric characters that makes it possible for each one to be identifiable from others. (This depends on such features as strokewidth, form of characters, contrast, and illumination.)
3. Readability: A quality that makes possible the recognition of information when represented by alphanumeric characters in meaningful groupings,

such as words, sentences, or continuous text. (This depends more on the spacing of characters and groups of characters, on their combination into sentences or other forms, on the spacing between lines, and on margins, than on the specific features of the individual characters.)

Typography — The typography of alphanumeric material refers to the various features of the characters and their arrangement.

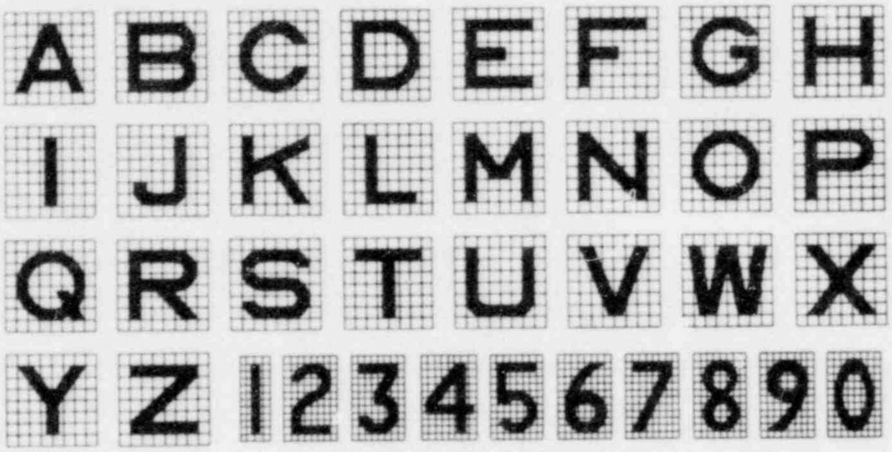
Strokewidth — The strokewidth of alphanumeric characters is usually expressed as the ratio of the thickness of the stroke to the heights of the letters or numerals. Some examples of strokewidth-to-height ratios are shown in the Figure. White characters on black should have thinner strokewidths than black on white. Black on white is preferable for control room display panels.

VISUAL DISPLAYS



Illustrations of strokewidth-to-height ratios of letters and numerals.

Width-Height Ratios — The relationship between the width and height of alphanumeric characters is usually described as the width-height ratio (expressed as a ratio such as 4:5, or as a percent such as 80 percent). In the case of capital letters, the ratio should be about 1:1, although this can be reduced to about 3:5 without serious loss in legibility. In the case of numerals, the standard recommendation is a ratio of about 3:5. These ratios are illustrated in the figure on page VD-39. The letters as shown have a width-height ratio of 1:1 (except for I, J, L, and W). These ratios can be reduced to about 2:3 without any appreciable reduction in legibility. The numerals have a width-height ratio of 3:5 (except 1 and 4).



Letter and numeral font of United States Military Specification No. MIL-M-18012B (July 20, 1964), also referred to as NAMEL (Navy Aeronautical Medical Equipment Laboratory) or as AMEL.

<u>Font of Alphanumeric Characters</u> — Most conventional fonts of alphanumeric characters (and many of the nonconventional styles) can be read with reasonable accuracy under normal conditions where size, contrast, illumination, and time permit. There are, however, significant differences in the legibility and readability of different type fonts when viewing conditions are adverse, where time is important, or where accuracy is important. In this connection, the font of capital letters and numerals shown in the Figure (United States Miliary Specification No. MIL-M-18012B) has been rather widely tested and found to be generally satisfactory.

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z
0 1 2 3 4 5 6 7 8 9

Another set of characters that is rather widely used by the military services is that shown in this figure (MIL Standard MS 33558 (ASG). The basic stroke width-to-height ratio is 1:8, and the width is about 70 percent of the height. These are sometimes referred to as AND (Air Force-Navy Drawing 10400).

<u>Size of Alphanumeric Characters</u> — The ability of people to make visual discriminations (such as of alphanumeric characters) depends on such factors as size, contrast, illumination, and exposure time. A systematic procedure has been developed for determining the size of alphanumeric characters which takes into account certain such factors (illumination, viewing conditions, viewing distance, and importance of reading accuracy). This procedure is based on the following formula:

$$H \text{ (height of letter, in.)} = 0.0022D + K_1 + K_2$$

where

- D = viewing distance,
- K_1 = correction factor for illumination and viewing condition,
- K_2 = correction for importance (for important items such as emergency labels, K_2 = .075;

for all other conditions, $K_2 = .0$)

This formula has been applied to various viewing distances, in combination with the other variables, to derive the heights of letters and numerals for those conditions as given in the table. The lower bounds of these values for a reading distance of 28 inches (for K_1 values of 0.06) are 0.12 for nonimportant and 0.20 inch for important markings. For greater viewing distances, of course, the sizes of characters need to be increased.

Table of Heights H of Letters and Numerals Recommended for Labels and Markings on Panels, for Varying Distance and Conditions, Derived from Formula H (in) = $0.0022D + K_1^* + K_2$

Viewing distance, in	0.0022D value	Nonimportant markings, $K_2 = .0$			Important markings, $K_2 = .075$		
		$K_1 = .06$	$K_1 = .16$	$K_1 = .26$	$K_1 = .06$	$K_1 = .16$	$K_1 = .26$
14	0.0308	0.09	0.19	0.29	0.17	0.27	0.37
28	0.0616	0.12	0.22	0.32	0.20	0.30	0.40
42	0.0926	0.15	0.25	0.35	0.23	0.33	0.43
56	0.1232	0.18	0.28	0.38	0.25	0.35	0.45

*Applicability of K_1 values:

K_1 = .06 [illegible]ove 1.0 fc, favorable reading conditions)
K_1 = .1[illegible] [illegible]ove 1.0 fc, unfavorable reading conditions)
K_1 = .16 (below 1.0 fc, favorable reading conditions)
K_1 = .26 (below 1.0 fc, unfavorable reading conditions)

One additional point should be made about the size of characters. Some styles of letters have longer "ascenders" and "descenders" than others (i.e., the tip of letters such as b, and the tails of letters such as y).

Legibility is largely influenced by the height of the main body of the letters, and is not influenced much by the length of the ascenders or descenders.

Readability — The readability of printed or typed text, and its comprehension, is a function of a wide assortment of factors such as type style (font), type form (capital, lowercase, boldface, italics, etc.), size, contrast, leading (spacing between lines), length of lines, and margins.

In the use of words as labels (such as on instrument panels for identification), words in all capital letters are more readable than those in lowercase or mixed type.

C. **HUMAN ERROR:** Reading errors.

D. **DOCUMENTATION:** McCormick (1976).

E. **TYPICAL BACKFIT:** Relabel, modify, replace, or relocate display or workspace.

A. TITLE: CATHODE RAY TUBES (CRT)

B. GUIDELINES: Signal Size — When a displayed character or symbol of complex shape is to be distinguished from another character shape that is also complex, the character signal should subtend not less than 20 minutes of visual angle and should subtend not less than 10 lines or resolution elements. Image quality shall be consistent with the operator's needs. (See VD-14)

Alphanumerics — Alphanumeric characters shall subtend not less than 12 - 15 minutes of visual angle. The characters shall be composed of upper case letters with a resolution of not less than ten lines per symbol height.

Height-to-Width Ratio — The height-to-width ratio for alphanumerics shall be between 7:5 and 3:2.

Stroke Width-to-Height Ratio — Stroke width shall be in the range of 1:6 to 1:10 character height, with the thinner width used for light characters on a dark background.

Character Separation — Wider spacing between characters shall be used for light symbols on a dark background rather than for dark symbols on a light background. Generally, character separation shall be between 25 and 63% of the symbol height, with the lower limit preferred under low ambient illumination (1 Ft.c.) or when the visual angle subtended by the characters is less than 16 minutes of arc. When the illumination level is increased between 20 and 40 Ft.c., character separation should be two times the symbol height.

Viewing Distance — A viewing distance of 18 inches shall be provided whenever practicable. When periods of scope observation will be short or where dim signals must be detected, the viewing distance may be reduced to 14 inches. Due to eye strain and fatigue effects, viewing distances of less than 16 inches shall be avoided. The maximum viewing distance for a single seated operator shall be 28 inches, unless the screen size and symbol subtense are adjusted accordingly.

Viewing Angle — The optimal horizontal angle for viewing a CRT display is 90° straight-on. No viewer should be seated with a viewing angle smaller than 45° and under no circumstances shall an observer be required to view the display from an angle smaller than 30°.

Screen Luminance — The ambient illuminance shall not contribute more than 25% of screen brightness through diffuse reflection and phosphor excitation. A minimal screen luminance of 25mL shall be maintained, with a preferred screen luminance of 50mL. Under low ambient conditions (1.0fL), light symbols on a dark background shall be used. Dark symbols on a light background shall be used under medium and high ambient illumination levels. A contrast of 88% is recommended, while 94% is preferred.

Ambient Illuminance — The ambient illumination should be maintained at a level below the brightness of the CRT background.

Reflected Glare — Reflected glare shall be minimized by proper placement of the scope relative to the light source. The light source should not be located within 60° of the viewer's central field-of-view. The light shall be diffused and distributed evenly over the work area, with the ratio between light and dark portions of the work surface not exceeding 7:1. In addition, glare shall be minimized by proper placement of the scope relative to the light source, through the use of a hood or shield; by optical coatings or filters over the light source; or by directional or spectrum filters. All surfaces adjacent to the CRT shall have a dull matte finish. The reflectances of these surfaces shall be such that the resultant luminances will be consistent with the criteria established above.

Phosphor — The choice of phosphor depends primarily upon system application, but generally should be one which emits in the green region of the visible spectrum and reduces flicker. Short persistence phosphors (decay rates less than 10^{-3} sec.) should be used with displays having high regeneration rates and slow image movements. Medium persistence phosphors (decay rates not more than 0.1 sec.) should be used with moderate image movement, while the longer persistence phosphors are best for displays where information update is relatively infrequent, between 30 seconds and several minutes apart. Red symbols on a green background shall be avoided.

Signal-To-Noise Ratio — The signal-to-noise ratio shall be one which is large enough to achieve system objectives. Generally, a signal-to-noise ratio of 10:1 is considered satisfactory, 30:1 is considered good, and 50:1 is considered excellent.

Shades of Gray — To insure character recognition and to provide realistic TV images, at least 10 shades of gray should be used.

Resolution — Point resolution is conventionally a fixed percentage of display [illegible]. On a 12-inch CRT, resolution is about 85 points per inch (1023 x 1023 points per display surface). A 4-foot display of 1023 x 1023 points would have a resolution of about 21 points to an inch. This has little effect on alphanumeric data, but puts a definite limitation on graphic displays. On this 4-foot screen, lines or points must be separated by .05 inch. In both the CRT and the large screen display, line thickness is also proportional to display area.

Regeneration Rate — The regeneration rate for a particular display depends on a number of factors, but generally shall be above the critical frequency at fusion such that the occurrence of disturbing flicker is not perceptible.

Response Time — The time from initiation of computer output until a new CRT page appears on the screen should be no longer than one second and shall not exceed three seconds.

Geometric Distortion — The cumulative effects of all geometric distortion should not displace any point on the screen from its correct position by more than 2 - 5 percent of picture height.

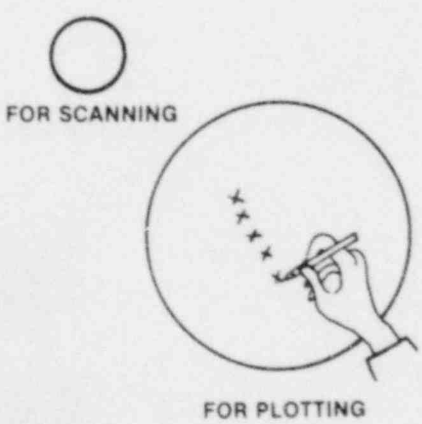
Graphics — Lines should be composed of at least 20 points per cm (50 points per inch) to provide the illusion of continuity.

Symbology — Geometric and pictorial symbols shall subtend a minimum of 16 minutes of visual angle. Symbolic codes should be displayed according to the following basic principles whenever technically feasible.

1. Number of categories — The number of discrete symbols used to provide information in symbolic form should be held to a minimum.
2. Symbol meanings should be standardized. Wherever used, a symbol should have the same meaning.
3. Absolute identification — Operators must be able to decode or interpret symbols quickly, without referring to comparison standards. This type of readout requires absolute recognition of a symbol standing alone or in a complex display, including the entire symbology alphabet.

4. Combination codes — If a single symbol cannot convey sufficient information, or if a symbol conveys more than one type of information, then a combination code may be used. The respective meanings must be decodable separately without confusion.
5. Ease of learning — Operators must be able to learn the code system easily, and its interpretation should not be degraded by emergencies or adverse conditions.
6. Symbol-readout compatibility — The symbol should be naturally related to the event it symbolizes. Their association should conform to well-established habits or population stereotypes.
7. Size-symbols should be large enough for good legibility, yet small enough to fit on a screen without cluttering it or interfering with reading other information. Size should be at least 20 minutes of arc at the normal viewing distance.
8. Evaluation Guide for symbolic coding:

Code	Number of Steps in Code	Evaluation	
Alpha-numerics	Unlimited	Excellent	High information-handling rate. Unlimited number of coding steps.
Geometrics	20 or more	Excellent	Certain shapes easily recognized. Many coding steps.
Color	4	Excellent	Difficulty in techniques of reproducing for CRT. Objects easily and quickly identified.
Blink	2	Poor	Distracting and fatiguing. Interacts poorly with other codes. Best for attention getting. Few steps in code.
Brightness	2	Poor	Limited number of steps. Fatiguing. Detrimental to decoding performance.
Line Lengths	4	Fair	Limited number of steps. Clutters displays.
Angular Orientation	12	Fair	95 percent of estimates correct within 15 percent.
Inclination	24 or more	Fair	Many coding steps, especially with combinations.
Visual Number (dots)	6	Fair	Few steps.
Combinations	Unlimited	Good	Avoid overloading symbols with too much information. Complex combination can degrade decoding speed and accuracy.



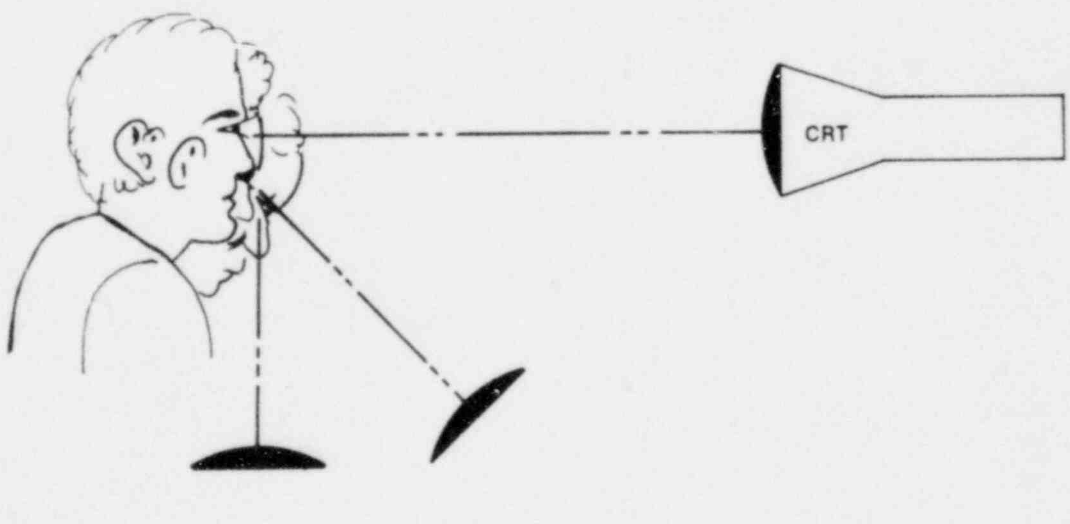
When electronic displays are usually presented on cathode-ray tubes in rectangular or polar-coordinate form, display considerations that affect operator performance are:

Display Size — At a 28 inch viewing distance for a single seated operator, the screen size should be 12 inches in diagonal.

When plotting or simultaneous viewing by several operators is not important, there is no significant advantage between large or small tubes. More time is required to scan the whole scope of an extremely large tube, but such a tube will allow use of a more adequate grid overlay and thus improve accuracy.

Shape — The bezel or frame around a CRT display should conform to the general configuration of the type of presentation - rectangular for an A-scan.

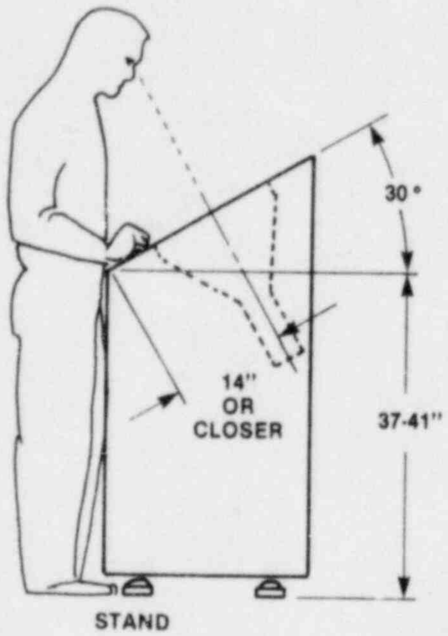
Mounting Position — CRTs should be mounted so that the visual axis of the operator is perpendicular to the face of the tube at its center.

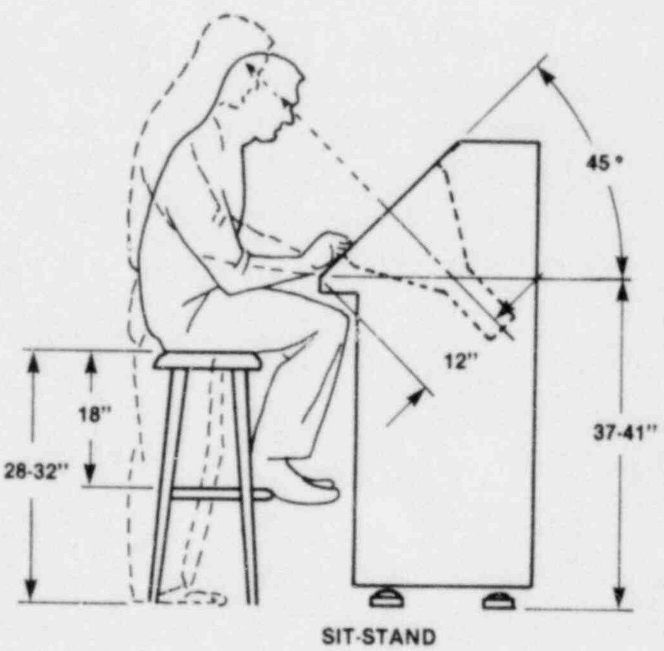


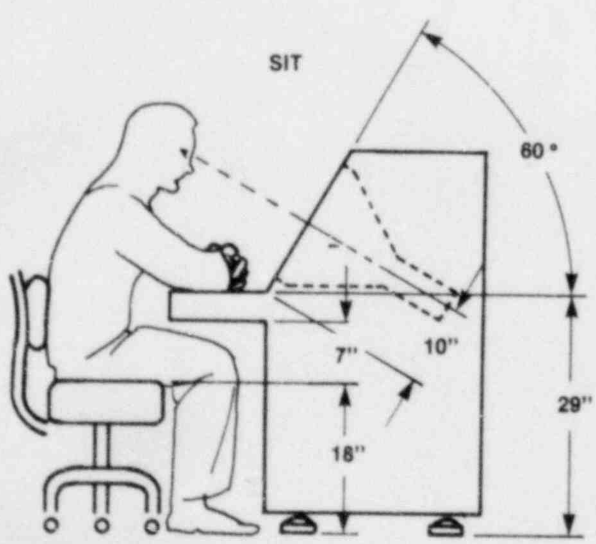
Console Design for CRTs — The illustrations show recommendations for angular mounting of visual

CONSOLE DESIGN FOR CRT'S

The illustrations show recommendations for angular mounting of visual displays such as CRT's. These dimensions are only approximate. They do, however, represent usable standards for about 90 percent of the male population.







displays such as CRTs. These dimensions are only approximate. They do, however, represent usable standards for about 90 percent of the male population.

Control Devices — Control Devices for CRT permit the operator to point out, request information, or act on a specified object. The light pen is a pointing device which recognizes only bright line structures specifically called by the computer program and falling within a field of approximately one symbol diameter. To avoid problems, the following constraints must be considered:

1. No light pennable character shall be coded by a blink rate because it is difficult to capture a blinking character.
2. Two individual light pennable characters must be separated by at least one symbol area.
3. The cord connecting the light pen to the console body shall be positioned to minimize interference with the viewed screen area.
4. The light pen cord shall either be retractable or guarded so that it cannot catch on the console shelf.
5. Since the light pen accepts the first appropriately coded line that it sees, light pen sensitivity

should not be turned on until the light pen is over the symbol to be designated.

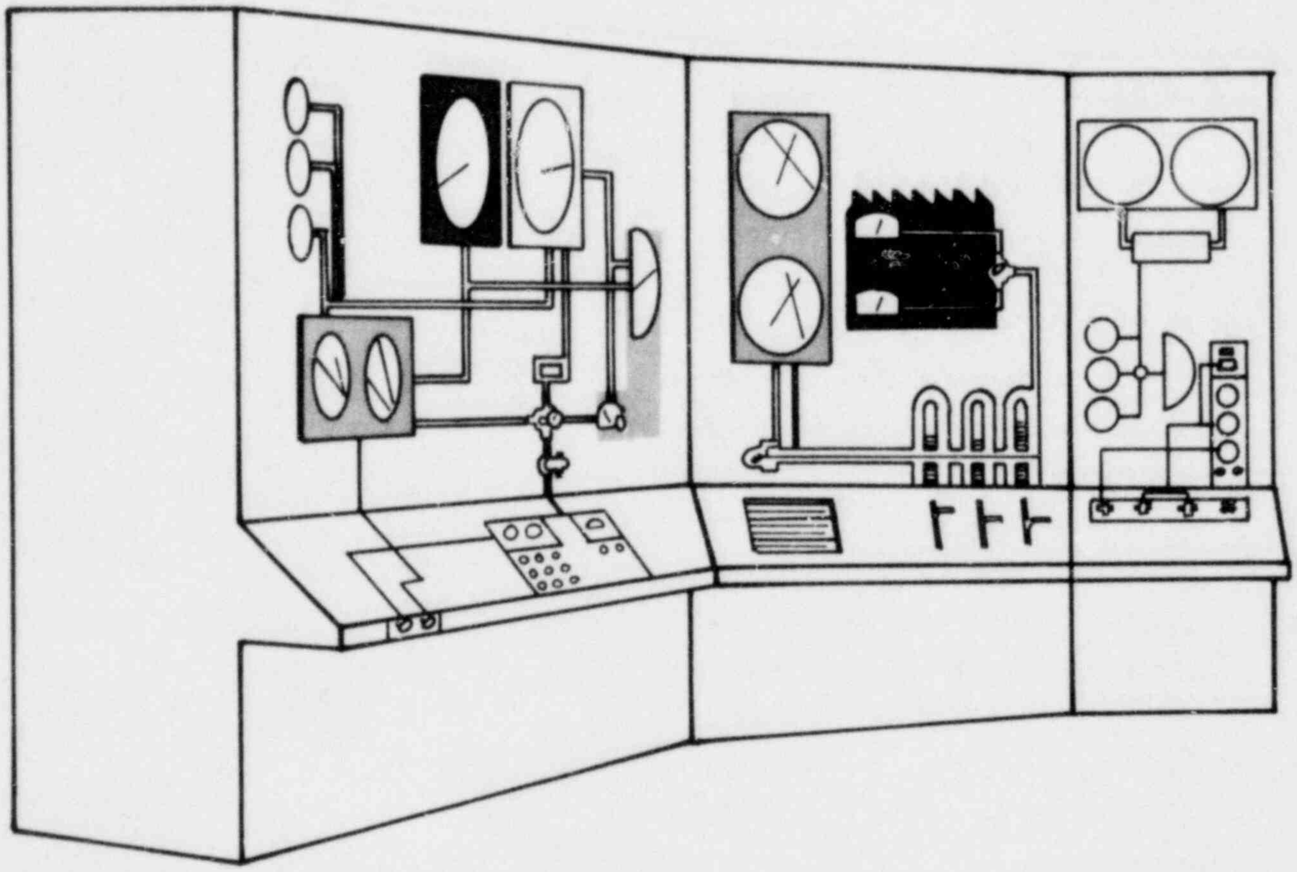
C. **HUMAN ERROR:** Erroneous system status conclusions.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-STD-1472, Essex Revision, (1980); MIL-HDBK-759 (1975); Van Cott and Kinkade (1972); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Modify or replace hardware or software.

A. TITLE: MIMIC BOARDS AND GRAPHIC PANELS

B. GUIDELINES: Operational Status Portrayal — A graphic representation of a complex control system conveys operational status to an operator more clearly than the typical array of abstract meters and controls. The graphic panel should pictorialize the salient features of a system directly on the panel, so that the operator has a better appreciation for the parts, direction of flow, and subsystem relationships. The extent to which the elements of the display are static or dynamic will depend upon system complexity. In the simplest case, elements of the system are painted on the panel. For more complex renditions, the elements (including flow lines) are made to appear dynamic by means of illuminated indicators, edge- or back-lighted lines, or by use of electro-luminescent panels and strip elements. Color coding should be used for segregating various subsystems or for emphasizing certain critical elements of the display. A flashing light can be used for attracting attention to important elements of the display — especially when it is important for the operator to react quickly to the signal.



C. **HUMAN ERROR:** Late response; premature response; incorrect switch operation; inadequate or excessive magnitude of control action and failure to obtain or apply all relevant decision information; or failure to identify all applicable alternatives.

D. **DOCUMENTATION:** Woodson & Conover (1964)

E. **TYPICAL BACKFIT:** Redraw, repaint, recolor or replace existing mimic lines or develop new ones. If the decision is made to install modern mimic boards or graphic panels, the following guidance is offered:

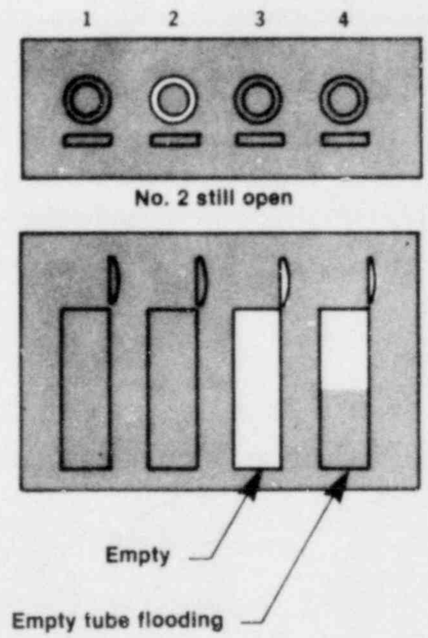
A typical application is a panel which displays open or closed valve conditions. In the upper illustration to the right, the circles (when illuminated) indicate that a particular valve is still open.

In the lower illustration, tubes or tanks are pictorialized, showing when the hatch is open and also when a tube is being flooded.

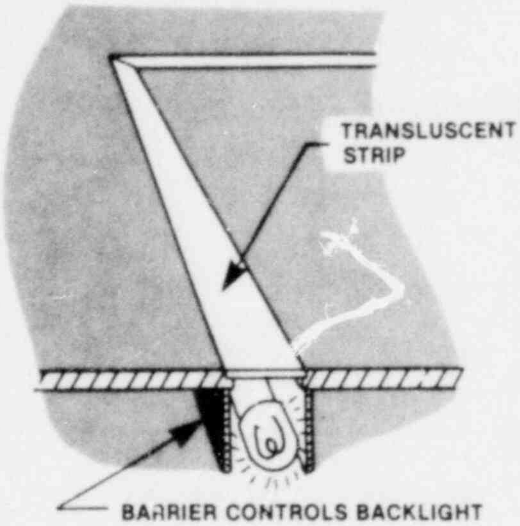
Electro-luminescent panels are very useful in making up displays of this type.

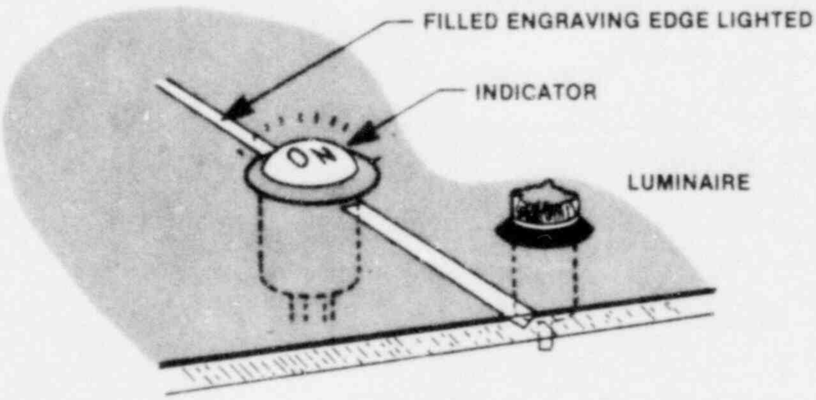
Combinations of edge-lighted lines, areas, symbol and indicator lights, annunciators, or illuminated instruments are useful in developing a graphic layout of complex systems.

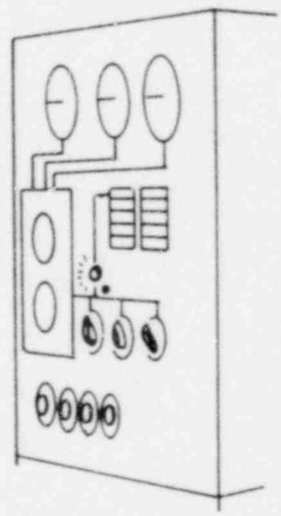
In the design of graphic panels using edge-lighting techniques, it is important to control the spread of light in the plastic transilluminating medium. Barriers must be provided between elements to avoid having stray light from one part of the

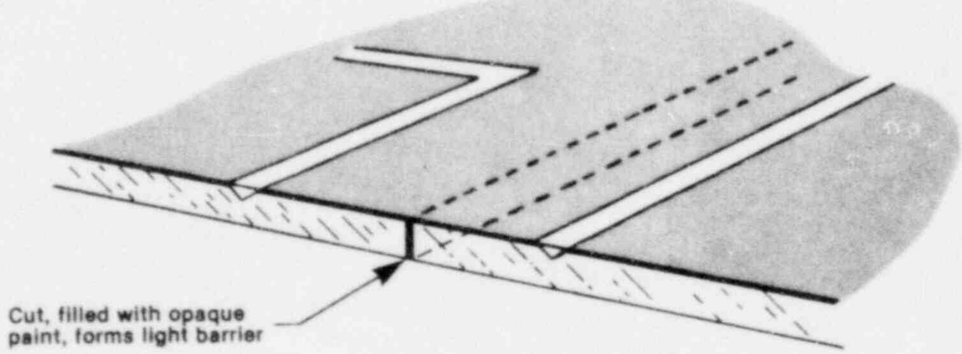


graphic affect another. Also, it is important to position the lamps in such a way that there is a good balance among various parts of the display. If it is impossible to locate the lamps in an optimal position, it is sometimes possible to balance the illumination by means of filters.









A. TITLE: ASSESSMENT OF MECHANICAL INSTRUMENTS

B. GUIDELINES: The criteria in the table are provided for general guidance in the gross assessment of the effectiveness of mechanical instrument displays in a con*rol room.

APPLICATION OF VARIOUS TYPES OF MECHANICAL DISPLAYS

USE	SCALES		COUNTERS	PRINTERS	FLAGS
	Moving Pointer	Fixed Pointer			
QUANTITATIVE INFORMATION	FAIR May be difficult to read while pointer is in motion.	FAIR May be difficult to read while scale is in motion.	GOOD Minimum time and error for exact numerical value.	GOOD Minimum time and error for exact numerical value. Provides reference records.	N/A
QUALITATIVE INFORMATION	GOOD Location of pointer easy. Numbers and scale need not be read. Position change easily detected.	POOR Difficult to judge direction and magnitude of deviation without reading numbers and scale.	POOR Numbers must be read. Position changes not easily detected.	POOR Numbers must be read. Position changes not easily detected.	GOOD Easily detected. Economical of space.
SETTING	GOOD Simple and direct relation of motion of pointer to motion of setting knob. Position change aids monitoring.	FAIR Relation to motion of setting knob may be ambiguous. No pointer position change to aid monitoring. Not readable during rapid setting.	GOOD Most accurate monitoring of numerical setting. Relation to motion of setting no less direct than for moving pointer. Not readable during rapid setting.	N/A	N/A
GENERAL	Requires largest exposed and illuminated area on panel. Scale length limited unless multiple pointers used.	Saves panel space. Only small section of scale need be exposed and illuinated. Use of tape allows scale.	Most economical of space and illumination. Scale length limited only be number of counter drums.	Limited application.	Limited application

Types of Scale Indicators — The types of scale indicators that should be considered are:

1. Moving-pointer, fixed-scale, circular, curved (arc), horizontal straight, and vertical straight.
2. Fixed-pointer, moving-scale, circular, curved (arc), horizontal straight, and vertical straight.

Applications — The appropriateness of scale indicators for various applications should be based on the criteria in the table as well as the specific criteria contained in this section. Moving-pointer, fixed-scale indicators shall be used in preference to fixed-pointer, moving-scale indicators. If a fixed-pointer, moving-scale indicator is found in a control room it must be replaced or the responsible authority must demonstrate that it is necessitated by operational requirements or special conditions.

Quantitative Information — Scale indicators should be used to display quantitative information in combination with qualitative information (such as trend and direction-of-motion) and where only quantitative information is to be displayed and there is no requirement (such as speed and accuracy of response) which demands the use of printers or counters.

Linear Scales — Except where system requirements clearly dictate nonlinearity to satisfy operator information requirements, linear scales shall be used in preference to non-linear scales. Non-linear scales should be used in situations where it is necessary to condense a large range into a small space in such a way as to permit sensitive readings at certain critical ranges of the scale.

Scale Markings —(See VD-71)

1. Graduations - Scale graduations shall progress by 1, 2, or 5 units or decimal multiples thereof. Graduation-interval values of 2 are less desirable than values of 1 or 5 and should be avoided when possible.
2. Intermediate Marks - The number of minor or intermediate marks between numbered scale marks shall not exceed nine.

Nume. als —

1. Major Marks - Except for measurements that are normally expressed in decimals, whole numbers shall be used for major graduation marks.
2. Starting Point - Display scale shall start at zero, except where this would be inappropriate for the function involved.

Pointers —

1. Length - The display shall be designed so that the control or display pointer will extend to, but not obscure, the shortest scale graduation marks.
2. Width - The width of the pointer, where it intercepts the graduation marks, shall not exceed the width of the intermediate marks.
3. Mounting - The pointer shall be mounted as close as possible to the face of the dial to minimize parallax.

Luminance Contrast — Luminance contrast of at least 50 percent shall be provided between the scale face and the markings and pointer.

Calibration Information — Provision shall be made for placing calibration information on instruments without interfering with dial legibility.

Coding —

1. Use of Coding - Coding on the face of scale indicators may be used to convey such information as desirable operating range, dangerous operating level, caution, undesirable, and inefficient.
2. Pattern or Color Coding - When certain operating conditions always fall within a given range

on the scale, these areas shall be made readily identifiable by means of pattern or color coding applied to the face of the instrument.

3. Choice of Colors - For use under white lighting, the colors red, yellow, and green may be applied, provided they conform to the meanings specified herein and are distinguishable under all expected lighting conditions.

4. Pattern Coding - Zone scales may be shape coded when the indicator must be viewed in blackout stations or where the illuminant color will cause difficulty in color band discrimination.

Moving-Pointer, Fixed-Scale Indicators —

1. Numerical Progression - The increase of numerical progression on fixed scales shall read clockwise, from left to right, or from the bottom up, depending on display design or orientation.

2. Orientation - Numbers on stationary scales shall be oriented in the upright position.

Circular Scales —

1. Scale Reading and Pointer Movement - The magnitude of the scale reading shall increase with

clockwise movement of the pointer.

2. Zero Position and Direction of Movement - When positive and negative values are displayed around a zero or a null position, the zero or null point shall be located at either the 12 o'clock or 9 o'clock position. Positive values shall increase with clockwise movement of the pointer, and negative values shall increase with counterclockwise movement.
3. Scale Break - There shall be an obvious break of at least 10° of arc between the two ends of the scale, except on multirevolution instruments such as clocks.
4. Number of Pointers - Whenever precise readings are required, not more than two coaxial pointers shall be mounted on one indicator face.
5. Pointer Alignment - When a stable value exists for given operating conditions in a group of circular-scale indicators, they shall be arranged either in rows so that all pointers line up horizontally on the 9 o'clock position under normal operating conditions or in columns so that all pointers line up vertically in the 12 o'clock position under normal

operating conditions. If a matrix of indicators is needed, preference shall be given to the 9 o'clock position.

6. Placement of Numerals - Numerals shall be placed outside graduation marks to avoid having numbers covered by the pointer. Numerals may be placed inside of graduation marks when it is necessary to avoid constriction of the scale. In any case, the pointer shall extend to, but not obscure, the shortest graduation marks.

Curved (Arc), Horizontal Straight, and Vertical Straight Scales —

1. Scale Reading and Pointer Movement - The magnitude of the scale reading shall increase with movement of the pointer up or to the right.
2. Zero Position and Direction of Movements - When positive and negative values are displayed around a zero point, the positive values shall increase with movement of the pointer up or to the right, and negative values shall increase with movement of the pointer down or to the left.
3. Placement of Pointers - Pointers shall be located to the right of vertical scales and at the bottom of horizontal scales.

4. Placement of Numerals - Numerals shall be placed on the side of graduation marks away from the pointer to avoid having numbers covered by the pointer. If space is limited (for curved or arc scales) numerals may be placed inside graduation marks to avoid undue constriction of the scale.

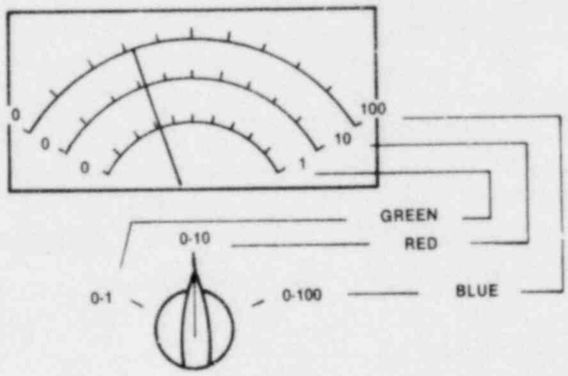
C. **HUMAN ERROR:** Reading errors.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-STD-1472 (Essex Revision, 1980)

E. **TYPICAL BACKFIT:** Modify or replace.

A. **TITLE: MULTIPLE-RANGE METERS**

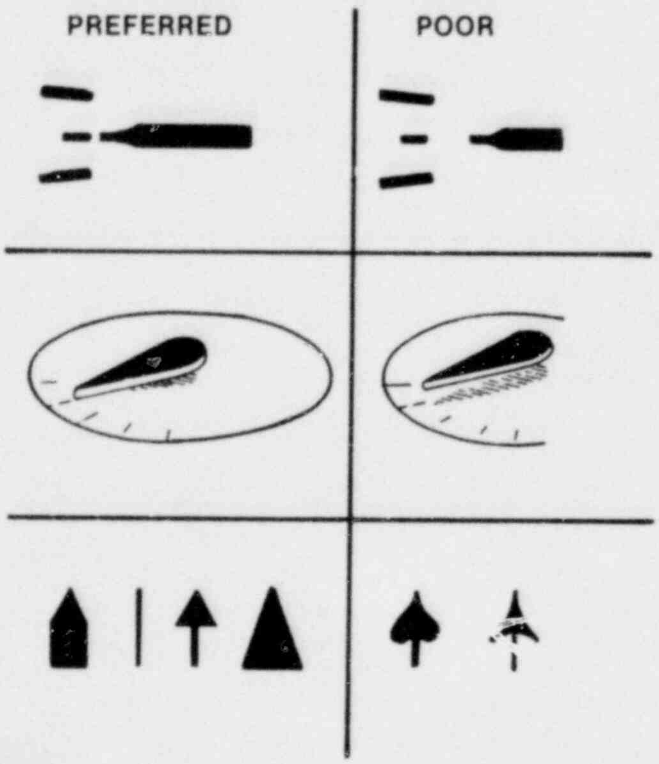
B. **GUIDELINES:** Ordinarily, multiple scales should not appear on the same display. When such a compromise is necessary, color coding should be used to help the observer associate the right scale with the proper selector-switch position.



C. **HUMAN ERROR:** Moving a control to the wrong position; confusing one scale with another.

D. **DOCUMENTATION:** Woodson and Conover (1964)

E. **TYPICAL BACKFIT:** Color code scales; replace meters.



A. TITLE: POINTERS

B. GUIDELINES: Preferred Types — The pointer should be designed so that there is a minimum distance between tip and index — 1/16 inch maximum.

Avoid use of pointers which overlap index.

The pointer should be mounted so that visual parallax is minimized.

The pointer should be painted the same color as numbers and indices when possible.

When reciprocal readings are necessary, the two ends of the pointer must be identifiable.

Simplicity in pointer-tip design is important for reading speed and accuracy.

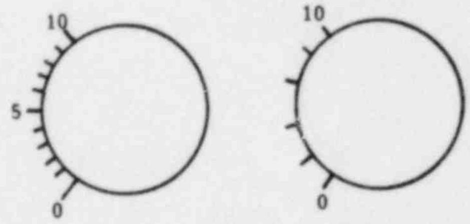
C. HUMAN ERROR: Parallax, spacing and poor coding can produce reading errors.

D. DOCUMENTATION: Woodson (1964)

E. TYPICAL BACKFIT: Modify or replace.

A. TITLE: SCALE MARKINGS

B. GUIDELINES: Similar Scales — When two or more similar scales appear on the same panel, they should have compatible numerical progression and scale organization. (See VD-63)



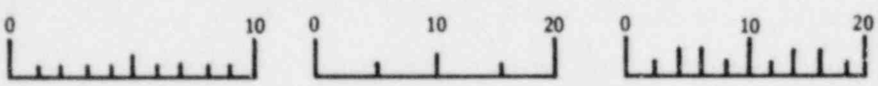
POOR

RECOMMENDED NUMERICAL PROGRESSION

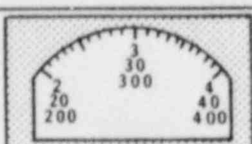
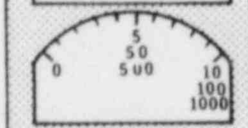
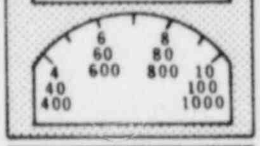
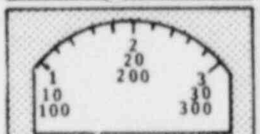
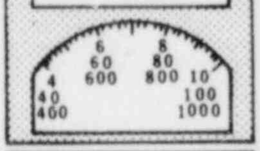
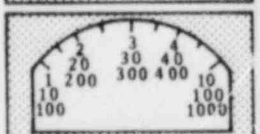
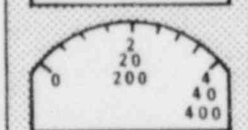
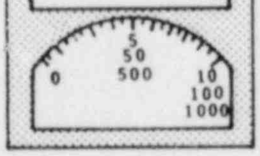
GOOD					FAIR					POOR			
1	2	3	4	5	2	4	6	8	10	3	6	9	12*
5	10	15	20	25	20	40	60	80	100	4	8	12	16
10	20	30	40	50						1.25	2.5	5	7.5

* Except for bearing dials where cardinal directions are standard orienting points or where operating doctrine specifies conditions of time scales, or turn rates.

RECOMMENDED SCALE BREAKDOWN



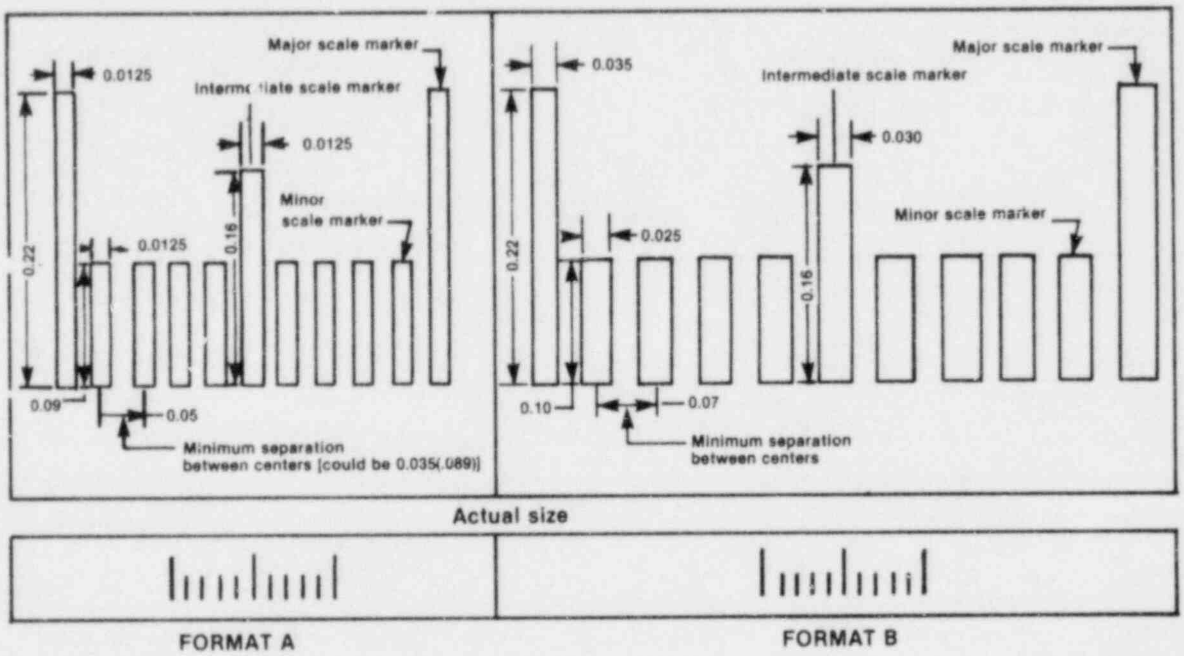
Scale Ranges and Interval Valves — Scales that are to be read under normal illumination should have the same relative proportions as are shown in the figure, but the graduation marks may be spaced as closely as .04 inch. In any case, the minimum distance between major graduation marks should not be less than 0.5 inch, and the heights of the major, intermediate, and minor marks should not be less than 0.22, 0.16, and 0.09 inch, respectively.

GRADUATION INTERVAL VALUE		NUMBERED INTERVAL VALUE	GRADUATION MA[illegible]		
			MAJOR	INTERMEDIATE	MINOR
0.1, 1, 10		1, 10, 100	X	X	X
		5, 50, 500	X		X
		2, 20, 200	X	X	
0.2, 2, 20		1, 10, 100	X		X
		2, 20, 200	X	X	X
0.5, 5, 50		1, 10, 100	X	X	
		2, 20, 200	X	X	X
		5, 50, 500	X	X	X

Recommended scale ranges and interval values.

Recommended format of quantitative scales, considering length of scale unit and graduation markers. Format A is proposed for normal illumination conditions under normal viewing conditions, and B for low illumination.

Basic sketches, measurements in inches



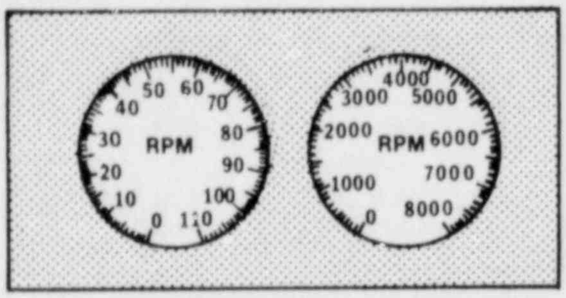
C. **HUMAN ERROR:** Incorrect display reading and interpretation.

D. **DOCUMENTATION:** Woodson (1964); McCormick (1970); Chapanis (1965); Van Cott (1972)

E. **TYPICAL BACKFIT:** Reconfigure scale markings.

A. TITLE: DIAL MARKING

B. GUIDELINES: Usable Values — The least precise scale that fulfills the needs of the operator shall be used. All displays should indicate values in an immediately usable form without mental conversion by the operator.

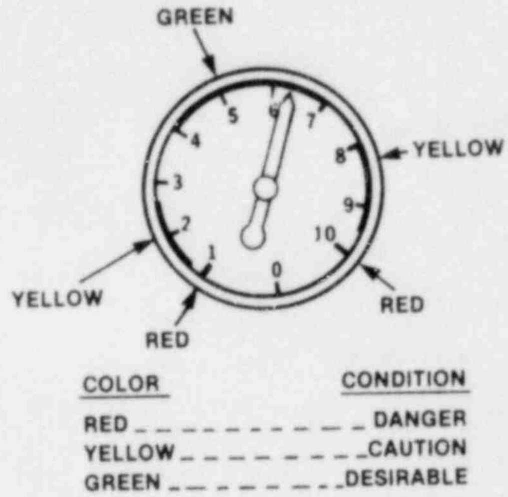


Comparing percentages and actual values of functions being displayed.

Transforming Values — Transforming the scale values into percent rpm relieves the operator of the necessity of remembering operating rpm values for different engines. In addition, the range from 0 to 100% is more easily interpreted than a range of true values, such as 0 to 8,000 rpm, and the smaller numbers on the dial make a more readable scale. In the figure, the two tachometers illustrate these advantages. The less cluttered dial on the left can be read more precisely than the one on the right.

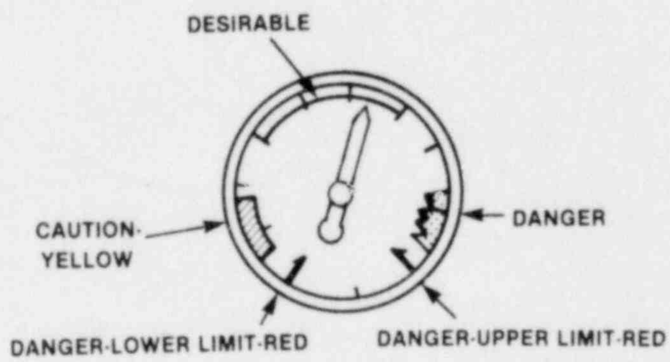
Zone Marking — Zone markings indicate various operating conditions on many indicators: such as, operating range; upper, lower or danger limits; caution; etc. These zone markings can be color or shape coded. Because of frequent need for relocation, they are placed on the indicator's window in preference to the dial face.

Color Coding — The figure shows recommended colors associated with various operating conditions. If the indicator is illuminated with colored light, do not use color coding. Colors are not readily distinguishable when illuminated by colored light.



Color coding of instrument range markers.

Shape Coding — Zone marking shapes can indicate various operating conditions. The shapes in the figure are recommended because they are easy to learn and are distinguishable under low and colored illumination.



Shape coding of instrument range markers.

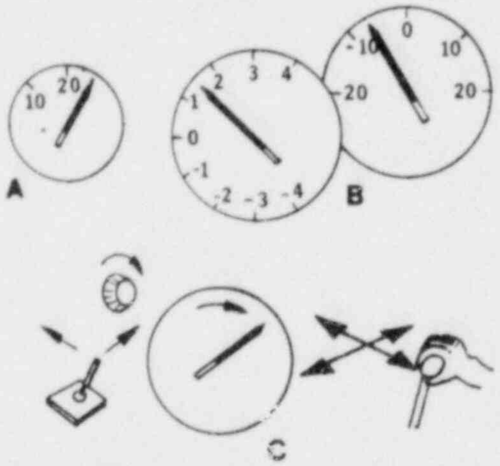
C. **HUMAN ERROR:** Incorrect display reading and interpretation.

D. **DOCUMENTATION:** Van Cott (1972)

E. **TYPICAL BACKFIT:** Replace; repaint; renumber; or reletter dial face.

A. TITLE: MOVING-POINTER, FIXED SCALE INDICATORS

B. GUIDELINES: Circular Scales — The magnitude of reading should increase with a clockwise movement of the pointer (see A). Where positive and negative values around zero are being displayed, the zero should be located at the 9 or the 12 o'clock position (B). This arrangement provides for pointer increases upward or to the right, which are expected directions. Thus, positive values will increase with clockwise movement of the pointer and the negative values will increase with counterclockwise movement. In addition, clockwise movement of a pointer should result from clockwise movement of the associated knob or crank; movement forward, upward, or to the right of an associated lever; or movement upward or to the right of the associated equipment (C).



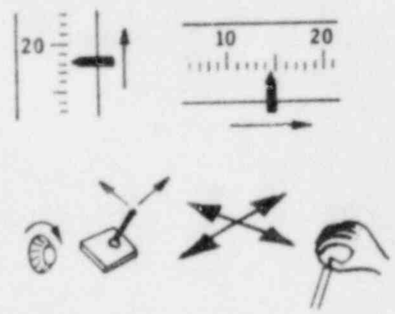
Recommended direction of motion on circular moving-pointer indicators.

Straight Scales — The pointer should move up or to the right to indicate an increase in magnitude. This movement should result from: (a) clockwise rotation of the associated knob or crank; (b) movement forward, upward, or to the right of a lever; or (c) movement upward or to the right of the associated equipment.

C. **HUMAN ERROR:** Control errors of direction and time.

D. **DOCUMENTATION:** Van Cott (1972)

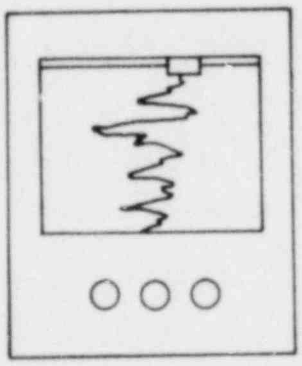
E. **TYPICAL BACKFIT:** Modify or replace dial (or face).

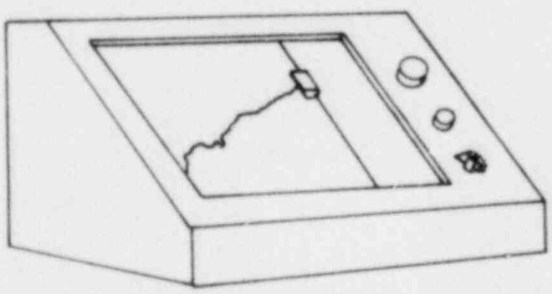


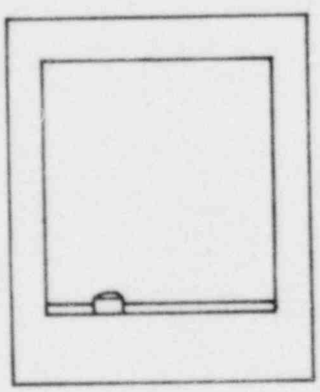
Recommended direction of motion on straight-scale, moving-pointer indicators.

A. TITLE: PRINTERS, GRAPHIC RECORDERS

B. GUIDELINES:







1. Application — Printers or plotters should be used when a visual record of data is necessary or desirable, especially trend data.
2. Form of Information — Printed information shall be presented in a directly usable form with minimal requirements for decoding, transposing, and interpolating. When an operator is required to interpret graphic data, aids (e.g., graphic overlays) shall be provided but such aids shall not obscure or distort the data.
3. Insertion & Removal of Materials — Captive-paper storage should be provided so that the operator isn't required to provide some make-shift method collecting the paper as it comes from the machine. The method reloading chart paper should be quick and easy. Pen assemblies should be designed so that they are easy to refill and do not leak or lead to spillage because the operator did not adjust the assembly properly.

4. Annotation — Recording devices should be designed so that, when applicable, it is possible for the operator to make notes directly on the chart. Continuously variable paper-speed control is recommended. Manual controls should be placed so that the operator does not cover the tracing as he adjusts the control knobs.
5. Supplies — A positive indication of the remaining supply of recording materials (e.g., paper, ink and ribbon) shall be provided.
6. Chart Tapes — The information on the tapes shall be recorded in such a manner that it can be read directly when it is received from the machine without requiring the cutting and pasting of sections of tape. A simple, sure method of tearing or cutting off finished chart-paper segments shall be provided.
7. Illumination — The printer shall be designed with internal illumination if the printed matter is not completely and easily readable in the operational ambient illumination.
8. Contrast — A minimum of 50% luminance contrast shall be provided between the recorded material and the background.

9. Visibility — The recorded matter shall not be in any way hidden, masked, or obscured so that direct reading cannot be easily and accurately accomplished. Plotting points shall be readily visible and shall not be obstructed by the pen assembly or arm. Pen-recording devices should be designed so that the pen assembly covers no more of the chart than is absolutely necessary. Design of chart paper to be used in automatic pen-recording equipment should consider visibility and legibility. Under normal lighting conditions, the paper should be white, graph lines black, and pen tracing red, green, or some other color which shows up well against the black graph lines. For single-sheet chart systems, the pen should always move from left to right. For moving-chart systems, the paper should move from right to left. For printers (e.g., teletype), the paper should move from bottom to top.

C. **HUMAN ERROR:** Failure to obtain or apply all relevant decision information.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Woodson & Conover (1964)

E. **TYPICAL BACKFIT:** Modify or replace.

VISUAL DISPLAYS

A. TITLE: COUNTERS

B. GUIDELINES: <u>Movement — Snap Action</u> - Numbers shall change by snap action in preference to continuous movement.

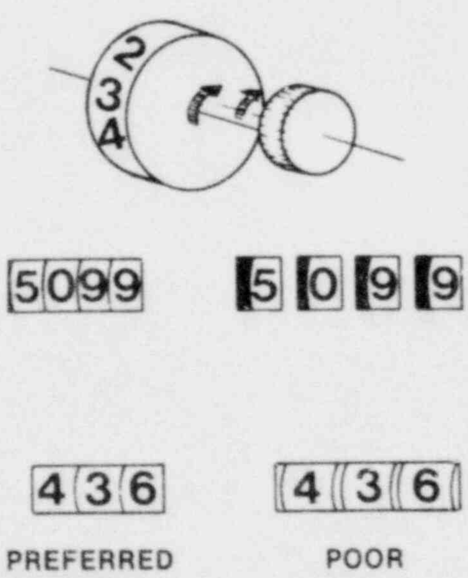
<u>Rate</u> - Numbers shall follow each other not faster than 2 per second when the observer is expected to read the numbers consecutively.

<u>Direction</u> - An "upward" movement of the counter drum should indicate a numerical increase. If a manual control is associated with the counter, clockwise rotation of the control should result in numerical increase. Control-display ratio should be such that one revolution of the control knob equals approximately 50 counts on the counter.

<u>Mounting</u> - Counters shall be mounted as close as possible to the panel surface so as to minimize parallax and shadows and maximize the viewing angle.

<u>Spacing Between Digits</u> - The horizontal separation between numerals shall be between one-quarter and one-half the numeral width.

<u>Numeral Proportions</u> - Except for the number "1", which shall be



one stroke width, the height-to-width ratio of numerals for counter-wheel read-outs should be 1:1 rather than the 3:2 recommended for other displays. This is because of the distortion from the curved drum surface.

Orientation - Counters should always be oriented horizontally to read from left to right.

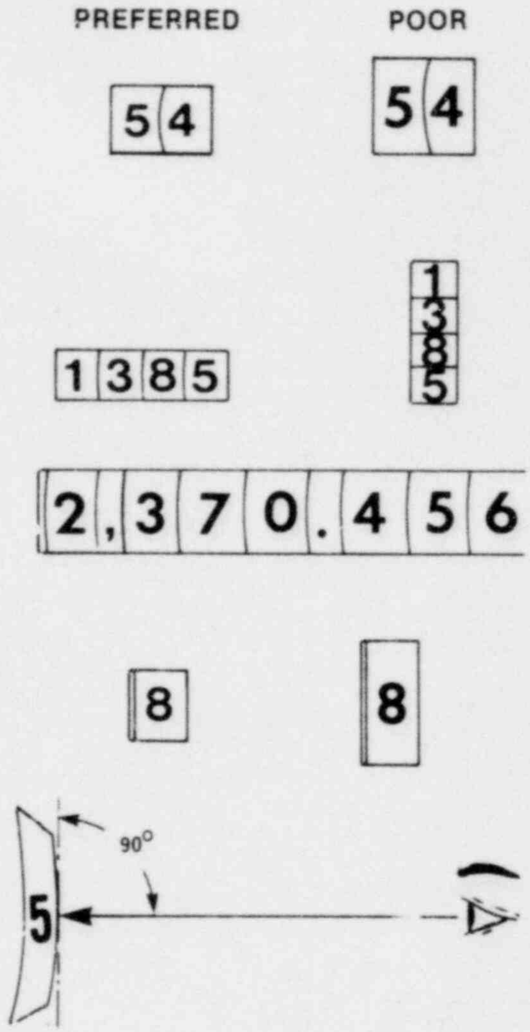
Several Digits - If more than four digits are required, it is easier to read and recall groups of digits if they are separated by slightly greater space or by a decimal symbol or commas.

Digit Window - No more than one digit should appear in the open window at one time.

Viewing Angle - Because of the limited viewing angle of drum-type counters, they should be mounted perpendicular to the observer's line of sight.

Automatic Reset - Counters used to indicate the sequencing of equipment shall be designed to be reset automatically upon completion of the sequence. Provision shall also be made for manual resetting.

Illumination - Counters shall be self-illuminated when used in areas in which ambient illumination will provide display luminance below 1 ft-L (3.4 cd/m^2).



Finish - The surface of the counter drums and surrounding areas shall have a dull finish so as to minimize glare.

Contrast - Color of the numerals and background shall provide high contrast (black on white or converse, as appropriate).

Application - Counters should be used for presenting quantitative data when a continuous trend indication is not required and when a quick, precise indication is required.

C. **HUMAN ERROR:** Errors in display (counter) reading.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Woodson (1964); and Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Modify or replace counters.

A. TITLE: CHECK-READING DIAL LAYOUT

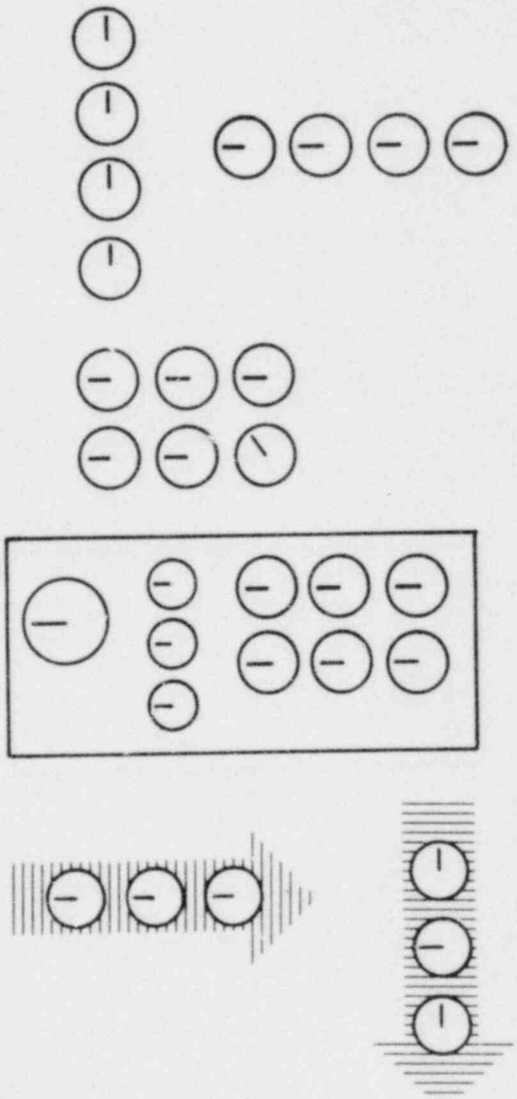
B. GUIDELINES: For a single group of five or fewer check-reading dials in a horizontal row, normal operating position of the pointers should be located at the 9-o'clock position; for the vertical groups, orient the pointers at the 12-o'clock position.

For groups of six or more use rows or columns rather than extend a single row; long rows or columns impose undesirable scanning requirements upon the operator.

For several groups on the same panel use a consistent pointer position regardless of the above recommendations.

Linear gauges or meters should follow the same general rules as specified for details.

The positions of specific dials which are grouped together should be determined by the sequence in which they are to be read, that is, the operator should be able to read in order of sequence from left to right or from the top of the panel to the bottom.



C. **HUMAN ERROR:** Activating the wrong control; not activating a control; misreading the display; reading the wrong display.

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Reorient displays; purchase new displays.

A. **TITLE: PANELS OF DISPLAYS FOR CHECK READING**

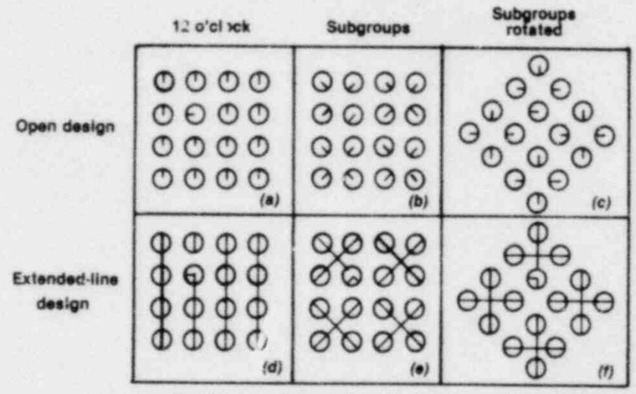
B. **GUIDELINES:** Pattern — When several quantitative displays are used for check reading (to determine if condition is normal or not), the arrangement of the displays can facilitate the identification of any nonnormal display.

The patterns in the illustration were compared and the errors resulting from this comparison are shown at the right. It is, therefore, recommended that the type d pattern with normal at the 12 o'clock position and extended lines drawn between displays.

C. **HUMAN ERROR:** Failure to detect nonnormal conditions.

D. **DOCUMENTATION:** McCormick (1976)

E. **TYPICAL BACKFIT:** Modify or replace to make the deviant dial more conspicuous. One approach is to install extended pointers, if short ones exist, and add extended lines.



Patterns of panels of check-reading dials.

Arrangement

	12 o'clock	Subgroups	Subgroups rated
Open	a. 53	b. 193	c. 201
Extended line	d. 8	e. 15	f. 41

A. TITLE: TRANSILLUMINATED DISPLAYS

B. GUIDELINES: General — The following three general types of transilluminated displays may be encountered:

1. Single- and multiple-legend lights, which present information in the form of meaningful words, numbers, symbols, and abbreviations.
2. Simple indicator lights, such as pilot, bull's eye, and jewel lights.
3. Transilluminated panel assemblies, which present qualitative status or system readiness information.

Use — Transilluminated indicators should be used to display qualitative information to the operator (primarily, information that requires either an immediate operator reaction or that calls operator attention to an important system status). Such indicators may also be used occasionally for maintenance and adjustment functions.

Equipment Response — Lights, including those used in illuminated pushbuttons, shall display equipment response and not merely control position.

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

Positive Feedback — The absence or extinguishment of a signal or visual indication shall not be used to denote a "go-ahead," "ready," "in-tolerance," or completion condition, nor shall such absence be 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. Changes in display status shall signify changes in functional status rather than results of control actuation alone.

Grouping — Master caution, master warning, master advisory and summation lights used to indicate the condition of an entire subsystem shall be set apart from the lights which show the status of the subsystem components, except as required under the paragraph on Maintenance Displays on the following page.

Location — When a trans-illuminated indicator is associated with a control, the indicator light shall be so located as to be immediately and unambiguously associated with the control and visible to the operator during control operation.

Location, Critical Functions — For critical functions, indicators shall be located within 15° of the normal line of sight of the operator responsible for monitoring that indicator. (See TITLE: Placement, page VD-18). 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.

Maintenance Displays — Indicator lights used solely for maintenance and adjustment, and referred to infrequently, shall be covered or non-visible during normal equipment operation, but shall be readily accessible when required.

Luminance — The luminance (brightness) of transilluminated displays shall be compatible with the normal ambient illuminance level, and shall be at least 10% greater than the surrounding luminance.

Luminance Control — When displays are 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 dimming the display from full ON to full OFF.

Reflection — Provision shall be made to prevent direct and/or reflected light from making indicators appear illuminated when they are not, or to appear extinguished when they are illuminated.

Contrast Within the Indicator — The contrast between the background and a figure equals the absolute difference in the higher luminance (L_1) and the lower luminance (L_2) divided by the higher luminance; i.e.,

$$C = \frac{|L_1 - L_2|}{L_1}$$

The luminance contrast within the indicator shall be at least 50%, as determined by the above method.

Lamp Redundancy — For incandescent displays, lamps shall be provided that incorporate filament redundancy or dual bulbs, so that when one filament or bulb fails, the intensity of the light shall decrease sufficiently to indicate the need for lamp replacement, but not so much as to degrade operator performance.

Lamp Testing — When indicator lights using incandescent bulbs are installed on a control panel, a master lamp test control shall be incorporated. When applicable, design shall allow testing of all control panels at one time. Panels containing three or fewer lights may be designed for individual press-to-test bulb testing. Circuitry should be designed to test the operation of the total indicator circuit.

Lamp Removal, Method — Where possible, provisions shall be made for lamp removal from the front of the display panel without the use of tools, or by some other equally rapid and convenient means.

Lamp Removal, Safety — Display circuits shall be designed so that bulbs may be removed and replaced while power is applied without causing failure of indicator circuit components or imposing personnel safety hazards.

Indicator Covers — Legend screen or indicator covers shall be designed to prevent inadvertent interchange or a means shall be provided for checking the covers after installation to insure proper installation.

C. **HUMAN ERROR:** Inaccurate display reading and associated control errors.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify or replace.

A. **TITLE: DISPLAYS ILLUMINATION**

B. **GUIDELINES:** General — Illumination level should be sufficient to provide the operator with a clear indication of equipment or system conditions for operation under all expected use conditions.

Where multiple displays are grouped together, the displays shall have brightness uniformity so that all appear of equal brightness across the range of full ON to full OFF. The lowest expected lumination level should be sufficient to read the smallest required display details at the required viewing distance.

C. **HUMAN ERROR:** Control error; operator inaction; reading errors.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott (1972).

E. **TYPICAL BACKFIT:** Replace or modify equipment or lighting.

VISUAL DISPLAYS

A. **TITLE: INDICATOR AND WARNING LIGHTS — GENERAL**

B. **GUIDELINES:** General Precautionary Notes — A control room should contain only the minimum number of lights required. The attention value of indicator and warning lights is reduced if there are too many of them, especially when they serve little purpose. For example, if a normal condition of "on" is indicated by sounds or the movement of a meter, etc., it is not necessary to have a pilot light indicating "on." On the other hand, when an operator looks at a console containing several channels, he will find it helpful if lighted indicators show which channels are activated.

C. **HUMAN ERROR:** Failure to notice signal.

D. **DOCUMENTATION:** Woodson & Conover (1964)

E. **TYPICAL BACKFIT:** Conduct human factors engineering analysis and remove all unnecessary lights. Maintain or add all required lights.

A. **TITLE: INDICATORS SIGNALS AND WARNING LIGHTS — CHARACTERISTICS**

B. **GUIDELINES:** Status Indicators — If basic data represent discrete, independent categories, or if basically quantitative data are always used in terms of such categories, displays should be used that represent each.

Signal and Warning Lights — Minimum size used must be consistent with luminance and exposure time.

With low signal-to-background contrast, red light is more visible.

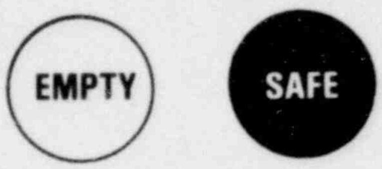
Flash rate of flashing lights of 1 to 10 per second can be detected by people.

C. **HUMAN ERROR:** Failure to detect status change or warning light.

D. **DOCUMENTATION:** McCormick (1976)

E. **TYPICAL BACKFIT:** Modify or replace.

A. TITLE: INDICATOR AND WARNING LIGHTS — SPECIFICS

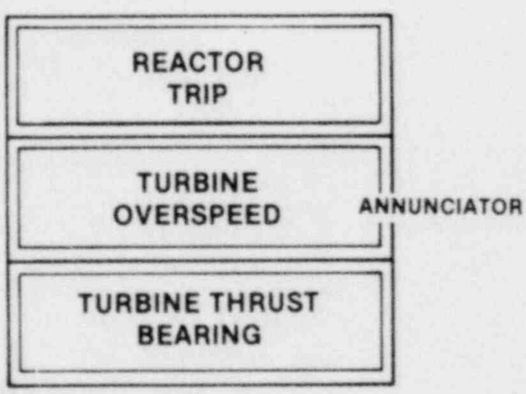


B. **GUIDELINES:** Identification should normally be provided with light displays. If the ambient conditions of illumination are sufficient, the identification does not have to be printed directly on the light.

Simple panel lights may be used for indicating certain types of operating conditions. For example:

GO, NO-GO condition
CAUTION
WARNING

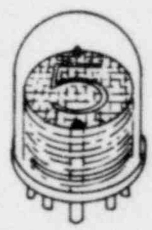
In addition, indicator lights with engraved nomenclature may be used to give visual commands or identify conditions. These are often referred to as annunciator displays.



Brightness factors are of prime concern in light displays. Lights which must attract immediate attention should be at least twice as bright as the immediate background. The background should be dark in contrast to the display and should be a dull finish. When a major panel area is light in color, it is possible to improve the effectiveness of the display by painting the immediate area around the display a dark matte finish.

Color combinations which can be easily confused, such as red and orange, purple and blue, etc., should not be used in control rooms.

<u>Electronic Register-Tubes</u> — Character configuration is reasonably good. These neon-glow displays are good to 60,000 hours and can be read up to 30 feet and 120 degrees. A response rate as low as 10 micro-seconds is possible. The tube must be shielded from ambient light to avoid spectral reflection from the curved surface of the tube.



DEFINITIONS

WARNING: Dangerous condition requiring immediate action!

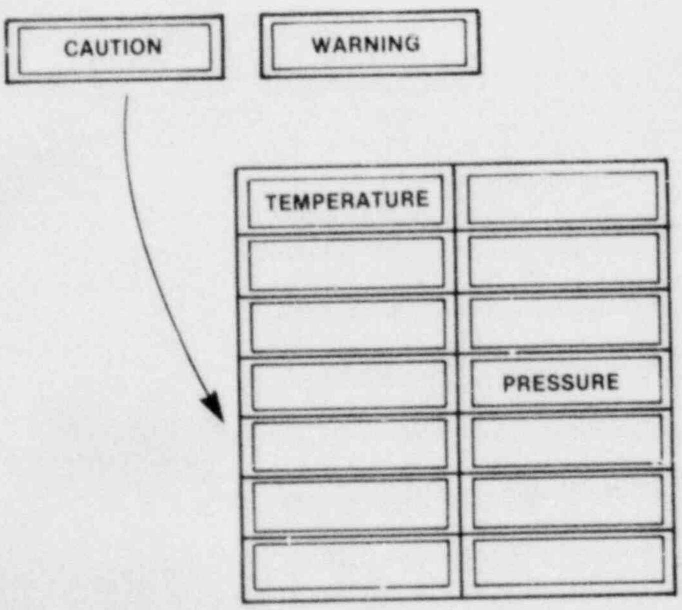
CAUTION: Abnormal condition not necessarily requiring immediate action.

<u>Lights for Warning Signals</u> — A warning light signals a dangerous condition requiring prompt action by the operator. Such lights normally should be red because red means danger to most people. Since red lights are commonly used as signals in control rooms, flashing red should be reserved for warning. Other signal lights in the warning light vicinity should be of other colors. In addition, the location, luminance, and attention value of lights for warning should be considered.

Location and Identification — Because warning lights become less effective as they are moved out of the center of the field of vision, urgent warnings should always be the central portion of the panel.

Sometimes many warning or caution signals must be used in an operator station. This situation not only adds to the operator's identification problem, but it also creates the problem of finding panel space near the operator's normal line of sight.

When there is insufficient panel space for all of the required system-malfunction indicators single master Warning and/or Caution lights may be located in a conspicuous position on the panel close to the normal work-station — with separate system-malfunction indicators grouped in another, less critical area.



The master light can be located near an operator's line of sight on the instrument panel, and the specific warning panel can be located where space is more readily available. Any time the master light comes on, the operator checks the specific warning panel. For very urgent warnings the master warning light may be supplemented by an auditory warning. This is particularly advisable if the operator's visual duties could cause him to miss the master light.

Because warning lights call for fast corrective action, their identification must be simple and positive. Ideally, each light should have a unique location and be easily distinguishable from other lights. As a further aid, the warning light may be near or built into the associated corrective control device.

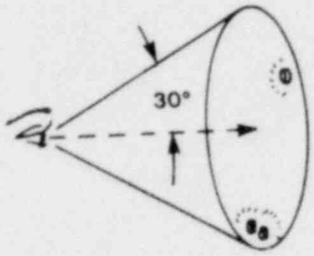
<u>Intensity</u> — Warning lights should be bright enough to stand out clearly against the panel on which they appear under all expected lighting conditions, but they should not be so bright as to blind the operator.

<u>Size of Lettering</u> — Inasmuch as speed of reading is important, any letters or numerals on warning lights should be large. For dark letters on a lighted background viewed at a distance of about 28 inches, a letter height of 0.2 to 0.3 inch is recommended. See <u>Viewing Distance</u>, No. VD-32.

<u>Attention Valve</u> — Flashing lights are good attention-getters. Flash rates of 3 to 10 per second with "on duration" of at least 0.05 second are recommended (four per second, with equal light and dark intervals, is preferred).

Important light indicators should be located within 30 degrees of the normal visual axis from the location where the operator is likely to be working, to insure that the observer will see the light when it comes on.

Caution Lights — The use of lights as caution signals must not be over-done. A large array can confuse the operator. Avoid using signal lights for information that the operator can get in other ways, such as from control position.



C. **HUMAN ERROR:** Failure to detect system malfunction.

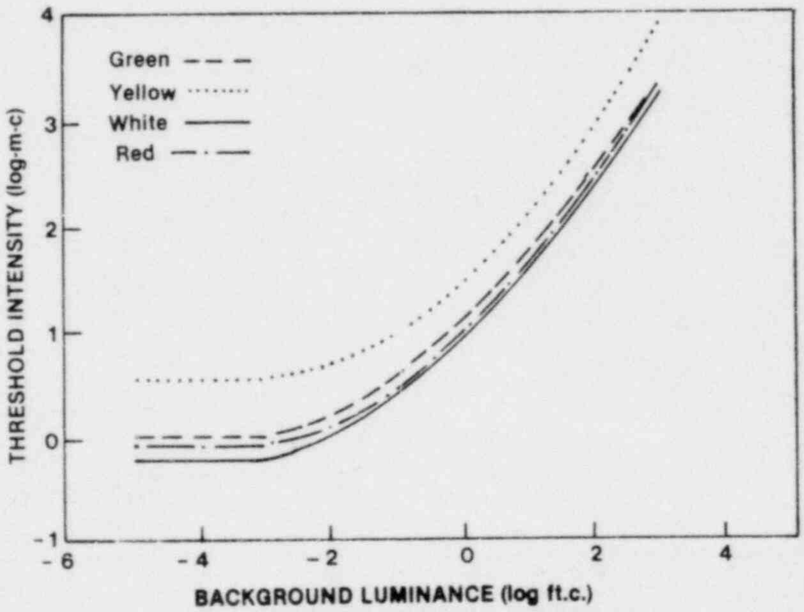
D. **DOCUMENTATION:** Woodson and Conover (1964) and Van Cott and Kinkade (1972)

E. **TYPICAL BACKFIT:** Modify or replace.

A. TITLE: LUMINANCE AND COLOR

B. GUIDELINES: Acuity -- Acuity is increased by luminance contrast. Making the object of focus and background two different colors does not increase acuity if there is high luminance contrast. If luminance contrast is low, color contrast improves visual acuity appreciably.

Detecting Colored Lights — There is a detection problem when color-coded lights are at a great distance. Signal color recognition depends on eye illumination from the light. This is proportional to the intensity of the light and inversely proportional to the square of the distance. It is also affected by the luminance of the background and the color of the light. The curves show in millicandles the threshold illumination for color recognition of point source signal lights when viewed against neutral backgrounds of various luminances. These are 90% thresholds. The curves show that red, green, and white are nearly equal in terms of threshold intensity for color identification. For yellow the threshold is somewhat higher



Intensity thresholds of point-source signal lights as a function of the background luminance for signal-light color. Figures are for 90% thresholds.

because of a tendency to confuse yellow with white.

C. **HUMAN ERROR:** Reading errors; failure to detect system status changes.

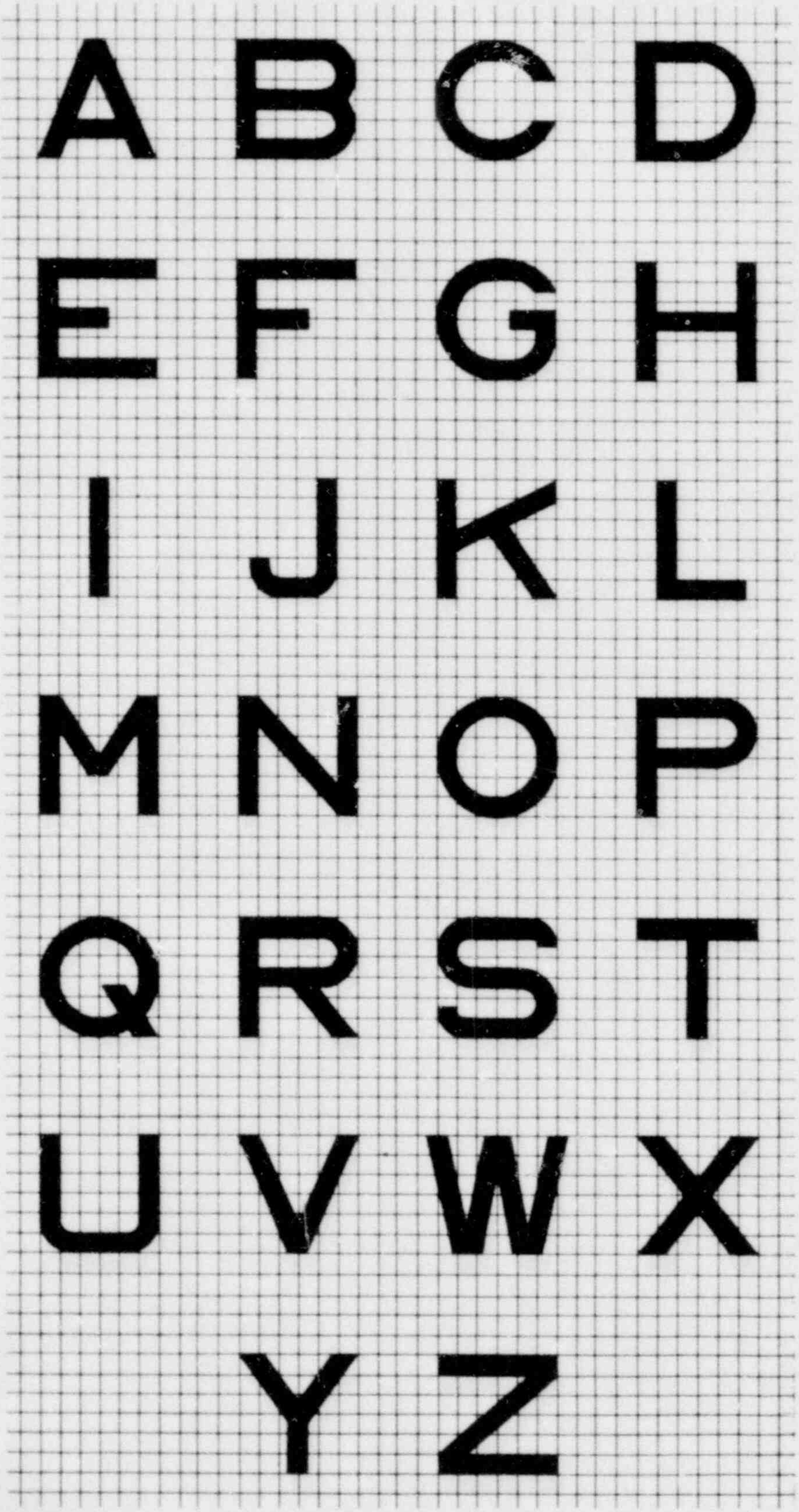
D. **DOCUMENTATION:** Van Cott and Kinkade (1972)

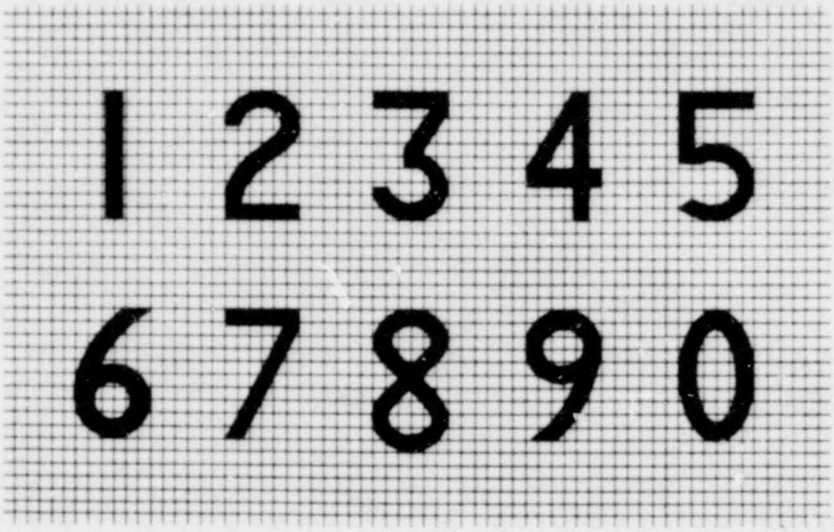
E. **TYPICAL BACKFIT:** Adjust luminance contrast and light intensity and modify colors.

A. TITLE: TRANSILLUMINATED NUMERALS AND LETTERS

B. GUIDELINES: Evaluation of Numerals and Letters — Transilluminated types of displays requiring special height-width and stroke-width specifications are not covered in numeral and letter recommendations found elsewhere in this guide. Special care must be taken in engraving the sandwich materials, for the slightest variation in the engraving depth makes a great difference in the brightness of the emitted light. If retrofits are required it should be noted that the thickness of commercially available plastic sheets varies considerably and the engraving techniques ordinarily used will not give satisfactory results. Engraving depth must be measured from the opaque top surface.

Letters should be all capitals, similar to Futura Demi-Bold type or Groton Extended engraving. Numerals should be similar to Futura Medium or Tempo Bold type or Groton Condensed engraving. For stroke width and height-width ratios, see the letter and numeral samples following.


A B C D
E F G H
I J K L
M N O P
Q R S T
U V W X
Y Z



Letters may be reduced in size to a height-width ratio of 5:3 when there is not sufficient space for the 1:1 ratio shown. The stroke width-to-height ratio should be 1:8 to 1:10, and for highly luminous letters, 1:12 to 1:20.

C. **HUMAN ERROR:** Misread displays.

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Modify or replace.

A. TITLE: CODING — WARNING, CAUTION ANNUNCIATORS

B. GUIDELINES: Objectives — Coding techniques shall be used to facilitate:

1. Discrimination between individual displays.
2. Identification of functionally related displays.
3. Indication of relationship between displays.
4. Identification of critical information within a display.

Techniques — Displays shall be coded by color, size, location, shape, flash rate, alphanumerics, brightness, motion, or inclination, as applicable.

1. Only one kind of information should be coded by one method. Compound coding for only one kind of information usually is less satisfactory than single coding if the single code used is the best available.
2. If two or more kinds of information are to be coded, the same number of coding methods should be used; do not use one coding method to code two or more kinds of information.

Standardization — All coding within the control room shall be uniform.

Color Coding — Color coding should be used when an observer must search for, pick out, or locate one or more characters from a matrix of displayed characters. With the exception of system status indicator lights, transilluminated light emitting diode (LED) and incandescent displays, when used as warning or caution signals, shall conform to the following color coding scheme:

1. RED shall be used to alert an operator that the system or any portion of the system is inoperative, or that a successful operation is not possible until appropriate corrective or override action is taken. Examples of indicators which should be coded RED are those which display such information as "no-go," "error," "failure," "malfunction," etc.
2. FLASHING RED shall be used only to denote emergency conditions which require operator action to be taken without undue delay, to avert impending personnel injury, equipment damage, or both.
3. YELLOW shall be used to advise operator that a condition exists

which is marginal. YELLOW shall also be used to alert the operator to situations where caution, recheck, or unexpected delay is necessary.

4. GREEN shall be used to indicate that the monitored equipment is in tolerance or a condition is satisfactory and that it is all right to proceed (e.g., "go-ahead," "in-tolerance," "ready," "function activated," "power on," etc.).
5. WHITE shall be used to indicate system conditions that do not have "right" or "wrong" implications, such as alternative functions (e.g., Make-up Pump No. 1 selected) or transitory conditions (e.g., action or test in progress, function available), provided such indication does not imply success or failure of operations.
6. BLUE may be used for an advisory light, but preferential use of BLUE should be avoided.

Choice of Color — No more than five chromatic colors (seven including black and white) shall be used when coding information within a display. The choice of colors shall be in conformance with the above paragraph.

Size and Spacing — Alphanumeric and geometric or pictorial symbols shall subtend a minimum viewing angle of 20 arc minutes, although 26-30 arc minutes is preferred. To prevent color fusion there should be a spacing of at least three lines between symbols.

Flashing Lights — The use of flashing lights shall be minimized. Flashing lights may be used only when it is necessary to call the operator's attention to some condition requiring immediate action. The flash rate shall be in the range between one to five flashes per second, with the on and off phases of about equal duration. No more than three frequencies shall be used, with no more than two, and preferably one blinking signal on the display at any given time. The frequencies should be equally spaced on a logarithmic scale, with the faster flash rates representing the more critical information. The indicator shall be designed such that, if energized and the flasher device fails, the light will illuminate and burn steadily. See section in Auditory/Visual warning.

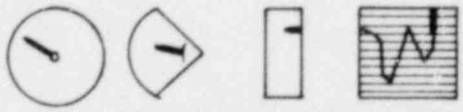
Legend Lights —

1. Use — Legend lights shall be used in preference to simple indicator lights except where design considerations demand that simple indicators be used.

2. Color Coding — Legend lights shall be color coded as for trans-illuminated displays and, where applicable, shall be further coded as to function by location, size, and flash coding. Legend lights required to denote personnel or equipment disaster (FLASHING RED), caution or impending danger (YELLOW), and master summation, go (GREEN) or no-go (RED), shall be discriminably larger, and preferably brighter, than all other legend lights.

Shape Coding — Shape coding should be used when a viewer must identify one or more objects from a matrix of displayed objects. Shape coding should also be used when the information represented on the display is qualitative in nature and when coding by color is not feasible. A maximum of 15 shapes shall be used, and only six under adverse display conditions. To augment object identification, color redundancy should be added. If possible, the symbols shall be associated with the objects they represent. Only simple, symmetrical symbols with enclosed areas and sharp angles or smooth curves should be used. Variations of a single geometric form shall be avoided.

Differences between rectangular, square, triangular, or round indicators are useful for identification. For example, the shapes in the illustration are suggested by the instrument movement.



Examples of shape coding of indicators.

Position Coding — One of the best means of assisting indicator identification is to maintain a consistent instrument position among various models of the plant or system.

Alphanumeric Coding — Letters and numbers should be used for identification tasks and short code words which represent one of a kind type items. For three-character combinations, a number should be used for the first and third characters, and a letter for the middle character. There is no maximum number of alphanumeric combinations which can be used.

Size Coding — The maximum number of steps which should be used at any given time is three. To insure that the sizes are equally identifiable, the steps should increase on a logarithmic scale.

Brightness Coding — Brightness coding is not generally recommended, but if used should employ no more than two levels (dim and bright). The higher level should represent items of primary interest with the lower level reserved for background or supplementary information.

Motion Coding — Motion coding is not generally advocated, however, if used, no more than two velocities are recommended.

Inclination Coding — The angular orientation of lines on a display shall contain no more than 24 inclinations. Where rapid, accurate reading of the display is required, eight inclinations are recommended while four are preferred. The line length should be between 0.2 and 0.3 inch. Intra-line orientation (measured in degrees) shall contain equally spaced deviations.

Grouping of Signals — By grouping signal lights or mechanical "flags" in appropriate patterns the panel design can help the operator to learn what is wrong. Such patterns make a different signal easy to detect. A pictorial pattern can be of even more help to the operator. By showing him the position of switches, valves, etc., as part of a diagram, the effects of their operation are easy to see.

Warning Requirements — A good warning device meets four requirements:

1. It attracts the attention of a busy or bored operator.
2. It tells him what is wrong or what action to take.

3. It should not prevent his continued attention to other duties.

4. The warning device should not itself be likely to fail or to give false warnings. Failures of the warning device should be easily detected (such as by a press-to-test button).

C. **HUMAN ERROR:** Undetected signals; misread displays.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-STD-1472, Essex Revision (1980); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Modify or replace.

A. **TITLE: AUDITORY SIGNALS**

B. **GUIDELINES:** Auditory signals should be used to supplement annunciator lights for displays which are not constantly monitored, when it is important that changes in their indication be noted immediately.

C. **HUMAN ERROR:** Failing to check a display at the proper time and failure to respond to displayed information.

D. **DOCUMENTATION:** Folley (1971)

E. **TYPICAL BACKFIT:** Modify or replace auditory warning signal(s).

AUDITORY DISPLAYS

(AD)

AD

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A. TITLE: GENERAL EVALUATION GUIDELINES

B. GUIDELINES:

1. Auditory signals should be compatible with system conditions (e.g., high frequencies used to denote high system values).
2. Two stage signals shall only be used for: 1) alerting; and 2) designation (provide system value information).
3. Ambient control room noises should not be confused with auditory signal(s).
4. Audio signal frequencies shall be minimized (in terms of numbers of distinct signal presentations over time).
5. The meaning of each audio signal should be invarient.

C. HUMAN ERROR:

1. Temporal errors in comprehending signal meanings/ interpretation errors in evaluating signal meaning.
2. Errors of omission (failure to detect signal presentation).
3. Habituation to signals (loss of signal significance due to over presentation).

4. Substitution errors due to failure to discriminate signals.

D. **DOCUMENTATION:** McCormick 1974); MIL-STD-1472B; Woodson & Conover (1966); and Van Cott & Kinkade (1972)

E. **TYPICAL BACKFIT:** Redesign; modify; or replace.

A. TITLE: GENERAL EVALUATION GUIDELINES

B. GUIDELINES:

1. Simultaneous presentation of auditory signals should be avoided.
2. Auditory signals should be prioritized according to importance/urgency of the information provided.
3. Short term memory requirements should be minimized by limiting rate (over time) of signal presentation.
4. Multiple auditory signals requiring individual responses should be temporally distinguishable.
5. Auditory signals shall be used in preference to visual signals for infrequently monitored variables.
6. Auditory signals should direct operator(s) to area(s) requiring operator action (auditory localization).
7. Important auditory signals should not compete for operator's attention with unimportant signals.

8. In quiet surroundings (below 30 dB) auditory signals should be 40 to 50 dB above threshold.
9. Wide band auditory signals should be used over narrow band signals (approximately 100 Hz).
10. Signals should be compatible as to meaning (e.g., high pitch tones for overpressure situations consistent for all overpressure alarms).

C. **HUMAN ERROR:**

1. Failure to conduct important operator actions.
2. Omission of important actions/ increased operator time requirements (to decide which signal to attend).
3. Decision errors, omission errors and incorrect activation errors.
4. Errors of omission due to perceptual masking.
5. Failure to locate controls/display within system time constraints.
6. Failure to discriminate between meanings of signals.

D. **DOCUMENTATION:** McCormick (1976); Van Cott & Kinkade (1972); MIL-STD-1472B (1974); and Woodson & Conover (1964).

E. **TYPICAL BACKFIT:** 1) Adjust sound qualities of auditory signals; 2) provide separate localized auditory signals; and 3) prioritize auditory signals.

A. **TITLE:** RELATION TO VISUAL DISPLAYS

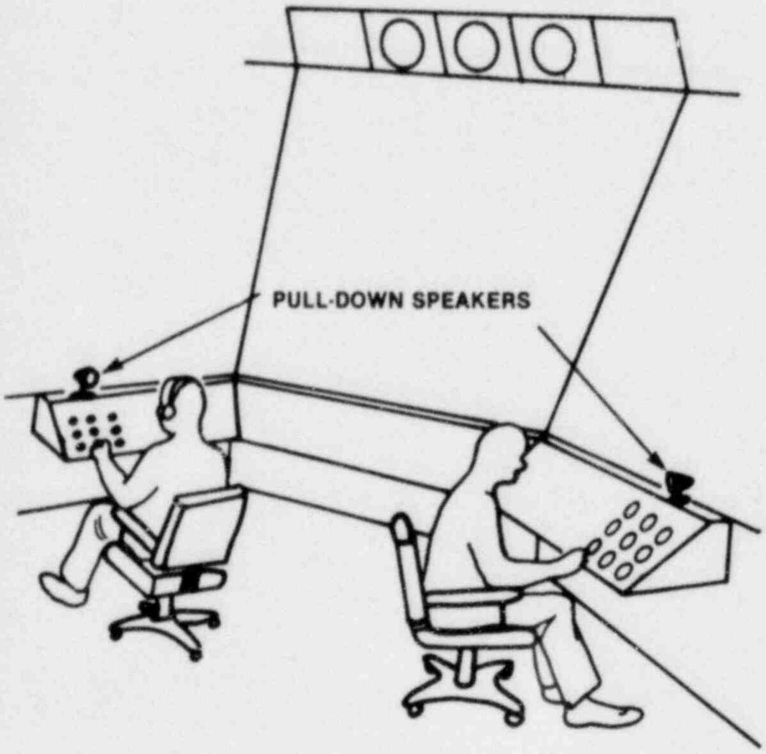
B. **GUIDELINES:** Audible signals should alert and direct operator attention to appropriate visual displays and control locations.

C. **HUMAN ERROR:** Failure to identify malfunctions/out-of-tolerance systems/components.

D. **DOCUMENTATION:** MIL-STD-1472 (1974).

E. **TYPICAL BACKFIT:** Conduct an analysis and redesign or rearrange the audible signals to help the operator locate the appropriate control or display.

AUDITORY DISPLAYS



A. **TITLE: PROPAGATION OF AUDIBLE DISPLAYS**

B. **GUIDELINES:**

1. Sound sources (buzzers, etc.) shall direct sound toward the operator.
2. Sound sources shall be placed at about the head level of the operator, or above.

C. **HUMAN ERROR:**

1. Temporal errors in locating sound source/auditory localization errors due to echo effects.
2. Errors due to attenuation of audible display due to intervening operators, equipment, etc.

D. **DOCUMENTATION:** Woodson & Conover (1964).

E. **TYPICAL BACKFIT:** Place audible displays at about 6' - 7' level and direct sound towards principle operating areas.

A. **TITLE: SIGNAL DURATION LIMITATIONS**

B. **GUIDELINES:** Signals that increase progressively in level should not be used where manual shut off is required.

C. **HUMAN ERROR:** Operator failure to attend to time constrained emergency actions.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Use a different signal.

AUDITORY DISPLAYS

A. TITLE: CONTROL OF AUDIBLE DISPLAYS

B. GUIDELINES:

1. Means to shut off audible displays should be provided (alarm silence).
2. Audibles should be shut off only <u>after</u> initiation of the signals. The plant should never be operated with the annunciator alarm defeated. Other methods must be employed to eliminate nuisance alarms.

C. HUMAN ERROR:

1. Masking of subsequent alarms due to inability to silence precedent annunciations.
2. Failure to detect system/component malfunctions or out-of-tolerance conditions.

D. DOCUMENTATION: MIL-STD-1472B (1974).

E. TYPICAL BACKFIT:

1. Provide automatic audible silence circuiting.
2. Provide manual audible silence capability.

A. TITLE: AUTOMATIC RESET

B. GUIDELINES:

1. An automatic reset function should be provided which automatically resets audible displays.
2. The automatic reset function should be controlled by the sensing mechanism which initiated the audible.

C. HUMAN ERROR: System failure to transmit subsequent audible signals.

D. DOCUMENTATION: MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Provide automatic reset function.

A. TITLE: TEST CIRCUITS

B. **GUIDELINES:** All audio displays shall be equipped with circuitry test devices.

C. **HUMAN ERROR:** Failure to detect hazardous or out-of-tolerance system conditions due to undetected failure of audible display circuitry.

D. **DOCUMENTATION:** MIL-STD-1472B; McCormick (1974).

E. **TYPICAL BACKFIT:** Provide means to test audible displays.

A. **TITLE: FAIL SAFE DESIGN**

B. **GUIDELINES:**

1. Failure of audible alarm circuiting should not adversly affect equipment.
2. System failures should not affect operability of audible alarm systems.

C. **HUMAN ERROR:** Misinterpretation of alarm (audible) status.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Redesign circuits.

AUDITORY DISPLAYS

A. TITLE: CHARACTERISTICS OF AUDIBLE DISPLAYS

B. GUIDELINES: Audible displays should be evaluated in accordance with the following.

1. Frequencies between 200 and 5000 Hz, and preferably between 500 and 3000 Hz should be used.
2. Frequencies below 1000 Hz should be used when signals have to travel long distances (over 1000 feet).
3. Frequencies below 500 Hz should be used when signals have to "bend around" major obstacles or pass through partitions.
4. Separate communication systems for warnings, such as loudspeakers, horns, or other devices should not be used for other purposes.

C. HUMAN ERROR:

1. Failure to detect signal due to stimulus masking.
2. Signal substitution due to failure to discriminate signals.
3. Temporal errors due to failure to detect/discriminate signals.

D. **DOCUMENTATION:** McCormick (1976); Van Cott & Kinkade (1972); MIL-STD-1472B (1974); and Woodson & Conover (1964).

E. **TYPICAL BACKFIT:** Modify or replace audible display system.

AUDITORY DISPLAYS

A. TITLE: FREQUENCY SELECTION

B. GUIDELINES: If changes in the frequency (Hz) of displays denote information, tones of 500 to 1000 Hz should be used.

C. HUMAN ERROR: Failure to detect frequency or intensity changes of the audible display (loss of information).

D. DOCUMENTATION: Van Cott & Kinkade (1972).

E. TYPICAL BACKFIT: Where frequency changes denote information, replace or modify system to use low frequency tones.

A. TITLE: CODING (FREQUENCY)

B. GUIDELINES:

1. Four to seven different frequencies shall be the maximum allowable.
2. The frequency levels used shall be spaced widely apart.
3. Intensity levels should be 30 dB above (ambient) thresholds.

C. HUMAN ERROR: Operator interpretation errors.

D. DOCUMENTATION: McCormick (1976).

E. TYPICAL BACKFIT: Adjust auditory signals using frequency coding to guidelines under entry 'B' above.

AUDITORY DISPLAYS

A. **TITLE: AUDITORY SIGNALS WITH TWO COMPONENTS**

B. **GUIDELINES:**

1. Where information is coded by both intensity and frequency, the maximum number of auditory signal combinations shall not exceed five.
2. If two components are used, the operators should be trained to discriminate those signals.

C. **HUMAN ERROR:**

1. Temporal errors due to information processing limitations in the auditory system of humans/information overload.
2. Substitution errors due to complexity of auditory discriminators.

D. **DOCUMENTATION:** Van Cott & Kinkade (1972); McCormick (1976); and MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify the existing system.

A. TITLE: **MASKING**

B. **GUIDELINES:** Audible signals should not interfere with any other audible warning or advisory signals.

C. **HUMAN ERROR:** Failure to detect audible signals due to masking.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:**

1. Select signal frequencies to avoid masking.
2. Use broad band signals.
3. Modulate signals.
4. Sequence signal presentation.

A. **TITLE:** AUDITORY DISPLAY MEANINGS

B. **GUIDELINES:** Similar audible signals shall not be contradictory in meaning.

C. **HUMAN ERROR:** Interpretation errors/substitute errors due to difficult auditory discriminations.

D. **DOCUMENTATION:** McCormick (1976); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Eliminate similar signals with contradictory meanings.

A. TITLE: CODING (SOUND DURATION)

B. GUIDELINES:

1. When sound duration is used to code audible signals, each signal should be approximately 1½ to 2 times as long as the preceding signal.
2. The maximum number of audible signals codes by sound duration on at any given time should not exceed 2 or 3.

C. HUMAN ERROR: Stimulus substitution due to failure to discriminate between sound duration differences.

D. DOCUMENTATION: McCormick (1976); MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Limit number of temporal auditory discriminations to 3 and make duration differences clearcut. (duration differences for each of 3 tone multiples of 2, e.g., 1 second, 2 seconds, 4 seconds.)

AUDITORY DISPLAYS

A. **TITLE: CODING SPATIAL INFORMATION (AUDITORY LOCALIZATION)**

B. **GUIDELINES:**

1. Changes in signal intensity should be used as a spatial coding cue. Frequency changes shall not be used to locate components.
2. Intermittent changes in signal intensity shall be used (versus a single change) in locating control room areas.
3. The maximum number of spatially coded signals (via intensity changes) shall not exceed four.

C. **HUMAN ERROR:** Errors in control/display localization due to auditory processing limitations in humans.

D. **DOCUMENTATION:** Van Cott & Kinkade (1972); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Conduct an analysis to determine spatial information coding requirements and replace or modify coding system accordingly.

A. **TITLE:** CODING (SOUND DIRECTION)

B. **GUIDELINES:** Differences in sound intensity (due to distance sound travels and direction of incidence to the ear around the horizon) should be distinct.

C. **HUMAN ERROR:** Temporal errors in locating sound source.

D. **DOCUMENTATION:** McCormick (1976); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Increase distances between spatially coded sound sources.

AUDITORY DISPLAYS

A. TITLE: CODING METHODS (INTENSITY)

B. GUIDELINES:

1. Five (5) levels of intensity should be used.
2. Wide band tones should be used.
3. Pure tones should be between 1000 to 4000 Hz.

C. HUMAN ERROR:

1. Misinterpretation of auditory signals/substitution errors/temporal errors
2. Stimulus masking (omission)
3. Omission (narrow band hearing loss/masking)

D. DOCUMENTATION: McCormick (1974).

E. TYPICAL BACKFIT:

1. Restrict intensity discriminations to five.
2. Increase band widths.
3. Avoid pure tones/restrict use to 1000 to 4000 Hz.

A. **TITLE: AUDITORY DISPLAYS AS WARNING SIGNALS**

B. **GUIDELINES:**

1. Audible alarms shall be used in conjunction with warning lights, unless the alarm is for evacuation, etc.
2. Audible alarms should sound 20 dB louder than the general ambient level.

C. **HUMAN ERROR:**

1. Temporal errors in locating malfunctioning/out-of-tolerance systems/components.
2. Errors of omission by failing to detect audible signals.

D. **DOCUMENTATION:** MIL-HDBK-759 and MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** 1) Provide warning lights for every audible communication; and 2) increase energy in audible display to 20 dB above ambient noise levels.

A. **TITLE: TWO-PHASE SIGNALS**

B. **GUIDELINES:** Where two phase signals are employed:

1. Alerting signals (which inform the operator that an information signal will follow) should have a duration of ½ second or longer.
2. Action/information signals (which provide an operator with system information) should have a duration of 2 seconds or longer.

C. **HUMAN ERROR:** Failure to respond to signals.

D. **DOCUMENTATION:** Woodson & Conover (1964).

E. **TYPICAL BACKFIT:** Adjust signal presentation times.

A. **TITLE:** CRITICAL AUDIBLE SIGNALS

B. **GUIDELINES:** When reaction time is critical, signals of short duration should be used. (½ second)

C. **HUMAN ERROR:** Inability to discriminate critical signals.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Redesign critical signals.

A. **TITLE:** CRITICAL SIGNALS/CODING

B. **GUIDELINES:** The first ½ second of a fast reaction audio signal should be discriminable from the first ½ sec. of any other signal that does not require immediate operator action.

C. **HUMAN ERROR:** Failure to discriminate critical warning signals from non-critical signals.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Code critical warning signals differently from non-critical signals.

A. **TITLE: EVACUATION SIGNAL TYPE**

B. **GUIDELINES:** The signal shall be unique in the plant or facility in which it is installed and shall not be employed for purposes other than immediate evacuation.

The signal shall be a mid-frequency complex sound wave that may be amplitude modulated at a subsonic frequency. The fundamental frequency should not exceed 1000 Hz. Modulation should be at a rate less than 5 Hz.

C. **HUMAN ERROR:** Mistaking evacuation signal with another.

D. **DOCUMENTATION:** ANSI/ANS-N2.3 (1979).

E. **TYPICAL BACKFIT:** Install appropriate signal.

A. TITLE: EVACUATION SIGNAL SOUND LEVEL REQUIREMENTS

B. GUIDELINES:

1. The signal generator should produce an overall sound pressure level which is not less than 10 dB (and preferably 20 dB)* above the overall maximum typical ambient noise level, and in any case not less than 75 dB (referenced to 20 $\mu N/m^2$) at every location from which immediate evacuation is deemed essential.
2. Since excessive noise levels can be injurious to personnel, the signal generator should not produce an A-weighted sound level in excess of 115 dB (referenced to 20 $\mu N/m^2$) at the ear of an individual. In areas with inherently high background noise, it may be necessary to supplement or replace the audible signal with visual signals.
3. A sufficient number of signal generators shall be installed so that the above requirements are met.
4. After initiation, the signal shall continue to sound as required by

emergency procedures for a time sufficient to allow people to leave the area to be evacuated.

*Advocated by authors.

C. **HUMAN ERROR:** Mistaking evacuation signal with another; not perceiving signal at great distances or behind barriers.

D. **DOCUMENTATION:** ANS/ANSI-N2.3 (1979).

E. **TYPICAL BACKFIT:** Increase sound pressure level (volume); Install new signal; Increase number and reposition loudspeakers.

A. TITLE: EVACUATION SIGNAL ACTIVATION AND DEACTIVATION

B. GUIDELINES:

1. The signal-generating system shall be automatically actuated by an initiating event without requiring human action.
2. The system should be equipped with a manual control as a supplement to automatic initiation.
3. A means of deactivating the system should be provided. Access to any means of deactivating or overriding the system should be limited to authorized personnel.

C. HUMAN ERROR: Activating the wrong signal; failure to activate the signal.

D. DOCUMENTATION: ANS/ANSI-N2.3 (1979).

E. TYPICAL BACKFIT: Install automatic/manual activation device.

A. **TITLE: CAUTION SIGNALS**

B. **GUIDELINES:**

1. Caution signals should be distinguishable from warning signals.
2. Caution signals should be used to indicate conditions requiring awareness but not immediate action.

C. **HUMAN ERROR:**

1. Temporal errors
2. Errors of omission due to learned responses to caution signals

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Provide separate coded (distinguishable) signals for caution and warning audible displays.

CONTROLS

(CON)

CON

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A. TITLE: CONTROL LABELING

B. **GUIDELINES:** Each control should have a visible and readily readable label indicating what its function is and the direction of activation, if it isn't obvious.

C. **HUMAN ERROR:** Operating the wrong control; operating the control in the wrong direction; lack of a timely control response.

D. **DOCUMENTATION:** MIL-STD-759.

E. **TYPICAL BACKFIT:** Add appropriate labeling.

A. **TITLE: CONTROL SURFACES**

B. **GUIDELINES:** Control surfaces should have a highly frictionalized surface to prevent the operator's hand from slipping.

C. **HUMAN ERROR:** Improper activation of a control.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Roughen control surface.

A. **TITLE:** CONTROL/PANEL CONTRAST

B. **GUIDELINES:** The color of the control should have a high contrast with the panel background.

C. **HUMAN ERROR:** Lack of a timely response due to time taken to locate a control.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Use demarcation lines or add color to control.

CONTROLS

A. **TITLE: CONTROL COMPATIBILITY WITH EMERGENCY GEAR**

B. **GUIDELINES:** Controls should be easy to activate while wearing emergency clothing. (e.g., gloves)

C. **HUMAN ERROR:** Inadvertent activation; improper activation; inability to activate.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify the control handle to be compatible with emergency handwear; if controls can not be separated enough, guard — protect from inadvertent activation.

A. TITLE: CONTROL SEPARATION

B. GUIDELINES: Different controls should be separated by the following distances:

MINIMUM SEPARATION DISTANCES FOR CONTROLS

	TOGGLE SWITCHES	*PUSH-BUTTONS	CONTINUOUS ROTARY CONTROLS	ROTARY SELECTOR SWITCHES	DISCRETE THUMBWHEEL CONTROLS
TOGGLE SWITCHES	0.75"	0.5"	0.75"	0.75"	0.5"
*PUSHBUTTONS	0.5"	0.5"	0.5"	0.5"	0.5"
CONTINUOUS ROTARY CONTROLS	0.75"	0.5"	1.0"	1.0"	0.75"
ROTARY SELECTOR SWITCHES	0.75"	0.5"	1.0"	1.0"	0.75"
DISCRETE THUMBWHEEL CONTROLS	0.5"	0.5"	0.75"	0.75"	0.4"

*For pushbuttons not separated by barriers

All values are for one hand operation. Distances are measured in inches and are measured from edge to edge of each control.

C. HUMAN ERROR: Inadvertent activation.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relocate controls; demarcation of panel areas; color or shape coding of controls.

A. **TITLE:** **PRIMARY CONTROL LOCATION**

B. **GUIDELINES:** The most frequently used and important controls should be located in the most favorable positions with respect to ease of reaching.

C. **HUMAN ERROR:** Lack of a timely control response; operator frustration and fatigue leading to activation errors.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Move controls to appropriate positions, demarcation lines.

CONTROLS

A. **TITLE:** CONSISTENCY OF CONTROL LOCATION AND ARRANGEMENT

B. **GUIDELINES:** Functionally similar or identical primary controls should be consistently arranged and located from panel to panel or throughout the system.

C. **HUMAN ERROR:** Activation of the wrong control by assuming a consistency.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-HDBK-759.

E. **TYPICAL BACKFIT:** Rearrange controls.

A. **TITLE:** CONTROL FUNCTIONAL GROUPING

B. **GUIDELINES:** All controls that are functionally related should be grouped together.

C. **HUMAN ERROR:** Incorrect control activated; lack of a timely control response.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relocate controls in functional grouping; demarcation lines.

A. TITLE: CONTROLS — SEQUENTIAL GROUPING

B. **GUIDELINES:** If controls are used in a specific sequence, they should be grouped so that the operator's hand moves in a smooth, continuous movement, preferably left to right or top to bottom.

C. **HUMAN ERROR:** Operating controls out of sequence; lack of a timely control response.

D. **DOCUMENTATION:** Chapanis (1965); MIL-HDBK-759.

E. **TYPICAL BACKFIT:** Regroup the controls.

A. **TITLE: CONTROL DIRECTION OF MOVEMENT**

B. **GUIDELINES:** To minimize operator error, control movement should conform to the following population stereotypes:

Direction of Motion
Conventions for Controls

Function	Control Action
On	Up, right, forward, clockwise pull
Off	Down, left, rearward, counterclockwise, push
Right	Clockwise, right
Left	Counterclockwise, left
Raise	Up
Lower	Down
Retract	Up, rearward, pull
Extend	Down, forward, push
Increase	Forward, up, right, clockwise
Decrease	Rearward, down, left, counterclockwise

C. **HUMAN ERROR:** Activating the control in the wrong direction; lack of a timely control response.

D. **DOCUMENTATION:** Kubokawa (1969); Chapanis (1965); Van Cott and Kinkade (1972); MIL-STD-1472B (1974); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Modify the existing control to conform to the population stereotypes.

A. TITLE: PREVENTION OF ACCIDENTAL ACTIVATION OF CONTROLS

B. GUIDELINES: Accidental activation of controls should be minimized by one of the following methods:

1. Locate and orient the controls so that the operator is not likely to strike or move them accidentally in the normal sequence of control movements.
2. Recess, shield, or otherwise surround the controls by physical barriers. The control shall be entirely contained within the envelope described by the recess or barrier.
3. Cover or guard the controls. Safety or lock wire shall not be used.
4. Provide the controls with interlocks so that extra movement (e.g., a side movement out of a detent position or a pull-to-engage clutch) or the prior operation of a related or locking control is required.
5. Provide the controls with resistance (i.e., viscous or coulomb friction, spring-loading, or

inertia) so that definite or sustained effort is required for actuation.

6. Provide the controls with a lock to prevent the control from passing through a position without delay when strict sequential activation is necessary (i.e., the control moved only to the next position, then delayed).
7. Design the controls for operation by rotary action.

C. **HUMAN ERROR:** Inadvertent activation.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Modify controls using one of the above methods, as appropriate.

A. **TITLE: CONTROL PROTECTION FROM INADVERTENT ACTIVATION**

B. **GUIDELINES:** Any method used to prevent inadvertent activation of a control should not interfere with the operation of other controls or the operation of the protected control within a required time period.

C. **HUMAN ERROR:** Inability to effectively operate a control; lack of a timely control response.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify the protecting mechanism.

A. **TITLE: CODING OF CONTROLS**

B. **GUIDELINES:** Methods and Requirements — Coding mode (e.g., size and color) for a particular application shall be determined by the relative advantages and disadvantages for each type of coding. Where coding is used for the purpose of differentiating among controls, application of the code shall be uniform throughout the system. (See Table for advantages and disadvantages.)

ADVANTAGES AND DISADVANTAGES OF VARIOUS TYPES OF CODING

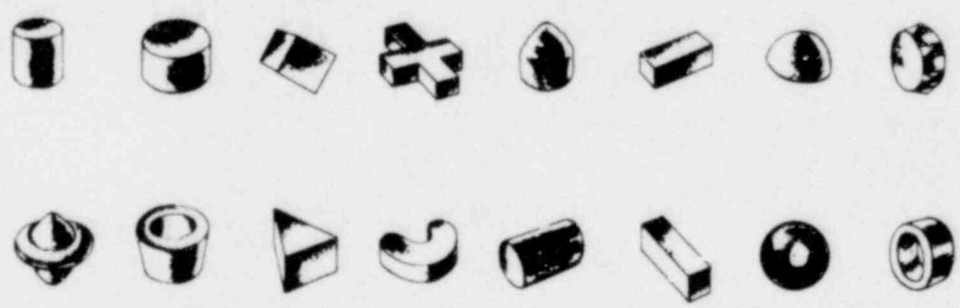
	TYPE OF CODING					
ADVANTAGES	LOCATION	SHAPE	SIZE	MODE OF OPERATION	LABELING	COLOR
Improves visual identification.	X	X	X		X	X
Improves nonvisual identification (tactual and kinesthetic).	X	X	X	X		
Helps standardization.	X	X	X	X	X	X
Aid identification under low levels of illumination and colored lighting.	X	X	X	X	(When trans-illuminated)	(When trans-illuminated)
May aid in identifying control position (settings).		X		X	X	
Requires little (if any) training; is not subject to forgetting.					X	
DISADVANTAGES						
May require extra space.	X	X	X	X	X	
Affects manipulation of the control (ease of use).	X	X	X	X		
Limited in number of available coding categories.	X	X	X	X		X
May be less effective if operator wears gloves.		X	X	X		
Controls must be viewed (i.e., must be within visual areas and with adequate illumination present).					X	X

The table is provided only as a general guideline for control coding evaluation and more specifically for trade-offs, in the event that retrofit is necessary. In the final analysis, control codes will be dictated by specific use and criticality or importance, e.g., if gloves are required during high radiation situations, then shape coded controls that can be detected by a gloved hand should be used. If there is a low probability of a control ever being used by a gloved hand, a shape coded control might be considered as a backfit. By the same token, if repainting controls conveys the necessary information, then the extra expense of relocating a control might not be warranted.

Location-Coding — Controls associated with similar functions should be in the same relative location from panel to panel.

Size-Coding — No more than three different sizes of controls shall be used in coding controls for discrimination by absolute size. Controls used for performing the same function on different items or equipment shall be the same size. When knob diameter is used as the coding parameter, differences between diameters shall not be less than 0.5 in. When knob thickness is the coding parameter, differences between thickness shall not be less than 0.4 in.

Shape-Coding — Control shapes shall be both visually and tactually identifiable and shall be designed to be free of sharp edges. If possible, the shapes chosen shall be associated with or resemble control function. The discrimination of shape-coded controls is essentially one of tactual sensitivity. At least two sets of eight lever knobs have been identified, such that the knobs within each group are rarely confused with each other. Knobs within each set are distinguishable by touch alone. The shapes in each set rarely are confused with each other.



Two sets of knobs for levers that are distinguishable by touch alone. The shapes in each set are rarely confused with each other.

The United States Air Force has developed 15 knob designs which are not often confused with each other. These designs are of three different types, each type being designed to serve a particular purpose.

Class A: Multiple Rotation — These knobs are for use on controls 1) which require twirling or spinning, 2) for which the adjustment range is one full turn or more, and 3) for which the knob position is not a critical item of information in the control operation.

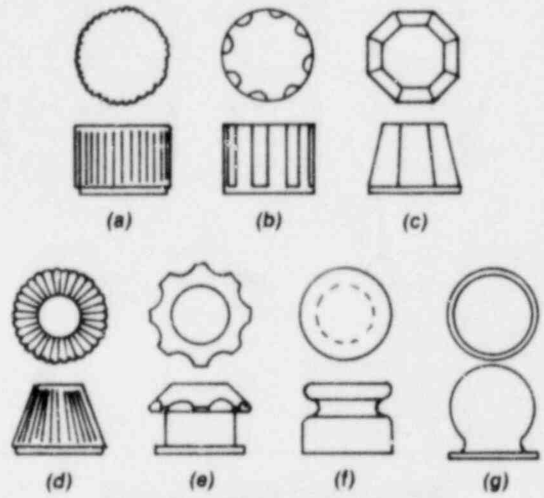
Class B: Fractional Rotation — These knobs are for use on controls 1) which do not require spinning or twirling, 2) for which the adjustment range usually is less than one full turn, and 3) for which the knob position is not a critical item of information in the control operation.

Class C: Detent Positioning — These knobs are for use on discrete setting controls.

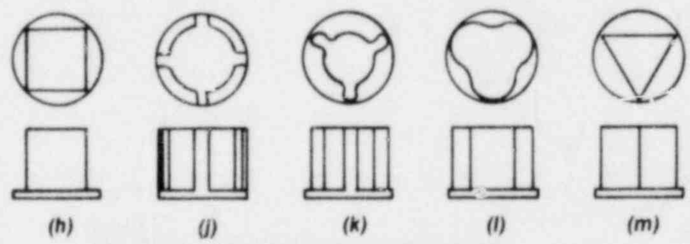
The 15 knobs in these three classes are shown in the Figure. In connection with sizes of knobs in these classes, it is recommended that they not be more than 4 in. in their maximum dimensions and not less than ½ in. (except for class C, 3/4 in. minimum). In height they should not be less than ½ in. but need not be more than 1 in.

Color-Coding —

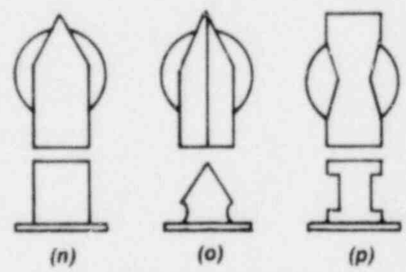
Choice of Colors — In general, only five colors should be used for single-color coding; red, orange-yellow, green, white, blue. Even under ideal conditions, an operator



Class *A*, multiple rotation knobs



Class *B*, fractional rotation knobs



ClassC, detent positioning knobs

Knob designs of three classes that are seldom confused by touch.

has difficulty attaching a name, or function, to more than 10 or 12 colors. However, by patterning a few colors, such as alternating red and black stripes, many distinctive combinations are possible.

Relation to Display — When color-coding is used to relate a control to its corresponding display, the same color shall be used for both the control and the display.

Control Panel Contrast — The color of the control shall provide contrast between the panel background and the control.

Labeling of Controls — Control labeling shall conform to the criteria in the Labeling section.

C. **HUMAN ERROR:** Control errors of commission and omission.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-STD-1472, Essex Revision (1980); Van Cott and Kinkade (1972); McCormick (1976).

E. **TYPICAL BACKFIT:** Modify or replace.

A. **TITLE: MULTIPLE CONTROLS**

B. **GUIDELINES:** When more than one control is used for adjusting a single (or interacting) function, the controls shall be placed on the same panel within functional reach of one another.

C. **HUMAN ERROR:** Incorrect sequence in operating several controls; confusing one control for another.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Relocate control(s); Replace panel.

A. **TITLE: MULTIPLE DISPLAYS**

B. **GUIDELINES:** 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 group of displays.

C. **HUMAN ERROR:** Confusing one control/display with another.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Center control accordingly; replace console.

A. **TITLE:** ROTARY CONTROL POINTER AND SCALES

B. **GUIDELINES:** To maximize control label readability, rotary controls should have a moving pointer and a fixed scale.

C. **HUMAN ERROR:** Placing the control in an inappropriate setting or misreading the current setting.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Replace moving scale control with a moving pointer knob and fixed scale.

A. **TITLE: ROTARY CONTROLS AND PARALLAX**

B. **GUIDELINES:** To minimize the problem of parallax, pointers on knobs should be mounted close to the scale markings.

C. **HUMAN ERROR:** Misreading of control position; incorrect positioning of control.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with appropriate controls; add retrofit pointers.

A. **TITLE:** ROTARY CONTROL POINTER CONTRAST

B. **GUIDELINES:** To maximize the readability of control position, rotary controls should be provided with a reference line on the pointer. This line should have at least 50 percent contrast with the control cover under all lighting conditions.

C. **HUMAN ERROR:** Improper positioning of control; misreading control position.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with control knob that has reference line.

CONTROLS

A. **TITLE:** ROTARY CONTROL DIRECTION OF ACTIVATION

B. **GUIDELINES:** To minimize error, rotary control setting values should increase with a clockwise rotation.

C. **HUMAN ERROR:** Incorrect control setting.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Replace the control with an appropriate control; label highlighting order.

A. **TITLE: ROTARY CONTROL SHAPE CODING**

B. **GUIDELINES:** If rotary controls used for widely different functions are placed on the same panel, shape coding should be employed.

C. **HUMAN ERROR:** Substitution.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace control knobs.

A. **TITLE: ROTARY CONTROL SHAPE CODING CHARACTERISTICS**

B. **GUIDELINES:** To facilitate control recognition, shape coding should be both visually and tactually identifiable. The shape should be free of sharp edges.

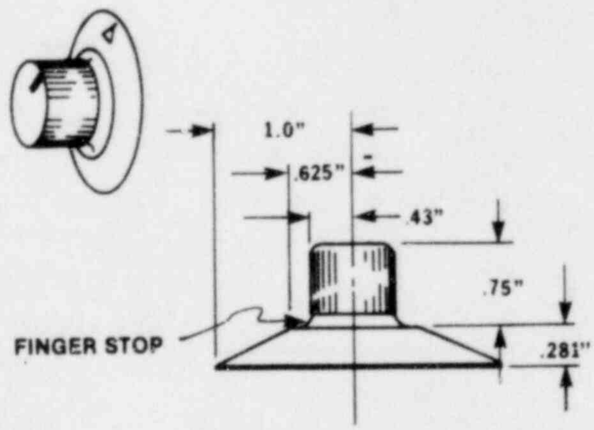
C. **HUMAN ERROR:** Actuation of incorrect control.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Woodson and Conover (1969).

E. **TYPICAL BACKFIT:** Replace with appropriate control knobs, demarcation and labeling.

A. **TITLE: ROTARY CONTROLS WITH KNOB SKIRTS**

B. **GUIDELINES:** If knob skirts are used, the knobs should conform to the dimensions at the right.



C. **HUMAN ERROR:** Operator's hand obscuring the points or labeling; improper activation due to poor grasping because of size.

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Replace control knobs.

CONTROLS

A. **TITLE:** DISCRETE ROTARY CONTROL APPLICATION

B. **GUIDELINES:** Discrete rotary controls are best used when three or more detented positions are required.

C. **HUMAN ERROR:** Inadvertent activation; misreading control position.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace control with appropriate type control.

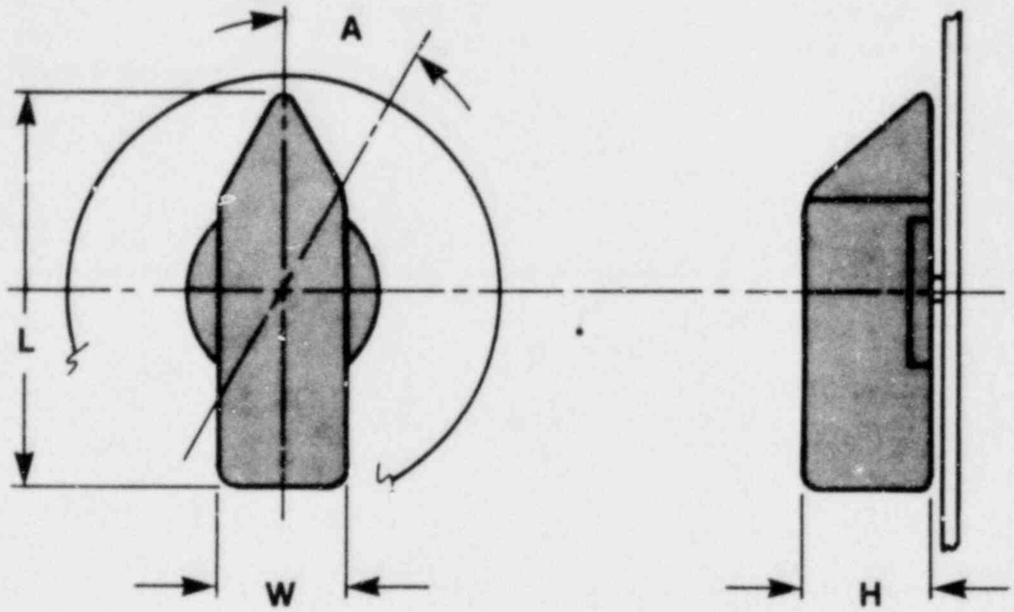
A. **TITLE:** DISCRETE ROTARY CONTROL SIZE AND SHAPE

B. **GUIDELINES:** The preferred shape and size of discrete rotary controls are given on the following page.

C. **HUMAN ERROR:** Inadvertent activation; misreading control position.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott and Kinkade (1972); and MIL-STD-1472C (1980).

E. **TYPICAL BACKFIT:** Replace with appropriate control, if necessary.



	DIMENSIONS			RESISTANCE
	L Length	W Width	H Depth	
Minimum	1.0"	*	0.625"	1.0 in.-lb
Maximum	4.0"	1.0"	3.0"	6.0 in-lb

	DISPLACEMENT		SEPARATION	
	A *	A **	One-Hand Random	Two-Hand Operation
Minimum	15 deg	30 deg	1.0"	3.0"
Maximum	40 deg	90 deg		
Preferred			2.0"	5.0"

* For facilitating performance.
** When special engineering requirements demand large separation.

A. **TITLE:** DISCRETE ROTARY CONTROL POSITIONS

B. **GUIDELINES:** To minimize error a maximum of 24 positions should be used on a rotary control.

C. **HUMAN ERROR:** Selecting incorrect control setting.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with an appropriate control.

A. **TITLE:** DISCRETE ROTARY CONTROL RANGE STOPS

B. **GUIDELINES:** To minimize the possibility of placing a rotary control in an unused position, stops should be provided at the beginning and end of the control range.

C. **HUMAN ERROR:** Adjustment error.

D. **DOCUMENTATION:** MIL-STD-1427B (1974).

E. **TYPICAL BACKFIT:** Replace with an appropriate control.

A. **TITLE:** DISCRETE ROTARY CONTROL DETENTS

B. **GUIDELINES:** To insure proper positioning of a discrete rotary control, detents should be provided at each control position. To prevent a control from being placed between detents there should be an elastic resistance that builds up then decreases as each control position is approached. This will cause the control to fall into place.

C. **HUMAN ERROR:** Adjustment errors.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with appropriate controls.

A. **TITLE: CONTINUOUS ADJUSTMENT ROTARY CONTROL APPLICATION**

B. **GUIDELINES:** To insure precise control along a continuous variable, continuous adjustment rotary knobs should be used if little force is required.

C. **HUMAN ERROR:** Adjustment.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Replace with appropriate control knob.

A. **TITLE:** CONTINUOUS ADJUSTMENT ROTARY KNOB SHAPE

B. **GUIDELINES:** Continuous adjustment rotary knobs should be round in shape with knurled or serrated edges.

C. **HUMAN ERROR:** Adjustment.

D. **DOCUMENTATION:** Woodson and Conover (1964); Van Cott and Kinkade (1972); Damon.

E. **TYPICAL BACKFIT:** Replace with appropriate control knob.

A. **TITLE:** **CONTINUOUS ADJUSTMENT ROTARY CONTROL DIMENSIONS**

B. **GUIDELINES:** To maximize the effectiveness of continuous adjustment of rotary controls, the dimensions on the following page should be followed:

C. **HUMAN ERROR:** Adjustment; inadvertent activation.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott and Kinkade (1972).

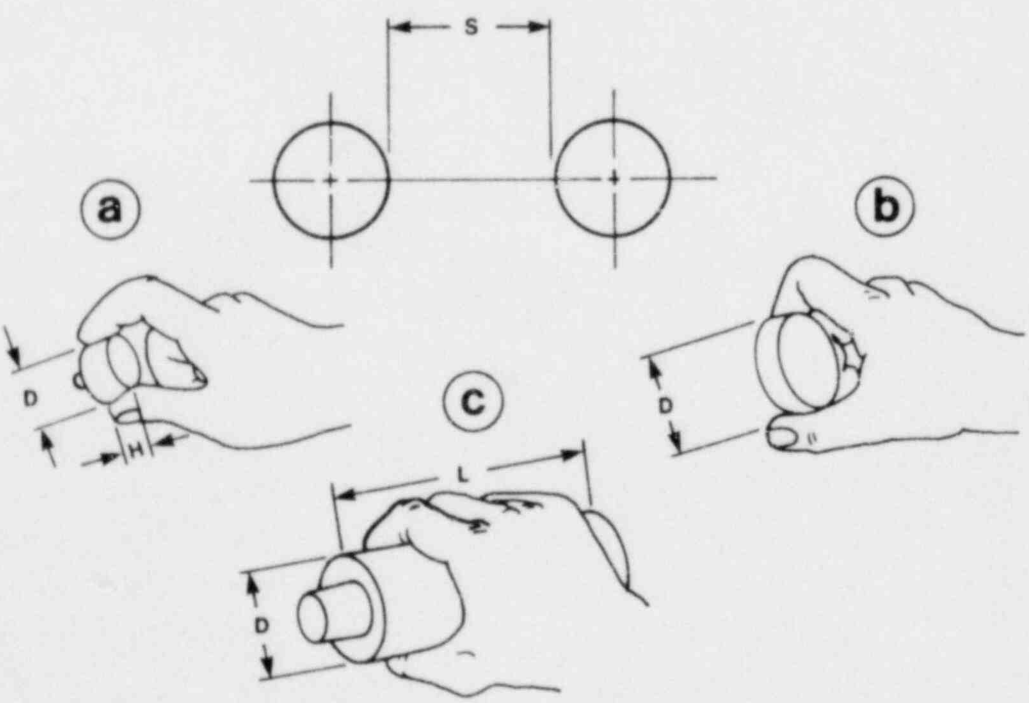
E. **TYPICAL BACKFIT:** Replace with appropriate control.

CONTINUOUS ADJUSTMENT ROTARY CONTROL KNOBS

	(a) Fingertip Grasp Height	 D Diameter	(b) Thunb and Finger Encircled D Diameter	(c) Palm Grasp D Diameter	 L Length
MINIMUM	0.5"	0.375"	1.0"	1.5"	3.0"
MAXIMUM	1.0"	4.0"	3.0"	3.0"	

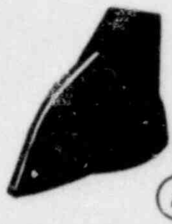
	TORQUE *	 **	SEPARATION S One Hand Individually	 S Two Hands Simultaneously
MINIMUM			1.0"	3.0"
OPTIMUM			2.0"	5.0"
MAXIMUM	4.5 in.-oz	6.0 in.-oz		

*To and including 1.0-in. diameter knobs
**Greater than 1.0-in. diamter knobs



CONTROLS

A. TITLE: ROTARY SELECTOR SWITCH-POINTERS

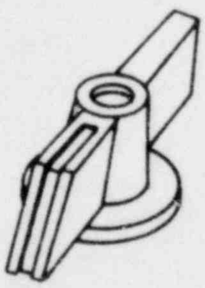


(A)

B. GUIDELINES: Pointers which are black or of a dark color (A) should have a contrasting white mark showing the pointer axis. However, the mark should not extend more than halfway down the top surface of the knob.

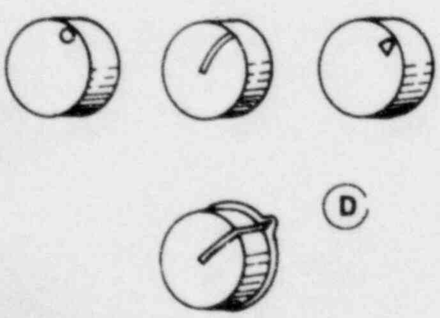
(B)

Pointers which are of a light color (B) should have a white marker outlined in black to provide sufficient contrast between the basic (light) color of the knob and the white marker.



(C)

Some switches (C) have insets which are painted white or filled with phosphorescent pigment. If the inset is too deep, the marker may not be seen because of parallax. Care should be taken to fill the inset completely or reduce the depth of the inset.



(D)

Even though some controls (D) don't require exact setting (dimmers, etc.), some indication of the position is desirable. The pointer configurations shown are all equally good. Where more accuracy is required, engrave (and fill with contrasting pigment) a line both on top and down the side as shown in the bottom example.

C. **HUMAN ERROR:** Moving a control to the wrong position.

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Replace control knobs.

A. **TITLE: CONCENTRIC KNOB USE**

B. **GUIDELINES:** Two concentric knobs are recommended but not more than three should be used.

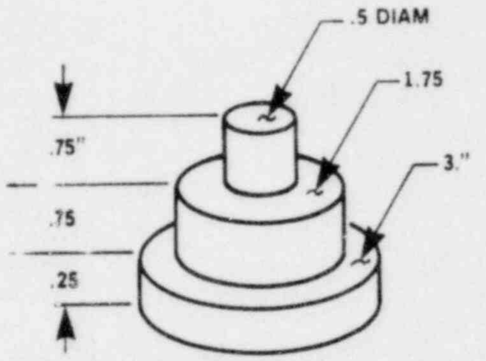
C. **HUMAN ERROR:** Inadvertent activation.

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Replace with appropriate knobs.

A. **TITLE:** CONCENTRIC KNOBS (GANGED) DIMENSIONS

B. **GUIDELINES:** To insure that humans can differentiate knobs by touch, the dimensions to the right should be used.



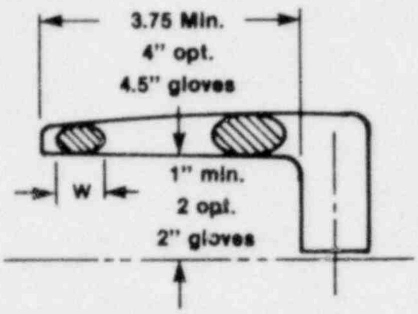
IDEAL DIMENSION FOR "GANGED" KNOBS

C. **HUMAN ERROR:** Inadvertent activation.

D. **DOCUMENTATION:** Woodson and Conover (1964); and McCormick (1976).

E. **TYPICAL BACKFIT:** Replace with appropriate sized controls.

OPEN OR J HANDLE



w = .875" to 1.25" optimum
w = .5" min. for over 40 lb.
Side clear: 2"C to wall

A. **TITLE: J HANDLE DIMENSIONS**

B. **GUIDELINES:** If J handles are used they should conform to the dimensions at the left:

C. **HUMAN ERROR:** Inadvertent activation; not being able to operate control within time constraints.

D. **DOCUMENTATION:** Dreyfuss (1967).

E. **TYPICAL BACKFIT:** Replace control handles with appropriately sized handles.

A. **TITLE: KEY OPERATED SWITCHES**

B. **GUIDELINES:** To maximize the effectiveness of key operated switches, the following should be conformed to:

1. Keys with a single row of teeth should be inserted into the lock with the teeth pointing up or forward.
2. If keys have teeth on both edges, they should fit the lock with either side up or forward.
3. Locks should be oriented so the key's vertical position is the OFF position.
4. Operators should normally not be able to remove the key from the lock unless the switch is turned OFF.
5. ON and OFF positions should be labeled.

C. **HUMAN ERROR:** Inadvertent activation; improper association of control position and function; lack of activation in a timely fashion.

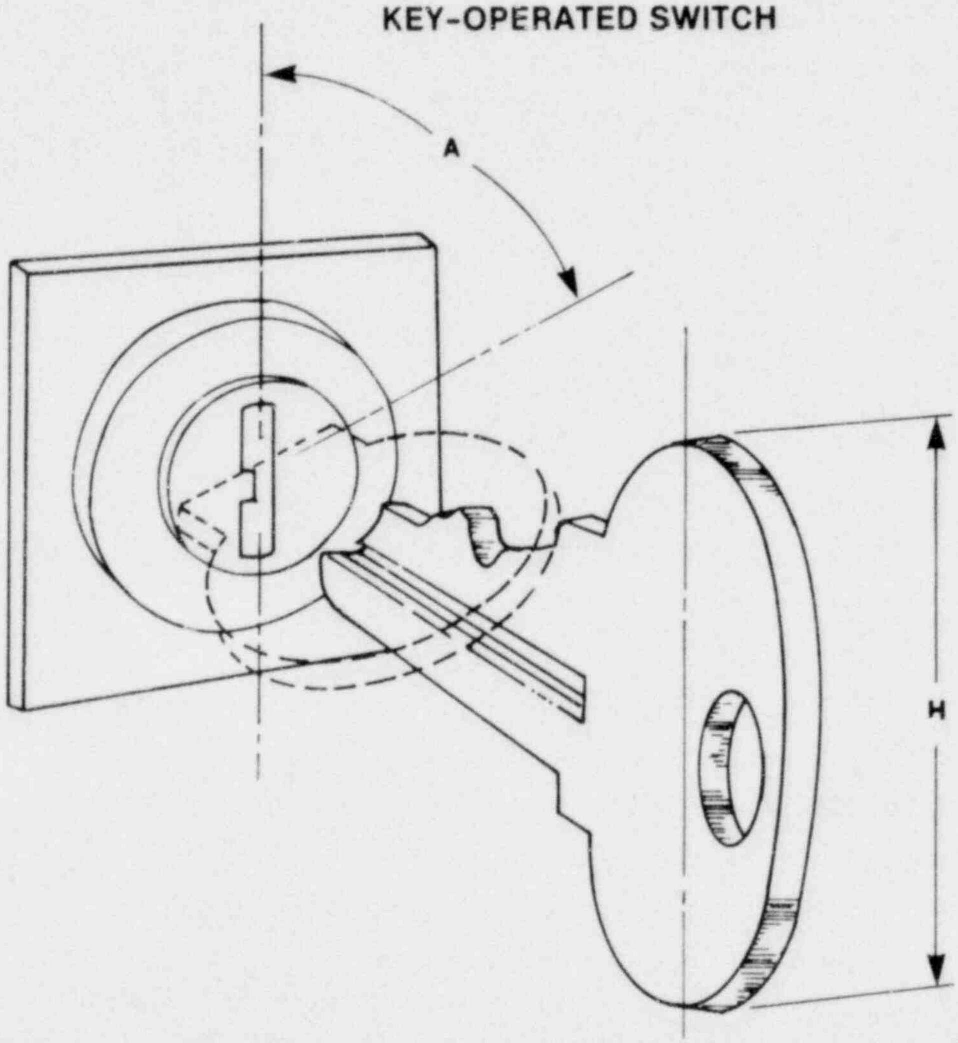
D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replacement of control with appropriate control; labeling; reorienting control.

A. TITLE: KEY OPERATED SWITCH DIMENSIONS

B. GUIDELINES: To insure ease of use, the following dimensions should be used for key operated switches:

KEY-OPERATED SWITCH



	DISPLACEMENT (A)	HEIGHT (H)	RESISTANCE
MINIMUM	80°	0.5 in. (13mm)	1 in.-lb (113mN·m)
MAXIMUM	90°	3.0 in. (75mm)	6 in.-lb (678mN·m)

C. **HUMAN ERROR:** Lack of recognition of control position; inadvertent activation.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with appropriate controls; labeling of control positions; changing size of key.

A. **TITLE: PUSHBUTTON ARRAYS**

B. **GUIDELINES:** Pushbutton arrays should be arranged in the natural sequence of operation; if possible, buttons numbered from one through zero should be arranged in a key-set arrangement.

C. **HUMAN ERROR:** Substitution; inadvertent activation.

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Rewiring and relabeling buttons; replacing with appropriate control arrays.

A. **TITLE: PUSHBUTTON GUARDS AGAINST INADVERTENT ACTIVATION**

B. **GUIDELINES:** A guard should be used when it is necessary to prevent accidental activation. This guard can be either a channel guard or a cover. When the guard is in the open position it should not interfere with the operation of the guarded control or other adjacent controls.

C. **HUMAN ERROR:** Prevention of activation; inadvertent activation.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-STD-1472C (1980).

E. **TYPICAL BACKFIT:** Adding appropriate guard.

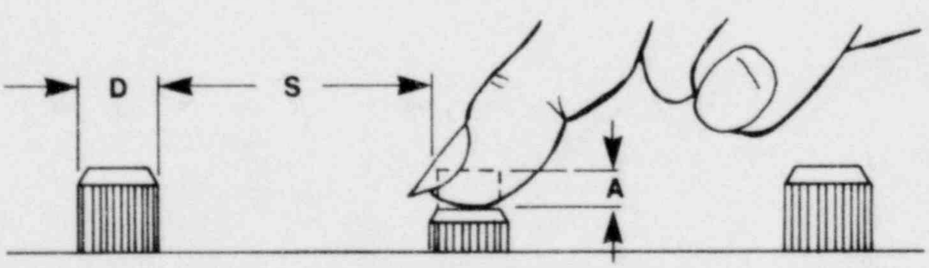
A. TITLE: PUSHBUTTON CONTROL DIMENSIONS

B. GUIDELINES: To insure effective use of pushbuttons, the following dimensions should be conformed to:

PUSHBUTTONS (FINGER OR HAND OPERATED)

	DIMENSIONS		RESISTANCE		DISPLACEMENT
	Diameter D Fingertip Operation	Thumb or Heel of Hand Operation	Fingertip Operation	Little Finger Operation	A Thumb or Finger Operation
Minimum	0.385"	0.75"	10 oz	5 oz	0.125"
Maximum	0.75"		40 oz	20oz	1.5"

	SEPARATION S		
	Single Finger Operation	Single Finger Sequential Operation	Operation by Several Fingers
Minimum	0.5"	0.25"	0.5"
Preferred	2.0"	1.00"	0.5"



C. **HUMAN ERROR:** Inadvertent activation; substitution.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott & Kinkade (1972); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Replace with appropriate controls.

A. **TITLE: PUSHBUTTON SURFACE**

B. **GUIDELINES:** To maximize the operation of pushbuttons, the surface should offer a high degree of resistance or be concave.

C. **HUMAN ERROR:** Lack of activation.

D. **DOCUMENTATION:** Van Cott & Kinkade (1972); Damon.

E. **TYPICAL BACKFIT:** Replace the buttons; roughen the surface.

A. **TITLE: PUSHBUTTON POSITIVE FEEDBACK OF ACTIVATION**

B. **GUIDELINES:** To insure that the operator knows that a pushbutton has been pressed far enough for activation, a positive indication should be provided in the form of a snap feel, audible click or integral light.

C. **HUMAN ERROR:** Lack of activation when pressed.

D. **DOCUMENTATION:** Van Cott & Kinkade (1972); MIL-HDBK-759; MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replacement of control.

CONTROLS

A. **TITLE: HEAVY DUTY SWITCH PUSHBUTTON DIMENSIONS**

B. **GUIDELINES:** Pushbuttons for heavy duty switches should conform to the following dimensions:

1. Minimum diameter = 0.75"
2. Maximum resistance = 5 lbs.
3. Minimum separation = 0.25"
4. Minimum displacement for single button = 0.125"; for double button = 0.25"

C. **HUMAN ERROR:** Inadvertent activation; substitution; lack of activation when pressed.

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Replace with appropriate control.

A. **TITLE:** LEGEND PUSHBUTTON DIMENSIONS

B. **GUIDELINES:** To maximize the effectiveness of legend pushbutton controls, the dimensions on the following page should be used.

C. **HUMAN ERROR:** Inadvertent activation.

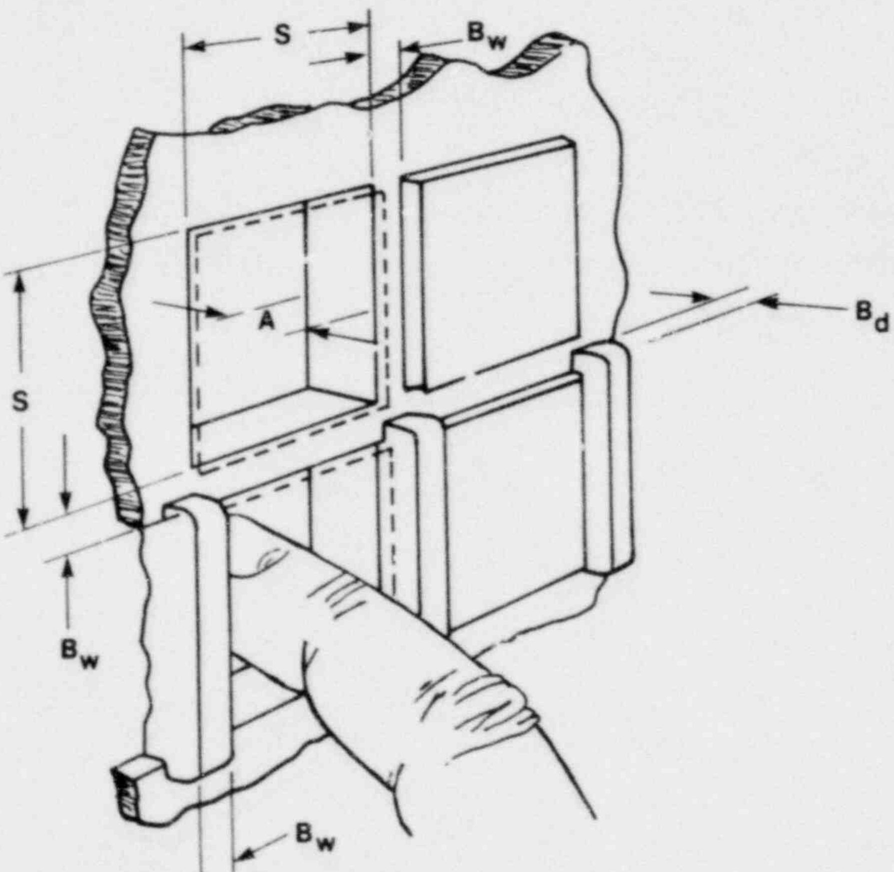
D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with appropriate controls.

LEGEND PUSHBUTTON

	S Size	A DISPLACEMENT	BARRIERS*		RESISTANCE
			B_w	B_d	
Minimum	0.75"	0.125"**	0.125"	0.183"	10 oz
Maximum	1.5"	0.250"	0.250"	0.250"	40 oz

*Barriers shall have rounded edges.
**3/13" (5mm) for positive position switches.



A. TITLE: LEGEND PUSHBUTTONS

B. GUIDELINES: To insure ease of operation of legend pushbuttons, the following guidelines should be followed:

1. For positive indication of switch activation, the legend switch shall be provided with a detent or click. When legend switches are touch sensitive and not mechanical, a positive indication of activation may be an integral light within or above the switch being activated.
2. The legend shall be legible with or without internal illumination.
3. A lamp test or dual lamp/filament reliability shall be provided, except for switches using LEDs in place of incandescent lamps.
4. Lamps within the legend switch shall be replaceable from the front of the panel by hand and the legends or covers shall be keyed to prevent the possibility of interchanging the legend covers.

5. There shall be a maximum of three lines of lettering on the legend plate.

C. **HUMAN ERROR:** Inadvertent activation; adjustment; substitution.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with appropriate controls.

A. **TITLE: PUSHBUTTON WHEEL SWITCHES**

B. **GUIDELINES:** If pushbutton-wheels are used they should conform to the following:

1. The pushbutton surface should conform to the guidelines for pushbuttons.
2. The operator should get a positive indication of the advancement on the rotary wheel.
3. There should be no unused positions of the rotary wheel.
4. The display window should not obscure any part of the number and the operator's hand should not obscure the window during operation.
5. The characters on the rotary wheel should conform to the standards set forth in the labels section of the guidelines.
6. Only the displayed numeral should be visible in the window.
7. The physical characteristics of the pushbutton should conform to the guidelines for pushbuttons.

C. **HUMAN ERROR:** Inadvertent activation; misreading or misinterpreting the display; lack of a timely response due to moving the control too far.

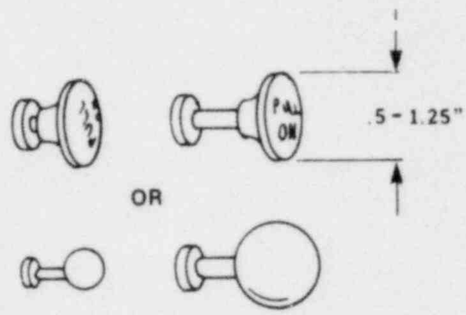
D. **DOCUMENTATION:** MIL-STD-1472C (1980).

E. **TYPICAL BACKFIT:** Modifying the location or orientation of the control; modifying the pushbutton; replacing with an appropriate control.

A. TITLE: PUSH-PULL CONTROLS

B. GUIDEL.NES:

1. Push-pull controls should have the operating position in the out position.
2. If there is labeling on the control, the control shaft should be locked in one position to prevent the labeling from being other than in the correct orientation.

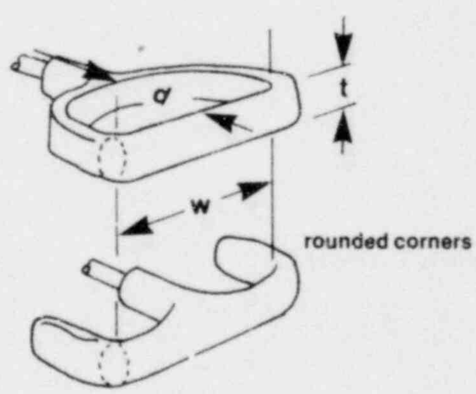


3. The dimensions to the right should be conformed to:

   w = 1.75 inches for two-finger operation (add 0.50 inch for gloved hand)
   2.75 inches for three-finger operation (add 0.625 inch for gloved hand)
   3.50 inches for four-finger operation (add 0.75 inch for gloved hand)

   t = 0.625 to 0.75 inch

   d = 1-inch minimum (1.50 inches for gloved hand)



4. The maximum resistance should be:

a. One hand along the body midline - 30 to 40 lbs. depending on distance from the body (the farther away, the greater the resistance).

b. Two handed - 60 to 100 lbs.

C. **HUMAN ERROR:** Inability to adequately activate the control; inability to easily read the label.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Replace control handle with appropriately sized handle; replace the control with a more appropriate control.

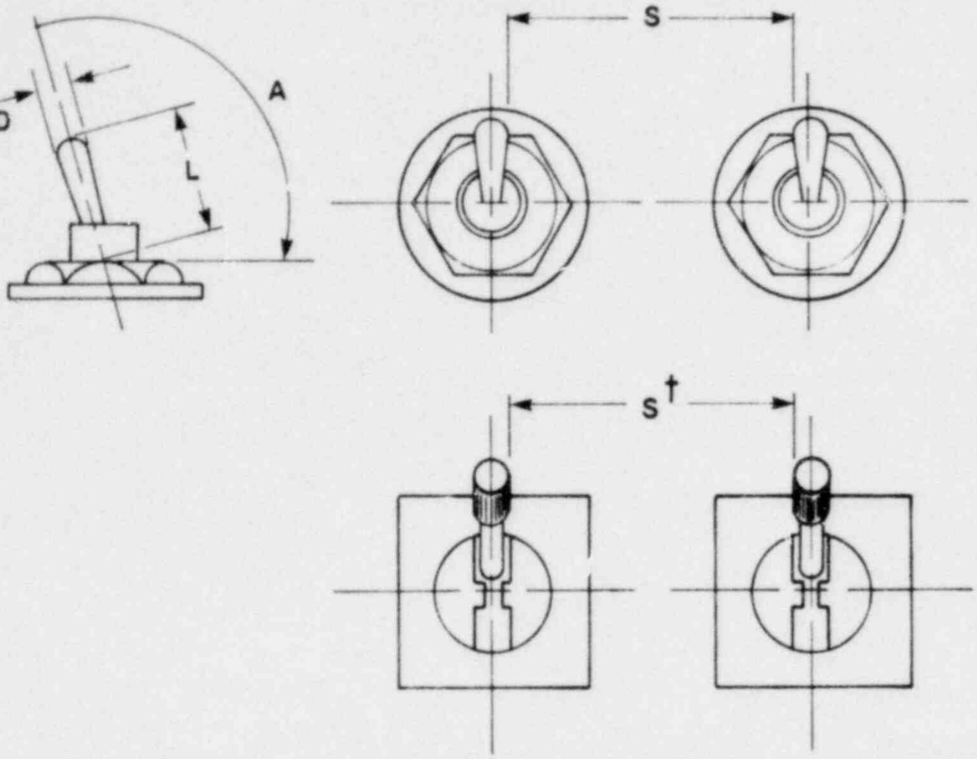
A. **TITLE:** TOGGLE SWITCH DIMENSIONS

B. **GUIDELINES:** To insure that toggle controls are used effectively, the dimensions on the following page should be conformed to.

C. **HUMAN ERROR:** Inadvertent activation; not being able to determine control position; not being able to activate easily enough.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Kubokawa (1969); Van Cott and Kinkade (1972); Damon.

E. **TYPICAL BACKFIT:** Modify existing controls; replace with appropriate controls.



	DIMENSIONS			RESISTANCE	
	L ARMLENGTH *	L ARMLENGTH **	D CONTROL TIP	SMALL SWITCH	LARGE SWITCH
MINIMUM	0.5"	1.5"	0.125"	10 oz	10 oz
MAXIMUM	2.0"	2.0"	1.0"	16 oz	40 oz

	DISPLACEMENT	
	TWO POSITION	THREE POSITION
MINIMUM	30°	18°
MAXIMUM	120°	60°
DESIRED		25°

	SEPARATION			
	SINGLE FINGER OPERATION	SINGLE FINGER OPERATION †	SINGLE FINGER SEQUENTIAL OPERATION	SIMULTANEOUS OPERATION BY DIFFERENT FINGERS
MINIMUM	0.75"	1.0"	0.5"	0.625"
OPTIMUM	2.0"	2.0"	1.0"	0.75"

* USE BY BARE FINGER ** USE BY GLOVED FINGER †USING A LEVER LOCK TOGGLE SWITCH

TOGGLE SWITCHES

A. **TITLE:** TOGGLE SWITCH RESISTANCE

B. **GUIDELINES:** To minimize the possibility of inadvertent activation and control placement between activation positions, toggle switches should have an elastic resistance that increases slowly as the control is moved and then drops to zero as the switch snaps into position.

C. **HUMAN ERROR:** Inadvertent activation; placing the control in a position that doesn't activate the switch.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Kubokawa (1969); Van Cott and Kinkade (1972); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Replace with an appropriate control.

CONTROLS

A. **TITLE:** TOGGLE SWITCH ORIENTATION

B. **GUIDELINES:** To conform to population stereotype and to maximize performance, toggle switches should be oriented vertically with the on, go, or increase functions in the up position. Horizontal orientation should only be used to make the control consistent with the orientation of a control function, equipment location or display location.

C. **HUMAN ERROR:** Placing the control in an incorrect position.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Reorient the control and/or function.

**IMAGE EVALUATION
TEST TARGET (MT-3)**

6″

A. **TITLE:** TOGGLE SWITCH ACTIVATION FEEDBACK

B. **GUIDELINES:** Toggle switches should be provided with an audible click to provide feedback of activation.

C. **HUMAN ERROR:** Assuming a control has been positioned correctly when it hasn't; accidentally activating a control without knowing it.

D. **DOCUMENTATION:** MIL-HDBK-759; Van Cott and Kinkade (1972); Kubokawa (1969).

E. **TYPICAL BACKFIT:** Replace with an appropriate control.

A. **TITLE: TOGGLE SWITCHES AND PREVENTION OF INADVERTENT ACTIVATION**

B. **GUIDELINES:** When it is critical to prevent inadvertent activation of a toggle switch, a guard should be provided. This guard may be a lift-to-unlock mechanism, a safety cover or any equivalent device. If a lift-to-unlock mechanism is used, resistance should not exceed 48 oz. If a cover guard is used, its location should not interfere with the activation of the guarded control or any adjacent controls.

C. **HUMAN ERROR:** Inadvertent activation of a critical control; inability to activate a control within a given time limit.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-STD-1472C (1980); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Installing an appropriate guard; replacing a guard with appropriate guard.

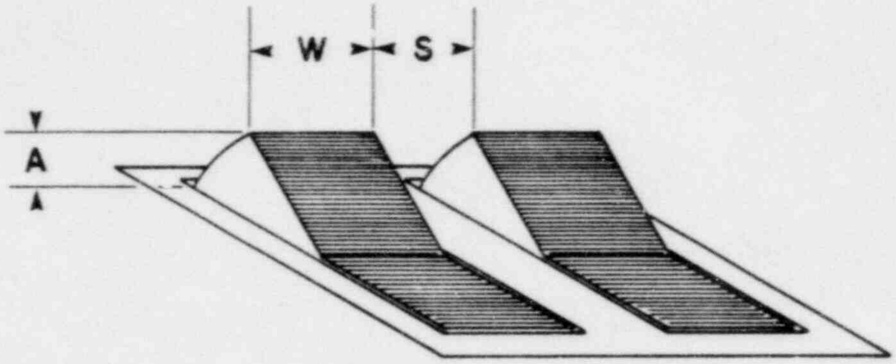
A. **TITLE:** ROCKER SWITCH DIMENSIONS

B. **GUIDELINES:** To maximize effectiveness, rocker switches should conform to the dimensions on the following page.

C. **HUMAN ERROR:** Inadvertent activation; making false assumption about control position; inability to activate control in a timely fashion.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify the existing control or replace with an appropriate control.



	W WIDTH	RESISTANCE
MINIMUM	0.75"	10 oz
MAXIMUM	1.5"	40 oz

	S SEPARATION	A DISPLACEMENT	
		2 POSITION	3 POSITION
MINIMUM	0.5"	30°	18°
MAXIMUM	— — —	120°	60°
OPTIMUM	2.0"	— — —	25°

ROCKER SWITCHES

A. TITLE: ROCKER SWITCHES

B. GUIDELINES: To maximize the ease of operation of rocker switches, they should conform to the following:

1. Orientation - Rocker switches should be oriented vertically with activation of the upper part controlling the on or increase function. Horizontal orientation should be used only to be compatible with the controlled function or equipment location.
2. Indication of Activation - Control activation should be indicated by a snap feel, audible click, associated or integral light. The on position should be flush with the panel surface.
3. Resistance - Control resistance should gradually increase, then drop to zero when the control snaps into position. The resistance should preclude the switch being placed between positions.
4. Inadvertent Activation - The switch should be protected by channel guards or other means to prevent inadvertent activation. (If it controls a critical function.)

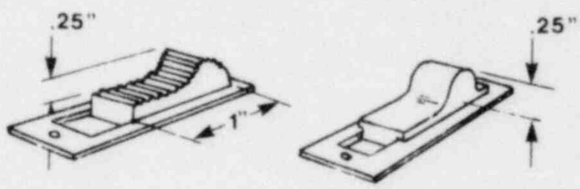
C. **HUMAN ERROR:** Inadvertent activation; incorrect activation of the control.

D. **DOCUMENTATION:** MIL-STD-1472C (1980); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Modify existing controls by placement and addition of guards; replace with appropriate controls.

A. **TITLE: SLIDE SWITCH DIMENSIONS**

B. **GUIDELINES:** If slide switches are used, the dimensions at the right should be conformed to for maximum effectiveness. Serrations or knurling should be provided.



C. **HUMAN ERROR:** Inability to activate the control on the first attempt; too much effort required to operate.

D. **DOCUMENTATION:** Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Cut serrations; replace with appropriately sized control.

A. TITLE: KEYBOARD KEY DIMENSIONS

B. GUIDELINES: To maximize the effectiveness of keyboards, the following dimensions should be conformed to:

KEYBOARDS

	Dimensions Diameter D		Resistance		
	Bare-handed	Gloves	Numeric	Alpha-numeric	Dual Function
Minimum	0.385"	0.75"	3.5 oz	0.9 oz	0.9 oz
Maximum	0.75"		14.0 oz	5.3 oz	5.3 oz
Preferred	0.5"	0.75"			

	Displacement			Separation
	Numeric	Alpha-numeric	Dual Function	(between adjacent key tops)
Minimum	0.03"	0.05"	0.03"	0.25"
Maximum	0.19"	0.25"	0.19"	
Preferred				0.25"

C. HUMAN ERROR: Inadvertent activation; substitution; activation of improper keys.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify existing keyboard or replace with new keyboards.

CONTROLS

A. **TITLE: KEYBOARD SLOPE**

B. **GUIDELINES:** To optimize operator use, keyboards should have a slope between 15 and 25 degrees; 16 to 17 degrees is the optimum.

C. **HUMAN ERROR:** Inadvertent activation; substitution; fatigue of operator.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Adjust console to provide adequate slope.

A. **TITLE: USE OF MULTIPLE KEYBOARDS**

B. **GUIDELINES:** If multiple keyboards are used in a control room, the key configuration should be the same.

C. **HUMAN ERROR:** Incorrect keys will be activated when an operator transfers from one keyboard to another.

D. **DOCUMENTATION:** MIL-STD-1472C (1980).

E. **TYPICAL BACKFIT:** Modify existing keyboards to be consistent or replace.

CONTROLS

A. TITLE: ALPHA-NUMERIC KEYBOARD ARRANGEMENT

B. **GUIDELINES:** Alpha-numeric keyboards should conform to the "QWERTY" arrangement.

C. **HUMAN ERROR:** Pressing improper keys due to different arrangement from typewriter.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Modify keyboard.

A. **TITLE: NUMERIC KEYBOARD**

B. **GUIDELINES:** The configuration of the keyboard which shall be used to enter solely numeric data should be a 3x3+1 matrix, numbered sequentially from left to right, top to bottom, beginning with 1, 2, 3 on the top row, with the zero digit centered on the bottom row (i.e., telephone style).

LIKE THIS			NOT THIS		
1	2	3	9	8	7
4	5	6	6	5	4
7	8	9	3	2	1
	0			0	

C. **HUMAN ERROR:** Incorrect actuation.

D. **DOCUMENTATION:** Lutz and Chapanis (1955); Paul, et al. (1955); Conrad (1967); Conrad and Hill (1968); McCormick (1976).

E. **TYPICAL BACKFIT:** Replace keyboard.

A. **TITLE: JOYSTICKS**

B. **GUIDELINES:** To maximize the effectiveness of joysticks, they should conform to the following:

1. For most applications, joystick controls should be provided with a spring return to center position.
2. The delay between control movement and display response shall not exceed .3 sec.
3. The ratio of the control's displacement to the resulting display movement shall be consistent with the speed and accuracy requirements of the operator.
4. For precise adjustments in which the operator grasps the joystick "pencil style" below the tip rather than at the tip, the pivot point shall be recessed below the surface on which the wrist rests.

C. **HUMAN ERROR:** Lack of consistent, appropriate control.

D. **DOCUMENTATION:** MIL-STD-1472C (1980).

E. **TYPICAL BACKFIT:** Modify the existing control or replace with an appropriate control.

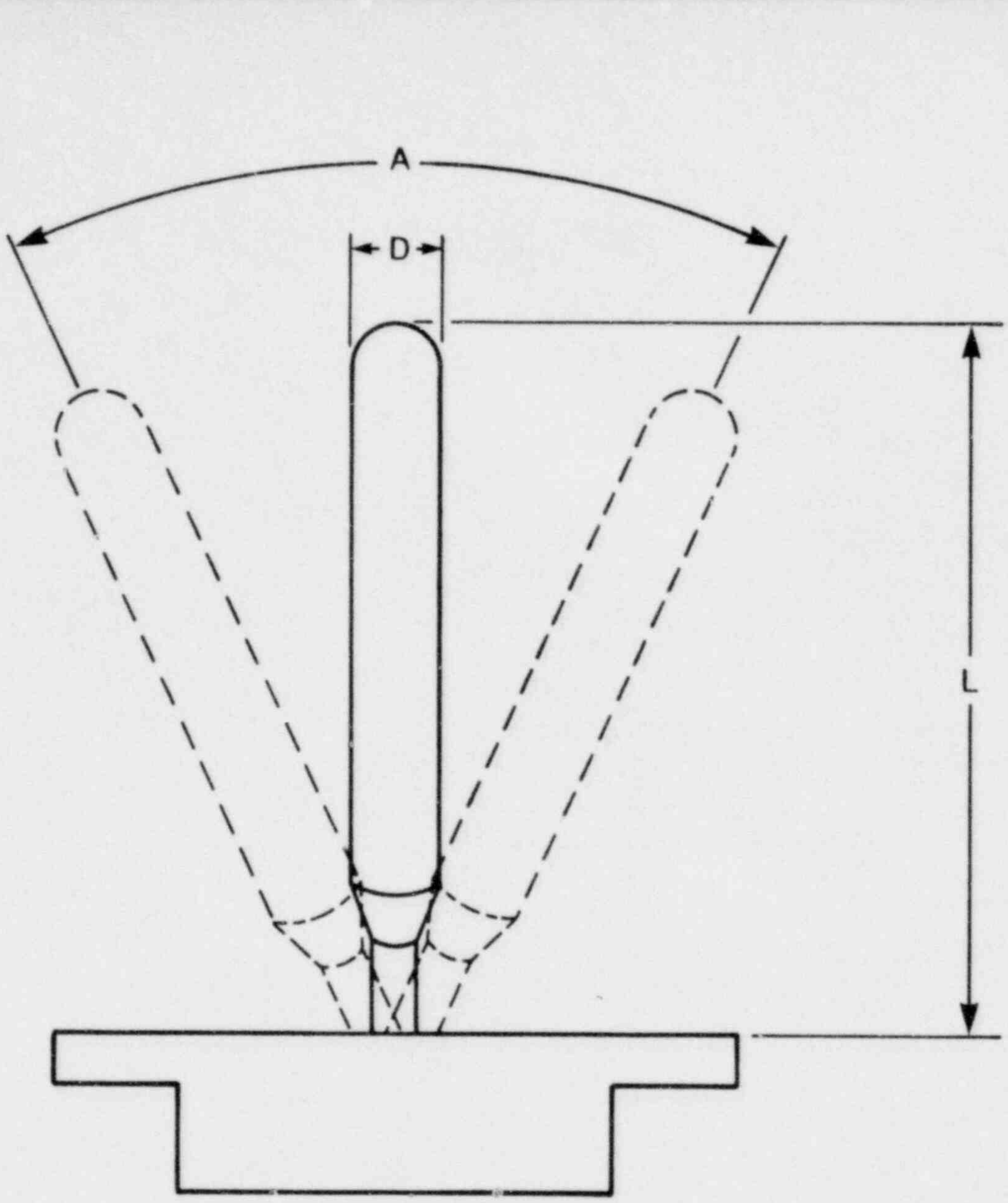
A. **TITLE: JOYSTICK DIMENSIONS**

B. **GUIDELINES:** To maximize their effectiveness, joysticks should conform to the dimensions on the following page.

C. **HUMAN ERROR:** Inadvertent activation; insufficient activation.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify existing control or replace with appropriate control.



	DIMENSIONS		RESISTANCE	DISPLACEMENT
	L ARM LENGTH	D DIAMETER		A CONE OF ROTATION
MINIMUM	3"	0.25"	12 oz.	0° *
MAXIMUM	6"	1.0"	32 oz.	57°
OPTIMUM	— — —	— — —	— — —	5°-20°

* ISOMETRIC (FORCE) JOYSTICK

JOYSTICK CONTROL

A. **TITLE: LIMB SUPPORT FOR JOYSTICK CONTROLS**

B. **GUIDELINES:** If precise or continuous control is required, the operator should have an arm rest supplied with the joystick.

C. **HUMAN ERROR:** Fatigue leading to improper activation or termination of activation prior to termination time.

D. **DOCUMENTATION:** MIL-STD-1472, Essex Revision (1980).

E. **TYPICAL BACKFIT:** Supply an arm rest.

A. **TITLE: LEVER DIMENSIONS**

B. **GUIDELINES:** To maximize the effectiveness of levers, the dimensions on the following page should be conformed to.

C. **HUMAN ERROR:** Inadvertent activation; fatigue leading to incorrect activation; incorrect activation due to inadequate size.

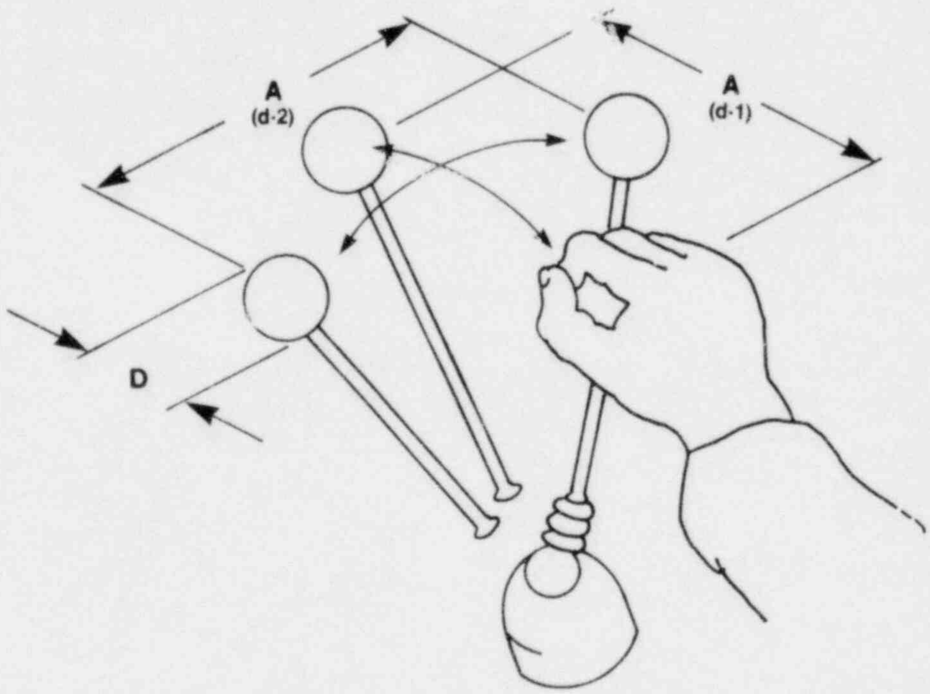
D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Modify existing control or replace with more appropriate control.

LEVER

	DIAMETER D		RESISTANCE			
			(d-1)		(d-2)	
	Finger Grasp	Hand Grasp	One Hand	Two Hands	One hand	Two Hands
MINIMUM	0.5"	1.5"	2 lb	2 lb	2 lb	2 lb
MAXIMUM	3.0"	3.0"	30 lb	50 lb	20 lb	30lb

	DISPLACEMENT A		SEPARATION	
	Forward (d-1)	Lateral (d-2)	One Hand Random	Two Hands Simultaneously
MINIMUM			2.0"	3.0"
PREFERRED			4.0"	5.0"
MAXIMUM	14.0"	33.0"		



CONTROLS

A. **TITLE:** LEVER LABELING AND CODING

B. **GUIDELINES:** Levers should be labeled as to function and direction of motion. If lever labels are grouped together the lever handles should be coded.

C. **HUMAN ERROR:** Substitution; improper activation of the control.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Code handles with shapes or labels; label controls in an appropriate manner.

A. **TITLE: THUMBWHEEL VISIBILITY**

B. **GUIDELINES:** To minimize error, thumbwheel readouts should be visible from all operator positions.

C. **HUMAN ERROR:** Misreading a display; not reading a display.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with a control that is readable or reposition.

A. **TITLE: THUMBWHEEL CONTROL APPLICATION**

B. **GUIDELINES:** The use of thumbwheels is discouraged but if the function requires a compact digital control-input device and a readout of inputs for verification, they may be used.

C. **HUMAN ERROR:** Adjustment; inadvertent activation.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Determine requirements for thumbwheel control. If required use guidance in MIL-STD-1472B (1974).

A. **TITLE: THUMBWHEEL VISIBILITY**

B. **GUIDELINES:** To minimize error, thumbwheel readouts should be visible from all operator positions.

C. **HUMAN ERROR:** Misreading a display; not reading a display.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with a control that is readable or reposition.

A. **TITLE: THUMBWHEEL COLOR AND INTERNAL ILLUMINATION**

B. **GUIDELINES:** To facilitate character recognition, digits on thumbwheels should be bold with black numerals engraved on a light (or white) background. If the ambient illumination provides a display luminance of 1 ft-Lambert or less, internal illumination should be provided with characters being illuminated on a black background.

C. **HUMAN ERROR:** Misreading display; not being able to see the numerals.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Replace with appropriate control.

CONTROLS

A. **TITLE: THUMBWHEEL CODING**

B. **GUIDELINES:** If the thumbwheels are used as input devices, the off or normal positions should be color coded to facilitate visual recognition of status.

C. **HUMAN ERROR:** Misreading; misinterpreting of control position.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

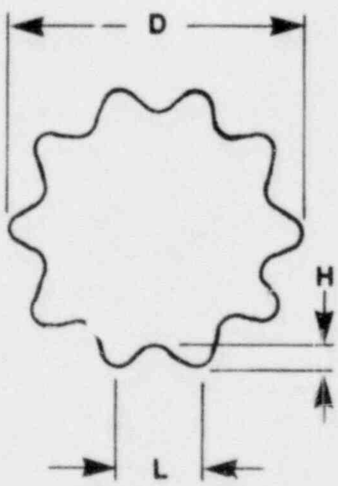
E. **TYPICAL BACKFIT:** Replace with appropriate control.

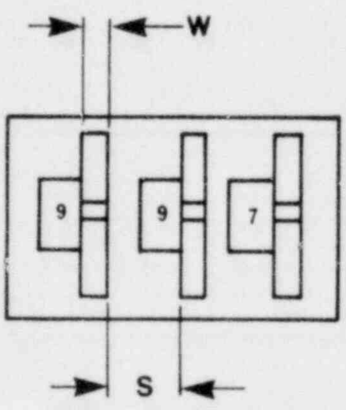
A. TITLE: DISCRETE THUMBWHEEL DIMENSIONS

B. GUIDELINES: To maximize the ease of operation of discrete thumbwheel controls, the following guidelines for size, separation, etc., should be followed:

DISCRETE THUMBWHEEL CONTROL

	D DIAMETER	L TROUGH DISTANCE	W WIDTH	H DEPTH	S SEPARATION	RESISTANCE
MINIMUM	1.5 in.	0.45 in.	0.1 in.	0.125 in.	0.4 in.	6 oz
MAXIMUM	2.5 in.	0.75 in.		0.5 in.		20 oz





C. **HUMAN ERROR:** Inadvertent activation; adjustment.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Replace with appropriate control.

A. **TITLE: DISCRETE THUMBWHEEL CONTROL — DIRECTION OF MOTION**

B. **GUIDELINES:** To conform to population stereotype, a downward control movement should be associated with a decrease and an upward control movement with an increase.

C. **HUMAN ERROR:** Adjustment; reversal.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Reverse the direction of movement.

A. **TITLE:** DISCRETE THUMBWHEEL CONTROL RESISTANCE

B. **GUIDELINES:** To minimize control error, discrete thumbwheel controls should have detents with resistance that builds up and then decreases as the detent is approached. This causes the control to snap into position and minimizes the possibility of positioning between detents.

C. **HUMAN ERROR:** Adjustment.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with a control that has sufficient resistance.

CONTROLS

A. **TITLE:** DISCRETE (DETENTED) THUMBWHEEL CONTROL CHARACTER:

B. **GUIDELINES:** To maximize interpretation of discrete thumbwheels, 10 positions should be provided representing 0-9.

C. **HUMAN ERROR:** Misreading control positions.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with appropriate control.

A. **TITLE:** CONTINUOUS THUMBWHEEL CONTROL DIMENSIONS

B. **GUIDELINES:** To maximize the operability of continuous thumbwheel controls, at least 1 inch of the wheel should be exposed. The controls should be separated by at least .25 inch. Resistance should be between 3 and 6 ozs.

C. **HUMAN ERROR:** Inadvertent activation, adjustment.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL STD-1472, Essex Revision (1980); Van Cott and Kinkade (1972); Woodson and Conover (1964).

E. **TYPICAL BACKFIT:** Replace with appropriate controls.

CONTROLS

A. **TITLE:** CONTINUOUS THUMBWHEELS — DIRECTION OF OPERATION

B. **GUIDELINES:** To maximize the control/display relationship, continuous thumbwheels should have a movement up, forward or to the right to increase. The display should respond in a corresponding manner.

C. **HUMAN ERROR:** Adjustment; reversal.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Change the control and display, if necessary, to conform.

A. **TITLE: CONTINUOUS THUMBWHEEL CONTROLS — OFF POSITION**

B. **GUIDELINES:** If a continuous thumbwheel has an off position, a detent should be provided to let the operator know that the control is off.

C. **HUMAN ERROR:** Leaving a function on when it should be off.

D. **DOCUMENTATION:** MIL-STD-1472, Essex Revision (1980).

E. **TYPICAL BACKFIT:** Replace with an appropriate control.

HANDWHEELS

Parameter	Minimum	Maximum
Size:		
Diameter (in.)*	7.0	21.0
Rim thickness (in.)	0.75	2.0
Displacement	(†)	‡90-120°
Resistance (lb.):		
Precision operation:		
Up to 3.5 in. radius	n.a.	n.a.
5.0 to 8.0 in radius	2.5	8.0
Resistance at rim:		
One hand	5.0	30.0
Two hands	5.0	50.0
	Minimum	**Preferred**
Control separation (in.)§	3.0	5.0

Adapted from MIL STD-803A (USAF) and AFSCM SO-3.
* Two-hand grasp.
† Determined by desired C/D ratio.
‡ Provided optimum C/D ratio is not hindered.
§ Edge-to-edge separation.

A. **TITLE: HANDWHEEL CONTROL — DIMENSIONS**

B. **GUIDELINES:** To maximize the effectiveness of handwheels, the dimensions to the left should be conformed to.

C. **HUMAN ERROR:** Inadvertent activation; insufficient or over-activation.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Modify present control; if possible, replace handwheel; replace entire control.

A. **TITLE: HANDWHEEL RIMS**

B. **GUIDELINES:** To be most effective handwheel rims should be provided with contoured molding and have a high degree of frictional resistance.

C. **HUMAN ERROR:** Slippage of the operator's hands that leads to incorrect activation.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Modify the existing handle.

CONTROLS

A. TITLE: HANDWHEELS AND INADVERTENT ACTIVATION

B. GUIDELINES: To prevent accidental activation of a handwheel, a locking pin should be used.

C. HUMAN ERROR: Inadvertent activation.

D. DOCUMENTATION: Van Cott and Kinkade (1972).

E. TYPICAL BACKFIT: Install a locking pin.

A. TITLE: HAND CRANK DIMENSIONS

B. GUIDELINES: To insure the effectiveness of hand cranks, they should conform to the dimensions to the right.

C. HUMAN ERROR: Inadvertent activation; setting control at improper position.

D. DOCUMENTATION: Van Cott and Kinkade (1972).

E. TYPICAL BACKFIT: Modify existing control size, resistance or replace control.

Parameter	Minimum	Maximum
Radius/Length (in.)	0.5	4.5 (light load) 20.0 (heavy load)
Handle Diameter (in.)	1.0	3.0
Handle Length (in.)	3.0	
Resistance (lbs.)		
Radius less than 3.5 in.	2.0	5.0
Radius of 5 to 8 in.	5.0	10.0
Radius of 5 to 8 in. with requirement for precise settings	2.5	8.0
Separation (in.)		
One hand, randomly	2.0	4.0
Two hand, sequentially	3.0	5.0

A. **TITLE: HAND CRANK HANDLES**

B. **GUIDELINES:** To maximize efficiency of use, hand cranks should have a handle that turns freely around its shaft; the handle surface should be provided with a high degree of frictional resistance.

C. **HUMAN ERROR:** Improper setting of the control; not operating the control within specific time period.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Replace handle.

CONTROL/DISPLAY INTEGRATION

(CDI)

CDI

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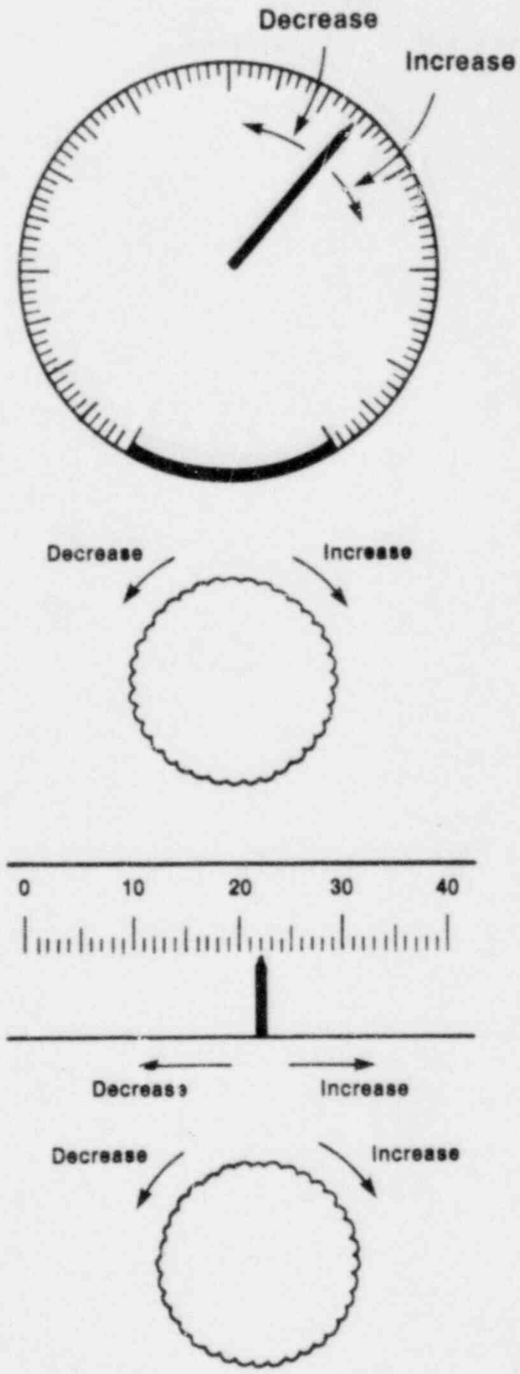
A. **TITLE:** CONTROL/DISPLAY COMPATIBILITY: MOVING POINTER FIXED SCALE

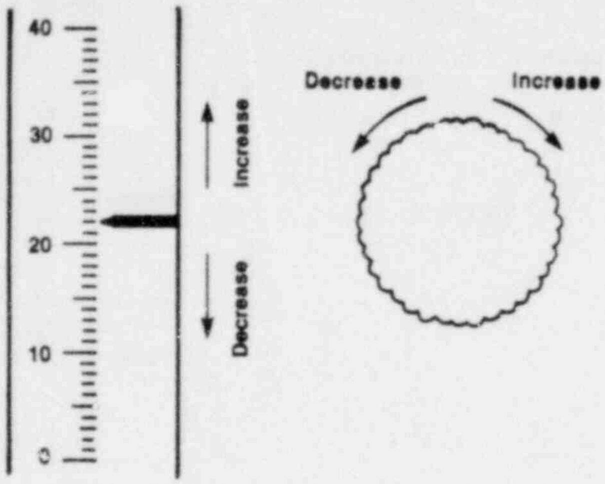
B. **GUIDELINES:** In display control systems in which a control movement is associated with a movement of some feature of the display (such as a pointer), a clockwise increment of a rotary control or movement of a linear control forward, up, or to the right shall produce:

1. A clockwise movement of circular scale pointers and an increase in the magnitude of the settings, or
2. A movement up or to the right for vertical and horizontal scale pointers and an increase in the magnitude of the reading.

C. **HUMAN ERROR:** Moving a control to the wrong position; moving a control in a direction opposite to that necessary to produce a desired effect.

D. **DOCUMENTATION:** DeGreene (1970); Bioastronautics Data Book (1973); MIL-STD-1472B (1974); MIL-HDBK-759 (1975); and McCormick (1976).





E. **TYPICAL BACKFIT:** Change control/display movement relationship; replace displays.

A. **TITLE:** CONTROL/DISPLAY COMPATIBILITY: FIXED POINTER MOVING SCALE

B. **GUIDELINES:** Displays with moving scales and fixed pointers should be avoided. However, if necessary, clockwise movement of a rotary control or movement of a linear control forward, up, or to the right shall produce:

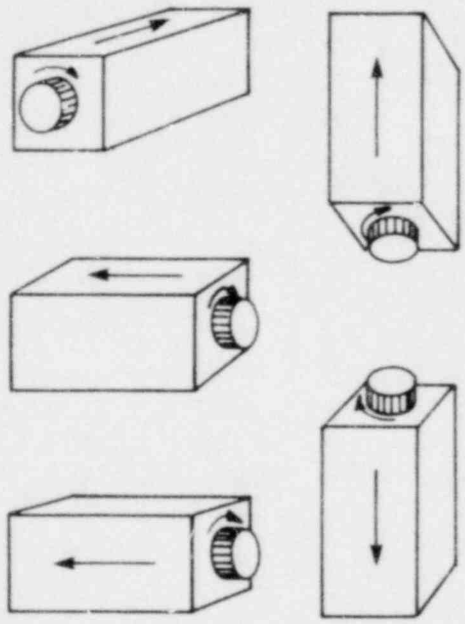
   1. A counterclockwise movement of the scale and an increase in the magnitude of the reading , or
   2. A movement of the scale down or to the left and an increase in the magnitude of the reading.

C. **HUMAN ERROR:** Moving a control to the wrong position; moving a control in a direction opposite to that necessary to produce a desired effect.

D. **DOCUMENTATION:** Chapanis (1965); MIL-STD-1472B (1974); McCormick (1976).

E. **TYPICAL BACKFIT:** Change control display movement relationship; replace displays.

CONTROL/DISPLAY INTEGRATION



A. **TITLE:** CONTROL/DISPLAY COMPATABILITY: DIFFERENT PLANES

B. **GUIDELINES:** In systems where control devices are located in different planes from the displays with which they are associated, the relationship between control movement and direction of pointer movement shall be in accordance with the movement relationships as depicted in the figure at left.

C. **HUMAN ERROR:** Moving a control to the wrong position; moving a control in a direction opposite to that necessary to produce a desired effect.

D. **DOCUMENTATION:** McCormick (1976).

E. **TYPICAL BACKFIT:** Change control/display movement relationship; replace displays.

A. TITLE: CONTROL/DISPLAY RATIO

B. GUIDELINES: Knob, Coarse Setting — When a knob is provided for making coarse display element settings on linear scales —0.016 to 0.100 inch tolerance — approximately 6 inches of display element movement shall be provided for one complete turn of the knob.

Knob, Fine Setting — For fine setting on linear scales — 0.007 to 0.015 inch tolerance — 1 to 2 inches of display element movement shall be provided for one complete turn of the knob.

Lever, Coarse Setting — When a lever is provided for coarse settings — 0.016 to 0.100 inch tolerance — one unit of display element movement shall be used to three units of lever movement.

Lever, Two-Dimensional Setting — When a lever is provided to make settings in two dimensions to coarse tolerances —0.1 inch, one unit of display element movement shall be used to two and one-half units of lever movement.

Counters — When counters are provided, the control-display ratio shall be such that one revolution of the knob equals approximately 50 counts (i.e., the right hand drum rotates five times).

C. **HUMAN ERROR:** Operating a control too slowly or too rapidly; excessive continuance of control action; inadequate continuance of control action.

D. **DOCUMENTATION:** Chapanis (1965); Kubokawa (1969); MIL-STD-1472B (1974); MIL-HDBK-759 (1975).

E. **TYPICAL BACKFIT:** Adjust control-display ratios; purchase new gears, caps, linkages, etc; replace controls/displays.

OPTIMUM CONTROL-DISPLAY RATIOS

Control	Approximate Control Movement	Display Movement
Knob, coarse setting	1 complete turn	6 inches
Knob, fine setting	1 complete turn	1 - 2 inches
Lever, coarse setting	3 units	1 unit
Lever, coarse setting, two dimensions	2-½ units	1 unit
Counter	1 complete turn (or reset knob)	Approximately 50 counts (right drum rotates 5 times)

A. **TITLE:** ROTARY VS. LINEAR CONTROLS: MOVEMENT RELATIONSHIPS

B. **GUIDELINES:** When there is a direct linkage between control and display (e.g., 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 the path of control movement parallels the average path of the indicator movement and the indicator and control move in the same relative direction.

C. **HUMAN ERROR:** Wrong direction of control action; inadequate continuance of control action; excessive continuance of control action.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace control or display.

CONTROL/DISPLAY INTEGRATION

A. TITLE: PRINCIPLES OF CONTROL-DISPLAY ARRANGEMENT

B. GUIDELINES: Visual displays and controls should be arranged in such a way that it is not possible for the operator to obstruct his view of any of the displays. Furthermore, the arrangement of controls and displays shall conform to one of the following principles of control panel layout:

1. Sequence-of-Use Principle — In the use of certain items, there are sequences or patterns of relationship that frequently occur in the operation of the equipment. In applying this principle, the items would be so arranged so as to take advantage of such patterns; thus, items used in sequence would be in close physical relationship with each other.
2. Functional Principle — The functional principle of arrangement provides for the grouping of components according to their function, such as the grouping together of displays, or controls, that are functionally related in the operation of the system.

3. Frequency-of-Use Principle — As implied by the name, this concept applies to the frequency with which some component is used.

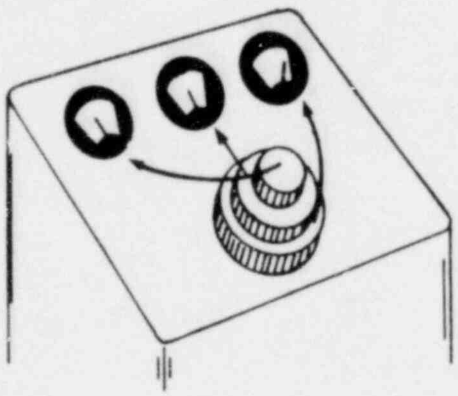
4. Importance Principle — This principle deals with operational importance, that is, the degree to which the performance of the activity with the component is vital to the achievement of the objectives of the system or some other consideration.

C. **HUMAN ERROR:** Activating the wrong control; reading the wrong display; temporal error.

D. **DOCUMENTATION:** Woodson and Conover (1964); Meister (1971); McCormick (1976).

E. **TYPICAL BACKFIT:** Redesign control panel layout; use of demarcation lines and markings.

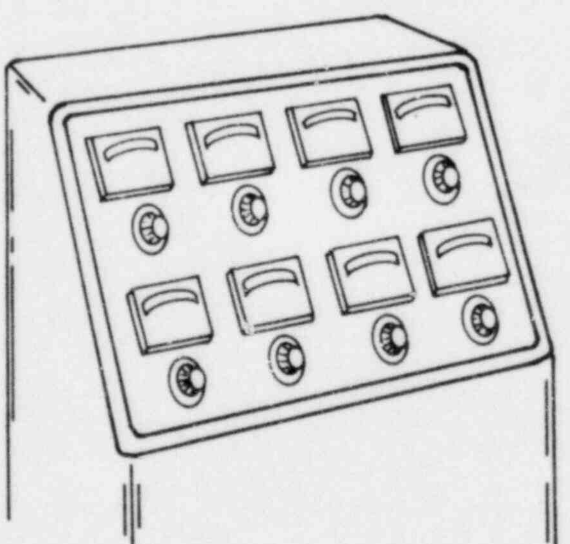
CONTROL/DISPLAY INTEGRATION



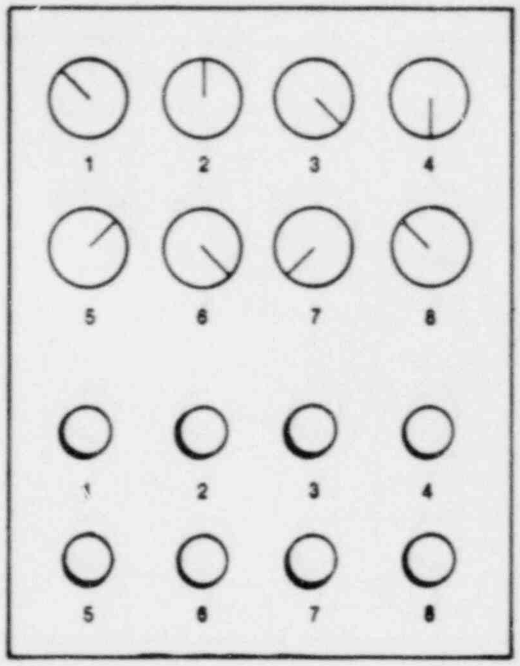
A. TITLE: CONTROL/DISPLAY ARRANGEMENT

B. GUIDELINES:

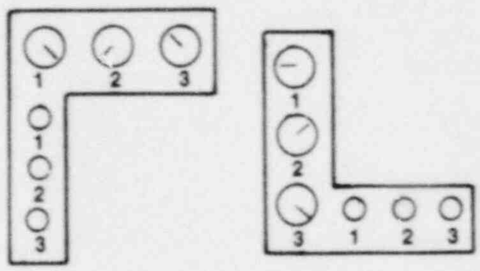
1. If concentric or ganged knobs are used to control a set of displays, the central (smallest) knob should operate the display further left, the middle knob should operate the center display, and the bottom (largest) knob should operate the display to the right, with the combined control underneath the center of the displays.
2. Displays and controls that are to be used in a fixed order should be arranged in sequence (a) from left to right (preferred) (b) from top to bottom, or (c) in rows from top to bottom, and from left to right within the rows.
3. When a number of displays and controls are each associated with a group of similar components, the arrangement of the controls and displays should correspond to the arrangement of the components.
4. Controls associated with specific displays should be located so



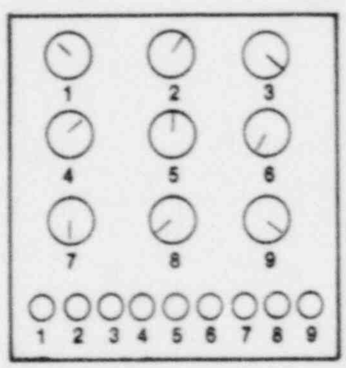
that the operator's hand does not prevent him from seeing the display. When a number of associated controls and displays appear on a panel, (a) put each control directly below its corresponding display or (b) group all the displays above and all the controls below, but arrange the controls and the displays in exactly the same order.



5. 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 ar[illegible], etc. However, this type of arrangement shall be avoided whenever possible.



6. Left-to-Right Arrangement - If controls must be arranged in fewer rows than displays, controls affecting the top row of displays shall be positioned at the far left; controls affecting the second row of displays shall be placed immediately to the right of these, etc.



C. **HUMAN ERROR:** Operating wrong control/display; reading wrong display; incorrect sequence in operating several controls.

D. **DOCUMENTATION:** Chapanis (1965); Van Cott and Kinkade (1972); and MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Rearrange control/display layout; replace consoles.

A. TITLE: ACCENTUATING CONTROL/DISPLAY GROUPS

B. **GUIDELINES:** One or more of the following techniques should be used for setting apart functionally similar groups.

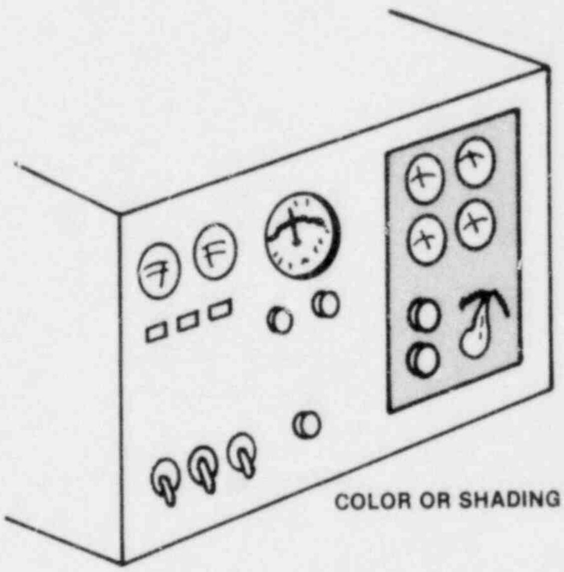
1. Contrasting color or shading between subpanel and basic panel.
2. Outlining with contrasting color (a line border around a group of items).
3. A panel relief.
4. An insert panel.
5. Alternating slopes and modular supplement.

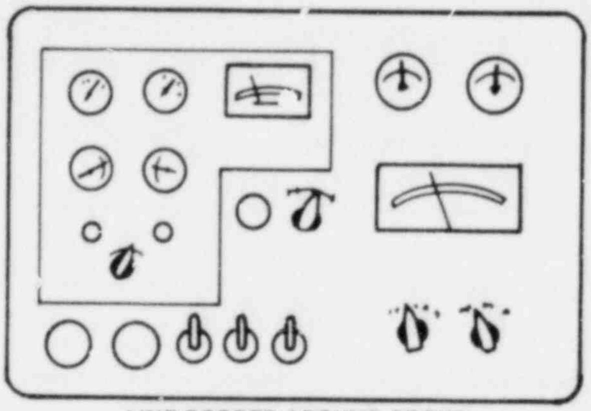
If functional groups are to be accentuated by outlining with contrasting lines, a 1/16 inch border should designate secondary or non-critical groups, and a 3/16 inch border should designate primary, emergency, or extremely critical operations.

C. **HUMAN ERROR:** Failure to respond to a signal change; late response to a signal change; and monitoring the wrong display.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972) and MIL-STD-1472B (1974).

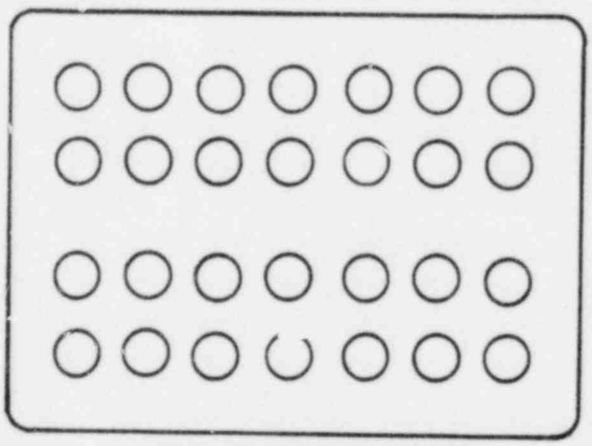
Methods for accentuating grouping and functional association.



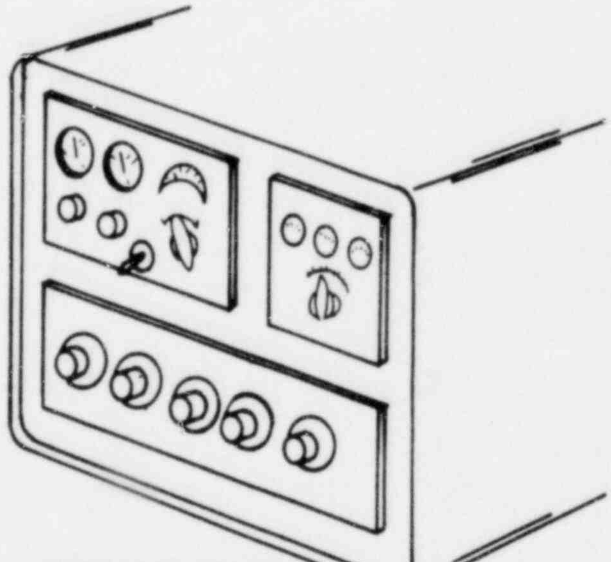


LINE BORDER AROUND GROUP

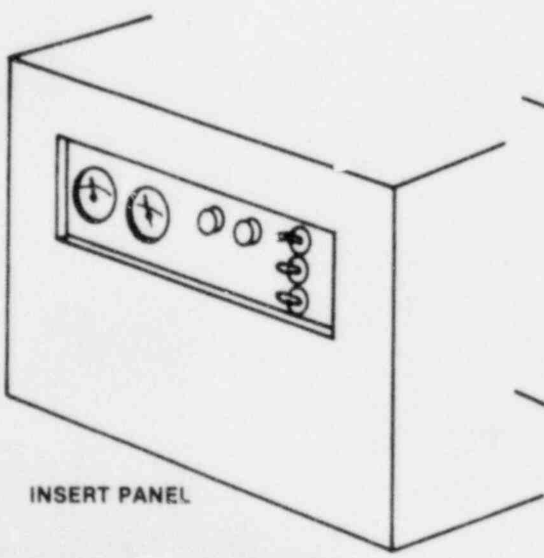
E. **TYPICAL BACKFIT:** Add demarcation lines or provide a similar method of accentuation.



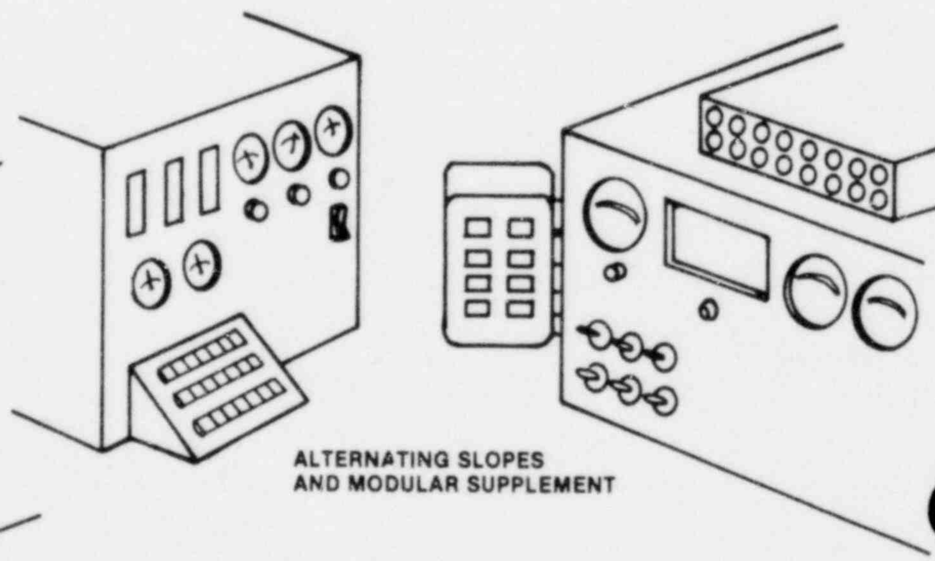
SPACING BETWEEN GROUPS



ADDED PANEL RELIEF



INSERT PANEL



ALTERNATING SLOPES
AND MODULAR SUPPLEMENT

A. **TITLE: PANEL CONSISTENCY**

B. **GUIDELINES:** Location of recurring functional groups and individual items shall be similar from panel to panel. 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.

C. **HUMAN ERROR:** Confusing one control with another; activating the wrong control; incorrect sequence in operating several controls; wrong direction of control action.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify or replace panels.

CONTROL/DISPLAY INTEGRATION

A. TITLE: MIRROR IMAGING

B. **GUIDELINES:** The use of mirror-imaged control panels should not be used in multi-unit control rooms. The arrangement of functionally similar or identical primary controls and displays should be consistent from panel to panel.

C. **HUMAN ERROR:** Recording or reporting a signal change in the wrong direction; confusing one control/display with another; failing to identify a needed control/display; moving a control to the wrong position; incorrect sequence in operating several controls; moving a control in a direction opposite to that necessary to produce a desired effect.

D. **DOCUMENTATION:** EPRI Report NP-309 (1977).

E. **TYPICAL BACKFIT:** Limit operational crews to one or the other mirrored half of the boards; use two different color schemes to differentiate the two units (e.g., the board surface areas, the operator stations, and the carpeting).

OPERATOR/COMPUTER INTERFACE AND DIALOG

(OCI)

OCI

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A. **TITLE: DATA PRESENTATION**

B. **GUIDELINES:** Data shall be presented to the operator in a readily usable and readable format. Requirements for transposing, computing, interpolating, or mental translation into other units or numerical bases shall be avoided. When practicable, data shall be presented to conform to the following:

1. Illustrations shall be used whenever possible to supplement or exemplify text.
2. When five or more digits and/or alphanumerics are displayed, and no natural (i.e., population stereotyped) organization exists, characters shall be grouped in blocks of 3 to 4 characters each. Groups shall be separated by a minimum of one blank character.
3. When data fields contain a naturally occurring order (e.g., chronological), such order shall be reflected in the organization of the field.
4. Identical data shall be displayed in a consistent, standardized manner, irrespective of their module of origin.

5. Tasks involving counting shall commence with the number "one," tasks related to measuring shall start with zero.
6. Numbers shall be used as designators when listing selectable items.
7. Lists shall be vertically aligned and left-justified. Indentation should be used for subclassifications.
8. Data which must be scanned and compared shall be presented in tabular or graphic form.
9. The use of hyphenation shall be minimized.
10. When presented in tabular form, alphanumeric data shall be left justified; numeric data shall be right justified by decimal point.
11. Periods shall be placed after item selection numbers, at the end of a sentence, and where necessary for classification.
12. The use of contractions or shortened forms of words should be avoided.
13. Each individual field shall be labeled. The operator should not have to rely on contextual cues to identify a field.
14. The following standardized fields shall be used:
    a. Telephone Number: (914) 555-1212

b. Time: HH:MM:SS, HH:MM, MM:SS:(.S)

c. Data: MM:DD:YY

15. Where lists extend over more than one display page, the last of one page shall be the first line on the succeeding page.

C. **HUMAN ERROR:** Failure to obtain or apply all relevant decision information.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Rewrite or modify software.

OPERATOR/COMPUTER INTERFACE AND DIALOG

A. TITLE: SCREEN LAYOUT AND STRUCTURING

B. **GUIDELINES:** Operational tests on simulators or mockups should be used to develop screen layouts and structuring that minimize operator scanning and reading requirements, and minimize the probability of operator error. When practicable, screen layout and structuring shall conform to the following:

1. Displayed data shall be organized in a logical, consistent manner, reflecting some obvious and inherent quality of the data groups (e.g., hierarchical, sequential or mimic relationships).
2. Physical location of specific data groups on the screen shall be consistent throughout the operation of the system, irrespective of the module or program in use.
3. Screen layout and separation shall be made apparent to the operator through the use of blank spaces, lines, or some other form of visible demarcation.

4. Lists of options shall be organized according to the probability of selection for each item, with high probability items presented first.
5. Non-option lists or lists of equal-probability options shall be presented in alphabetical or numerical order.
6. Text paragraphs shall be separated by at least one blank line.
7. Formats shall be organized to minimize positioning movements of the cursor.
8. Selection numbers shall be separated from text descriptors by at least one blank space.
9. Items contained in a numbered list and described on "continue" pages shall be numbered relative to the first number on the first page of the list.
10. When directions to the operator accompany a list of options, such directions shall precede presentation of the list.
11. Critical messages requiring immediate operator response shall be highlighted, and, when practicable, placed in the center of the operator's field of view relative to the display or window.
12. The size of the selectable area for an operator option shall

encompass, at a minimum, the alphanumeric string of the option designator.

C. **HUMAN ERROR:** Omitting a procedural step; mis-ordering a procedural step; failure to obtain or apply all relevant decision information.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Redesign hardware.

A. TITLE: HIGHLIGHTING

B. **GUIDELINES:** Highlighting shall be used when a particular data item or message is critical to operator decision or action requirements. The following methods of highlighting are acceptable:

1. Contract enhancement — (i.e., dual level illumination)
2. Blinking — rate between 2-3Hz, with a minimum flash duration of 50 msec.
3. Inverse video.
4. Graphics — (i.e., the use of highlighting symbology, such as arrows, asterisks, boxes, underlining, etc.). Lines should be composed of at least 50 points per inch to provide the illusion of continuity.

C. **HUMAN ERROR:** Failure to record or report a signal change.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Redesign software or hardware.

OPERATOR/COMPUTER INTERFACE AND DIALOG

A. TITLE: **MECHANICAL OVERLAYS**

B. **GUIDELINES:** Mechanical overlays such as coverings over the keyboard or transparent sheets placed on the display should be avoided.

C. **HUMAN ERROR:** Activating the wrong k misreading the display.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Remove overlays and redesign controls/displays as appropriate.

A. **TITLE:** **FRAME CONTENT: GENERAL**

B. **GUIDELINES:** Frame content shall be limited to that information required by the operator for a specific action or decision. Information requirements shall be determined by task analysis or some similar procedure.

C. **HUMAN ERROR:** Failure to make correct decision; omitting a procedural step; failure to obtain or apply all relevant decision information.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Modify software.

A. TITLE: FEEDBACK

B. **GUIDELINES:** Feedback shall be provided to the operator to indicate the status of system functioning. When practicable, feedback shall conform to the following:

1. When a displayed message or datum is selected as an option or input to the system, the subject item shall be highlighted to indicate acknowledgement by the system.
2. When system functioning requires the operator to standby, periodic feedback shall be provided the operator to indicate normal system operation.
3. When a process or sequence is completed by the system, positive indication shall be presented to the operator concerning the outcome of the process and the requirements for subsequent operator actions.
4. If the system rejects an operator input, feedback shall be provided to indicate the nature of the problem and the required corrective action.

C. **HUMAN ERROR:** Late response to a system change; premature action; recording or reporting a system change when none has occurred.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Redesign software and hardware.

OPERATOR/COMPUTER INTERFACE AND DIALOG

A. TITLE: LABELING

B. **GUIDELINES:** Each individual data group or message shall contain a descriptive title, phrase, word or similar device to designate the content of the group or message. Where practicable, labeling shall conform to the following:

1. Labels shall be located in a consistent fashion adjacent to the data group or message they describe. Labels should be oriented horizontally and located above the functional groups they identify.
2. Labels shall be highlighted or otherwise accentuated to facilitate operator scanning and recognition. The technique used to highlight labels shall be easily distinguished from that used to highlight emergency or critical messages.
3. Labels shall reflect some characteristic common to the group or message being designated. Labels shall be sufficiently unique to preclude operator confusion.

4. When presenting a list of operator options, the label shall reflect the question being posed to the operator.

C. **HUMAN ERROR:** Reading the wrong information; failure to obtain or apply all repeat decision information; and delaying a decision beyond the time it is required.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Rewrite software.

OPERATOR/COMPUTER INTERFACE AND DIALOG

A. TITLE: MESSAGES

B. GUIDELINES: Messages shall be concise and provide the operator with the information necessary to complete a specific action or decision sequence. When practicable, messages shall conform to the following:

1. Information contained in a message shall be necessary, complete and readily usable. Messages which require the operator to reference external data sources or translate message content shall be avoided.
2. Messages shall contain adequate feedback to the operator to indicate that operator choices or actions have been accepted.
3. Critical information shall be presented at the beginning of the message.
4. Information required for the next operator entry shall be placed at the end of the message.
5. The terminal's output speed should approximate the mean reading speed of the expected user population. Capability for adjusting output speed should be provided.

6. Messages shall be restricted to factual and informative data. No attempts at humor, sarcasm or other irrelevant modes of presentation shall be made, unless specifically requested by the procuring activity.

C. **HUMAN ERROR:** Failure to use available information to derive needed solution; failure to obtain or apply all relevant decision information; failure to identify all reasonable alternating; making an unnecessary or premature decision; delaying a decision beyond the time it is required.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Rewrite software.

OPERATOR/COMPUTER INTERFACE AND DIALOG

A. TITLE: INTERFRAME CONSIDERATIONS

B. GUIDELINES: Interframe design shall minimize the requirements for operator memory. When practicable, interframe design shall conform to the following:

1. When frames are organized in a hierarchical fashion, containing a number of different paths through the series, a visual audit trail of the choices made shall be available upon operator request.
2. When the operator is forced to scroll on a large logical frame, the present and maximum locations shall be presented on the viewable portion of the frame (e.g., line 62 of 112).
3. The operator shall be capable of controlling the amount, format and complexity of information being displayed by the system (e.g., core dumps, program outputs, error messages, etc.).
4. When text is presented in the form of prose, upper and lower

case letters shall be used consistent with established orthographic principles, except in cases requiring accentuation (e.g., labels).

5. All data relevant to a specific operator entry shall be displayed on a single frame. Requirements for operator recollection of data between frames shall be avoided.
6. The meaning and context of technical words or phrases shall be consistent between frames.
7. A message occurring in more than one frame shall maintain a constant physical location on the screen. If the message is a variable option list, common elements shall maintain their physical relationship to other recurring elements.
8. Data, text, formats, etc., which have been designated as essential to system performance shall be under system control. Voluntary compliance by the operator shall be avoided.

C. **HUMAN ERROR:** Failure to obtain or apply all relevant decision information; delaying a decision beyond the time it is required; failure to use available information to derive needed solutions.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Redesign software and hardware.

A. TITLE: **ERROR MESSAGES**

B. **GUIDELINES:** The system shall be capable of recognizing and reporting detectable errors. The error message shall reflect the following considerations:

1. Feedback — Displayed indication shall be provided which describes the type and location of the error.
2. Directional Guidance — Error messages shall contain instructions to the operator regarding required corrective action.
3. Temporal and Spatial Proximity — Error messages and prompting shall be displayed adjacent to the affected data field as quickly as possible.
4. Corrective Action — Capability shall be provided to the operator to immediately rectify detected errors. This capability shall permit the operator to address the error individually without affecting adjacent entries.

C. **HUMAN ERROR:** Failure to record or report a system change; failure to respond to a system change; iate response to a system change; failure to obtain or apply all relevant decision information.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Rewrite software.

A. **TITLE: COMMAND LANGUAGE**

B. **GUIDELINES:** Command language shall be logical, and used in a consistent manner reflective of the vocabulary and syntax of the expected user population.

C. **HUMAN ERROR:** Incorrect command to computer.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Rewrite software and modify hardware to receive and process acceptable command language.

OPERATOR/COMPUTER INTERFACE AND DIALOG

A. TITLE: COMMAND LANGUAGE — ENTRY LENGTH AND ABBREVIATIONS

B. GUIDELINES: Requirements for typed inputs shall be minimal. The length of individual input words (e.g., Keywords) should not exceed 5-7 alphabetic characters, and should approximate real words. Abbreviations shall be used whenever possible to minimize operator input requirements. The use of abbreviations for output shall be avoided. When practicable, abbreviations shall conform to the following:

1. If the operator is using a synonym or abbreviation for a system command name, the system should use the same synonym or abbreviation when referring to that command in messages, prompts, etc., to the operator.
2. Critical operator inputs, responses or actions, in which an error could significantly degrade system performance, shall not be dependent on a single keystroke.

C. **HUMAN ERROR:** Inputing the wrong command and delayina a decision beyond the time it is required.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Rewrite software.

A. TITLE: COMMAND LANGUAGE — PROMPTING AND STRUCTURING

B. GUIDELINES: The system shall contain prompting and structuring features capable of requesting additional or corrected information when an error is detected, providing orientation to the operator throughout all interactive sessions. When practicable, prompting and structuring shall conform to the following:

1. When operating in special modes, the system shall display the mode designation and the file(s) being processed.
2. The system shall be designed to permit correction of individual errors without requiring re-entry of correctly entered data.
3. The system shall contain an historical file of operator entries, in sequence, available upon operator request.
4. Before processing any operator requests which would result in extensive, final and permanent changes to existing data, the system shall display the potential implication of such changes,

and require operator acknowledgement.

5. Nomenclature shall be constant for similar or identical functions across components, tasks, and roles for command names, subcommand names, and parameters.
6. Work activities shall be programmed in a closed loop, requiring the operator to issue an explicit command in order to exit.
7. Command language shall reflect the operator's point of view, not the programmer's.
8. The system shall be designed to provide hard copy of any frame upon user request. If the copy will be printed remote to the operator, a print confirmation or denial message shall be displayed. Print operation shall not permanently alter screen content.

C. **HUMAN ERROR:** Not activating a control; taking too much time to respond; and failure to identify all reasonable alternatives.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Rewrite software; expand hardware.

OPERATOR/COMPUTER INTERFACE AND DIALOG

A. TITLE: EDITING

B. GUIDELINES: When inserting characters, words or phrases (e.g., editing), items to be inserted shall be collected and displayed on a buffer area of the screen, and then simultaneously inserted by operator command.

C. HUMAN ERROR: Inserting the wrong character, word, or phrase; carrying out an incorrect command.

D. DOCUMENTATION: Engel and Granda (1975).

E. TYPICAL BACKFIT: Rewrite software.

A. **TITLE:** OPERATOR ENTRY TECHNIQUES —KEYBOARDS

B. **GUIDELINES:** Data being entered via keyboard shall be displayed as keyed on the screen. Additional keyboard requirements shall conform to those guidelines outlined on pages CON-50 and CON-74 of this guidebook.

C. **HUMAN ERROR:** Incorrect spelling; incorrect entry; incorrect command.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Modify software.

OPERATOR/COMPUTER INTERFACE AND DIALOG

A. TITLE: OPERATOR ENTRY TECHNIQUES — LIGHT PENS

B. **GUIDELINES:** If light pens are used as an input medium, the following requirements shall be adhered to:

1. Dimensions — Light pens shall be approximately 0.5 inch in diameter, and 6.0 inch in length.
2. Activation — Light pens shall be equipped with a discrete activating mechanism. For most applications, a push-tip switch requiring 2-5oz. of force to activate, is preferred.
3. Feedback — Two forms of feedback shall be provided to the operator when using a light pen: a) feedback concerning light pen placement, preferably in the form of an illuminated circle projected from the light pen onto the display screen, and b) feedback that the light pen has actuated and the input received by the system.

C. **HUMAN ERROR:** Breaking the light pen; inadvertent actuation; failure to activate the system.

D. **DOCUMENTATION:** Engel and Granda (1975).

E. **TYPICAL BACKFIT:** Order new light pen; rewrite software; redesign hardware.

PERFORMANCE AIDS

(PA)

PA

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Pages PA-1 through PA-27 have been intentionally omitted.

A. TITLE: LABELING GENERAL REQUIREMENTS

B. GUIDELINES:

1. Controls, displays and any other items of equipment that must be located, identified, read or manipulated shall be appropriately and clearly labeled.
2. To permit rapid and accurate human performance, labels shall be prepared in capital letters, except extended copy which shall be in lower case letters.

C. HUMAN ERROR: Failing to identify a needed control or display.

D. DOCUMENTATION: Woodson and Conover (1964); Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Change or modify labeling.

A. **TITLE: LABELING**

B. **GUIDELINES:** Each access opening should be labeled with nomenclature for items visible or accessible through it, nomenclature for auxiliary equipment to be used with it and recommended procedures for accomplishing operations.

Accesses shall be labeled with warning signs, advising of any hazards existing beyond the access and stating necessary precaution.

If instructions applying to a covered item are lettered on a hinged door, the lettering shall be properly oriented to be read when the door is open.

Warning notices shall be clear, direct and attention-getting and of 25% larger letter size than any detailed instructions which follow (e.g., Danger! Deadly Shock Hazard! rather than Warning-High Voltage).

C. **HUMAN ERROR:** Personal injury; omitting a procedural step; system damage.

D. **DOCUMENTATION:** MIL-STD-1472B.

E. **TYPICAL BACKFIT:** Provide necessary labels and/or procedures.

A. **TITLE: SIZE GRADUATION**

B. **GUIDELINES:** To reduce confusion and operator search time, labels shall be graduated in size. The characters used in group labels shall be larger than those used to identify individual controls and displays. The characters identifying controls and displays shall be larger than the characters identifying control positions. With the smallest character determined by viewing conditions each label shall be at least 25 percent larger than the next smaller label.

C. **HUMAN ERROR:** Confusing one control with another; excessive response time resulting in system degradation.

D. **DOCUMENTATION:** MIL-STD-1472B (1974)

E. **TYPICAL BACKFIT:** Change or modify labeling.

PERFORMANCE AIDS

A. TITLE: FUNCTIONAL CONTROL/DISPLAY LABELING

B. **GUIDELINES:** Each control and display shall be labeled according to function, and the following criteria shall apply:

1. Highly similar names for different controls and displays shall be avoided.
2. Instruments shall be labeled in terms of what is being measured or controlled taking into account the user and purpose.
3. Control labeling shall indicate the functional result of control movement (e.g., increase) and may include calibration data where applicable. Such information shall be visible during normal operation of the control.
4. When controls and displays must be used together (in certain adjustment tasks), appropriate labels shall indicate their functional relationship.

C. **HUMAN ERROR:** Confusing one control/display for another; moving a control to the wrong position.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relabel control/displays according to function.

A. TITLE: LABELING — CHARACTER HEIGHT AND VIEWING DISTANCE

B. GUIDELINES: For general panel and dial design, with the luminance normally above 1 ft-L, character and numeral height shall approximate the values below for various distances.

RECOMMENDED SIZE FOR LETTERING ON LABELS

	Viewing Distance	Critical Labels	Routine Labels
For illumination greater than 1 ft-l	28 in. 3 ft 6 ft *20 ft	.10 to .20 in. .13 to .26 in. .26 to .51 in. .86 to 1.71 in.	.05 to .15 in. .06 to .19 in. .13 to .39 in. .43 to 1.29 in.

Critical labels refer to key control or component identifiers and to position markings on such controls (i.e., numerals on counters, & scales).

Routine labels refer to over-all instrument identifiers, routine instructions, or any marking required only for initial familiarization.

*For greater viewing distances: Letter height = $\frac{\text{Viewing distance (") x 0.15"}}{28}$

C. HUMAN ERROR: Failure to identify a needed control or display; activating the wrong control.

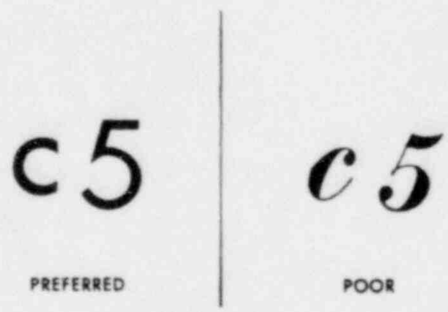
D. DOCUMENTATION: Woodson and Conover (1964); Kubokawa (1969); Van Cott and Kinkade (1972); MIL-STD-1472B (1974); MIL-HABK-759 (1975).

E. **TYPICAL BACKFIT:** Change or modify labeling.

A. TITLE: FONT STYLE

B. GUIDELINES:

1. Instruction plates are read more easily if they are printed in "caps-and-lower-case" lettering. The identifying heading, however, should be "all caps." The use of letters of the style found in commercial lettering guides is satisfactory, as long as the aspect ratios are in agreement with the recommendations herein.



2. The design of letters and numerals shall be without flourishes and serifs. Diagonal portions of the characters should be as near 45 degrees as possible and such characteristic features as openings and breaks should be readily apparent.

C. **HUMAN ERROR:** Delaying a decision beyond the time it is required.

D. **DOCUMENTATION:** Woodson and Conover (1964); Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relabel equipment with appropriate Font-Style.

A. **TITLE: WIDTH-TO-HEIGHT RATIO**

B. **GUIDELINES:** The width of the letters and numerals shall be 3/5 of the height, except the numeral "4" which shall be one stroke width wider; the numeral "1" and the letter "I" which shall be one stroke width, and the letters "M" and "W" which shall be 4/5 of the height. On curved surfaces and mechanical counters the basic width-to-height ratio may be increased to 1:1.

C. **HUMAN ERROR:** Failure to identify a needed control or display.

D. **DOCUMENTATION:** MIL-M-18072 (1964); Woodson and Conover (1964); Kubokawa (1969); Van Cott and Kinkade (1972); MIL-STD-1472B (1974); MIL-HDBK-759 (1975).

E. **TYPICAL BACKFIT:** Change labeling.

A. **TITLE: STROKE-WIDTH-TO-HEIGHT RATIO**

B. **GUIDELINES:** Where panel labels are illuminated by ambient or individual illumination, the stroke width s' all be in conformance with the guide lines below.

For dark characters on a light background, the stroke width shall be 1/6 of the letter height; for light characters on a dark background, the stroke width shall be 1/8 of the letter height.

C. **HUMAN ERROR:** Failure to identify a needed control or display.

D. **DOCUMENTATION:** Woodson and Conover (1964); Kubokawa (1969); Van Cott and Kinkade (1972); MIL-STD-1472B (1974); MIL-HDBK-759 (1975).

E. **TYPICAL BACKFIT:** Change labeling.

A. **TITLE:** TRANSILLUMINATED DISPLAYS: LETTERING

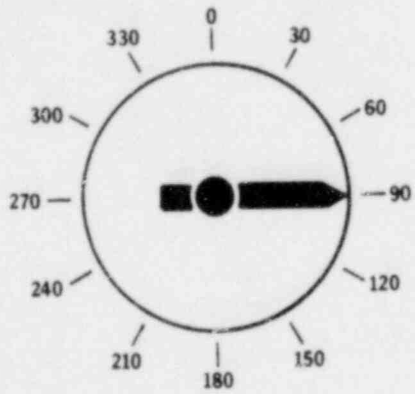
B. **GUIDELINES:** Lettering should be all capitals with font style similiar to Futura Demibold type or, Groton Extended engraving. Numerals should be similar to Futura Medium and Tempo Bold type or Groton Condensed engraving. Letter width-to-height ratio should be 1:1, but may be reduced in size to 3:5. The stroke width-to-height ratio should be 1:8 to 1:10, and for highly luminous letters, 1:12 to 1:20.

C. **HUMAN ERROR:** Late response to displayed information.

D. **DOCUMENTATION:** Heglin (1973).

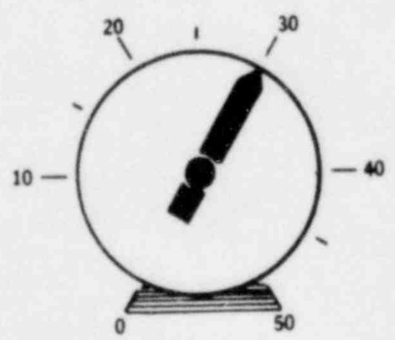
E. **TYPICAL BACKFIT:** Replace or modify display(s).

A. TITLE: FIGURE ORIENTATION ON INSTRUMENTATION

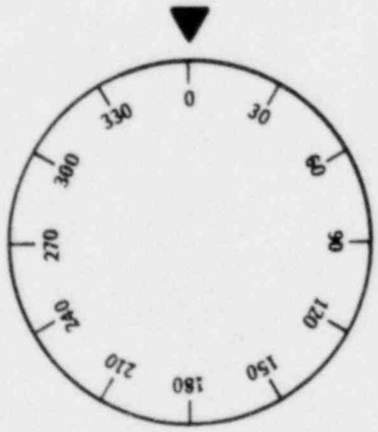


B. **GUIDELINES:** All labels should be normally oriented so that they can be read from left to right. Special cases of vertical orientation are permissible when the label is generally ignored and confusion might arise if it were adjacent to more critical labels.

For ease in reading, figures should be oriented according to the type of scale or dial used:

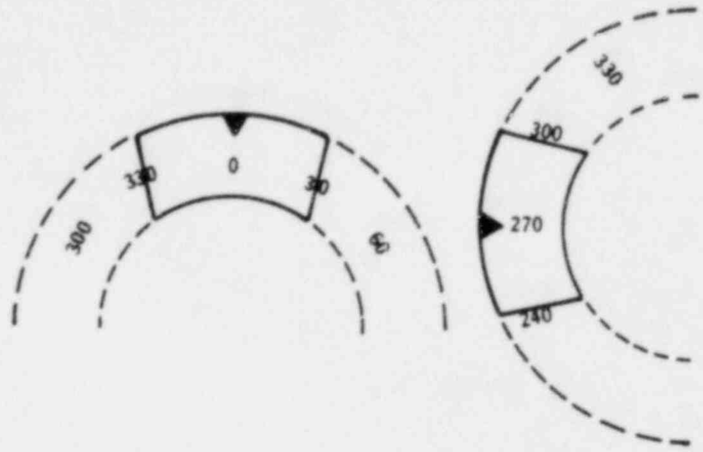


1. Orient figures vertically on dials which have a fixed scale and moving pointer.
2. When the scale is of finite length there should be a break between the end and the beginning of the scale. The break should be equal to or greater than a major scale division. Place break as shown.
3. Orient figures radially on dials which have a fixed pointer and moving scale. When possible, orient the index at the 12-o'clock position.

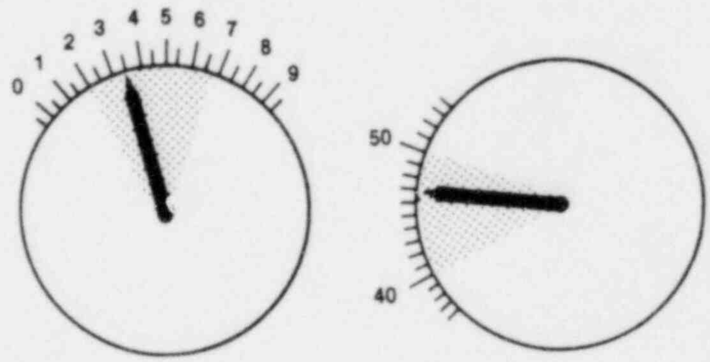


4. When the figures of a dial move past an open window, they should be oriented so that they appear vertically at the window opening

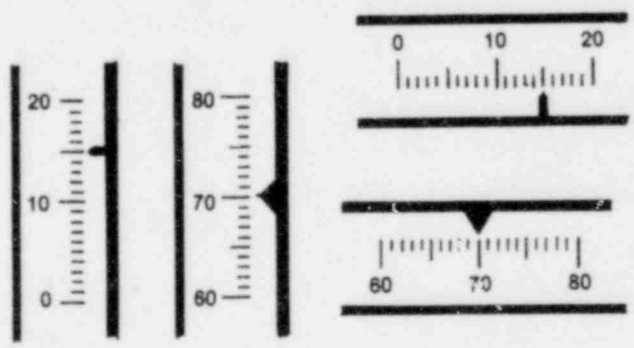
Two or more figures should appear in the window simultaneously.



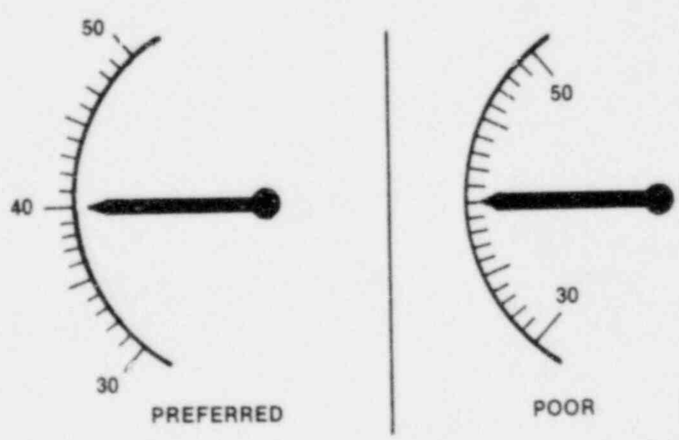
5. Numbers should appear to increase in a clockwise direction, left to right, or bottom to top.
6. Whenever possible, orient a dial scale so that the critical range to be read will appear as left to right or bottom to top, to avoid confusion as to direction of increase. This is especially important for check-reading instruments.

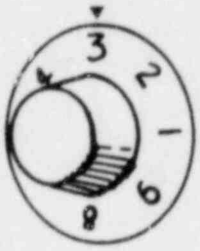


7. For multirevolution dials, orient zero at the 12-o'clock position.
8. Pointers and scale indices should be oriented so that the pointer, either moving or fixed, is close to the index and yet does not cover the number.



9. Although moving-scale displays are generally to be avoided, they will undoubtedly be used at times. If the control is a gross approximator of position and is detented (i.e., it steps mechanically from one position to another), the numbers should increase from right to left. This will be compatible with the natural inclination to turn the knob "right" for an increase in value.





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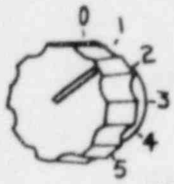
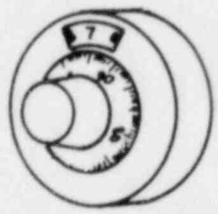
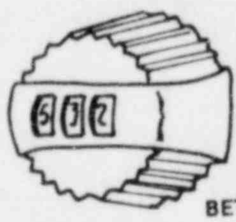


AVOID



AVOID



BETTER

10. If more exact setting is required (as shown at the left), the numbers should increase from left to right, making the interpretation of the unmarked scale indices easier.

11. Note that numbers are oriented normal to the index pointer. Although the 12 o'clock index position is preferred, other cardinal positions may be used in special cases. When other index positions are used, remember to change number orientation.

C. **HUMAN ERROR:** Incorrect reading; failure to identify a reading.

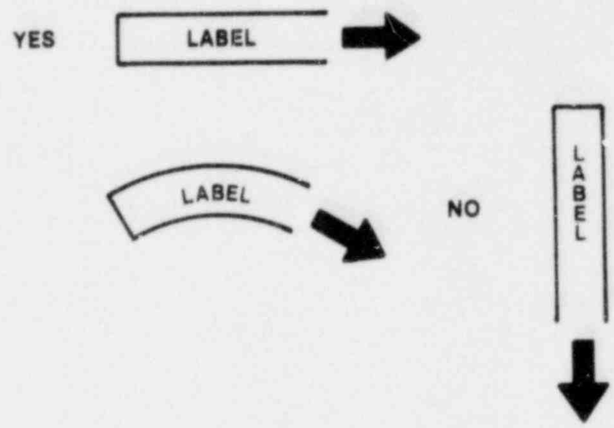
D. **DOCUMENTATION:** Woodson and Conover (1964)

E. **TYPICAL BACKFIT:** Replace or modify instrumentation.

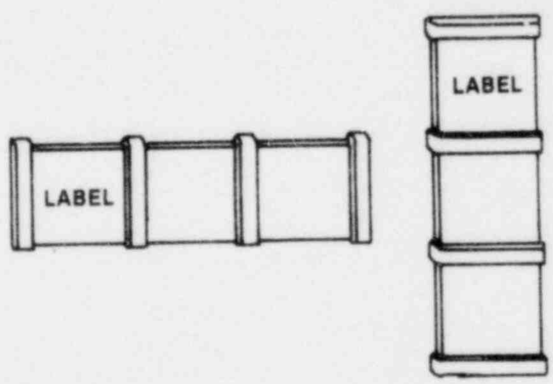
A. **TITLE: ORIENTATION**

B. **GUIDELINES:**

1. Labels and information thereon should be oriented horizontally so that they may be read quickly and easily from left to right. Vertical orientation shall be used only when labels are not critical for personnel safety or performance and where space is limited. When used, vertical labels shall read from top to bottom. Avoid use of curved patterns of labeling.



2. Labels should appear upright even though the assembly array changes from a horizontal to a vertical position.



C. **HUMAN ERROR:** Failure to identify a needed control; excessive response time in activating a control.

D. **DOCUMENTATION:** Woodson and Conover (1964); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Reorient labels; replace labels; replace displays.

PERFORMANCE AIDS

A. **TITLE:** LABEL LOCATION — GENERAL

B. **GUIDELINES:** The gross identifying label on an assembly or major component shall be located:

1. Externally in such a position that it is not obscured by adjacent assemblies or components.
2. On the flattest, most uncluttered surface available.
3. On a main chassis of the equipment.
4. In a way to minimize wear or obscurement by grease, grime, or dirt.
5. In a way to preclude accidental removal, obstruction, or handling damage.

C. **HUMAN ERROR:** Failure to identify a needed control or display; confusing one control/display with another.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-HDBK-759 (1975).

E. **TYPICAL BACKFIT:** Reposition label.

A. TITLE: LABEL LOCATION — CONTROLS AND DISPLAYS

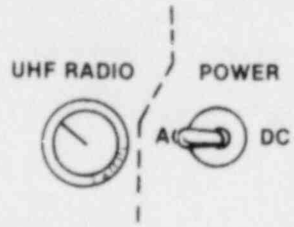
B. GUIDELINES: The following criteria shall apply to the location of control and display labels.

1. Ease of control operation shall be given priority over visibility of control position labels.
2. Labels should normally be placed above the controls and displays they describe. When the panel is above eye level, labels may be located below if label visibility will be enhanced thereby.
3. The units of measurement (e.g., volts, psi, meters) shall be located on the panel.
4. Labels shall be used to identify functionally grouped controls and displays. The labels shall be located above the functional groups they identify. When a line is used to enclose a functional group and define its boundaries, the label shall be centered at the top of the group either in a break in the line or just below the line. When colored pads are used, the label shall be centered at the top

within the padded area. If a new equipment is to be used later with an older piece of gear, make the new panel consistent with the old, unless it is too poorly labeled. In the latter case, the old equipment labels should be modified.

5. Arrange labels close to the component being identified and make sure two different labels aren't so close together that they appear to be "one a continuation of the other."

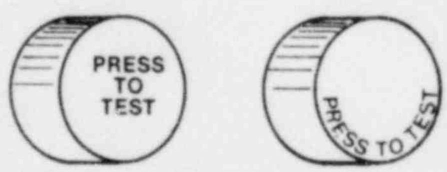
POOR



6. Label indicators in terms of what is being measured and not by the name of the device.

7. Unusual technical terms should be employed only when absolutely necessary and only when they are familiar to all operators.

8. Whenever possible, labels should appear on the control itself. Labels or directions should appear "upright" to the observer. The label or direction should be brief but "clear" in its meaning. If you have any doubt, test it with persons who are unfamiliar with the operation. If abbreviations are necessary because of limited space, use only standard abbreviations. Capital letters shall be used. Periods



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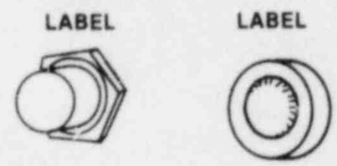
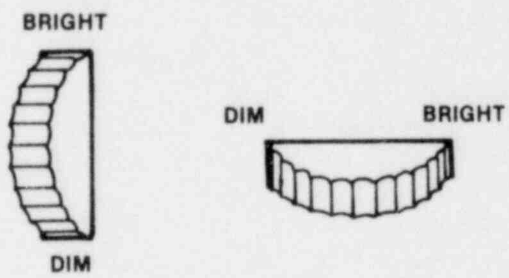
shall be omitted except when needed to preclude misinterpretation. The same abbreviation shall be used for all tenses and for both singular and plural forms of a word.

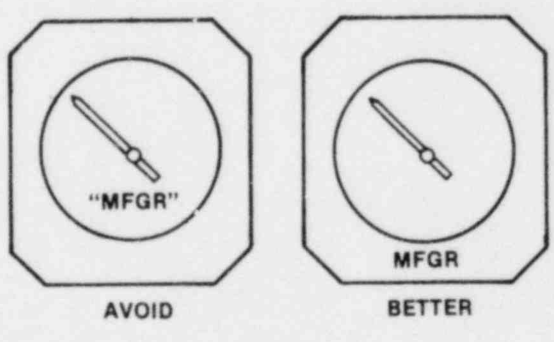
9. For controls too small to accommodate labels, place the label as close to the control as is practicable and make sure the position is standardized for all controls on the same panel (e.g., all above, or all below).



10. Certain types of controls, such as the thumb control, are not designed for putting labels or directions right on the control. Lettering should be oriented as shown.



11. When labels are used on an instrument face, they should not obscure or detract from the important figures or scales which must be read by the operator. Avoid use of manufacturer's labels placed directly on the instrument face.



C. **HUMAN ERROR:** Inadvertent activating; confusing one control/display with another; failure to identify a needed control/display.

D. **DOCUMENTATION:** Woodson and Conover (1964); Van Cott and Kinkade (1972); MIL-STD-1472B (1974); MIL-HDBK-759 (1975).

E. **TYPICAL BACKFIT:** Determine control and display label requirements and label accordingly.

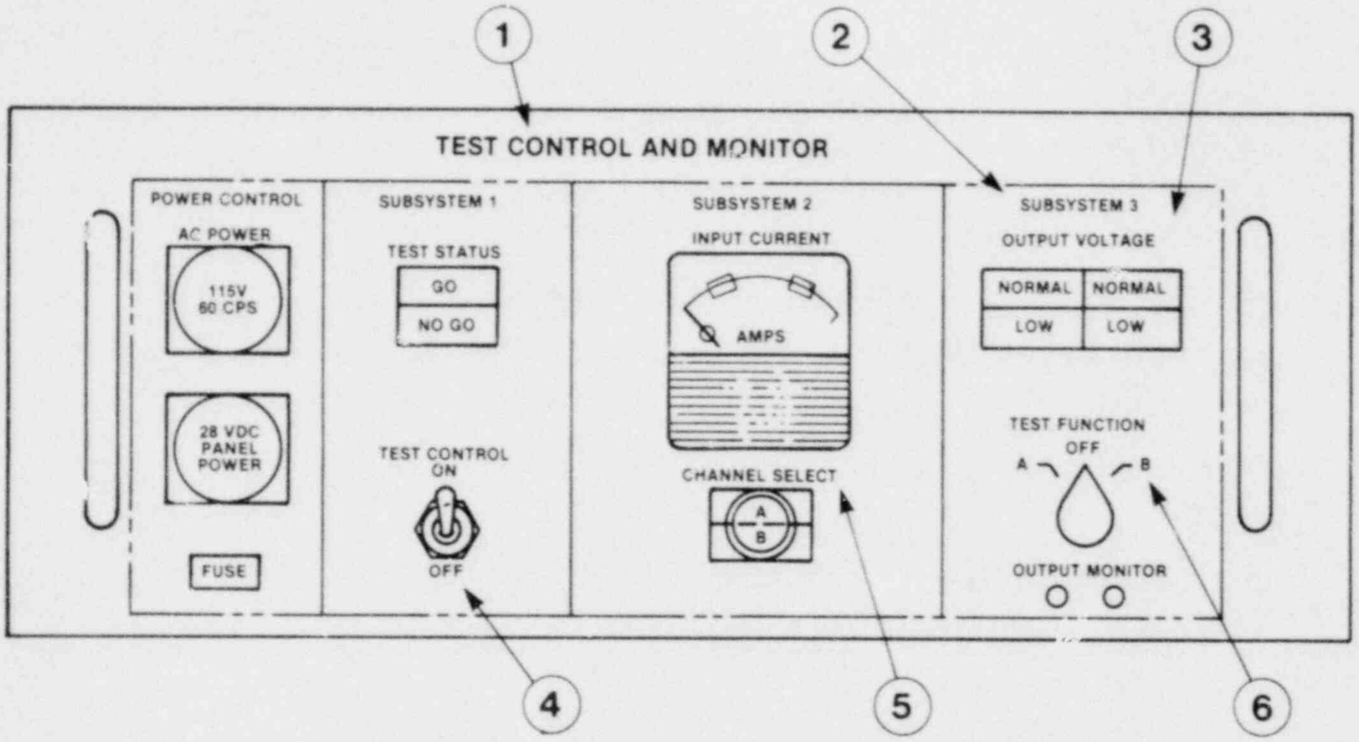
A. **TITLE: PANEL LABELING**

B. **GUIDELINES:** The placement of labels on control panels shall conform to the recommended standards depicted in the figure on page PA-50.

C. **HUMAN ERROR:** Confusing one control with another; activating the wrong control.

D. **DOCUMENTATION:** Kubokawa (1969).

E. **TYPICAL BACKFIT:** Relabel controls and displays as necessary.



Typical Panel Labeling Standards

Label Designation	Letter Size	Location
1. Panel title	18 pt (0.187 in.)	Centered; 1/4 in. from top edge of panel
2. Panel subsection	14 pt (0.156 in.)	Centered at top of subsection; 3/4 in. from top edge of panel
3. Subtitle	12 pt (0.125 in.)	1/4 in. above component(s) or 1/8 in. above labels of individual components
4. Toggle Switch	10 pt (0.093 in.)	1/4 in. above and below standard switch
5. Single Component	12 pt (0.125 in.)	1/4 in. above component
6. Rotary switch positions	10 pt (0.093 in.)	1/4 in. from apex of pointer, line from pointer to label

A. **TITLE:** SELECTOR SWITCHES — INTERNAL LABELING

B. **GUIDELINES:** When selector switches have to be used with the cover panel off, duplicate switch-position labels shall be placed on the internal unit.

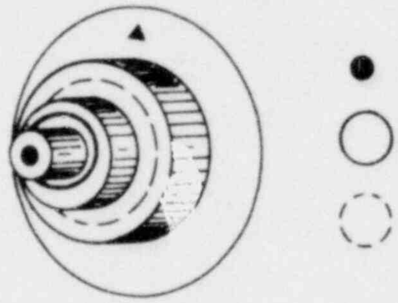
C. **HUMAN ERROR:** Moving the switch to the wrong positions.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Provide switch position labels on the internal unit.

PERFORMANCE AIDS

A. **TITLE: LABELING CONCENTRIC CONTROLS**



B. **GUIDELINES:** The labeling of concentric controls shall consist of a hierarchy provided by a small solid dot, a larger solid line and a still larger broken circle, for the smallest to largest kinds, respectively. A similar set of nomenclature shall be located adjacent to the controls on the panel identifying the function of each knob. Color coding should be employed to further increase the code-symbol reliability.

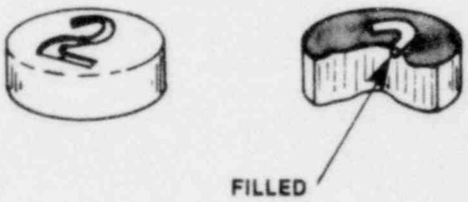
C. **HUMAN ERROR:** Confusing one control for another; failure to identify a needed control; activating the wrong control.

D. **DOCUMENTATION:** Woodson and Conover (1964); Lamps: Human Engineering Design Document (1978).

E. **TYPICAL BACKFIT:** Relabel controls.

A. **TITLE: ENGRAVED SURFACES**

B. **GUIDELINES:** Engraved labels and controls shall be filled with a paint pigment or covered with a clear plastic cover to prevent the alpha and/or numeric etching from filling with dirt or grease causing a reduction in printing legibility.



C. **HUMAN ERROR:** Confusing one control with another; failure to identify a needed control.

D. **DOCUMENTATION:** Woodson and Conover (1964); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Fill or emboss etched surface.

A. TITLE: STANDARDIZATION

B. GUIDELINES: Labels shall be located in a consistent manner throughout the equipment and system, in such a way that they are not covered or obscured by other units in the equipment assembly.

C. HUMAN ERROR: Failure to identify a needed control or display; activating the wrong control; reading the wrong display; confusing one control and/or display for another.

D. DOCUMENTATION: MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Relabel equipment accordingly.

A. TITLE: LABEL CONTENT

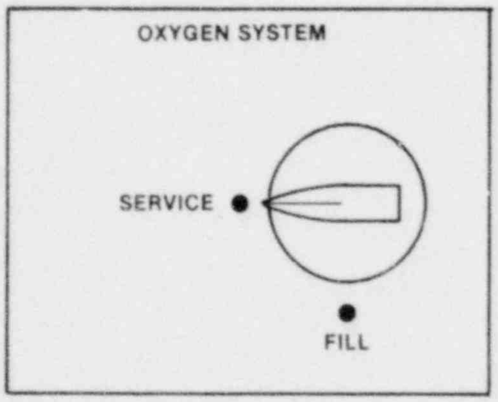
B. GUIDELINES:

1. Word Selection — Words and sentences are more immediately recognized depending on their degree of familiarity. Therefore, decals, check lists, and labels should be composed of common words, but only if the words will say exactly what is intended. For particular populations, common technical terms may be used even though these words occur infrequently in general language.
2. Clarity of Meaning — Instructions should be clear and direct; avoid complex or lengthy sentence structures.
3. Brevity — Labels shall be as clear and concise as possible without distorting the intended meaning. Redundancy shall be minimized. Where the general function is obvious, only the specific function shall be identified (e.g., frequency as opposed to frequency factor).
4. Familiarity — Words shall be chosen on the basis of operator

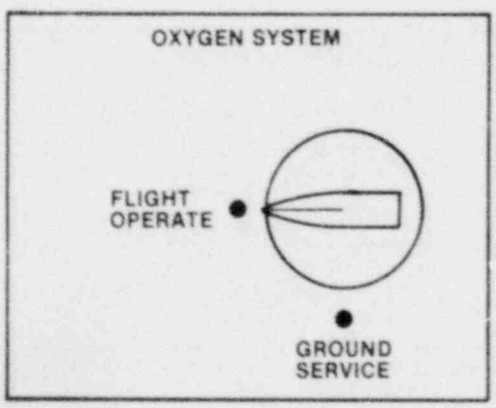
familiarity whenever possible, provided the words express exactly what is intended. Brevity shall not be stressed if the results will be unfamiliar to operating personnel. For particular users (e.g., maintenance technicians), common technical terms may be used even though they may be unfamiliar to non-users. Abstract symbols (e.g., squares and Greek letters) shall be used only when they have a commonly accepted meaning for all intended readers. Common, meaningful symbols (e.g., % and +) may be used as necessary.

5. Equipment Functions — Labels should primarily describe the functions of equipment items. Secondarily, the engineering characteristics or nomenclature may be described.
6. Similarity — Avoid the use of similar words if these could lead to an error in interpretation.

C. **HUMAN ERROR:** Using available information to derive erroneous solution; reading inappropriate data; confusing one control/display with another.



CONFUSING



BETTER

D. **DOCUMENTATION:** Woodson and Conover (1964); Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relabel equipment as necessary.

A. TITLE: LEGIBILITY OF COLOR COMBINATIONS

B. GUIDELINES: The color combinations for the print and background of written procedures shall be in conformance with the first four rankings in the table at right, with preference given to the first rank.

Rank Order	Printing	Background
1	Blue	White
2	Black	Yellow
3	Green	White
4	Black	White
5	Green	Red
6	Red	Yellow
7	Red	White
8	Orange	Black
9	Black	Purple
10	Orange	White
11	Red	Green

C. HUMAN ERROR: Misinterpretation; omitting a procedural step; temporal error.

D. DOCUMENTATION: Folley (1971)

E. TYPICAL BACKFIT: Reprint procedures.

A. TITLE: CONTRAST

B. GUIDELINES: To ensure adequate contrast, black characters should be provided on a white background. If colored print is used for coding purposes, colors shall be chosen for maximum contrast against the background.

C. HUMAN ERROR: Failure to identify a needed control/display; activating the wrong control.

D. DOCUMENTATION: Woodson and Conover (1964); Kubokawa (1969); Van Cott and Kinkade (1972); MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Conform with recommendations herein.

Relative Legibility of Color Combinations Under Reflected Light

Legibility Rating	Color Combination
Very good	Black letters on white background
Good	Black on yellow Dark blue on white Grass green on white
Fair	Red on white Red on yellow
Poor	Green on red Red on green Orange on black Orange on white

A. TITLE: CHARACTER SPACING

B. **GUIDELINES:** The minimum space between characters shall be one stroke width.

C. **HUMAN ERROR:** Misreading a label; delaying a decision beyond the time it is required.

D. **DOCUMENTATION:** MIL-STD-1472B (1974); MIL-HDBK-759 (1975).

E. **TYPICAL BACKFIT:** Relabel with appropriate character spacing.

A. TITLE: WORD SPACING

B. **GUIDELINES:** The minimum space between words shall be the width of one character.

C. **HUMAN ERROR:** Misreading a label; delaying a decision beyond the time it is required.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relabel with appropriate word spacing.

A. TITLE: LINE SPACING

B. **GUIDELINES:** The minimum space between lines shall be one-half the character height.

C. **HUMAN ERROR:** Misreading a label; delaying a decision beyond the time it is required.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Relabel with appropriate line spacing.

A. TITLE: PROCEDURE/DISPLAY CONTINUITY

B. **GUIDELINES:** There should be no mismatch between the parlance as outlined in the procedures and the technical specifications as printed on the display. For example, if a particular procedure refers to volume in gallons, then the corresponding display should read in gallons, rather than in units of feet.

C. **HUMAN ERROR:** Recording or reporting a fallacious system change; misinterpreting a conversion chart.

D. **DOCUMENTATION:** EPRI Report NP-309 (1977).

E. **TYPICAL BACKFIT:** Rewrite technical specifications in conformance with the display; re-calibrate and relabel display in conformance with the procedural technical specification.

A. TITLE: MIMIC LINES

B. GUIDELINES:

1. Primary lines should be discriminably larger than secondary lines at all operating distances. See VD-32 and VD-35.
2. Mimic lines depicting flow of the same contents (e.g., steam, water, electricity, etc.) should be colored the same throughout the control room.
3. No more than seven colors (including black and white) should be used for mimic lines. See PA-58 and PA-59.
4. Flow directions should be indicated at all branches and all controls/displays by arrowheads with the upstream (flat) side obviously larger than the mimic lines.
5. All mimic line terminals should be at labeled components or at labels specifying the destination of the line.
6. Primary mimic flow directions should be left-to-right, right-to-left, top-to-bottom, and bottom-to-top.

7. Mimics should be sized to enable the operator to accurately assess system status with no head movement.
8. No more than 4 mimic lines of the same color should run in parallel, if the operator must quickly identify any one of the lines.
9. Symbols for pumps, breakers, etc., should be identical to Piping and Instrumentation Diagram Symbology.
10. The function of components on the mimic line should be identified on their labels.
11. Mimics should have a summary label and as needed, demarcation lines to identify systems.

C. **HUMAN ERROR:** Incorrect display or control selection; incorrect interpretation of system operating status; increased time to interpret/make decisions on system status.

D. **DOCUMENTATION:** Guidelines prepared by Essex human engineering personnel.

E. **TYPICAL BACKFIT:** Redesign and replace mimic lines or labels as necessary.

COMMUNICATIONS

(COM)

COM

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A. TITLE: COMMUNICATION SYSTEM CHARACTERISTICS

B. GUIDELINES: Amplifier, Transmitter, and Receiver Characteristics — These components should have the following characteristics:

1. Sufficient bandwidth to provide a "flat" audio-frequency response from at least 250 to 4000 Hz (preferably 200 to 6100 Hz for intelligibility and 100 to 7500 Hz for quality of reproduction).
2. Sufficient dynamic range and gain to handle the range of instantaneous pressures found in speech and to develop the necessary signal level at the headset or loudspeaker terminals.
3. They should introduce less background noise than is introduced by a microphone.

Recommendations for Dynamic Range

1. Very high-quality communications call for a dynamic range of 60 dB.
2. For commercial broadcast purposes, the dynamic range can be 40 to 45 dB.

3. With a mechanism that compensates for variations in average speech levels among talkers, a dynamic range of 30 dB is adequate, though not recommended.
4. With practiced talkers and listeners, communication can be quite effective at a dynamic range of only 20 dB.

DESIRABLE CHARACTERISTIC FOR VOICE COMMUNICATION SYSTEM

Telephone or Radio Communications	See MIL-STD-188
Speech transmission equipment	
Optimal frequency response	150-4800 Hz
Minimum frequency response	200-3000 Hz
Microphone dynamic range	Signal input variations of 30 dB minimum
Noise cancelling microphones	Improvement at least 10 dB peak speech to RMS noise ratio
Pre-emphasis	9 db/octave, positive, over 140-4800 Hz
Speech reception equipment	
Multichannel/multispeaker f range	± 5 dB over range 100-4800 Hz
Separation of speakers for multichannel monitoring	10° apart radially relative to central operator position
Filtering for multichannel speaker monitoring	2 channels F = 1800 Hz(lo-pass) on one channel 3 channels F = 1000 Hz(hi-pass) = no cutoff = 2800 Hz(lo-pass)
De-emphasis	9 dB/octave, negative, over 140-4800 Hz

C. **HUMAN ERROR:** Misunderstanding the communicated message; failure to respond.

D. **DOCUMENTATION:** Kubokawa (1969); Van Cott and Kinkade (1972)

E. **TYPICAL BACKFIT:** Modify or replace equipment.

A. **TITLE:** SPEECH INTELLIGIBILITY/COMMUNICATIONS COMPONENT SELECTION

B. **GUIDELINES:** Communication components should provide:

1. Gain control.
2. High pass filters on microphones to reduce high frequency noises (to increase speech intelligibility).
3. Peak limiter if communications system has an appreciable amount of interval noise.

C. **HUMAN ERROR:** Failure to obtain all relevant message information; misinterpretation of message.

D. **DOCUMENTATION:** Chapanis (1966); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Add high pass filters microphones.

COMMUNICATIONS

A. **TITLE: OPERATING CONTROLS**

B. **GUIDELINES:**

1. Volume or gain controls should be provided for each communication receiving channel.
2. Controls should be capable of controlling sound pressure level to 110 dB.
3. Minimum setting of volume controls should be audible in ambient noise environment.

C. **HUMAN ERROR:** Failure to receive communications; misinterpretation of messages; partial loss of communications information.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with appropriate device.

A. **TITLE: SPEECH RECEPTION EQUIPMENT**

B. **GUIDELINES:** Headphones and loudspeakers should be capable of reproducing sound from 100 to 4000 Hz. (± 5 dB)

C. **HUMAN ERROR:** Misinterpretation of speech signals.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with appropriate devices.

COMMUNICATIONS

A. TITLE: SPEECH TRANSMISSION EQUIPMENT (FREQUENCY) DYNAMIC RANGE

B. GUIDELINES:

1. Speech system input devices should respond to 200 to 6100 Hz.
2. The minimum dynamic range of input devices should be 50 dB.

C. HUMAN ERROR: Communication errors: information loss; misinterpretation of spoken messages.

D. DOCUMENTATION: MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Replace with appropriate devices.

A. **TITLE: SPEECH INTELLIGIBILITY**

B. **GUIDELINES:**

Microphones should:

1. Have high sensitivity to acoustic speech signals.
2. Transduce acoustic sounds well.
3. Reject other acoustic signals and noises at the speakers location.

C. **HUMAN ERROR:** Failure to accurately receive messages.

D. **DOCUMENTATION:** Chapanis (1966); MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Provide microphones which have high sensitivity to speech sounds; provide noise-cancelling microphones.

COMMUNICATIONS

A. **TITLE: FEEDBACK**

B. **GUIDELINES:** Headset/handset users should hear their own voice in headset/handset in phase with speech.

C. **HUMAN ERROR:** Communication errors.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Replace with appropriate device.

A. **TITLE:** REVERBERATION ATTENUATION: SPEAKER PLACEMENT

B. **GUIDELINES:** If speaker reverberation is a problem, many low-powered loudspeakers should be used rather than a few powerful loudspeakers. The loudspeakers should be directional in nature, and oriented to cover, but not overlap, the most important parts of the room.

C. **HUMAN ERROR:** Misunderstanding communicated message.

D. **DOCUMENTATION:** Chapanis (1965); Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Purchase new speakers; relocate speakers.

A. TITLE: MULTICHANNEL LISTENING

B. GUIDELINES: The following guidelines are recommended for enhancing the intelligibility of multichannel broadcasts.

1. A separate loudspeaker should be used for each speech channel, and located at different angles from the listeners.
2. If there are two speech channels, one channel should be fed into one ear and the other channel into the other ear so the listener can switch his attention. If this is not done, both signals should be "picket-fenced" at 30 to 40 Hz and interleaved.
3. Frequency-selective filters should be used to give characteristic timbre to signals. If there are three channels involved, one channel should be unfiltered, a high-pass filter (with 1000-Hz cutoff) should be used in the second channel, and a low-pass filter (with a 2500 Hz cutoff) in the third channel.
4. A visual signal should be used to show which channel is in use.

5. If feasible, a message-storage device should be used for all incoming messages. A separate recording channel is best for each communication channel and switching arrangements should be setup for message review. The oldest messages should be automatically erased to make recording space available for new messages.

C. **HUMAN ERROR:** Misunderstanding the communicated message; failure to respond to message.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972).

E. **TYPICAL BACKFIT:** Modify or replace equipment.

COMMUNICATIONS

A. TITLE: GENERAL GUIDELINES FOR CODING INFORMATION SOURCES

B. GUIDELINES:

1. Where these are different communication systems (e.g., intercoms, radios, etc.) use audible alerting signals; each should have a different signal.
2. Loudspeakers of different communication channels should be separated, at a minimum, of 10^{o} from the operators' position.
3. Where channel identification is important, each channel should have an indicator light showing source.

C. HUMAN ERROR: Temporal errors in identifying sources of communications.

D. DOCUMENTATION: MIL-HDBK-759; Woodson & Conover (1966)

E. TYPICAL BACKFIT: Separate speakers; code, by alerting tones or indicator lights, sources of communications.

A. **TITLE:** **COMMUNICATION THROUGH GAS MASKS**

B. **GUIDELINES:** To improve sound transmission and divorce it from exhaust valve action, operator worn masks should be equipped with diaphragms especially designed to transmit speech.

C. **HUMAN ERROR:** Misunderstanding communicated message.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972)

E. **TYPICAL BACKFIT:** Modify or replace with masks equipped with speech accentuation diaphragms.

A. TITLE: OPERATOR COMFORT

B. GUIDELINES: Communication equipment to be worn by the operator should preclude discomfort.

C. HUMAN ERROR: Communication errors due to discomfort distractions.

D. DOCUMENTATION: MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Replace with appropriate devices to eliminate problem.

A. TITLE: MICROPHONES

B. GUIDELINES:

1. Choose a microphone with a smooth frequency-response characteristic as wide as that of the rest of the system. It should extend, at least, from 200 to 6100 Hz for highest intelligibility.
2. The dynamic range of the microphone, when working into the selected amplifier, should be great enough to admit 50-dB variations in signal input as a minimum.
3. For close talking, consider only microphones that do not overload with signals as high as 125 to 130 dB.
4. Avoid condenser microphones if the bias voltage (typically 200) would constitute a safety hazard, i.e., in a high oxygen environment.
5. Avoid carbon microphones in which "packing" of the carbon granules occur.
6. Do not use carbon microphones if the quality criteria demand a

truly linear resonse characteristic of very low background noise.

7. Do not use a ribbon microphone for close talking unless the microphone has been designed specifically for this use.
8. For close talking, protect a microphone against breath blast, which may damage it and will certainly make the reproduced sound quality objectionable. Protect it also against moisture condensation, particularly saliva.
9. If feedback "squeal" is a problem, use a directional microphone.

C. **HUMAN ERROR:** Misunderstanding communicated message; failure to transmit intelligible message.

D. **DOCUMENTATION:** Van Cott and Kinkade (1972)

E. **TYPICAL BACKFIT:** Modify or replace microphones.

A. TITLE: MICROPHONE/TELEPHONE HANDSETS

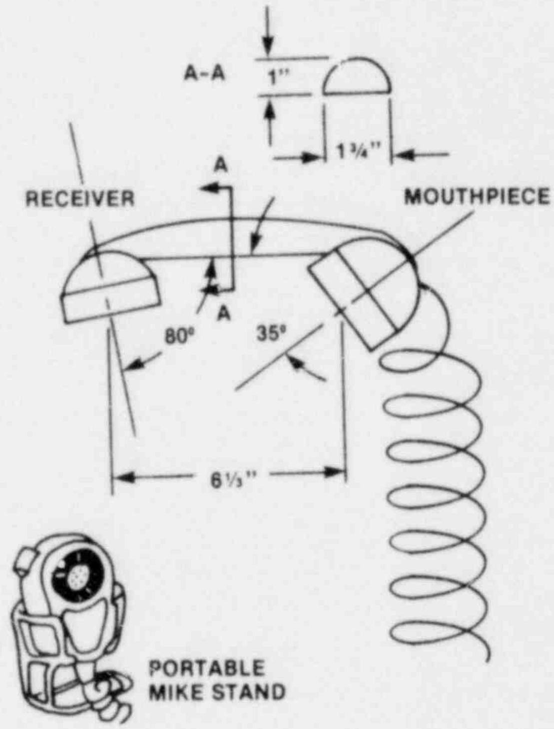
B. GUIDELINES: The hand-held microphone or the telephone handset must be convenient to the operator's (5th percentile female to 95th percentile male) hand size. Avoid the use of angular packages unless special hand grips are attached, for they are uncomfortable over long periods of use and prevent the operator from applying a secure grip to the handset.

Non-kink or self-retracting cords are another convenience which makes for higher operator efficiency.

Mouth and ear pieces should be spaced on the handset package so that the operator may seat the earpiece firmly on his ear and yet maintain a minimum distance and direct mouth position with respect to the mouthpiece.

Press-to-talk switches on handsets should be located so that they are convenient to either the right or left hand.

When the operator's hands must be used for other manipulatory tasks, provide him with such conveniences as boom-type microphones, and/or



foot-actuated press-to-talk switches. The boom microphone is especially useful to the operator who changes head positions often.

C. **HUMAN ERROR:** Fouling microphone or telephone cord; failure to transmit intelligible message.

D. **DOCUMENTATION:** Woodson and Conover (1964)

E. **TYPICAL BACKFIT:** Modify or replace equipment.

A. TITLE: ACCESSIBIILITY OF HANDSETS

B. GUIDELINES:

1. The most frequently used and the most important handsets should be most accessible.
2. Where many handsets are located close together, color coding or labeling of units should be employed.

C. HUMAN ERROR: Temporal errors in locating and using handsets.

D. DOCUMENTATION: MIL-STD-1472B (1974).

E. TYPICAL BACKFIT: Color code handsets by communication functions; place frequently used/critical handsets in immediatly accessible CR areas.

A. **TITLE: HEADSETS — HANDS FREE OPERATION**

B. **GUIDELINES:** Headphones and microphones should permit hands free operation.

C. **HUMAN ERROR:** Inability to communicate and perform operational tasks concurrently.

D. **DOCUMENTATION:** MIL-STD-1472B (1974).

E. **TYPICAL BACKFIT:** Modify or replace with appropriate device.

A. TITLE: HEADSET CHARACTERISTICS

B. GUIDELINES:

1. The headset's frequency response should be as broad as that of the remainder of the system.
2. Be sure that the dynamic range, without appreciable distortion, is at least 40 dB and that the power-handling capacity is adequate to receive the peaks of the amplifier output.
3. Pick a combination of earphone and socket or cushion for which the earphone sensitivity and the earcap attenuation together will provide an adequate signal-to-noise ratio.
4. The earphone cushion should be comfortable enough to permit the user to wear it as long as necessary. The ear cushion should cover the outer ear without crushing it. There should be a minimum of ear enclosed within the cushion socket.
5. Supporting structures for the ear pieces should be designed so that they do not impose discomforts

of weight, concentrated pressures, or metal contact with the skin. They should be easy to remove but in turn must hold the earpiece firmly in place.

C. **HUMAN ERROR:** Misunderstanding communicated message; failure to respond to message.

D. **DOCUMENTATION:** Woodson and Conover (1964); Van Cott and Kinkade (1972)

E. **TYPICAL BACKFIT:** Modify or replace headphones.

A. TITLE: HEADSET RECEIVER CHARACTERISTICS

B. GUIDELINES: Headset receivers should possess the following operational characteristics:

1. Sufficient electrical power to drive peak sound-pressure level to 131 dB when using two earphones.
2. A gain control with dynamic range sufficient to make the signal 15 dB more intense than the ambient noise.
3. A reduction in frequency range below 500 cps and above 4000 cps if it results in an increase in the average power of the audio signal.
4. A uniform frequency response of receiver and headset between 300 and 4000 cps to avoid unpredictable distortions.
5. Layout of the operating controls for a typical communications receiver should provide the "turning or station-select" control for the right hand and the volume control for the left hand.
6. Intercom station consoles should be arranged so that there is

plenty of space for the several station labels.

C. **HUMAN ERROR:** Misunderstanding communicated message; failure to respond to message.

D. **DOCUMENTATION:** Woodson and Conover (1964)

E. **TYPICAL BACKFIT:** Modify or replace receiver.

A. **TITLE: USE OF HEADSETS VS. LOUDSPEAKERS**

B. **GUIDELINES:** Headsets should be used instead of loudspeakers when:

1. Ambient noise levels are high.
2. Ambient white noise or low frequency noises are of high levels.
3. Different messages presented to different operators and conflicting/extraneous messages compete for operators' attention.
4. Control room subject to acoustic reverberation and echo effects.

C. **HUMAN ERROR:** Failure to receive messages; misinterpretation of messages; receiving an incorrect message (channel shared systems with loudspeakers).

D. **DOCUMENTATION:** Chapanis (1965).

E. **TYPICAL BACKFIT:** Replace loudspeakers with headsets.

A. TITLE: REMOTE AREA PAGING

B. **GUIDELINES:** Remote areas (e.g., restrooms and kitchens) frequented by operator's which are out of normal voice call range shall contain a loud-speaker permitting an audible page of the missing operator(s).

C. **HUMAN ERROR:** Unsuccessful attempt to control system status due to insufficient control room staffing.

D. **DOCUMENTATION** EPRI Report NP-309 (1977).

E. **TYPICAL BACKFIT:** Install speaker in restrooms and/or kitchen.

A. **TITLE:** ARRANGEMENT OF COMMUNICATION EQUIPMENT

B. **GUIDELINES:** Phones and page systems should be arranged at the operator's desk so that the operator sits facing the control panels. In addition, the distribution of phones and length of phone cords should be sufficient to allow operators to communicate with others while at the control panels.

C. **HUMAN ERROR:** Failure to monitor; failure to record or report a system change.

D. **DOCUMENTATION:** EPRI Report NP-309 (1977).

E. **TYPICAL BACKFIT:** Rearrange phones, page system or desks; install longer phone cords.