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Human Factors Design Guidelines for Maintainability of Department of Energy Nuclear Facilities

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June 18, 1985

Lawrence Livermore National Laboratory

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HUMAN FACTORS DESIGN GUIDELINES FOR MAINTAINABILITY OF DEPARTMENT OF ENERGY NUCLEAR FACILITIES

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FOREWORD

This document, Human Factors Design Guidelines for Maintainability of Department of Energy (DOE) Nuclear Facilities, was prepared by BioTechnology, Inc., Falls Church, VA, under the auspices of the Office of Nuclear Safety, U.S. Department of Energy. This project was performed as a subcontract to the Nuclear Systems Safety Program, Human Factors Engineering, Lawrence Livermore National Laboratory.

Thanks is also expressed to Dr. Richard F. Pain, Project Director for BioTechnology, and the following members of the BioTechnology support staff: Kristy L. Donnelly, editing and production coordination, Betty J. Price, word processing, and Tammy S. Black, graphics.

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PURPOSE AND SCOPE

The intent of these guidelines is to provide design and design review teams of DOE nuclear facilities with human factors principles to enhance the design and aid in the inspection of DOE nuclear facilities, systems, and equipment.

These guidelines are concerned with design features of DOE nuclear facilities which can potentially affect preventive and corrective maintenance of systems within DOE nuclear facilities. Maintenance includes inspecting, checking, troubleshooting, adjusting, replacing, repairing, and servicing activities. Other factors which influence maintainability such as repair and maintenance support facilities, maintenance information, and various aspects of the environment are also addressed.

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OVERVIEW OF SYSTEMS DESIGN FOR MAINTAINABILITY

Reliability vs. Maintainability

Reliability, that is, whether something is available and able to perform its required function, is a property inherent to the system or piece of equipment. Reliability may be further defined as "the probability that the system or component is available for use when needed."* One measure of reliability is a numerical probability indicating the likelihood of failure-free operation for a specific period of time. Another measure of reliability is mean time between failures (MTBF), which refers to the total system operating time divided by the number of system failures during that time. The reliability of a piece of equipment or a system is predominantly dependent upon the merits (or demerits) of its design.

Maintainability is that characteristic of design and installation which affects the amount of time necessary to repair, test, calibrate, or adjust an item to a specified condition, when using defined procedures and resources. The two classes of maintainability, preventive and corrective, are highly dependent upon the characteristics of the user. Both classes, regardless of how well a piece of equipment is designed, are "intimately bound to the existing knowledge, practices, skills, facilities, environment, and supplies of the user-maintainer."** Each of these factors must be considered when designing for maintainability. Each will be bound by the limitations of the user. One must additionally consider equipment reliability. If a piece of equipment never fails, corrective maintenance will not be necessary.

Background of Systems Design for Maintainability

Systems design for maintainability has, as a prime objective, the design of equipment and systems capable of being maintained in the least amount of time, at the lowest cost, and with a minimum expenditure of support resources. Attempts to achieve this objective have evolved into the engineering discipline of maintainability.

Maintainability engineering was a direct result of reliability programs being performed primarily by the military in the late 1940s and early 1950s. This research indicated that the goal of designing equipment with 100% reliability (i.e., equipment that would never fail) was impossible. The concept of maintainability evolved from the increase in complexity, size, and quantity of items that comprise a system, and the associated technical problems, increased support costs, and technological advances. Therefore, the problem of maintenance became a fact of life that had to be effectively managed. The discipline of maintainability engineering was established to provide designers with a source of specialized knowledge and skill about the support and maintenance of equipment and systems.

Application of Systems Design for Maintainability (in an emerging design)

To realize the goal of maintainability, that is, to restore a system or device that has failed to operational effectiveness easily and cost effectively, requires that maintainability and the associated human factors contributions be considered as part of the *total* systems design process. Maintainability must be designed into the system and equipment during the beginning stage of development to ensure that costly maintenance and/or redesign are avoided. Systems design for maintainability is an evolutionary process that starts in the equipment concept stage and ends after the equipment has been built and tested.

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*Evans, R.A., "Reliability Optimization," in E.J. Henley and J.W. Lynn (Eds.). *Generic Techniques in Systems Reliability Assessment.* Leyden, the Netherlands: Noordhoff International Publishing, 1976, 117-131.

**Morgan, C.T., Chapanis, A., Cook, J.S., III, & Lund, M.W. (Eds.). *Human engineering guide to equipment design.* New York: McGraw-Hill, 1983, 368.

Though the process of designing for maintainability will vary to some extent, depending on the level of effort required by the type of system and/or equipment being designed, there are elements which are standard to any systems design for maintainability. As a minimum, designing for maintainability should include the following steps: planning, designing, and testing and revising the design.

During the *planning* step, requirements and objectives for maintainability are established by defining such parameters as the goal or mission of the system, the availability and dependability required by the system, personnel and support equipment, facilities and resources available, levels of maintenance that will be required (i.e., field, shop, factory), etc. By the time functional diagrams, specifications, and drawings are being produced, *designing* for maintainability should be well underway. This second step in a systems design process for maintainability is when the design team determines maintainability design criteria for the system and/or equipment being designed. These criteria will focus on accomplishing objectives such as:

- Reducing the need for and frequency of design-dictated maintenance.
- Reducing system/equipment down-time.
- Reducing design-dictated maintenance support costs.
- Limiting maintenance personnel requirements.
- Reducing the potential for maintenance error.
- Using standard procedures, equipment, and tools, when possible.

The Human Factors Design Guidelines for Maintainability of DOE Nuclear Facilities has been assembled to provide the design team with generic design principles to help satisfy the above-mentioned objectives. It is important to remember that the principles contained in the guidelines which follow are malleable, especially for an emerging system. It is quite likely that during the application of these guidelines to an emerging design, modification, addition, or elimination of some principles might occur in favor of alternative criteria for effective maintainability. The "goodness of fit" of the guideline principles can be adequately judged only if the next step of the design program, testing and revising the design, is accomplished.

The *testing and revising* step is where a developmental model of the equipment (e.g., scale model, bench mock-up, or simulator) is tested under conditions that duplicate, as nearly as possible, the actual conditions under which the equipment will be maintained.

For any system design for maintainability to be successful, regardless of the degree of complexity of the equipment and/or system being designed, there are certain considerations that should be observed in applying the concept of maintainability and in using the guidelines which follow successfully:

1. The concept of maintainability cannot be accomplished by an individual, one specific skill type or level, or by a single organizational entity. Implementing a successful systems design for maintainability (or retrofit) requires a cooperative effort by a number of professional disciplines.

2. Maintainability in equipment design can be specified, predicted, measured, and demonstrated.

3. Planning for maintainability must occur concurrent with equipment design. Lack of consideration for maintainability during the initial stages of design will result in either costly product support throughout the equipment life cycle or the need for costly product design changes.

4. Existing capabilities of facilities, test equipment, personnel, spare parts, etc. should be considered in determining design criteria for maintainability. Theoretical maintainability principles may be waived in favor of existing capabilities.

5. During equipment design, the concept of maintainability is applied in conjunction with reliability, human engineering, and other system effectiveness characteristics. A sacrifice of any of these characteristics might be necessary to obtain the best overall design configuration.

6. Equipment or systems that represent the ideal maintainability design characteristics may be prohibitive because of cost. A successful application of maintainability considers costs incurred during design, development, and production, as well as costs associated with equipment support.

7. Maintainability should complement operational requirements of a system.

8. Safety provisions which protect personnel and equipment should receive special consideration in the design for maintainability. If necessary, otherwise desirable design features are rejected to retain safety provisions.

9. Maintenance is a consequence of design. Properly applied maintainability forestalls the requirement of maintenance and alters the course of design to eliminate or reduce the effect.*

*Blanchard, B.S., & Lowery, E.E. *Maintainability: Principles and practices.* New York: McGraw-Hill, 1969, 11-12.

INTRODUCTION TO THE GUIDELINES

Limitations

Research in human factors for maintenance has been conducted for over 30 years. The recommendations in this guidelines document are "rules of thumb" or generally accepted practices. However, some principles that are directly related to the nuclear field are not yet adequately supported by empirical research. Therefore, these guidelines do not provide answers to all problems in the design for maintainability of DOE facilities. It is the author's hope that these guidelines will provide general direction to the design team and facility personnel in the design and/or review of DOE nuclear facilities for effective maintainability practices. The users of these guidelines are encouraged to add their own examples of effective techniques for enhancing the maintainability of systems and equipment. This document is assembled in loose leaf format to facilitate addition of information the user finds helpful.

These guidelines contain human factors principles. Therefore, they emphasize the human element in the design for maintainability of DOE facilities. Prime consideration is given to describing systems and equipment characteristics that will facilitate the technician's performance of required maintenance tasks. These guidelines do not emphasize maintainability from an engineering science perspective. The mathematical techniques used to quantify various parameters such as down time, repair time, costs associated with maintenance, etc. or engineering concepts (e.g., mean time between failures) that are relevant to equipment reliability or maintainability are not the focus of these guidelines. While the principles presented in these guidelines are generally applicable to all systems—military, commercial nuclear, or non-nuclear—they are not intended to be applied blindly. A thorough understanding of underlying system design criteria and overall objectives is necessary for these principles to be applied effectively. In some cases, trade-offs in a given design or function of a system may require certain design features and/or guidelines to be modified or perhaps replaced by some unique practice.

Though these guidelines do provide general considerations for planning and scheduling for maintainability, no attempt is made to detail procedures for developing a maintainability program. Designing a maintainability program that will satisfy user needs is not within the scope of this present effort. However, source references relevant to maintainability program design are listed in the references.

Organization and Content

The guidelines are organized into three sections, which correspond to major influences on system design for maintainability: engineered hardware, facility support, and personnel. Each section is further divided into guidelines that contain relevant definitions and, in most cases, general and specific human factors design principles for maintainability. These guidelines may be used for designing new facilities, and for evaluating and modifying existing ones. Each section is tabbed for ease of reference. The user may selectively apply a set of principles to a system, subsystem, equipment, or component to ensure conformance to recommended human factors practices for maintainability. To further aid the user, at the beginning of each guideline there is a topical index to the principles contained in the guidelines which directs the user to the specific page on which the principle is identified.

Application

These guidelines may be used as a source reference for designers of new facilities and by reviewers of existing facilities concerned with retrofit operations. They are intended for use, as appropriate, with other related sources such as applicable industry standards (e.g., ANSI standards), NUREGs (e.g., NUREG-0700, Guidelines for Control Room Design Reviews), Military Standards (e.g., MIL-STD 1472C), facility-specific procedures, and manufacturer's specifications.

During the design of a new system and/or equipment, the guidelines may be used by the design team to establish maintenance requirements and develop hypotheses on how maintenance will be provided. The guidelines will aid the design team in establishing parameters such as types and levels of maintenance that will be required, and kinds, numbers, and levels of training and organization of personnel that will be needed to support the engineering design. Application of these guidelines during the initial stage of design (i.e., the "hypothetical design phase"*) will also facilitate allocating functions to humans or automation. Hypothesizing the engineering and human factors requirements for maintenance of a system or equipment is essential for answering the crucial question of which system and task responsibilities are best assigned to humans, which to machine, and which to some combination of the two components.

As part of a retrofit operations, these guidelines may be used by the design review team to determine the existence of human engineering discrepancies (HEDs) in the design of systems and/or equipment for maintainability. An HED, as applied to systems design for maintainability, may be considered as a deviation from some benchmark, such as a standard of human engineering practice or convention, a technician preference or need, or an instrument/equipment characteristic implicitly or explicitly required for a maintenance task.** The review team may use these guidelines as a source for developing detailed checklists for surveying systems and equipment to identify deficiencies which may affect maintenance tasks.

Source Credits

These guidelines represent a compilation of information from a wide variety of sources which has been selected for application to the design for maintainability and/or retrofit operations of Department of Energy nuclear facilities. While the presentation format and selection of materials is original, the material itself is not new. The sources of information used for these guidelines are listed in the references and the source reference document.

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* Pulliam, R., Price, H.E., Bongarra, J.P., Jr., Sawyer, C.R., & Kisner, R.A. A methodology for allocating nuclear power plant control functions to human or automatic control (NURGE/CR-3331). U.S. Nuclear Regulatory Commission, Washington, D.C., 1983, 70.

** This definition has been adapted from Guidelines for Control Room Design Reviews (NUREG-0700), U.S. Nuclear Regulatory Commission, Washington, D.C., 1981, 1–4.

HUMAN FACTORS DESIGN GUIDELINES FOR MAINTAINABILITY OF DOE NUCLEAR FACILITIES

This section contains human factors guidance for designing systems and equipment to be maintained with ease and cost effectiveness. The organization of this section follows. As an aid to the user, each guideline is also preceded by a topical index.

1.0 ENGINEERED HARDWARE

- 1.1 Unitization and Modularization for Maintainability
- 1.2 Unit Layout, Packaging, and Mounting for Maintainability
- 1.3 Hardware Identification for Maintainability
- 1.4 Equipment Accessibility
- 1.5 Controls and Displays for Maintainability
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- 2.1 Workspace, Storage, and Repair Facility Design for Maintainability
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- 2.5 Platform and Shelter Design for Maintainability
- 2.6 Design of Computer Systems for Maintainability

3.0 PERSONNEL

- 3.1 Engineering Anthropometry in the Design for Maintainability
- 3.2 Environmental Conditions and Constraints Affecting Maintainability
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1.0 ENGINEERED HARDWARE

1.1 Unitization and Modularization for Maintainability

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1.1.2 DEFINITIONS

Unitization refers to separating equipment into physically and functionally distinct units to allow for easy removal and replacement. This type of equipment separation will permit division of maintenance responsibility, especially troubleshooting, among various maintenance levels. Specifically, unit design of equipment will:

a. Maximize the efficiency and accuracy of on-line replacement of system components.

b. Facilitate and minimize troubleshooting time at each level of maintenance activity.

c. Minimize duplication of maintenance efforts between levels of maintenance activity.

d. Permit production line repair at the higher maintenance level.

e. Permit use of automatic or semi-automatic techniques where practicable.

f. Allow test, checkout, troubleshooting, and repair procedures to be unit specific and structured to aid in identification of faulty units, then subunits, etc.

g. Reduce downtime.

Unitization will also:

a. Provide easy access to malfunctioning components.

b. Allow for high degree of standardization.

c. Minimize time and cost of maintenance training.

d. Simplify new equipment design and shorten design time by using previously developed, standard "building blocks."

Modularization refers to the range of complete interconnected functional units or unitized equipment built on a single structure, down to the smallest printed circuit insert.

Disposable module refers to any module designed to be thrown away rather than repaired after its first failure, assuming that the original diagnosis of failure is validated before disposal.

1.1.3 PRINCIPLES

1.1.3.1 UNITIZATION/MODULARIZATION

a. Equipment should be divided into as many modules as are electrically and mechanically feasible in keeping with efficient use of space and overall equipment reliability.

b. An integrated approach to design should be used, considering simultaneously the problems of materials, component design, and application of the modular concept.

c. All modules and component parts should be approximately uniform in basic size and shape for the best packaging.

d. A module should contain components that contribute to a single, common function rather than providing multiple, divergent functions.

e. Modules and units should be designed to permit operational testing when removed and require little or no calibration after replacement.

f. Testing should accept or reject each module or unit on a go-no-go basis.

g. The physical separation of equipment into replaceable units should be matched with the functional design of the equipment to maximize the functional independence of units and minimize interaction between units.

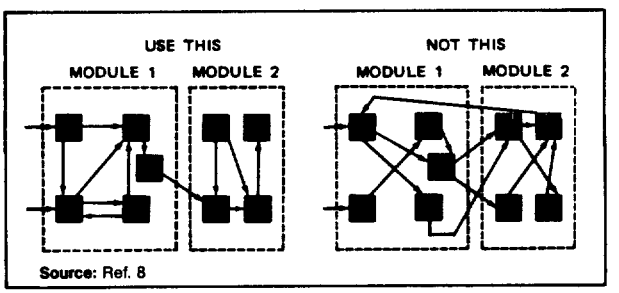

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Exhibit 1.1.1 A Hypothetical Equipment Design Incorporating Modularization and Functional Unitization

h. Where an assembly can be made of two or more subassemblies, the major assembly should be designed so that it consists of subassemblies which can be removed independently, without removal of the other subassemblies. This is particularly valuable when the various subassemblies have widely varying life expectancies.

i. All equipment should be designed so that rapid and easy removal and replacement of malfunctioning components can be accomplished by one technician, unless this is structurally or functionally not feasible.

j. Where possible, modules and units should be small and light enough for one person to handle or carry. The weight of removable units should not exceed 45 lbs. Units weighing more than 10 lbs. should have handles.

k. Where possible, each module should be capable of being checked independently. If adjustment is required, design for adjustment separate from other modules.

l. Control levels and linkages should be designed so they can be easily disconnected from components to permit easy removal and replacement.

m. Modularization for forward levels of maintenance should be emphasized to enhance operational capability. Modularization versus parts replacement for shop maintenance can be determined to a considerable extent by cost factors.

n. Unitizing the module with the unreliable components removable from the exterior of the package should be considered if all components of a module except for one or two are reliable.

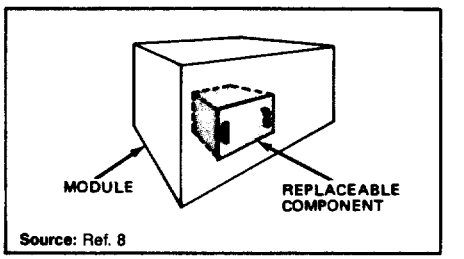

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Exhibit 1.1.2 Unitization of a Module for Easy Replacement of Low Reliability Components

1.1.3.2 DISPOSABLE MODULES

a. All decisions and requirements for disposable modules should be concurred on by the purchasing activity and should be based on exhaustive and clearly decisive analyses which prove that:

(1) Maintenance is either impractical or costs more than replacement.

(2) The advantages of disposable modules outweigh the disadvantages.

Advantages	Disadvantages
1. Savings in repair time, tools, facilities, and manpower	1. Increased supply burdens because modules must always be on hand
2. Smaller, lighter, denser, simpler, more durable, and more reliable design	2. Reduction in failure and maintenance data to aid design improvement
3. Fewer types of spares and a one-way supply system, at least for the item	3. Excessive usage rules, through excessive and/or erroneous replacement
4. More concise and less difficult troubleshooting procedures	4. Redesign problems and costs because such modules cannot be modified
5. Use of sealing and potting techniques which further improve reliability	5. Degraded performance and/or reliability as a result of production efforts to keep modules economical enough to justify disposal
6. Improved standardization and interchangeability of modules and assemblies	
Source: Ref. 8	

Exhibit 1.1.3 Advantages and Disadvantages of Disposable Modules

(3) Significant and favorable differences exist between the values of:

- End costs of the disposable versus the maintainable module.
- Man-time, materials, tools, etc. necessary to maintain each.
- Supply, storage, handling, and procuring costs and problems.
- Other costs and problems as determinable and applicable.

b. Disposable modules should be designed, manufactured, and installed to meet the following criteria:

(1) Expensive parts are not thrown away for failure of inexpensive parts.

(2) Long-life parts are not discarded for failure of short-life parts.

(3) Low-cost and non-critical items are, in general, made disposable.

(4) Throw-away modules are encapsulated wherever practical.

(5) All encapsulated modules are designed for disposal-at-failure.

(6) Modules costing $50 or less are disposable wherever practical.

(7) Modules costing more than $50 are encapsulated as necessary to meet performance and reliability requirements.

(8) The maintenance level of throw-away modules is clearly identified.

(9) Test procedures to be applied before disposal are clearly specified and provide clear and unequivocal results.

(10) The identification plate or marking contains the statement: "Dispose of at Failure."

1.0 ENGINEERED HARDWARE

1.2 Unit Layout, Packaging, and Mounting for Maintainability

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1.2.2 DEFINITIONS

Layout refers to the general arrangement and placement of units and components within a system.

Packaging refers to the particular method used to systematically configure units or components.

Mounting refers to a means of attaching and positioning components emphasizing accessibility for maintenance technicians.

Effective layout, packaging, and mounting should:

a. Satisfy unitization and modularization objectives.

b. Minimize place-to-place movement of the technician during servicing, check-out, and troubleshooting.

c. Be organized according to maintenance specialties so that maintenance performed by one specialist does not require removal or handling of equipment maintained by another specialist, especially where the equipment is so critical that it requires highly specialized skills.

1.2.3 GENERAL PRINCIPLES

1.2.3.1 LAYOUT OF UNITS AND COMPONENTS

a. Equipment components should be located to minimize the possibility of equipment damage and personnel injury.

b. Delicate components should be located where they will not be damaged while equipment is being worked on.

c. Components should be positioned so that oil, other fluids, and dirt are not likely to contaminate them.

d. High temperature parts should be guarded or located such that personnel contact will not occur during operation or maintenance. Heat-producing equipment should be shielded so that technicians are not made uncomfortable.

e. High-current switching devices should be enclosed to protect personnel.

f. Internal controls should be located away from dangerous voltages.

g. Check points, adjustment points, cable end connections, labels, and tools required should be placed in full view and reach of the technician.

h. Small, hinge-mounted units, which must have access from the back, should be free to open their full distance and remain open without being held.

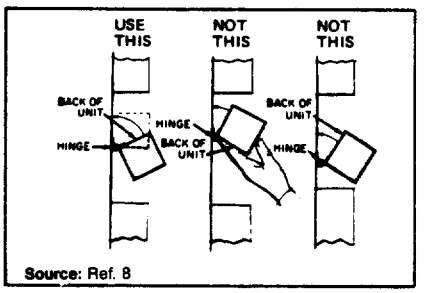

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Exhibit 1.2.1 Design of Hinged Units

i. Components and systems which require frequent inspections should be as easily accessible as possible.

j. Units should be located so other equipment does not have to be removed to gain access.

k. Units should not be stacked. If necessary, place the less frequently accessed unit in the rear or bottom.

l. Frames or structural members should not interfere with maintenance activities.

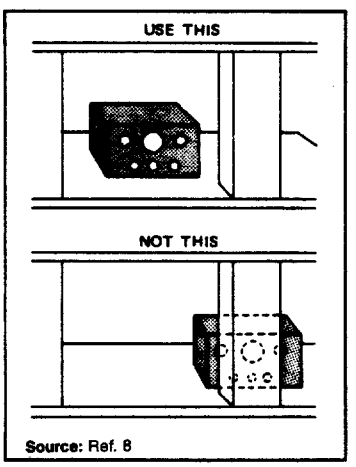

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Exhibit 1.2.2 Proper Placement of Components

m. Components that require frequent visual inspection should be installed in positions where they can be easily seen without removing panels, covers, or other units.

n. Components to be serviced or repaired in position should be at the most favorable working level, i.e., between hip and shoulder height.

1.2.3.2 PACKAGING

a. Labels and codes should be provided on and within the packaging arrangement, as required to:

(1) Outline and identify functional groups of equipment.

(2) Identify each item or part by name or common symbol.

(3) Identify each test or service point, and the sequence in which used.

(4) Identify the value and tolerances of parts such as resistors; this identification should be direct rather than in color code where possible.

(5) Indicate the direction of current or flow to aid systematic elimination of possibilities without continuous cross-reference to schematics.

(6) Provide "maintenance highways" to guide the technician through routine process. The following code has proven useful:

- Black for line maintenance
- Green for shop maintenance
- Red for off site maintenance
- Other codes as necessary.

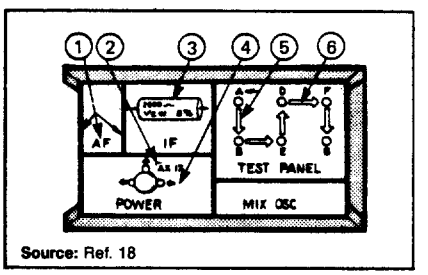

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Exhibit 1.2.3 Labeling and Coding a Packaging Arrangement

b. Provisions should be made for the following instructions to appear on packaging arrangements when appropriate:

(1) The weight of units over 45 lbs. should be prominently labeled.

(2) Warning and caution labels should be provided as necessary.

(3) Instruction plates should be provided to outline procedures not made obvious by design and to supply whatever information is necessary for troubleshooting and maintenance.

(4) The presentation and/or recording of historical data where practicable, particularly to:

- Display periodic readings at test points to allow development of trends where these are fundamental to maintenance decisions.
- Allow recording of replacement dates or other data necessary to replenishing or preventive maintenance.

c. Labels and codes used in packaging arrangements should be compatible with principles established under "Identification," and should be:

(1) Consistently and unambiguously used throughout the system.

(2) Of such a nature as to be easily read and interpreted.

(3) Durable enough to withstand expected wear and environmental conditions.

(4) Coordinated and compatible with:

- Codes and labels on related test and service equipment
- Other coding and labeling within the system
- Related job aids, instructions, handbooks, and manuals.

1.2.3.3 MOUNTING

a. Mounting of components is influenced by:

(1) How often components will be removed for maintenance or replacement.

(2) The accessibility of other components which may be affected.

(3) The size and weight of components to be mounted.

(4) How much space will be required for access, removal, and replacement of the component or for using test equipment, tools, etc.

(5) The required preventive maintenance for an installed component.

b. Mounting fixtures, e.g., rollers, brackets, slide rails, should be designed so that:

(1) Only interconnecting wire and structural members are permanently attached to units. All other fixtures should be removable.

(2) Built-in fixtures to the chassis are either strong enough to withstand use over the life of the system or are removable.

(3) Mounting is compatible with the size and weight of the part to prevent breakage or damage from fatigue, under vibration, handling stress, etc.

c. Design for mounting of components, modules, and parts should be such as to prevent their being inadvertently reversed, mis-mated, or misaligned during installation or replacement.

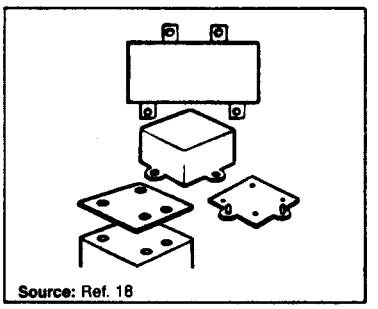
d. Design should make errors physically impossible, by:

(1) Coding, labeling, or keying symmetrical components to indicate the proper orientation for mounting or installation.

(2) Providing mounting brackets which are asymmetrical, to prevent incorrect mounting, as below.

(3) Providing side alignment brackets which permit mounting in only one position, as below.

(4) Providing asymmetrical mounting holes, studs, or alignment pins, as below.



Source: Ref. 18

Exhibit 1.2.4 Error-Free Mounting Designs

e. Components of the same form, function, and value should be completely interchangeable throughout the system or related systems.

f. Components of the same or similar form, but of different functional properties, should be:

(1) Mounted with standard orientation throughout the unit.

(2) Readily identifiable, distinguishable, and not physically interchangeable.

1.2.4 SPECIFIC PRINCIPLES

1.2.4.1 PACKAGING. The packaging of equipment, assemblies, and/or components should follow one or a combination of the following methods (in order of preference):

a. **LOGICAL FLOW PACKAGING.** This method requires that:

(1) Circuits, parts, and components should be packaged and located in an arrangement parallel to their functional relationships.

(2) Methods and subassemblies be selected so that only single input and output checks are necessary to isolate a fault within an item.

(3) The unidirectional signal flow within a given piece of equipment is clearly indicated.

b. **CIRCUIT PACKAGING.** This method uses the following techniques:

(1) All parts of a given circuit, or of logically or generally related groups of parts, are located in a common volume.

(2) Each circuit should be placed in a separate module. If a tube is associated with the circuit, place it on top of the module.

(3) The circuit should consist of a single terminal board or plug-in type module when possible.

(4) Plug-in printed circuit boards should be structurally rigid and easy to remove and replace.

c. **COMPONENT PACKAGING.** This method should incorporate the following:

(1) All similar components should be found in one place on the equipment.

(2) Relays should be located in a single or small number of relay panels.

(3) Resistors, capacitors, tube sockets, etc. should be segregated in a minimum number of locations on subassemblies or terminal boards.

(4) Inexpensive components should be placed on separate, plug-in type boards mounted beneath the chassis to facilitate disposal at failure.

(5) Multiples of similar parts (e.g., tubes, transistors) that are likely to require replacement about the same time should be grouped together.

(6) Components should be segregated based on significant variations in the maintenance tasks which are required. For example, items which must be cleaned by different methods (steam, gunk, solvent, etc.) should be packaged so cleaning is possible with minimal masking.

1.2.4.2 MOUNTING. The mounting of equipment, assemblies, and/or components should use one or a combination of the following techniques:

a. **FOLD-OUT CONSTRUCTION.** This method of constructing subassemblies should be used whenever feasible. The parts and wiring should be positioned to prevent damage to them when opening and closing this assembly.

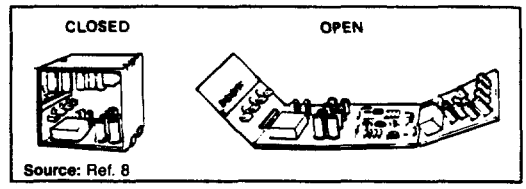


Exhibit 1.2.5 Example of Fold-Out Construction

b. **BRACES.** Braces or similar items should be provided to hold hinged assemblies in the "out" position while they are being worked on. Rests or stands should be provided to prevent damage to delicate parts. If feasible, the rests or stands should be a part of the basic chassis.

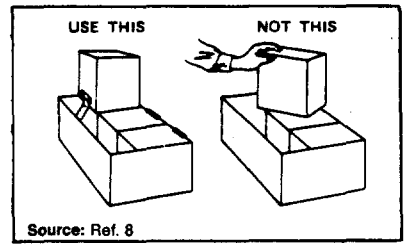


Exhibit 1.2.6 Bracing of Hinged Assemblies

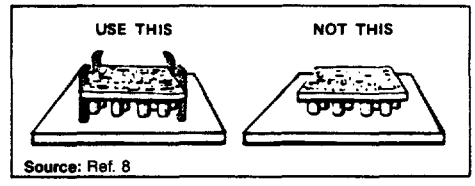


Exhibit 1.2.7 Use of Stands for Component Maintenance

c. **STRAPS AND BRACKETS.** Straps and brackets should be used:

(1) As necessary for tying down large components.

(2) Particularly to support items mounted on the underside of assemblies.

(3) Instead of cantilever brackets for mounting parts.

(4) As necessary to prevent the mounted item from sliding or jumping out of position. "U" straps should only be used to "tie-down" components, not to secure or support them.

(5) Which are thick or rounded enough so they have no sharp edges.

(6) Which are shorter than mounted units to provide a clamping action.

(7) Which are twist- or push-to-lock mounting types for small components. Such brackets should be designed so that locking studs are visible when the component is in place, and locking screws or dimples are provided as necessary to ensure security of the mount.

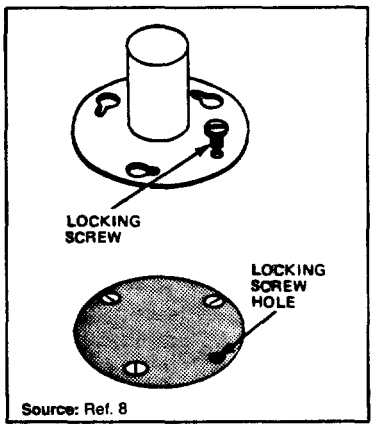


Exhibit 1.2.8 Twist-to-Lock Type Mounting Bracket

d. **SHOCK MOUNTS.** Shock mounts should be used, as necessary, to:

(1) Eliminate vibrational fluctuations in displays, markings, etc.

(2) Protect fragile or vibration-sensitive components and instruments.

(3) Control sources of high or dangerous noise and vibration.

e. Other methods to be considered in the mounting of components are as follows:

(1) Hinged bars are useful for tying down and permitting access to a number of small components at one time. Such bars should be padded or provided with springs as necessary to prevent damage to the items secured.

(2) Where rigid mounting may result in damage to components, a device which permits some flexibility should be used. For example, a frequent cause of thread-stripping of "T" fittings is the rigid mounting of the fittings.

(3) Where blind mounting is required, the inaccessible side should be secured with mounts which will allow exceptionally easy mating and do not require access (such as friction lugs, tongue and groove fittings, etc.).

(4) Spring clamps should be used to mount tubing, pipes, or wiring which may require frequent removal and replacement. For overhead mounting, a spring clamp similar to that used for floor mounting should be used, but a hinged locking latch should be provided over the open side of the clamp to prevent accidents.

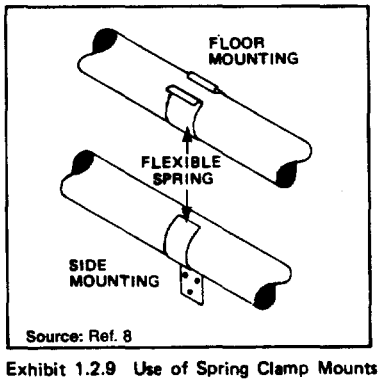


Exhibit 1.2.9 Use of Spring Clamp Mounts

1.0 ENGINEERED HARDWARE

1.3 Hardware Identification for Maintainability

1.3.1 INDEX

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1.3.2 DEFINITION

Hardware identification refers to the adequate marking or coding of parts, components, controls, and test points to facilitate repair and replacement during maintenance operations. Hardware identification is used to:

a. Identify the purpose or function of specific units, parts, controls, displays, test points, etc.

b. Present critical information for equipment maintenance procedures.

c. Present safety information, i.e., cautions and warnings which lead to prevention or avoidance of hazards to maintenance personnel or damage to equipment.

Proper labeling or coding is present if the component is readily identified for repair, replacement, or service with minimum effort by the technician.

1.3.3 GENERAL PRINCIPLES

1.3.3.1 Hardware identification (labels, legends, placards, signs, markings, codes, or combinations of these) should be provided whenever personnel must identify, interpret, follow procedures, or avoid hazards.

1.3.3.2 Identification characteristics should be consistent with factors such as:

a. Accuracy of identification required.

b. Time available for recognition or other responses.

c. Location and distance at which identification must be read.

d. Level and color of illumination.

e. Criticality of the function identified.

f. Consistency of the identifying information within and between systems.

1.3.3.3 Label-making devices should be readily available for creating new labels to replace missing, damaged, or deficient identifiers.

1.3.3.4 Identifiers used in multi-unit facilities should be sufficiently distinctive to prevent confusing one unit with another.

1.3.3.5 Periodic facility-wide surveillance checks should be made to ensure that all equipment and facilities are properly identified, and that informal labels added by operators and maintenance technicians are systematically replaced with accurate, easily read, high-contrast, permanent labels and tags.

1.3.3.6 Maintenance procedures should include a step to check for the availability of identification tags and labels as part of the system restoration process.

1.3.3.7 Quality control inspection procedures should include measures to ensure that identification tags and labels are replaced when necessary subsequent to maintenance tasks.

1.3.3.8 Equipment (except detailed assemblies and parts) should be identified with a securely attached, permanent, non-fading, oil-, gasoline-, and corrosion-resistant name plate. The name plate should be permanently and legibly marked with the following information:

a. Contract order or task no.

b. Item name (noun first).

c. Specification number.

d. Manufacturer's part no. (or Government Standard Part No.).

e. Serial no. (when available).

f. Stock no. (when available).

g. Manufacturer's name and address. Manufacturers' logos should be eliminated or removed if they interfere with identifying or interpreting equipment functions.

1.3.3.9 Equipment identification should include pertinent information about its function, capacity, capabilities, limits, ranges, frequency, and current requirements. Weight, rpm, horsepower, and other basic information should be included.

1.3.3.10 Electrical assembly connections should be marked according to MIL-STD-195, or comparable industry standards.

1.3.3.11 Insulated wire should be color- or number-coded per MIL-STD-681, or comparable industry standards.

1.3.3.12 For color coding, no more than nine easily distinguishable colors should be used for color-normal and color-deficient observers.

Color	Spec. No.*	Color	Spec. No.*
Red	1110	Gray	1625
Orange	1210	Buff	1745
Yellow	1310	White	1755
Blue	108 7/6	Black	1770
Purple	2715		

*From Fed. Spec. II-C-595 except for blue, which is from Munsell (1942).

Source: Ref. 25

Exhibit 1.3.1 Surface Colors for Color-Normal and Color-Deficient Persons

1.3.4 SPECIFIC PRINCIPLES

1.3.4.1 INSTRUCTION PLATES

a. Instruction plates should describe or illustrate, as necessary:

(1) Basic operating instructions.

(2) Calibration data and adjustment instruction.

(3) Simple wiring or fluid flow diagrams.

(4) Warning and safety precautions.

(5) Test point locations.

(6) Transistor and other pertinent electronic equipment.

(7) Valve settings.

(8) Type of fuels, oils, or greases applicable.

(9) Other similar data for routine preventive maintenance.

b. Permanent instruction plates should be attached in an easily visible and suitable location.

c. Where required, a permanent pocket or similar device should be attached for containing various maintenance aids such as signal flow diagrams, diagnostic procedures, pictorial presentations, and maintenance records.

1.3.4.2 PARTS AND REFERENCE DESIGNATIONS

a. MIL-STD-16 or comparable industry standards should be used in the formation and application of alpha-numeric parts and reference designations. The unit numbering method should be used for all new equipment.

b. **COLOR AND STYLE**

(1) Designations should be clear and easily distinguished in subdued light at a distance of 28 inches.

(2) Black markings should be used on light backgrounds such as light-gray painted surfaces, unfinished brass, aluminum, and all bright, plated surfaces. White markings should be used on dark backgrounds such as medium-gray surfaces.

(3) Recommended letter and numeral heights for viewing distance of 28 inches are given. For other viewing distances, multiply given values by the distance in inches divided by 28.

Nature of Markings	Low Brightness down to 0.03 ft-lambert (in.)	High Brightness down to 1.0 ft-lambert (in.)
Critical markings—position variable (numerals on counters and settable or moving scales)	0.20 to 0.30	0.12 to 0.20
Critical markings—position fixed (numerals on fixed scales, control and switch markings, emergency instructions)	0.15 to 0.30	0.10 to 0.20
Noncritical markings (instrument identification labels, routine instructions, any markings required for initial familiarization only)	0.05 to 0.20	0.05 to 0.20

Source: Ref. 8

Exhibit 1.3.2 Recommended Letter and Numeral Heights (for 28-inch viewing distance)

c. **LOCATION OF DESIGNATIONS**

(1) Designation markings on equipment should be placed on or immediately adjacent to the part to which it pertains in a consistent manner.

(2) Small electrical parts (e.g., resistors, capacitors, terminals) affixed to mounting boards should be identified by marking on the boards.

(3) Multiple terminals should be identified by markings on the component or adjacent chassis.

(4) Parts which protrude from an electronic chassis should be marked on the wiring side.

(5) Terminals of transformers, relays, capacitors, and all socket-mounted items, except standard vacuum tubes, should be marked adjacent to each terminal.

(6) Receptacles for plugs, modules and units, and similar parts that are accessible from the top side should have both bottom and top side identification.

(7) Markings should be placed so that they are visible without removing parts.

(8) Markings should be oriented so that they can be read with the unit in the normal, installed position.

d. **MARKING PARTS**

(1) Parts should be identified by designations which refer to parts descriptions on a drawing or schematic.

(2) Wires, sockets, plugs, receptacles, and similar parts should carry designations from wiring diagrams prepared in accordance with the schematic diagrams.

(3) Replaceable mechanical parts should have standard designations.

(4) Semi-fixed electrical items (e.g., fuses, ferrule-clip-mounted resistors) should carry the electrical rating in addition to the standard designation.

(5) Critical polarity and impedance ratings should be shown on items having these ratings.

(6) If an assembly is complex, a concise wiring diagram should be affixed to the unit.

(7) Markings should be accurate and sufficient to identify the referenced part.

(8) Markings should be permanent enough to last the life of the equipment.

(9) Stacked parts and modules should be marked so that they can be individually recognized.

(10) Individually enclosed or shielded parts should be identified on the outside of the enclosure.

(11) Fixed and removable parts of a plug-in assembly should be marked identically.

(12) Individual sections of dual parts should be clearly identified.

1.3.4.3 LABELS

a. Labels are lettered indications of the name, identifying number, and function of equipment which are affixed on or near the relevant equipment.

b. It is usually better to over-label than under-label, especially in cases where equipment is separated from operation and instruction manuals.

c. **COLOR AND SIZE**

(1) Color combinations of printing and background should be provided which will maximize legibility. Best color combinations for labels, in descending order, are:

- Blue on white
- Black on yellow
- Green on white
- Black on white
- Green on red
- Red on yellow.

(2) If color coding of labels is necessary, colors should be selected on the basis of recognizable differences. The following colors are suitable for surface coding because they are easily recognizable by both normal and color deficient persons.

Color	FED-STD-595 Spec. No.
Black	1770
White	1755
Yellow	1310
Blue	108 7/6

(3) Labels should be printed in capitals. Periods should not be used after abbreviations.

(4) The width of letters should be 3/5 of the height, except for "M" and "W" which should be 4/5 of the height and "I" which should be one stroke wide.

(5) The width of numerals should be 3/5 of the height, except for "4" which should be one stroke width wider and "1" which should be one stroke wide.

(6) When conditions demand the use of wider characters (e.g., on curved surfaces), basic height-to-width ratios may be increased to 1:1.

(7) When black characters are used on a white (or light) background, the stroke width should be 1/6 to 1/7 of the height.

(8) Where areas are dimly illuminated or legibility at night is critical, and white characters are specified on a black background, the stroke width of the characters should be from 1/7 to 1/8 of the height (i.e., narrower than for daytime vision). The stroke width should be the same for all letters and numerals of equal height.

(9) Minimum spacing between characters used in labels should be one stroke width.

(10) Minimum spacing between words should be the width of one character.

(11) Minimum spacing between lines should be one-half the character height.

(12) Recommended numeral and letter heights for a viewing distance of 28 inches are the same as for parts identification and reference designations, Exhibit 1.3.2. Other viewing distance and character height values are given below.

	Viewing Distance	Minimum Height
a.	Less than 500 mm (19.7 in.)	2.3 mm (0.09 in.)
b.	0.5 – 1.0 m (19.7 – 39.4 in.)	4.7 mm (0.18 in.)
c.	1.0 – 2.0 m (39.4 –78.7 in.)	9.4 mm (0.37 in.)
d.	2.0 – 4.0 m (78.7 – 157.5 in.)	19 mm (0.75 in.)
e.	4.0 – 9.0 m (157.4 – 3.5.5 in.)	38 mm (1.50 in.)

Source: Ref. 11

Exhibit 1.3.3 Viewing Distance and Character Height Values

d. **COMPOSITION**

(1) Labels should be brief yet explanatory. Brief, familiar words should be used. Abbreviations should be used only when known to all personnel. Key action words should be used instead of abbreviations when possible.

USE THIS	NOT THIS
CAUTION Open all eight compartments before purging system.	When the system is being purged, all "A" compartments and "B" compartments must be open, as there is not enough air flow to adequately purge the system.

Source: Ref. 8

Exhibit 1.3.4 Label Composition

(2) Labels containing a number of steps to be performed sequentially should itemize the steps rather than present them in paragraph form.

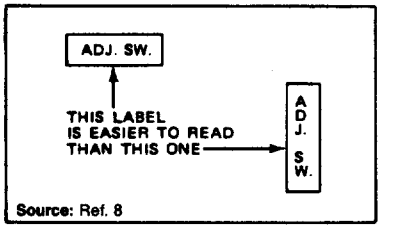
USE THIS	NOT THIS
ASSEMBLING INJECTOR TAPPING TOOL	ASSEMBLING INJECTOR TAPPING TOOL
1. Replace defective part. 2. Install nut and washer on hand-tap shank. 3. Install Rollpin in nut. 4. Check tapping tool for proper operation.	First replace the defective part from supply. Install nut and washer on hand-tap shank. Next, place the Rollpin in the nut. Upon completion, check the tapping tool for proper performance.

Source: Ref. 8

Exhibit 1.3.5 Label Containing Sequence of Steps

(3) Codes and labels on equipment should be consistent with instruction manuals and equipment parts catalogs.

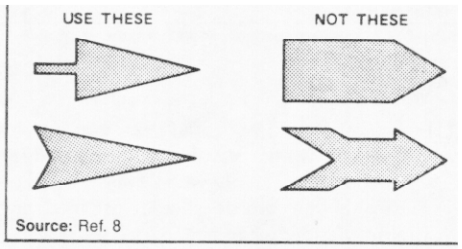
(4) Labels should read horizontally rather than vertically.



Source: Ref. 8

Exhibit 1.3.6 Use of Horizontal Rather Than Vertical Labeling

(5) Arrows used in labels should be clearly recognizable and easily identifiable when read from a distance. It is easier to interpret the direction of arrows with sharp angles and clean lines from a distance than arrows which use wide angles and



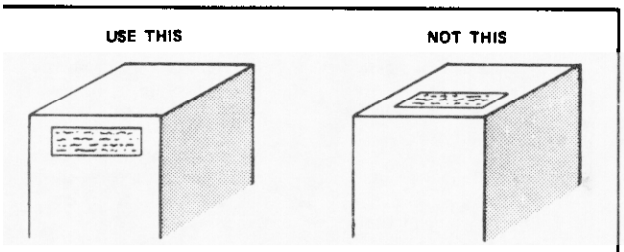
Source: Ref. 8

Exhibit 1.3.7 Use of Arrows With Narrow Width-to-Length Ratios

(6) Wording of labels should be chosen based on the operator's familiarity with them when possible. Common technical terms, if familiar to the maintenance technician, may be used as necessary. Abstract symbols (e.g., squares and Greek letters) should be used only if they are understood by all intended readers.

e. LOCATION OF LABELS

(1) Labels should be located so they will not be obscured by grease, filings, dirt, or moisture. Where a label may be particularly susceptible to being covered by material droppings from above, it should be mounted vertically.



Source: Ref. 8

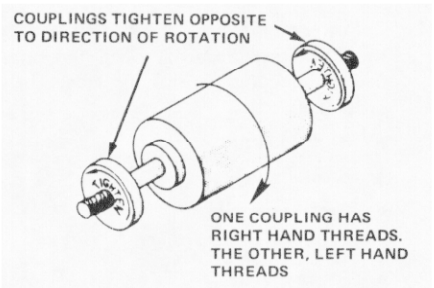
Exhibit 1.3.8 Label Positioning

(2) Labels used on similar pieces of equipment should be placed in relatively the same position.

(3) Labels should not be hidden from view, crowd each other, or obscure other useful information.

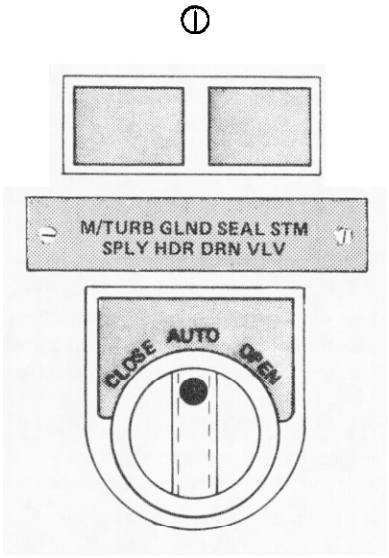
(4) Parts that look similar but are not physically interchangeable and cannot be physically keyed should be labeled. Labels should be located on several sides of the part, if possible, with precautions about interchangeability or use-distinctive markings that correspond with markings on the assembly in which the part will be placed.

(5) Labels or other markings should be provided to indicate control positions. A rider may be attached to the shaft of a valve to indicate position. Labels may also include calibration data where applicable.



ource: Ref. 8

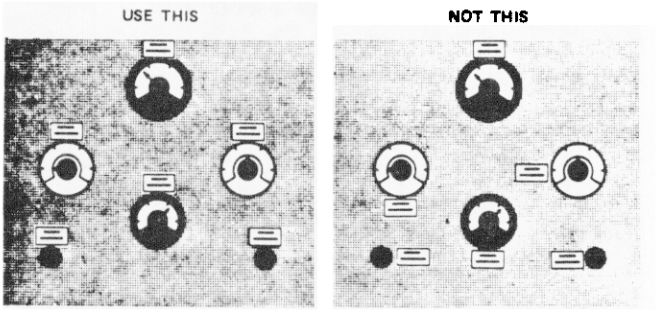
Exhibit 1.3.9 Component Labeling to Preclude Operating Erro



ource: Ref. 10

Exhibit 1.3.10 Label Indicating Control Positions

(6) Labels should be placed consistently in the same place in relation to the instrumentation on a panel. Labels normally should be placed above the controls and displays they describe. If a panel is above eye level, labels may be located below if the visibility is enhanced.



Source: Ref. 8

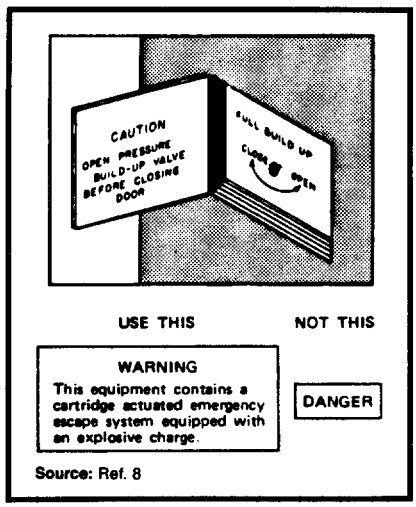
Exhibit 1.3.11 Relating Labels to Controls and Displays

(7) Functionally grouped controls and displays should be identified by labels located above the functional groups which they identify. If a functional group is demarcated by a line, the label should 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 should be centered at the top within the pad area.

1.3.4.4 WARNING LABELS AND PLACARDS

a. Warning labels should be installed whenever a maintenance technician or mechanic must consult a technical manual before working on the equipment.

b. Warning labels should be as informative as possible given space constraints present (see examples below).



Source: Ref. 8

Exhibit 1.3.12 Examples of Warning Labels

c. Though content of warning labels will vary, they should inform the technician of:

(1) Why a dangerous condition exists.

(2) Places to avoid.

(3) Behavior to avoid.

(4) Sequence to follow to obviate the danger.

(5) Where to refer for more information.

(6) Radiation protection precautions or procedures.

(7) What to do in case of injury.

d. High visibility warnings should be erected when personnel may be subjected to harmful noise or a sudden increase or decrease in pressure or exposure to radiation.

e. Tolerance or safety load limits of an apparatus should be permanently displayed.

f. The following are examples of specific applications of warning labels and placards:

(1) **WARNING PLACARDS**—Warning placards should be mounted adjacent to any equipment which presents a hazard to personnel (e.g., from high voltage, heat, toxic vapors, explosion, ionizing radiation).

(2) **CENTER OF GRAVITY AND HEIGHT**—Where applicable, the center of gravity and the weight of equipment should be marked.

(3) **WEIGHT CAPACITY**—The weight capacity should be indicated on stands, hoists, lifts, jacks, and similar weight-bearing equipment to prevent overloading.

(4) **IDENTIFICATION OF PROTECTIVE ITEMS**—Operation and maintenance areas requiring special clothing, tools, or equipment (e.g., insulated shoes, gloves, suits, respirators) should be specifically and conspicuously identified.

(5) **"NO-STEP" MARKINGS**—These markings should be provided, when necessary, to prevent injury to personnel or damage to equipment.

(6) **ELECTRICAL LABELS**—All receptacles should be marked with their voltage, phase, and frequency characteristics as appropriate.

(7) **HAND GRASP AREAS**—Hand grasp areas should be conspicuously and unambiguously identified on equipment.

(8) **PIPE, HOSE, AND TUBE LINE IDENTIFICATION**—Pipe, hose, and tube lines for liquids, gas, steam, etc. should be clearly and unambiguously coded for contents, pressure, heat, cold, or other specific hazardous properties. MIL-STD-1247 or comparable industry standards should be used for further guidance.

(9) **LONG RUN CABLES, PLUMBING LINES, AND CONDUITS**—These should be clearly identified or coded, not only at the terminal ends but also at periodic distances between ends to facilitate accurate tracing of lines.

1.0 ENGINEERED HARDWARE

1.4 Equipment Accessibility

1.4.1 INDEX

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- 1.4.4.3 Location of Accesses 1.4-5
- 1.4.4.4 Access Safety Requirements 1.4-6

1.4.2 DEFINITION

Equipment accessibility refers to the relative ease with which an assembly or component can be approached for repair, replacement, or servicing. If the steps required are few and simple, then the component is accessible; the component is inaccessible if the steps are many or difficult to perform. Accesses include entrance doors; inspection windows; and lubrication, pneumatic, and hydraulic servicing points. Accesses should provide:

a. Sufficient clearance to use the tools needed to complete the task.

b. Adequate space to permit convenient removal and replacement of components.

c. Adequate visual exposure to the task area.

1.4.3 GENERAL PRINCIPLES

1.4.3.1 Access must be provided to all points, items, units, and components which require or may require testing, servicing, adjusting, removal, replacement, or repair.

1.4.3.2 The type, shape, location, and size of accesses should be determined by thoroughly understanding:

a. Operational location, setting, and environment of the unit.

b. Frequency with which the access must be entered.

c. Maintenance functions to be performed through the access.

d. Time requirements for the performance of these functions.

e. Types of tools and accessories required by these functions.

f. Work clearances required for performance of these functions.

g. Type of clothing likely to be worn by the technician.

h. Distance to which the technician must reach within the access.

i. Visual requirements of the technician in performing the task.

j. Packaging of items and elements, etc. behind the access.

k. Mounting of items, units, and elements behind the access.

l. Hazards involved in or related to use of the access.

m. Size, shape, weight, and clearance requirements of logical combinations of human appendages, tools, units, etc. that must enter the access.

1.4.3.3 An access should be designed to make the repair or servicing operation as simple as possible.

1.4.3.4 Where possible and feasible, accessibility should be designed for on a grand scale by:

a. Using hinged or removable chassis.

b. Designing major units and assemblies (especially engines, turbines, etc.) with removable housings to allow for complete inspections.

c. Correlating the design of unit accessibility features with the accessibility requirements of the overall system.

1.4.3.5 Accesses should be designed, located, covered, and fastened to avoid the need for removing components, wires, etc. to reach the item requiring maintenance.

1.4.3.6 Accesses should be designed so that the removal of any replaceable unit requires opening of only one access, unless the accesses are of the latched or hinged door type.

1.4.3.7 Items that require visual inspection (e.g., hydraulic reservoirs, gauges) should be located so they can be observed without the removal of panels or other components.

1.4.3.8 All access covers that are not completely removable should be self-supporting in the open position.

1.4.3.9 When access covers must serve as stress-bearing structural members, large screws should be used rather than small ones.

1.4.3.10 On hinged access doors, the hinge should be placed on the bottom or a prop should be provided so that the door will stay open without being held if unfastened.

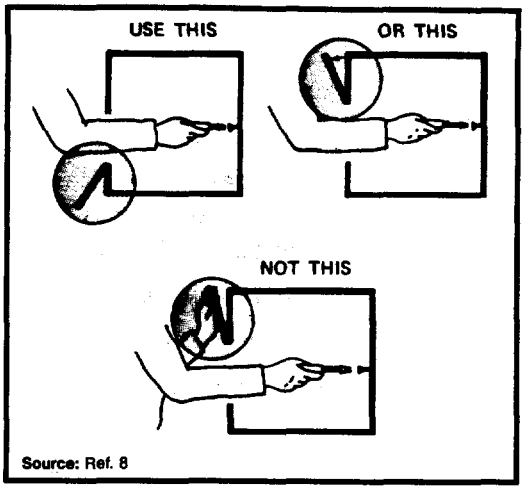


Exhibit 1.4.1 Access Door Hinges

1.4.3.11 If the manner in which a cover is opened is not obvious from its structure, it should be labeled with appropriate instructions.

1.4.3.12 When a tube or plug has to be put through a small hole, a conspicuous label can be used to show how the pins on the tube or plug will line up with the holes in the socket.

1.4.3.13 An access should be labeled with a number, letter, or other symbol that identifies it in the maintenance instructions.

1.4.3.14 Labels should be used to indicate items that can be reached through an access and the service equipment, if any, to be used there.

1.4.3.15 Equipment should be left exposed (without coverings or housings) for maintenance whenever permitted by structural, environmental, operational, and safety conditions. This pertains especially to test and service points, maintenance controls and displays, and rack-mounted units.

1.4.3.16 The table following provides guidance for selecting equipment accesses:

Desirability	For Physical Access	For Visual Inspection Only	For Test and Service Equipment
Most Desirable	Pullout shelves or drawers	Opening with no cover	Opening with no cover
Desirable	Hinged door (if dirt, moisture or other foreign materials must be kept out)	Plastic window (if dirt, moisture or other foreign materials must be kept out)	Spring-loaded sliding cap (if dirt, moisture or other foreign materials must be kept out)
Less Desirable	Removable panel with captive, quick-opening fasteners (if there is not enough room for hinged door)	Break-resistant glass (if plastic will not stand up under physical wear or contact with solvents)	
Least Desirable	Removal panel with smallest number of largest screws that will meet requirements (if needed for stress, pressure, or safety reasons)	Cover plate with smallest number of largest screws that will meet requirements (if needed for stress, pressure, or safety reasons)	Cover plate with smallest number of largest screws that will meet requirements (if needed for stress, pressure, or safety reasons)

Source: Ref 8

Exhibit 1.4.2 Equipment Access Selection Criteria

1.4.4 SPECIFIC PRINCIPLES

1.4.4.1 SIZE OF ACCESSES

a. Size of accesses should be determined by what the maintenance technician will have to do and should depend on factors such as:

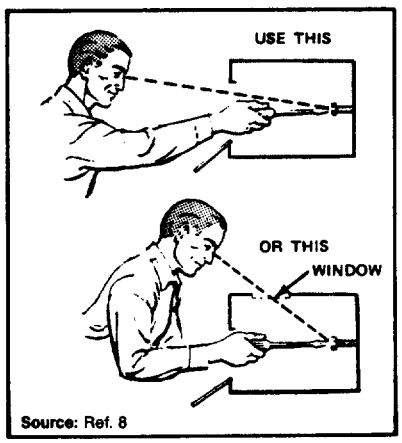
(1) Size and shape of the part, component, or assembly to which access is desired.

(2) Whether or not the object must be removed and replaced through the openings.

(3) Movements of the human body member or members required once access is gained (turning, pulling, pushing, etc.).

(4) The size of the body member or members required to enter through the access.

b. Generally, one large access is preferred to two or more small ones. Where there are structural or other requirements, visual and physical access may be provided separately.



Source: Ref. 8

Exhibit 1.4.3 Proper Visual Access

c. The following are recommended minimum standards standards for one-hand access openings without visual access.

	Height	Width
Empty hand, to wrist:		
Bare hand, rolled:	3.75" sq. or dia.	
Bare hand, flat:	2.25" x	4.0" or 4.0" dia.
Glove or mitten:	4.0" x	6.0" or 6.0" dia.
Protective mitten:	5.0" x	6.5" or 6.5" dia.
Clenched hand, to wrist:		
Bare hand:	3.5" x	5.0" or 5.0" dia.
Glove or mitten:	4.5" x	6.0" or 6.0" dia.
Protective mitten:	7.0" x	8.5" or 8.5" dia.
Hand plus 1" dia. object, to wrist:		
Bare hand:	3.75" sq. or dia.	
Glove or mitten:	6.0" sq. or dia.	
Protective mitten:	7.0" sq. or dia.	
Hand plus object over 1" in dia. to wrist:		
Bare hand:	1.75" clearance around object.	
Glove or mitten:	2.5" clearance around object.	
Protective mitten:	3.5" clearance around object.	
Arm to elbow:		
Light clothing:	4.0" x	4.5" or 4.5" dia.
Protective Clothing:	7.0" sq. or dia.	
With object:	Clearances as above.	
Arm to shoulder:		
Light clothing:	5.0" sq. or dia.	
Protective clothing:	8.5" sq. or dia.	
With object:	Clearances as above.	

Source: Ref. 11

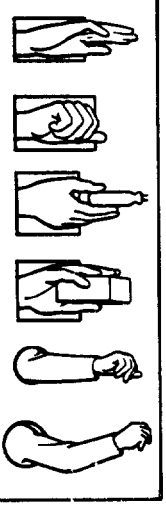


Exhibit 1.4.4 Standards for One-Hand Accesses Without Visual Access

d. The following are recommended dimensions for two-hand access openings without visual access.

Reaching with both hands to depth of 6 to 19.25 inches:		
Light Clothing:	Width:	8" or the depth of reach*
	Height:	5"
Protective clothing:	Width:	6" plus 3/4 the depth of reach
	Height:	7"
Reaching full arm's length (to shoulders) with both arms:		
	Width:	19.5"
	Height:	5"
Inserting box grasped by handles on the front:		
1/2" clearance around box, assuming adequate clearance around handles		
Inserting box with hands on the sides:		
Light Clothing:	Width:	Box plus 4.5"
	[1]Height:	5" or 0.5" around box*
Protective clothing:	Width:	Box plus 7"
	[1]Height:	8.5" or 0.5" around box*

*Whichever is larger

[1]If hands curl around bottom, allow an extra 1.5" for light clothing, 3" for protective clothing.

Source: Ref. 11

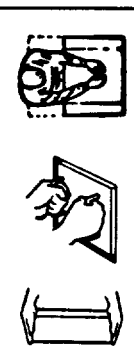


Exhibit 1.4.5 Standards for Two-Hand Accesses Without Visual Access

Note: Special consideration (larger access) must be given when user may be wearing protective clothing while performing a task.

e. The following are dimensions for various types of hand coverings during specified functions. These dimensions are generalizable to any situation which requires a definable hand clearance, or to similar types of protective hand coverings.

	Anticontact Glove			Wet-Cold Glove			Wet-Cold Mitten			Protective Mitten		
Hand Attitude	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Extended flat:	10.3	4.5	2.5	10.5	5.5	3.0	14.0	5.8	3.2	16.4	5.2	3.6
Closed as fist:	7.0	5.0	3.3	7.3	5.8	3.7	11.5	5.8	3.8	14.3	5.2	5.4
Grasping handle:												
.25" diameter:	7.0	5.0	3.5	7.3	5.5	3.5	11.0	5.7	4.2	14.0	5.5	4.5
1.0" diameter:	7.0	5.0	3.5	7.3	5.3	4.0	11.0	5.2	4.5	14.7	5.2	4.5
2.0" diameter:	7.5	4.5	4.2	8.0	4.7	4.0	12.0	5.2	4.7	15.0	5.4	5.0
Grasping knob:												
.25" diameter:	8.0	3.8	4.3	9.0	4.6	4.0	11.5	5.0	4.2	15.5	4.8	4.5
1.0" diameter:	9.0	3.5	4.0	9.0	4.5	4.0	12.0	5.0	4.0	15.8	4.8	4.5
2.0" diameter:	9.5	3.7	3.7	9.2	4.5	4.2	12.5	4.6	4.4	16.0	4.7	4.5

*The largest dimension in each column in underlined.

Source: Ref. 18

Exhibit 1.4.6 Gloved-Hand Access Clearances

f. The following are design guides for minimal finger access to first joint dimensions.

Push button access:	Bare hand:	1.25" dia.
	Gloved hand:	1.5" dia.
Two finger twist access:	Bare hand:	object plus 2.0" dia.
	Gloved hand:	object plus 2.5" dia.

Source: Ref. 18

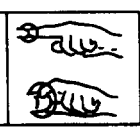


Exhibit 1.4.7 Standards for Finger Access to First Joint

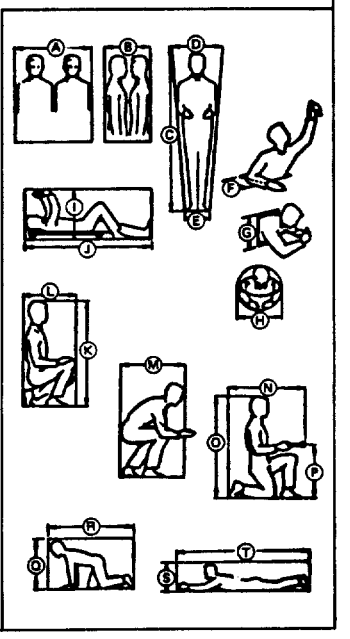
1.4.4.1 SIZE OF ACCESSES (Cont'd)

g. The following are recommended whole body dimensions for passing through limited accesses in various configurations.

	Min.	Best	Arctic
A. Two men passing abreast:	42"	54"	60"
B. Two men passing facing:	30"	36"	36"
Catwalk dimensions:			
C. Height:	63"	73"	75"
D. Shoulder width:	22"	24"	32"
E. Walking width:	12"	15"	15"
F. Vertical entry hatch: Round or square:	18"	22"	32"
G. Horizontal entry hatch: Shoulder width:	18"	22"	32"
Height:	15"	20"	24"
H. Crawl through pipe: Round or square:	25"	30"	32"
Supine work space:			
I. Height:	20"	24"	26"
J. Length:	73"	75"	78"
Squatting work space:			
K. Height:	48"	–	51"
L. Width:	27"	36"	40"
Optimum display area:		27-43"	
Optimum control area:		19-34"	
Stooping work space:			
M. Width:	36"	40"	44"
Optimum display area:		32-48"	
Optimum control area:		24-39"	
Kneeling work space:			
N. Width:	42"	48"	50"
O. Height:	56"	–	59"
P. Optimum work point:		27"	
Optimum display area:		28-44"	
Optimum control area		20-35"	
Kneeling crawl space:			
Q. Height:	31"	36"	38"
R. Length:	59"	–	62"
Prone work or crawl space:			
S. Weight:	17"	20"	24"
T. Length:	96"	–	–

Distribution parameters significant to tradeoffs in work clearance for lightly clad technicians:

Dimensions:	Mean:	S.D.
Max. body depth:	11.5	.88
Max. body breadth:	20.9	1.19
Overhead grasp:	82.5	3.33
Kneeling height:	32.0	1.56
Kneeling length:	43.0	3.26
Crawling height:	28.4	1.30
Crawling length:	53.2	2.61
Prone height:	14.5	1.28
Prone length:	90.1	3.41



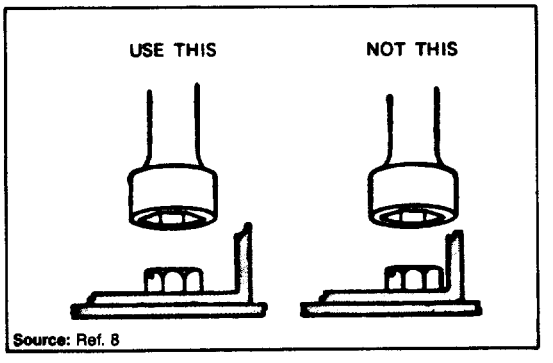
Source: Ref. 18

Exhibit 1.4.8 Recommended Whole Body Dimensions for Various Accesses

*OSHA Standard 1910.23(C)(2) requires an 18" width for catwalks/runways.

h. **SPACING REQUIREMENTS FOR HAND TOOLS**

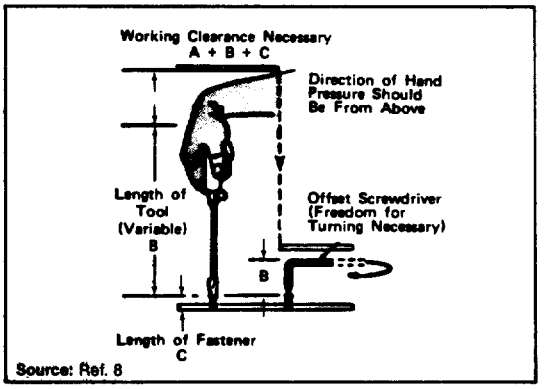
(1) Nuts and bolts should be spaced with enough clearance to allow a wrench to be used.



Source: Ref. 8

Exhibit 1.4.9 Nut and Bolt Spacing Clearances

(2) Screwdriver-type tools should have an overhead clearance of no less than the full length of the tool itself, plus the length of the fastener and at least 3 inches for the technician's hand. A minimum size (stubby) screwdriver (about 3 inches long) would require an overhead clearance of at least 6 inches. An off-set screwdriver would require less overhead clearance, but would require additional space for radial movement.



Source: Ref. 8

Exhibit 1.4.10 Hand Tool Working Space Clearances

1.4.4.2 SHAPE OF ACCESSES

a. Accesses may be of regular geometric shapes or any irregular shape, as long as the shape satisfies both structural and accessibility requirements. Shape of the access should permit easy passage of required items, body appendages, implements, etc., and should consider:

(1) Dimensions of the various units that must be replaced through the access.

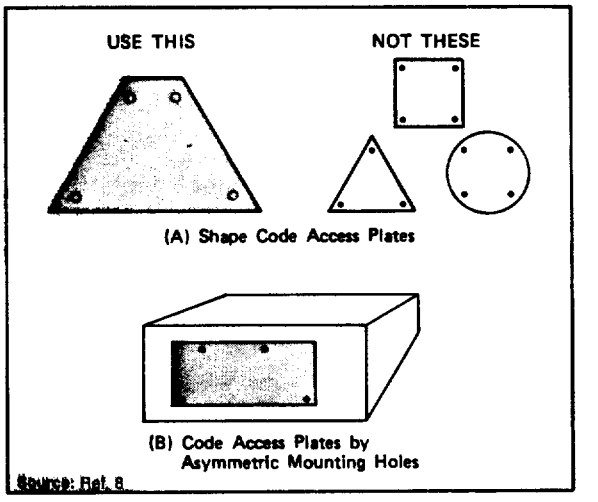
(2) Protuberances, attachments, handles, etc. on these units.

(3) Methods of grasping units during removal, and the required clearances.

(4) Requirements for work clearance for work within the compartment.

(5) Requirements for visual control of functions performed within the compartment.

b. If a removable access plate must be attached in a certain way, i.e., to prevent damage to equipment mounted on the back of the plate, shape code the access plate to prevent incorrect attachment, or use asymmetric mounting holes.



Source: Ref. 8

Exhibit 1.4.11 Coding Removable Access Plates

1.4.4.3 LOCATION OF ACCESSES

a. Accesses should be located:

(1) Only on unit faces that will be accessible to normal installation.

(2) To permit direct access and maximum convenience for job procedures.

(3) On the same face of the equipment as the related displays, controls, test points, cables, etc.

(4) Away from high voltages or dangerous moving parts, or provide adequate insulation, shielding, etc. around such parts to prevent injury to personnel.

(5) So that heavy units can be pulled out rather than lifted out.

(6) So that the bottom edge of a limited access is no lower than 24 inches or the top edge no higher than 60 inches from the floor or work platform.

(7) To conform to heights of work stands and carts related to use of the access.

1.4.4.4 ACCESS SAFETY REQUIREMENTS

a. Edges of accesses that might injure the technician's hands or arms should be protected with internal fillers or other protection.

b. To minimize the possibility of injuries and equipment damage, access covers, cases, and handles should have rounded corners and edges.

c. Accesses that lead to equipment with high voltages should be equipped with safety interlocks so that electrical circuits will be opened when the access cover is removed. If the technician must work on the equipment with the power on, provide a "cheater" switch that automatically resets to its safety-protection position when the access cover is replaced.

d. Conspicuous warning labels should be provided on all accesses leading to high voltages, rotating machinery, or other hazards.

e. Positive indications should be designed to show that access covers are unsecured, even when they are in place.

f. Screwdriver guides should be provided to adjustment points which must be operated near high voltages.

g. Visual access should be provided the technician for all maintenance operations which require visual control, especially where hazards are present within the access. The technician should not be required to work blindly.

1.0 ENGINEERED HARDWARE

1.5 Controls and Displays for Maintainability

1.5.1 INDEX

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1.5.4.1 Maintenance Controls 1.5-4
1.5.4.2 Maintenance Displays 1.5-4

1.5.2 DEFINITIONS

Controls are the means by which a maintenance technician inputs information/instruction into the equipment. Many of the same controls may be used by both the technician and the operator. Some controls may be built into the equipment and used strictly for maintenance purposes. Maintenance controls include not only knobs and switches, but tool-operated controls such as screwdriver adjustment points, setscrews, and lockouts.

Displays provide the technician with information about whether or not the total system and its various units are operating within tolerance.

NOTE

The design of controls and displays is not a function which is specific to maintainability. Control and display design has been more extensively covered under operator activities. In particular, NUREG-0700, "Guidelines for Control Room Design Reviews," Division of Human Factors Safety, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, is a principal source for control and display design criteria for the nuclear power industry. In addition, MIL-STD-1472C, "Military Standard: Human Engineering Design Criteria for Military Systems, Equipment and Facilities provides data concerning general human engineering criteria, principles, and practices to be applied in designing systems, equipment, and facilities. Therefore, only considerations which have been determined pertinent to maintainability are presented.

1.5.3 GENERAL PRINCIPLES

1.5.3.1 MAINTENANCE CONTROLS

a. Internal controls should be located so the technician will be able to manipulate the control while at the same time observe its related display. This will eliminate the need for two technicians—one to operate the control, the other to provide/interpret feedback from the display.

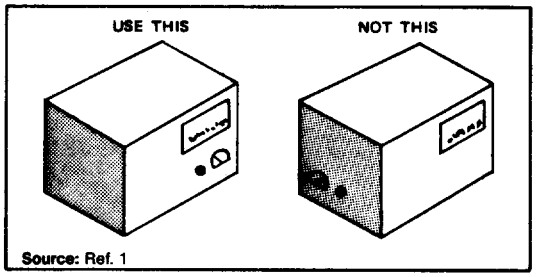

Exhibit 1.5.1 Locating Internal Controls

NOTE: This design should be used only when the access, as shown, does not interfere with normal operation of the equipment.

b. If it is impractical to provide an access to an internally located to remotely located control, a remote control should be provided.

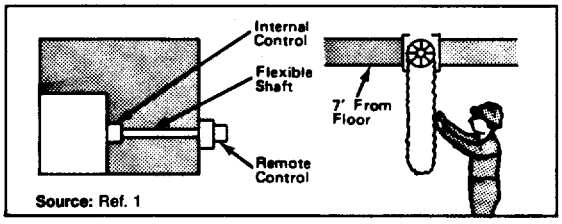

Exhibit 1.5.2 Remote Controls

c. Emergency controls should be located so that they may be activated from any position in the maintenance area. If the work area is especially large and access to a single emergency control is difficult, duplicate controls should be provided.

d. Maintenance controls located on operators' panels should be shielded with removable covers so as not to interfere with the operator's performance while remaining accessible to the maintenance technician.

e. Tool-operated controls should be designed to be operated with hand tools from the technician's standard tool kit. If a special tool is required, it should be attached near the control which it operates.

f. If the maintenance task is one of selecting and calibrating several functionally related variables, a single control and a switching mechanism should be provided to allow simultaneous or sequential operation of each variable as desired.

1.5.3.2 MAINTENANCE DISPLAYS

a. Displays should be located so they are easily visible to the technician.

b. Front panel access should be provided for changing indicator lights when possible.

c. Instrumentation should be designed for mounting and removal from a front panel.

d. All maintenance displays which are relevant to a particular task should be grouped together and observable to the technician while performing the task.

e. If maintenance and operator displays must be located on the operator's panel, maintenance displays should be separated and grouped away from operator displays.

f. Auditory as well as visual warnings should be provided to indicate malfunctions when maintenance must be performed in an area with a high degree of ambient illumination. Visual and auditory displays should operate on separate circuits.

g. Instrument amplifiers should be located as close as possible to their indicators, which will require only one technician to make the needed calibrations.

1.5.4 SPECIFIC PRINCIPLES

1.5.4.1 MAINTENANCE CONTROLS

a. Tank and reservoir drain valves should be located so they may be removed from outside the tank or reservoir.

b. Labels or other marking devices should be provided to clearly designate the position of a valve control. A rider may be attached to the shaft with marks to indicate the fully opened and fully closed positions.

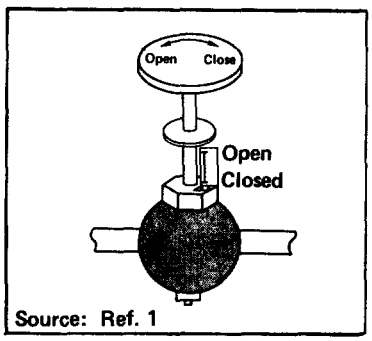

Exhibit 1.5.3 Valve Control Labels

c. Valves should be color-coded by content of the substance which they control.

Contents	USAF Color
Fuel	Red
Water Injection	Red-Gray-Red
Lubrication	Yellow
Hydraulic	Blue & Yellow
Pneumatic	Orange & Blue
Instrument Air	Orange & Gray
Coolant	Blue
Breathing Oxygen	Green
Air Conditioning	Brown & Gray
Fire Protection	Brown
De-icing	Gray
Compressed Gasses	Orange
Electrical Conduit	Brown & Orange

Source: Ref. 1

Contents	Navy Color for Valve Handwheels & Operating Levers	Fed. Std. 595 Color Number and Chip	Navy Standard for Interior Pipe Lines*
Steam	White	17886	A and B
Potable-Water	Dark Blue	15044	A and B
Nitrogen	Light Gray	16376	A
H.P. Air	Dark Gray	16081	A
L.P. Air	Tan	10324	A
Oxygen	Light Green	14449	Light Green
Salt Water	Dark Green	14062	A and B
Fuel Oil	Yellow	13538	A
Lube Oil	Yellow	13538	A
Fire Protection	Red	11105	A
Foam Discharge	Striped Red/Green	11105/14062	A
Gasoline	Yellow	13538	Yellow
Feedwater	Light Blue	15200	A and B
Hydraulic	Orange	12246	A
Freon	Dark Purple	17100	A
Hydrogen	Chartreuse	23814	A
Sewage	Gold	17043	A

*Applies to valves on weather decks and interior piping only.

Exhibit 1.5.4 Examples of Valve Color-Coding Scheme

1.5.4.2 MAINTENANCE DISPLAYS

a. Liquid level indicators should be located so that a minimum of visual parallax is present.

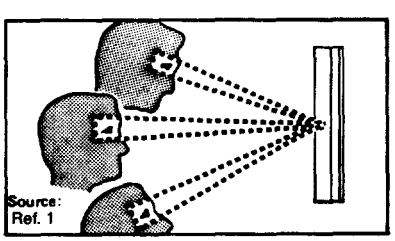

Exhibit 1.5.5 Minimizing Visual Parallax

b. Liquid level indicators should be used for oil tanks or similar reservoirs so that maintenance technicians can tell whether the reservoirs are filled properly.

c. Liquid level indicators should have adequate contrast between the background of the indicator and the color of the liquid it contains.

d. Markings should be etched or painted on the glass of a liquid level indicator to eliminate the need for looking through the liquid to the scale.

e. Plug-in meters/displays should be designed in such a way that they are visually accessible while performing a maintenance task.

f. Means of indicating a "tripped circuit breaker" should be provided.

g. Where possible, direct-reading type indicators should be used for hydraulic and other fluid tanks. For example, to facilitate quick visual inspection of the presence of oil in gear cases, oil level sight plugs may be used. This eliminates the need for dipsticks or fluid level gauges.

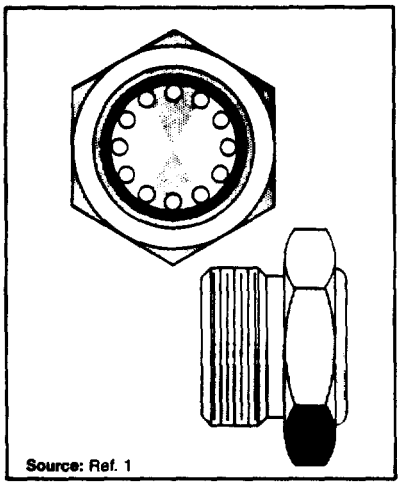

Exhibit 1.5.6 Oil Level Sight Plug

h. To avoid computational errors in weight and balance from a volumetric figure for fuel, a gauge should be provided which measures the weight of fuel in pounds.

i. The lubrication system of an assembly should be provided with gauges necessary to keep the maintenance technician fully informed about the condition of the equipment, i.e., oil temperature, inlet, and outlet pressure gauges should be provided.

j. Oil dipsticks should be designed to:

   (1) Provide contrast between the finish of the dipstick gauge and clear thin oil.

   (2) Make interpolation of liquid level observations unnecessary by graduating the dipstick in increments.

k. Magnetic chip detectors should be provided in lube systems rather than electrical detectors since the latter create maintenance problems.

1.0 ENGINEERED HARDWARE

1.6 Line and Cable Design for Maintainability

1.6.1 INDEX

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1.6.2 DEFINITIONS

Lines refer to any single length of pipe, wire, or tubing.

Cables refer to a number of lines bound together within a single, permanent sheath.

1.6.3 GENERAL PRINCIPLES

1.6.3.1 Lines and cables should be selected, designed, bound, mounted, and routed to:

a. Preclude wearout, breakage, or damage.

b. Facilitate logical and efficient divisions of maintenance responsibilities.

c. Allow for quick and easy:

(1) Troubleshooting, testing, checking and isolation of malfunctions.

(2) Tracing, removal, repair, and replacement.

(3) Connecting and disconnecting.

1.6.3.2 Lines and cables should be designed to minimize the number of:

a. Types and varieties of lines and cables.

b. Different lengths of identical lines or cables.

c. Related connectors, fittings, and fixtures.

1.6.3.3 Lines and cables should be routed and mounted to be accessible:

a. With minimum disassembly required or removal of other equipment or items.

b. Especially at connect, test, mount, and splice points.

c. For complete removal and replacement in case of damage.

1.6.3.4 Lines and cables should be routed over the shortest runs allowable by lead, mounting, and other requirements.

1.6.3.5 High pressure or high voltage lines and cables should be routed away from sensitive equipment, high temperature sources, work areas, controls, etc. where personnel may require access.

1.6.3.6 Lines and cables should *not* be routed through remote switches or valves which may be inadvertently used while work is being performed on equipment.

1.6.3.7 Lines and cables should be routed so they will *not* be:

a. Used for hand-/footholds.

b. Bent or sharply twisted.

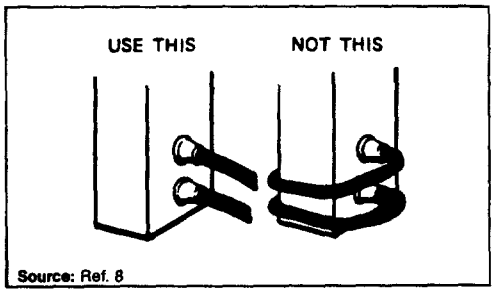

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Exhibit 1.6.1 Proper Routing of Cable to Avoid Sharp Bends

c. Walked on or rolled over by heavy traffic.

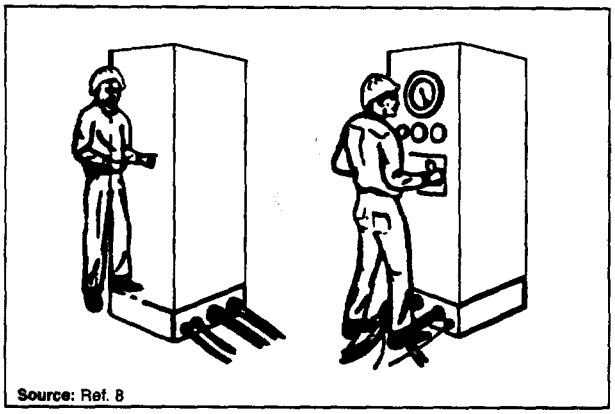

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Exhibit 1.6.2 Proper Routing of Cable to Avoid Walking On

d. Pinched or stressed by loose objects, doors, lids, covers, sliding drawers, or roll-out racks.

1.6.3.8 Lines and cables should be mounted so that:

a. They will not interfere with other maintenance operations.

b. They will not chafe or flex excessively under predicted conditions of use.

c. Protection from metal edges is provided by grommets or pads.

d. They are securely anchored to the chassis by clamps or plates.

e. They are not terminated or mounted on the front of cabinets or control-display panels (test cables excepted).

1.6.3.9 Clamps or mounting plates used for mounting should:

a. Fit snug without deforming or crimping the line or cable.

b. Be spaced no more than 24 inches apart.

c. Be put at both ends of bends where the bending radius is 3 inches or less.

d. Be lined with heat resistant material if the line is likely to become extremely hot.

e. Be non-conductive or properly insulated if they are securing a conductor.

f. Require only one-handed operation with common hand tools.

g. Be of a quick release, hinged, or spring type if the line or cable must be frequently removed. Hinged clamps are preferred; they support the weight of the line during maintenance, freeing the technician's hands for other tasks.

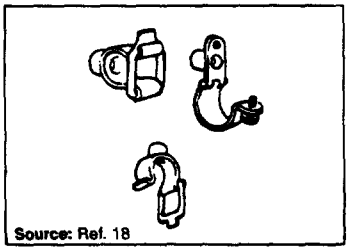

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Exhibit 1.6.3 Quick Release, Hinged and Spring Type Clamps

h. For overhead mounting, be of a spring clamp type with a hinged locking latch over the open side of the clamp to prevent accidents.

1.6.3.10 Adequate storage and handling provisions should be made for extension-type lines and cables such as:

a. Covered storage space in ground support equipment for storing lines and cables.

b. Suitable racks, hooks, or cable winders within the storage place to hold lines and cables conveniently.

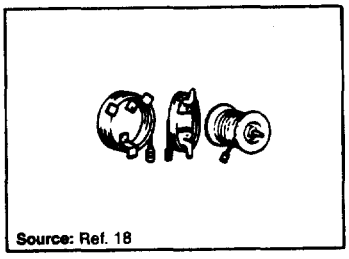

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Exhibit 1.6.4 Line and Cable Rack, Winder, and Hook

c. Reels or reel carts for handling large, heavy, or long lines or cables. Automatic rewind should be available, where possible, to minimize damage and kinking.

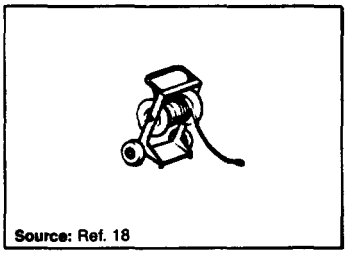

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Exhibit 1.6.5 Line and Cable Reel Cart

d. Wheels or other mobile supports for especially large lines or cables that must be frequently moved.

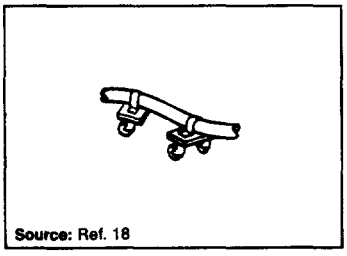

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Exhibit 1.6.6 Line and Cable Mobile Support

1.6.4 SPECIFIC PRINCIPLES

1.6.4.1 ELECTRICAL WIRE AND CABLE DESIGN

a. The layout and routing of wires and cables should be predetermined and made as simple and functionally logical as possible by:

(1) Combining conductors into cable wherever practical.

(2) Combining conductors into harnesses wherever cables are not used.

(3) Segregating conductors into and within cables or harnesses according to their functions and relationships to replaceable equipment.

(4) Using preformed cables wherever possible to minimize wiring errors and to allow more flexible and efficient assembly methods. Provide spare leads in cables to allow for growth and to speed wiring time.

(5) Where possible, use physical measures, such as cable length, to prevent interchanging units or components with the same or similar form, that are not, in fact, functionally interchangable (MIL-STD-1472C, pg. 179, 5.9.1.9a).

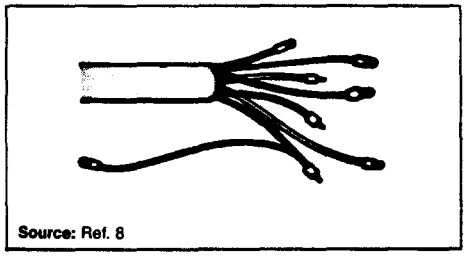

Exhibit 1.6.7 Preformed Cables

b. Wire connections should conform to the following recommendations:

(1) For easy maintenance, plug-in contacts are better than screw terminals and screw terminals are better than solder connections.

(2) The end of a wire soldered to a terminal should be left out of the solder so that the wire will be easy to remove.

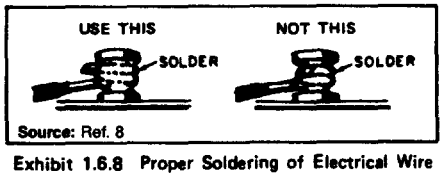

Exhibit 1.6.8 Proper Soldering of Electrical Wire

(3) U-lugs should be used rather than O-lugs whenever practicable.

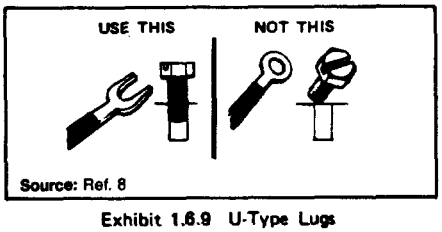

Exhibit 1.6.9 U-Type Lugs

(4) Separate terminals to which wires are to be soldered should be separated far enough apart so that work on one terminal does not damage neighboring ones.

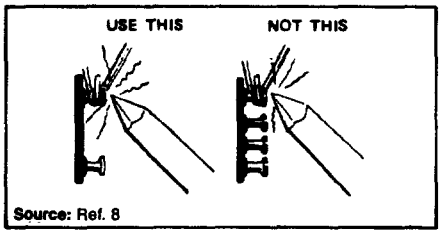

Exhibit 1.6.10 Proper Spacing of Wire Leads

(5) Terminals or other connections to which wires are soldered should be made long enough so that insulation and other materials are not burned by the hot soldering iron.

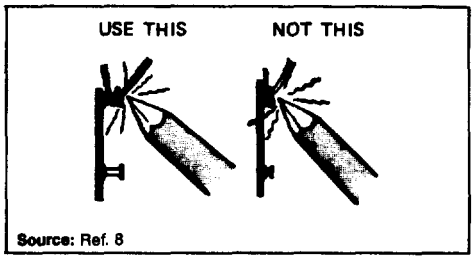

Exhibit 1.6.11 Proper Length of Terminals and Connections

c. Harnesses should:

(1) Be designed, fabricated, and installed as units.

(2) Be held securely with lacing twine or other means acceptable to the user.

(3) Keep the individual conductors essentially parallel, so they do not intertwine, though twisted pairs may be used when required.

d. Lead lengths should be as short as is consistent with the task to be performed, but long enough to allow:

(1) Easy connection and disconnection, with enough slack to back the wire away from the point of attachment to facilitate removal of the unit.

(2) Sufficient slack for at least two (preferably six) replacements of terminal fittings, electrical considerations permitting.

(3) Movements of moving parts to which they may be attached (doors, covers, etc.) without undue stress or bending.

(4) Connection, disconnection, or movement without requiring a bending radius of less than six times the diameter of the lead.

(5) Movement of the units which are difficult to handle in their mounted position to a more convenient position for connection or disconnection.

e. Extension cables should be planned, designed, and provided to:

(1) Increase the efficiency and ease of maintenance.

(2) Avoid removal of assemblies or components for testing.

(3) Allow each functioning unit to be checked in a convenient place.

(4) Allow support equipment to be parked or set in a convenient place.

(5) Serve as many related functions as possible, yet avoid the possibility of misuse or misconnection.

f. Mounting of wires and cables, in addition to satisfying the General Principles previously listed, should:

(1) Ensure that lightly insulated wires clear parts normally at ground potential by at least 0.75 inches under operating conditions.

(2) Employ raceways, stuffing tubes, conduit, junction boxes, and insulation as necessary to obtain the required degree of protection, security of mounting, and ease of maintenance.

(3) Ensure that adequate accessibility is provided to raceways, stuffing tubes, etc.

(4) Allow checking of the signal flow through each conductor by arrangement, location, and mounting of leads; provide test points where leads are unavailable for testing; and provide test points in connectors.

g. Leads should be mounted so they:

(1) Do not bear the weight of the cable, harness, or other components.

(2) Are provided with support at splices and points of connection.

(3) Are "fanned out" to provide adequate clearance for the technician's hand and/or any tool required for checking or connection.

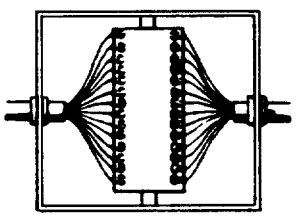

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Exhibit 1.6.12 Cable "Fanning" for Ease of Maintenance

(4) Are oriented, where possible, in such a manner as to prevent erroneous connection or "crossing."

(5) Do not allow flexing at weak areas, e.g., at splices, solder points, or where the conductor is bare or crimped, or strands are tinned together.

h. Leads or cables to moving parts, doors, covers, etc. should have adequate slack and protection so they:

(1) Allow movement of the part (door, etc.) without their disconnection.

(2) Fold out of the way automatically when the part is moved.

(3) Do not chafe or break under the repeated flexing required.

(4) Are not pinched or otherwise damaged by movement of the part.

i. When determining materials to be used for wire and cable applications, the following should be considered.

(1) Clear plastic insulation allows rapid detection of internal breaks.

(2) When polyvinyl wire is used, care should be taken so there will be no cold flow of insulation due to tightness of lacing or mounting.

(3) Neoprene-covered rather than aluminum-sheathed cable should be used in areas where intense vibration or corrosive substances may cause failures.

(4) High-temperature wire should be used when wires are routed near ducts carrying pressures over 50 psi and/or temperatures above 200° C (392° F).

(5) Metallic shielding unprotected by outer insulation should be secured to prevent the shielding from contacting exposed terminals or conductors.

j. Wire and cable insulation should be protected from termite destruction by coating them with compounds of creosote, antimony, or other mixtures acceptable to the user.

k. Insulated wire or cable should be color- or number-coded in accordance with standards acceptable to the user (e.g., MILSTD-195; MILSTD-681).

1.6.4.2 FLUID AND GAS LINE DESIGN

(a) Lines for fluids and gases should be designed and routed to prevent:

(1) Misconnection during servicing or maintenance operations.

- Fittings should be standardized so it is impossible to interchange lines that differ in content.
- Employ arrangement, size, shape, and color coding as necessary to prevent interchange of adjacent lines.
- All fluid carrying lines should be identified by color bands.

(2) Spraying or draining on personnel or equipment during disconnections.

- Connections should be located away from work areas and sensitive components.
- Shielding should be provided for sensitive components where required.
- Drains and bleed fittings should be provided to allow draining or reduction of pressure prior to disconnection.
- High visibility warning signs should be provided at disconnect areas or where pressures or the content of lines could injure personnel.

(3) Drainage problems.

- Lines should be designed to be completely emptied when required.
- Avoid low points or dips in lines that are difficult to drain.
- Make bends, where possible, in the horizontal rather than the vertical plane, to avoid fluid traps.
- Low point drains should be provided where required to drain such traps.

b. Lines for fluids and gases should be mounted and installed.

(1) Rigid lines should be installed with fittings that do not require the line to be backed-off for disconnection.

(2) Tubing should be used instead of rigid lines, because it allows more flexibility in handling, can be backed-off easily, and is easier to thread through equipment when replacement is required.

(3) Flexible hose should be used rather than pipes or tubing where minimum space is available for removing, handling, or replacing lines.

(4) Adequate supports should be provided for lines which run from external service or test equipment, or where extensions will be attached for other purposes. These supports must withstand:

- The initial surges of pressure through the line.
- The weight of the external extensions.
- The rigor of handling and repeated connection and disconnection.

(5) Lines should be mounted and installed in such a way as to preclude kinking by:

- Employing sufficient mounts and supports to prevent kinking.
- Employing quick-disconnect fittings to reduce manhandling of lines during connection or disconnection.
- Eliminating work space restrictions around mounts and connections that may cause the technician to bend the line in installation, disconnection, or removal.

1.0 ENGINEERED HARDWARE

1.7 Test and Service Point Design for Maintainability

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1.7.4.2 Service Points 1.7-5

1.7.2 DEFINITIONS

Test points are means for conveniently and safely determining the operational status of equipment and isolating malfunctions. Test points, strategically placed, make signals available to the technician for checking, adjusting, or troubleshooting.

Service points are means for lubricating, filling, draining, charging, and similar service function. Service points allow adequate adjustment, lubrication, filling, changing, charging, and other services to be provided on all equipment and components requiring such service between overhauls.

1.7.3 GENERAL PRINCIPLES

1.7.3.1 Requirements for periodic or repetitive testing and servicing of components should be avoided when possible by using sealed bearings, oil impregnated bushings, highly reliable components, etc.

1.7.3.2 To reduce the number of test and service points required, built-in indicators, pressure gauges, direct reading fluid level gauges, etc. should be used for quick checks without the need of auxiliary equipment.

1.7.3.3 Test and service points should be designed for compatibility with checking, troubleshooting, and servicing procedures and test/service equipment.

1.7.3.4 Different types of the following items should be minimized:

a. Test and service equipment and accessories required.

b. Fixtures required (fittings, connectors, etc.).

1.7.3.5 Distinctively different connectors or fittings should be provided for each type of test or service equipment, probe, grease, oil, etc. to minimize the likelihood of error or misuse.

1.7.3.6 Test and service points should be located so they are:

a. Recessed, guarded, or otherwise protected from damage by personnel, moving cargo or equipment, dust, moisture, etc.

b. Within each functional reaching and/or seeing distance of related or corresponding controls, displays, fittings, switches, etc.

c. Convenient to related maintenance support equipment and compatible, in terms of work space and clearance requirements, with the various features and characteristics of such equipment.

d. Away from dangerous electrical, mechanical, or other hazards. More than a hand's width (4.5") separation from the nearest hazard should be provided, and guards and shields should be provided as necessary to prevent injury.

e. Not concealed or obstructed by bulkheads, brackets, other units, etc., and so it is not necessary to disassemble, remove, or support other units, wires, etc. to test, service, or troubleshoot.

1.7.3.7 Locations of internally located points should be indicated on the access plate or adjacent surface of the equipment.

1.7.3.8 Safety valves should be located where they are readily accessible, but where pop-off action will not injure personnel or damage equipment.

1.7.3.9 Fluid fill areas for combustible materials (fuel, oil, etc.) should be located away from sources of heat, sparking, or potential voltage shorts.

1.7.3.10 Fluid fill areas should be located so there is little chance of spillage during servicing, especially on personnel or easily damaged equipment.

1.7.3.11 Connectors or fasteners for test and service points should:

a. Use direct insertion or quick disconnects except on pressurized systems.

b. Key the connectors on pressurized systems so they are properly seated before an opening occurs, to prevent loss of gases or fluids and reduce the hazards involved.

c. Require only hand operation by common hand tools. Special tools should not be required for the connection of test and service equipment.

d. Incorporate holding devices, clamps, and auxiliary shelves to support test probes, test sets, etc., and free the technician's hands for other tasks, such as making adjustments.

e. Incorporate guards and shields to protect personnel and test or service equipment, particularly if the equipment must be serviced while running.

f. Employ self-sealing elastomers or similar devices to allow probing into hermetically sealed units. Such devices should be provided with tool guides to ensure that proper contact is made.

1.7.3.12 Test and service points should be designed so they are easily distinguishable. Color coding with a distinctive color may make them more easily located by the technician. Color for test points should be clearly different from the color used for service points.

1.7.3.13 Luminescent markings for test and service points should be used if they must be used in low illumination.

1.7.3.14 When a test or service point is internally located, its location should be indicated on the access plate on the surface of the equipment.

1.7.3.15 Dangerous test and service points should be labeled as such. The labeling should be clearly visible, using capital letters.

1.7.4 SPECIFIC PRINCIPLES

1.7.4.1 TEST POINTS

a. **DESIGN OF TEST POINTS**

(1) If internal probing of hermetically sealed units is required, accesses should be covered with self-sealing elastomers, and needle probes should be used.

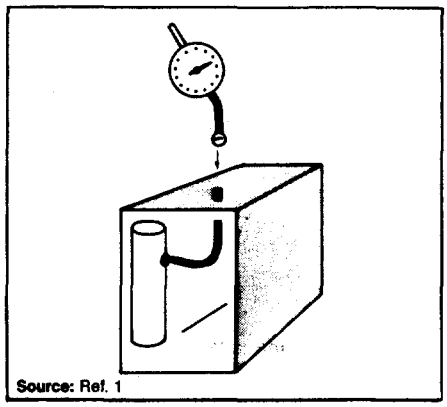

Exhibit 1.7.1 Internal Needle Probe and Self-Sealing Elastomer

(2) High pressure test indicators should be built wherever possible to avoid some of the dangers in temporary high pressure connections.

(3) A special "ground" point should be provided if a good grounding point is not available and connection to ground should be made during tests of a given unit. Technicians may have difficulty if only painted surfaces are available for ground connections.

(4) Suitable guides for test probes should be provided when test points are located internally.

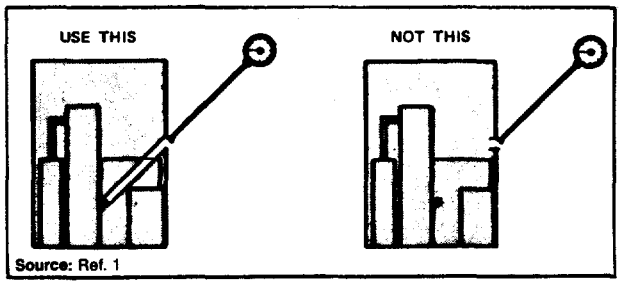

Exhibit 1.7.2 Test Probe Guides

b. **LOCATION AND GROUPING OF TEST POINTS**

(1) The functional location of test points should be fixed by determining from maintenance procedures the signals that must be available to the technician and at what points they must be available.

(2) Generally, test points should be concentrated in one place, but practical limitations do not always make this possible.

(3) Highly accessible test points should be provided for checking and troubleshooting.

(4) Accessible test points should be provided on fuel, hydraulic, and pressure systems that will eliminate the need for:

- Removing fittings to attach test equipment.
- Removing components such as fuel pumps and actuators during troubleshooting.

(5) Test accesses should be provided for mechanical components likely to wear. For example, brake assemblies should be provided with an inspection opening to permit insertion of a gauge for determining the clearance between the brake lining and drum.

(6) On electrical equipment, cables should be fanned out on terminal strips if special test points are not provided.

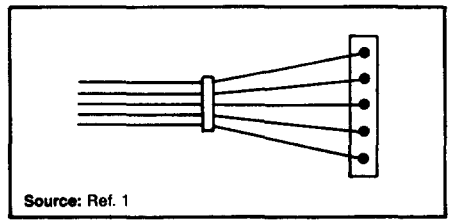

Exhibit 1.7.3 Fan Out Cables for Test Points

(7) When possible, test points should be grouped on a central panel to facilitate checking and troubleshooting.

(8) Test points should be located so they are in a convenient arrangement for sequential checking.

(9) When test points are located on one central test panel, they should be grouped according to the units which are used for testing.

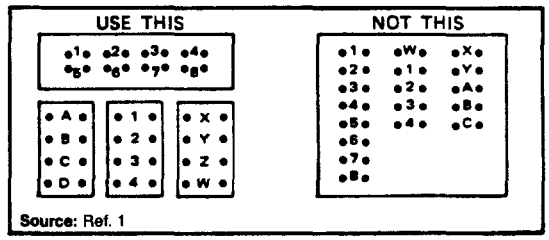

Exhibit 1.7.4 Proper Test Point Grouping

(10) Test points should be located close to the controls and displays which are used in the checking operation. The technician should be able to activate the control and see the display at the same time.

c. **ALTERNATE TEST POINT ARRANGEMENTS**

(1) **A BUILT-IN TEST UNIT.** *An arrangement built in* as part of the installation is most desirable for efficient maintenance and troubleshooting. If voltages and wave shapes must be checked, for example, the test unit might consist of a meter, an oscilloscope, and a rotary switch for selecting circuits. The meter and oscilloscope should have fixed, preset circuits so that the meter always reads center scale and the oscilloscope needs no adjustment. Either an in-tolerance meter reading or an in-tolerance waveform on the oscilloscope should be coded for each position of the rotary switch. If more test points are needed than can be handled by a single switch, multiple switches could be used.

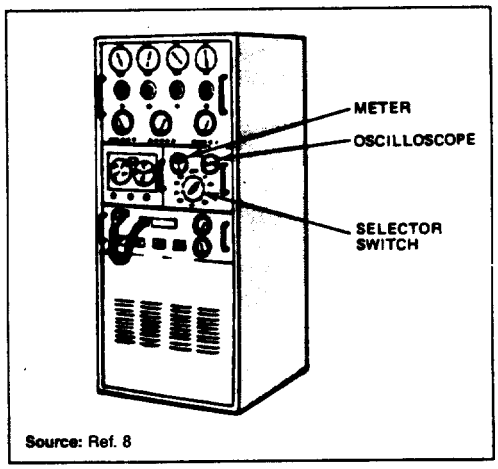

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Exhibit 1.7.5 Built-In Test Unit

(2) **A PARTIALLY BUILT-IN TEST UNIT.** Because some oscilloscopes are large, heavy, and expensive, it may not be practical to design a test unit such as that recommended in (1) above for each major component of a system. An acceptable compromise is to mount a center-reading meter on each major component that can be checked by meter and then provide a set of test jacks as an outlet for signals requiring an oscilloscope. The selector switch and circuits for this arrangement should be designed as before.

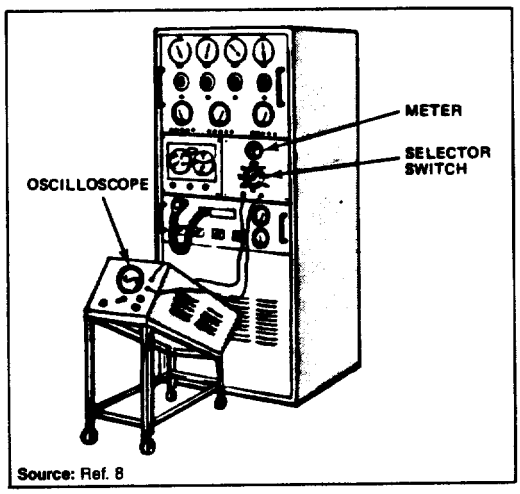

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Exhibit 1.7.6 Partially Built-In Test Unit

(3) **A PORTABLE TEST UNIT.** If neither of the two built-in test arrangements is practical because of space or weight limitations, an integrated portable test unit resembling the built-in unit may be used. A single, multiprong contact on the end of a cable can be used to attach the test unit.

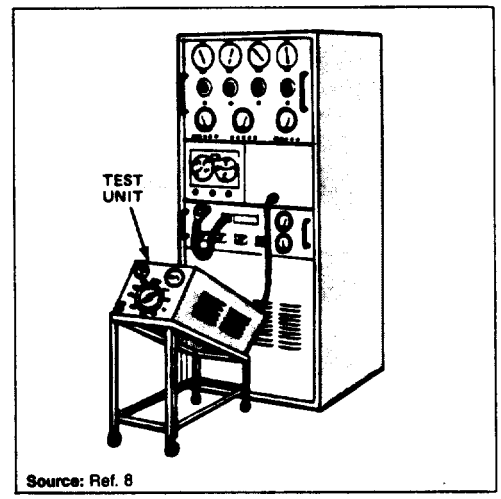

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Exhibit 1.7.7 Portable Test Unit

(4) **A BUILT-IN TEST PANEL.** If, for some reason, none of the alternatives described previously is practical, a test panel should be provided on the equipment. With this arrangement, the outputs of each test point should be designed for checking with standard test equipment, and the points should be planned to provide a miniature block diagram of the system, with each block representing a line replaceable unit. Overlays for the test panel should direct the technician to test points he should check and the order in which he should check them. In-tolerance signals should be shown on the overlays, and test points should be coded on the panel with full instructions provided in the maintenance manual in the event the overlay is lost.

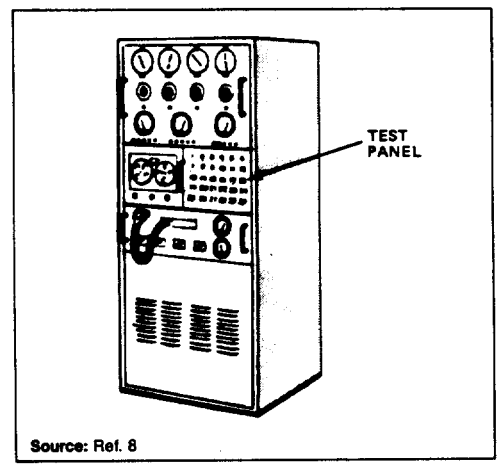

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Exhibit 1.7.8 Built-In Test Panel

(5) **TEST POINTS ON REPLACEABLE UNITS.** If none of these arrangements is practical, test points should be provided for the inputs and outputs on each replaceable unit. If possible, components

should be mounted on one side of the board or chassis and wiring on the other side. Even if the wiring is mounted on the same side as the parts, test leads should be brought through to the back. An advantage in having test points on the back is that full identifying information for each test point can be marked on the back without being obscured by parts.

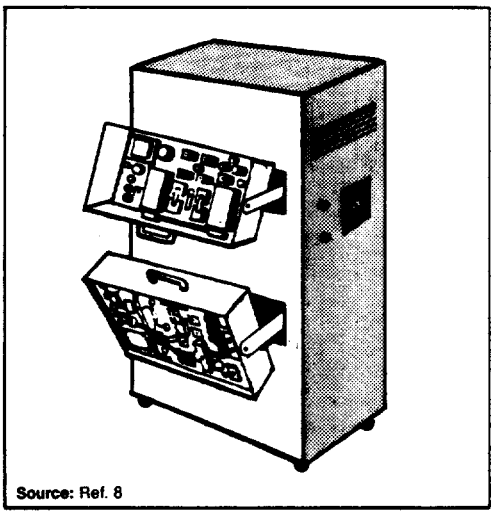

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Exhibit 1.7.9 Test Points on Replaceable Units

d. **LABELING AND CODING**

(1) Test points should be labeled with the name of what is being tested. If it is not possible to include the name on the test point, it should be coded with a symbol. Explanations for symbols used should be in tables placed near the equipment or in job instructions.

(2) Test point labels should be located consistently throughout the system and should be consistent with identifiers used in maintenance instructions.

(3) Test points should be labeled with in-tolerance indications or tolerance limits of the signal being measured there.

(4) Color coding of test points should be considered for easy location.

(5) Phosphorescent or chemoluminescent markings should be used on test points, selector switches, and meters that require reading in low light conditions.

1.7.4.2 SERVICE POINTS

a. **DESIGN OF SERVICE POINTS**

(1) Lubrication points should be designed with a reservoir to reduce the frequency of required lubrication.

(2) Service fittings should be designed to be hand operable or to require only common hand tools. Petcocks and valves are preferred to drain plugs.

(3) Guards should be provided around lube points which may be serviced while equipment is operating.

(4) Grease fittings should be standardized for a given lubricant so that the number of different grease gun tips required is minimized.

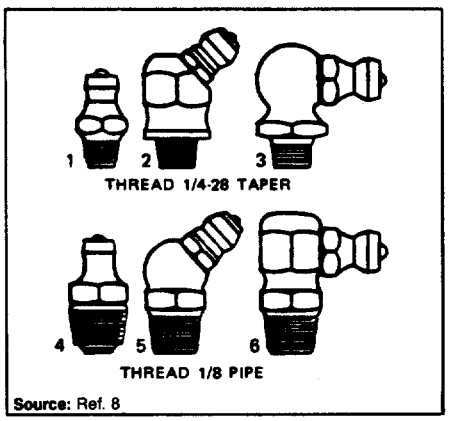

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Exhibit 1.7.10 Example of Typical Lubrication Fittings

(5) Oil filler caps should be designed so they:

- Snap and remain open and closed.
- Provide a large round opening for oil filling.
- Permit application of breather vents, dipsticks, and strainers.
- Use hinges rather than chains for attaching the lid.
- Look different when opened or closed.

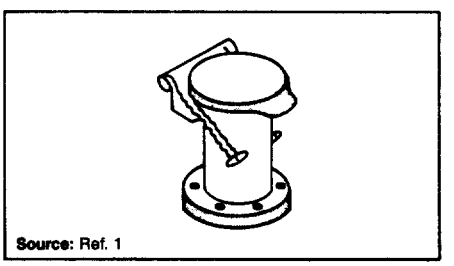

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Exhibit 1.7.11 Example of Well-Designed Oil Filler Cap

(6) Pressure fittings should be provided for applying grease to bearings which are shielded from oil.

(7) The same fuels and lubricants should be used in auxiliary or mounted equipment, as in the prime unit, when possible.

(8) Lubrication requirements should be reduced to two types, if possible; one for engine and another for gear lubrication.

(9) If lubrication is required, lubrication points rather than equipment disassembly should be provided.

(10) If lubrication points are not feasible, easy access to equipment should be provided.

b. **FLUID LEVEL INDICATORS**

(1) Direct reading gauges are preferable to dipsticks or other methods of indicating fluid levels, because they allow rapid, immediate, and continuous inspection, and thus remove requirements for inspection tables.

(2) If used, gauges or dipsticks should be calibrated in terms of functional units (quarts, pounds, gallons, etc.), rather than in general terms such as dry, low, add, etc.

(3) If used, gauges or dipsticks should be immediately accessible and quickly and easily read, i.e., there

should be good contrast between the finish of the gauge and the fluid.

c. **DRAIN POINTS/BLEED FITTINGS**

(1) Provide drains on all fluid tanks and systems, fluid filled cases or pans, filter systems, float chambers, and other items which are designed or likely to contain fluid that would otherwise be difficult to remove.

(2) Use drain fittings of a few types and sizes, and standardize these according to application throughout the system.

(3) Use valves or petcocks in preference to drain plugs. Where drain plugs are used, they should require only common hand tools for operation, and design must ensure adequate tool and work clearance for operation.

(4) Drain cocks or valves should be clearly labeled to indicate open and closed positions, and the direction of movement required to open.

(5) Drain cocks should always close with clockwise motion and open with counterclockwise motion.

(6) Provide instruction plates as necessary to ensure that the system is properly prepared prior to draining.

(7) Design, locate, and install drain points:

- Where they are readily reachable and operable by the technician.
- So fluid will not drain or spill on equipment or personnel.
- At the lowest point in the system when complete draining is required or when separation of fluids is desired.
- At other points in the system as required to permit selective draining or bleeding to facilitate maintenance procedures.
- To permit drainage directly into a waste container without use of separate adapters or piping.
- So fuel or other combustible fluids cannot run down to or collect in the starter, exhaust, or other hazardous areas.

d. **LOCATION AND GROUPING**

(1) Lubrication points should be located so that they are easily accessible. Lead tubes or extended fittings should be provided if required to avoid equipment disassembly or locating a lubrication point in a hard to reach area.

(2) Removing cases, covers, or other pieces of equipment should be avoided to obtain access to lubrication points by:

- Locating oil dipsticks and other such level indicators so that they may be fully withdrawn without touching other pieces of equipment.
- Locating lubrication test points close to corresponding lubrication add points, if possible.

(3) When possible, a central lubrication point or grouping of points should be provided for applying lubricant to all areas which require lubrication within a system, subsystem, or major component.

(4) The oil quantity dipsticks should be placed in an accessible location.

e. **LABELING AND CODING**

(1) Lubrication, fuel, and other filling points should be labeled with the type of lubricant or other material which is being replaced or replenished. A log and instructions for lubrication schedule should be included where possible.

(2) Servicing instruction plates should be provided adjacent to servicing points.

(3) Cautions (or overflow mechanisms) should be provided adjacent to lubrication points where excess lubrication is unwanted.

(4) Drain systems should be labeled to indicate proper position of equipment for draining.

(5) Service points should be clearly distinguished from other fittings or breathing holes not to be lubricated or otherwise serviced.

1.0 ENGINEERED HARDWARE

1.8 Test Equipment Design for Maintainability

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1.8.2 DEFINITIONS

Four general types of test equipment are used in maintenance tasks:

a. Built-in test equipment is an integral part of the prime equipment. It may be a complex automatic checker or a simple voltmeter with external leads.

b. Go, no-go test equipment provides only one of two alternative answers to any question. It tells only whether a given signal is in or out of tolerance.

c. Automatic test equipment checks two or more signals in sequence without the intervention of a technician. The test usually stops when the first out-of-tolerance signal is detected.

d. Collating test equipment presents the results of two or more checks as a single display. For example, a light may come on only if a number of different signals are in tolerance.

All test equipment should be designed to satisfy the following functions:

a. Simplify the job of the on-line maintenance technician.

b. Reduce the preparation or turn-around time for systems.

c. Reduce total maintenance costs.

1.8.3 GENERAL PRINCIPLES

1.8.3.1 SELECTION OF TEST EQUIPMENT

a. Test equipment should be designed and selected so that it is easy, fast, and safe to use.

b. The type of test equipment to be used should be decided upon in the early stages of prime equipment design and should be firm by the system/subsystem stage of development.

c. Selecting test equipment depends on:

(1) The mission and operational characteristics of the equipment.

(2) The anticipated reliability of the equipment.

(3) The maintenance structure.

(4) Personnel available.

(5) Operational environment.

(6) Logistics support requirements.

(7) Development time and costs.

d. Advantages and disadvantages of various types of test equipment.

Built-in Test Equipment

Advantages	Disadvantages
• Less likely than portable test equipment to be lost or damaged.	• Likely to add to the weight and space requirements of the prime equipment.
• Available when needed.	• More built-in test equipment may be required because a separate item is usually required for each prime equipment.
• No special storage facilities are required.	• Transportation of built-in test equipment to a point for convenient calibration may be more difficult than transportation of portable test equipment.
• Transportation to the prime equipment for use in maintenance is not required.	• Permanent installation of the test equipment may increase the complexity of wiring for the system and may even increase the amount of required maintenance for the prime equipment.

Go, No-Go Test Equipment

Advantages	Disadvantages
• Presents information that is clear and unambiguous.	• Unique circuitry usually required for each signal value to be tested. Sometimes, however, ordinary displays can be converted to go, no-go by appropriate use of reference scales such as a colored section on a meter dial.
• Usually easy to read.	• The increase in the number and complexity of circuits usually required adds to initial cost and development time; it is also likely to increase the rate of test equipment breakdown.
• Can simplify difficult tasks such as balancing circuits or checking complex waveshapes.	• Except in long, fast check sequences, go, no-go equipment is of relatively little help to the technician in checking common voltages or simple waveshapes.
	• Likely to require modification when prime equipment is modified. A special model may be required for each model of prime equipment.

Automatic Test Equipment

Advantages	Disadvantages
• Can make a rapid sequence of checks with little or no chance of omitting any steps.	• Cost, size, weight, and maintenance requirements are relatively high.
	• This type of equipment is relatively specialized, with little versatility.
	• Must almost necessarily have self-checking features to detect test equipment malfunctioning. This adds to cost and to problems of maintaining the test equipment.
	• More likely to require modification when prime equipment is modified. A special model may be required for each model of prime equipment.

Collating Test Equipment

Advantages	Disadvantages
• Reduce the number of displays the technician must read, thereby reducing check time and probably reducing errors.	• Similar to those for go, no-go and automatic test equipment.

Collating test equipment should indicate not only that all signals are or are not in tolerance; it should also provide an indication of which signal, if any, is out of tolerance. If only the collated display is presented, the equipment will not be an aid to troubleshooting.

1.8.3.2 CHARACTERISTICS OF TEST EQUIPMENT

a. Controls and displays required on test equipment should be kept to a minimum.

b. The number and complexity of steps required to operate the test equipment should be minimal. This may be accomplished by "ganging" certain controls or by making certain operations automatic.

c. Operating instructions for the test equipment should be available to the technician, clearly written, and easily understandable. A complete set of instructions should be stored with the equipment, and/or a checklist for operating the equipment should be printed on a plate attached to it.

d. Test equipment should be designed either to prevent the technician from making errors or warn him of his errors.

e. Circuit breakers should be grounded on all test equipment to safeguard against damage if the wrong switch or jack position is used.

f. Fail-safe features should be incorporated into the test equipment to minimize the danger to the technician and equipment in case of equipment failure.

g. Test equipment should be built to withstand the rigors of the job.

h. When required to support operations or maintenance functions, rests or stands should be provided on which units can be placed. These stands should include space for test equipment, tools, technical orders and manuals. When permitted by design requirements, such rests or stands shall be part of the basic unit, rack, or console chassis.

1.8.4 SPECIFIC PRINCIPLES

1.8.4.1 ELECTRICAL CONNECTIONS

a. Selector switches should be used on test equipment instead of many plug-in connections (if the effects of switching will not degrade information desired).

b. Test points, adjustment points, cable end connections, and labels should be in full view of the technician making connections or adjustments at that point.

c. The technician should not be required to assume an awkward position to make connections.

1.8.4.2 OPERATION AND MAINTENANCE

a. Equipment should be simple to operate and have self-checking and calibrating features.

b. Test equipment should be designed for operation by one technician.

c. Test equipment should be easily calibrated or equipped with a go, no-go indicator or simple check to determine whether the instrument requires calibration or is malfunctioning.

d. A warm-up indicator should be provided if applicable. Required warm-up time should be shown clearly near the display if no visual signal is provided.

e. A simple check for testing the accuracy of results should be incorporated into the test equipment.

f. Conversion tables should be attached to test equipment when they are required. Standards and tolerances should be explicit.

g. Adjustments required by technicians should be limited to only those that are essential. They should be made by means of "low-go-high" type indicators. Feedback information to the technician should be by qualitative, positive signaling means, such as color-code signals and zero-center meters.

h. Controls and displays should be designed to permit misalignment which may be caused by vibration, service use, or accidental contact.

i. Automatic shut-off capability should be built into the test equipment to insure the equipment is turned off when not in use.

j. Power switches should shut off automatically when instrument's lid is closed.

1.8.4.3 SAFETY

a. Test equipment should be designed so that all exposed moving and cutting parts are shielded.

b. Protrusions, rails, corners, etc. that technicians might come into contact with on the test equipment should be covered with rubber or other appropriate materials.

c. Internal controls should be located away from dangerous voltages.

d. High voltage areas should be insulated or guarded.

e. Wherever a potential hazard exists, adequate warning should be provided.

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1.9.2 DEFINITION

A connector is any fixture designed and intended to join or connect lines (any single length of pipe, hose, wire, or tubing) or cable (number of lines, bound together within a single, permanent sheath).

1.9.3 GENERAL PRINCIPLES

1.9.3.1 SELECTION, DESIGN, AND USE OF CONNECTORS. Decisions affecting the selection, design, and use of connectors should be compatible and co-ordinated with:

a. Line and cable principles.

b. Fastener principles.

c. Mounting and packaging principles.

d. Environmental factors to be endured.

e. Maintenance routines in which connectors will be involved.

f. Reliability of the system in which connectors will be used. Connectors are sources of unreliability and should be considered as such in system design.

g. Reliability of components whose connection they affect. Components of low reliability should be easiest and fastest to disconnect.

1.9.3.2 CONNECTOR OBJECTIVES. Connectors should be selected, designed, and mounted to:

a. Maximize the rapidity and ease of maintenance operations.

b. Facilitate the removal and replacement of components and units.

c. Minimize set-up time of test and service equipment.

d. Ensure compatibility between prime and ground support or auxiliary systems.

e. Minimize dangers to personnel and equipments from pressures, contents, or voltages of lines during the release of connectors.

f. Be operated by hand where possible, or with common hand tools. Requirements for special tools to effect connection, disconnection, or removal of connectors should be avoided.

1.9.3.3 TYPES OF CONNECTORS

a. **PLUG-IN CONNECTORS.** These are the fastest and easiest to use, e.g., simply push in or pull out, but they have low holding power. Plug-in connectors:

(1) Should not be used where stresses or pressures will overcome holding power.

(2) Should not be used where holding power is such that lines are likely to be damaged or connectors loosened by the pulling required to disconnect.

(3) Should be used where possible for all connections that will not be seriously stressed and particularly for those that must be frequently disconnected.

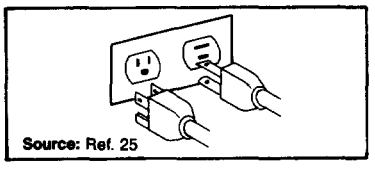
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Exhibit 1.9.1 Example of Plug-In Connector

b. **QUICK-DISCONNECT DEVICES.** These are very fast and easy to use. They exist in a variety of forms and include any type of connector that can be released by snap action, twisting up to a full turn, triggering a latch or spring device, or removing an external pin. Quick-disconnect devices should be:

(1) Designed for hand operation, while catches, pins, etc. should be designed for operation with gloved hands.

(2) Designed to prevent loosening which allows leakage or overheating from pressures or voltages involved.

(3) Provided with self-locking catches, as necessary, to prevent loosening, resist stress, and ensure secure connection.

(4) Used for all connections of:

- Auxiliary, test, or support equipment to other major units.
- Units which require frequent disconnection or replacement.
- Units which require replacement within critical readiness times.

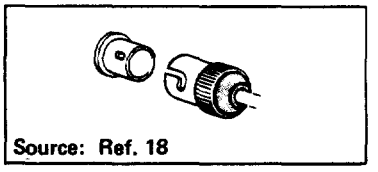
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Exhibit 1.9.2 Example of Quick-Disconnect Connector

c. **LUGS AND CRIMP-ON DEVICES.** These are most useful to connect or splice single wires. Both can be used, and are preferable to soldering, at elevated temperatures.

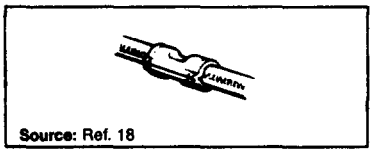
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Exhibit 1.9.3 Example of Crimp-On Lug

(1) Lugs must be compatible with the terminal post requirements.

(2) Where lugs and crimp-on devices are used, slack should be provided for at least six replacements of those devices which must be cut off.

(3) Lugs and crimp-on devices should clamp the insulation as well as the conductor, to provide support for the line and preclude flexing of the conductor against the end of the connector.

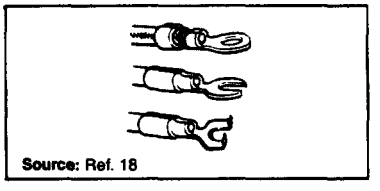
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Exhibit 1.9.4 Example of Proper Attachment of Crimp-On Devices

(4) "U-lugs" should be used rather than "eye-lugs." U-lugs:

- Are easier and faster to connect and disconnect.

- Do not require complete removal of the connecting fastener.
- Are more likely to disconnect rather than allow the line to break under extreme stress.

d. **BOLT OR SCREW ASSEMBLIES.** These provide very secure connection, but also require time-consuming handling and operation of bolts or screws. They are particularly useful for connecting large or high pressure lines.

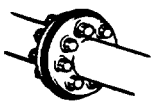

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Exhibit 1.9.5 Example of Bolt Assembly

Bolt or screw connector assemblies must:

(1) Satisfy fastener preferences and requirements.

(2) Ensure adequate work and tool clearances about these fasteners.

(3) Employ the minimum possible number of separate parts.

(4) Satisfy gasket and seal requirements.

e. **THREADED CONNECTORS.** These provide very secure connection, particularly when locked into place by set screws, retainers, or safety wires. They require more time to operate, depending upon the ease of operation, number of turns required, and types of tools required. Connectors should be right-hand threaded.

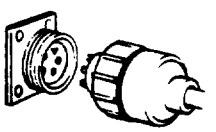

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Exhibit 1.9.6 Example of Threaded Connector

Threaded connectors should:

(1) Require as few turns as are consistent with holding requirement.

(2) Be operable by hand when used for electrical connection.

(3) Require only common hand tools or special tools which are immediately accessible.

(4) Be so designed that the line need not be backed-off to effect connection or disconnection, especially in the case of rigid lines.

(5) Be designed and arranged to reduce the danger of loosening other connectors while working on one. This is a major problem with threaded fasteners on continuous pipe or tube systems.

(6) Be designed so that aligning guides and connector pins are easy to engage and start efficiently to ensure accurate engagement before the threaded section makes contact.

f. **SOLDERING, BRAZING, OR WELDING.** Such methods provide the securest connection, and are often the most efficient way of securing small connection points or maintaining hermetic seals. But such connections require considerable maintenance time for connection or disconnection.

(1) Soldering should satisfy terminal post requirements.

(2) Welding and brazing should be used only for connections that are very unlikely to require disconnection.

(3) These methods should never be used to effect connection of lines or assemblies that may require disconnection by line maintenance personnel.

g. **WIRE-WRAPPING OR PIG-TAILING.** Such methods are only useful for electrical connections and should be avoided because they require more maintenance time, damage conductors, and do not provide reliable contact.

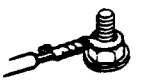

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Exhibit 1.9.7 Example of a Wire-Wrap Connection

1.9.4 SPECIFIC PRINCIPLES

1.9.4.1 ELECTRICAL CONNECTIONS

a. **CONTACT.** Inadequate electrical contact is an ever-present source of intermittent faults. To achieve adequate electrical contact:

(1) Whenever possible, superior insulating materials, corrosion-proof platings, and moisture-proof connectors should be used. If moisture-proof connectors cannot be used, the connector case should contain a drain hole. Vertical mounting of connectors should be avoided.

(2) To protect against corrosion, all parts and mating surfaces of connectors should be coated with an electrical lubricating compound. Metal parts of all medium-, very-high, and ultra-high frequency (MF, VHF, and UHF) connectors should be silver-plated inside and out.

(3) Insertion forces should be kept low to minimize the possibility of damaging contact surfaces on connector parts.

(4) Contacts should be avoided which depend on wires, lugs, terminals, etc. clamped between metal and insulation. These contacts should be clamped between metal members.

(5) Both ends of static discharge lines and grouped wires should be securely fastened. Alligator clips should be used only for temporary grounding or testing because they are fast and easy to use. They should not be used for permanent grounding because they may become inadvertently detached.

(6) Spring contacts should be used which are:

- Relatively long to avoid concentrating stress and permit contact surfaces to wipe each other clean as contact is made.
- Made of beryllium copper where contact is to be frequently stressed—copper is adequate for most other purposes.
- Not stamped from flat metal—these tend to resume flat shape after a number of flexings.

(7) Contact surfaces should be plated with non-tarnishing materials such as:

- Gold—a perfect plating material but very costly.
- Cadmium—satisfactory for most purposes.
- Silver—may be used wherever its tendency to migrate in humid environments does not interfere with circuit operation.

b. **TERMINAL POSTS**

(1) Loose or poorly arranged terminal posts require about three times as long to solder or connect than adequately secured ones. Therefore, posts should be located, constructed, and arranged so that:

- They are accessible.
- A maximum of three wires will be attached to a single post.
- Good electrical contact is assured.
- Posts will not loosen, rotate, or break with repeated usage.
- Wires can be repeatedly removed and replaced, disconnected, and/or soldered without damaging or loosening the posts.
- Adequate hand and tool clearances are provided for connection and disconnection.
- Posts are far enough apart so work (particularly soldering) on one terminal does not damage neighboring connections, insulations, or other parts.

(2) Solder type posts should, in addition, be designed and mounted so that:

- They are completely plated with tin or silver.
- They are notched or provided with other means for mechanically securing the wire prior to soldering.
- The free end of the wire sticks out of the solder and thus can be easily grasped with pliers to facilitate disconnection.
- Supports are provided, where stranded copper wire is to be soldered, to prevent flexing where the strands are tinned together.

c. **ELECTRICAL PLUGS.** Plugs should be designed, mounted, and installed so that:

(1) It is impossible to insert the wrong plug into a receptacle or insert a plug the wrong way into a receptacle. For example, plugs of different sizes may be used for nearby connections; different keys or alignment pins, and/or color-coded paint may also be used on the plug receptacle to which it belongs.

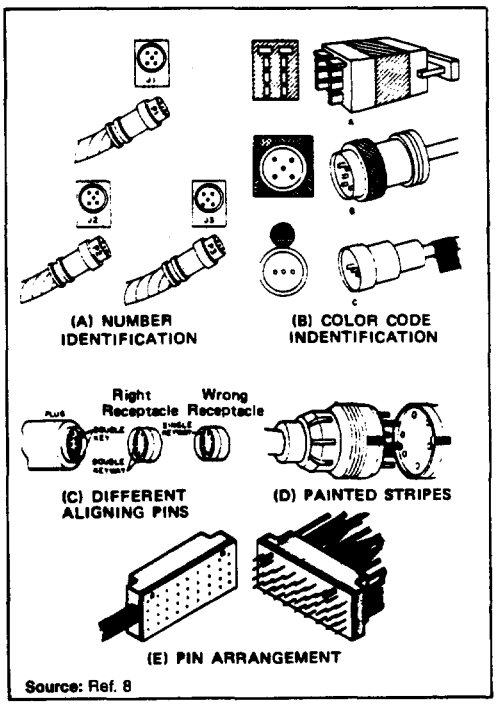

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Exhibit 1.9.8 Plug and Receptacle Identification Methods

(2) Each pin on each plug should be clearly identified, e.g., number and/or letter identification.

(3) Quick-disconnect plugs or plugs that can be disconnected with usually no more than one turn should

be used rather than plugs with fine threads that require numerous turns.

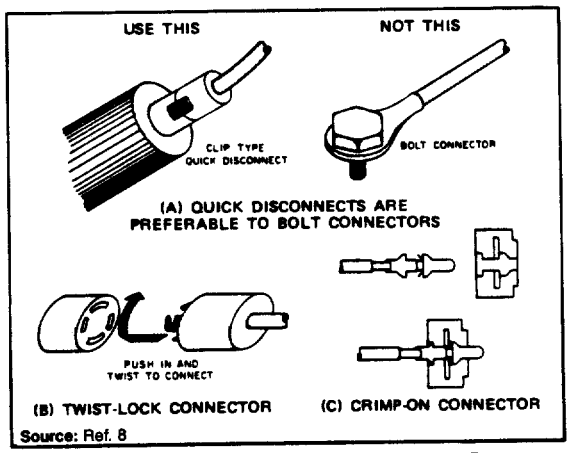

Exhibit 1.9.9 Examples of Quick-Disconnect Plugs

(4) Plugs should be used in which the aligning pins or keys extend beyond the electrical pins. This arrangement protects the electrical pins from damage through poor alignment or twisting of the plug when it is partially inserted.

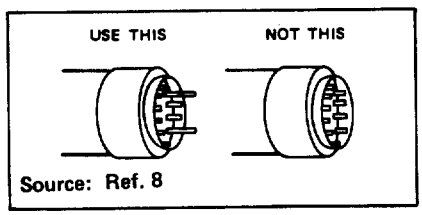

Exhibit 1.9.10 Example of Extended Alignment Guides

(5) Symmetrical arrangements of aligning pins or keys should be avoided so that plugs cannot be inserted 180° from the correct position.

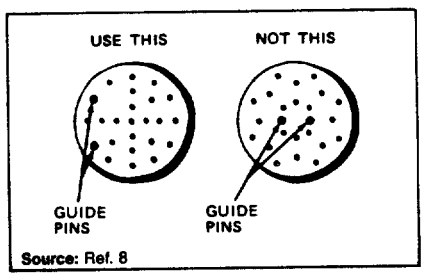

Exhibit 1.9.11 Example of Asymmetrical Aligning Pin Arrangement

(6) Connectors should be located far enough apart so they can be gripped firmly for connecting and disconnecting. The actual space required will vary with the size of the plug, with 2-5 inches between plugs being minimum separation.

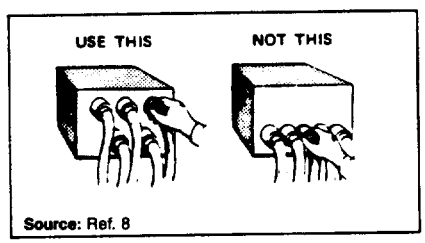

Exhibit 1.9.12 Proper Arrangement of Electrical Connectors

(7) When a part can be removed for maintenance, cables connecting the removable part with the rest of the machine or system should have plugs and receptacles that will disconnect before the cables will break, particularly if non-electronics personnel do the removing. A jerk-open plug will separate before any damage is done; a screw plug will not.

(8) Plugs and receptacles should be used for connecting cables to equipment instead of pig-tailing them. Pigtailed connections are more difficult to replace.

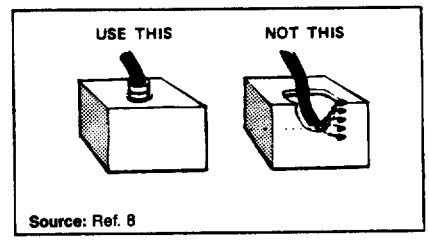

Exhibit 1.9.13 Plug vs. Pig-Tailing Connections

(9) Plugs should be used with integral test points for each input and output that cannot be easily checked. Otherwise, an integral sliding cover for the test points in the plug should be provided if dust or moisture is a problem. As an alternative, a test point adapter may be provided for insertion between plugs and receptacles.

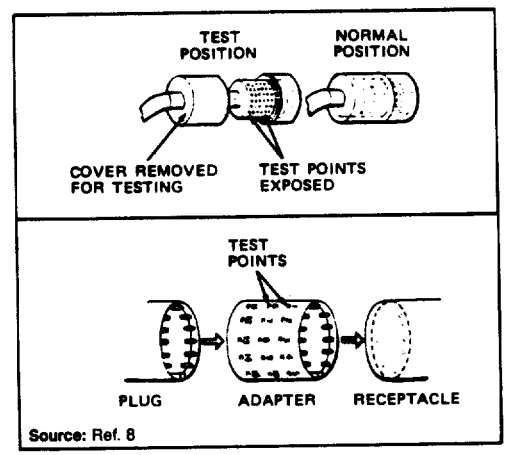

Exhibit 1.9.14 Examples of Plugs With Integral Test Point or Test Point Adapter

(10) Fewer plugs with many pins should be used rather than many plugs with few pins. It takes about the same amount of time to connect a plug with many pins as it does one with few pins.

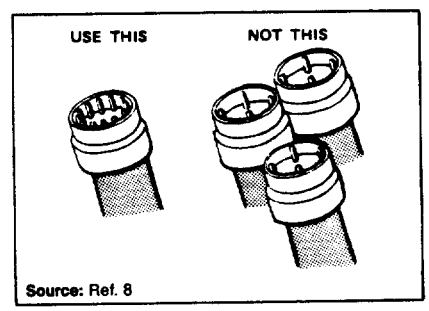

Exhibit 1.9.15 Example of Proper Use of Plugs With Many Pins

(11) Connectors should be used in which electrical contacts cannot be shorted by external objects.

(12) Receptacles should be "hot" and plugs "cold."

(13) Plugs should have a self-locking safety catch rather than require safety wiring. If safety wiring is required, holes and slots should be designed for most efficient and rapid attachment of safety wire.

(14) Plugs and leads should be ensured not to transmit stored charges when being disconnected.

(15) Lead pins and plugs should be designed strong enough to withstand rough use.

(16) Individual power disconnects should be used to permit power to be turned off in one part of the system without disconnecting the entire system.

(17) Power receptacles should be clearly labeled for primary, secondary, or utility systems to prevent injury to personnel or damage to equipment.

1.9.4.2 FLUID AND GAS CONNECTORS

a. Fluid and gas connectors should be located and installed so that:

(1) Backing-off of the line or removal of other components is not required to effect disconnection or removal of related items.

(2) Draining, filling, or other maintenance involving the connectors can be accomplished without jacking up the equipment.

(3) Leakage tests can be performed easily and without endangering the technician. Tests should be planned so the technician does not have to insert his head into areas of extreme noise, vibration, or other danger while the equipment is running.

b. Gaskets and seals used in connections of fluid and gas lines should be selected and installed to:

(1) Be replaceable or have renewable wearing surfaces, rather than require throw-away of the connector when the seal is damaged or worn.

(2) Be easily replaceable without removal of other connector parts or disassembly of other equipment.

(3) Be identifiable with part numbers so they can be easily ordered and handled logistically; the job instructions should specify the life of seals and gaskets and recommend when they should be changed.

(4) Contain or provide features, where required, which:

- Permit lubricant escape under conditions of high pressures.
- Prevent leakage of fluid when disconnect is made.
- Prevent air from entering disconnected lines where such air would create maintenance problems, as in hydraulic lines.
- Allow tightening to offset shrinkage, particularly of rubber seals and gaskets.

c. Gaskets and seals should be used which:

(1) Are visible externally after they are installed, to reduce the common failure to replace seals during assembly or repair.

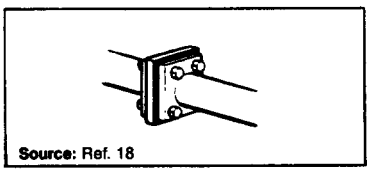

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Exhibit 1.9.16 Example of Externally Visible Gasket

(2) Do not protrude or extrude beyond the coupling. Protruding seals are chipped and shredded by vibration or contact and the damage spreads internally to destroy sealing power and deposit pieces in the line. Tapered nylon or teflon washers of appropriate size can be employed to prevent extrusion.

1.0 ENGINEERED HARDWARE

1.10 Cover, Case, and Shield Design for Maintainability

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1.10.2 DEFINITION

Covers, cases, and shields refer to all protective and packaging devices which guard equipment from damage during shipping or during operation and maintenance on the job site. When necessary to use, covers, cases, and shields should:

a. Maintain the degree of enclosure required by structural, operational, or environmental protection or contol.

b. Divide enclosures into sections which differ because of temperature or ventilation control, types of cleaning methods to be used, etc.

c. Protect personnel from coming into contact with dangerous electrical or mechanical parts.

d. Protect moving parts, fuels, lubricants, etc. from dust, dirt, moisture, etc.

e. Protect delicate or sensitive equipment from damage by movements of personnel, shifting of cargo of loose objects, or actions involved in the installation and maintenance of nearby assemblies.

1.10.3 GENERAL PRINCIPLES

1.10.3.1 GENERAL DESIGN REQUIREMENTS. Covers, cases, and shields should be designed and evaluated based on:

a. The degree to which they contribute to or detract from the speed and ease with which required maintenance is performed. (Refer to Guidelines for Equipment Accessibility, 1.4.)

b. The manner in which they are fastened. (Refer to Guidelines for Fastener Design, 1.11.)

c. Their size, weight, and ease of handling. (Refer to Guidelines for Engineering Anthropometry, 3.1)

d. Provisions for handles or tool grips. (Refer to Guidelines for Handle Design, 1.13, and Tool Design, 2.3.)

e. Work space and clearance around them. (Refer to Guidelines for Workspace Design, 2.1.)

f. The frequency with which they must be opened or removed (in terms of the reliability and maintenance requirements of the enclosed components).

1.10.3.2 SIZE REQUIREMENTS. Covers, cases, and shields should:

a. Be lightweight, if possible, but allow the degree of accessibility required.

b. Be openable, removable, and transportable by one hand, one individual, or, at most, two individuals, in that order of preference.

c. Be provided with lifting eyes and planned for crane handling if more than 100 lbs.

d. Be provided with handles or tool grips if heavy or difficult to open or move.

e. Allow sufficient clearance around enclosed components to minimize damage to these components and to avoid requirements for extremely fine or careful positioning and handling.

f. Be designed and located so that bulkheads, brackets, or other units will not interfere with operation of the cover or case and so the cover or case, when opened, will not interfere with other maintenance operations.

g. Be designed for ease of use, in terms of equipment accessibility for maintenance. (Quick release and connection covers, cases and sheilds, should be used with equipment that is frequently tested or adjusted.)

1.10.3.3 SHAPE REQUIREMENTS. Covers, cases, and shields should:

a. Be whatever shape is necessary to accomplish the degree of enclosure, allow the degree of accessibility, and provide the clearances required.

b. Make obvious, if possible, the manner in which the item must be positioned or mounted.

c. Make obvious, if possible, the orientation of enclosed delicate components, to minimize damage to these during removal.

d. Be free from sharp edges or protrusions which could injure personnel or damage lines and wires.

e. Be free of indentations or settling areas on top surfaces, to reduce rust, corrosion, and the accumulation of dirt and grease.

1.10.3.4 MOUNTING REQUIREMENTS. Covers, cases, and shields should be designed, located, and mounted so they:

a. Do not bear any part of the structural load. It should not be necessary to support, download, or disassemble any equipment to remove the item.

b. Are completely removable and replaceable in case of damage. Irregular extensions and accessories should be readily removable.

c. Can be opened or removed as necessary when the equipment system is completely assembled and auxiliary equipment has been installed.

d. Do not cause the equipment to become unbalanced when opened. Props, retainers, or other support should be provided where required to prevent this.

e. Do not obscure or interfere with controls, displays, test points, or connections related to work within the access or enclosure, when in the open position.

f. Are provided with adequate stops and retainers to prevent them from swinging into or being dropped on fragile equipment or personnel.

g. Are provided with locking devices or retainer bars to lock them in the open position if they might otherwise fall or shut and cause damage, injury, or inconvenience. This is particularly necessary for doors, covers, and shields which may be used in strong wind conditions.

1.10.3.5 FASTENER REQUIREMENTS. Fasteners for covers, cases, and shields should be selected, applied, and mounted so that:

a. They optimally satisfy the applicable Guidelines for Fastener Design for Maintainability, 1.11, requirements.

b. Maximum use is made of hinges and latches or catches to minimize the number of fasteners and requirements for handling and stowing covers and cases.

c. Fasteners for a given item or identical items are interchangeable, i.e., are the same type, size, diameter, and pitch of thread.

d. Fasteners align themselves with their retaining catches, nuts, blocks, or inserts without sticking and without damage to their threads or latches.

e. The cover or case will not open or loosen automatically under whatever stress, vibration, or other conditions are expectable.

f. It is obvious when a cover or case is not in place or securely fastened. Where possible, fasteners should be spring-loaded so they stand out or the cover itself stays ajar when not secure.

1.10.3.6 LABELING REQUIREMENTS. Labels and markings on covers and cases should be provided which:

a. Provide opening, removal, or positioning instructions, if methods for accomplishing these are not obvious from the design.

b. Provide stock references so that covers, cases, and shields can be replaced when damaged.

c. Adequately reveal the functions of units behind the enclosure and/or the functions which are to be performed through the access, such as "Battery," "Fuel Pump," "Oil Here," etc.

d. Adequately warn against dangers or hazards involved in removing the cover or case or working within the enclosure.

e. Provide the proper orientation or connection of units, service equipments, etc. to go through the opening, if this is not clear or visible.

f. Do not provide instructions, such as preventive maintenance instructions, which are subject to revision or change.

g. Do not provide instructions which will be required but will not be visible when the cover, door, or case is open. Such instructions should be placed in a visible location on the structure behind or to the side of the access.

1.10.3.7 TYPES OF COVERS, CASES, AND SHIELDS

a. **HINGED DOORS, HOODS, AND CAPS.** The use of hinges allows the fastest and easiest access, reduces the number of fasteners required, supports the cover so the technician does not have to handle it, and makes it unnecessary to disconnect wires or components mounted on the cover before entering the access. This type of cover, however, requires "swinging space," and may interfere with other operations or components.

b. **SLIDING DOORS OR CAPS.** Large sliding doors may create structural design problems but are particularly useful where "swinging space" is limited. Small, sliding caps are particularly useful for small accesses that do not require a close seal.

c. **REMOVABLE DOORS, PLATES, OR CAPS.** These require little space for opening and, once removed, do not interfere with work space; however, their handling requires time and effort (searching, bending, reaching, etc.).

d. **REMOVABLE PANELS OR SECTIONS.** These are useful to allow access to whole sides of a cabinet or equipment. They discourage non-maintenance personnel from opening the access. They do not require "swinging space." However, they may be damaged easily and may be awkward to handle. They may also interfere with maintenance activities.

1.10.4 SPECIFIC PRINCIPLES

1.10.4.1 HINGED DOORS, HOODS, AND CAPS

a. Double-hinged or split doors should be used if opening space is a problem.

b. Hinges should be placed on the bottom; biased; or a prop, catch, or latch should be provided if the door is to stay open without being held.

c. Adjacent hinged doors should open in opposite directions to maximize accessibility, and cabinets should be arranged so that functionally related cabinets are adjacent and open in opposite directions.

d. Hinged caps over service or test points should be designed not to interfere with the insertion or attachment of service or test equipment.

e. Stops, retainers, etc. should be provided when needed to prevent the door from swinging into adjacent displays, controls, or fragile components, and to prevent springing the hinges.

1.10.4.2 SLIDING DOORS AND CAPS

a. Sliding doors and caps should lock positively.

b. They should be designed to avoid jamming or sticking.

c. They should be easy to use and should not require tools for operation (unless limited or restricted access is intended).

d. Their movement should not interfere with, damage, or have the potential for harmful contact with wires or other equipment items.

1.10.4.3 REMOVABLE DOORS, PLATES, AND CAPS

a. Maximum use should be made of tongue and slot or similar catches for small plates, doors, and caps to minimize the number of fasteners needed.

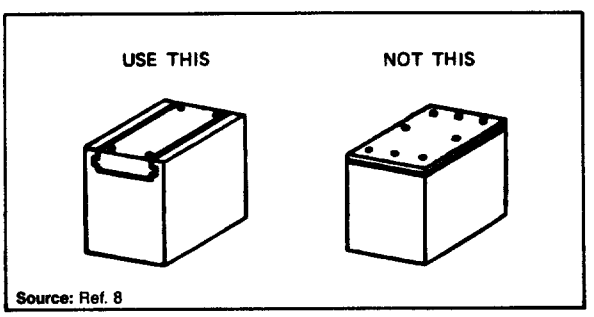

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Exhibit 1.10.1 Example of Tongue and Slot Cover

b. Small plates and caps that are likely to be misplaced or damaged should be secured with retainer chains.

c. If a removable plate must be attached in a certain way, it should be designed so that incorrect attachment is impossible, e.g., an asymmetric plate shape should be used, mounting holes should be located asymmetrically, or aligning labels should be used.

1.10.4.4 REMOVABLE PANELS OR SECTIONS

a. Panels intended for removal should be held with a minimum number of combination-head captive fasteners; spring-loaded, quarter-turn fasteners are recommended.

b. These fasteners should show position when they are released, i.e., release should be clear before panel is moved.

c. Panels and sections should be removable, carriable, and installable by one technician using common hand tools.

d. Panels and sections should be provided with handles to facilitate removal, handling, and replacement.

e. It should not be necessary to disconnect wires, components, etc. from panels before they can be removed. If such items are attached to the panel, they should be hinged to make removal unnecessary.

1.10.4.5 CASES. Cases should be designed, selected, and mounted so that:

a. They are lifted off units, rather than units lifted out of cases, particularly when heavy units are involved.

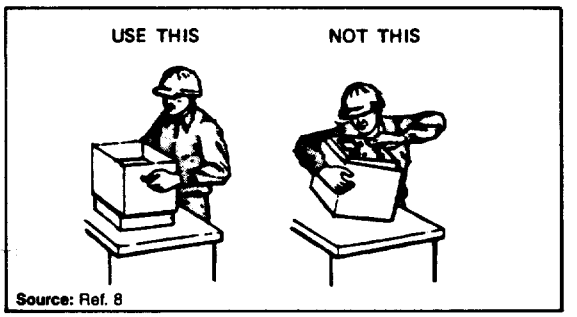

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Exhibit 1.10.2 Example of Lift-Off Case

b. They are sufficiently larger than the units they cover to expedite removal and replacement and prevent damage to wires or other components during removal or replacement.

c. Guidepins and tracks are provided as necessary to help align the case, prevent it from cocking or binding, and prevent damage to delicate or sensitive components during movement of the case.

d. Access is provided, where feasible, to frequently used adjustment, test, or service points, so that the case need not be removed in routine maintenance.

e. All maintenance-significant aspects and portions of the unit are fully exposed when the case is removed.

f. Adequate mounting or locking devices are provided and the unit is secure while the case is being moved, particularly if the unit is to be detached from the bottom of the case.

g. Rubber stripping or other sealing material is selected and mounted so it will not be damaged or jam when the case is moved.

1.10.4.6 SHIELDS. Shields should:

a. Employ light-weight material.

b. Allow rapid and easy installation, removal, transportation, and storage.

c. Provide handles and tool grips as necessary to facilitate handling.

d. Minimize the possibility of damage to the equipment during installation, removal, or other operations related to the shield.

e. Avoid or minimize permanent fixtures on the equipment as a consequence of the shield, e.g., mounts, safety features.

f. Permit performance of maintenance functions without removal of the shield; for instance, radial engine shields should permit cranking while the shield is in position.

g. Be mounted in a manner that does not interfere with the operating characteristics of the equipment.

1.0 ENGINEERED HARDWARE

1.11 Fastener Design and Application for Maintainability

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1.11.2 DEFINITION

Fastener refers to a device used to join two or more parts, components, or units together. Fasteners include:

a. Quick disconnects.

b. Latches and catches.

c. Captive fasteners.

d. Combination head-bolts and screws.

e. Regular screws.

f. Internal wrenching screws and bolts.

g. Rivets.

Each device has certain advantages for particular applications.

1.11.3 GENERAL PRINCIPLES

1.11.3.1 Fasteners should be selected and evaluated based on:

a. Durability.

b. Ease of operation.

c. Speed.

d. Ease of replacement.

1.11.3.2 Design, selection, and application of fasteners should consider the following:

a. Stress and environmental factors the fasteners must withstand.

b. Work space, tool clearance, and wrenching space around the fastener.

c. Types of tools required for operation of the fastener, as a function of fastener type, application, and location.

d. Types and varieties of fasteners being used elsewhere in the system, or commonly used by the using utility.

e. The frequency with which the fasteners will be operated.

f. The time requirements of tasks involving operation of the fasteners.

1.11.3.3 The number of types and sizes of fasteners used within a system should be minimized.

a. The same type and size of fastener should be used for the same application (e.g., all mounting bolts for a given type of item).

b. Screws, bolts, and units of different thread sizes should be clearly different in physical size or shape of the head to preclude being interchanged.

c. Requirements for special or close tolerance fasteners should be avoided.

d. The number of different torque requirements used within a system should be minimized.

   (1) Only a few basic values should be used.

   (2) These values should be keyed to clearly differing types, sizes, or coded fasteners.

   (3) Where precise torquing is required, clearance should be provided for wrenches or sockets with variable torque settings.

e. The number of tool types and sizes that are needed for fastener operation should be minimized.

f. The ease of use, in terms of equipment accessibility for maintenance. (Quick release and connection fasteners should be used with equipment that is frequently tested or adjusted.)

1.11.3.4 Fasteners should be fabricated of specific materials.

a. Fasteners should be made of corrosion-resistant materials (e.g., stainless, galvanized, cadmium-coated, non-ferrous).

b. Fasteners should not use aluminum alloy threaded into aluminum alloy parts.

c. Fasteners should not be the cause of galvanic action (e.g., a titanium fastener used with magnesium would cause galvanic corrosion).

d. Fasteners should be metallic where high tensile or shear strength is required.

1.11.3.5 Ease of replacing stripped, worn, or damaged fasteners should be a design consideration. Fasteners which are part of a unit's housing should be avoided.

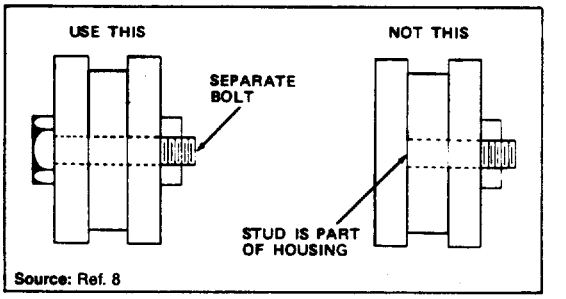

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Exhibit 1.11.1 Example of Proper and Improper Design of Bolt Fastener

1.11.3.6 The number of fasteners and fastener parts should be minimized.

1.11.3.7 The use of hinges, catches, latches, and quick disconnect fasteners should be maximized to reduce the number of fasteners required.

1.11.3.8 A few large fasteners should be used rather than many smaller ones (except where many are needed to maintain a fluid or air-tight seal).

1.11.3.9 No more than four fasteners should be used to mount a unit. (A common fault is to use too many fasteners when a more rigid construction is preferred.)

1.11.3.10 Fasteners should be mounted so that:

a. Fastener mounting holes or other tolerances are large enough to allow "starting" of fasteners without perfect alignment.

b. Hinges, catches, latches, locks, and other quick disconnect devices are attached by means of small bolts or screws, not rivets.

c. Bolts are mounted with the head up so they will stay in position if the nut falls off.

d. Nuts and bolts (particularly those which are frequently operated or poorly accessible) are mounted so they can be operated with one hand or one tool by:

   (1) Providing recesses to hold either the nut or bolt.

   (2) Semi-permanently attaching either the nut or bolt.

   (3) Using double nuts on terminal boards and similar applications.

   (4) Using nut plates, gang-channeling, or floating nuts.

1.11.3.11 Fasteners should be located so they:

a. Can be operated without prior removal of other parts or units.

b. Can be operated with minimum interference from other structures.

c. Do not interfere with each other or other components.

d. Do not constitute a hazard to personnel, wires, or hoses.

e. Are surrounded by adequate hand or tool clearance for easy operation.

1.11.3.12 Fasteners should be coded so that:

a. All external fasteners which are manipulated during normal maintenance provide strong color contrast with the color of the surface on which they appear.

b. All other external fasteners and assembly screws are of the same color as the surface on which they appear.

c. The heads of "special" bolts and screws are color- or stamp-coded to ensure that they are properly handled and are replaced by identical fasteners.

d. Only markings which designate the size, type, or torque value of the fastener are used. Manufacturers' names or trademarks should be omitted.

e. Fastener markings are etched or embossed to withstand exposure to chemicals, fuels, weather, or other operational conditions.

f. One fastener marking code is used throughout the system. This code should be determined and standardized ahead of time, and it should conform to prevailing standard practices.

1.11.4 SPECIFIC PRINCIPLES

1.11.4.1 QUICK RELEASE FASTENERS (COWL OR PANEL FASTENERS). These are fast and easy to use, require no tools, may be operated with one hand, and are very good for securing plug-in components, small components, and covers. However, their holding power is low and they cannot be used where a smooth surface is required. These fasteners:

a. Should be carefully evaluated on the basis of type and application.

b. Should be used wherever possible for components that must be frequently dismantled or removed.

c. Should fasten and release easily, without the use of tools.

d. Should fasten or unfasten in a maximum of one complete turn.

e. Should be obvious when they are not correctly engaged.

f. Should be located, shaped, sized, or coded so that only the correct male section may be attached.

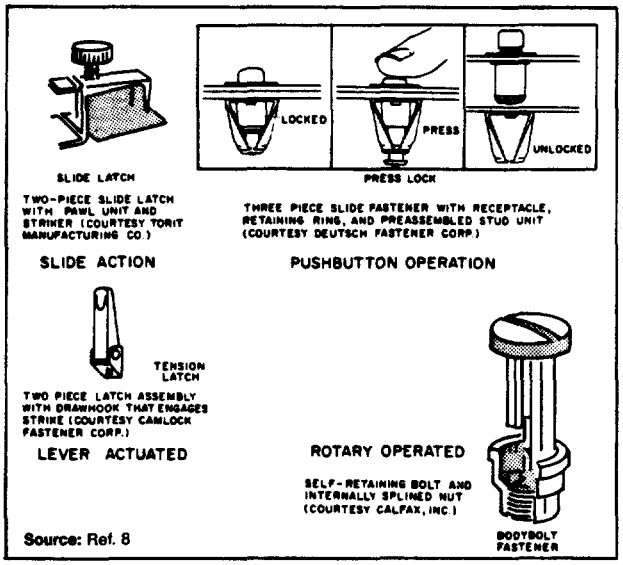

Exhibit 1.11.2 Examples of Quick-Release Type Fasteners

1.11.4.2 LATCHES AND CLAMPS. These are very fast and easy to use, require no tools, have good holding power, and are especially good for large units, panels, covers, and cases. They cannot be used where a smooth surface is required.

a. Long latch catches should be provided so that accidental springing is minimized.

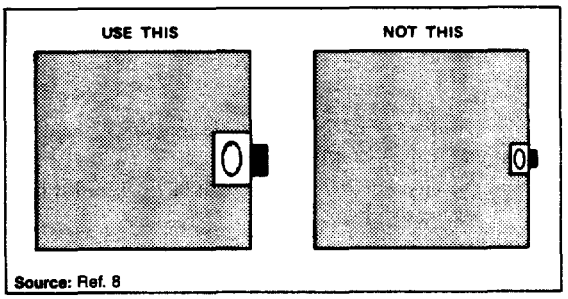

Exhibit 1.11.3 Example of Effective Latch Catch Fastener

b. Latches and catches should be located and positioned so they will not open accidentally under usual operating conditions.

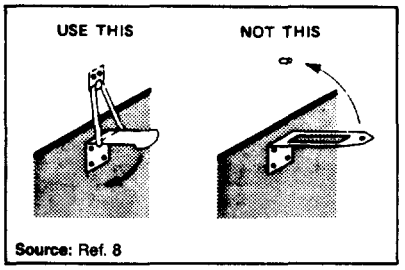

Exhibit 1.11.4 Example of Effective Positioning of Latches

c. Catches should be spring-loaded so they do not require positive locking, but lock on contact.

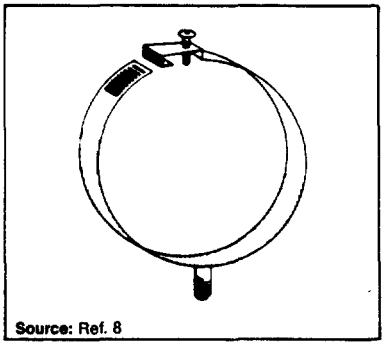

Exhibit 1.11.5 Example of Quick-Release Clamp

d. A latch loop and locking action should be used if positive locking is necessary to meet structural or stress requirements.

e. If a handle is used in conjunction with the latch, the latch release should be located on or near the handle so that only one hand is needed for operation.

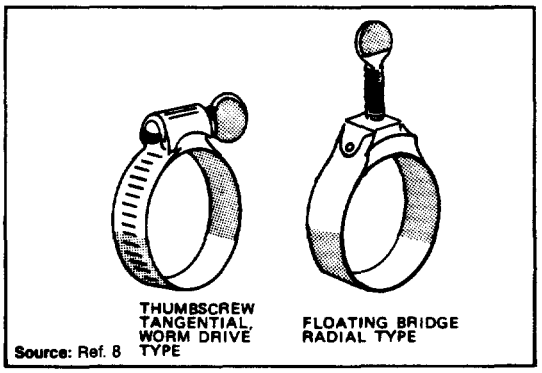

Exhibit 1.11.6 Example of Clamp Requiring One Hand Operation

1.11.4.3 CAPTIVE FASTENERS. These are slower and more difficult to use (depending upon type), and require use of common (usually) handtools; but they stay in place, save the time spent handling and looking for bolts and screws, and require only one-handed operation.

a. Captive fasteners should be used wherever lost screws, bolts, or nuts might cause a malfunction or excessive maintenance time.

b. Only fasteners which may be operated by hand or common handtools should be used.

c. Only fasteners which may be easily replaced in case of damage should be used.

d. Self-locking, spring-loaded action should be provided on captive fasteners of the quarter-turn type.

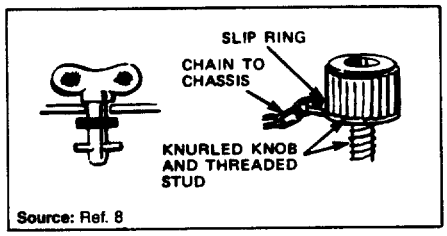

Exhibit 1.11.7 Example of Captive Fasteners

1.11.4.4 COMBINATION HEAD-BOLTS AND SCREWS. These should be used in preference to other screws or bolts simply because they may be operated more rapidly with either a wrench or a screwdriver. This allows use of the more convenient tool and reduces the possibility of slot damage and stuck fasteners. In general, slotted, hexagonal heads are preferable to knurled and slotted heads.

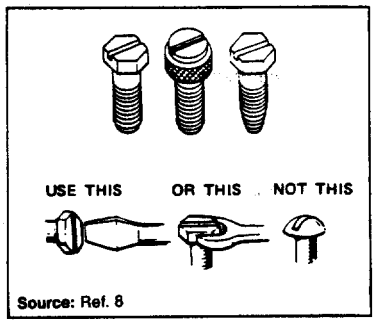

Exhibit 1.11.8 Examples of Combination Head Bolts and Screws and Slotted Hexagon Screws

1.11.4.5 REGULAR SCREWS. Round, square, or flat-headed screws require more time and are more subject to loss, slot damage, stripping, and misapplication than the above; but they require less wrenching space, only one-handed action to operate, and do not involve a number of extra parts. Square-headed screws are generally preferable to round or flat since they provide better tool contact, are less subject to slot damage, and may be removed with pliers.

a. The number of turns required to tighten or loosen a screw should be less than 10.

b. When tightened, the screw must fully engage to a distance at least equal to its diameter.

c. Deep slots should be provided on screw heads to minimize slot damage and tool slippage.

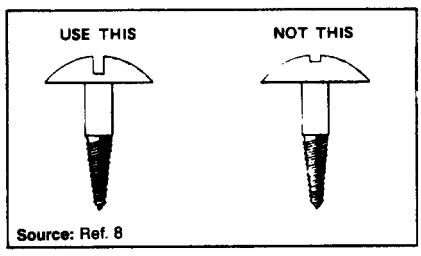

Exhibit 1.11.9 Example of Deep-Slotted Screw Heads

d. Screws should be used only when screwdrivers may be used in a straight-in fashion.

e. Use of offset screwdrivers should not be required.

f. If a screw must be operated blindly, a tool guide should be provided in the assembly.

g. Fine thread screws are recommended for pressurized units.

h. Countersunk screws should be used only where necessary to provide a smooth surface.

i. Round-head rather than flat-head screws should be used on panels less than 3/32 inch thick, to prevent screws from ripping through the panel.

j. Self-tapping screws should have one type of head and be of one size, where feasible, or a minimum number of sizes.

1.11.4.6 BOLTS AND NUTS. Bolts are usually slow and difficult to use. They require two-handed operation, access to both ends of the bolt, and often use of two tools. They also require precise movements in starting nuts and have many loose parts to handle and lose (nuts, washers, etc.).

a. **BOLTS.**

(1) Bolt length should not be more than required for a given purpose.

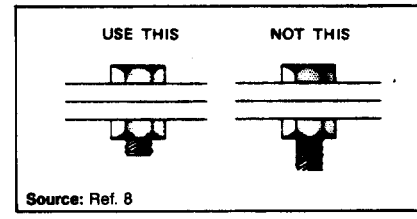

Exhibit 1.11.10 Example of Appropriate Bolt Length

(2) Bolt threads should be no finer than strength requirements dictate.

(3) The number of turns to tighten a bolt should be less than 10.

(4) When tightened, the bolt should extend a minimum of two threads beyond the nut.

(5) Hexagonal-head bolts should be used generally, and especially for high torque usages.

(6) Left-hand threads should be used only when stress conditions require; and both bolts and nuts should be clearly identifiable by marking, shape, or color.

(7) Self-locking bolts (in tapped holes) should be used only when one surface must be smooth or is inaccessible and temperatures will be below 250° F.

b. **NUTS.**

(1) Regular hexagonal nuts are preferred, in a few easily distinguishable sizes.

(2) Different sizes of nuts should be used for different thread requirements.

(3) Wing or knurled nuts, which require no tools, should be used for low tension applications. Wing nuts are the easier to use.

(4) Self-sealing nuts should be used for fastening equipment to fluid tanks to prevent leaking around fastener.

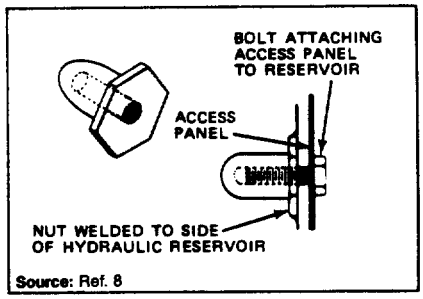

Exhibit 1.11.11 Example of Self-Sealing Nut

(5) Lock nuts may be used for mounting light components; but they must withstand heat requirements, and cannot be used where fallen nuts could damage equipment.

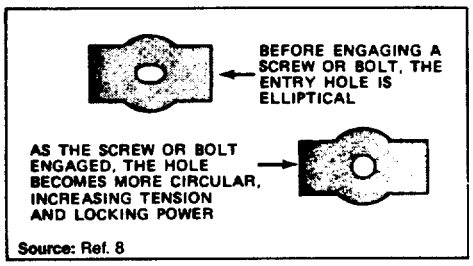

Exhibit 1.11.12 Example of Lock Nut

(6) Clinch nuts should be incapable of rotating or moving with respect to the surface on which they are mounted.

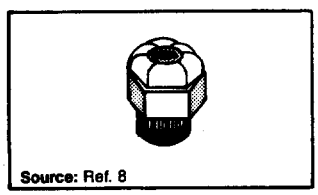

Exhibit 1.11.13 Example of a Clinch Nut

(7) Floating nuts should have an allowable shift of only plus or minus 1/16 inch.

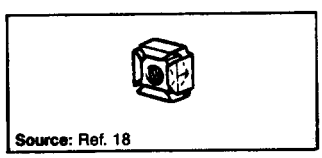

Exhibit 1.11.14 Example of Floating Nut

1.11.4.7 INTERNAL WRENCHING SCREWS AND BOLTS. These allow higher torque, better tool grip, and less wrenching space. However, they are easily damaged, difficult to remove when damaged, and require special tools.

a. The number of different sizes should be minimized to require only one, or as few as possible, tools.

b. Slots should be deep, to eliminate damage to the fasteners.

c. Design should allow and plan for the removal of damaged internal wrenching fasteners in terms of clearances, power outlets, etc.

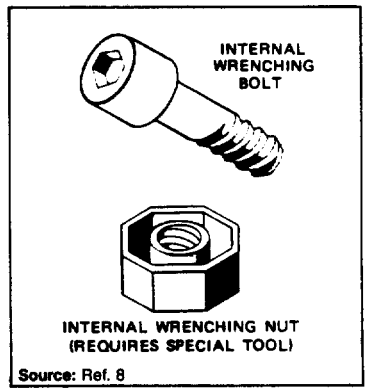

Exhibit 1.11.15 Example of Internal Wrenching Bolt and Nut

1.11.4.8 RIVETS. Permanent fasteners are hard and slow to remove and replace; they should not be used on any part which may require removal. Wire stapling or metal stitching is generally preferable to rivets for maintenance purposes.

a. Rivets should not be used on latches, hinges, or retainers.

b. Rivets should be of softer material than the pieces they fasten.

c. The heads of countersunk rivets should be larger than the thinnest of the pieces they fasten, to prevent them from ripping through.

d. Shear rivets do not expand to fill the hole, so holes must be drilled to close tolerances. Maintenance instructions should specify these tolerances and the sizes of plug gauges and reamers to be used.

e. For minor maintenance of light components, rivets which expand by chemical charge rather than by peening should be used. These rivets expand when heat is applied to a chemical charge contained within the rivet. Rivets are especially useful in blind applications.

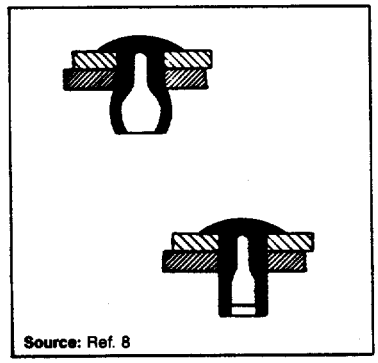

Exhibit 1.11.16 Example of Chemical Charge Rivet

1.11.4.9 FASTENER ACCESSORIES

a. **WASHERS.**

(1) Washers should fit tightly against the underside of the fastener head.

(2) Washers should fit the shaft snugly, but should be easy to remove.

(3) Split-ring lock washers should be used with static loads in excess of 2 oz.

(4) Lock washers should be used with lock nuts, for maximum locking action.

b. **METALLIC INSERTS AND BLOCKS.** These should be secured so that tightening of the screw or bolt will not loosen or move the insert or block.

(1) Gang-channeling of nuts can save time in handling many nuts when they are in a straight line. Only channels should be used in which nuts can be replaced individually.

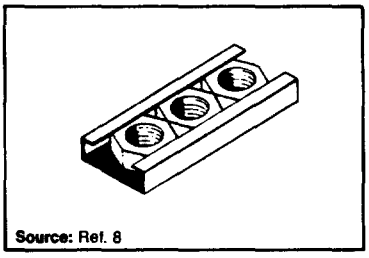

Exhibit 1.11.17 Example of Gang-Channeled Nuts

(2) Nut-plates are heavy and expensive to replace when a hole is stripped, but they may be used when several bolts are to be fastened on one surface and alignment is not problem.

c. **COTTER PINS AND KEYS.**

(1) Keys and pins should fit snugly, but should not require driving in or out.

(2) Heads of cotter keys should be large, to facilitate removal and prevent the keys from slipping through.

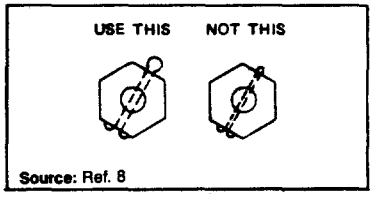

Exhibit 1.11.18 Example of Adequate Size Cotter Key Head

d. **SAFETY WIRE.**

(1) Safety wire should be used only when self-locking fasteners or cotter pins are not adequate to withstand the expected vibration or stress.

(2) Safety wire should be attached so it can be easily removed and replaced.

(3) Safety wire should be used where visible means of detection is required to determine if a fastener has become loosened or has changed position.

e. **RETAINER RINGS.**

(1) Only rings which may be removed and replaced easily when worn should be used.

(2) Rings which hold with a positive snap action should be used when possible.

(3) Spring tension should be used to prevent loosening or unlocking of twist-to-lock rings.

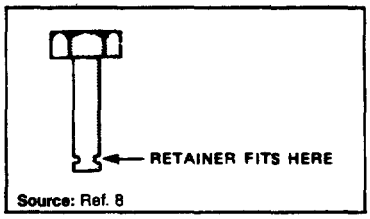

Exhibit 1.11.19 Example of Retainer Ring

f. **RETAINER CHAINS.**

(1) Only link, sash, or woven-mesh type chains should be used. Bead-link chain is not recommended because it breaks more easily than other types.

(2) Chains should be attached with screws or bolts; attachment should be strong and positive, but easily disconnected when required.

(3) Eyelets should be provided at both ends of the chain for the attaching fasteners.

(4) Chains to filler caps should be attached externally rather than internally to facilitate replacement and prevent broken parts from damaging equipment.

(5) Chains should not be used wherever they might interfere with moving parts.

(6) Chain covers, where required to prevent chains from becoming tangled, should be flexible, durable, and easy to bend.

(7) Retainer chains or locking bars should be used to:

- Keep hatches or doors from opening too far and springing their hinges.
- Turn doors or covers into useful shelves for the technician.
- Prevent small covers, plates, or caps from being misplaced.
- Secure small, special tools to the location in which they will be used.
- Secure objects which might otherwise fall and cause personnel injury.

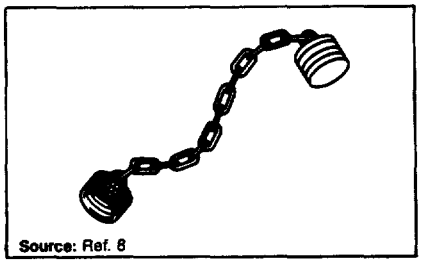

Exhibit 1.11.20 Example of Retainer Chain

1.0 ENGINEERED HARDWARE

1.12 Drawer and Rack Design for Maintainability

1.12.1 INDEX

Page

1.12.2 DEFINITION 1.12-2

1.12.3 PRINCIPLES 1.12-3

1.12.2 DEFINITION

Drawers and racks refer to pullout, roll-out, slide-out, or hinged equipment assemblies designed to:

a. Optimize work space, tool clearance, and accessibility.

b. Reduce the need for the technician to handle fragile or sensitive items.

c. Facilitate the handling and/or positioning of heavy or awkward items.

d. Facilitate the maintenance of items which must be frequently moved from their installed positions for checking, servicing, or repair.

1.12.3 PRINCIPLES

1.12.3.1 Drawers and racks should require a minimum number of operations to open or release them.

1.12.3.2 A force of less than 40 lbs. should be required to open and release drawers and racks.

1.12.3.3 A smooth operating bearing assembly should be used, as needed.

1.12.3.4 Drawers and racks should lock automatically in both servicing and operating modes.

1.12.3.5 Handles should be provided on drawers and racks, when necessary, to facilitate operation and handling.

1.12.3.6 Assemblies should be accessible without breaking internal connections which are necessary for required maintenance.

1.12.3.7 To prevent possible damage to fragile or sensitive parts during movement of the assembly, drawers and racks should be provided with guards and shields as necessary.

1.12.3.8 Rests, limit stops, guards, and/or retaining devices should be provided as part of the basic chassis. They should:

a. Prevent the assembly from being dropped.

b. Prevent heavy assemblies from tipping the equipment.

c. Allow complete and convenient removal of the assembly.

d. Allow the assembly to open to its full distance and remain open without being held.

1.12.3.9 If internal connection is not required for maintenance, connectors to the drawer or rack may be attached to the assembly so that closing the assembly establishes connection. This requires:

a. Connector parts to be mounted on the assembly's rear wall.

b. Locks to ensure that the connectors remain engaged.

c. Guides to ensure proper orientation of the assembly prior to pin engagement.

d. Insulation to the connectors, as needed, for safety.

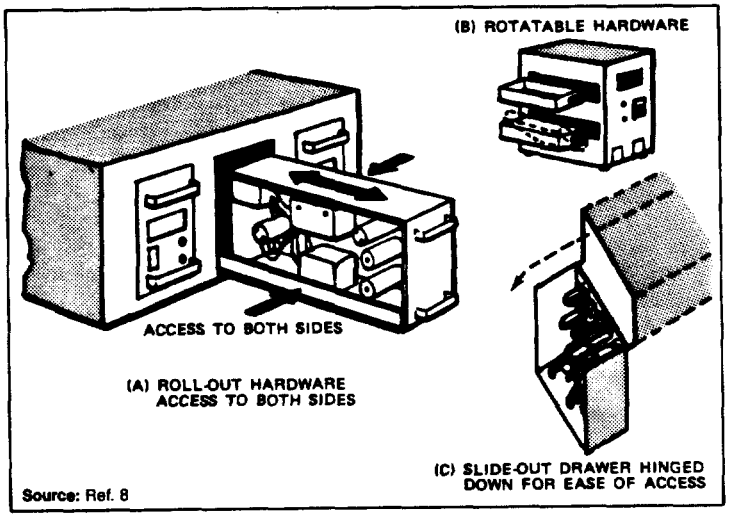

Exhibit 1.12.1 Examples of Drawer and Rack Design for Maintainability

1.0 ENGINEERED HARDWARE

1.13 Handle Design for Maintainability

1.13.1 INDEX

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1.13.2 DEFINITION 1.13-2

1.13.3 PRINCIPLES 1.13-3
1.13.3.1 Factors Influencing Handle Design 1.13-3
1.13.3.2 Types of Handles with their Dimensions 1.13-3
1.13.3.3 Handle Design Recommendations 1.13-4

1.13.2 DEFINITION

Handles refer to means for grasping removable or replaceable units. Handles should be provided on all packages, units, components, and covers whenever these items are handled frequently, difficult to carry, hold fragile components, or weigh over 10 lbs.

1.13.3 PRINCIPLES

1.13.3.1 FACTORS INFLUENCING HANDLE DESIGN

The size, location, and positioning of handles depends upon:

a. Weight and center of gravity of the item or unit.

b. Number of persons, or hands, required to lift or carry the item.

c. Type of clothing and gloves worn.

d. Operational position of the item relative to other items.

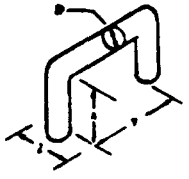
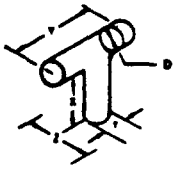
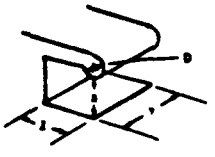
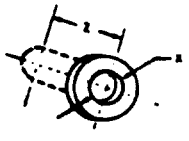
e. Manner in which the item is to be handled or positioned.

f. Distance over which the item must be carried.

g. Frequency with which the item must be handled or carried.

h. Additional uses the handles could serve.

1.13.3.2 TYPES OF HANDLES WITH THEIR DIMENSIONS

ILLUSTRATION	TYPE OF HANDLE	DIMENSIONS IN mm (in inches)								
		(Bare Hand)			(Gloved Hand)			(Mittened Hand)		
		X	Y	Z	X	Y	Z	X	Y	Z
	Two-finger bar	32 (1-1/4)	65 (2-1/2)	75 (3)	38 (1-1/2)	75 (3)	75 (3)	Not Applicable		
	One-hand bar	48 (1-7/8)	111 (4-3/8)	75 (3)	50 (2)	125 (5)	100 (4)	75 (3)	135 (5-1/4)	150 (6)
	Two-hand bar	48 (1-7/8)	215 (8-1/2)	75 (3)	50 (2)	270 (10-1/2)	100 (4)	75 (3)	280 (11)	150 (6)
	T-bar	38 (1-1/2)	100 (4)	75 (3)	50 (2)	115 (4-1/2)	100 (4)	Not Applicable		
	J-bar	50 (2)	100 (4)	75 (3)	50 (2)	115 (4-1/2)	100 (4)	75 (3)	125 (5)	150 (6)
	Two-finger recess	32 (1-1/4)	65 (2-1/2)	50 (2)	38 (1-1/2)	75 (3)	50 (2)	Not Applicable		
	One-hand recess	50 (2)	110 (4-1/4)	90 (3-1/2)	90 (3-1/2)	135 (5-1/4)	100 (4)	90 (3-1/2)	135 (5-1/4)	125 (5)
	Finger-tip recess	19 (3/4)	–	13 (1/2)	25 (1)	–	19 (3/4)	Not Applicable		
	One-finger recess	32 (1-1/4)	–	50 (2)	38 (1-1/2)	–	50 (2)	Not Applicable		

Curvature of Handle or Edge	Weight of Item	Minimum Diameter	
(DOES NOT PRECLUDE USE OF OVAL HANDLES)	Up to 6.8 kg (up to 15 lbs)	D - 6 mm (¼ in)	Gripping efficiency is best if finger can curl around handle or edge to any angle of $\frac{2}{3}\pi$ rad (120°) or more.
	6.8 to 9.0 kg (15 to 20 lbs)	D - 13 mm (½ in)	
	9.0 to 18 kg (20 to 40 lbs)	D - 19 mm (¾ in)	
	Over 18 kg (over 40 lbs)	D - 25 mm (1 in)	
	T-bar Post	T–13mm (½ in)	

Source: Ref. 11

Exhibit 1.13.1 Minimum Dimensions for Various Handle Designs

1.13.3.3 HANDLE DESIGN RECOMMENDATIONS

a. Handles that must be gripped firmly should be at least 4.5 inches wide and 2.0 inches deep.

b. Single handles should be located over the center of gravity of the unit. When two or four handles are required, they should be placed at equal distances from the center of gravity.

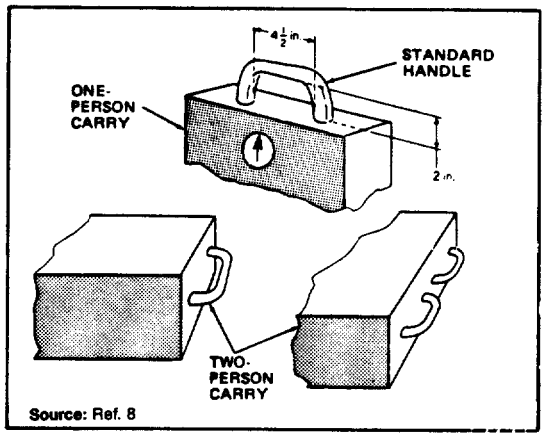


Exhibit 1.13.2 Handle Location for Easy Carrying

c. Covers should be provided with handles to facilitate removing them and also for carrying the unit.

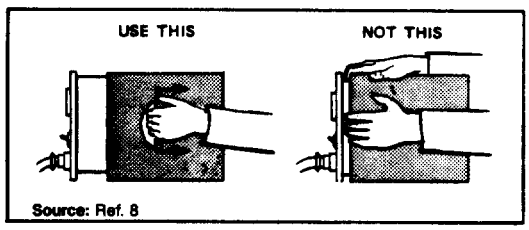


Exhibit 1.13.3 Handle Location for Covers and Carrying Units

d. Handles should meet the following lifting criteria:

Weight To Be Lifted	Handle Diameter (in.)	Finger Clearances (in.)	Handle Width (in.)
Under 25 lb	0.25 - 0.5	2	4.5
Over 25 lb	0.5 - 0.75	2	4.5
Lifted by Gloved Hand		2.5	5

Source: Ref. 8

Exhibit 1.13.4 Lifting Criteria for Handles

e. Units weighing more than about 25 to 40 lbs. (depending on the size and bulkiness of unit) should be provided with handles for two-person carrying. For units weighing more than 100 to 150 lbs. (depending on size and bulkiness of unit), suitably labeled hoist eyes should be provided.

f. Handles should be comfortable and easy to grasp. When units must be frequently carried for long periods of time, a molded handle should be used to prevent size pressure on the fingers.

g. Recessed grips should be provided near the back of heavy units to facilitate handling. Recessed, concealed, or folding handles may be used to conserve space, but they must be accessible without tools and folding handles must remain securely folded when not in use.

h. Handles should be equipped with quick-release pins to make them easier to insert and remove.

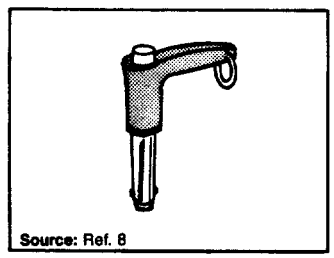


Exhibit 1.13.5 Handle Equipped With Quick-Release Pins

i. Handles may be used for the withdrawal and handling of printed circuit boards.

j. Handles may be used to fulfill a variety of supplemental functions.

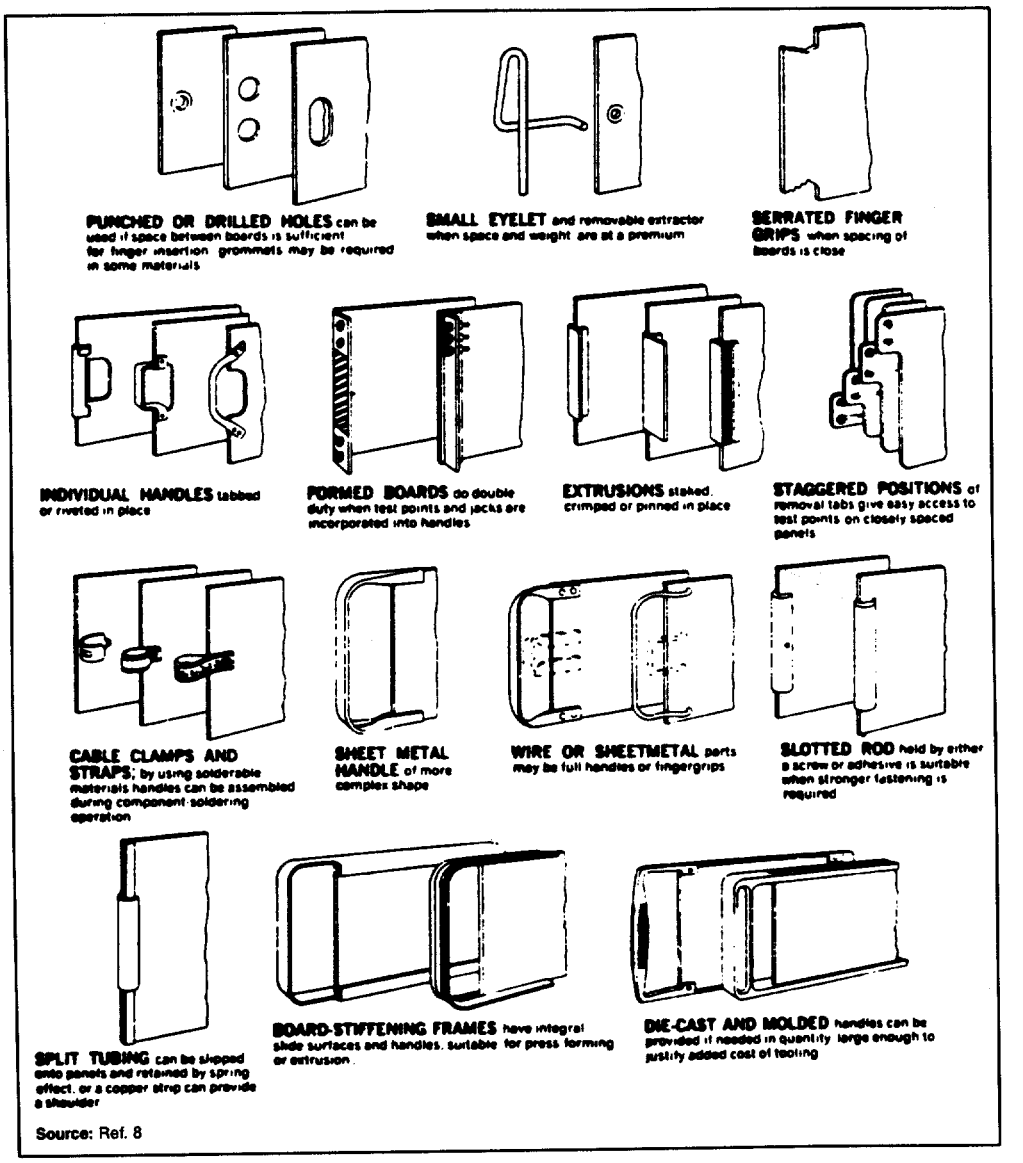


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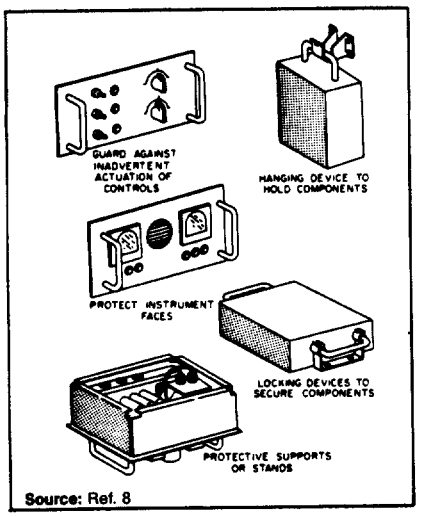
Exhibit 1.13.6 Examples of Handles for Withdrawing Printed Circuit Boards



Source: Ref. 8

Exhibit 1.13.7 Examples of Miscellaneous Uses for Handles

2.0 FACILITY SUPPORT

2.1 Workspace, Storage, and Repair Facility Design for Maintainability

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2.1.2 DEFINITION

Workspace, as used in these guidelines, refers to the locations within a DOE nuclear facility where maintenance, storage, and repair operations are performed.

2.1.3. GENERAL PRINCIPLES

2.1.3.1 Workspace should allow the technician to change posture if the maintenance task being performed requires prolonged kneeling, crawling, or crouching.

2.1.3.2 To assist the technician in performing the required maintenance, the following should be provided at the workplace whenever practical:

a. Auxiliary hooks, holders, lights, outlets, etc.

b. Auxiliary stands/shelves built into equipment to support test equipment, removable units, or items to be repaired.

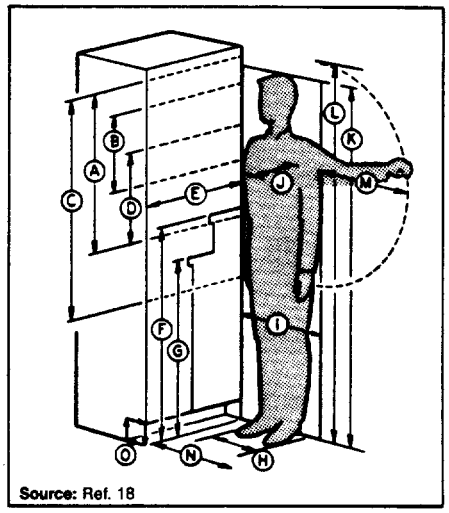
c. Lattice work, low cabinets, mirrors, open space, etc. as necessary to allow observation of related displays, moving parts, fasteners, test points, etc.

d. Communication aids.

2.1.3.3 Non-skid treads, expanded metal flooring, or abrasive coatings should be provided on all surfaces which may be used for walking, climbing, or footholds.

2.1.4 SPECIFIC PRINCIPLES

2.1.4.1 REQUIREMENTS FOR STANDING WORKSPACE AND CLEARANCE. Whenever possible, workspace design should allow routine, frequent, and/or short-term maintenance to be performed from a standing position. The specific requirements which follow are keyed to the illustration below, and others as indicated.



Source: Ref. 18

Exhibit 2.1.1 Standing Workspace Dimensions

a. **VISUAL AND MANIPULATION WORKSPACE REQUIREMENTS**

(1) Displays, markings, etc. which must be read from the standing position should be within the following distances from the floor:

Ⓐ Maximum limits: 40-70" for all visual displays on vertical panels.

Ⓑ Optimum limits: 40-55" for critical or high-force controls.

(2) Controls, test points, fasteners, etc. which require manipulation from a standing position should be within the following distances from the floor:

Ⓒ Maximum limits: 30-70" for all controls.

Ⓓ Optimum limits: 40-55" for critical or high-force controls or fasteners.

(3) Work area length Ⓔ for standing work is limited by time to move between points and/or requirements for reaching or visual contact between points. For work performed at a given position, distances from the center line should be:

- 22.5" for all related work points.
- 17.0" for critical manipulation points.
- 11.5" for critical visual work points.

b. **WORK CLEARANCES FOR STANDING OPERATIONS**

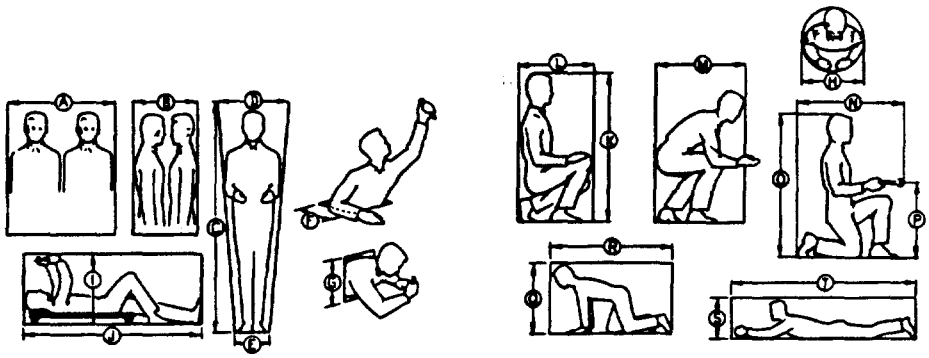
		Minimum	Best
(1)	Walking space width:	12"	15"
(2)	Passing body width:	20"	32"
(3)	Passing body depth:	13"	15"
(4)	Overhead clearance:	73"	80"
(5)	Maximum overhead reach:		76"
(6)	Maximum depth of reach:		23"

(7) Standing space Ⓝ of at least 30", and preferably 36", should be provided before all work surfaces where appropriate.

(8) Kick-space Ⓞ, 4" high by 4" deep, should be provided wherever personnel stand or sit close to cabinets, benches, or other work surfaces.

2.1.4.2 REQUIREMENTS FOR SEATING WORKSPACE AND CLEARANCE . Whenever personnel are required to perform in the sitting position for more than one hour at a time or more than 20% of the time, chairs should be provided. Stools or benches will suffice for other sitting operations. For further detail regarding seating workspace and clearance, refer to NUREG-0700, Section 6.1.2.3.

2.1.4.3 REQUIREMENTS FOR MOBILE WORKSPACE. When technicians are required to work in or pass through limited spaces, appropriate values to determine clearances should be selected from those provided below.



	Min	Best	Arctic
A. Two men passing abreast:	42"	54"	60"
B. Two men passing facing:	30"	36"	36"
Catwalk dimensions:			
C. Height:	63"	73"	75"
D. Shoulder width:	22"	24"	32"
E. Walking width: *	12"	15"	15"
F. Vertical entry hatch:			
Round or square:	18"	22"	32"
G. Horizontal entry hatch:			
Shoulder width:	18"	22"	32"
Height:	15"	20"	24"
H. Crawl through pipe:			
Round or square:	25"	30"	32"
Supine work space:			
I. Height:	20"	24"	26"
J. Length:	73"	75"	78"
Squatting work space:			
K. Height:	48"	--	51"
L. Width:	27"	36"	40"
Optimum display area:	27-43"		
Optimum control area:	19-34"		
Stooping work space:			
M. Width:	36"	40"	44"
Optimum display area:	32-48"		
Optimum control area:	24-39"		

	Min	Best	Arctic
Kneeling work space:			
N. Width:	42"	48"	50"
O. Height:	56"	--	59"
P. Optimum work point:		27"	
Optimum display area:	28-44"		
Optimum control area:	20-35"		
Kneeling crawl space:			
Q. Height:	31"	36"	38"
R. Length:	59"	--	62"
Prone work or crawl space:			
S. Height:	17"	20"	24"
T. Length:	96"	--	--

Distribution parameters significant to tradeoffs in work clearance for lightly clad technicians:*

Dimensions:	Mean	S.D.
Max body depth:	11.5	.88
Max body breadth:	20.9	1.19
Overhead grasp:	82.5	3.33
Kneeling height:	32.0	1.56
Kneeling length:	43.0	3.26
Crawling height:	28.4	1.30
Crawling length:	53.2	2.61
Prone height:	14.5	1.28
Prone length:	90.1	3.41

*Adapted From Ref. 26.

Source: Ref. 18

Exhibit 2.1.2 Mobile Workspace Dimensions. Note: OSHA Standard 1910.23(C)(2) requires using a 18" minimum width for catwalk/runways. Special consideration (larger access) must be given when users may be wearing bulky or protective clothing when performing a task.

2.1.4.4 REQUIREMENTS FOR WORKSHOPS

a. Maintenance workshops should be located and integrated into the overall facility layout in a manner that minimizes the time required for maintenance personnel to go back and forth between the shops and work areas within the facility.

b. In multiunit facilities, where units contain different major systems, separate maintenance organizations and workshops should be available for each unit.

c. The facility should offer convenient spaces and support facilities for temporary or permanent outside contractor personnel.

d. Lockers or cabinets should be available for personal storage so that workbenches and seats stay free of clutter.

e. Entry and exit routes through the maintenance workshops should be maintained free of impediments to the passage of personnel, carts, vehicles, and moving and lifting devices.

f. Workshop areas should not be used as major thoroughfares for all facility personnel.

g. Maintenance activities that generate heat, smoke, sparks, or noxious odors should be conducted in separated, screened-in, and well-ventilated areas.

h. Appropriate cranes, monorails, forklifts, carts, and other movement aids should be available within the workshop to allow for moving of heavy equipment and hardware.

i. The tool room should be integrated within the maintenance shop area or be in proximity to the shop area.

j. The warehouse should be located close to the maintenance workshop.

k. Maintenance workshops should be properly shielded from plant noise.

l. Workshops should be designed to be free of drafts that may cause discomfort or affect the availability of maintenance technicians to maintain close tolerances in operating plant machinery.

m. The thermal/humidity environment within the workshop should be maintained at a comfortable level year round.

n. Separate "hot shops" should be available in normally contaminated areas to prevent the necessity for working on contaminated hardware in normally "clean" shops. Expedients such as tents, portable walls, plastic, fabric, or wood barriers may be used. Boundaries of contaminated "hot" areas should be clearly marked and labeled.

o. Workbench surfaces for standing positions should conform to the following dimensions:

(1) Standard workbenches (see illustration below, also):

- Height: 36-40" above the floor
- Width: 30" maximum
- Length: As required.

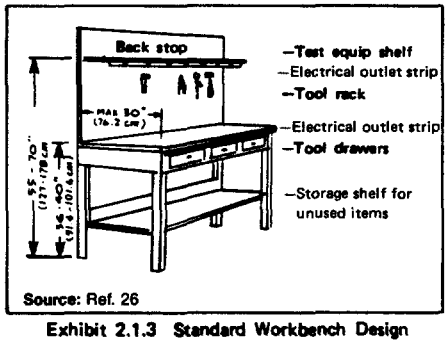


Exhibit 2.1.3 Standard Workbench Design

(2) Podium type workbenches or high precision surfaces (see illustrations below, also):

- Height: 30–40" above floor
- Width: 36" maximum
- Length: 44" maximum.

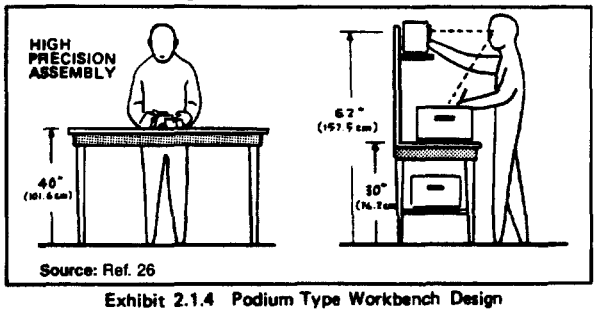


Exhibit 2.1.4 Podium Type Workbench Design

(3) Double-sided workbench and workbench accessories configuration (see illustrations below):

p. Workbenches should offer illumination aids; space and supports for accommodating procedures, prints, and manuals; access to power sources; magnifiers as required; and built-in test equipment as needed.

q. "Hot" shops should be fully enclosed or glove boxes provided to avoid spreading contaminated particles that may result when maintenance machines are used to repair contaminated components.

r. Work surfaces for supporting job instruction manuals, worksheets, etc., should be 36" above the floor.

s. For tasks requiring force, it is recommended that work surfaces be 36" above the floor.

t. It is recommended that tasks requiring precision be done on surfaces 40" above the floor.

u. Factors to be considered when determining workbench height and design:

- Characteristics of the equipment that will be placed on the surface.
- How technicians will perform tasks.
- Lifting problems (size or weight) for equipment to be placed on surface.
- Uniqueness of tasks to be completed.

v. For sitting/standing work stations, provide adjustable seats to accomodate technicians of various heights and body dimensions.

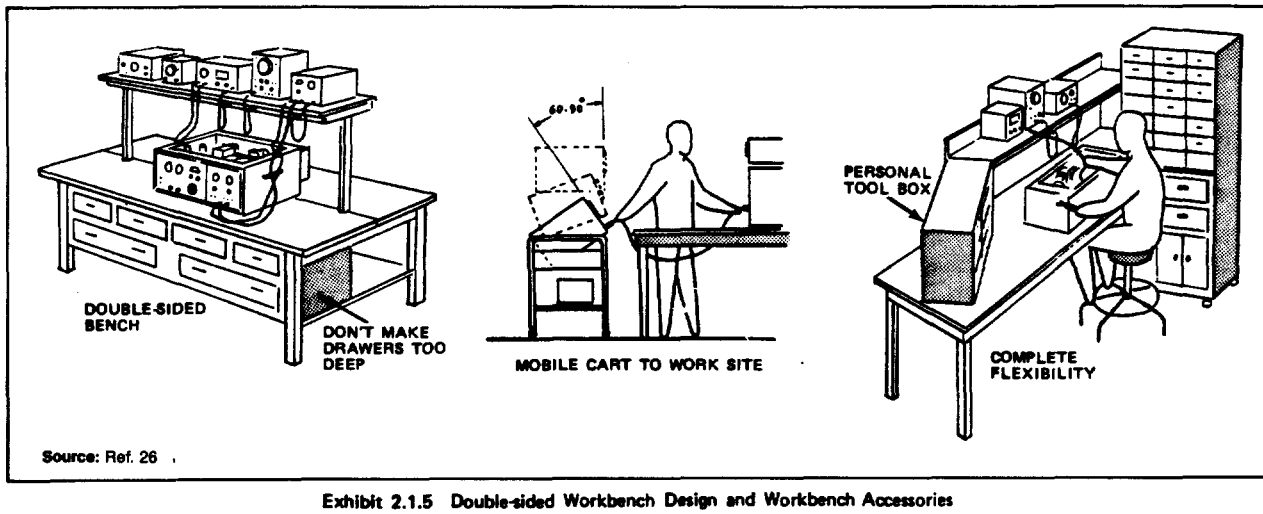


Exhibit 2.1.5 Double-sided Workbench Design and Workbench Accessories

2.1.4.5 REQUIREMENTS FOR STORAGE AREAS

a. Organized storage facilities should be available for seasonally used items such as fans and heaters.

b. Adequate storage should be provided for materials and spares used on a recurrent basis that are not kept in a warehouse.

c. Special storage should be provided for tools and special equipment used during overhauls or outages.

d. Special storage should be provided for contaminated equipment that is used during outages.

e. Items stored in special locations should be controlled and inventoried.

f. Seasonally or infrequently used items should be stored so as not to interfere with normal entrance and exit pathways, vehicular traffic paths, and emergency escape routes.

2.1.4.6 MISCELLANEOUS WORKSPACE REQUIREMENTS

a. Instrument and control facilities should be located near the control room.

b. Maintenance technicians should have easy access to a well-organized and controlled technical library which includes procedures, vendors' manuals, plant schematics, etc.

c. Health Physics facilities should be located as conveniently as possible for maintenance technicians so delays in making transitions from "clean" to "hot" areas and vice versa can be avoided.

2.0 FACILITY SUPPORT

2.2 Maintenance Support Equipment

2.2.1 INDEX

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- 2.2.4.2 Design Principles for Cradles 2.2-4
- 2.2.4.3 Design Principles for Cranes 2.2-4
- 2.2.4.4 Design Principles for Hoists 2.2-4
- 2.2.4.5 Design Principles for Elevators 2.2-5
- 2.2.4.6 Design Principles for Remote Handling Equipment 2.2-5

2.2.2 DEFINITION

Maintenance Support Equipment (MSE), as used in these guidelines, refers to apparatus which are used for handling, lifting, positioning, towing, fueling, and lubricating tasks in the performance of maintenance. Specific apparatus included are jacks, cradles, cranes, hoists, elevators, and various remote handling equipment. Excluded from this definition are tools and test and service equipment.

2.2.3 GENERAL PRINCIPLES

All MSE should be selected and designed so that it:

2.2.3.1 Is as simple as possible to operate, use, and maintain.

2.2.3.2 Is compatible with the maintainability features built into related equipment, and with the maintenance environment in which it will be used.

2.2.3.3 Provides maximum protection for components and working parts to minimize the need for repair.

2.2.4 SPECIFIC PRINCIPLES

2.2.4.1 DESIGN PRINCIPLES FOR JACKS

a. Jacks should be designed so they can be transported, handled, and stored easily.

(1) Small jacks that must be lifted and carried by one person should not exceed 40 lbs.

(2) Larger jacks should be mounted on wheeled carts that have locking wheels. Repositioning and accurate centering can be accomplished using a cart with swivel wheels.

(3) Large hydraulic jacks may be designed with wheels that may be retracted or folded into the base of the cart, thus allowing the Ram base to touch the ground for added stability.

b. Jack handles should be removable or folding. If a jack handle is left protruding during maintenance, there is a possibility that personnel or equipment may strike against the handle, knocking the jack from under the load.

c. Jacks should be labeled to show direction of crank rotation for raising or lowering as well as the load they are designed to handle.

d. On hydraulic jacks, one or more access plates, at least 6 inches in diameter, should be permitted to allow inspection and cleaning of the hydraulic fluid reservoir.

e. Mechanical safety-locking devices should be provided to prevent accidental lowering of the load in the event of hydraulic system failure.

2.2.4.2 DESIGN PRINCIPLES FOR CRADLES

a. Cradles should be designed so that a load can be quickly, effectively, and safely positioned on them.

b. When a cradle is designed to carry a specific load, guidelines should be marked on the equipment and cradle so that when it is loaded into the cradle, perfect positioning will occur simply by matching guidelines.

c. Cradles should be shaped to fit the equipment to be carried. Cradles may be adjustable or fitted with adapters to handle various sizes of equipment.

d. The cradle should have sufficient load-bearing area to support the load when the equipment must remain on the cradle without support bands or hoists.

e. Metal straps should be provided for attaching equipment to the cradle during positioning procedures.

f. If cradles are designed as integral parts of other equipment, basic equipment with controls for positioning the cradle should be provided.

g. When practical, a platform should be attached to the lift cradle to allow a technician standing on the platform to directly observe positioning of the component.

h. Mechanical safety devices should be provided to prevent inadvertent dropping of the load because of hydraulic failure. Check valves or ratchet devices are acceptable safety provisions.

2.2.4.3 DESIGN PRINCIPLES FOR CRANES

a. "Through" type bolts with conventional nuts and lock washers or lock nuts should be used for assembling structured members.

b. Hook eyes should be provided on boom sections at the centers of gravity for easy boom assembly and disassembly.

c. Provisions for adjusting the boom length to accommodate operational requirements and to make the equipment more versatile should be provided when possible.

d. Two identical and interchangeable winch assemblies should be provided to operate the cables of the crane, one for hoisting the load and the other for controlling the boom height.

e. Heavy maintenance support equipment such as portable electric winches and cranes should be mounted for ease of movement.

f. An operator's cab should be designed that will rotate with the crane to allow continuous surveillance of the work operation.

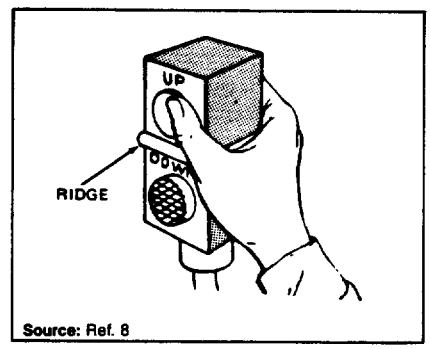
g. The crane operator's seat should be located to allow optimum view of the load, ground, and equipment in the vicinity, and at the same time permit easy operation of the crane's controls.

h. Lights should be mounted on cranes used outdoors so that movement of the load carried by the crane can be followed during night operation.

i. Control direction labels. Use absolute directions (North, South, East, West) instead of relative directions (Forward, Reverse, Left, Right).

2.2.4.4 DESIGN PRINCIPLES FOR HOISTS

a. Hoist controls should be incorporated into a portable, lightweight, hand-held control box. The box should have the following design features (refer also to the illustration):



Source: Ref. 8

Exhibit 2.2.1 Hand-Held Hoist Control Box

(1) Two spring-load, recessed pushbuttons, one above the other.

(2) The top button should be "green" and labeled "Up," the bottom button should be "red" and labeled "Down." Where possible, color code functions: up should be green, and down should be red.

(3) Each pushbutton should have a flat (or slightly concave) surface, large enough to be pushed, repeatedly, without discomfort.

(4) Pressure to activate either button should be 10 to 40 oz.

(5) A 2-inch clearance should be provided between each pushbutton to further prevent accidental activation of the wrong button. Ridging between the buttons should be provided.

(6) The control box should be manageable enough so the technician can reach both control buttons while holding the box securely and comfortably in one hand.

b. Moving parts such as belts, chains, gears, and linkages should be placed where operations and maintenance personnel are least likely to come into contact with them. Guards should be provided if danger from contact exists.

c. Sufficient clearance for lugs used for attaching hoist beams to equipment structures should be provided so the attachment can be made easily and quickly.

d. Pins should be used that have automatic locking features and do not require the insertion of cotter pins for locking. The pins should be attached to the hoist by a wire or chain. Matching lugs should be provided on the component or cradle so that the hoist beam lugs can be set into the matching lugs to facilitate insertion.

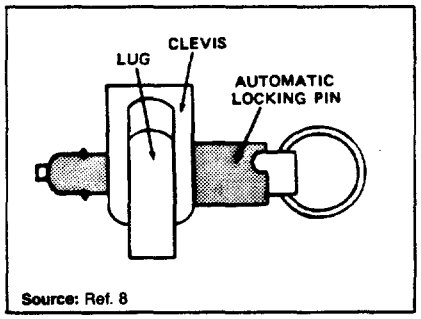


Exhibit 2.2.2 Example of Hoist Lug and Lock Pin

e. Hoist capacity should be indicated on the side of the hoist closest to the operator to prevent possible overloading.

f. Positive locking devices to hold hoist beams in the raised position in case of power failure should be provided.

2.2.4.5 DESIGN PRINCIPLES FOR ELEVATORS

a. Elevator coverage should extend to each level of the facility that maintenance personnel must reach to service heavy equipment.

b. Elevators that are available to maintenance technicians should be capable of accommodating personnel, hardware, and job aids.

c. Elevators should be designed for reliable service in their intended environments, e.g., high temperature, humidity, radiation.

d. Elevators should provide straight-line coverage from the lowest to the highest elevations in the facility, avoiding the need to transfer personnel and materials from one elevator to another at some mid-point elevation.

e. Where possible, elevator drive machinery which requires access for preventive and corrective maintenance should be located in non-contaminated areas although the elevator may provide service within contaminated areas of the facility.

f. Elevators that are used to transport hardware should be padded or otherwise protected to withstand potential damage.

g. Elevators that are located in potentially hazardous areas should have emergency escape and/or communication devices.

h. The top button should be green and labeled up; the bottom button should be red and labeled down.

i. When possible, provide directional cues (such as pointing arrowheads) for up and down.

j. An automatic fail-safe brake, or other self-locking device should be provided in case the lift mechanism fails.

k. Guards should be provided to prevent the accidental operation of the lift. (For example, consider guarding the "Emergency Stop" switch.

2.2.4.6 DESIGN PRINCIPLES FOR REMOTE HANDLING EQUIPMENT

a. Operator performance should be optimized by organizing consecutive tasks and subtasks to be performed by the equipment.

b. Equipment which must be remotely handled should be designed so that it can be broken down completely by the remote manipulator.

c. Components to be handled remotely should be tested for compatibility with the remote handling system that is being used before being included in system design.

d. General purpose manipulations (including master-slave and rectilinear arm manipulators) should be provided with the following capabilities:

(1) A minimum of seven degrees of freedom of movement.

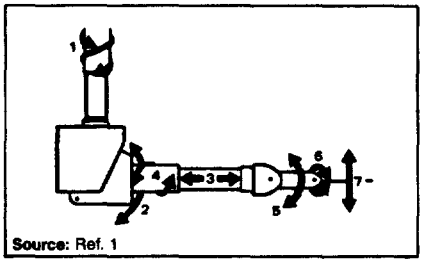


Exhibit 2.2.3 Degrees of Freedom of Movement for Manipulator Arm and Wrist Assembly

(2) Ability to grasp and manipulate tools. The slave hands provided must be designed to produce the appropriate movement, grip, thrust, and torque required by the task.

(3) A bilateral drive system to reflect force to the technician's arm in a natural and meaningful way. The system must be completely reversible so that a force or movement of the output will give a corresponding force or movement of the input member (knob or handle).

(4) Optimal shape of the manipulator arm. The wrist joint and lower portion of the arm should be as small as possible to permit unobstructed vision by the technician as well as to permit remote manipulation of equipment in close quarters.

e. Rectilinear arm manipulators should have the following capabilities:

(1) Grip force indication, visual and/or auditory.

(2) Horizontal movement to permit handling at any location in the "hot" area.

(3) Portable control console to "follow" the arm to various locations in the "hot" area.

(4) Provide positive stops to preclude danger to the objects being handled and/or "hot" area if one of the servo-loops should fail.

f. Master-slave manipulators should have the following functions and capabilities:

(1) Manipulator design to utilize the natural characteristics of the operator, with conformity of the control and effector portions with regard to spatial orientation and position. Errors greater than 20° or 30° in the synchronous arrangement of slave jaws and master control handle are detrimental to operator performance.

(2) High mechanical efficiency, low inertia, and low friction.

g. Electronic master-slave manipulators should have the following functions and capabilities:

(1) Variable ratios of control-effector movement.

(2) Variable ratios of force reflection (kinesthetic feedback).

(3) Positive stops to preclude danger to the objects being handled and/or "hot" area if one of the servo-loops should fail.;

h. Manipulator hands should permit a wide range of lifting, holding, and clamping capacities. Several illustrations of useful hand configurations for maintenance tasks are shown:

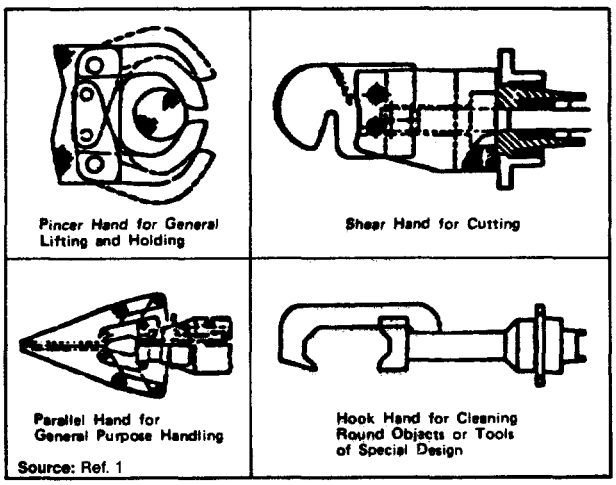


Exhibit 2.2.4 Examples of Manipulator Hand Configurations

i. Handling controls should be designed to provide kinesthetic and tactile feedback to the maintenance technician so that a sense of "feel" is provided as to the amount of torque or force being applied or the direction of movement being taken.

(1) Where possible, the arm on which the control handle is attached should have a shape similar to the manipulator arm to maximize the similarity of motions.

(2) For precise measurement and feedback of torque, grip force, or thrust force, calibrated instruments on the control console should be provided. For example, a hand grip force display should be provided which indicates a force reflection over a range from a few ounces to several hundred pounds.

j. A means of direct vision should be provided through shielding windows where possible. A means of achieving this is by using turntables designed to rotate the equipment so that any side can be shown to the maintenance technician. Direct vision is preferred because it provides little or no distortion of dimensions, clarity, and color discrimination.

k. Where direct vision is not possible or an adjunct to it is needed, an optical system should be provided such as binocular, or stereoscoptic periscopes or microscopes where three-dimensional viewing is essential.

l. Where direct vision and optical systems are not possible, closed circuit television systems should be provided for visibility.

(1) The usefulness of closed circuit television as a means to provide visual feedback for a remote performance field appears to be seriously limited when the visual field is displaced from the normal line of sight.

(2) Two cameras oriented at right angles to one another with a separate monitoring screen for each are frequently substituted for stereo television.

(3) Color enhances the sensation of depth but black and white TV is ordinarily preferred because of its better resolution.

(4) Visibility is more dependent upon strong contrasts and shades than on stereoscopic effect.

m. Special windows should be provided to shield maintenance technicians from radiation while providing maximum visibility. Liquid-filled windows must provide the following:

Shielding effectiveness (The same shielding per unit of thickness as afforded by the remainder of the biological shield.)	**Optical efficiency** (High transmission of a large portion of the visible spectrum, minimum haze high refraction index, large angle of view through small window aperture.)
Stability of color and clarity (Against both time and radiation.)	**Nontoxicity of window materials** (in case of breakage.)

n. In order to preserve the contrast effect which is important in discriminating detail, care should be taken to control factors such as haze in liquid windows, cleanliness of glass surfaces, and multiple surface reflections.

o. To minimize distortion, objects should not be viewed near the window or with an angle of incidence for the line of sight which is greater than 60°.

p. Sufficient light should be provided for remote handling operations:

(1) Auxiliary lighting should be provided for visually inaccessible locations in the equipment being handled. For example, lights should be provided on tools, test probes, and servicing adapters that are inserted into dark recesses of equipment.

(2) To increase visibility, higher intensities of achromatic lighting is just as efficient as monochromatic lighting.

(3) Monochromatic light should be used only where white light would actually interfere with observation, as with very small components in which the parts would not be distinguishable under white light.

q. If possible, symbol coding rather than color codes should be used when codes must be recognized by the maintenance technician both under conditions of direct viewing and color television use. Symbol coding may not be applicable for very complex equipment. However, any adaptation of color codes to correct for distortion by color television will confuse the technician who is viewing the code directly. Therefore, another method of coding other than color should be used when both direct and television viewing are required.

r. Tools and support equipment that are used in conjunction with remote handling equipment should be designed so that they are easily accessible to the manipulator hand and easily decontaminated.

2.0 FACILITY SUPPORT

2.3 Hand Tool Design for Maintainability

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2.3.4 SPECIFIC PRINCIPLES 2.3-4

2.3.2 DEFINITION

Hand tools, as referred to in these guidelines, include only those which are commonly used in maintenance work for inspecting, adjusting, servicing, removing, or replacing components.

Though tool design is accomplished separate from system design, it is important to ensure that equipment is designed to be maintained (in order of priority):

a. Without tools, where possible.

b. With the minimum number of tools for the system.

c. With the minimum number of tools for the maintenance task.

d. With common hand tools, where possible.

e. With specialized tools only when absolutely required.

2.3.3 GENERAL PRINCIPLES

2.3.3.1 Tools should be designed for maximum simplicity, practicality, and universality.

2.3.3.2 Requirements for tools should be derived directly from the maintenance tasks to be performed and the design characteristics of the equipment involved.

2.3.3.3 Each equipment system should be accompanied by a comprehensive list of tools required for all maintenance tasks.

2.3.3.4 Tools should be used during developmental testing of the system/equipment to find duplications and omissions, and to determine if the equipment requires additional tools.

2.3.3.5 Only those tools usually found in the maintenance technician's tool kit should be required for maintenance operations.

2.3.3.6 Speed or power tools such as ratchets, speed screwdrivers, or power wrenches should be provided the technician when they are required because of torque demands or space limitations.

2.3.3.7 Remotely controlled tools should be provided where feasible and where such tools will reduce maintenance time and labor hours.

2.3.3.8 Holding tools such as pliers or clamps should be designed so that they are skid-proof and do not mar or scratch holding surfaces.

2.3.3.9 Adequate gripping surfaces should be provided on the handles of tools. Knurling, grooving, or shaping the handle to fit the hand are desirable.

2.3.3.10 In evaluating the finish to be applied to tools, consider that tools having a dull finish prevent reflected glare in areas of high illumination. However, dull-finished tools are often overlooked when closing assemblies, etc., causing loss of tools and possible damage to the equipment. The designer should therefore carefully consider the advantages and disadvantages of this type of finish in relation to the potential application of the tool.

2.3.3.11 Using plastic, heat- or cold-resistant handles on tools which are to be used in extremely hot or cold climates should be specified. The use of metal handles is undesirable, particularly for cold climates and for electricians' tools.

2.3.4 SPECIFIC PRINCIPLES

2.3.4.1 Screwdrivers for small-size adjustment screws should be provided with a funnel-like guide that will aid placement of the screwdriver on the adjustment point.

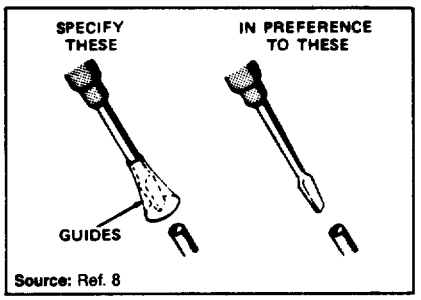


Exhibit 2.3.1 Screwdriver for Small-Sized Adjustments

2.3.4.2 Magnetized screwdrivers, if they will not adversely affect electronic circuits, should be provided to hold free screws that cannot be held easily with the fingers. If magnetized screwdrivers are not desirable, screwdrivers should have clips. Design the clip so that it can be slid up the screwdriver shaft when not in use.

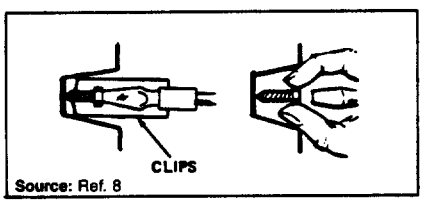


Exhibit 2.3.2 Example of Clip Screwdriver

2.3.4.3 Push-type tools should be provided wherever screws must be rotated through many revolations, provided the attendant resultant force on the equipment will not be harmful.

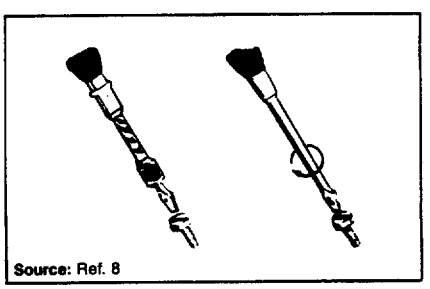


Exhibit 2.3.3 Example of Push-Type Tool

2.3.4.4 Tools should be specified which are compatible with the design of the equipment on which they will be used as well as with the job to be performed. For example, a tool size should be specified which is consistent with the size of the prime equipment. Lever handles should be specified rather than screwdriver handles when high torque is to be applied, and tools should be provided which are consistent with working space available on the prime equipment.

2.3.4.5 Positive snap-locking action should be used for connecting sockets to the various components of a socket set. Design them so they can be easily connected and disconnected.

2.3.4.6 Ratchet screwdrivers should be provided where torque requirements are low and space is limited. They require only one-handed operation and usually require less clearance.

2.3.4.7 Equipment should be designed so that only straight type screwdrivers can be used. Offset screwdrivers are not satisfactory because there is a lack of normal force on the screw head slots and the slots become damaged easily. However, the use of offset screwdrivers reduces the amount of space required to turn a screw and because of space limitations may be the only solution. The overhead space requirement for offset tools and two special type offset tools for removing fasteners are illustrated below.

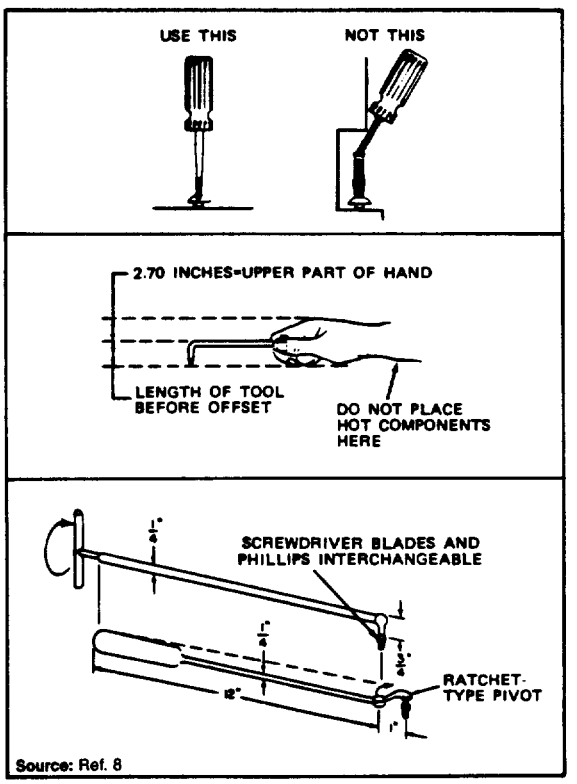


Exhibit 2.3.4 Uses of Straight and Off-Set Screwdrivers

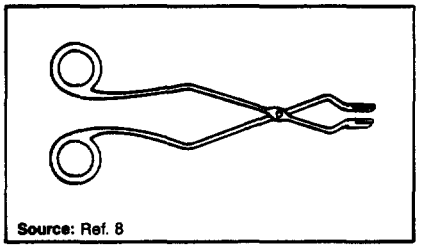
2.3.4.8 Drills with floating chucks for drilling fastener holes for rivets should be used. These will insure that the hole is drilled at the proper right angle so that maximum fit tolerances are reached.

2.3.4.9 Spanner wrenches should be designed to be operable from various angles to avoid obstructions in operations.

2.3.4.10 The technician should be provided with templates for making surface control adjustments (rigging) or for mounting links, arms, rods, or other such parts on a flat surface. Markings should be provided on the templates to show the desired setting or placement of the control or part.

2.3.4.11 High-speed soldering devices should be provided to melt connections being serviced without damaging adjacent elements.

2.3.4.12 Clamping devices should be provided to remove small, closely packed plug-in devices.



Source: Ref. 8

Exhibit 2.3.5 Example of Clamping Device

2.3.4.13 Long-nosed hemostat-type pliers should be provided which can lock, hold their grip, and be used as heat sinks.

2.3.4.14 Printed circuit card extenders and card extractors should be available to the technician for use with computerized units.

2.3.4.15 SAFETY SUGGESTIONS

a. Adequate insulation should be provided on handles or other parts of tools which the technician is likely to touch while doing maintenance work near voltages in excess of 50 volts.

b. Spark-resistant tools should be provided if they are to be used in areas where fire or explosion hazards are present.

c. Adequate storage for tools should be provided so they cannot fall and cause personal injury or be easily misplaced or lost.

d. Sharp corners and edges on tool chests should be eliminated.

e. Tool chests which are too large to be easily handled by one person should have casters or a sufficient number of handles to facilitate moving. Handles should be located so the chest will be balanced when it is being moved.

2.0 FACILITY SUPPORT

2.4 Stair, Ladder, and Ramp Design for Maintainability

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2.4.2 DEFINITIONS

Stairs, ladders, and ramps refers to structures which allow personnel to abruptly change elevations by more than 12 inches. Stairs (stiles) and ramps may be used to allow for safe and easy passage over low objects (e.g., pipes, lines) in corridors and passageways. Types of structures (in order of preference) are:

a. Stairs allow the fastest, safest, and easiest passage of personnel, especially when they are carrying loads.

b. Stair ladders are preferred to ladders because they provide better footing and faster, safer passage. However, sure balance and fast movement require the use of both hands on the handrails. Carrying loads up stair ladders is also hazardous.

c. Ladders are not desirable for frequent passage. They are comparatively unsafe, difficult to climb, and difficult to work from. Only loads which are strapped to personnel can be carried up ladders. Fixed ladders are preferable to semi-permanent or movable ladders; the former are more stable, less subject to clearance problems, and can be affixed with guardrails and other safety features. Portable ladders should be required and provided only for emergency functions or for use during infrequent maintenance tasks. Permanent ladders or maintenance stands are preferable.

d. In general, ramps are of value only when rolling stock must be moved between different levels and this same space can be used for pedestrian traffic. Long ramps are undesirable except for self-propelled vehicles. Requirements for personnel to push or pull rolling stock up ramps should be carefully evaluated in terms of safety and human strength.

2.4.3 GENERAL PRINCIPLES

2.4.3.1 Layout and design of stairs, ladders, and ramps should consider:

a. Limitations in the amount of space and clearance available.

b. Predictable environmental conditions that will affect the structure (particularly if it will become wet or covered with ice, snow, or mud).

c. Type, direction, and frequency of traffic over the structure.

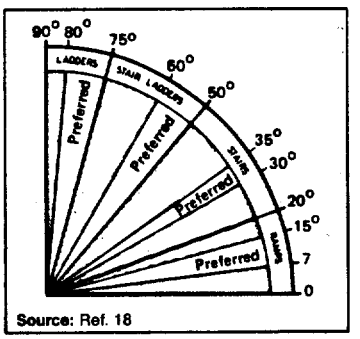
d. Relative efficiency of alternate traffic patterns.

e. Loads or other encumberances to be carried by personnel over the structures.

f. Size and weight of other equipment that may have to be moved over the route.

g. Need for decontamination and clean up.

2.4.3.2 The type of structure chosen to be used should be based on the angle of the structure's inclination in relation to the available space and structural constraints. The illustration shows the preferred and critical angles of incline suitable for these structures.



Source: Ref. 18

Exhibit 2.4.1 Preferred and Critical Angles for Ladders, Stair Ladders, Stairs, and Ramps

2.4.3.3 Stairs, ladders, and ramps should be:

a. Designed, installed, or provided to effect the most immediate and efficient access to and between work places and areas.

b. Constructed of materials which are lightweight, non-conductive, splinter-proof, waterproof, weatherproof, humidity-resistant, and resistant to chemical action.

c. Designed to withstand the combined weights and strengths of the largest number of personnel likely to be on them at one time, multiplied by a safety factor of at least two. Two hundred and fifteen pounds per person should be used to calculate weight.

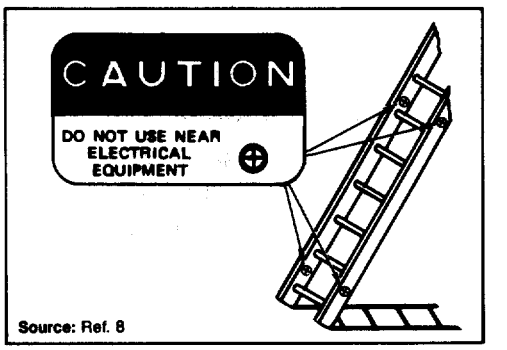
d. Provided with non-skid surfaces on all areas where personnel are expected to step, walk, or stand.

e. Free of obstruction, edges, notches, or burrs which could injure personnel or damage hoses or cables.

f. Designed to be de-iced, when necessary, by using hot water or steam.

g. Adequately lighted.

h. Adequately marked against hazards in their use, e.g., against low overhead, possible shock.



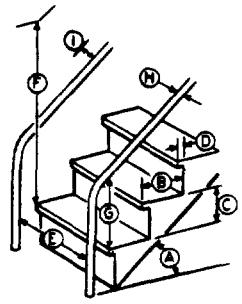
Source: Ref. 8

Exhibit 2.4.2 Example of Hazard Marking on Ladder

2.4.4 SPECIFIC PRINCIPLES

2.4.4.1 DESIGN REQUIREMENTS FOR STAIRS

a. Critical dimensions for stair design follow:



		Min.	Max.	Best
A	Angle of rise:	20"	50"	30-35"
B	Tread depth:	9.5" [a]	12"	11-12"
C	Riser height:	5" [b]	8" [c]	6.5-7"
D	Depth of nosing:	.75"	1.5"	1"
E	Width (handrail to handrail)			
	One-way stairs:	20"	–	22"
	Two-way stairs:	48"	–	51"
F	Min. overhead clearance:	76"	–	78"
G	Height of handrail:	30"	36"	33"
H	Diameter of handrail:	1.25	3"	1.4"
I	Hand clearance: [d]	1.75"	–	2"

Notes: a. Building Officials & Code Administrators (BOCA) Basic Building Code (1981) recommends a minimum tread depth of 11".

b. BOCA Basic Building Code (1981) recommends a minimum riser height of 4".

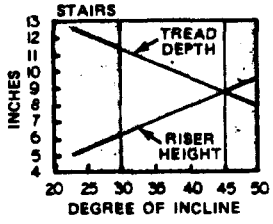
c. BOCA Basic Building Code (1981) recommends a maximum riser height of 7".

d. OSHA Standard 1910.23(C)(6) recommends a mimimum hand clearnace of 3".

Source: Ref. 18

Exhibit 2.4.3 Critical Dimensions for Stairs

b. Tread depth and riser height may vary with the angle of inclination according to the graph below. But loads carried and length of the stairs should also be considered. In general, deep treads (12") and low risers (5") should be used when loads over 20 pounds are to be carried or stairs are over two stories high.



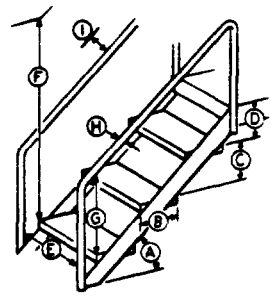
Source: Ref. 18

Exhibit 2.4.4 Tread Depth vs. Riser Height

Avoid long flights of stairs. Landings are recommended every 10-12 treads and must be provided for every story (8-12 ft. elevation).

2.4.4.2 DESIGN REQUIREMENTS FOR STAIR LADDERS

a. Critical dimensions for stair ladder design follow:



		Min.	Max.	Best
A	Angle of rise:	50"	75"	50-60"
B	Tread depth:			
	For 50" rise:	6"	10"	8.5"
	For 75" rise:	3"	5.5"	4"
C	Riser height:	7"	12"	8-9"
D	Height, step to landing:	6"	Riser	Riser
E	Width (handrail-handrail):	21"	24"	22"
F	Min. overhead clearance:	68"	–	76"
G	Height of handrail:	34"	37"	35"
H	Diameter of handrail:	1.25"	2"	1.4"
I	Min. hand clearance *	2"	–	3"

*OSHA Standard 1910.23(C)(6) recommends a minimum hand clearance of 3".

Source: Ref. 18

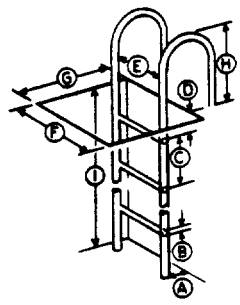
Exhibit 2.4.5 Critical Dimensions for Stair Ladders

b. Clearance on stair ladders should be sufficient for one person only. If simultaneous two-way traffic is desired, separate up and down ladders should be provided. If these are located side by side, a double center handrail should be provided with a minimum of 6" between rails (8" recommended).

c. Treads should be open (without risers). But metal screening (or kick plates) should be fastened to the underside where required to prevent injury to personnel or damage to equipment.

2.4.4.3 DESIGN REQUIREMENTS FOR FIXED LADDERS

a. Critical dimensions for fixed ladder design follow:



		Min.	Max.	Best
(A)	Angle of rise:	75"	90"	80"
(B)	Rung or cleat diameter:			
	Wood:	1.13"	1.5"	1.4"
	Protected metal:	.75"	1.5"	1.4"
	Metal that may rust:	1.0"	1.5"	1.4"
(C)	Rung spacing (R-S): [a]	9"	16"	11-12"
(D)	Height, rung to landing:	6"	R-S	R-S
(E)	Width between stringers:	12"	–	18-21"
(F)	Climbing clearance width:	24"	–	30"
(G)	Min. clearance depth: [b]			
	In back of ladder:	6"	–	8"
	On climbing side:	36" for 76",		30" for 90"
(H)	Height of string above landing:			36"
(I)	Max. height of climb:	–	10'	8'

[a]OSHA Standard 1910.27(b)(1)(i) and (ii) recommends a maximum rung spacing of 12".

[b]OSHA Standard 1910.27(c)(4) recommends a minimum clearance in back of ladder of 7".

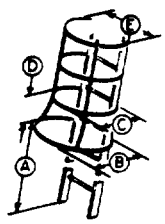
Source: Ref. 18

Exhibit 2.4.6 Critical Dimensions for Fixed Ladders

b. If ladders are used between several floors, they should be offset and guarded landings should be provided at every floor.

c. Guardrails should be provided at the top entrance to ladders, if the ladder well is open.

d. Ladder cages should be provided for fixed ladders over 20 feet long. Dimensions of cage should be as follows:



(A)	Height of cage from base of ladder:	7 feet
(B)	Flare at bottom of the cage:	32 inches
(C)	Depth of cage from center of ladder:	28 inches
(D)	Max. distance between cage ribs:	18 inches
(E)	Width of cage:	27 inches

Source: Ref. 18

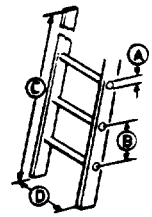
Exhibit 2.4.7 Ladder Cage Dimensions

e. The inside of the cage must be clear of obstructions.

f. Round rungs provide better hand holds, but level steps, 3–4" wide, may be used if handrails are provided on both sides of the ladder.

2.4.4.4 DESIGN REQUIREMENTS FOR PORTABLE LADDERS

a. Critical dimensions for portable ladder design follow:

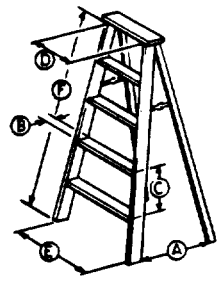


Rung-ladder dimensions:

(A)	Rung diameter:	Same as "Fixed ladders"
(B)	Rung spacing:	Same as "Fixed ladders"
(C)	Maximum ladder length:	
	Single section ladders:	30 feet
	Two-section, metal ladders:	48 feet
	Two-section, wood ladders:	60 feet
(D)	Min. width between side rails:	
	Metal ladders:	12 inches
	Wood ladders:	
	Up to 10 feet long:	11.5 inches
	Add .25 inches for each added 2 feet of length.	

Source: Ref. 18

Exhibit 2.4.8 Critical Dimensions for Portable Ladders



Step-ladder dimensions:

(A)	Spread:	3.5 inches per foot length of front section plus 2.0 inches per foot length of back section.
(B)	Tread width:	Min. 3 inches; best 3–4 inches
(C)	Step spacing:	Min. 9 inches; best 11-12 inches
(D)	Min. width between siderails at top step:	
	Metal ladders:	12.0 inches
	Wood ladders:	11.4 inches
(E)	Width at bottom:	Add 1 inch per foot of length
(F)	Length of ladder:	Maximum of 20 feet.

Source: Ref. 18

Exhibit 2.4.9 Critical Dimensions for Step Ladders

b. Ladders should be provided with rubber-cleated, pivoted feet for use in non-freezing weather, and steel cleats for use in ice or snow.

c. Permanent hinges and locks should be used in preference to bolts and nuts for assembly of two-section extension ladders.

2.4.4.5 SPECIAL REQUIREMENTS FOR FIXED AND PORTABLE LADDERS

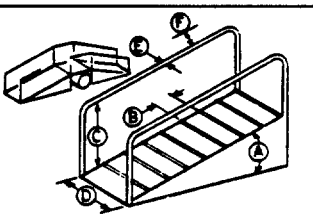
a. Safety devices should be provided on either fixed or portable ladders whenever length, use, or operating conditions require. For instance, pole lashing devices should be provided for ladders to be used against poles, or carrier rails and safety belts should be provided for long ladders to be used in adverse weather or under emergency conditions.

b. Kick plates should be installed behind ladders for special applications where feet may damage the surface of the equipment.

c. Metal ladders should be marked with signs or decals warning against the danger of shock. These should be placed inside the stringers, on both sides, and 3 feet from both ends and read: "CAUTION. Do not use or store near electrical equipment."

2.4.4.6 DESIGN REQUIREMENTS FOR RAMPS

a. Critical dimensions for ramp design follow:



		Min.	Max.	Best
(A)	Angle of rise:	–	20°	7-15°
(B)	Distance between cleats:	9"	16"	14"
(C)	Height of handrails:	38"	44"	42"
(D)	Width: Determined by function and usage. Particularly size of rolling stock and loads.			
(E)	Diameter of handrail:	1"	3"	1.4"
(F)	Clearance around handrail:	2"	–	3"

Source: Ref. 18

Exhibit 2.4.10 Critical Dimensions for Ramps

b. Where a smooth surface or runway for wheeled vehicles is needed, it should be located in the center or to one side of the ramp, with cleated portions on the outside below the handrails. A combination of ramp and stairway is preferred, however, especially for slopes greater than 7 degrees.

2.0 FACILITY SUPPORT

2.5 Platform and Shelter Design for Maintainability

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2.5.4.3 Guardrails 2.5-4

2.5.2 DEFINITIONS

Platforms refer to supports which are used to provide maintenance technicians with support at a tolerable working distance to equipment.

Shelters are used to provide enclosure and protection of maintenance technicians and equipment during maintenance tasks.

2.5.3 GENERAL PRINCIPLES

2.5.3.1 MOBILITY REQUIREMENTS. Platforms and shelters should be permanently installed whenever possible. Where they must be mobile, they should be:

a. Lightweight enough for no more than two people to handle, erect, and install.

b. Collapsible or adjustable for easy handling and transporting.

c. Provided with self-locking devices for all attachments, adjustments, and collapsible supports.

d. Provided with wheels, as necessary, that should:

(1) Have wheel locks or brakes to insure stability.

(2) Be large enough to allow easy passage over ridges up to 0.75 inches high or higher.

(3) Provide firm grip and adequate support on slippery surfaces, snow, ice, and sand.

2.5.3.2 STABILITY REQUIREMENTS. Platforms and shelters should be:

a. Provided with low centers of gravity, wide wheel bases, anchors, and/or outriggers as needed to achieve stability.

b. Properly balanced and supported to allow using without tipping when the weight of personnel and/or components is applied to any one side.

2.5.3.3 FIXTURE REQUIREMENTS. Where practical and feasible, platforms and shelters should have:

a. Electrical outlets and fixtures to provide adequate lighting and facilitate use of test equipment and powered tools.

b. Shelves or other places for resting test equipment, tools, or components at a convenient operating or working level.

c. Hooks, eyes, clip fasteners, supports, etc. to facilitate the support and connection of associated wiring, hoses, block-and-tackle arrangements, etc.

d. Storage space, cable winders, supports, clamps, etc. to provide storage for associated manuals, slings, special tools, extension cables, etc.

2.5.3.4 SIZE AND CONFIGURATION REQUIREMENTS

Platforms and shelters should provide:

a. Easy passage of personnel when access doors, cowl flaps, etc. are open.

b. Adequate work space and work clearances for the maximum number of personnel and range of tasks required in these operations.

c. Easy access to all equipment, mounts, and features integrally related to the maintenance operations they support; e.g., to an engine and all its associated parts, accessories, and points of connection.

d. Safe and easy handling in these operations of all related:

(1) Components that are likely to be removed.

(2) Spare parts, tools, etc. that must be handled.

(3) Slings, hoses, lines, and other supports to be handled.

(4) Cowls, panels, or other major items that must be handled within the shelter or from the platform or stand.

2.5.4 SPECIFIC PRINCIPLES

2.5.4.1 PLATFORMS. Platforms should be designed to:

a. Satisfy the preceding "General Principles."

b. Provide a minimum of 6 square feet of workspace.

c. Permit the technician to have both hands free for work.

d. Provide a continuing work surface around or between related portions of the work area, e.g., the engine.

e. Have a capacity in excess of the heaviest combination of persons and/or equipment to be supported at any one time. Use 215 lbs. per person to calculate weight. A minimal capacity of one ton in recommended.

f. Conform closely to the work surface.

(1) General conformation should be within 2 inches.

(2) Gaps greater than 6 inches are normally objectionable.

(3) Contact plates, cushions, bumpers, or pads should be provided as necessary to protect equipment surfaces.

2.5.4.2 SHELTERS. Shelters should be designed so that:

a. They satisfy the preceding "General Principles."

b. Time to install and enclose is minimal and does not exceed one hour.

c. Maximum practical enclosure and protection are provided in terms of the environment in which the shelter is to be used.

d. Ventilation and environmental control are within tolerable limits, considering the type of clothing to be worn.

e. Allowances are made for variations in configurations of the sheltered equipment.

f. They can be used side by side where appropriate.

g. Covered openings are provided as necessary to facilitate removal of major components such as complete engines.

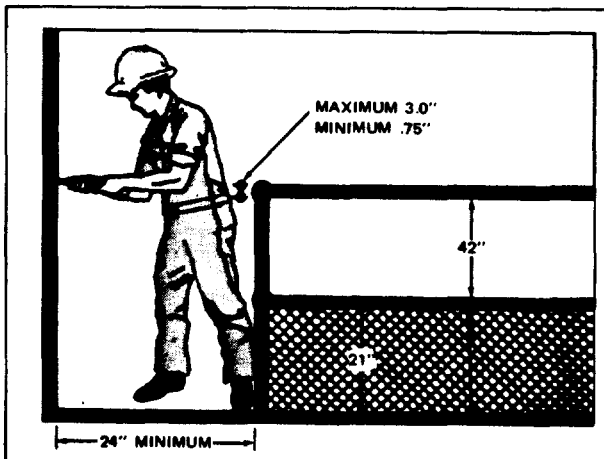
h. They are compatible with, provide openings for, and allow employment of associated support equipments such as cranes, stands, slings, etc.

i. Their design does not prevent operations essential to related maintenance.

2.5.4.3 GUARDRAILS. Guardrails should:

a. Satisfy the requirements shown below.

b. Have screening or lattice work.



Source: Ref. 12

Exhibit 2.5.1 Critical Dimensions for Guardrails

2.0 FACILITY SUPPORT

2.6 Design of Computer Systems for Maintainability

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2.6.2 DEFINITIONS

a. **COMPUTER SYSTEM.** A computer system consists of computer hardware components and other electronic components which are connected together and operate under control of computer software.

b. **UNIQUE INTERFACES.** These are electronic interfaces of unique design which interface the computer to sensors and other electronic and electrical devices. These interfaces will be used most often in control and monitoring device applications. Examples are analog to digital converters (ADCs) and digital to analog converters (DACs).

c. **INPUT DEVICES.** These devices provide input information to the computer. Typical devices are keyboards, numeric key pads, disk drives, magnetic tape drives, and punched cards and paper tape readers.

d. **OUTPUT DEVICES.** Computer information is sent as output to these devices either as stored data or as a direct response to computer operator commands. Typical devices are video displays, printers, plotters, magnetic tape drives, disk drives, and paper tape punches.

e. **INPUT/OUTPUT DEVICES.** These are devices which can serve both as input and output devices. Typical examples are video display terminals with keyboards, magnetic tape drives, and disk drives.

f. **COMPUTER SOFTWARE.** Software normally means more than one computer program which functions to control operation of a computer and allow computer system users to perform specific tasks. These tasks may be computational, data-handling, control, monitoring, analysis, graphics, editing, and other. Typical software storage devices are computer memory, magnetic tape, disks, paper tape, and punched cards.

g. **ENVIRONMENT** (Equipment). Environment refers to all conditions which surround a computer system or one of its system components and which directly affect operation of equipment. These conditions take into account air, electromagnetic interference (EMI), electrostatic discharges, and power line noise. Factors which affect air conditions are humidity, temperature, cleanliness of the air, and air flow distribution.

h. **ENVIRONMENT** (Personnel). Environment refers to air, acoustic noise, electrostatic discharges, and room lighting.

i. **POWER FACTOR (PF).** This factor numerically gives the phase relationship between a.c. voltage and current when a system or component is connected to an electrical power source. It is defined using watts consumed and the products of voltage times current.

$$PF = \frac{\text{watts}}{\text{voltage x amperes}}$$

j. **POWER DISTURBANCES.** These are changes in the electrical power source which might produce an undesirable response in the computer system or one of its components. Computer equipment manufacturers often specify allowable power line disturbances.

2.6.3 GENERAL PRINCIPLES

2.6.3.1 SPACE REQUIREMENTS FOR COMPUTER SYSTEMS. Maintainability of a computer system and all its components largely depends on the system operating in properly designed facilities. The design of the facilities includes establishing criteria for space. Many factors directly influence long-term space needs:

- Equipment
- Work areas
- Furniture
- Storage
- Expansion.

Initial design considerations for space should include room structural requirements for walls, floors, and ceiling. These may require acoustic properties to reduce noise levels generated by equipment. Floors which are of the raised type can accommodate cables and air flows for equipment cooling. Suspended ceilings can incorporate acoustic properties, lighting, and fire control systems. Each computer system site is different and consequently each will have different requirements for space. The following points should be considered at each site:

a. **SPACE FOR EQUIPMENT.** Adequate space should be allowed for system components. Generally, at least three (3) feet of space should be allowed between equipment components in rows and equipment components and walls. This will provide a minimum amount of work area to service equipment.

b. **SPACE FOR WORK AREAS.** Adequate space should be allowed for work areas around equipment. Furniture used by personnel, such as tables and chairs, and areas used for storage, should be taken into account.

c. **WORK-FLOW PATTERNS.** Space requirements should be considered to allow sufficient work-flow patterns between work areas. Input/output devices usually require ease of visual observation from more than one location.

d. **STORAGE SPACE.** Storage space should be provided for supplies necessary for system operation.

e. **ELECTRICAL POWER.** Electrical power requires space for isolation transformers and line voltage regulators if used. Electrical panel boxes require space to allow access by personnel. Overhead space is required for lighting and wall space and/or raised floor space for power outlets.

f. **CABLES.** Power cables and equipment cables should occupy floor or overhead space if raised floors are not used.

g. **ENVIRONMENTAL EQUIPMENT.** Air conditioning and/or humidifying equipment may require both floor space and duct space.

h. **FIRE EQUIPMENT AND HARDWARE.** Space requirements should be considered for spinkler systems, fire extinguishers, and alarm systems.

i. **FUTURE SYSTEM EXPANSION.** Space considerations should be given for future expansion of the system.

2.6.3.2 ENVIRONMENTAL REQUIREMENTS FOR COMPUTER SYSTEMS. Reliability of computer systems and their components depends largely on operation of equipment in a controlled environment. This requires temperature and humidity levels to be maintained within specified ranges. The control of air flow and good distribution prevents equipment from overheating. It is desirable to consider separation of some types of equipment. Printers can contribute to air contamination, whereas disk drive systems demand a clean air environment for long-term reliability. Both EMI and power line noise can interfere with operation of electronic circuits. Potential EMI problems may require shielded equipment rooms. Power line noise usually requires line isolation and may require special filtering and/or line regulation. Noise levels for system components may need to be determined and site designs should take into account acoustic shielding techniques. Control over lighting and proper placement of light fixtures in a room can minimize problems of reflections and glare from video display screens.

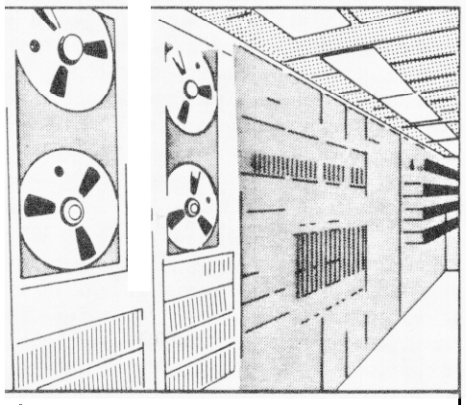

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Exhibit 2.6.1 Illustration of Computer System in Controlled Environment, Highlighting Effective Placement of Light Fixtures, and Sound-Deadening Ceiling Tiles

2.6.3.3 ELECTRICAL POWER REQUIREMENTS FOR COMPUTER SYSTEMS. Electrically powered computers and their components are designed to operate from a clean, constant supply of a.c. power. This a.c. power must be kept within manufacturer-specified tolerances in order for equipment to operate properly and safely. Power disturbances are a common occurrence at computer sites and are a major cause of malfunctions in computers. These disturbances fall into five categories:

a. **DECAYING OSCILLATORY TRANSIENTS.** These are caused by the switching of power factor correction capacitors and from other network load switching.

b. **VOLTAGE SPIKES.** These are caused by power network switching, user equipment operation, and lightning.

c. **UNDERVOLTAGES AND OVERVOLTAGES.** These conditions of duration greater than ½ cycle are caused by the application of heavy loads to the power line, by faults, and by the subsequent lag time of fault-clearing devices.

d. **POWER OUTAGES.** These conditions of duration greater than one cycle are caused by faults within the user network or by a breakdown of utility power transmission equipment.

e. **NOISE.** This noise comes from sources external to the system and is injected into the power line. These sources include welding equipment, X-ray machines, and other sources which may generate radio frequency (RF).

The effects of these disturbances must be kept to a minimum within electrical wiring and grounding designed for the computer system. Grounding systems should incorporate the concept of a single point ground to minimize their effects.

2.6.4 SPECIFIC PRINCIPLES

2.6.4.1 ENVIRONMENTAL REQUIREMENTS FOR COMPUTER SYSTEMS. Site design for maintainability and reliability of a computer system requires that reasonable control be maintained over the system's operating environment. The following points should be considered:

a. **OPERATING TEMPERATURE.** 65 to 75°F (18 to 24°C); temperature rate of change—3.6°F/hr. (2°C/hr).

b. **RELATIVE HUMIDITY.** 40 to 60% non-condensing; humidity rate of change—2%/hr.

c. **AIR.** An air distribution system should provide cool, well-filtered, humidified air with room air pressure kept higher than the pressure of adjacent areas to prevent dust infiltration. Windows and doors should be weather tight. Slow-operating door closers should be avoided. Double glass is recommended for large window areas. Some equipment generates more heat than others and requires more cooling air. It is desirable to have an efficient method for distributing and balancing the flow of air.

d. **AIR FILTERS.** Air circulating through an air conditioning system and air entering a computer room should be filtered. Permanent filters or combinations of replaceable and permanent filters should be used. Permanent filters should be easily washable and in compliance with fire code standards. Other filter considerations include:

- High efficiency at low pressure drop.
- Trouble-free operation.
- Elimination of downstream dirt during replacement.
- Minimum maintenance.
- Simple installation.
- Particle-free air at minimum cost.

Special air filtration is necessary only where installations are exposed to corrosive gases, salt air, or unusual dirt or dust conditions. If these conditions exist, an air filtration specialist should be consulted. The recommended operating environment should filter the air to 10 microns.

e. **STATIC ELECTRICITY.** Static electricity can affect the operational characteristics of computer system components. Floor covering material can contribute to the build-up of high static electrical charges which result from the motion of people, carts, furniture, etc. in contact with the floor material. Static build-up on the floor can be minimized by taking the following precautions:

(1) Use floor tile or other floor surface material which has a surface resistance of 0.5 megohm (minimum) to 20,000 megohms (maximum) at operating limits of 20 to 80% relative humidity and temperatures of 60 to 90°F (15 to 25°C), measured between floor surface and building ground.

(2) Use carpeting of the type designed to minimize the effects of static electricity. Carpeting may have a brass mesh woven throughout the backing or be designed to prevent build-up of static through special ionized nylon filaments.

(3) Adequately ground flooring consisting of metal panels or flooring with metal edges.

f. **ELECTROMAGNETIC INTERFERENCE (EMI).** Sources of radiation, such as highpower radio frequency (RF) or pulse transmitters, which are in proximity to a computer system or its components, may affect system operation. The effect of these emissions can be mini-minimized through facility designs and equipment installations which incorporate good shielding practices. Design and installation practices should include:

- Grounding window screens and other large metal surfaces.
- Using interconnection cables with a grounded shield.
- Using additional grounding within system cabinets—chassis to cabinet.
- Building a screened room or EMI enclosure.
- Posting signs stating that use of EMI generators (e.g., radio transmitters) is prohibited within a designated area.

g. **ACOUSTIC NOISE.** Facility designs should minimize acoustic noise which may interfere with maintenance operations by:

- Grouping high level noise devices (disk and magnetic tape drives) and isolating them in acoustically damped rooms.
- Designing walls and ceilings using acoustic materials and allowing for use of sound-absorbing partitions.
- Using double windows (two panes of glass) where offices or other personnel work areas are adjacent to the computer system installation.

h. **LIGHTING.** Video display terminals and stand-alone computers utilize cathode ray tubes as output viewing devices. To enable a technician to view a display, surrounding room illumination may need to be reduced or controlled. In particular, reflections and glare from overhead light should be considered in room designs.

2.6.4.2 ELECTRIC POWER REQUIREMENTS FOR COMPUTER SYSTEMS. Electrical power stability in terms of voltage and frequency and a well-designed distribution system employing proper grounding techniques contribute to the maintainability of a computer system and its components.

a. **VOLTAGE AND FREQUENCY.** Line voltage disturbances greater than ±10% from nominal and a duration greater than ¼ cycle at the input to an operating computer system may cause system malfunctions or errors. Accepted tolerances are ±10% for a.c. voltages and ±2% for frequency at 60 Hz.

b. **SYSTEM POWER REQUIREMENTS.** The available supply of a.c. power should be adequate to handle power loads of the contemplated computer system and any loads which are likely to be imposed by future expansion.

c. **POWER TRANSFORMER.** A separate power transformer is advisable for the computer system. Transformers specifically designed for computer systems offer noise suppression through the use of an electrostatic shield.

d. **POWER FACTOR.** A power factor of greater than 0.85 is desirable for a fully operational computer system.

e. **MAINLINE CIRCUIT BREAKER.** The feeder lines supplying power to the computer system should be protected by a mainline circuit breaker and be accessible to operating personnel. A light should indicate when power is "ON."

f. **POWER RECEPTACLES.** Power lines should terminate, where possible, in National Electric Manufacturers Association (NEMA) receptacles. To minimize the effects of ground loops and other forms of noise induction, receptacles should not have the safety ground connected to the conduit tabs internal to the socket. If safety ground is not isolated from conduit by a constant voltage isolation transformer, efforts should be made to isolate ground from conduit and neutral throughout the power distribution system. Required grounding should be made at the service entrance.

g. **PROTECTIVE OR SAFETY GROUND.** The protective or safety equipment ground is a green covered conductor in a multi-conductor cable and is used to prevent the build-up of dangerous voltages on equipment and provides protection for personnel. It assures that any short circuit between a power phase and the cabinet will draw enough current to trip the circuit's protective device immediately, rather than raise the potential of the equipment to a dangerous level. A single-point ground system should be used and all "green-wire" grounds tied together at the circuit breaker load center. The load center panel should have a copper ground bus to which all equipment grounds can be attached.

h. **CONDUIT AND PROTECTIVE GROUND.** Conduit and protective ground are often connected together by the NEMA receptacles or at the circuit breaker neutral bus bar. Attempts should be made to isolate conduit ground from protective ground and a.c. neutral. Ideally, the equipment frame ground should be isolated from the protective ground and a.c. neutral all the way back to the building's main ground stake.

i. **A.C. NEUTRAL.** A.C. neutral must not be confused with protective ground and never be connected to it except at the building's main electrical service entrance. A.C. neutral must not be connected to equipment on conduit ground. A.C. neutral must be isolated from all building structures, equipment frames, cabinets, panels, and grounds if it is to prevent unwanted signals and noise from being introduced in the computer system.

j. **CABINET OR RACK GROUNDS.** Cabinets or racks bolted together should have their frames electrically tied together using #4AWG (5mm, 0.2 in.) copper conductor or silver copper mesh straps.

k. **EARTH CONNECTIONS** (Ground). The resistance between the site grounding structure and the actual earth must be maintained at less than 10 ohms. A copper ground rod of greater than 0.625-inch diameter should be driven at least 12 feet into the soil or deeper if subsequent measurements indicate that the impedance exceeds 10 ohms. Chemicals (e.g., common salt, magnesium sulphate) and periodic watering may need to be added to the soil surrounding the rod within a three-foot diameter and to a depth of two feet. A maintenance schedule to measure ground impedance should be maintained.

3.0 PERSONNEL

3.1 Engineering Anthropometry in the Design for Maintainability

3.1.1 INDEX

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3.1.2 DEFINITION

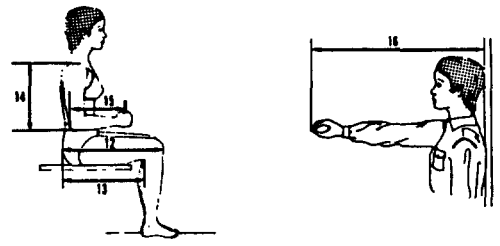
Engineering anthropometry, as used in these guidelines, refers to the application of physical measurement methods to human subjects with respect to such characteristics as size, mobility, and strength.

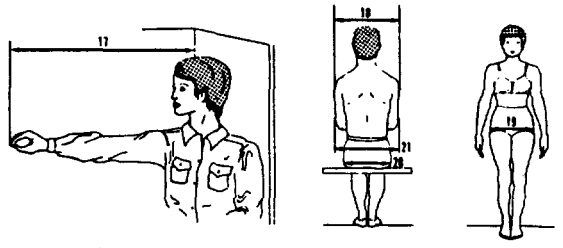
NOTE

The dimensions presented in this section will directly impact workspace design for maintainability (Section 2.1) and should be used in conjunction with those principles.

3.1.3 PRINCIPLES

3.1.3.1 ANTHROPOMETRICS. Plant systems and facilities should be designed to accommodate the 5th to the 95th percentile technician. Major body-size dimensions are presented below:





Variable	Mean	SD	5th	10th	25th	50th	75th	90th	95th
			Percentiles						
1. Weight (pounds)									
Male	178.9	23.5	143.3	149.8	161.7	177.0	194.6	211.4	221.2
Female	127.3	16.6	102.3	106.9	115.5	126.1	137.1	148.6	156.3
2. Stature (inches)									
Male	70.6	2.5	66.4	67.3	68.9	70.7	72.3	73.7	74.5
Female	63.6	2.4	60.0	60.7	62.1	63.8	65.4	66.9	67.8
3. Shoulder Height (inches)									
Male	57.9	2.3	54.0	54.8	56.3	58.0	59.5	60.8	61.5
Female	51.9	2.2	48.4	49.1	50.4	51.9	53.4	54.8	55.6
4. Elbow Height (inches)									
Male	44.8	1.8	41.6	42.3	43.5	44.8	46.1	47.1	47.7
Female	(Not measured in 1968 survey)								
5. Fingertip Height (inches)									
Male	26.9	1.4	24.5	25.0	25.9	26.8	27.8	28.7	29.2
Female	(Not measured in 1968 survey)								
6. Sitting Height (inches)									
Male	37.0	1.3	35.0	35.4	36.1	37.0	37.9	38.7	39.1
Female	33.7	1.3	31.7	32.1	32.8	33.7	34.6	35.3	35.8
7. Sitting Eye Height (inches)									
Male	32.2	1.2	30.2	30.6	31.3	32.2	33.0	33.8	34.3
Female	29.0	1.2	27.1	27.5	28.2	29.0	29.8	30.6	31.0
8. Sitting Shoulder Height (inches)									
Male	24.3	1.1	22.5	22.9	23.6	24.3	25.1	25.8	26.2
Female	(Not measured in 1968 survey)								
9. Elbow Rest Height (inches)									
Male	10.1	1.1	8.3	8.7	9.3	10.0	10.8	11.4	11.8
Female	8.9	1.0	7.4	7.7	8.3	8.9	9.6	10.2	10.5
10. Knee Height Sitting (inches)									
Male	22.2	1.0	20.6	20.9	21.6	22.3	22.9	23.5	23.8
Female	(Not measured in 1968 survey)								
11. Popliteal Height (inches)									
Male	17.4	0.9	15.9	16.3	16.8	17.5	18.1	18.6	18.9
Female	16.2	0.7	15.0	15.3	15.7	16.2	16.6	17.1	17.4
12. Buttock-Knee Length (inches)									
Male	24.1	1.1	22.3	22.6	23.3	24.1	24.8	25.5	25.9
Female	22.6	1.0	21.0	21.3	21.9	22.6	23.3	24.0	24.4
13. Buttock-Calf Length (inches)									
Male	20.1	1.0	18.4	18.7	19.4	20.1	20.8	21.4	21.8
Female	18.8	1.1	17.1	17.4	18.0	18.7	19.5	20.2	20.7
14. Shoulder-Elbow Length (inches)									
Male	14.3	0.7	13.2	13.4	13.8	14.3	14.8	15.2	15.4
Female	(Not measured in 1968 survey)								
15. Elbow-Grip Length (inches)									
Male	14.0	0.6	13.0	13.2	13.6	14.0	14.4	14.8	15.0
Female	(Not measured in 1968 survey)								
16. Thumb-tip reach (inches)									
Male	32.0	1.6	29.4	30.0	30.9	31.9	33.0	34.0	34.6
Female	29.2	1.5	26.6	27.2	28.1	29.2	30.2	31.1	31.7
17. Thumb-tip Reach Extended (inches)									
Male	35.6	1.8	32.6	33.3	34.4	35.6	36.8	38.0	38.7
Female	33.0	1.9	29.9	30.6	31.7	32.9	34.3	35.6	36.3
18. Shoulder Breadth (inches)									
Male	19.1	1.1	17.5	17.8	18.4	19.1	19.8	20.5	21.0
Female	16.5	0.9	15.1	15.4	15.9	16.4	17.1	17.7	18.1
19. Hip Breadth (inches)									
Male	14.0	0.8	12.8	13.1	13.5	14.0	14.6	15.1	15.5
Female	13.8	0.9	12.4	12.7	13.2	13.7	14.3	14.9	15.3
20. Hip Breadth Seated (inches)									
Male	15.1	1.0	13.6	13.9	14.4	15.0	15.7	16.4	16.8
Female	15.0	1.1	13.3	13.7	14.3	15.0	15.7	16.5	17.0
21. Forearm to Forearm Breadth (inches)									
Male	21.6	1.5	19.1	19.6	20.5	21.5	22.6	23.6	24.2
Female	(Not measured in 1968 survey)								

Source: Ref. 20

Exhibit 3.1.1 Power Plant Anthropometric Data Base

3.1.3.2 HUMAN STRENGTH CAPACITIES

a. Equipment systems and facilities should be designed so that excessive strength demands are not made on the technician.

b. Maintenance tasks should not require weightlifting values which exceed the following values:

Height of Lift From Ground	Maximum Weight of Item
1 ft.	85 lbs.
2 ft.	80 lbs.
3 ft.	65 lbs.
4 ft.	50 lbs.
5 ft.	35 lbs.
6 ft.	29 lbs.

NOTE: The above values assume that the item to be lifted is of convenient configuration (not more than 15 inches long or 12 inches high, and with acceptable handles or grasp areas). For a two-person lift, the values provided above can be doubled.

Source: Ref. 20

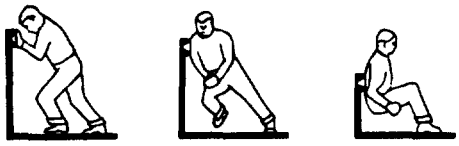
Exhibit 3.1.2 Maximum Weight-Lifting Values

c. Push and pull forces required by technicians should be within the following limits:

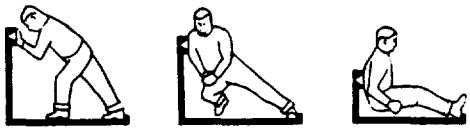
Horizontal Force*; At Least	Applied With	Condition (μ: Coefficient of Friction)
100N (25 lbs.) push or pull	both hands or one shoulder or the back	with low traction $0.2 < \mu < 0.3$
200N (45 lbs.) push or pull	both hands or one shoulder or the back	with medium traction $\mu \sim 0.6$
250N (65 lbs.) push	one hand	If braced against a vertical wall 510-1525 mm (20-60 in.) from and parallel to the push panel
300N (70 lbs.) push or pull	both hands or one shoulder or the back	with high traction $\mu > 0.9$
500N (110 lbs.) push or pull	both hands or one shoulder or the back	If braced against a vertical wall 510-1780 mm (20-70 in.) from and parallel to the panel, or if anchoring the feet on a perfectly nonslip ground (like a footrest)
750N (165 lbs.) push	the back	If braced against a vertical wall (600-1100 mm) (23-43 in.) from and parallel to the push panel or if anchoring the feet on a perfectly nonslip ground (like a footrest)

*May be doubled for two and tripled for three technicians pushing simultaneously. For the fourth and each additional technician, not more than 75% of their push capability should be added.

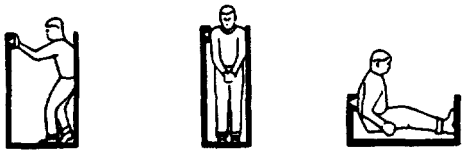
LOW/MEDIUM/HIGH TRACTION



USE OF FOOTREST



BRACED AGAINST VERTICAL WALL



Source: Ref. 11

Exhibit 3.1.3 Maximum Push-Pull Forces (for males)

Values in pounds
Data for Men and Women, 5th and 95th percentiles

A. STANDING TWO-HANDED PULL: 38 cm (15") LEVEL

Standing with feet 45 cm (18") apart and knees bent, bending at waist, grasping both sides of 45 cm (18") long handle located directly in front, 38 cm (15") above standing surface, and pulling, using primarily arms, shoulders and legs.

	M5th	W5th	M95th	W95th
Mean force	166	74	304	184
Peak force	190	89	323	200

B. STANDING TWO-HANDED PULL: 50 cm (20") LEVEL

Standing with feet 45 cm (18") apart and knees straight, bending at waist, grasping both sides of 45 cm (18") long handle located directly in front, 50 cm (20") above standing surface, and pulling, using primarily arms and shoulders.

	M5th	W5th	M95th	W95th
Mean force	170	73	302	189
Peak force	187	84	324	203

C. STANDING TWO-HANDED PULL: 100 cm (39") LEVEL

Standing erect with feet 45 cm (18") apart, grasping both sides of 45 cm (18") long handle located directly in front, 100 cm (39") above standing surface, and pulling, using the arms.

	M5th	W5th	M95th	W95th
Mean force	100	42	209	100
Peak force	113	49	222	111

D. STANDING TWO-HANDED PUSH: 150 cm (59") LEVEL

Standing erect with feet 45 cm (18") apart, grasping from below, both sides of 45 cm (18") long handle located directly in front, 150 cm (59") above standing surface. Pushing upward using arms and shoulders.

	M5th	W5th	M95th	W95th
Mean force	92	34	229	85
Peak force	106	42	246	97

E. STANDING ONE-HANDED PULL: 100 cm (39") LEVEL

Standing erect with feet 15 cm (6") apart, dominant hand grasping underside of D-ring located directly to the side, 100 cm (39") above standing surface, pulling upward while keeping shoulder square and other arm relaxed at side.

	M5th	W5th	M95th	W95th
Mean force	48	23	141	64
Peak force	58	30	163	72

F. SEATED ONE-HANDED PULL: SEAT CENTERLINE 45 cm (18") LEVEL

Sitting erect with feet 55 cm (22") apart, dominant hand grasping underside of D-ring located directly to the front, 45 cm (18") above the floor, pulling upward while keeping shoulders square and other arm resting in lap.

	M5th	W5th	M95th	W95th
Mean force	51	24	152	88
Peak force	61	29	170	101

(Exhibit 3.1.4 Continued on next page)

G. SEATED ONE-HANDED PULL: SIDE OF SEAT, 45 cm (18") LEVEL

Sitting erect with feet 55 cm (22") apart, dominant hand grasping underside of D-ring located a short distance to side, 45 cm (18") above the floor, pulling upward while keeping shoulders square and other arm resting in lap.

	M5th	W5th	M95th	W95th
Mean force	54	25	136	76
Peak force	61	30	148	89

H. SEATED TWO-HANDED PULL: CENTERLINE OF SEAT, 38 cm (15") LEVEL

Sitting erect with feet 55 cm (22") apart, bending slightly at waist, grasping both sides of 15 cm (6") long handle located directly to the front, 38 cm (15") above the floor, pulling upward, using arms and shoulders, keeping arms off thighs.

	M5th	W5th	M95th	W95th
Mean force	134	54	274	173
Peak force	157	64	298	189

I. SEATED TWO-HANDED PULL: CENTERLINE OF SEAT, 50 cm (20") LEVEL

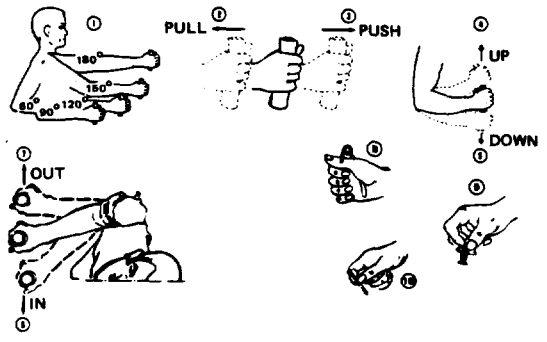
Sitting erect with feet 55 cm (22") apart, bending slightly at waist, grasping both sides of 15 cm (6") long handle located directly to the front, 50 cm (20") above the floor, pulling upward, using arms and shoulders, keeping arms off thighs.

	M5th	W5th	M95th	W95th
Mean force	118	46	237	142
Peak force	134	53	267	157

Source: Ref. 11

Exhibit 3.1.4 Maximum Pull Forces for Men and Women (5th and 95th Percentiles)

d. Arm, hand, and thumb-finger strengths required of technicians should be within the following limits:



Arm Strength (Lb)												
(1)	(2)		(3)		(4)		(5)		(6)		(7)	
Degree of Elbow Flexion (deg)	Pull		Push		Up		Down		In		Out	
	L	R*	L	R	L	R	L	R	L	R	L	R
180	50	52	42	50	9	14	13	17	13	20	8	14
150	42	56	30	42	15	18	18	20	15	20	8	15
120	34	42	26	36	17	24	21	26	20	22	10	15
90	32	37	22	36	17	20	21	26	16	18	10	16
60	26	24	22	34	15	20	18	20	17	20	12	17

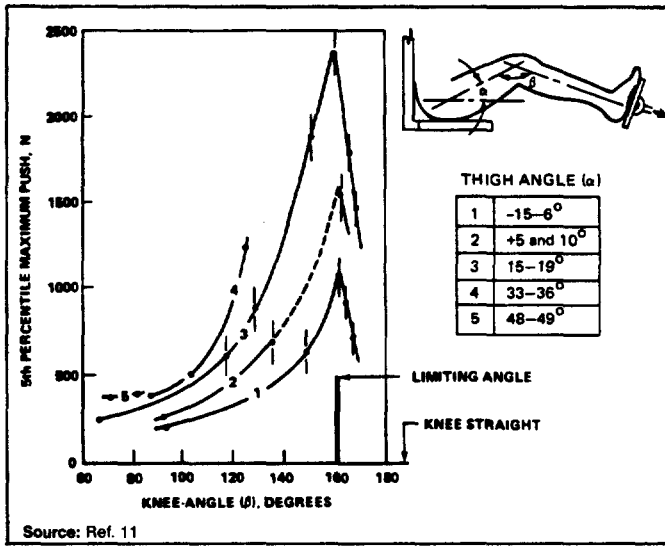
Hand, and Thumb-Finger Strength (Lb)				
	(8) Hand Grip		(9) Thumb-Finger Grip (Palmer)	(10) Thumb-Finger Grip (Tips)
	L	R		
Momentary Hold	56	60	13	13
Sustained Hold	33	36	8	8

*L = Left; R = Right.

Source: Ref. 11

Exhibit 3.1.5 Arm, Hand, and Thumb-Finger Strength (5th Percentile, Male)

e. Leg strengths required of technicians should be within the following limits:



Source: Ref. 11

Exhibit 3.1.6 Leg Strength of Various Knee and Thigh Angles (5th Percentile, Male)

3.0 PERSONNEL

3.2 Environmental Conditions and Constraints Affecting Maintainability

3.2.1 INDEX

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3.2.2 DEFINITION

Environmental conditions and constraints, as used in these guidelines, refer to certain aspects of the total system within which maintenance is performed and external to the equipment itself that can affect task performance of the technician. These conditions and constraints originate from the following sources: temperature, humidity, noise, vibration, illumination, and radiation.

NOTE

No attempt is made in these guidelines to cover all aspects of environmental factors that affect maintainability. The intent of the guidelines is to emphasize human tolerance limitations and recommended levels for environmental factors as they are significant to maintainability.

3.2.3 GENERAL PRINCIPLES

3.2.3.1 Systems should be designed to accommodate deviations from specified tolerable conditions. These deviations may result in:

a. The need for using protective clothing, devices, etc. which may affect the mobility and accessibility of the technician.

b. The need for increased maintainability because of reduced equipment reliability.

c. Use of procedures which require longer maintenance times.

d. Conditions that cause increased errors, oversights, etc. which are detrimental to overall system performance.

3.2.3.2 In the design of systems for maintainability, the following environmental influences must be taken into consideration:

a. Effects from the natural or geographic environment.

b. Specific subsystem effects, materials, or elements such as vibration sources, pressure and temperature from steam lines, toxic gas discharge, radiation, etc.

c. The cumulative, conflicting, or interacting effects of environmental influences in the final and full system configuration.

3.2.4 SPECIFIC PRINCIPLES

3.2.4.1 EQUIPMENT OPERATING CONDITIONS. Unsheltered equipment for outdoor use should be designed to operate to the following tolerances. (Note: These tolerances have been derived for aeronautical equipment and are meant to serve only as reference benchmarks.)

a. **TEMPERATURE**

(1) Standard area:

- Operating: -29 to 52°C (-20 to 125°F).
- Non-operating: -54 to 54°C (-65 to 130°F).

(2) Cold weather area:

- Operating: -40°C (-40°F) if operator is unsheltered.
- Operating: -54°C (-65°F) if operator is sheltered.
- Non-operating: -62°C (-80°F) for 3 days and achieve rated capacity after 30 minutes pre-heating and warm-up.

(3) Desert and tropical areas:

- Operating: 52°C (125°F).
- Non-operating: 71°C (160°F) for 4 hours per day indefinitely.

b. **HUMIDITY:**

(1) Operating: Up to 100% at 37°C (100°F) including condensation.

(2) Non-operating: Up to 100% including condensation.

c. **SOLAR RADIATION:**

Endure a solar intensity of 360 BTU per square foot, per hour for a period of 4 hours (minimum) at 52°C (125°F).

d. **WIND:**

Withstand wind pressures up to 30 pounds per square foot of projected surface, either empty or under load.

e. **OTHER CONDITIONS TO BE CONSIDERED:**

(1) Salt atmosphere, as encountered in coastal regions or ocean transport.

(2) Sand and dust, as encountered in desert regions.

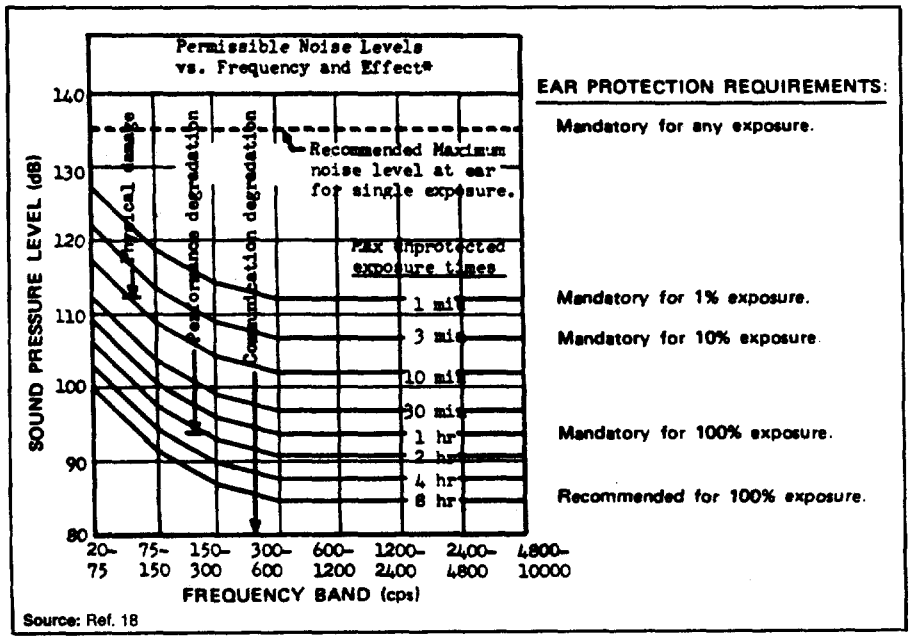
(3) Insects and fungi, as encountered in the tropics.

(4) Ice and snow loads.

(5) Rainfall.

3.2.4.2 NOISE LEVELS AND PROTECTION

a. Noise levels should be minimized wherever practical and should never exceed the following limits:



Source: Ref. 18

Exhibit 3.2.1 Noise Level Limits

b. Warnings should be posted to prevent unprotected technicians from entering areas with noise levels above 130db, even for short periods of time.

c. When possible, freely moving parts which contribute to noise should be dampened or eliminated.

d. Where it is not possible to design equipment to eliminate noise production, the amount of noise transmitted should be reduced by:

(1) Increasing the distance between the work area and the noise source.

(2) Enclosing noise-producing sources.

(3) Placing noise-producing sources on mounts that reduce vibration.

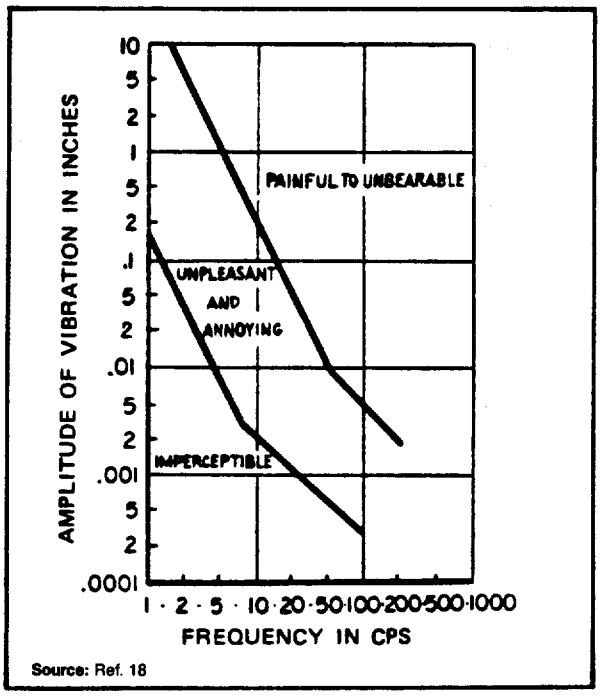
(4) Soundproofing the work area to reduce vibration and reverberation.

(5) Designing auditory alert and warning signals to be at least 10db above maximum ambient noise levels.

e. Where noise levels cannot be reduced by equipment or system design, technicians should be provided with suitable ear protection.

3.2.4.3 VIBRATION LEVELS AND PROTECTION

a. Vibration should be minimized whenever practical and should never exceed the following limits:



Source: Ref. 18

Exhibit 3.2.2 Vibration Level Limits

b. Equipment should be designed to resist vibration and shock or to be isolated from such action by shock absorbers, cushioned mountings, springs, or fluid couplings.

c. Rotating equipment elements should be properly balanced.

d. Seated technicians are most affected by vertical vibrations; prone technicians by horizontal vibrations. Damping materials or cushions should be provided for standing or seated technicians.

e. For seated technicians, vibrations of 3–4 cps should be avoided since this is the resonant frequency for a person seated.

f. For critical maintenance operations which require letter or digit discrimination on displays mounted on machinery that is not vibration-free, display size and/or illumination should be increased to improve reading speed and accuracy.

3.2.4.4 LIGHTING LEVELS AND PROTECTION

a. Adequate light levels should be provided for the technician to perform in all work areas. Recommended levels are presented below:

Light Level	Task Conditions	Type of Lighting
100 or more	Very difficult and prolonged visual tasks with objects of low brightness and contrast; high speed and extreme accuracy required.	Supplementary; special fixtures such as desk lamps.
50 or more	Small detail, fair contrast, close work, speed not essential.	Supplementary.
25 or more	Prolonged reading, assembly, general office, ordinary bench, or laboratory work.	Local lighting; ceiling fixtures directly overhead.
10 or more	Occasional reading, washrooms, power plants, waiting rooms, and kitchens.	General lighting.
5 or more	No detail vision, stairways, or supply warehouses.	General or supplementary lighting.

Source: Ref. 18

Exhibit 3.2.3 Recommended Illumination Levels (in Foot-Candles at the Work Point)

b. Lighting should be arranged in such a way as to provide an equal level of illumination over the entire work area. To help determine task lighting requirements, the following brightness ratios should not be exceeded:

Area	Luminance Ratio
Task area versus adjacent darker surroundings	3:1
Task area versus adjacent lighter surroundings	1:3
Task area versus more remote darker surfaces	10:1
Task area versus more remote lighter surfaces	1:10
Luminaries versus surfaces adjacent to them	20:1
Anywhere within normal field of view	40:1

Source: Ref. 10

Exhibit 3.2.4 Maximum Task Area Luminance Ratios

c. Glare, usually due to the presence of direct or reflected light within the field of vision, should be avoided by:

(1) Using surfaces and paints which diffuse rather than reflect light.

(2) Avoiding bright surfaces within the working visual field.

(3) Avoiding bright light sources within 60° of the central visual field.

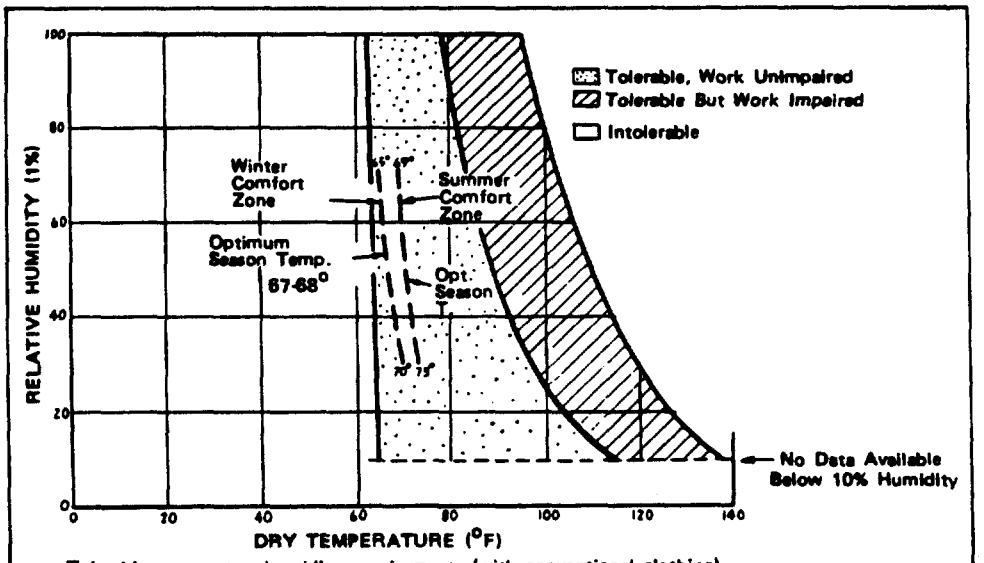
(4) Placing lights high and directly above the work area.

(5) Using indirect lighting wherever possible.

(6) Using diffused lighting where possible, spaced high and close together.

(7) Arranging light sources to avoid equal lighting and viewing angles.
(8) Providing shields, hoods, and visors to reduce or prevent glare.
(9) Using numerous low intensity sources rather than a few intense ones.

3.2.4.5 TEMPERATURE AND HUMIDITY LEVELS AND PROTECTION. The environment within which the maintenance technician must work should not exceed the tolerance limits provided below:



Tolerable temperature-humidity requirements (with conventional clothing)

Source: Ref. 26

Exhibit 3.2.5 Temperature and Humidity Tolerance Limits

3.2.4.6 NUCLEAR RADIATION LEVELS AND PROTECTION

a. Long-handled tools, remotely operated controls, and similar approaches should be used, where feasible, to separate maintenance technicians from sources of radiation to the maximum extent possible.

b. Equipment located in radioactive areas should be designed to accommodate maintenance technicians wearing protective clothing.

c. Equipment located in radioactive work areas should be designed to allow completing maintenance work efficiently given the reduced manual dexterity because of protective clothing.

d. The designs for facilities and equipment which are located in radioactive areas should optimize speed of maintenance operations to minimize stay times and associated exposure levels.

e. Traffic routes near radiation sources or through potentially radioactively contaminated portions of the facility should route personnel away from radiation exposure sources as much as possible.

f. Access openings associated with equipment in radioactive areas should be sited to allow convenient and speedy entry and exit by technicians who span the anthropometric range while being burdened by protective clothing.

g. Permanent or fixed access provisions should be available to equipment which is located in radioactive work areas to eliminate radiation exposure incurred by erecting temporary accesses, e.g., scaffolding, shielding.

h. Control and storage of contaminated debris, work aids, spare parts, etc. should be adequate to prevent hindrance to the mobility of personnel and vehicles.

i. Storage provisions for contaminated equipment and stores used during outages should be adequate to prevent these items from obstructing normal passageways for personnel and vehicles.

j. Normally contaminated work areas or facilities should be sited and configured to allow ample room for radiation waste barrels, step-off pads, contaminated clothing collection barrels, cordon stands, etc.

k. Remote viewing techniques such as closed circuit TV should be considered for coordinating maintenance activities with a minimum of exposure to radiation on the part of those who support maintenance, i.e., operators, QC inspectors, etc.

l. Use of viewing provisions (that block radiation exposure) in normally opaque shielding walls should be considered to protect personnel who oversee maintenance work.

m. Protective clothing and associated gear should be designed to withstand multi-stress environments, e.g., heat and radiation.

n. Facilities should be available to ensure an adequate supply of clean, decontaminated protective clothing, especially during peak workload periods (e.g., laundering facilities for washable gear, store facilities for issue of one-time use disposable gear).

o. Procedures or other maintenance information sources should be readily available to the technician working in contaminated areas. Where procedures and forms

must make the transition from "hot" to "clean," copies should be used so that contaminated paper stays behind. A copy machine, strategically located at the boundary of the "hot" area should also be considered.

p. Both inhouse and contractor personnel assigned to work in radioactive areas should receive sufficient training, including mockup rehearsals, to ensure maximum task performance and minimum stay times.

3.0 PERSONNEL

3.3 Maintenance Information

3.3.1 INDEX

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3.3.2 DEFINITION 3.3-2

3.3.3 GENERAL PRINCIPLES 3.3-3

3.3.4 SPECIFIC PRINCIPLES 3.3-4
3.3.4.1 Troubleshooting Procedures 3.3-4
3.3.4.2 Maintenance Manuals/Job Instructions/Procedures 3.3-4

3.3.2 DEFINITION

Maintenance information, as used in these guidelines, refers to procedures, manuals, instructions, and job aids (e.g., flow diagrams, schematics, drawings, decision trees) used by the maintenance technician to perform his/her job.

NOTE

No attempt is made in these guidelines to identify or summarize the numerous military and civilian specifications and guides which address the preparation of instructional materials.

3.3.3 GENERAL PRINCIPLES

3.3.3.1 Ideally, every maintenance operation should be covered by a procedure(s) prepared and tested during the development of the system. Without procedures, maintenance effectiveness will be reduced because of excessive trial-and-error performance required by the technician.

3.3.3.2 Information contained in procedures, manuals, instructions, and job aids should not be excessively redundant among the maintenance documentation and with information the technician already possesses.

3.3.3.3 Maintenance information should be compatible with the capabilities and limitations of the personnel who will be using it and with the anticipated environmental conditions, equipment characteristics, and task requirements.

3.3.3.4 Maintenance instruction should not require the technician to work near dangerous voltages or delicate components. Procedures which require work to be performed in areas of contamination should always specify the protective equipment and measures necessary to work safely in this environment.

3.3.3.5 Maintenance information should be based on a systematic analysis of the tasks which are required in the performance of the maintenance activity.

3.3.3.6 Maintenance information should be prepared and/or reviewed by personnel who are knowledgeable in techniques of instructional preparation and the technical subject covered by the information.

3.3.3.7 Maintenance information should be validated by means of field tests to ensure clarity, comprehensiveness, and effectiveness.

3.3.3.8 Job performance aids (JPAs) should be considered for use by maintenance technicians in highly complex tasks or major tasks with important safety or availability implications.

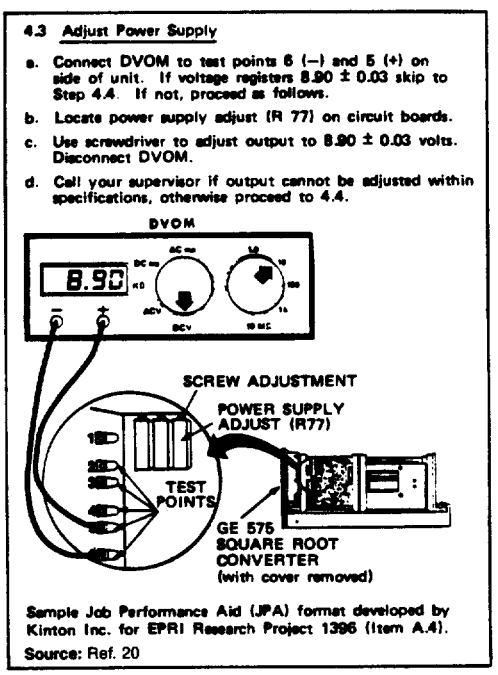

Exhibit 3.3.1 Example of Job Performance Aid (JPA)

3.3.3.9 Maintenance information should be kept current with equipment. Whenever new equipment or modifications to equipment are introduced, old maintenance information should be revised to reflect these changes.

3.3.3.10 Following are some of the more important features that apply to preparing maintenance procedures:

a. Maintenance procedures should be as brief as possible without sacrificing necessary information.
b. Procedures should provide unambiguous results.
c. Required tolerances should be realistic for the level of maintenance being performed (i.e., field tolerances, shop or factory tolerances, new part tolerances, replacement part tolerances, in-service tolerances).
d. Procedures should be easy for the technician to follow. Ideas and words should be as simple to comprehend as possible. Procedures sometimes can be simplified by designing test equipment to do some or all of the programming or sequential operations.
e. The number of decisions required to be made by the technician should be kept as few as reasonable and as straightforward as possible.
f. Exact, step-by-step procedures should be used (compared to narratives). This form will allow inexperienced technicians to learn the procedure easily.

USE THIS	NOT THIS
Assembling Injector Tapping Tool	**Assembling Injector Tapping Tool**
1. Replace defective part.	First, replace the defective part from supply. Install nut and washer on hand-tap shank.
2. Install nut and washer on hand-tap shank.	Next, place the rollpin in the nut. Upon completion, check the tapping tool for proper performance.
3. Install rollpin in nut.	
4. Check tapping tool for proper operation.	
Source: Ref. 1	

Exhibit 3.3.2 Example of Step-by-Step Instruction

g. Each procedure, if necessary, should explain how to start up and shut down the equipment.
h. Systematic troubleshooting procedures should always be provided for the technician. Failure to do this may result in the technician following inefficient or even dangerous methods.
i. Pages should be numbered "___ of ___" for recognition of missing pages of a procedure.
j. Requirements should be stated at the outset of a procedure for the number, level, and types of maintenance personnel required to accomplish the tasks described by the procedure.
k. All applicable documents pertaining to a procedure should be listed in the initial portions of the procedure, to include list of tools required, list of parts and materials required, safety precautions, and related reference documents (e.g., specifications, drawings).
l. Procedures should be as self-contained as possible. The content and structure of procedures should minimize the need for consulting other references.

3.3.3.11 Maintenance or test support functions, rests or stands on which technical orders, manuals, or procedures should be provided when required. When permitted by design requirements, such rests or stands shall be part of the basic unit, rack, or console chassis.

Maintenance or test practices, procedures, or conditions that may result in hazards or injury to personnel or damage to equipment should be presented in the form of caution statements.

Maintenance or test practices, procedures, or conditions of special interest or importance that will aid in or simplify job performance should be presented in the form of note statements.

Caution and note statements should:

a. Be located with the material to which it applies.
b. Stand out on a page full of other material.
c. Attract the user's eye, but not be overpowering.
d. Be apparent to the user no matter what method is used to access information and enter the manual.
e. Contain all necessary information.
f. Be easy to read and understand.

Caution statements should include the following information, when applicable:

a. The specific nature of the hazard.
b. The steps to be taken to avoid or minimize the hazard.
c. The location or source of the hazard.
d. The consequences of failing to heed the warning or caution.
e. Corrective or first-aid actions to be taken if the hazard materializes.
f. Time considerations when critical.

Maintenance or test information which should be brought to the user's attention.

Caution statements should precede and appear on the same page as the text or procedural steps to which they apply.

A note statement should always preceed a procedural statement to which it applies.

Caution and note statements should not contain procedural steps.

When it is necessary to preceed a procedural step with both caution and a note statements, the caution statement(s) should appear first.

General caution statement(s) should be placed at the beginning of the procedural steps, or on a "Precautions" page at the front of the procedure or manual.

3.3.4 SPECIFIC PRINCIPLES

3.3.4.1 TROUBLESHOOTING PROCEDURES. Fault isolation is perhaps the most demanding maintenance operation for a technician to perform because it involves complex diagnostic problems and decision processes.

a. Troubleshooting procedures should follow a systematic strategy. A troubleshooting method, common to diagnosing electronic equipment failures, is presented below in a summary form.
   (1) Step 1—Visual checks for clues such as smoke, loose connections, or missing or damaged parts.
   (2) Step 2—Operational checks by evaluating readings from meters, gauges, and other indicators. Checklists are typically used for this step.
   (3) Step 3—Intermediate checks to isolate the malfunction to a particular stage, i.e., unit, assembly, or component.
   (4) Step 4—Systematic checks by an ordered inspection of, for example, circuits within a component.

   Decision trees and computer-aided techniques are other effective troubleshooting approaches.

b. When available, probability data should be used for developing troubleshooting procedures.
c. Short sentences with concise and unambiguous language should be used.
d. When applicable, special diagrams should be provided for the technician which help in analyzing symptom patterns by indicating which components affect each system output for each step in an operational or intermediate check.
e. Double check lists should be provided for an independent observer to check specially critical activities.

3.3.4.2 MAINTENANCE MANUALS/ JOB INSTRUCTIONS/PROCEDURES

a. Content should contain only job-relevant information.
b. Instructions should be prepared specifically for each organizational level (i.e., field, shop, factory) of maintenance and each skill level of maintenance technician required to perform the work rather than for all levels being combined.
c. Nomenclature that is used on the equipment should be used in the instructions.
d. Instructions should contain an index with key words the technician is likely to look for when locating a particular item in the instructions.
e. Photographs or high-quality drawings should be used to clarify written instructions or to provide extra information that the technician may require.
f. Tables with instructions on how to use them should be used for presenting data.
g. Diagrams to describe processes and interrelationships should be used.

h. Components shown in data flow diagrams should be in the same relative position that they are in the equipment.

i. Foldout pages should be avoided or kept to a minimum.

j. Tagging and switching instructions should be listed in the initial portions of the procedures.

k. Checklists and/or data tables should be provided for lengthy prerequisites, tests, or calculations.

#1 Initials	#2 Initials		
		4.0 **Procedure**	
____	____	4.1 Verify main steam lines are blocked.	
____	____	4.2 Verify steam generator level between 75% and 90% (wide range)	
		NOTE: If level is less than 75%, fill steam generator to 75% using Auxiliary Feed System.	
		4.3 Perform the following valve line-up:	
		CLOSE OR VERIFY CLOSED	
____	____	4.3.1 2-MS-158	Chain Valve to Aux. Feed
____	____	4.3.2 2-MS-377	2-MS-158 Bypass
____	____	4.3.3 NRV-MS-202C	Isolation to Decay Heat Release
____	____	4.3.4 TV-MS-201C	M.S. Trip Valve
____	____	4.3.5 2-MS-155	M.S. Trip Valve Bypass
____	____	4.3.6 PRV-MS-201C	Power Operated Relief
____	____	4.3.7 2-MS-208	M.S. TV Trap Isolation
____	____	4.3.8 2-MS-149	M.S. TV Trap Isolation
____	____	4.3.9 2-MS-152	M.S. TV Trap Bypass
____	____	4.3.10 TV-BD-200E	Inside TV
____	____	4.3.11 TV-BD-200F	Outside TV
		NOTE: It is the intent of the below steps to compress the vapor contained in the steam generator thereby increasing steam generator pressure to determine the location of the tube leak(s). However, it may be required to completely fill the steam generator and main steam lines to obtain sufficient pressure.	
		CAUTION: MONITOR STEAM GENERATOR PRESSURE THROUGHOUT THE TEST. 760 PSIG MAX. PRESSURE.	
____	____	4.4 Start one (1) Auxiliary Feed Pump.	
____	____	4.5 Using Auxiliary Feed MOV's for "C" steam generator maintain feed flow approximately 140 gpm.	
____	____	4.6 Monitor steam generator pressure and level.	
____	____	4.7 Check for tube leakage on primary side.	

Source: Ref. 20

Exhibit 3.3.3 Example of a Double Check List for an Independent Observer

CAL-CN-025
6-30-77

DATA TABLE

Sys: Condensate Storage Tank (300,000 Gal.) Tested: _____ Date: _____
Sub Sys: Channel L-CN204 Verified: _____ Date: _____
Procedures: LT-CN024, Magnetic Amplifier Controller DVM: _____
Decade Box: _____

LT-CN204 Inches H_2O	LS-CN204A Input Des. v	Act. v	Error v	LI-CN204 Des. %	Act. %	Error %	LR-CN204 Pen #2 Des. %	Act. %	Error %
20.5	1.183	____	____	4.6	____	____	4.6	____	____
111.9	2.000	____	____	25	____	____	25	____	____
223.75	3.000	____	____	50	____	____	50	____	____
335.6	4.000	____	____	75	____	____	75	____	____
447.5	5.000	____	____	100	____	____	100	____	____
223.75	3.000	____	____	50	____	____	50	____	____
20.5	1.183	____	____	4.6	____	____	4.6	____	____

Noise measurement: _____ mv @ _____ ma

Notes or Comments:

Magnetic Amplifier

			Des.	Act.	Error
Actuation:	De-energize on Hi: Contact No. 11 & 13; 39 feet in a 39 feet span	Bias:	4.900v	____	____
		Defense:	4.750v	____	____
		Alarm/Interlock Actuated:		____	

Notes or Comments:

Controller

	Des.	Act.	Error
Gain:	1.0	____	____
Reset Time:	20 seconds	____	____
Rate Time:	Off	____	____

Notes or Comments:

Reviewed: _____ Date: _____

Source: Ref. 20

Exhibit 3.3.4 Example of a Data Table

l. Procedures and instructions should be identified by:
- Title
- Applicability (if not title)
- Revision date
- Approval status
- Indexing designation or code.

m. Procedures and instructions should be self-contained documents, as much as possible, to avoid the need for shifting back and forth between the procedure and other procedures or supporting documents.

3.0 PERSONNEL

3.4 Design Plan and Schedule for Maintainability

3.4.1 INDEX

Page

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3.4.2 DEFINITION

Design plan and schedule refer to the preferred phasing or sequencing of maintainability design activities.

NOTE

Only basic principles for developing and implementing a design plan and schedule for maintainability are presented in these guidelines. No attempt is made to detail characteristics of a design program for maintainability.

3.4.3 GENERAL PRINCIPLES

3.4.3.1 Operation equipment, resembling the type being designed, should be studied by the design team. Particular attention should be paid to maintenance features of the equipment and to those features that are lacking in the equipment.

3.4.3.2 The entire system (within which the equipment is to be installed) should be reviewed to determine information such as where the equipment will be installed, access opening measurements, etc.

3.4.3.3 Test equipment and tools already in use on related equipment and that might be adapted to the equipment being designed should be determined.

3.4.3.4 Maintenance technician availability and required skills and level of proficiency should be determined.

3.4.3.5 Existing storage and work facilities, if any, should be determined.

3.4.3.6 A determination should be made of the type and quantity of maintenance information (diagrams, manuals, job aids, etc.) that will be required to maintain the equipment, how much of the information is available, and how much information must be developed.

3.4.3.7 Supply facilities should be determined which are available to provide spare parts for the equipment.

3.4.3.8 Flow diagrams, event trees, state diagrams, schedule charts, or other visual displays should be used to show maintenance or design sequences and relations.

3.4.4 SPECIFIC PRINCIPLES

3.4.4.1 An overall plan for maintainability should be developed to include the following tasks to insure the design for maintainability will proceed in an orderly and effective manner:

a. **PROJECT DEFINITION PHASE**—Proposals for new systems should include quantitative maintainability objectives as an inherent portion of the performance objectives. A maintainability program and appropriate documentation, including the maintainability objectives, and a plan for achieving and evaluating objectives should be included.

b. **DEVELOPMENT PROGRAM PHASE**—The development program phase should include or provide for the following essential elements:

(1) **PROGRAM PLAN**—Contains maintainability objectives, plans, goals, and milestones for accomplishment and evaluation which can be demonstrated on a time basis. This plan can also serve as a guide for all design, production, and product assurance engineers.

(2) **QUANTITATIVE MODEL**—Provides goals for maintainability, availability, etc. to serve as a standard for demonstrating the design achieved. This model can also be used in determining the maintainability status and effectiveness of the system during all stages of design, development, and testing.

(3) **SPECIFICATION REVIEW**—Emphasizes the importance of maintainability as part of the overall design program. As an initial effort of the program, a complete and thorough study of maintainability and other related product assurance specifications should be made.

(4) **PREDICTION AND ANALYSIS**—Provides preliminary maintainability predictions based on data supplied through integrated test program.

(5) **TRAINING PROGRAM**—Orients to maintainability all engineering personnel participating in equipment or system development.

(6) **HUMAN FACTORS ENGINEERING**—Reviews equipment design concepts for logic, display control configurations, and operations emphasizing system maintainability.

(7) **CHANGE CONTROL**—Procedure assures that design changes required for and affecting maintainability are carefully reviewed.

(8) **SCHEDULED DESIGN REVIEWS**—Insures that design changes required for and affecting maintainability are carefully reviewed.

(9) **METHODS FOR CONSIDERING DESIGN TRADEOFFS**—Considers in early development phase, the designs which, while conforming to maintainability specifications, do not always meet other specified requirements; i.e., operational requirements, reliability, economic limitations, and performance requirements.

(10) **VENDORS INDOCTRINATION PROGRAM**—Provides subcontractors with maintainability guidelines and specifications.

(11) **DEMONSTRATION AND TASK**—Conducted to obtain maintainability data that cannot be evaluated by analytical methods, or as required to verify that maintainability requirements have been met.

(12) **SCHEDULED EVALUATION AND IMPROVEMENT**—Evaluates data feedback from demonstrations, tests, and field areas for supporting design improvement recommendations and for verification of maintainability predictions.

c. **PRODUCTION PHASE**—During this phase, the maintainability requirements and objectives must be consistent with those established during design and development, i.e., with the maintenance support plan. Close surveillance should be provided to assure that quality assurance requirements and maintainability specifications are met. This phase considers:

(1) **QUALITY CONTROL**—Maintains high quality in workmanship and manufacturing standards with respect to maintainability. Poor quality control practices must be isolated and corrective action initiated to preclude maintainability problems in the field.

(2) **MODIFICATION AND CHANGE CONTROL**—Establishes coordination procedures between design and manufacturing activities to insure that changes or modifications to equipment design are agreed upon before they are initiated. In all cases the designer must concur with the changes.

d. **OPERATIONAL PHASE**—The final validation of maintainability predictions is accomplished during this period. This phase includes:

(1) **INITIAL DEVELOPMENT STAGE**—Based upon evaluation of data accumulated relative to design tests, engineering costs, user tests, system demonstrations, transportation, storage assembly, emplacement and check-out. Data should be analyzed and recommendations made for product improvement for future equipment.

(2) **FIELD OPERATING STAGE**—Active maintenance data should be analyzed from all equipment sites and used to validate predicted maintainability figures. Unsatisfactory Equipment Reports (UER), Equipment Improvement Reports (EIR), or equivalent methods, should be utilized.

3.4.4.2 An example of a maintainability plan is provided in the following exhibit:

Task or Function	Responsible Activity
Phase I—Concept or Study	
Analyzation by logistics engineering of the type, purpose, function, and utilization of the equipment; qualitative maintainability requirements; customer maintenance concepts; organization; and policies. Establish the following maintainability program:	
Define system requirements	System engineering
System concept	System engineering
Analyze maintainability and logistic requirements	Logistics engineering
Preliminary maintenance concept and maintainability guidelines	Logistics engineering
Preliminary maintainability procedures, *functions, and goals*	Logistics engineering
Preliminary maintenance support procedures and functions	Logistics engineering
Preliminary maintainability and logistics costs	Logistics engineering
Design reviews	System engineering
Trade-offs	System engineering
Revised maintainability data and goals	Logistics engineering
Revised maintenance support data	Logistics engineering
Maintainability and logistics plan	Logistics engineering
Equipment design	Engineering
Phase II—Design and Development	
Equipment design	Engineering
Maintainability and logistics plan	Maintainability and logistics
Maintainability functions (updating)	Logistics engineering
Personnel skills and training program	Logistics engineering and training
Support equipment requirements (updating)	Logistics engineering
Spares and documentation program	Supply support
Publications program and implementation	*Publications*

Task or Function	Responsible Activity
Phase II—Design and Development (Cont'd)	
Vendor and/or subcontractor equipment design	Customer
Field support and field engineering plans.	Logistics engineering
Maintainability test plan	Logistics engineering
Modification and status	Configuration control
Phase III—Production and Test	
Maintainability equipment reviews conducted by logistics engineering. System, subsystem, and supporting equipment tests include review, evaluation, and validation of the following:	
Prototype production	Manufacturing
Maintainability testing and publications verification *program*	Maintainability and publications
Maintainability design verification	Maintainability
Design changes and recommendations	Maintainability
Engineering change board	System engineering
Revision of maintainability data	Maintainability
Revision of support equipment	Logistics engineering
Finalization of prototype spares requirements	Supply support
Phase IV—Maintainability and Maintenance Reviews	
Maintainability and maintenance reviews conducted, and a logistic support program implemented during the testing and user phase for the following tasks:	
System test plan	Reliability test and evaluation
Logistic test plan	Logistic support division
Support of system testing	Engineering
Verification of maintainability goals	Maintainability
Verification of logistic support function	Logistic support division
Test report and recommendations	Maintainability
System test summary	Reliability test evaluation

Source: Ref. 8

Exhibit 3.4.1 Example of Plan for Maintainability

3.4.4.3 To successfully implement a design program for maintainability, the maintainability plan should:

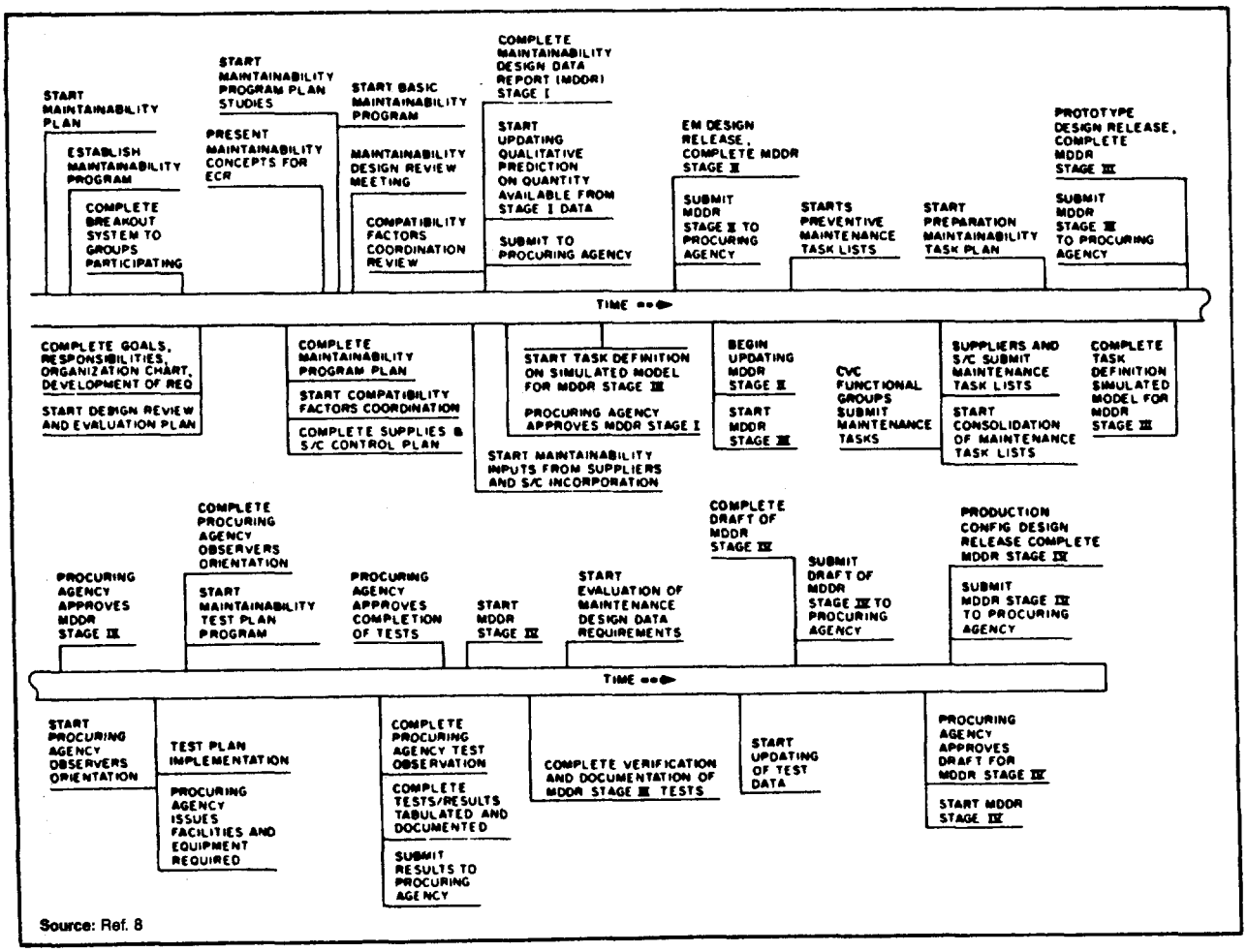
a. Be sufficiently flexible to permit revision and updating at any point in the program.

b. Include the various tasks and milestones, and approximate times required to accomplish each. (This is the design schedule.)

c. Show each key event, and the coordinated sequence of occurrences, and the interrelationship of events. (This may be shown within the design schedule.)

d. Provide valuable impetus for determining project costs and the most economical allocation of personnel.

3.4.4.4 An example of a design schedule for maintainability is shown in the following exhibit:



Source: Ref. 8

Exhibit 3.4.2. Example of Maintainability Design Schedule

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		Folley & Altman 1956	Altman et al 1961	Rigby et al 1961	Morgan et al 1963	Eng. Des. Hdbk. 1972	Crawford & Altman 1972	Mil. Hdbk. 759 1975	NUREG 0700 1981	Mil. Std. 1472-C 1981	Woodson 1981	Seminara 1982	Other/Notes	
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		Folley & Altman 1956	Altman et al 1961	Rigby et al 1961	Morgan et al 1963	Eng. Des. Hdbk. 1972	Crawford & Altman 1972	Mil. Hdbk. 759 1975	NUREG 0700 1981	Mil. Std. 1472-C 1981	Woodson 1981	Seminara 1982	Other/Notes	
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