DOE/NBM 1053

DESIGNER'S GUIDEBOOK FOR

FIRST WALL/BLANKET/SHIELD ASSEMBLY, MAINTENANCE, AND REPAIR

FUSION POWER

MASTER

First Wall/Blanket/Shield
Engineering Technology Program

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Prepared for
First Wall/Blanket/Shield
Engineering Technology Program
of the
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Argonne National Laboratory
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PREFACE

The Designer's Guidebook for First Wall/Blanket/Shield (FWBS) Assembly, Maintenance and Repair (AMR) has been prepared for Argonne National Laboratory under Contract No. 31-109-38-6429 with McDonnell Douglas Astronautics Company - St. Louis and with Remote Technology Corporation of Oak Ridge as a subcontractor responsible for preparation of the guidebook material. Argonne National Laboratory is conducting a FWBS Engineering Technology Program of which the development of the Designer's Guidebook is a part.

This is the initial issue of the guidebook. Since a guidebook of this type must incorporate information concerning a wide range of subjects, much additional data will eventually be included. The guidebook will document, in summary and easily referenceable form, data, designs, design concepts, design guidelines and background information useful to the FWBS and to the Maintenance System designer. In providing guidelines for the AMR of the FWBS, the guidebook must, of necessity, include guidelines for all aspects of maintenance associated with the FWBS. These include most maintenance operations within the reactor room necessary to gain access, identify faults, and handle equipment related to FWBS maintenance. In addition, the guidelines include those required to define facility requirements for handling and repair of FWBS and related reactor components external to the reactor room. Particular emphasis is given to remote maintenance design and operations.

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This guidebook is specifically intended for fusion devices. Another general guidebook for nuclear maintenance (ANS-11) is being prepared by the American Nuclear Society to provide data primarily for issues related to maintenance of fission devices. Of necessity, this guidebook will be referenced where common issues and solutions exist. At present, guidelines are included in this guidebook for pure fusion reactors and devices only since no interest currently exists in the national program for other fusion related devices such as fusion-fission hybrids.

This issue has been reviewed and most of the revisions suggested by review comments have been incorporated. However, a number of review revisions require extensive effort. These will be incorporated in a later issue. A

Because of the broad scope of information covered in this issue, the depth of detail available for the designer may need to be increased in many sections at a later time. As an example of the level of detail believed compatible with the purpose of this guidebook, Section 7.2 has been partially completed and included in this issue. Further effort in this direction is necessary.

The guidebook will be built by periodic revisions and additions. Data is solicited from experts in all applicable fields. Since the scope is broad, many different sources will be required to establish valid guidelines in all areas. The periodic supplements will be forwarded to registered holders of the guidebook with complete instructions for integrating the supplement into the existing copy. These supplements will revise existing sections as well as add new data and guidance for the designer. Those interested as potential sources or having need of other information should contact one of the following persons.

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The Revision A for the Designer's Guidebook includes all revisions made as a result of the review of the initial issue. Many of the comments point up deficiencies that require extensive effort to correct and these will be included at some later time. Every effort was made to correct all errors pointed out during the review and to increase the utility of the document as a reference.

The most extensive revisions are found in Chapter I and a complete rewrite of Chapter II. The additional information on contact materials and mechanical joint concepts derived as a result of the maintainability studies for ANL is included in Chapters V and VI, respectively. A

Cross checking of this guidebook with the completed Sections of ANS-11 remains to be conducted at some future date. Therefore, some differences may still exist at this time.

*Status - C - Complete as of this issue
I - Incomplete, some sections omitted
NA- Not Available, not included as of this issue (A)

Insert Latest Changed Pages, Destroy Superseded Pages

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*Zero in this column indicates an original page.

I INTRODUCTION

*Not available at this time.

It is important for any fusion reactor designer or maintenance system designer to know what is good engineering practice and what is not good practice when either designing a reactor for maintenance or designing the maintenance system and integrating it with the reactor. This guidebook presents the information necessary to establish what is good maintenance/maintainability practice on all subjects related to maintenance of the first wall/blanket/shield (FWBS) subsystem.

The principal emphasis in this guidebook is the presentation of acceptable remote maintenance design practices, maintenance designs and maintainable equipment together with procedures or techniques for their application and potential sources for additional information. The emphasis is on remote maintenance since the FWBS of any fusion device will become activated and require the use of remote maintenance techniques. Since the FWBS is such an integral part of any fusion device, the maintenance/maintainability characteristics of subsystems which interface with it must also be included to supply the complete information required by the maintainability or maintenance system engineer. For these reasons the breadth of material covered in this guidebook extends beyond the FWBS subsystem to include interfacing subsystems and all types of remotely operable equipment, tools and design features required to conduct the FWBS maintenance, including gaining access to the FWBS. In no other place has the information required by a fusion designer been assembled in a complete, concise and readily available format. A

This section summarizes the objectives used in formulating the material presented in this guidebook, the rationale of its organization and its content. As stated in the Preface and reiterated here, this guidebook is intended to be a living document. That is, it will constantly be increasing in scope and updated to incorporate new technology. Therefore, gaps are evident in the text and Table of Contents. The total context planned at this time is outlined but will likely change as revisions required in the coverage become evident. A

1.1.1 Guidebook Objectives - The Designer's Guidebook is a source book for the fusion energy device or reactor designer who is interested or responsible for: A

- The development of a maintainable design of a first wall, blanket and shield system and its associated interfaces, or
- The design of a maintenance system applicable to the first wall, blanket and shield system.

This guidebook is prepared for use in design of First Wall, Blanket and Shield (FWBS) systems and for use in detailed planning of Assembly, Maintenance and Repair (AMR) operations for near term and commercial devices.

The FWBS information is sufficiently broad in scope that it also provides a source of data, although somewhat incomplete, for the design for maintenance of other fusion device or reactor subsystems and their appropriate maintenance systems.

The information included in this guidebook provides:

- Design guidelines,
- Design solutions (hardware), and
- Design data.

These are defined in the following paragraphs.

Maintenance design guidelines define:

- Design principles which are applied to achieve maintainability,
- A design checklist for use in formulating maintenance systems, or
- Maintainable fusion reactor, device or maintenance system equipment techniques which can be used in a design.

Maintenance system and fusion reactor or device hardware design concepts are described throughout the guidebook. These concepts are examples of techniques, methods or designs that can be applied by the designer to fulfill maintenance requirements. In many cases the concept shown may only serve to illustrate a principle which can be applied to satisfy the unique requirements imposed on the designer.

Supporting data is provided to assist in the design of a FWBS or maintenance system without unnecessarily duplicating existing sources found in standard references. The concepts illustrated are generally in three classes:

- Existing verified concepts or hardware with their operational histories (i.e., with demonstrated capabilities),
- New hardware concepts which have been only partially verified with available analytical and operational data, and
- Conceptual design evaluations.

1.1.2 Guidebook Content — The objectives of the guidebook chapters are listed in abbreviated form in Table 1.1-1. These objectives are expanded at the beginning of each chapter in the section which defines the chapter contents and scope. A

In addition to the information provided in the guidebook, the sources will be listed for all data extracted and reproduced in the guidebook. Other possible sources for additional data on specific subjects will be given either in the text or, when too numerous, in an appendix. The discussion of several of the subjects covered is derived from extensive surveys of the current state-of-the-art. For these subjects a summary of this data will be inserted in the text when the survey data is too extensive for reasonable inclusion. A separate appendix may be used to incorporate synopses of the full body of data accumulated in the survey.

Table 1.1-1 Guidebook Purpose by Chapter

Chapter	Title and Purpose
I	Introduction to FWBS AMR - Orients the designer and defines the maintenance issues requiring special attention in fusion device design.
II	Maintenance Approaches - Defines guidelines and provides supporting information to aid in selection of the type of maintenance system/maintenance personnel relationship applicable to any fusion FWBS design.
III	General Approach to Remote Equipment Design - Defines guidelines and provides supporting information to aid in selection of the general equipment design approach for all maintenance functions and equipment general design problems where remote maintenance is required.
IV	Specific Component Designs for Remote Maintenance - Compiles design concepts with supporting information and related guidelines for specific equipment types which affect the maintainability of a broad range of design concepts.
V	FWBS Remote Maintenance Design Guidelines - Compiles design concepts with supporting information and defines design guidelines for development of maintainable components of fusion FWBS systems.
VI	FWBS Interface Equipment Remote AMR Design Guides - Compiles design concepts with supporting information and defines guidelines for development of maintainable components of systems interfacing with fusion FWBS.
VII	Remote Fault Isolation and Inspection Systems - Describes performance, design and operation of specific candidate fault diagnosis, fault isolation and other inspection system/equipment concepts and guidelines for application in sufficient detail for selection of the concept and/or equipment appropriate for the required maintenance functions.
VIII	Remote Maintenance Materiel Handling Systems - Describes performance, design and operation of candidate materiel handling system equipment concepts and guidelines for application in sufficient detail for the designer to select the concept and/or specific equipment and integrate it into the maintenance system.
IX	Remote Maintenance Viewing Systems - Describes performance, design and operation of specific candidate viewing system/equipment concepts and guidelines for application in the necessary detail for selection of the concept and/or equipment appropriate for the required viewing applications.
X	Specific Remote Maintenance Equipment - Describes performance, design and operation of the types of maintenance systems and/or equipment not included in Chapters VII, VIII or IX.
XI	Facility Remote Maintenance Design Guidelines - Compiles design concepts with supporting information and defines guidelines for selection of the design features required by the facility in which the fusion device/reactor is maintained.
XII	Remote Maintenance Control Systems - Defines the characteristics of systems used for control of remote maintenance systems and/or equipment.
XIII	FWBS System Maintainability Definition Analyses - Defines analytical systems for comparing the effectiveness of variations in remote maintenance systems as an aid in selecting the maintenance system design.
XIV	Guidebook Supporting Information - Collects the procedures for generating and maintaining the guidebook and information useful in interpreting and using the guidebook material.

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1.1.3 Guidebook Organization — For ease in locating material this guidebook is divided into chapters and sections, each dealing with a specific maintenance function of the FWBS system or related fusion reactor maintenance requirement. The scope of coverage will be modified as necessary in keeping with the living nature of the document. | A

The general flow of the guidebook information is as follows:

- Orientation of the designer to Fusion Maintenance and the Guidebook (Chapter I)
- Definition of General Maintenance Guidelines (Chapters II and III)
- Definition of Specific FWBS Component or Related Subsystem Guidelines (Chapters IV, V and VI)
- Description of Remote Maintenance Equipment Technology (Chapters VII, VIII, IX and X)
- Description of Facility Requirements for Remote Maintenance (Chapter XI)
- Remote Maintenance System Derivation Analysis and Control Technology (Chapters XII and XIII)
- Detailed Organization and Data Sources (Chapter XIV and Appendixes)

A formalized review process is employed to validate the material incorporated in the guidebook. All material entered in the guidebook will be initially marked "Preliminary" and will be reviewed before final acceptance. In addition, it is desired to distinguish the type of information according to the degree of confirmation available. Therefore, colored pages will be used to indicate the level of review and confirmation as follows:

White — demonstrated, verified concepts that have been reviewed and accepted.

Yellow — partially verified new concepts not yet demonstrated but reviewed and accepted. | A

This system alerts the designer to the fact that certain concepts and data must be used with discretion.

The primary purpose of a First Wall, Blanket and Shield (FWBS) Assembly, Maintenance and Repair (AMR) system is to achieve the functions of Assembly, Maintenance and Repair, particularly disassembly, maintenance and reassembly, with a minimum of shutdown time and at minimum cost or interference to the reactor operations. For a typical tokamak commercial reactor, such as STARFIRE,[1] a shutdown of one day results in a loss in 1980$ of approximately $\$1 \times 10^6$ in electricity not produced when operating at an annual availability of 75%. This availability is considered moderate. However, the benefit of a higher availability, say 80%, is sufficiently important that a capital expenditure of approximately $\$120 \times 10^6$ is justified in the STARFIRE case to achieve this goal without increasing the cost of electricity. Thus, the importance of developing a maintainable reactor is strongly justified in terms of the reactor economics.[2],[3],[4] In a similar manner, the justification for designing maintainable research devices or reactors is based on the cost per experiment hour.[5] In this case the cost of down time is not in the loss of electricity produced but in the reduced number of experiment hours available to produce research or in the reduced scope of research that can be conducted. Some significant examples are available to illustrate this point. More details of the impact of economics on the viability of maintenance systems has been included in Chapter XIII. A

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(1) *STARFIRE, A Commercial Fusion Power Plant Study, Argonne National Laboratory, ANL/FPP-80-1, 1980.*

(2) *Fuller, G. M., "Fusion Reactor First Wall/Blanket Systems Analysis, Final Report," Electric Power Research Institute, Research Report 472-1, October 1976.*

(3) *Fuller, G. M., et.al. "Developing Maintainability for Tokamak Fusion Power Systems, Phase II Report, Volume II, Study Results," Prepared for U.S. DOE by McDonnell Douglas Astronautics Co., Report No. COO-4184-6, November 1978.*

(4) *Zahn, H. S., et.al., "Developing Maintainability for Fusion Power Systems, Final Report, Prepared for U.S. DOE by McDonnell Douglas Astronautics Co., Report No. COO-4184-8, November 1979.*

(5) *Hager, E. R., "Design Considerations for Remote Maintenance of the Engineering Test Facility," General Atomic, Published in Proceedings of 27th Conference on Remote Systems Technology, 1979.*

In addition to this brief economic summary, this section includes additional definitions of the scope of the maintenance system and some examples of reactor designs which illustrate the impact of maintenance requirements on reactor configurations. While the maintenance of the FWBS subsystems involves only a portion of the total maintenance system, all functions of such a system that relate to these maintenance operations must be an integral part of the total system. These considerations define the significant role that FWBS AMR must take in the design of a fusion reactor or device so that it will be a viable machine.

1.2.1 Scope of a FWBS AMR System - The importance of AMR associated with a fusion reactor or experimental device FWBS necessitates the integral development of the maintenance system and the reactor. This section describes the scope of maintenance system functions and the operations and design characteristics that must be considered when developing the maintenance system. The converse is also true, i.e., the maintenance operations and equipment design must also be considered when developing the FWBS and the interfacing systems of the reactor. This discussion encompasses only the broader aspects of the system to illustrate the interactions necessary when developing an effectively maintainable FWBS. A

1.2.1.1 Maintenance System Composition and Functions - The Assembly, Maintenance and Repair functions considered are limited to those associated with the FWBS. The general approach to developing the maintenance system which performs these functions requires examination of each operation that the system must perform. Definition of the precise operations to be performed evolves with development of the FWBS and maintenance equipment design. As a result, the relative cost and time required to perform each function also changes as the design evolves. A

A maintenance system includes:

- FWBS and interfacing system design features to enhance maintainability A
- Maintenance assembly/disassembly equipment
- Maintenance repair equipment
- Maintenance and repair facility features A
- Maintenance training
- Spares
- Logistic support (transportation, disposition of waste, etc.)
- Logistic management (control, records, etc.)

These functions vary extensively with the type of reactor and type of maintenance but all must be considered in the system design. A

For Assembly, Maintenance and Repair of the FWBS, the reactor and maintenance operations conducted are generically common among most reactor and experimental device concepts. The sequence related to FWBS is generally: A

- Preplanning
- Shutdown
- Access
- Disassembly
- Replacement
- Reassembly
- Closure and withdrawal
- Startup

In examining these operations particular attention must be paid to include:

- Placement of maintenance equipment and spaces
- Repair of reactor and maintenance equipment
- Decontamination and waste disposal
- Equipment preparation A
- Manpower availability/effectiveness
- Fault isolation
- Calibration and adjustment

The capability to perform these functions is necessary for most maintenance systems.

1.2.1.2 <u>Reactor Operations Affecting FWBS AMR</u> - Maintenance and repair operations result in two types of reactor outages (scheduled or unscheduled [forced]) and are for the purpose of conducting two types of maintenance (preventive or restorative). (While these operations usually apply to commercial machines, they also are appropriate for experimental devices.) The particular combination of maintenance used for a given reactor subsystem or component assembly will determine the reactor operations necessary to allow this maintenance to be performed. A

The principal reactor operations affected by the FWBS maintenance system are shutdown/startup and access/withdrawal. While the latter is primarily an assembly or maintenance function, it affects reactor operations also. A

Varying degrees of shutdown are required for different maintenance operations. The level of shutdown is also determined by the design of the reactor and maintenance equipment. For example, in a tokamak reactor the shutdown may be designed to occur at one of several levels. The selection determines the downtime, maintenance equipment design features and startup requirements. Typical shutdown levels are: A

- Power reduction
- Plasma quench
- Reactor room atmosphere cleanup
- Field magnet dumping
- Vacuum pressure release
- Afterheat decay
- Field magnet warmup
- Radiation decay

Additional definition of these shutdown levels follows:

- Power Reduction — This level of shutdown is primarily useful in aiding maintenance of systems external to the nuclear island where redundancy or cross connections exist that allow individual equipment to be taken off-line for maintenance. Power reduction is generally an unacceptable shutdown mode for work on FWBS interfacing equipment.
- Plasma Quench — Quenching the plasma provides for quick access to systems outside of vacuum stop valves, e.g., neutral beam or fuel feed systems, or to systems directly affected by the plasma, e.g., continuous flow tritium recovery or diagnostic systems. For some maintenance of this equipment it may be unnecessary to shutdown further and startup time can be significantly reduced. Only a limited amount of maintenance of FWBS interfacing equipment can be conducted at this shutdown level.

- Reactor Room Atmosphere Cleanup — Cleanup of the reactor room atmosphere may or may not require a level of reactor shutdown or be required to conduct maintenance. This function is required primarily if contact maintenance is to be performed or if a failure mode has resulted in excessive contamination. It need only be accomplished to the level necessary to allow use of protective clothing or some types of maintenance equipment, primarily diagnostic or calibration. In most reactor rooms, such cleanup operations may use a continuous atmosphere control system.
- Field Magnet Dumping — With present maintenance system concepts the equipment is designed to work in environments without intense magnetic fields. Unless special equipment design requirements are employed, the Toroidal Field (TF) and Poloidal Field (PF) magnets must be deenergized during maintenance. This may also become a requirement where personnel work close to the nuclear island but outside of a biological shield. Work on the FWBS and interfacing equipment will usually be in this region. Deenergizing superconducting magnets can be done in a relatively short time and does not imply that magnets must be warmed up.
- Vacuum Pressure Release — Bringing the reactor torus up to atmospheric pressure is usually required for any direct maintenance on the torus interior. It is also required for most current reactor designs for maintenance on the blanket or shield systems. The shutdown time required for raising the vacuum vessel to atmospheric pressure can be very short (<< 1 hour). However, depending on the work done, the atmospheric composition and the materials used in the design, the startup time may be on the order of several days if outgassing or virtual leaks are present and a bakeout is required. A
- Afterheat Decay — In most reactor designs this is the controlling shutdown time function before work can be initiated on FWBS and interfacing equipment. For most maintenance operations other than work conducted from inside the reactor through a port in the vacuum wall, the coolant system must be disconnected. This can only be permitted after a significant portion of the afterheat is removed. The time required is

characteristically on the order of one-half day, but will vary considerably with the design.

- Field Magnet Warmup - Superconducting magnets are not required to be at room temperature during maintenance operations on most FWBS and interfacing equipment systems. These maintenance operations usually require removal and replacement of components or major portions of the FWBS either with or without magnets attached. Unless the design requires segmenting a superconducting magnet for replacement of FWBS elements, warmup can be avoided. Estimated warmup and subsequent cooldown times vary considerably with current designs, having been estimated from several days to a month, and extensive effort is required to ascertain the real time required. However, since this is, at least, a time consuming task, it should only be considered for maintenance operations directly on the magnet, e.g., for annealing the conductor material or repair of a dewar, etc.
- Radiation Decay - The requirement to allow radiation dose levels to decay to predetermined values before initiating contact maintenance operations applies primarily to shutdown operations on those devices which are experimental in nature and have limited neutron generation. It also applies to those reactors that are designed to allow for such decay before contact maintenance can be conducted. In maintenance operations conducted on FWBS and interfacing equipment systems for most design concepts, fully remote maintenance is used and delays for decay of radiation levels are not considered. For maintenance of these subsystems in most designs, the reactor must be opened to the reactor room and the activation levels are of such a magnitude that allowing time for decay to radiation levels suitable for manned access becomes impractical. For other designs where the FWBS and interfacing equipment systems are only slightly activated, as in the case of some experimental devices, delays to allow for contact maintenance are usually on the order of one day. Generally, such delays are considered primarily for experimental devices or for commercial reactors where the design provides for manned access to certain areas A

external to the FWBS for maintenance. The activation of materials is discussed in Section 1.3.3. A

The shutdown operations are determined by the type of shutdown, i.e., whether scheduled or forced, the maintenance activities to be performed, and the maintenance system approach used for a given plant design. Scheduled outages for general maintenance are frequently conducted at one year intervals and last about one month. For such outages all phases of shutdown are employed except, possibly, superconducting magnet warmup. However, on experimental devices, a weekly shutdown may be employed, or on commercial reactors frequent scheduled maintenance, e.g., replacement of neutral beam ion sources, may require frequent partial shutdowns. For these operations only a plasma quench and/or magnet deenergizing may be used. A Failures during reactor operation can be classed as requiring no shutdown, minor shutdown (requiring only a few hours to repair) or a major shutdown. Maintenance equipment and reactor operations vary with each type and are defined by the reactor design and availability requirements.

1.2.1.3 Maintenance System/FWBS Design Integration - In a reactor or experimental device development program, the maintenance system concept and its influence on the design must be established during the conceptual phase. Postponing consideration is likely to result in severe cost, availability and/or performance penalties. Figure 1.2-1 outlines the major development requirements for the maintenance system and the reactor systems, with the interfacing data required from the conceptual design phase through the construction phase. The emphasis of each phase changes from feasibility, cost and performance to operations and performance as development progresses and this results in a changing A output of the maintenance system design. The figure depicts the type of effort required in the maintenance system design. This will likely be unique to each development program. Also, the flow of effort shown is usually adjusted to suit specific circumstances, i.e., budgets and schedules. The efforts required for FWBS maintenance system design will be similar to that required for other reactor subsystems.

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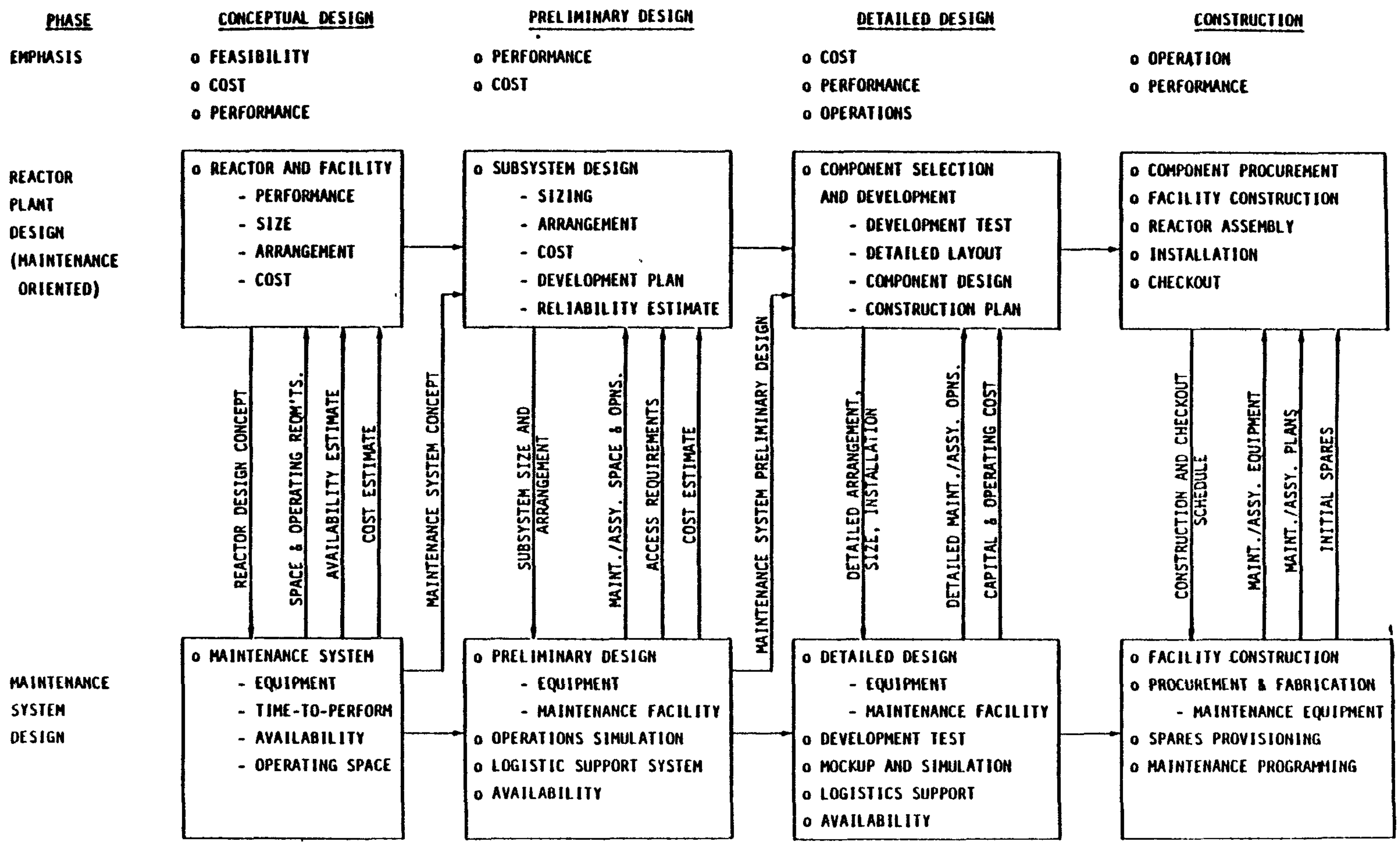
Figure 1.2-1 Example of Integration of Maintenance and Reactor System Development



During the conceptual design phase, the objective is to assure that the FWBS concept can feasibly be maintained within the derived cost estimates. This necessitates interacting the maintenance system concept with the FWBS and interfacing subsystem designs and conducting tradeoffs to define the required equipment, space and time for achieving the reliability and mean time to repair (MTTR) goals at minimum total cost. Techniques available for achieving this objective are discussed in Chapter XIII. A

Frequently, during conceptual design little attention is given to the maintenance system concept. However, at the start of preliminary design, the reactor design concept imposes limits on a maintenance concept. Major revisions in concept are then difficult to achieve without making significant revisions in the reactor or reactor subsystem concept. The maintenance concept and operations required are usually driven by the FWBS system. Of most importance is the development of access provisions for AMR of the FWBS and the equipment design for assembly and removal of heavy reactor equipment elements, e.g., FWBS sectors or Toroidal Field magnets. Simulation of maintenance operations either with or without mockups during this phase increases the accuracy of the cost and availability estimates. A

Maintenance system development during detailed design requires increased emphasis on AMR operations, logistic support and development testing. The maintenance equipment must be developed in parallel with the detailed reactor design to assure that maintenance is possible when required and that the effectiveness of the maintenance system is thoroughly understood. In this manner the number of changes to the reactor and maintenance equipment and the cost of these changes made during detailed design is reduced. The design of the facility provisions for maintenance and repair and the design of the maintenance equipment for each planned operation is finalized during detailed design. Prior to the detailed design phase, access provisions to each component should be substantially fixed, leaving little opportunity for any major changes in concept during this phase. A

Emphasis is principally on maintaining costs at or below the earlier estimates. Once construction has begun, design changes which can have a major impact on cost reduction are extremely limited. A

When detailed design is completed, the maintenance system is considered fixed and it is put into being in the construction phase. Refinements in maintenance plans and availability estimates and corrections in design are also made during this phase.

The concept of using maintenance equipment for initial assembly of the device is receiving increased recognition. This concept, however, should be introduced in the conceptual phase with trade studies conducted during preliminary design. In most cases some assembly operations and the remotely operated equipment may be required very seldom during the life of the reactor and, therefore, would be omitted from consideration for most maintenance systems. If this concept is used, these specialized operations and equipment must be designed in detail. It will probably be more practical to apply this concept to only those maintenance operations and equipments where remote operations are foreseen during the life of the reactor, such as for replacement of the first wall and blanket. A

1.2.2 Examples of AMR Impact on FWBS Configurations - Fusion reactor configurations conceived to date vary widely in their general arrangement and size and in the ability to efficiently assemble, maintain, and repair them. The FWBS configurations vary with and within each reactor configuration. These configurations are generally categorized as: A

- o Tokamaks
- o Mirrors
- o ELMO Bumpy Torus
- o Other Toroidal Concepts
- o Compact Toroids
- o Linear Systems
- o Very Dense (Pulsed-Linear) Systems
- o Hybrids

Of these categories, the first three have shown most potential for a commercial reactor and the majority of development has been expended on tokamaks and tandem mirrors. A representative configuration in each of these categories is described in this section together with generalized configuration characteristics of the FWBS. Detailed FWBS design characteristics are found in Chapter V. A glossary of the terms used is found in Reference 1.2-6. A

In defining a configuration and its capability to be maintained, those parameters which critically affect mean time to repair (MTTR) and mean time between failure (MTBF) are of primary importance. MTTR and MTBF are the two parameters which most significantly affect performance of the maintenance and repair system and reactor availability. The most important aspects of a configuration that affects these two parameters is the general arrangement and size of the components, subassemblies and subsystems that make up the configuration. These affect the access operations and AMR equipment handling capacities. Other configuration characteristics by subsystem that affect both MTTR and MTBF and the selection of equipment required to maintain the FWBS for most of the reactor types categorized include:

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(6) Whitson, M. O., Editor, "Glossary of Fusion Energy, Revision 1," Department of Energy, Technical Information Center, DOE/TIC 10192, Rev. a, January 1982.

- General Arrangement:
  - Equipment locations
  - Equipment interfaces (interference, disconnects)
  - Size (overall subassemblies, components)
- First Wall:
  - Materials (wall, armor, coatings)
  - Life (wall loading (MW/m^2), fluence ($MW\text{-}yrs/m^2$))
  - Fatigue loading (steady state or pulsed operation)
  - Modularization
- Blanket:
  - Materials (breeder, multiplier, coolant, hybrid fuel)
  - Modularization
  - Maximum module weight/size
- Shield:
  - Materials (structure, coolant)
  - Modularization (location)
  - Maximum module weight/size
- Vacuum Boundary:
  - Location
  - Joints (welded, mechanical)
- FWBS Manifolding:
  - Location (coolant, etc.)
  - Joints (type, number)
- Magnets:
  - Type (superconducting, normal)
  - Number
  - Field strength
  - Modularization
  - Arrangement (interlocked, stand alone)
  - Maximum weight/size
- Plasma Heating:
  - Neutral beam, radio frequency, and others

- o Impurity Control:
  - Type (limiter, divertor)
  - Materials (wall, armor, coatings)
  - Location/modularization
- o Fueling:
  - Type
  - Fuels

This list is typical and can be extended. Each concept has its own set of critical configuration characteristics which will be similar to the foregoing. Reference 1.2-7 examined 36 reactor conceptual designs which reflected significant differences in many of the foregoing characteristic parameters that affect FWBS maintenance and maintainability. This section will identify some of the more viable and further advanced concepts to illustrate the impact of configuration characteristics on the ability to conduct maintenance effectively. A

1.2.2.1 Tokamak Power Reactors - STARFIRE - The STARFIRE reactor conceptual design[1] is illustrated in Figure 1.2-2. This figure shows only the nuclear island portion of the complete power plant. Figure 1.2-3 is an overview of the complete plant. STARFIRE is designed to produce 1200 MW net electrical power. A

The AMR system employed for this reactor relies primarily on a remove, repair and replace approach for relatively large modules such as are used in the FWBS system. The principal capability required for efficient maintenance of a tokamak reactor FWBS is ease of access. The STARFIRE design relies on access horizontally around the reactor periphery and FWBS modules are removed as indicated in Figure 1.2-2. The figure indicates that access to the FWBS affects the design of most of the reactor subsystems. Handling equipment runs on a monorail A

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[7] *DeFreece, D. A., et. al., "Examination of Magnetic Confinement Fusion Engineering Opportunities on Existing and Planned Facilities," Electric Power Research Institute*, EPRI AP-2489, *Project 1971-2, July 1982.*

[1] *See page 1.2-1.*

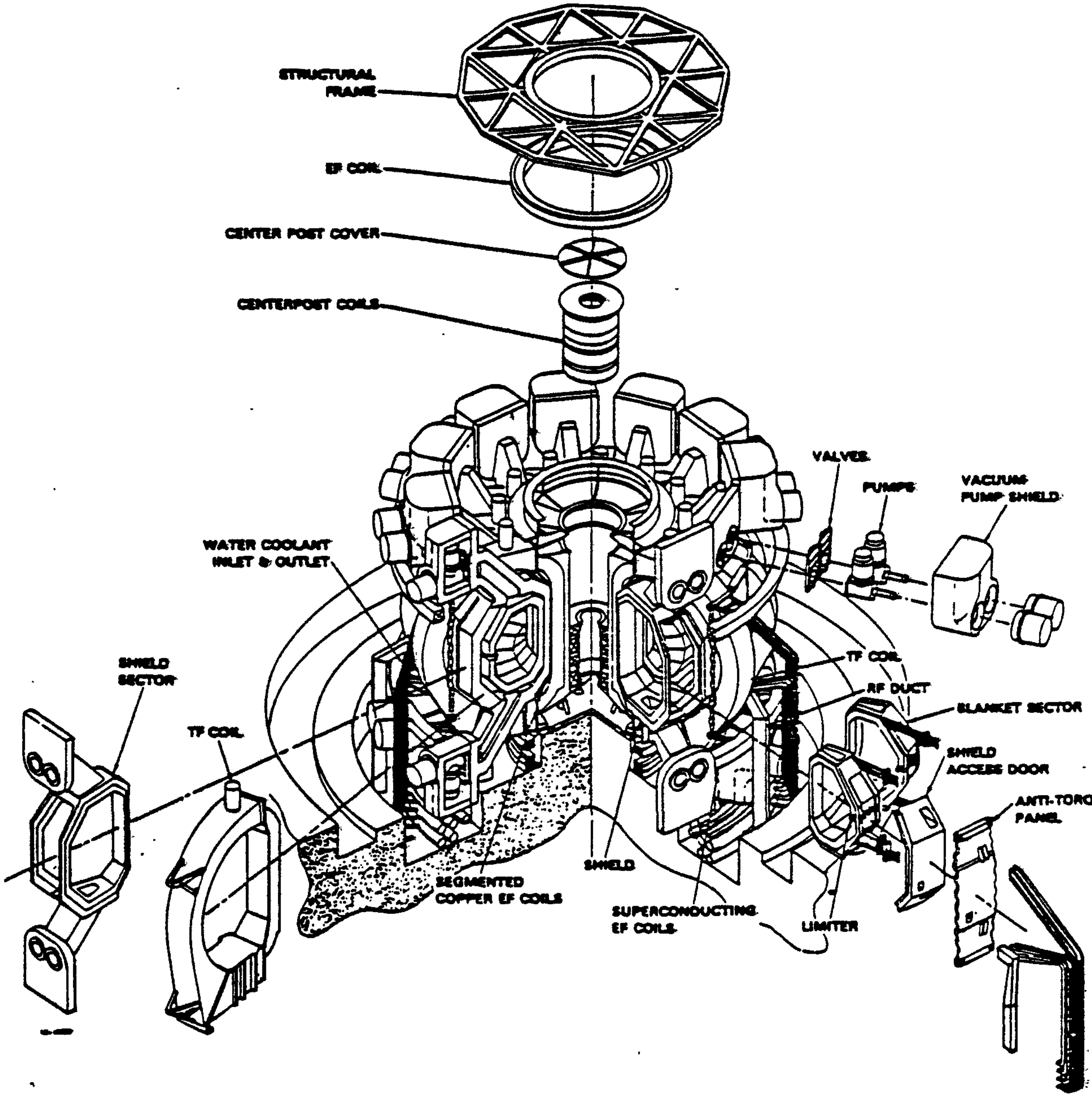

Figure 1.2-2. STARFIRE Reference Design.

A

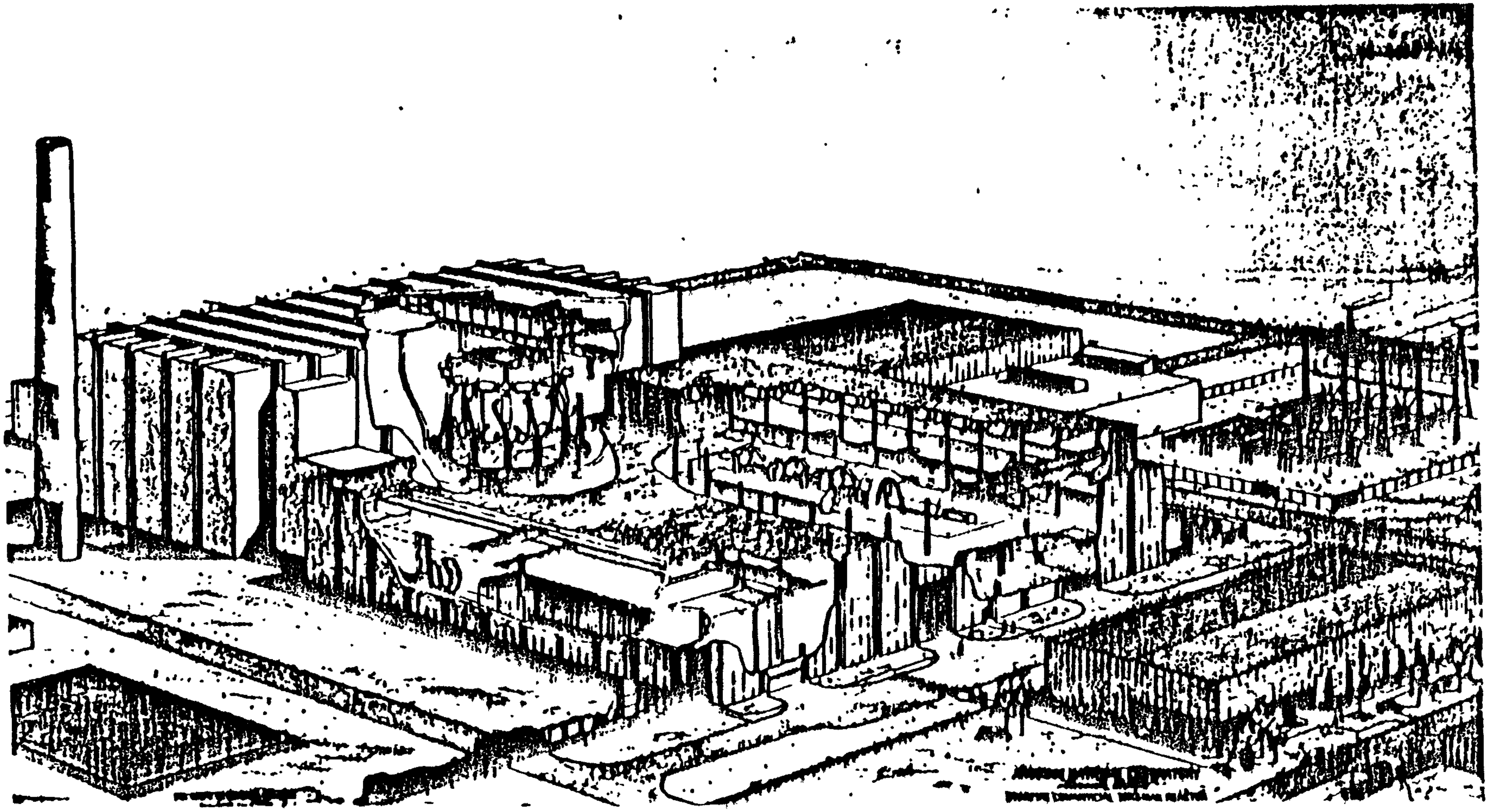

Figure 1.2-3. STARFIRE — A Commercial Tokamak Fusion Power Reactor.

around the periphery and into hot cells. While the system is designed to perform all AMR remotely, biological shielding is provided to allow personnel access to the reactor building within 24 hours after shutdown if the first wall and/or blanket have not been accessed and exposed to the reactor norm. A

Figure 1.2-4 is a cross section of the reactor and identifies many of the features. A more detailed maintenance discussion is found in Reference 1.2-8. Table 1.2-1 lists significant characteristics of the STARFIRE design that affect the design of the FWBS AMR system. A

The weight and size of the principal FWBS components or subassembly modules are listed in Table 1.2-2. The handling techniques and equipment for this reactor are determined by the maximum dimensions and weight as well as by the access requirements of the configuration. A

Significant FWBS AMR Configuration Characteristics - STARFIRE - Several specific design elements of the STARFIRE configuration have a major influence on the downtime and equipment required for some subsystem maintenance and repair (particularly FWBS and magnets). These include: A

- o The use of a common dewar for all TF coils at the reactor center post imposes a severe restriction on TF coil replacement. A
- o The antitorque structure between TF coils is designed for room temperature operation which increases the complexity of access and access time for maintenance operations on the nuclear island, including the FWBS modules.
- o Tokamak reactors generally employ poloidal field (PF or EF, CF) magnets wound through the bore of the toroidal field (TF) magnets which require disassembly of the poloidal field magnets before the toroidal field A

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[8] *Graumann, D. W., et. al., "STARFIRE Remote Maintenance and Reactor Facility Concept," Proceedings of the Fourth Topical Meeting on the Technology of Controlled Nuclear Fusion, Conf. 801011, July 1981.*

magnets can be removed. These poloidal field magnets also frequently inhibit access to the FWBS components or modules. A

- o Two blanket modules per TF coil increases maintenance time for blanket module operations over that required if one module is used.
- o A spare, but trapped, EF coil is provided to allow removal of EF coil without rebuilding a replacement. A

The efficiency of this arrangement remains to be established. Many other designs may be included, but these are deemed of particular importance. Alternative designs are feasible for these functions. The designer must determine the best for his application. Guidelines will be provided in Chapter V.

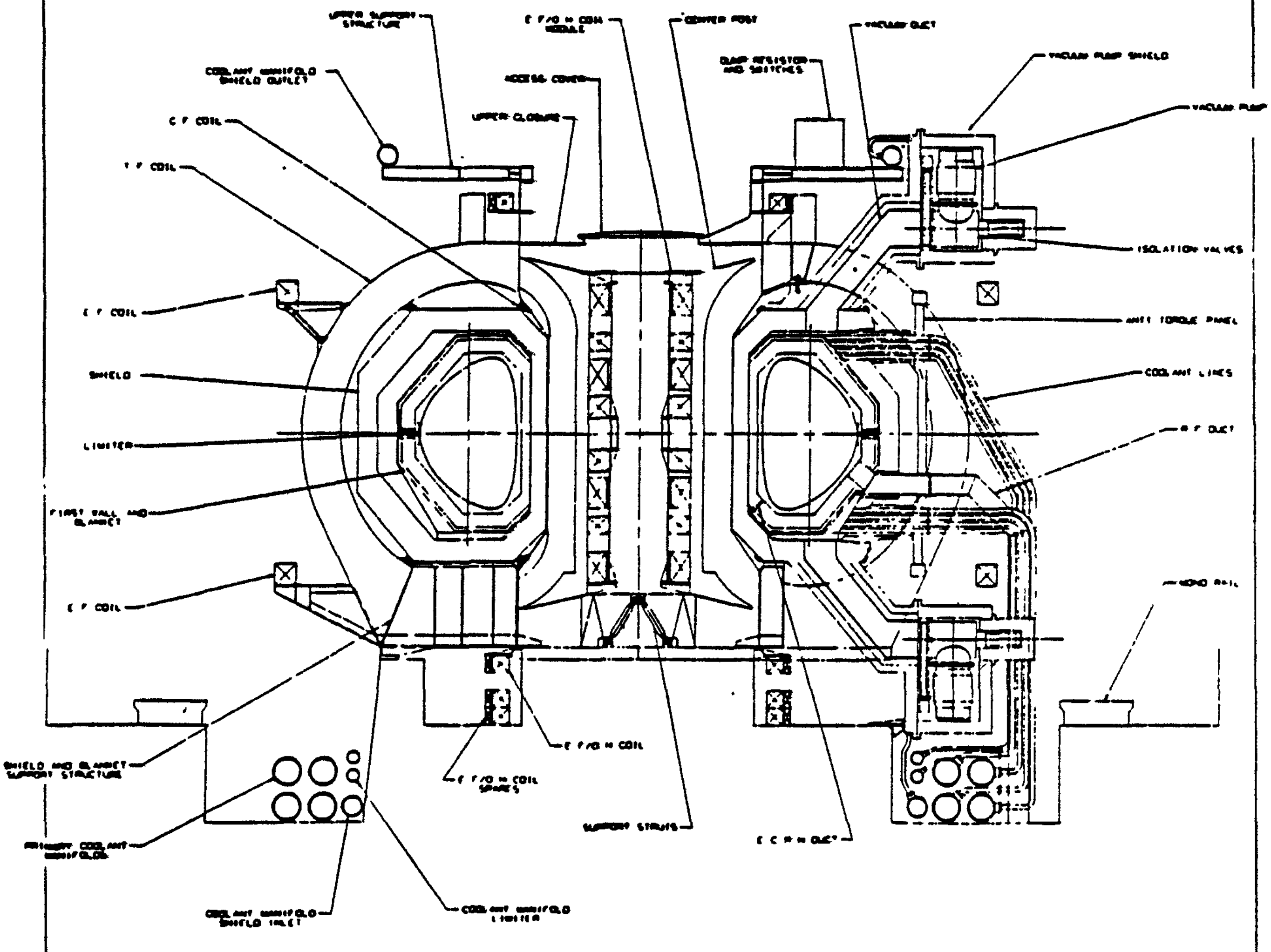

Figure 1.2-4. STARFIRE Commercial Tokamak - Cross-Section. A

Table 1.2-1. STARFIRE Characteristics Affecting FWBS AMR

Subsystem	Factor	Configuration/Parameter Value
First Wall	Materials - Wall	Prime Candidate Alloy (Ti modified 316 aus. S. S.)
	- Coatings	Beryllium
	Life - Wall Loading	4.0 MW/m^2 (peak)
	- Fluence	16.0 $MY\text{-}Yrs/m^2$
	Fatigue - Plasma Operation	Steady state
	Modularization	24 sectors (w/blanket)
Blanket	Materials - Breeder	α - $LiAlO_2$
	- Multiplier	Zr_5Pb_3
	- Coolant	Water
	Modularization	24 sectors (w/first wall)
Shield	Materials - Inboard	W_1 steel, B_4C, H_2O
	- Outboard	Ti-6-4, TiH_2, B_4C, Steel, H_2O
	- Coolant	H_2O
Vacuum Boundary	Location	Outside shield, inside TF coil
	Joints	Mechanical
Manifolding	Location	Inside shield
	Joints	Single bundle/sector, outside vacuum boundary
Magnets	Type - Toroidal Field (TF)	Superconducting
	- Poloidal Field (PF)	
	- Equilibrium Field (EF)	Superconducting
	- Ohmic Heating (OH)	Superconducting
	- Control Field (CF)	Normal
	Number - Toroidal Field	12
	Field - TF Coils	11.1T (5.8T on plasma axis)
	Modularization	Unit design (TF, EF, OH) Segmented (CF)
	Arrangement	EF, OH outside of TF coils CF inside of TF coils
Impurity Control	Type	Limiters/vacuum
	Location	Outer wall
Fueling	Type	Gas puffing
	Fuels	Deuterium-Tritium (D-T)

A

Table 1.2-2. STARFIRE Subassembly/Component Weights and Dimensions

Subassembly/Component	Unit Weight Tonnes*	# Units	Size
Center Post (4 segment total)	280	1	m x m x m
TF Coil	583	12	≈ 11 x 15 high
EF Coil (Center Post)	45	4	≈ 4 dia.
OH Coil (Center Post)	39	4	≈ 4 dia.
EF/OH Coils (Upper and Lower)	155	2	≈ 12 dia.
EF Coils (Outer)	450	2	≈ 30 dia.
CF Coils (Inner)	17	2	
CF Coils (Outer)	53	2	
Blanket			
--Large Sector (16.3°)	65	12	3.9 x 12.4 x 13.8 high
--Small Sector (13.7°)	60	12	
Shield Sector (w/o door)	179	12	3.5 x 7.8 x 12.75 high
Under Coil Shield Sector	226	12	
Shield Door	156	12	
Vacuum Duct	116	24	
Vacuum Pump Pod	160	24	

*Reference 1.2-1 (See page 1.2-1) A

Several characteristics of the environment attributable to fusion reactors have a specific influence on the maintenance of the FWBS of these reactors. The characteristics discussed in the literature are summarized in this section. Details of the nature and behavior of each environmental characteristic can be found in much of the literature abstracted in the designer's guidebook appendix. The influence of these characteristics must be understood when defining a FWBS AMR system. A A

Commercialization of fusion power will require that these plants be licensed and meet the requirements and regulations set by all applicable local, state, and federal agencies for power plant operations to assure the health and safety of the public and to balance the benefits of the electrical power produced against the risk and the environmental impact of the plants. Demonstration plants constructed by the U.S. Department of Energy do not normally require official licensing but must meet the applicable requirements of the Code of Federal Regulations and the DOE regulations. A

1.3.1 Maintenance in a Tritium Intensive Environment - One of the most challenging aspects of dealing with the FWBS AMR in the tritium intensive environment of a fusion reactor (especially a D-T fueled reactor) relates to the propensity for tritium to penetrate virtually all of the materials with which it is likely to come into contact. This penetration can occur by:(1) | A

- o The process of bulk diffusion,
- o Molecular infiltration through pores and cracks,
- o Adsorption (physical and chemical) on surfaces, and
- o Implantation mechanisms.

To counter the problem of potential tritium contamination, methods should be employed that either remove the contaminant or prevent its subsequent release from free surfaces prior to maintenance and repair on components that have been exposed to tritium, primarily within the reactor. Otherwise, significant quantities of tritium contained in and/or on a particular component could be released to the reactor building and to auxillary FWBS maintenance bays. (There are also other pressing incentives for the consolidation and recycle of tritium lodged in components to be removed from the reactor. These stem from safeguard and tritium economy issues.)

Many of the difficulties to be encountered in conducting AMR on FWBS tritium contaminated components from fusion reactors have already been confronted in other technology programs, principally those involved in nuclear weapons development and fabrication; some specialized component detritiation procedures have been developed and defective components to be repaired and/or replaced have been developed to have low failure probability. Special clothing items, including air-supplied protective suits, have been developed and successfully tested. It is recognized that the use of such suits tends to restrict mobility and, hence, increases worktime. These suits do not always give complete protection against tritium contamination of the wearer.

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(1) *Baskes, M. I., et. al., "Tritium Permeation in Fusion Reactors: INTOR," Sandia National Laboratories, SAND81-8264, December 1981.*

While the problems associated with conducting AMR on presently conceived fusion reactor systems should not be minimized, there is a substantial technology base for tritium containment and control available from other programs. Furthermore, there is ongoing within the fusion program a major engineering activity aimed at resolving many of the critical fusion-specific FWBS AMR issues involving tritium containment and control. This activity, the Tritium Systems Test Assembly at Los Alamos Scientific Laboratory, should eventually provide much guidance on matters related to AMR in the fusion tritium environment. Additional information related to maintenance in a tritium environment is given in Section 1.3.4. A

1.3.2 Radiation Damage to Materials — Examples of potential changes in materials characteristics associated with radiation damage are:

- Embrittlement (metals and organics)
- Loss of strength (ceramics and organics)
- Distortion from swelling (metals, graphites, and ceramics)
- Distortion from irradiation creep (all materials)
- Lowering of resistivity (ceramics and organics)
- Lowering of dielectric strength (ceramics and organics)
- Lowering of thermal and electrical conductivity (metals and graphite)

The nature of radiation damage in specific materials is sensitive to many important variables including the type of radiation (e.g., gamma rays, neutrons), the energy spectrum by type of radiation, the irradiation temperature and the chemistry of the material. This discussion will identify some of the radiation effects in three broad areas of fusion applications: (1) high exposure applications such as limiters, first walls, and blankets; (2) short-lived moderate flux applications, for example, some diagnostics; and, (3) low exposure applications such as gaskets, seals, and organic insulators.

High Exposure Applications — Apart from obvious concerns over the lifetime of structural members after exposure to intense neutron radiation in a fusion reactor, the following two phenomena may directly affect maintenance and repair of these components. First, the mechanical properties of a material can be significantly altered by irradiation. For example, work-hardened materials can soften and ductile materials may become brittle. These changes are sensitive to temperature, stress, and minor variations in alloy chemistry. Therefore, material responses can vary with location and may be different, for example, for welds than for bulk material. Secondly, the high energy neutrons in a fusion environment (from a few MeV to 14 MeV) produce hydrogen and helium gases by nuclear transmutation reactions. For example, in the stainless steel Berilium clad first wall of the STARFIRE Reactor, the concentration of helium in stainless steel would reach over 400 ppm in its first year of operation. Because of this high gas content, welding and high temperature brazing may have only limited applications as repair techniques.

In addition to these phenomena, radiation resistant repair equipment will be required for in-vessel inspection and repair work. Using STARFIRE as an example, first wall components will have a residual activation dose level of over 10^6 Rem/hr. Many electronic components fail at 10^5 Rads, normal glass darkens at 10^7 Rads, conventional lubricants break down at 10^4 Rads, and some elastomers (teflon) fail at 10^6 Rads. It is important that all components used in the equipment be selected based upon the lifetime needed to perform the repair as inspection operations. A

Short Lived Moderate Flux Applications — Examples of applications that may require short or moderate exposure in high intensity neutron flux areas are sensors for test articles in near term devices (e.g., INTOR, FED) and instrumentation and diagnostics designed for ready replacement as radiation sensitive elements fail. The electrical properties of materials, in particular ceramic insulators and semiconductors, may be sensitive to the instantaneous neutron flux as well as to the accumulated neutron fluence. Atomic defects that act as charge carriers result in instantaneous responses, e.g., leakage currents. Other permanent changes in the material, e.g., long term changes in electrical properties, are more a function of total fluence than the neutron flux intensity.

Low Exposure Applications — Low exposure applications cover a great variety and number of material uses. Some examples are: the thermal and electrical insulation in superconducting magnets (permanent damage and components nonrepairable); neutral beam sources and sensors, mirrors and electrical leads for diagnostics penetrating the shield (components replaceable and/or repairable); and elastomeric seals in proximity to shield or penetrations (components and parts readily replaceable). Potential problems are the degradation of useful electrical and mechanical properties. For example, excessive exposure of organic seals can result in gas formation and either embrittlement (due to cross linking) or slumping and creep (due to scission).

Radiation Units — Consultation with materials experts familiar with radiation damage is advisable when establishing even preliminary design criteria or applying data on radiation damage. The nomenclature of radiation damage can be somewhat mystifying to the unfamiliar. Units such as n/cm^2 (neutrons per square centimeter) can be understood as fluence, a simple time integrated flux. Units such as dpa (displaced atoms), rads and rems (radiation equivalent measure) are useful because they indicate the materials response to radiation. Dpa in metals is a useful tool for comparing the radiation damage in situations where the same numbers of neutrons (n/cm^2) in differing neutron spectra impart different total amounts of "damage energy" into the specimen. A rad is a measure of the energy deposited in materials by gamma radiation (100 ergs/gram) and a rem is a specialized unit where the energy deposited is biased for the spectral effects appropriate for the human body. These specialized units are necessary because the simple numbers of incoming neutrons (or gammas) are not sufficient to predict material responses or to extrapolate from one set of conditions to another, e.g., from fission exposure to fusion exposure.

1.3.3 Activation of Materials - The following considerations stemming from neutron activation of materials (excluding tritium) can affect FWBS AMR activities: | A

- Activation of stationary components (e.g., first wall, shield, etc.)
- Local activation of peripheral components caused by neutron streaming along joints, ducts, etc.
- Transport of activated corrosion products in coolant loops and redeposition, notably in pumps, valves, joints, and heat exchangers
- Transport of activated plasma impurities to the vacuum system ducts and components
- Spills or leaks of activated coolant
- Distribution of activated particles or dust during removal or inspection of activated components
- Release of activated material in gas or chips during machining and welding of activated structures

Permeation, absorption, and general containment of tritium are also important and are specifically covered elsewhere in Sections 1.3.1, 1.3.4 and 6.7.

The high energy neutrons resulting from the fusion reaction cause activation reactions not present in the fission and fast fission spectra and, consequently, fission activation studies do not provide a useful guide, even in general, for fusion reactor component activation and shielding. Typically, in design studies activation dosages range from very high levels at the first wall, over 10^6 rem/hr in STARFIRE, to levels at the outside of the shield which are low enough to permit contact maintenance. | A

1.3.4 Tritium Breeder Blankets — While the assembly, maintenance, and repair issues of tritium breeder blankets for D-T fusion reactors present a number of new engineering challenges, there is much experience in the fission industry and in defense programs for guidance in resolving the resultant problems. In considering the FWBS AMR impacts of various types of candidate breeder materials (ceramics and alloys containing lithium as well as lithium itself), a number of parallels can be drawn with other ongoing technology programs. For example, handling and containment of liquid metals have been advanced considerably by developments in the Liquid Metal Fast Breeder Reactor Program (LMFBR) which has been successful in the operation and maintenance of large liquid sodium loops where radioactive material (including tritium) is present and where potential damage due to sodium reaction with air is minimized by prudent design. Much of this methodology is applicable to liquid lithium and its molten alloys in fusion reactor blanket applications. | A

Expertise in tritium handling has been developed in both the fission industry and defense-related work which can provide useful insights for fusion applications. Several laboratories (the Mound Facility and the Lawrence Livermore National Laboratory) have developed many concepts and employed them successfully to handle and maintain tritium production and processing equipment. Repairing and replacing tritium-contaminated components, although not a totally routine matter, has been done successfully, and significant further advances are expected in tritium systems AMR. More information concerning specific AMR-related tritium handling issues is given in Section 1.3.1. Some of the experience gained in the fabrication, installation, removal, and subsequent handling of nuclear fuel bundles can be applied to handling and maintenance of segments of irradiated fusion breeder blankets. Furthermore, much of the hot fuels reprocessing technology that is likely to evolve in the coming years to support the fission industry should have many applications pertinent to fusion systems.

However, even in the face of a reasonably substantive technology base from several other industries and activities, there are still many AMR issues relating to the design and sustained operation of fusion breeder blankets. Some of these issues are caused specifically by the following unique fusion reactor configuration characteristics:

- The constrained geometry of fusion blanket systems,
- The complex material embodiments in many breeder blankets (breeder, coolant, multiplier, moderator, and structure), and
- The complicated interfaces with adjacent electrical, magnetic vacuum, coolant, and instrumentation hardware.

Resolving these issues will require additional development beyond that which can be expected from the advances of other technologies.

1.3.5 Magnetic Effects — Fusion reactors require the use of high magnetic fields for the containment and control of the plasma. This results in residual magnetism in ferritic materials or in permeable impurities in materials that are exposed to the fields. The use of certain types of motors, pumps, and instrumentation systems is precluded or requires special protection on reactors employing such materials in their design. Magnetic fields, either actively generated or residual, existing when maintenance is conducted, present problems when using maintenance tools made from permeable materials. Standard operations may desire to keep the large superconducting coils energized while minor FWBS related AMR work or inspection is in progress. Such strong magnetic fields would affect the operation of most maintenance equipment currently in existence. A

1.3.6 In-Vessel Clean Up — Plasma excursions and normal operating erosion will cause the formation of radioactive ash and debris within the vacuum vessel. Clean up or confinement of this material is desirable to prevent gross contamination of areas occupied by personnel during maintenance. An additional requirement exists to clean up such material or to prevent the introduction of contaminating materials during maintenance which could poison the plasma during reactor operation. A

Effect of Operational Issues on FWBS AMR - A variety of operations conducted by and on fusion reactors and devices have a strong influence on the FWBS AMR of these machines. The characteristics of these operations which are of importance to FWBS AMR as discussed in the literature are summarized in this section. Some of the details of the operations and their influence on the maintenance, repair and design of fusion FWBS systems can be found in the literature to be abstracted in the designer's guidebook appendix. A

1.4.1 Large Component Handling - An inherent part of the FWBS maintenance scenario for fusion reactor concepts requires the periodic handling of large components. These include: A

- Sectors of the first wall vacuum vessel
- Blanket modules
- Neutral beam injectors
- Diagnostic equipment
- RF antennas or launchers
- Vacuum pumps
- Magnets

The actual replacement and handling of these components must be by remote means because of their size and mass alone. However, most reactor concepts include the use of contact techniques wherever possible for light operations such as the disconnect/reconnect of utility service lines. A

The designers of large component handling equipment and the FWBS AMR system must consider the following and other similar requirements:[1] A

- The FWBS sector modules to be handled will be on the order of 3.9 m x 12.4 m x 13.8 m with a weight of 65 tonnes.
- The estimated number of utility service connections to a removable FWBS sector module varies from 34 to 95 among major fusion reactor concepts.
- The number of bolts that attach a FWBS sector module to the reactor or that fasten the vacuum wall closure for a FWBS sector module varies from 200 to 700 (welding is an option to bolting). A
- Radiation dose levels on the inner wall of the FWBS are expected to exceed 10^6 rem/hr.
- Tritium release during removal of a large component may exceed the Maximum Permissible Concentration (MPC) levels for air in a reactor building.[2] A

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[1] "STARFIRE - A *Commercial Tokamak Fusion Power Plant Study*," *Argonne National Laboratory*, ANL/FPP-80-1, September 1980.

- Large components must be moved with precision in order to achieve fitup with the reactor for high vacuum seals.
- Access space for maintenance personnel and remote manipulators will be limited.
- Allowable downtime for the replacement of large components will be limited.

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(2) *USNRC, "Standards for Protection Against Radiation," USNRC Rules and Regulations, Title 10, Chapter I, Part 20, 1975.*

1.4.2 In-Vessel Inspection -- Remote inspection of the vacuum vessel interior is needed in fusion reactors for:

- Preventive maintenance surveillance,
- Diagnosis of malfunctions,
- Observation of surface deterioration,
- Observation of wear of components,
- Prediction of failures,
- Planning preventative maintenance tasks, and
- Identifying and locating the position of:
  --Cracks,
  --Leaks,
  --Material erosion,
  --Surface melting,
  --Missing parts,
  --Discolorations, and
  --Other maintenance.

The FWBS AMR designer must be critically involved in determining how access to the vessel interior is provided and how inspection devices are transported within the vessel if this is required. The designer is also required to select the specific devices that perform the inspections and can operate within the severe environmental conditions existing within the reactor vessel. One of the most important of these is the expected radiation level within the vessel. This can be on the order of 10^7 rem/hr at shutdown and 10^6 rem/hr 24 hours after shutdown.(1) Temperatures within the vessel during maintenance can be very high. For example, in reactors using liquid lithium where the lithium remains molten during maintenance, the temperatures could be on the order of 200°C. A

As a goal, a highly desirable system is one which could perform in-vessel inspections remotely under vacuum without affecting plant on-line availability.

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(1) *See Reference 1.4-1, Page 1.4-2.* A

1.4.3 <u>In-Vessel Repair</u> — Two basic approaches for performing in-vessel repair have been applied in current fusion reactor concepts. One is to install and remove all in-vessel components, usually in large assemblies or sectors of the reactor, which are accessible from outside of the vacuum vessel through ports or doors. This approach does not require the use of in-vessel manipulators and equipment. The other approach is to place in-vessel components such as limiters, divertors, plasma shields, armor tiles, and similar components within the vessel and make them individually removable through access ports. This approach assumes that the necessary in-vessel maintenance equipment can be developed. Reactor plant availability studies have shown the benefits of making repairs in-vessel during forced outages caused by failure of small replaceable components and also the benefits of removing large vessel sectors for efficient repair and replacement of large components and for multiple component maintenance during scheduled or forced outages.

The FWBS AMR designer is faced with significant challenges in providing an in-vessel repair capability. The major concerns include: A

- Access into the vessel for maintenance equipment,
- Access for the ingress/egress of reactor components,
- A transport system within the vessel,
- Developing or selecting the appropriate manipulator and viewing systems, and
- Special remote tools and fixtures.

Another major design feature required is to make provisions on the in-vessel reactor structure and on the attached components such that remote replacement is feasible.

1.4.4 Pipe and Duct Joint Systems — A common characteristic of all fusion reactor concepts is the large number of service pipe and duct connections required. For some concepts, it is estimated that over 1,500 connections will be needed. Most reactor concepts propose that these pipes/ducts be disconnected and reconnected using contact (hands-on) maintenance techniques. However, in many cases, a remote disconnect and reconnect capability is required. Major FWBS and interfacing subsystem design features are included to assist AMR because of: A

- The large number of pipes and ducts,
- The many different sizes and shapes of pipes and ducts,
- Severe temperature and pressure operating conditions, A
- The presence of ionizing radiation and tritium contamination,
- Limited access space for maintenance,
- The need for detection of leaks, and
- The need for remote removal and replacement.

1.4.5 Ex-Vessel Remote Manipulation and Handling Systems - A fundamental requirement of FWBS AMR work is that remote manipulation and handling systems be provided which can service FWBS equipment or equipment that interfaces with the FWBS within the reactor building. These systems assist in the remote removal and replacement of the in-vessel repair and inspection equipment and components, other components both large and small, pipe/duct joint systems, and elements of the other systems located in the reactor building. A number of design approaches have been proposed to date ranging from the equipment necessary for total remote maintenance to the use of manipulator vehicles with shielded personnel cabs. There are widely ranging views on the type of work remote manipulation systems can or should perform and the reliance that should be placed on the systems. In general, there has been a trend towards designing the ex-vessel reactor equipment to be maintained by contact means. Lack of a data base for using remote techniques restricts their application significantly.

A

A

The successful application of remote maintenance techniques within fusion reactor buildings will have a significant effect on the construction cost and availability of the plant and will decrease risks to maintenance personnel. This subject is discussed in more detail in Chapter II of this guidebook.

1.4.6 Downtime for FWBS AMR Work - A number of studies have been performed which analyze the impact of AMR downtime on a fusion plant on-line availability.(3-7) They all conclude that AMR downtime will determine whether fusion actually becomes an economic source of energy. Most of the studies conducted to-date address replacement of major reactor components such as vessel sectors, blankets, and neutral beam injectors. A total system and component analyses that considers, for example, pipe connector leaks, motor failures, instrument failures, and malfunctions in support equipment located outside of the reactor building is essential to determine the impact of maintenance and repair downtime requirements. A

FWBS AMR designers will be required to consider all facets of maintenance downtime when designing equipment and selecting components. The first rule is, of course, to obtain as high a reliability and operating life of equipment as possible but to consider this objective in a tradeoff with the total system life cycle cost. It must be recognized in these analyses that failures will occur over the plant lifetime and that very few components are totally exempt from failure. Time and motion analyses should be made for all failure possibilities and include activities such as: A

- Failure mode and effects analyses,
- Fault isolation to determine which component has failed,
- Establishing and maintaining an approved repair plan,

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(3) *Zahn, H. S., et. al., "Developing Maintainability for Tokamak Fusion Power Systems, Phase 1 Report; Volume 1, Study Results; Volume II, Appendixes," Prepared for USDOE by McDonnell Douglas Astronautics Co., Report No. COO-4184-4, October 1977*

(4) *See Reference 1.2-3, Page 1.2-1.*

(5) *Sniderman, M., "Fusion Reactor Remote Maintenance Study, Final Report," Electric Power Research Institute, Prepared by Westinghouse Electric Corp., Report No. ER-1046, Research Project 1044-1, April 1979.*

(6) *See Reference 1.4-1, Page 1.2-2.*

(7) *Flanagan, C. A., et. al., "Fusion Engineering Device Design Description," Oak Ridge National Laboratory, ORNL/TM-7948/VI, December 1981.* A

- Detailed downtime studies including:
  --Process shutdown
  --Transfer of repair equipment to work scene
  --Personnel suit up
  --Preparing for component removal
  --Obtaining a replacement component
  --Replacement of failed component
  --Requalification of the new component
  --Process start up

Experience at existing nuclear facilities has shown that the time required to actually replace a failed component is only a small percentage of the total downtime when considering all of these factors, most of which are concerned with gaining access to the component, reassembly, and checkout after replacement.

II MAINTENANCE APPROACHES

A

The development of fusion as a viable energy alternative is highly dependent on its ability to compete with other energy sources on a commercial basis. Thus, the capability of fusion machines, such as the tokamak, to attain high levels of availability is of utmost concern. It has been reported that on-line times of greater than 70% are required. To achieve this, future plants should be developed with both high maintainability and high reliability as design goals. Many of the maintenance operations must be performed using remotely operated devices because of the radiological hazards. A

The International Tokamak Reactor (INTOR) workshop report[(1),(2)] concluded that existing technologies could be used to remotely maintain INTOR and that viewing of remote welding, reliability analyses, and the toroidal field (TF) coil joints need further development. Two primary factors were reported to have an effect on high on-line availability of reactors: (1) failure rates, and (2) the time required to repair equipment. Projections were included that indicate high equipment reliability would be difficult to achieve; therefore emphasis should be placed on equipment repair time.

As noted in the INTOR report mentioned above, there is a broad base of usable remote maintenance experience in the non-fusion areas. This base, however, will not solve all of the fusion problems. For example, there is no existing equipment that can remotely perform visual inspection, leak testing, cleanup, cutting, and welding within the torus. Also, there are many jobs to be performed outside of the torus, including high amperage connectors, joints for large ducts, coolant connections, and the handling/positioning of large components requiring further development. A

As described in Chapter I, Section 1.3.2, there are significant radiological hazards expected in the maintenance of D-T machines. All structural materials exposed to the high-energy neutrons will become activated. This includes the first wall, in-vessel components, ducts, and even corrosion products within closed-loop coolant systems. Radiation levels are estimated to be above 10^6 Rem/hr in some areas. DOE standards[(3)] and United States Nuclear Regulatory

(1) *"International Tokamak Reactor, Zero Phase," Chapter XV, Assembly and Remote Maintenance, Vienna (1980).*

(2) *Stacey, W. M., Jr., "The INTOR Workshop," 4th Topical Meeting on Technology of Controlled Nuclear Fusion, King of Prussia (1980).*

(3) *DOE Standards for Radiation Protection, DOE 5480.1.*

Commission Regulations establish exposure limits to radiation. Table 2.0-1 defines the exposure limits to personnel[1]. These limits govern the need for remote maintenance in restricted areas. Special conditions applying to these limits are found in the referenced document. With legal exposure limits of 1.25 Rem/person/quarter and the ALARA (as low as reasonably achievable) requirement, it is certain that substantial shielding and/or the use of remote maintenance techniques, will be required on fusion machines. Another concern is the damage to materials caused by high radiation levels. For example, elastomeric gasket materials are usable up to an accumulated dose in the range of 10^4 to 10^8 Rads.

Another hazard is the control of particulate contamination, which includes activated corrosion products in coolant lines, chips released during equipment disassembly, and dust/debris resulting from plasma excursions and erosion within the torus. These particles can have high individual radiation levels and, unless confined, will increase the amount of exposure to personnel and thus complicate working conditions. Tracking of particulates between work areas has proven to be a major problem in other nuclear facilities. A

Table 2.0-1 Allowable Personnel Radiation Dosage
Rem/Calendar Quarter

1.	Whole body; head and trunk, active blood-forming organs; lens of eyes; or gonads.	1-1/4
2.	Hands and forearms; feet and ankles.	18-3/4
3.	Skin of whole body.	7-1/2

(1) *"United States Nuclear Regulatory Commission Rules and Regulations," Title 10, Chapter I, Code of Federal/Regulations-Energy, Part 20, Standards for Protection Against Radiation.*

A challenging aspect of maintaining a D-T machine is working with the tritium-intensive environment. Tritium has the ability to penetrate virtually all materials that it comes in contact with either by bulk-diffusion, molecular infiltration, or adsorption. A significant effort is currently underway to develop methods to (1) remove tritium from components that have been exposed to the machine, and (2) reduce the amount of tritium in the reactor containment building. It appears likely, however, that repair personnel within the reactor building, and perhaps other areas, must wear special (oxygen-supplied) protective clothing. A

There are three basic options that can be used for the maintenance of radioactive equipment. These include:

- Contact Maintenance. Personnel are required to enter the work area and make repairs by contact means using conventional hand tools. Work performed by personnel wearing protective clothing (with breathing air attachments) is classified as contact maintenance. A
- Semi-Remote Maintenance. This procedure is similar to the contact approach in that personnel must enter the work area; however, special equipment is used to reduce the radiation exposure. Equipment classified as semi-remote includes portable shielding, long-handled tools, and automatic devices for machining and welding. These automatic devices are installed and removed by contact means, but are operated remotely once they are installed. A
- Remote Maintenance. Personnel do not enter the radioactive work area. Maintenance is performed with remotely controlled cranes and manipulators while viewing through shielded windows, television, or periscopes. Both general purpose and special purpose automatic machines are also included. A

In designing a nuclear facility, one of the most difficult tasks is establishing a balance between contact, semi-remote, and remote maintenance techniques. Design and procurement costs for contact-maintained equipment are usually less than that of remote equipment. This advantage provides a strong incentive to maximize the amount of equipment that is placed into the contact category. However, experience in the fission industry has shown that this can be a trap which leads to severe operational and maintenance problems when radiation levels in equipment reach a point whereby remote techniques must be retrofitted into the plant. This problem can be minimized by applying more engineering effort into the original plant design. Also, the use of mockups to simulate maintenance operations is valuable in alleviating the retrofit problem, particularly when remote maintenance is required because of high radiation levels. In actual practice, a nuclear facility must apply a combination of these three options. A

The most commonly proposed maintenance concept for D-T machines is a combination of contact and remote. Components that will become radioactive are enclosed in a shielding structure to permit personnel entry for inspections and repairs within the reactor building. Personnel can also assist in the removal and replacement of highly radioactive components by performing tasks such as disconnecting coolant and electrical lines, unbolting flanges, cutting ducts, welding, and leak-testing. The actual removal and replacement of torus sectors would, of course, be performed remotely with no occupancy within the reactor building. A

Another combination provides the capability to conduct all maintenance remotely in the event of circumstances that require a fully remote operation such as radiation streaming or unplanned excessive increases in radioactivity in coolant lines. However, contact maintenance is normally planned outside of the biological shield but within the reactor room.

Several examples of fusion reactor concepts are presented in this section. These illustrate combinations of the basic options that are proposed.

2.2.1 Fusion Engineering Device[1] — This machine is being designed at the Oak Ridge National Laboratory (ORNL). The 1982 reference FED configuration is shown in Fig. 2.2-1. According to the designers, maintenance was a major consideration in developing the configuration. Key elements included are as follows:

- Modularity was applied where possible to all components that were expected to require replacement or frequent maintenance work.
- Accessibility was a central consideration of the overall configuration and has strongly influenced the design of the TF coils (size and number) and the torus.
- Hands-on capability was considered a practical necessity for all components external to the reactor shield and was adopted as a design requirement. It is expected that personnel will be able to enter the reactor building approximately 24 hrs. after shutdown. This requirement has strongly influenced the design of the reactor shield.
- Lifetime estimates for components were based on two categories--those expected to last the lifetime of the plant without replacement (TF coils), and those that will require replacement during the plant lifetime. A
- Maintenance ground rules included the following:
  - --Work is performed on the basis of three shifts per day, seven days per week;
  - --Spares are available for failed components;
  - --Radiation levels will be 2.5 mRem/hr outside of the reactor shield 24 hrs. after shutdown (8 tesla operation);
  - --Magnetic coils are discharged during shutdown;
  - --Superconducting coils and structure are maintained at liquid helium temperatures unless the cryostat must be opened; and
  - --A bakeout period of 24 hrs. is required before the vacuum vessel is opened to air and 168 hrs. after being closed.

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[1] *Steiner, D. and C. Flanagan, "Overview of the Fusion Engineering Device Design," 9th Symposium of Engineering Problems of Fusion Research (1981).*

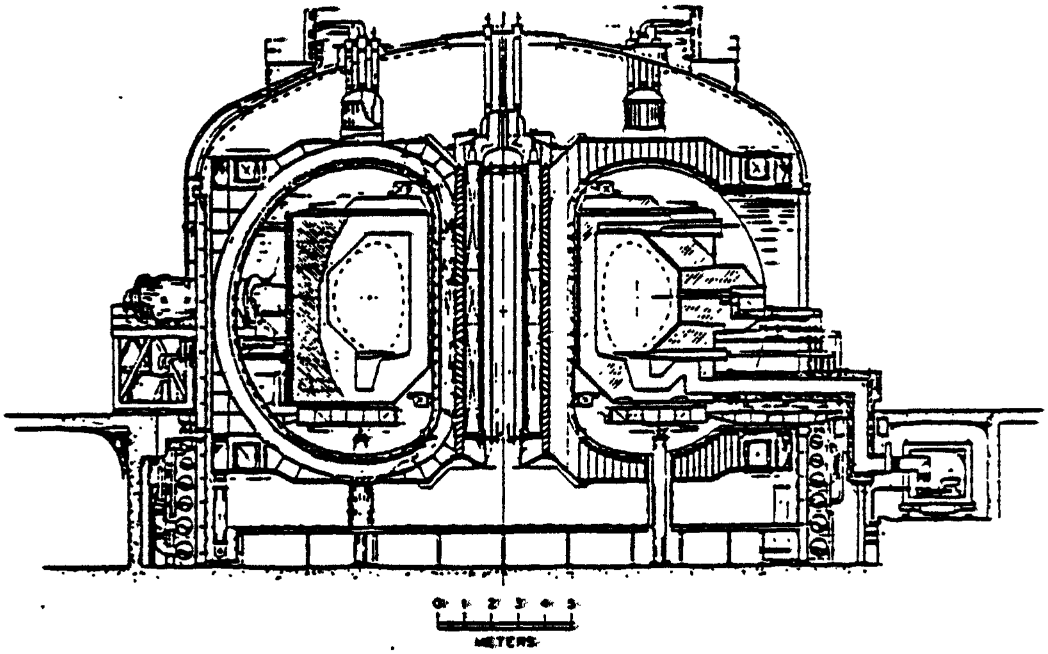

Fig. 2.2-1. FED Reference Design.

- Sector replacement may be performed by a combination of contact and remote operations as follows:[2] A

  --Disassembly of the structural attachments, cutting of the vacuum flange, uncoupling coolant and electrical connections, removing pipe assemblies, and installing the sector handling device are performed by contact.

  --Removal of the sector, inspection, cleaning, minor repairs to the open torus, and installation of a new sector are performed remotely.

  --Welding the reactor seal; weld inspection; and replacement of pipes, electrical, and structural components may be performed by contact.

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(2) *Spampinato, P. T., "Remote Maintenance Equipment for the Fusion Engineering Device," 30th Conference on Remote Systems Technology (1982).*

2.2.2 STARFIRE Plant(3) — This concept was developed by the Argonne National Laboratory (ANL) in 1980 for a commercial fusion power plant which included all service areas (e.g., hot cells for the refurbishment or disposal of radioactive components). Only the equipment containing significant radioactive contamination, such as the steam generators, primary heat transport components, and the atmospheric tritium cleanup system, was located within the reactor building. All equipment was designed in a modular fashion with emphasis placed on in-situ replacement of failed modules.

According to ANL, equipment located in the reactor building is to be maintained by total remote means using the crane and manipulation equipment shown in Fig. 2.2-2. The remote approach was selected because: A

- the total exposure to repair personnel would be significantly reduced;
- failed modules could be replaced more quickly;
- remote capability is needed for accident recovery;
- shielding can be minimized;
- decommissioning is simplified, and
- repairs can be started immediately after reactor shutdown.

Two levels of shielding were provided on the machine. An inboard shield protects the components of the superconducting TF coils from radiation exposure, and an outboard shield provides radiation protection to other equipment in the reactor building. The outboard shield also has a stated purpose of reducing the biological dose rate outside of the shield to about 1 mRem/hr 24 hrs. after reactor shutdown for contact maintenance. In this respect, the STARFIRE and FED are similar, since each apply the maintenance approach of remote with provision for contact.

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(3) *"STARFIRE – A Commercial Tokamak Fusion Power Plant Study," ANL/FPP-80-1 (1980).* A

PRELIMINARY

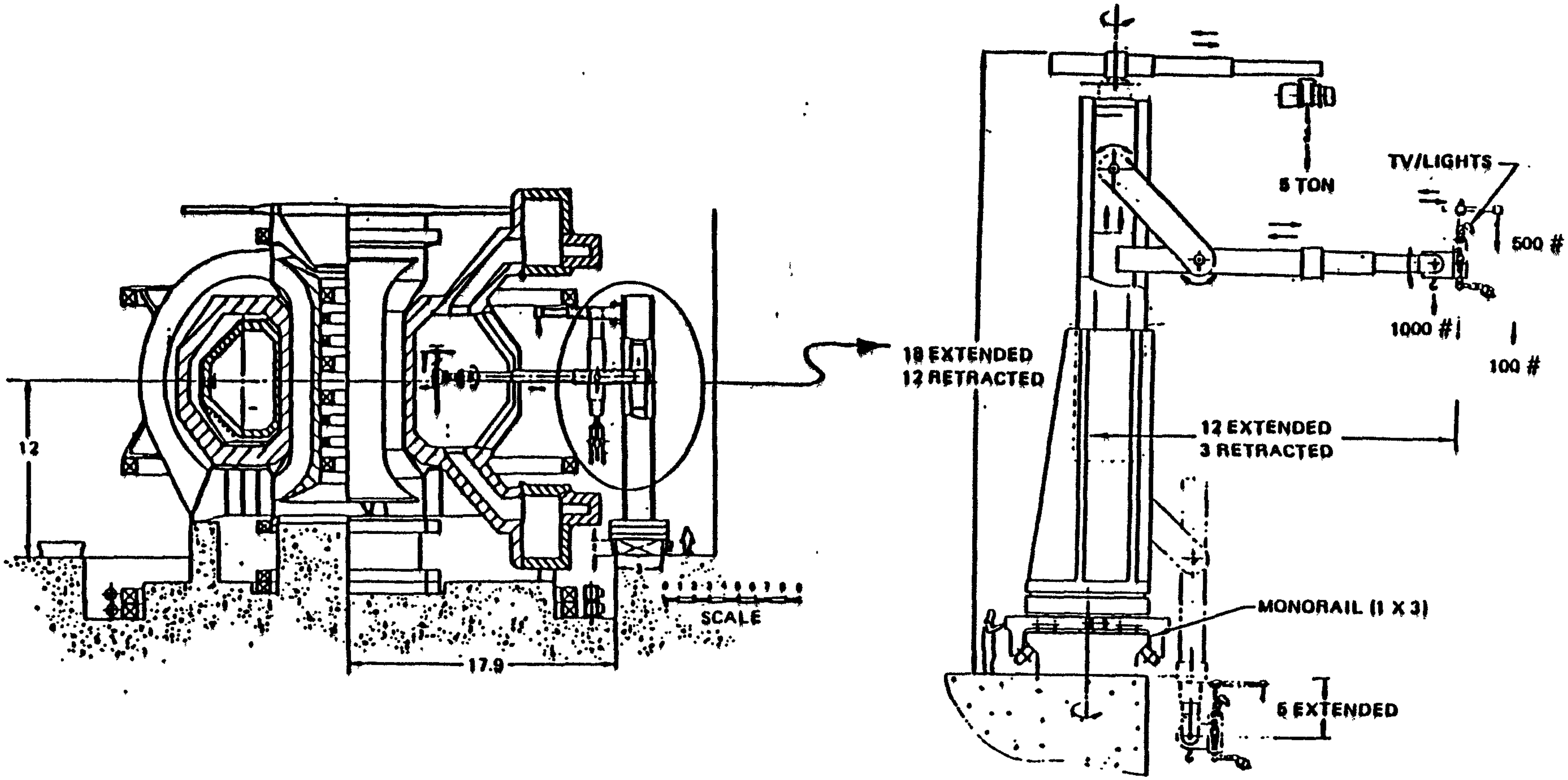

Fig. 2.2-2. STARFIRE With Maintenance Vehicle.

PRELIMINARY

2.2.3 International Tokamak Reactor (INTOR) — The International Atomic Energy Agency (IAEA)-sponsored workshops resulted in the conceptual design of a reactor that used the contact approach with provisions for remote maintenance.[4] A

[4] *Reference 2.0-1, See Page 2.0-1.* A

2.2.4 Tokamak Fusion Test Reactor (TFTR) - Consideration is being given to upgrading the TFTR for D-T operation by the Princeton Plasma Physics Laboratory. This upgraded reactor will apply an "igloo"-type shielding around the torus and removable shielding around peripheral ducting and equipment as shown in Fig. 2.2-3. There will be only a limited amount of contact work that can be done with the shield in place. Hence, many operations must then be performed remotely. A

PRELIMINARY

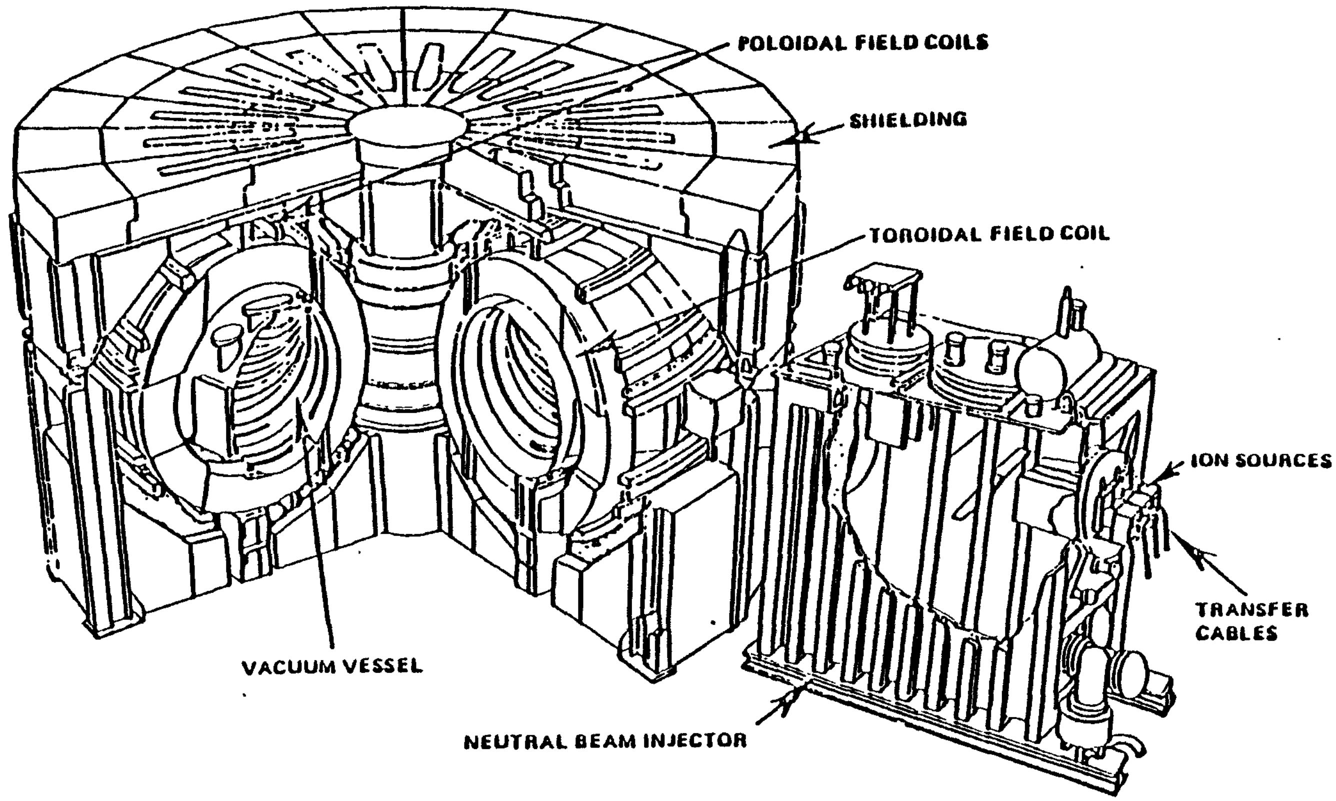

Fig. 2.2-3. TFTR.

PRELIMINARY

2.2.5 <u>Joint European Tokamak (JET)</u>[(5),(6)] — The JET machine is being constructed at Culham, England, and is planned for D-T operation. It has been designed for remote maintenance within the reactor building because contact operations required heavy shielding around the torus. The numerous penetrations through the shielding were considered to pose practically insurmountable radiation streaming problems. The major concern was that the massive shielding structures would prevent access to areas where remote operations had to be performed. A

General purpose manipulators (Fig. 2.2-4) were selected for JET because of the variety and unpredictability of the maintenance tasks. In addition, standard, commercially available components--designed for easy replacement--are favored over specially designed ones. The program at JET includes the development and testing of remote techniques and equipment that will be used for replacing (1) turbopumps, (2) neutral injector sources, (3) armour plates within the torus, and (4) water-cooled limiter panels.

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(5) *Raimondi, T., "Remote Handling in the Joint European Torus Fusion Experiment," 24th Conference on Remote Systems Technology (1976).*

(6) *Raimondi, T., "Remote Operations in JET, Problems and Solutions," First European Symposium, Remote Operations in Fusion Devices, Milan (1982).*

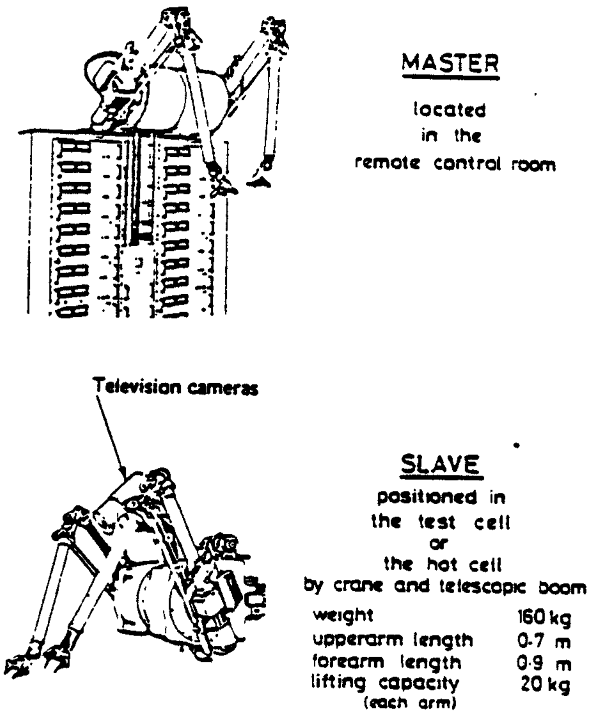

Fig. 2.2-4. Servomanipulator at JET.

2.2.6 Swimming Pool Test Reactor (SPTR)[7]— The SPTR concept was developed by Japan Atomic Energy Research Institute (JAERI) (Fig. 2.2-5) and is analogous to the design of existing fission water reactors. The water serves a number of purposes, for example, neutron absorption to minimize activation of equipment, radiation protection for susceptible components (such as magnets), and collection of tritium. In addition, the water serves as a biological shield that allows personnel to perform inspections and make repairs underwater with long-handled tools. Replacement of vacuum boundary components would, however, require lowering the water level and using remote equipment similar to that planned for the JET facility. JAERI has developed the concept in considerable detail, including the design of automatic machines to remotely cut and reweld sectors of the torus. A

(7) *Sako, K., et. al., "Next Tokamak Design (Swimming Pool Type)," 3rd Technical Committee and Workshop on Fusion Reactor Design and Technology (1981).* A

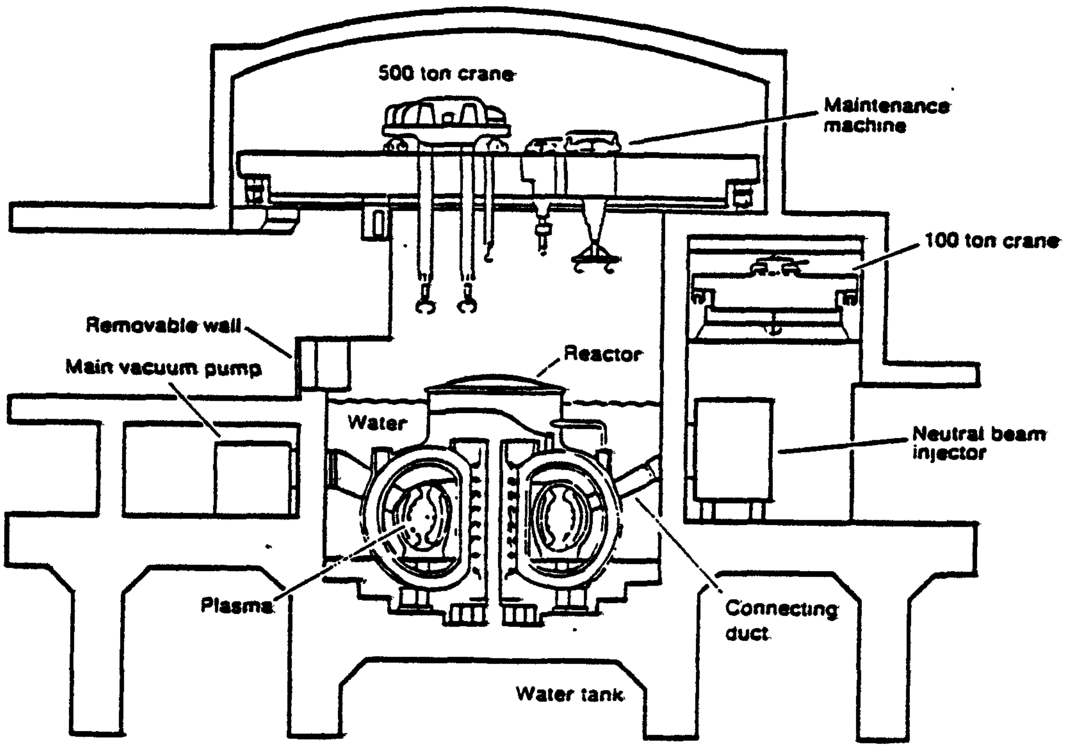

Fig. 2.2-5. SPTR Reference Design.

The development of remote handling techniques[1] for the nuclear industry began almost 40 years ago with the inception of the first nuclear reactor. The objective then, and still is, reduced radiation exposure of operating personnel. Contributions toward this effort over the years are numerous. These include the provision of facilities and equipment to:

- remove, store, and ship spent fuel assemblies from nuclear reactors;
- perform detailed examinations on radioactive fuel and materials;
- reprocess spent reactor fuel;
- consolidate, solidify, and package high-level waste;
- contain radioactive contaminants; and
- decontaminate and repair radioactively contaminated equipment.

Most of the remote systems development to-date has been associated with hot-cell type facilities. These are large shielded enclosures in which highly radioactive fuels and materials are examined, machined, dissolved, and packaged using specially designed equipment. General purpose equipment is used to support the in-cell operations and to perform remote maintenance on in-cell equipment. General purpose equipment includes remote cranes, manipulators, shielding windows, periscopes, lighting, ventilation, filtration, and transfer ports. A

Each hot-cell facility is uniquely designed based on the requirements of the operation to be performed. However, there is a commonality among the facilities in the use of commercially available general purpose remote systems.

The technology for designing hot-cell facilities in which equipment (up to about 5 m high) can be remotely operated and maintained is firmly established. This includes the technology for designing in-cell equipment to (1) withstand high radiation exposure and (2) be remotely maintained using currently available manipulator and viewing systems. Some of the more recent hot-cell facilities

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(1) *White, J. R., "Remote Systems in the Nuclear Industry," 29th Conference on Remote Systems Technology (1981).*

are operated and maintained totally by remote means such that entry into cells is not required during the facility lifetime. Filtration and containment equipment for the positive confinement of radioactive particulate is commercially available. A

There are usually no exposure problems associated with doing remote work inside the cells. The problems are encountered in occupied areas outside of the cells such as:

- Cell atmosphere equipment (includes blowers, coolers, purifiers, filters, valves, ducts, etc.) which is usually located outside of the cell to permit contact maintenance.
- Since the atmospheric system maintains the cell at a negative pressure, the out-of-cell equipment can become radioactive over a period of time.
- Contamination may be released to occupied areas when material or equipment is transferred into or out of the cells.
- Equipment used within the hot cells is usually removed remotely for repair by contact means. This includes the specialized process equipment as well as manipulators and cranes. Wet or dry decontamination methods are applied to reduce the radiation level of this equipment.

The fission plants that are most comparable to a fusion reactor (i.e., from a maintenance viewpoint) are those used to reprocess spent nuclear fuel. There is a large quantity of complex process equipment in these plants--some of which are 14 m high and weigh 35 t. The radiation levels range up to 10^8 Rem/hr, and large quantities of radioactive fission gases must be contained. The tanks, vessels, and columns are interconnected by thousands of pipes ranging in diameter from 12 mm to 450 mm. Numerous valves, thermocouples, and diagnostic instruments are used to control the process operations. The operating goals at these plants are very similar to fusion and include reducing the exposure of plant personnel and achieving high plant availabilities. A

A review of the maintenance philosophies and experiences in U.S. reprocessing plants[2] was recently completed which concluded that there has been a difference of opinion between proponents of contact and remote maintenance approaches for many years. Four basic approaches have been applied in these plants.

Both the Hanford Crane Canyon (Fig. 2.3-1) and Idaho Chemical Processing Plant (ICPP) (Fig. 2.3-2) concepts were developed in the 1940's before general-purpose remote manipulation equipment existed. The Hanford Canyon approach places the process equipment in remotely replaceable racks using an overhead bridge crane and an impact wrench. ICPP, however, places process equipment into small contact-maintained, shielded cells that require decontamination prior to personnel entry. The third approach was developed in 1956 for the Experimental Breeder Reactor II Fuel Cycle Facility (FCF) in Idaho (Fig. 2.3-3). The design of the FCF was based on the use of remote manipulators, cranes, and shielding windows (all of which became commercially available in the early 1950's). The fourth approach--developed during the conceptual design of a breeder fuel reprocessing plant called the Hot Experimental Facility (HEF)--uses electric master-slave manipulators (Fig. 2.3-4). The manipulators became commercially available in the early 1970's and are currently used for remote maintenance in several accelerator facilities.[3] A

The remote maintenance approach has been used in those process plants having the most successful operation. For example, the Savannah River Plant

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(2) *White, J. R. and H. W. Harvey, "The Evolution of Maintenance in Nuclear Processing Facilities," 30th Conference on Remote Systems Technology (1982).*

(3) *Feldman, M. and White, J. R., "Remotex - A New Concept for Efficient Remote Operations and Maintenance in Nuclear Fuel Reprocessing," 28th Conference on Remote Systems Technology (1980).*

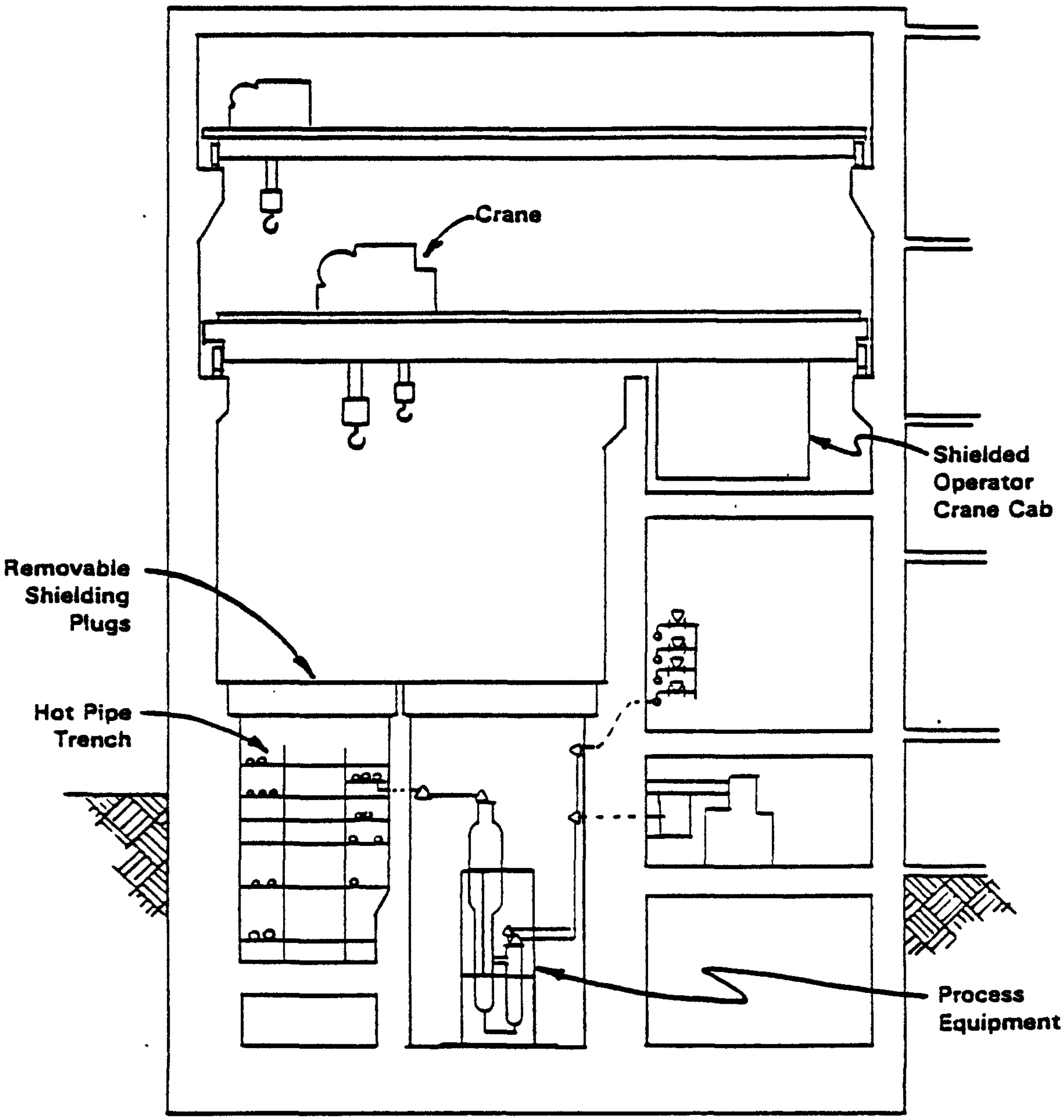

Fig. 2.3-1. Manned-Crane Canyon, Hanford (1943).

A

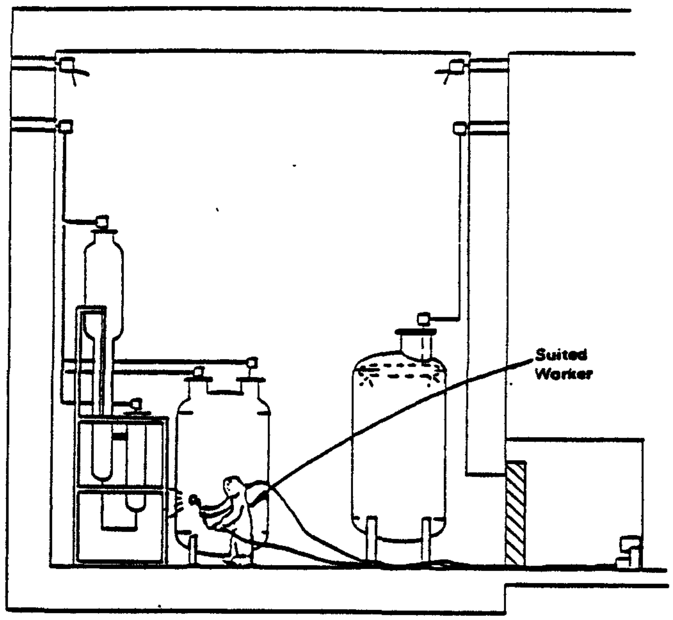

Fig. 2.3-2. Contact Cells, ICPP (1947). | A

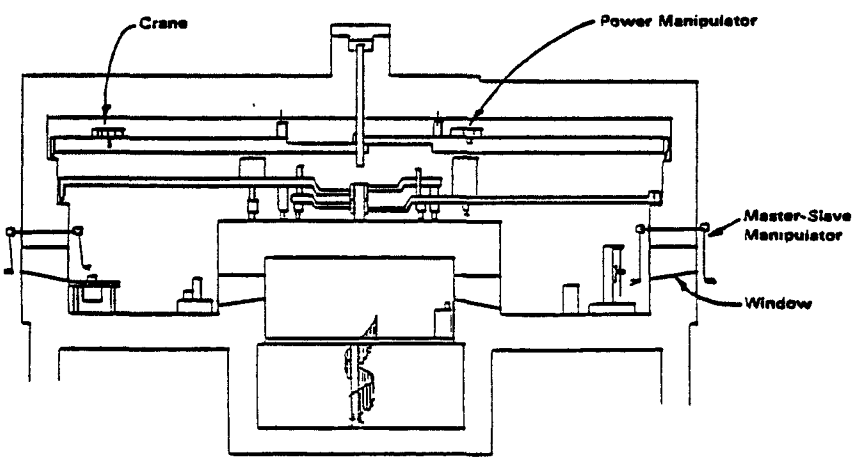

Fig. 2.3-3. Remote Cell With Windows, EBR-II (1956). | A

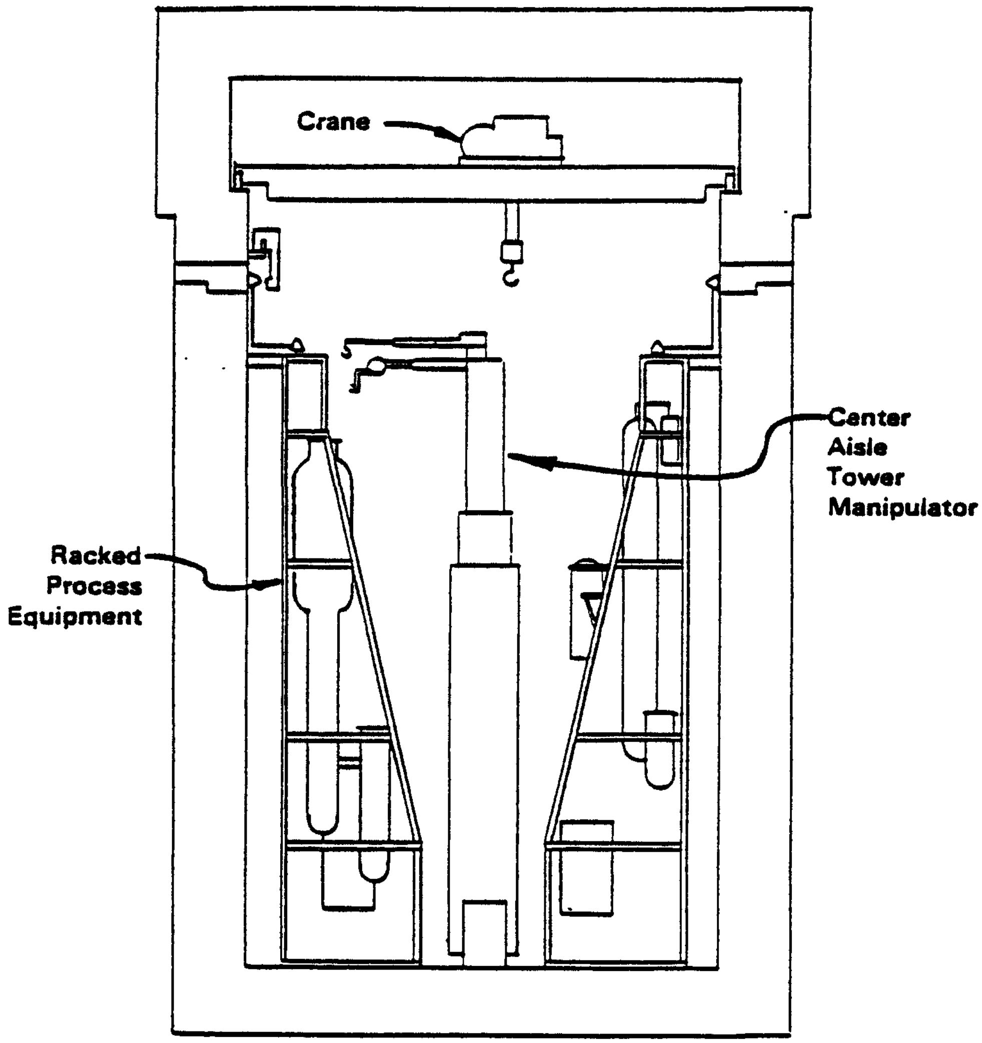

Fig. 2.3-4. Remote Cell With Center Aisle Manipulator, ORNL (1978). A

operated for 30 years with 80% availability, the Purex Plant operated for 16 years with 90% availability, and the FCF operated for 6 years with 90% availability. The least successful operation was the commercial Nuclear Fuel Services Plant (NFS), which used a combination of maintenance approaches. The NFS plant is of particular interest because its basic design has been used in other reprocessing plants around the world. It operated for 6 years with an availability of 70% the first year and less than 25% during the last 2 years. Total radiation exposure during each of the last two years exceeded 2000 man-rems, half of which has been attributed to contact repair of the remote cranes and manipulators.

Important lessons learned as a result of process plant operations are:

- There is no such thing as "maintenance-free" equipment. (Experiences at the ICPP, NFS, and some non-U.S. plants have proven this.) A
- The chances for achieving high plant availabilities and low radiation exposure to plant personnel are greater with the remote maintenance approach than with contact-maintenance.

Similar experiences have been encountered in the maintenance of water reactors. With the exception of tasks involving irradiated fuel or in-core components, the philosophy in these plants has been primarily contact-maintenance. Operators are being confronted with a variety of concerns as plants become older: (1) Equipment components, such as valves and heat exchangers, are failing at more frequent rates than originally expected. (2) The radiation levels in pipes, valves, and vessels are increasing to higher levels than originally expected. (3) Provisions made in the initial design for confinement of radioactive fission gases and particulate contamination have proven inadequate. Hence, repair personnel must wear protective suits with air-supplied hoods, and it is estimated that these suits increase the time required to do work task by factors of at least 5. Actual experience at HFEF indicates that unless temperatures are controlled within the work area, heat prostration and dehydration because of

perspiration will reduce the effective operating time to less than 8 hours per 24-hour shift. In addition, there are concerns regarding the ability to recover from unplanned failures such as occurred at the Three Mile Island reactor. A
Numerous studies are now in progress to evaluate the use of robotics and remotely-operated inspection and repair equipment to alleviate these concerns.

There are many important aspects of fission maintenance technology, including the problems identified in the previous section, which can be of value to fusion designers. For example, experience has certainly shown that radioactive equipment can be maintained by remote means, and that an over-reliance on contact techniques will result in increased exposure to personnel and plant downtime. Fusion designers evaluating these specific experiences can establish worthwhile guidelines that will reduce the uncertainties of using the contact approach.

Another area where fission technology can be directly applied to fusion is the design of equipment to be used in high radiation fields. Included are the selection of materials for radiation resistance, incorporating sensitive components into replaceable modules, and the design features needed to make the modules easily replaceable (captive screws, guides, lifting handles, manipulator access, etc.). Other areas include the design of equipment for ease of decontamination, techniques for performing the decontamination, and methods of confining gaseous and particulate contamination. These are described more completely in Chapters III and IV. A

There is an extensive base of experience with general purpose remote manipulators and viewing devices in the fission plants as described in Chapter VIII. Some of these are commercially available and others have been designed for a specific facility. Many can be directly used in performing fusion maintenance outside of the torus. Perhaps the most important point is that fusion designers must become familiar with the capabilities and limitations of the existing manipulators. This knowledge must then be factored into the arrangement and configuration of the fusion machines and peripheral equipment, especially in providing access for manipulative equipment.

A large number of special purpose equipment and components have been developed in fission plants. This includes equipment for remote cutting and welding, machining, measurements (dimensions, force, temperature), and torquing screws. There have also been developments in components such as piping and electrical connectors (Chapter VI). Many of these developments are unique to one plant and are not available commercially because of limited demand, but should be evaluated for use on fusion machines. A

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Chapter: Maintenance Approaches Section: Key Issues for Fusion Maintenance	Chapter: II Section: 2.5

The fusion designer must judge which concept should be used. That is, whether the total remote unshielded machine (JET), or a contact maintenance with provision for remote shielded machine (FED, INTOR, etc.), or a remote shielded machine with provision for contact maintenance (STARFIRE) should be used. For remote replacement of activated components, the JET concept is better because it provides greater access for manipulation and viewing. However, it is argued that most maintenance work will be required on peripheral components. Shielding around the torus will permit direct entry into the reactor building. Therefore, these repairs can be done more quickly.

If properly implemented, the "contact with provision for remote" approach may be successful. However, the uncertainties of estimating equipment failure rates, material activation, radiation streaming, activated corrosion products in coolant lines, and the tritium environment must be considered. Experience in fission plants has shown that radioactive "hot spots" cannot be effectively predicted and will severely prolong or prevent contact maintenance.

The following key issues will influence the maintenance approach selected. A

- Methods of Applying Remote Techniques - Equipment to be used for the remote replacement of radioactive components varies among the fusion plant concepts. Early approaches used large capacity manipulator vehicles with a shielded cab for the operator. Justification was based on achieving direct viewing of the work area as opposed to using television. This approach was applied to some fission plants from 1945 to 1960 when there was no other option. However, a fusion plant that is to be operated after the year 2000 should apply more advanced and less costly technology such as television viewing with the operators located in non-hazardous areas.

  Computerized maintenance is advocated in some fusion concepts. This involves the use of machines that are dedicated to perform specific tasks such as the replacement of a blanket module or torus sector with general purpose manipulators used as a backup. Other concepts suggest using general purpose manipulators to remotely operate dedicated machines that can handle and position heavy loads and do precision tasks such as welding and cutting.

- Machine and Facility Arrangement — Efficient maintenance can only be performed if the fusion machine, the maintenance equipment, and the maintenance areas are properly arranged. This is true for both contact and remote maintenance work. For example, removal of a sector or any component which opens a large hole into the torus must be performed remotely, and the task must be completed quickly. Since operating personnel will not be allowed into the reactor building during this time (i.e., in the contact with provision for remote approach), the location of replacement parts, shield plugs, and the transfer path for removing the failed unit become important. An optimized arrangement of cranes, manipulators, viewing, lighting, special fixtures, and set-down areas that can meet the requirements for all maintenance tasks is also very important.

- Contamination Control — Contamination control includes the detection, confinement, and cleanup of radioactive particulate and gaseous contamination. Most fission plants apply a multiple zone control technique in which air flows toward the more contaminated zone. This would require the interior of the fusion machine building and the hot cells to be at a negative pressure relative to surrounding areas. A major problem during performance of contact maintenance is that the removal of ducts, torus sections, or coolant lines may disperse particulate within the reactor building. If the specific activity of the particulate is high, it will be necessary to use remote decontamination techniques. Fusion machine configurations are very complex, therefore, it is doubtful that decontamination will be successful, and it may be impossible to decontaminate the facility. A

- In-Vessel Maintenance — Maintenance of items located inside a tokamak provides the designer/operator with many challenging problems. Maintenance activities can be divided into three main areas: problem identification, repair, and requalification. Inspection of the torus interior while the machine is still under a vacuum is extremely important. It will allow the operator to determine in advance when the machine should be shut down for repair. In addition, early inspection of problems will allow the maintenance department to start planning a repair task much earlier than if they had to wait until the torus was entered. This capability has a significant effect on downtime duration. The early development of reliable, in-vessel inspection devices is a major key to obtaining high machine availability. This capability also has application in the requalification of the machine following repair.

  The TFTR and JET machines require that a new manipulator and transporter system be developed to replace in-vessel components. Other machine concepts have taken the approach that in-vessel manipulators should be avoided and have designed in-vessel components that can be removed from outside of the torus. This approach causes significant complication in the shield design and in providing access space for the components. Studies and testing should be conducted to determine the feasibility of making remote repairs inside the torus because of the impact it will have on the overall machine and peripheral equipment arrangement in the reactor building. A

- Replacement of Large Components — Considerable effort has been applied by fusion designers to develop concepts for replacing torus sections, vacuum ducts, and fuel injectors, etc. Some appear to be potential solutions; however, none have been fully developed and demonstrated. Some of the problems are precision positioning, contamination control, seals, leak detection and location, method of transport, and connectors. The making and breaking of many welded joints is not conducive to high availability.

- Refurbishment and Disposal — Studies have indicated that large quantities of activated materials from fusion machines will have to be packaged and stored in waste repositories. However, equipment to remotely cut-up and consolidate large structural components must be developed since this type of operation has not been used in the fission industry. It may be possible that cut-up combined with a melting furnace would be an effective volume solution. Refurbishment of machine components to reduce the waste produced is another area that needs to be investigated. A

Close coordination must be established between all parties involved in the design of a fusion machine to achieve an optimized balance between function, cost, and maintainability. This section contains suggested guidelines for achieving this balance based on experiences derived from the design of fission plants. Fig. 2.6-1 describes the sequence of events. A

The first step is usually taken by the designers of the fusion machine and the support systems to size and arrange major equipment components for proper function. This effort should specify interface requirements for locating equipment components relative to each other, but only minimal consideration to the overall building configuration.

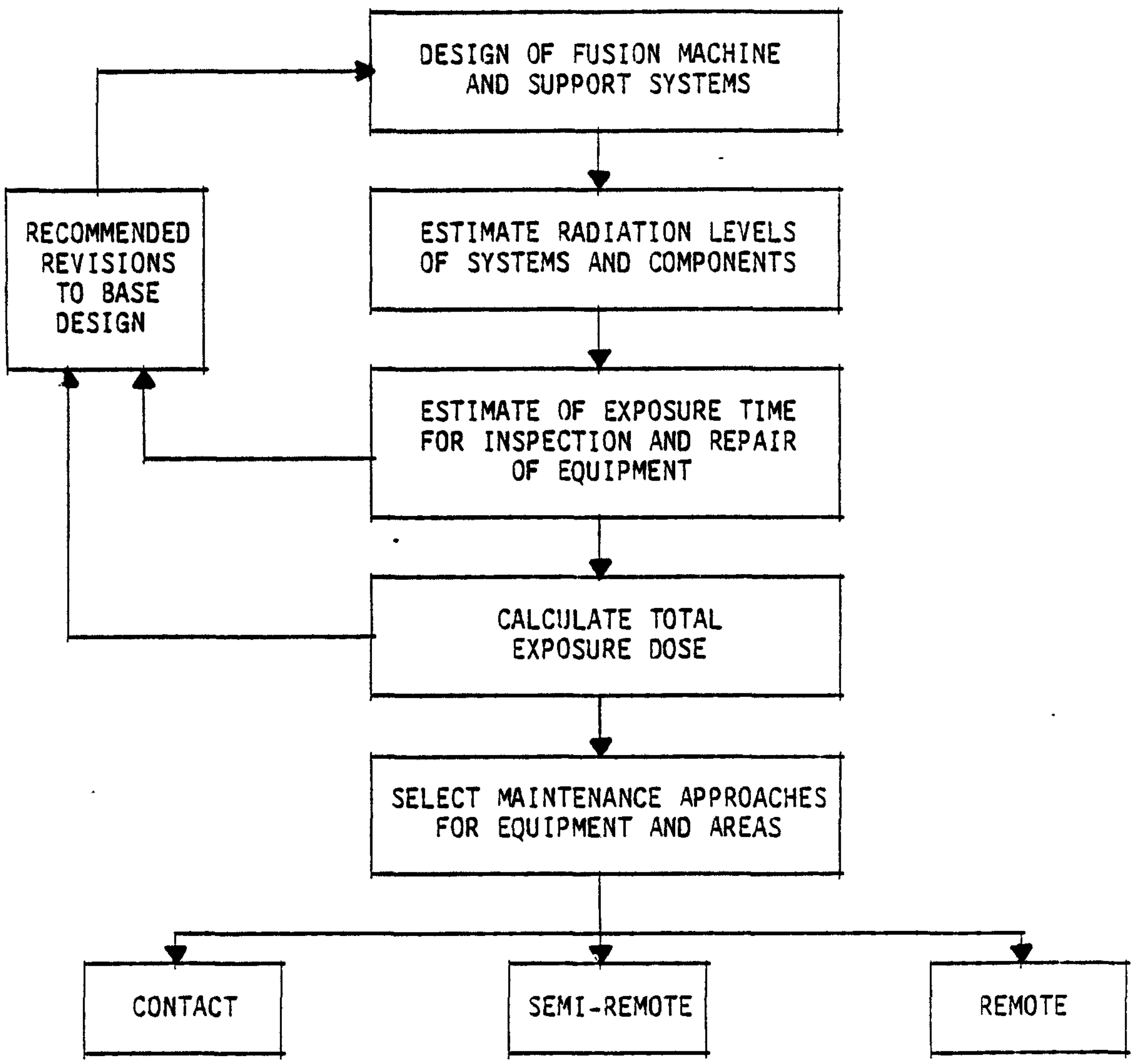

Fig. 2.6-1. Sequence of Events for Selecting a Maintenance Approach.

2.6.1 Estimating Radiation Levels — It is imperative that an estimate be made of the radiation levels to which people will be exposed when maintaining each plant system, subsystem, and equipment component. Other radiological hazards, such as the presence of radioactive gases or particulate that can be spread, must also be identified in the plant work areas. These hazards have the impact of significantly increasing the time that it takes to do work.

- Radiation levels of the equipment being repaired should be estimated based on a number of years of operation. Other factors that must be considered are the radiation decay that will occur between reactor shutdown and entry for maintenance, possible upset conditions which cause unexpected contamination within equipment, and the effect of built-in decontamination systems (if provided).

  The unexpected cases should be reviewed carefully since this has caused severe problems in other nuclear facilities. For example, filters are used to keep exhaust ducts clean. However, during filter replacement some contamination does escape, and over a period of years, the radiation levels will build up in the ducts. Similarly, coolant systems develop radioactive crud which tends to collect in valves, flow regulators, pumps, etc., and builds up to high radioactive levels over a period of years. It is also important to note that radiation levels in the range of 10 mRem/hr should not be ignored if the plant is to be maintained under ALARA exposure conditions. A

- Radiation levels from other equipment in the vicinity of the work area must also be evaluated to determine the total expected exposure. This is currently one of the problems being encountered in water reactor maintenance. Some of these plants have placed high maintenance secondary coolant system components (valves) in the vicinity of primary coolant system equipment. The secondary is clean but the primary system has radiation levels which exceed 1 Rem/hr. This same situation could easily occur in a fusion plant. A

The best technique for making this evaluation is to prepare a radiation map of the plant. This can be done by superimposing the estimated radiation levels from each item onto equipment placement drawings of the plant. The designer can then identify specific components requiring maintenance and make more accurate exposure estimates for each work task.

- Radioactive gases (such as tritium) in the atmosphere of the work area must be considered since personnel wearing air supplied suits cannot work efficiently. Estimates at some fission power plants is that people in these suits can only do effective work 3 hours or less out of an 8 hour shift.(1) Other plants simply state that the work output of suited personnel is 3 to 5 times less than unsuited personnel. Based upon these factors, it is highly desirable that clean equipment requiring maintenance be kept out of areas where radioactive gases may be encountered. A

  A controlled ventilation zoning system should be established in the fusion plant. Some areas will be clean, some suspect and others will always require personnel to wear air supplied suits. It should be noted that techniques such as plastic bagging when opening a system that contains radioactive gases, will be helpful but are not positive solutions. Personnel will still be required to have breathing equipment on or located in the immediate work area during these operations.

- Particulate contamination that can be spread to other areas within the facility will also decrease the efficiency of contact work. It is expected that radioactive ash and debris will exist within the vacuum vessel (from plasma excursions) and in the liquid coolant systems.

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(1) *"Limiting Factor Analysis of High Availability Nuclear Plants," EPRI Report NP 1136, Vol. 1 (1979).* A

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2.6.2 Estimate of Exposure Time — The other part of the maintenance problem is determining the time that personnel must spend in radiation areas. An evaluation should be made to identify the number of visits that personnel will make into radiation areas and the residence time required for each visit. This, of course, involves a failure frequency and time to repair analysis as described in Chapter XIII. The wearing of air supplied suits should be factored into the time estimates. Included should be:

- Inspection of equipment to read gauges, change valve settings, listen for unusual noise, etc.
- Preventative maintenance operations such as lubrication of bearings, tightening bolts, cleaning, etc.
- Equipment repair which includes failure diagnosis visits and the time required to remove a failed component, clean the work area, install a new component, and requalify the system.

2.6.3 Calculate Total Exposure Dose — The information obtained in Sections 2.6.1 and 2.6.2 should be combined to obtain an estimate of the total radiation dose projected for equipment maintenance in all areas of the plant. The output of these calculations should be superimposed onto facility equipment placement drawings. Information will be gained on high exposure areas and also on work areas where the density of maintenance personnel during plant shutdown is too high. If this is done early enough in the plant design, it may be possible to relocate and/or modify some equipment to maximize the maintenance tasks that can be performed by contact means and still meet the ALARA objectives. Suggestions for improving the ability to do contact work, based on experience at fission power plants, are as follows: A

- Maintain tight (leak-free) containment on contaminated systems.
- Minimize crud traps in radioactive liquid systems.
- Use auxiliary ventilating systems for local control of airborne contamination.
- Provide as much distance as practicable between the serviceable components and other radioactive sources in the area.
- Relocate components requiring frequent maintenance to low radiation areas.
- Locate readout equipment and controls in low radiation areas.
- Separate filter banks and components to reduce exposure from adjacent banks and components.
- Provide shields - either permanent or temporary - between the sources and the workers. Note: this measure must be applied with caution, taking care not to place shields so as to hamper productivity, thereby increasing the exposure time.
- Reduce streaming or scattering of radiation by the use of labyrinth passages and shadow shields over penetrations.
- Use shielded pipe chases.
- Provide ready access to equipment requiring maintenance by the use of permanently installed ladders, catwalks, and platforms.
- Provide large laydown areas.
- Provide a favorable working environment to increase work efficiency.

- Provide spare connections on tanks and components in high radiation areas to allow flexibility in operations. Exposure to personnel can be avoided if such connections are provided initially rather than subsequent modification in the presence of radiation.
- Install a central built-in radiation monitoring system to eliminate the exposure received during survey monitoring of the work area.
- Provide radiation-resistant materials to reduce replacement frequency.
- Place long-life lamps in high radiation areas.
- Place low-maintenance equipment in high radiation areas.
- Provide quick disconnects in lines that have to be made and broken frequently.
- Provide long-handled tools to increase worker distance from low level radioactive components either being maintained or in the vicinity of components requiring maintenance. A

2.6.4 Remote Maintenance Guidelines - The primary approach to equipment maintenance in a remotely maintained facility should be to repair the equipment in-situ, if at all possible. If in-situ repair is not practical, equipment must be modularized in such a manner that a minimum amount of handling operations are required for its replacement with new or repaired components. Overall guidelines for the design of remotely maintained systems are provided in Chapter III and IV of this guide. Additional considerations for equipment designed for remote maintenance include:

- Almost all remotely maintainable equipment must be of special construction. Items which do not lend themselves to remote handling operations must be modularized such that the item is removed with some other component.
- Normally a failed part should be replaced with a spare part. The failed part is then repaired, if time permits, or disposed of. The repaired parts can be returned to the spare parts inventory. For contaminated parts, decontamination will be required to reduce storage costs and allow for contact operations during repair when possible. A
- Manipulator dexterity lacks the speed, degrees of freedom and ability to operate within confined spaces available with manual operations.
- Manipulators can have difficulty reaching under, over, and around equipment items if these items are not properly designed.
- Powered manipulators are basically articulated cranes which can pick up, reorient and place equipment items either vertically or horizontally at any point within their reach. Their lift capability varies with distance from their support.
- Viewing and sound sensory systems frequently limit the operators ability to direct the remote maintenance equipment as well as is possible with contact maintenance equipment.
- It usually takes much longer to perform tasks with remotely operated equipment. The time required to perform operations is decreased many fold if special design practices are followed.

- Recovery from the failure of remote handling equipment must be analyzed and equipment supplied to maintain the equipment as required.

2.6.5 Selection of Maintenance Approaches - The output of Section 2.6.3 should provide enough information to place the equipment and building areas where maintenance will be performed into three categories:

- o Tasks that can be performed by contact means,
- o Tasks that must be performed by remote means,
- o Uncertain tasks where contact appears feasible but could become an exposure problem at a later date.

It is the uncertain category that causes most problems in a nuclear plant. There are two possible solutions. One is to place the equipment in a contact area with the provisions for installing supplemental shielding and applying semi-remote techniques, if necessary. The other is to initially place the equipment into a remotely-maintained area. Each task should be carefully evaluated to determine the most practical and effective solution. The cost and operations analysis evaluation techniques described in Chapter XIII are useful in conducting these evaluations and in selecting the overall maintenance approach. A

Once the determination is made as to which building areas must be maintained remotely, the next step will be selecting the remote maintenance systems and arrangement of equipment within the area.

The guidelines for this effort are contained in subsequent chapters of this designer's guidebook.

III EQUIPMENT DESIGN APPROACH

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*Not available at this time.

There is a broad base of remote AMR experience in nuclear fission facilities that can be directly applied to fusion plants. This experience shows that special design considerations must be applied to equipment which is to be remotely maintained. This includes both fusion reactor or related machine components and maintenance equipment within shielded areas. A generally accepted approach is to modularize the equipment such that a failed component can be quickly removed, replaced, and the fusion machine returned to operation. The failed component can subsequently be repaired or scrapped as depicted in Fig. 3.0-1. This chapter describes the general considerations that should be applied when modularizing equipment or applying other design principles for remote handling. Equipment that is designed to be maintained remotely usually can be disassembled, parts replaced and repairs completed much quicker if basic remote handling design practices are followed.

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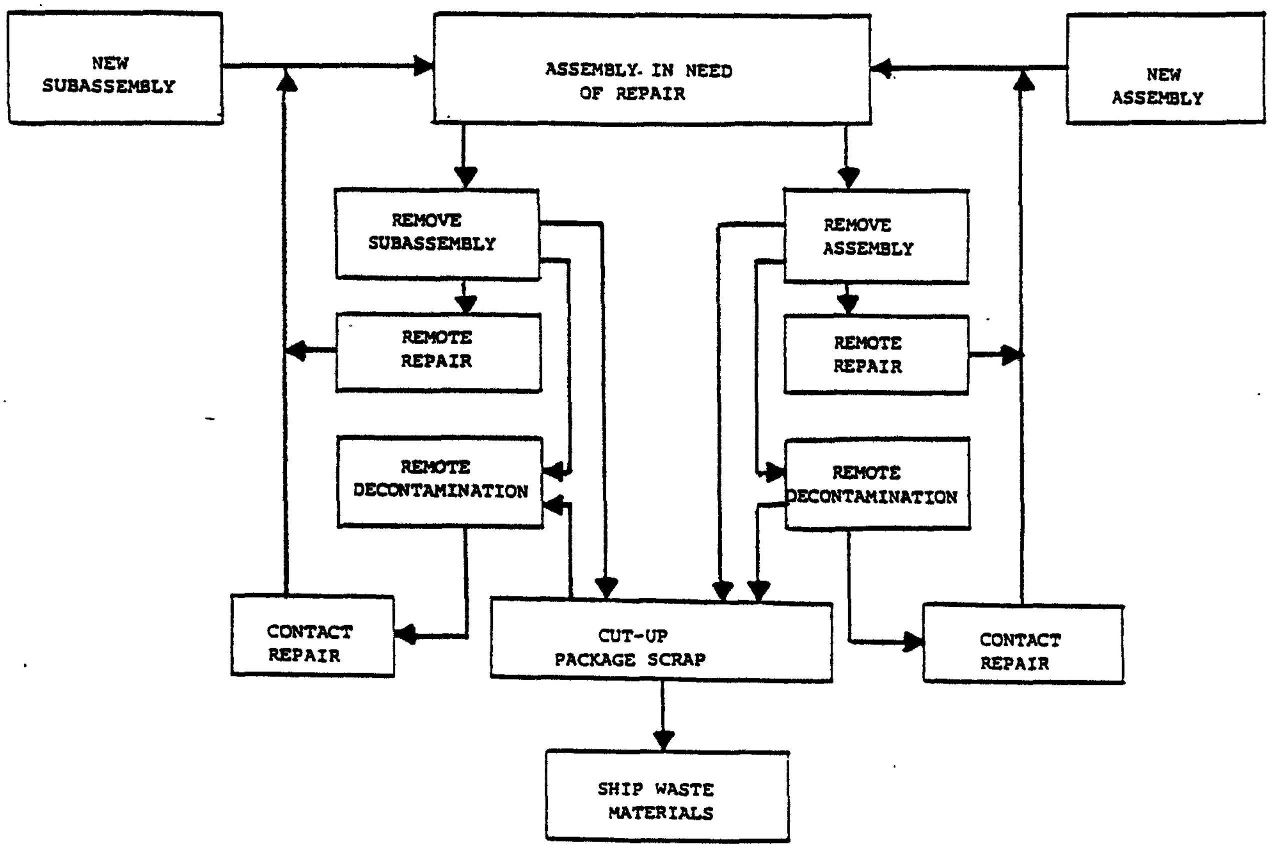

Fig. 3.0-1 Equipment Maintenance Options. A

It is important to note that the type of manipulator system used has a significant impact on both the design of the fusion machine and the time that it takes to perform remote maintenance. A number of studies and tests have been performed and documented to determine the time required to perform a set of instructured work tasks using different types of remote manipulators. The general results of these studies are shown in Fig. 3.0-2. In each case, an unsuited man was selected as the reference and assigned a value of one when performing a specific task. The same task was then performed by different types of manipulative systems, and the increased time required was determined. The numbers shown are multiplying factors; that is, it takes eight times longer to do a task using

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mechanical master-slave (M/S) manipulators than it does using human hands. Further, it takes 60 to 100 times longer to do the same task using power manipulators. The results of these studies show that master-slave manipulators can perform tasks in less time than power manipulators. It should be noted these tasks involved equipment that was not specially designed for remote work. Significantly different results would be achieved with specially designed equipment. A

	LANL*	MIT	NASA	MBA	CEA
Two-Armed Man (Unsuited)	1	1	1	1	1
Two-Armed Man (Suited)	---	---	---	8	---
Two-Arm Mechanical M/S	8	8-10	8	8	2-8
Power Manipulator (Position Control)	80	40-50	64	55	10-30
Power Manipulator (Switch Control)	480	80-100	640	---	50-100
Crane (Impact Wrench)	> 500	> 100	> 600	> 500	> 100

*LANL - Los Alamos National Laboratory
MIT - Massachusetts Institute of Technology
NASA - National Aeronautics & Space Administration
MBA - MB Associates
CEA - Commissariat a l'Energie Atomique

Fig. 3.0-2 Time Comparison to Perform Remote Tasks[1] A

The apparent extended time for maintenance operations when using remote handling, assembly/disassembly or repair systems, requires thorough design and tradeoff efforts to select the most effective combination of fusion machine and maintenance equipment designs. Also, in addition to the FWBS and its A

(1) *John Garin, et. al., "Availability Analysis as a Basis for Assessing Remote Maintenance Equipment Requirements," Proceedings 29th Conference on Remote Systems Technol., (1981).*

maintenance equipment, all reactor room equipment should be designed for remote repair or replacement. This provides for remote handling in the event the necessity arises even though contact maintenance may be used. It may also assist the contact maintenance operations. A

The first and most difficult task in maintenance operations is the diagnosis of failures, that is, determining the location and effect of a component failure and the method of repair to be used. The equipment required to isolate the failure is critical. Once the component has been repaired, its requalification is also a difficult task. In-place qualification of components to determine that they function as required prior to placing them in operation requires considerable planning and forethought. This is especially true when the component must be checked against a calibrated standard.

The selection of the design aids provided for the fusion machine and for maintenance equipment and the extent to which remote handling, repair, etc., should be provided for maintenance requires other tradeoffs. These include (1) In situ repair versus modular replacement; (2) Manually operated M/S manipulators versus varying degrees of automated control; (3) The cost of maintenance equipment versus the cost of down time; and evaluation of the reliability of each system module. These examples are typical of trade studies necessary to resolve how the fusion machine or maintenance equipment should be modularized and what design features should be included to minimize handling operations and down-time. A

The type of manipulators to be selected are a prime example of the equipment variations available. Many of the nuclear facilities currently in existence use mechanical manipulators. Their usage is acceptable where a fixed work station is suitable to perform the required remote operations. This application, however, is not practical for a fusion machine. Electric master-slave manipulators are A not restricted to a fixed position and are currently being applied for remotely maintaining large equipment in such facilities as fuel reprocessing plants.[(2)] When combined with television viewing, the electric manipulator system is equivalent to the mechanical manipulator with a shielding window. (Chapter VIII contains specific information on manipulation equipment.) A

The following sections provide general guidelines for equipment located in the radioactive sections of a fusion facility. These guidelines are typical of guides that are generally applicable to all remote handling applications.

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(2) J. R. White and H. W. Harvey, "The Evolution of Maintenance in Nuclear Processing Facilities," Proc. 30th Conf. Remote Syst. Technol., (1982).

All in-cell equipment that is located in areas with high radiation fields and may fail during the lifetime of a fusion facility must be remotely replaceable. Potential failures must be analyzed by equipment designers relative to consequences and recovery modes as discussed in Chapter XIII. Modularization will affect the design of equipment from a maintenance standpoint. Fusion facilities using different degrees of modularization will continue to be operable by repairing or replacing discrete segments of equipment. Modules [assemblies and subassemblies (S/A's)] to be repaired or replaced will range in size from individual components to large assemblies. Modularization of the STARFIRE fusion machine is shown in Fig. 3.1-1. Features for remote attachment and handling have been incorporated into the design of the STARFIRE modules. Modularization of a piece of equipment designed for use in a hot cell is shown in Fig. 3.1-2.[3] A small number of remote operations can be performed for replacing each section of this equipment.

The following definitions describe terms which are applicable to the general design of remote equipment:

- Part — an individual item such as a bolt, nut, washer, pipe, etc.
- Component — an individual item such as a valve, motor, or tank, usually made up from parts
- Subassembly — an independent unit which is a section of the assembly
- Assembly — a major grouping of components or subassemblies
- Modularization — the art of reviewing a system and determining which components can be assembled into specific subassemblies and assemblies that can be remotely assembled, disassembled, and handled as independent units

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(3) *J. R. White, et. al., "A Multipurpose Computer-Controllable Positioning Stage for the Hot Fuel Examination Facility," Proceedings of 20th Conference on Remote Systems Technology, (1972).*

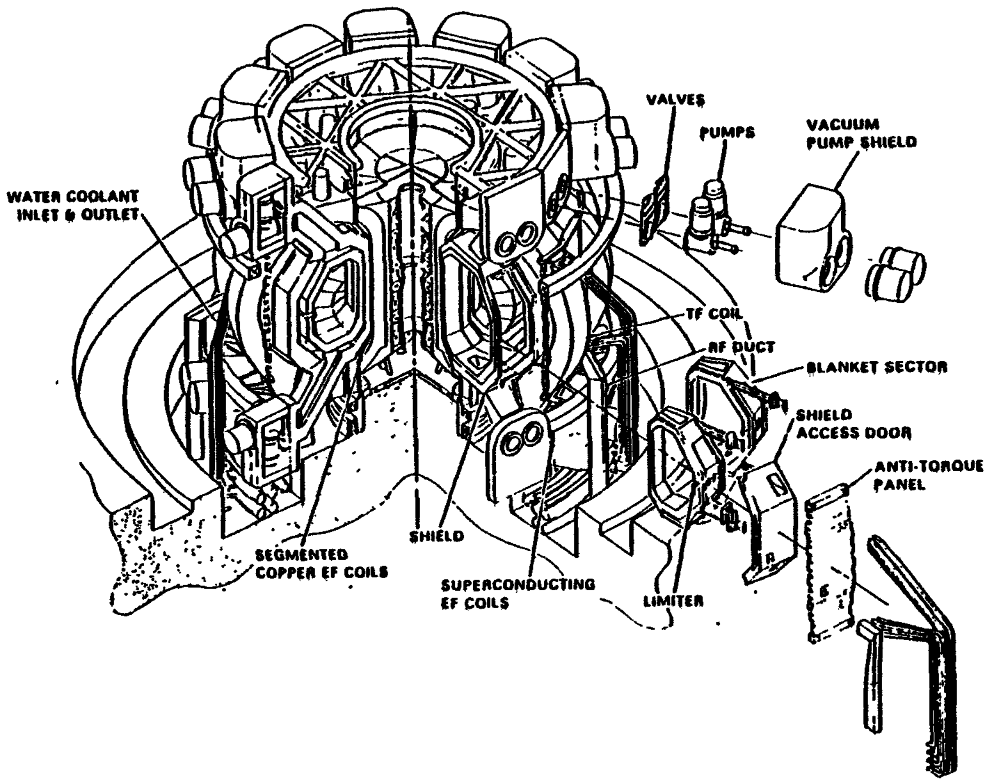

Fig. 3.1-1 STARFIRE Reference Design.

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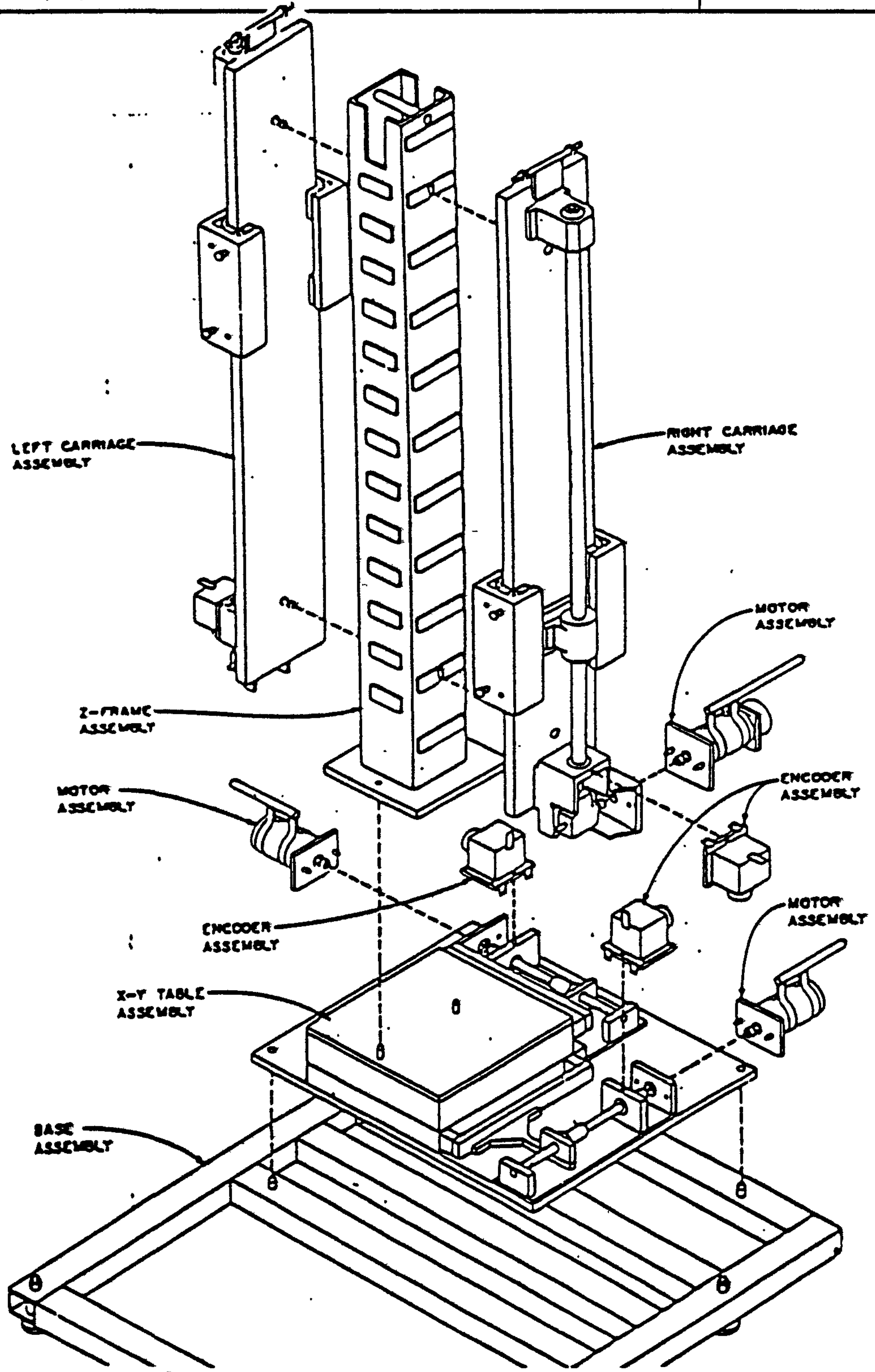

Fig. 3.1-2 Equipment Modularization.

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The following are a number of points to be considered during the design phase:

- Group high failure rate components in rapidly replaceable assemblies (e.g., motors and electrical wiring).
- Group components that are located near each other and have equivalent failure rates into common subassemblies, if possible.
- Subdivide complex assemblies into subassemblies to limit the size and weight of equipment that is to be handled.
- The designer must consider accessibility, handling, fastening, diagnosis, and alignment requirements when defining modularization of a system (see Sections 3.2 through 3.8 and Chapter IV - Sections 4.1 through 4.3 for specific techniques and/or guidelines to meet these requirements). A

Remotely maintainable facilities must be designed so that the remote handling equipment can perform the required operations. The following items must be considered when designing remote equipment:

- The lift point, fasteners, and clearances around the items to be maintained must be visible to the operator.
- The weight and center of gravity of replaceable assemblies must be determined for proper placement of lifting handles. A
- The lifting point and fasteners of the items to be maintained must be within reach of the cranes and manipulators. In addition, there must be room for the crane to make a straight lift.
- If an assembly is to be disassembled in situ, space must be provided to transfer the part being removed (e.g., if a tube sheet is being removed from a heat-exchanger, there must be enough space to move the tube sheet out of the heat-exchanger).

The outstanding feature of a remote system is the capability to handle all equipment in the facility with the manipulation equipment (i.e., crane and manipulators) provided. The equipment must be lifted, transferred, and set down safely without damage to the equipment being handled or adjoining equipment. Some of the general guidelines which must be considered are listed in Table 3.3-1. A

Table 3.3-1 Design Guides for Remote Replacement and Handling A

1. Keep the number of remote handling operations required to handle an item to a minimum.
2. Provide lift points for all items to be handled remotely (e.g., pads for attaching slings, lifting eye for crane hook, and handle for manipulator grasping).
3. Use only one manipulator during operations, if possible.
4. Use alignment and locating pins and other self-aligning features to facilitate the mating of parts.
5. Use straight-line motion during assembly and disassembly operations.
6. Remote handling operations are not always gentle; therefore, items to be handled should be designed for strength and ruggedness.
7. Do not cover up replaceable items with other components that are not designed for remote replacement.
8. Make handling operations and component design compatible for use with remote handling equipment provided in the facility. A
9. Provide resting points (i.e., set-down capability for and on parts to be handled remotely).
10. Avoid closely fitted mating parts wherever possible, especially on light parts, flanges, and ducts that are likely to deflect or warp.
11. Avoid sharp, square corners on mating parts to be handled remotely.
12. Items must hang plumb. Avoid use of counterweights and suspend the item over the center of gravity.
13. Allow space for the transfer of the largest item.
14. The facility must provide adequate floor set-down space for the largest component being handled.
15. Use gravitational forces whenever possible to hold equipment in position prior to bolting. A

A jumper is the interconnecting link between two components. There are two basic types of jumpers:

- Utility jumpers, which provide a service to a component (out-of-cell to in-cell) such as water, gas, and electrical power; and
- Interconnecting jumpers, which provide a link between two components (in-cell) such as the pipe between a pump and a tank.

Great care must be taken in the design of the jumper since it is possible to do a large amount of damage to mating parts and adjacent equipment during handling operations. Some general guidelines to be considered are listed in Table 3.4-1. A

Table 3.4-1 General Jumper Requirements

1. The remote equipment must be able to reach both ends of the jumper.
2. The removable ends of the jumper must be moved away from the fixed end without damaging seals, plugs, etc.
3. Guides are required to assist assembly and disassembly operations of the jumper.
4. The number of loose parts, such as bolts, nuts, washers, and clamps, should be kept to a minimum.
5. High failure components such as valves, and flowmeters should be designed into a jumper for ease of replacement.
6. Materials of construction must be compatible with the environment.
7. Strength levels of the connectors must be sufficient to withstand the anticipated pressure, temperature, structural and handling loading requirements.
8. Fluid jumpers must be free of discontinuities, recesses, cavities, or ledges and provide a smooth straight through flow path, which prevents restrictions, adherence, or accumulation of process media.
9. Fluid jumpers must be self-drainable.
10. Jumper assembly and disassembly sequences should be as simple as possible, restricting manipulator motions to straight-line paths.
11. Electrical jumper connectors may require environmental sealing upon completion of the connector.
12. A locking mechanism may be required to lock the electrical jumper connections. It is desirable to weight a connector so that a locking mechanism is not required.
13. It is desirable to have the jumper self-supporting in the operating position and during assembly/disassembly operations on the connector.
14. Jumpers should be grouped when practical and possible to minimize the number of handling operations.

Almost all components, subassemblies, and assemblies must be fastened together and/or attached to the building or some type of rigid structure. The most desirable type of fastening would be a passive system where very little action is required to actuate the fastener. There are two basic methods of fastening components together:

1. Permanent — welding, solder, etc. (These joints are described in Section 3.6.)
2. Nonpermanent — screws, pins, clamps, etc. (Design guides for use of this type are included in this section.) A

The fastening system will have a great effect on the total time to perform maintenance operations; therefore, care should be taken in the design of the system. Recovery operations after fastener failure should also be reviewed. Some general guidelines which must be considered are listed in Table 3.5-1. A

Table 3.5-1 Fastener Design Guidelines

1. Keep the number of remote handling operations required to a minimum.
2. Operations should be performed with only one manipulator, if possible.
3. There should be no loose parts to account for during fastening operations.
4. Commercially available fasteners should be used wherever possible, with modifications if needed.
5. The size of fasteners to be used should be standardized with a minimum number of different sizes. A
6. Screwdriver head fasteners should not be used.
7. Socket head fasteners can be used especially when there are space limitations. A
8. Use a coarse series of threads whenever possible.
9. The fastener (bolts, screws, pins, and clamps) should travel with the part being removed.
10. Guides are required during fastening operations (see Chapter IV, Section 4.1).
11. Minimize the number of fasteners.
12. Consider the use of gravity (add weight to the component) to hold components together, thus use of fasteners is eliminated.
13. Consider using dissimilar metals to prevent galling. Use of lubrication should be considered. Plating is an alternative which can be used.
14. Acceptable fasteners for joining components which require frequent remote actuation are (a) captive screws, bolts and nuts, (b) captive pins (ball lockpins which are attached to component to prevent dropping), and (c) toggle or swinglock clamps.
15. Unacceptable fasteners for joining components which require frequent remote actuation are (a) screws (sheet metal, self-tapping or wood screws), and (b) most non-threaded fasteners such as retaining snap rings, cotter pins, roll pins, and spring clips.

The design of both equipment and facilities must consider an analysis of potential failures. The analysis will suggest to the designer potential problem areas and possibly identify additional components needed to assist in diagnosing failures. An example would be the addition of a level indicator in a sump near a group of fluid-containing pipes or tanks. If the system is designed properly, the level indicator will indicate to the operator the presence of a leak before the process system can detect such an occurrence.

Failure diagnosis may be grouped into two major categories:

- Out-of-cell — diagnosis would include such items as checking amperage and resistance, and
- In-cell — diagnosis would include such items as visual, ultrasonic, and sound.

There are many types of failures that must be considered. Some of the typical types of items that may suffer from operation in a hazardous environment include motors, gearboxes, valves, instrumentation, heaters, and tanks and pipes.

Potential failures resulting from radiation damage, handling failures, "old-age" failures (such as mechanical wear and bearings), frequency of failures, and consequences of failures are items to be considered during equipment and facility design. Additional considerations are as follows:

- Failures that could result in a breach of containment should be eliminated.
- Components with high failure rates should be placed in packages that can be replaced with a minimum amount of remote manipulation.
- Special equipment and/or systems required for failure diagnosis should be provided and proven to work with the original system.
- Analysis of failures should be included in the preventative maintenance program.

Systems calibration must also be considered during the design phase if accurate readings and/or controls are necessary. If an instrument only provides an indication of a happening but is not used to control an event, its utility must be evaluated to see if it can be removed from the system. In almost all cases, special standards will be required to perform calibration operations remotely. Calibration operations may be undertaken either out-of-cell or in-cell. If handling operations will not change the calibration results, and the component is easily removed from the entire system, calibration can be performed out-of-cell. However, if handling operations affect the component's accuracy and is very time-consuming, calibration should be performed in-cell.

The following are some general requirements which must be considered:

- Special standards must be provided for in-cell calibration.
- Calibration adjustments in-cell must be avoided whenever possible. If in-cell adjustments are required, special designs may be necessary so that the remote equipment can perform the operation.

The amount of time required to perform an operation can be reduced if component, subassembly, and assembly sizes and shapes are standardized. In addition, it is possible to reduce operating, design, and construction costs if standardization controls are integrated early in a project.

Standardization can be achieved by:

- Limiting the number of screw sizes,
- Use the same type of lifting/handling bails wherever possible,
- Use commercial products when possible,
- Use uniform screw spacing in the event that special component hangers are required.

Identification of each subassembly and assembly is very important in a large facility. The identification system must lead back to the design drawings. Identification systems may consist of:

- stamped or engraved numbers (part or Dwg. No.),
- color coding, or
- etched or painted numbers.

Tagging has not been acceptable because tags are easily lost, hard to read, or in the wrong place and may interfere with operations.

The following items should be considered:

- Assembly and subassembly identification should be placed where it can be seen during normal operations.
- All remotely replaceable items must have some type of identification. Spare parts should have the same identification markings.
- Clear identification markings must survive remote handling and decontamination operations. A

The designer must review the system design and determine the failure frequency for all components. The initial spare parts list will be based on this review. The storage location for all spare parts must be determined. Although most of the spare parts will be stored in nearby warehouses, some of which may have to be designed for contaminated equipment storage, some storage may be in place in the reactor room. Transfer times required to get a spare part to the work area must also be determined.

All of the foregoing characteristics determined for the spares supply system will have an impact on plant availability. For this reason, it may be desirable to modify the system and have an intermediate location for storage of a limited number of parts. They can then be quickly moved to the work area. A

The following data, operations, equipment, and facilities are essential for an effective spares supply system:

- As-built dimension records must be maintained, primarily for interface dimensions.
- All spare parts must be tested and calibrated prior to installation.
- Some components, assemblies, etc., require special jigs or fixtures to check the fit and function (i.e., ensure that parts fit properly and work well) of spare parts prior to installation.
- Repaired contaminated parts must be kept in a controlled storage area.

All equipment and structures that are used in a contaminated environment will have to undergo decontamination at some point of time in their lifetime. However, the decontamination method must be considered, since some equipment will be reused. Processes currently being used are: air blast, sand blast, acid bath, ultrasonic bath (usually with a detergent), water or detergent blast, freon blast, and handwiping with damp rag. A

Contamination levels can be improved through proper material selections; use of electro polished or plated surfaces; and good design practices, such as minimization of cracks and pockets. A

The following are some additional items that must be considered:

- Do not use porous materials,
- Use continuous welds (as opposed to stitch welds), A
- Do not use blind holes or attempt to provide drain holes if blind bolt holes are required,
- Use smooth or polished metal surfaces,
- Avoid metals that corrode unless they are coated with a corrosive-resistant coating,
- Decontamination is very hard on rotating components such as bearings and electrical components. A

The prevention of galling threaded items and other close-fitting surfaces should be considered during the design of remote systems. Recovery from a galled condition can be very time-consuming.

The following items must be considered:

- Use dissimilar metals or nongalling, stainless steel (Nitronic 50 and 60) whenever possible, A
- Apply special coatings to threads,
- Thread plating may be required,
- Use coarse threads,
- Remove the first threads on bolts and studs, at least two, to the root diameter to help prevent cross-threading. Bevel or bullet nose end of bolt for ease of insertion and self alignment. A

IV SPECIFIC COMPONENT DESIGNS

A
A
A

*Not available at this time.

This chapter provides specific guidelines that are applicable to most remote equipment and facility design. Actual application of these specific guides will depend upon the specific conditions and configurations. It is the designer's job to select the appropriate approach.

Some of these guides have been presented in other documents. This chapter provides a compilation of these guides in one document. A

Remotely replaceable components usually incorporate built-in provisions to locate the component in its proper location and orientation. Guides are used to align components for a precision fit, speed up assembly operations, and limit damage to the components.

Many of the normal handling tasks are difficult to perform remotely. The use of guides makes it possible to perform these tasks. Some of the handling problems eliminated by proper guiding applications are loads swinging or rotating on cranes during precision operations, lack of visibility, and lack of clearances.

With normal guiding philosophy a rough guide is provided first. The amount of guidance and precision of the guide is then gradually increased until the component is seated in its final resting position. A guide system generally consists of one long guide and one that is somewhat shorter. The long guide provides the operator with the first indication that the component is being placed in the correct location. Once contact is made with the first guide, the component is rotated a small amount until the second guide is picked up. As the component is lowered on the guides to the proper location, the final fit is very snug. The shoulder height of guide pins above the mating surfaces is a function of the requirement not to allow the component to seize or tilt during assembly. A shoulder bearing length of a half pin diameter is usually sufficient. See Fig. 4.1-1 for an example of a typical guide application. A

There are many ways the designer can provide assistance to the operator in performance of operations. Various types of guides which are currently used are:

- pins,
- brackets,
- slots,
- proximity devices, A
- tapering parts that mate together, and
- a combination of the above.

General guide considerations are listed in Table 4.1-1.

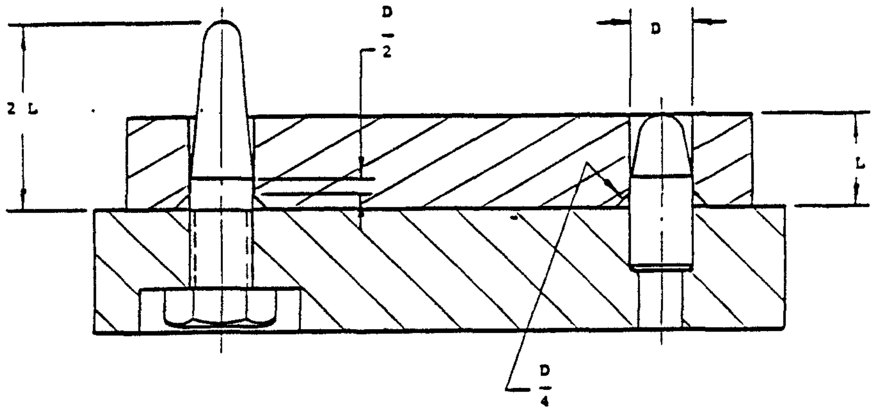

Fig. 4.1-1 Typical Guide Configurations.

Table 4.1-1 General Design Guidelines for Guides and Locating Devices

1. Precision guides must be designed so that the component does not seize or tilt during assembly/disassembly operations.
2. More than one guide is normally required.
3. Guides are normally designed to carry some of the joint structural loading. In some cases, they have been designed to carry all of the joint shear loading.
4. Guides should be designed so that the full weight of the components can be carried on one guide. The guide should also be capable of withstanding the impact load that may result from component handling operations, such as a load swinging on a crane.

4.1.1 Pins — Pins are the most widely utilized method of guiding components to the correct resting position. Guide pins for remote installation of components differ from ordinary pins in several respects. They are made so that mating parts can be engaged with coarse initial relative positioning. They generally are long to accommodate mating of parts having long guided lead-in requirements. They are sometimes used to support the weight of the guided part when the part must be moved horizontally for mating. The relative fit of a pin in the mating hole or slot is generally loose enough to allow parts to engage under the force of their own weight or within the capability of the manipulators available for the installation. They must be long enough to give the operator a good view of the initial engagement of parts. The pin requirements listed in Table 4.1-2 must be considered.

Table 4.1-2 Pin Requirements

1. Pins should generally be shaped as shown in Fig. 4.1-1.
2. Two pins are normally required.
3. Pins should be positioned asymmetrically for correct orientation (see Fig. 4.1-2).[1] A
4. One pin should be longer than the other so that mating components can be placed on the longer one and then rotated to fit on the other.
5. Pin mounting holes should generally be match-drilled with the mating part.
6. Pins are generally designed to take full module weight on one pin and to withstand impact loads that might result from the component swinging on a crane.
7. If the relative rotational orientation of mating parts is important, it may be desirable to use pins of different diameters.

(1) *Layman, D. C. and G. Thorton, "Remote Handling of Mobile Nuclear Systems," U.S. Atomic Energy Commission/Division of Technical Information, 1966.* A

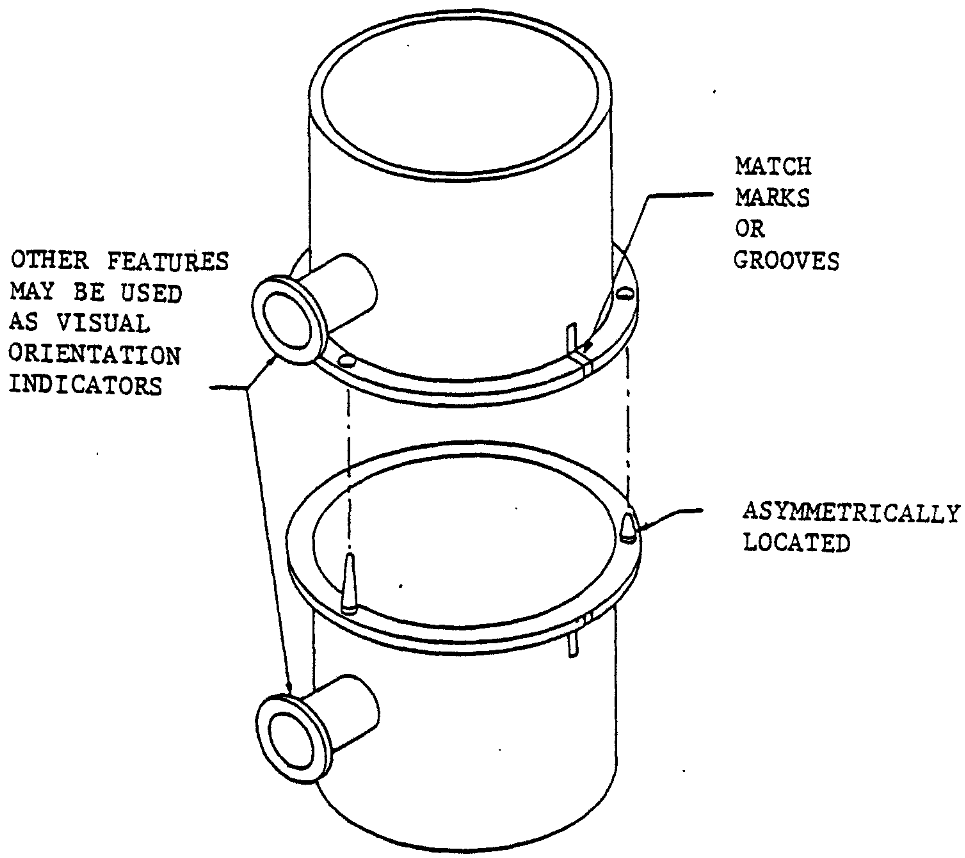

Fig. 4.1-2 Module Guide Features.

4.1.2 Guide Brackets — Guide brackets similar to those shown in Fig. 4.1-3 may be used where positioning accuracy is not required. This type of guide is often used in conjunction with guide pins. An example would be the positioning of a heavy cask over a penetration part. The bracket would provide the rough positioning to allow mating of the first stage of the pin.

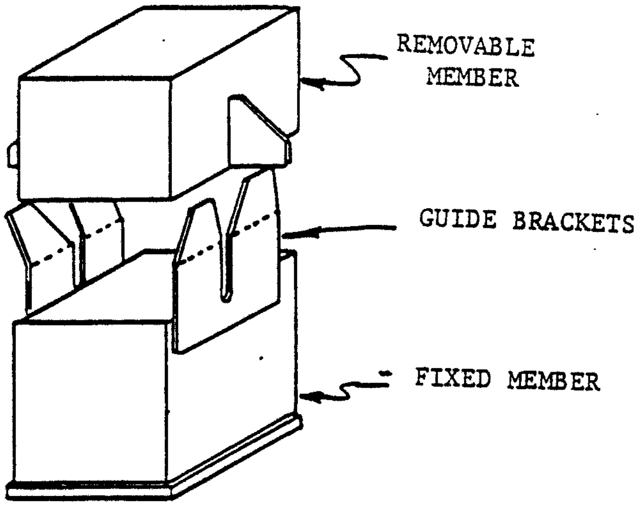

Fig. 4.1-3 Guide Brackets.

4.1.3 <u>Slots</u> — Slots similar to those shown in Fig. 4.1-4 have several useful applications that must be considered.

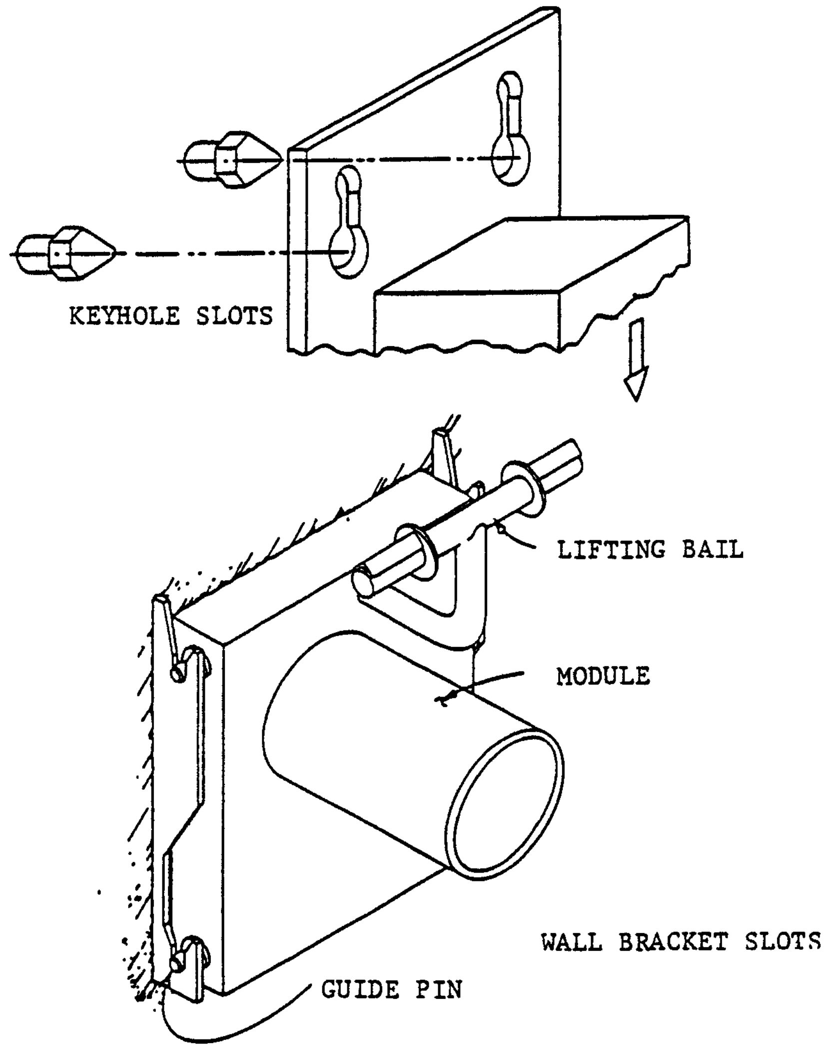

Fig. 4.1-4 Slots.

4.1.4 Tapers — Almost all components designed to be mated together (i.e., remotely) include the use of tapers to some degree. Figure 4.1-5 shows illustrations for several typical applications. Normally, it is best to use the maximum amount of tapers practical for the specific applications.

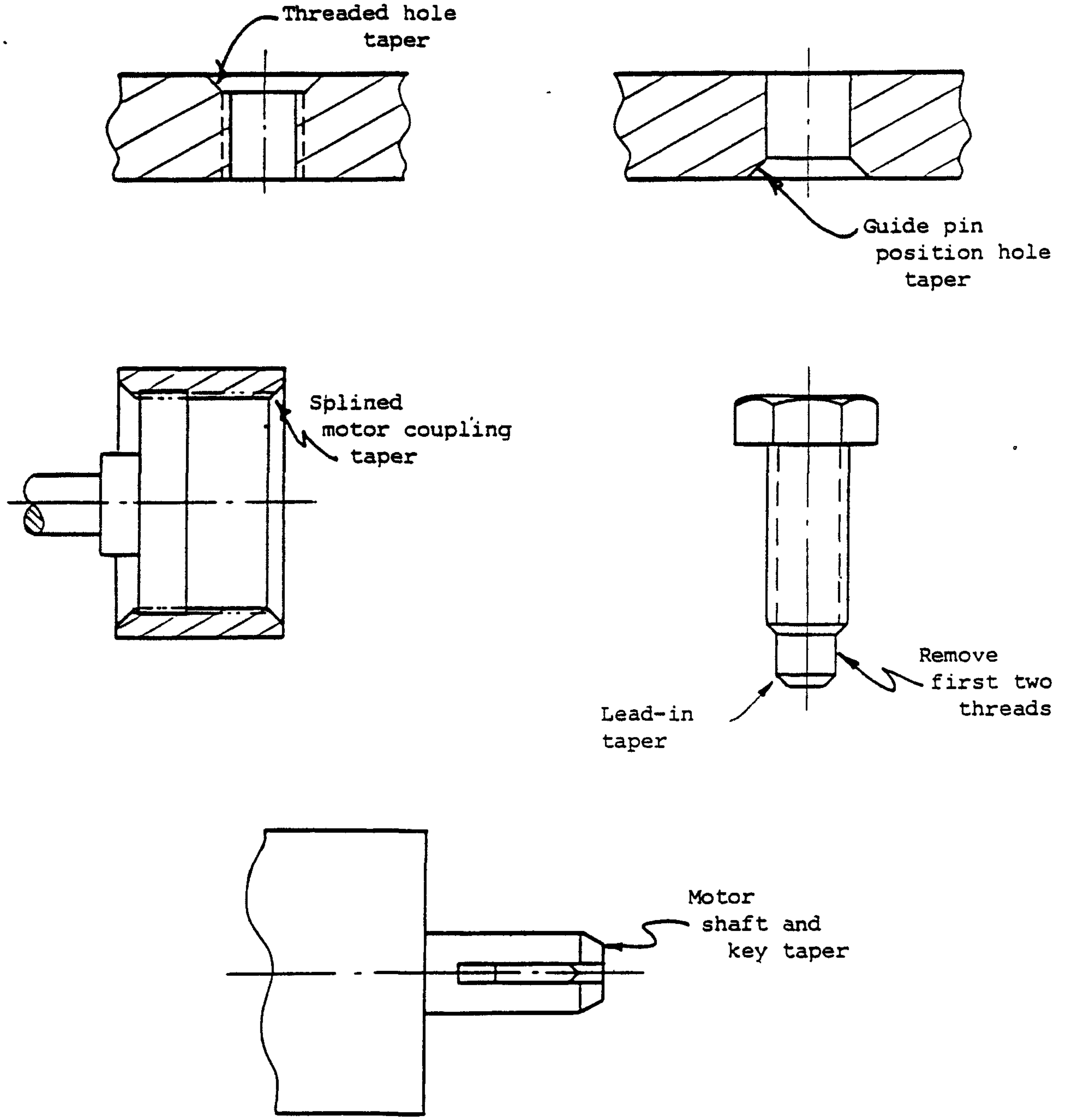

Fig. 4.1-5 Tapers.

4.1.5 Miscellaneous Guides — Handling operations are best performed if components can be fit together with one simple operation; however, this is not always possible. Figure 4.1-6 shows a motor subassembly which is first placed over one pin and then rotated horizontally into its final position against the stop pin. (Note: The coupling should use a taper to help align two halves.) When the subassembly is in its final position, a bolt or pin is installed as a lock.

Ball guides (Fig. 4.1-7) have been successfully used in a number of applications. This type of guide would normally be used in conjunction with some other type of guide prior to contact with the ball, such as a bracket.

Figure 4.1-8 shows the usage of a tapered coupling, pins, and a hanger hook to mount a motor on the end of a shaft.[2] The motor hangs off-plumb from a cable bale as shown in View (a). The motor hanger hook is first placed over the motor pivot hanger. The motor is next lowered which allows it to pivot around the hanger. Tapered guide pins align the motor so that the end of the coupling on the motor will mate with its companion half. When the entire motor load is taken off the lifting bale, the motor is in its operating position, View (c). This design normally does not require that the motor be bolted to the base. A

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[2] *Adam, M. F., "Remotely Connectable Drive Coupling," American Nuclear Society Proc. of 26th Conf. on Remote Systems Technol., 1978.* A

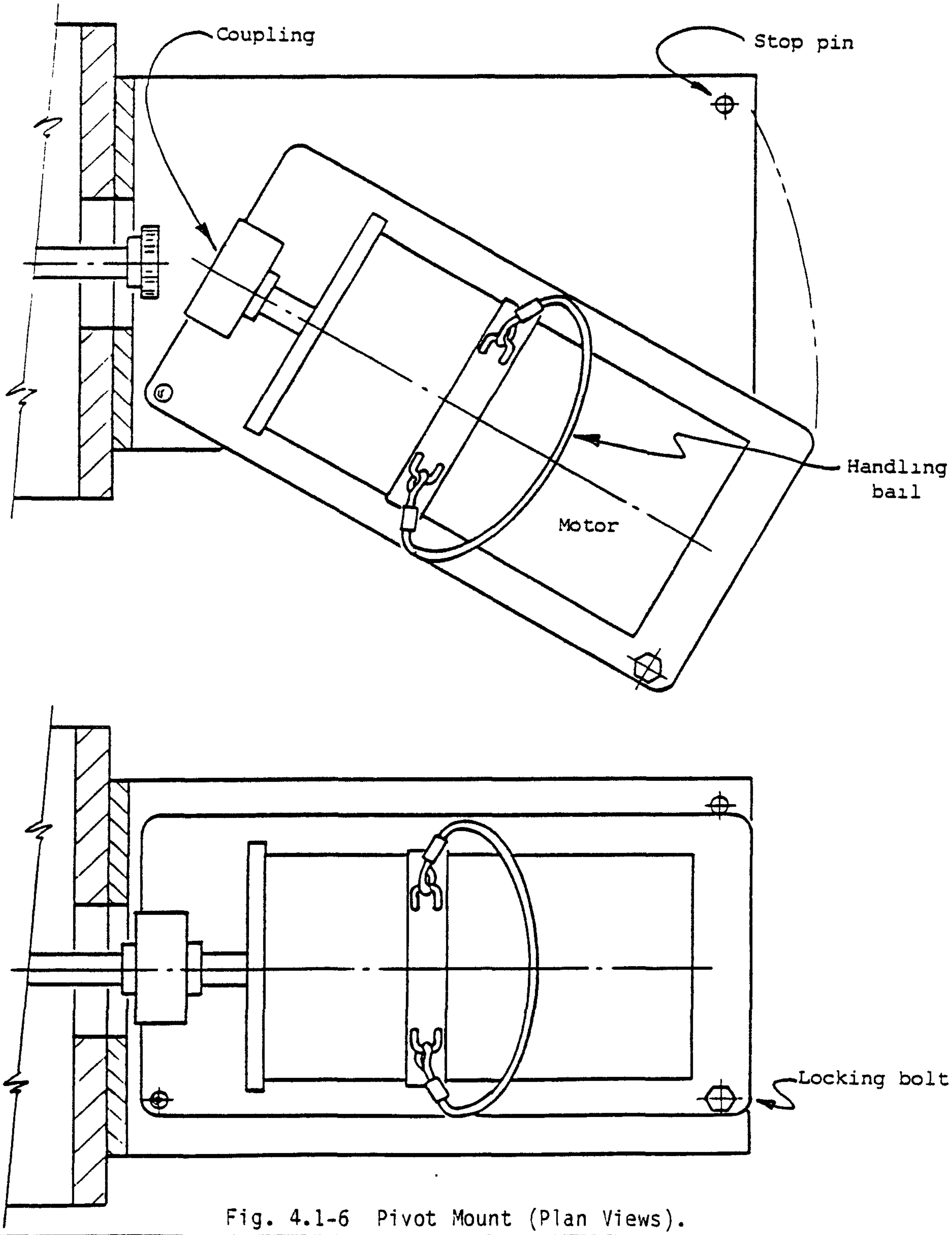


Fig. 4.1-6 Pivot Mount (Plan Views).

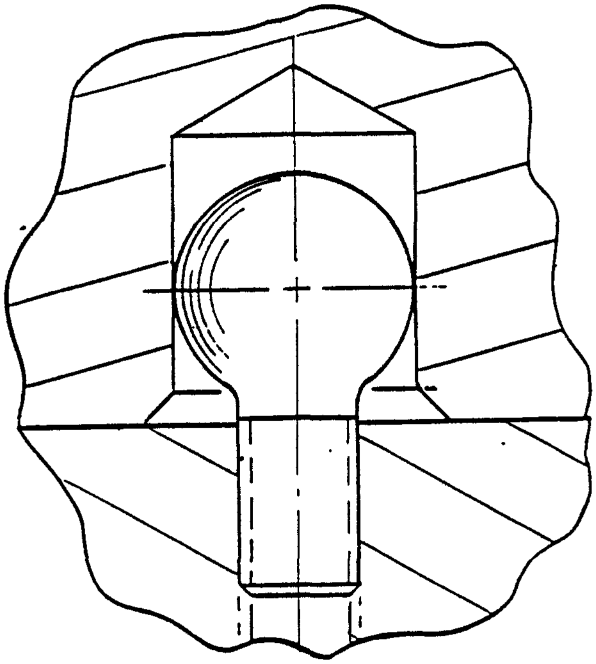


Fig. 4.1-7 Ball Guide.

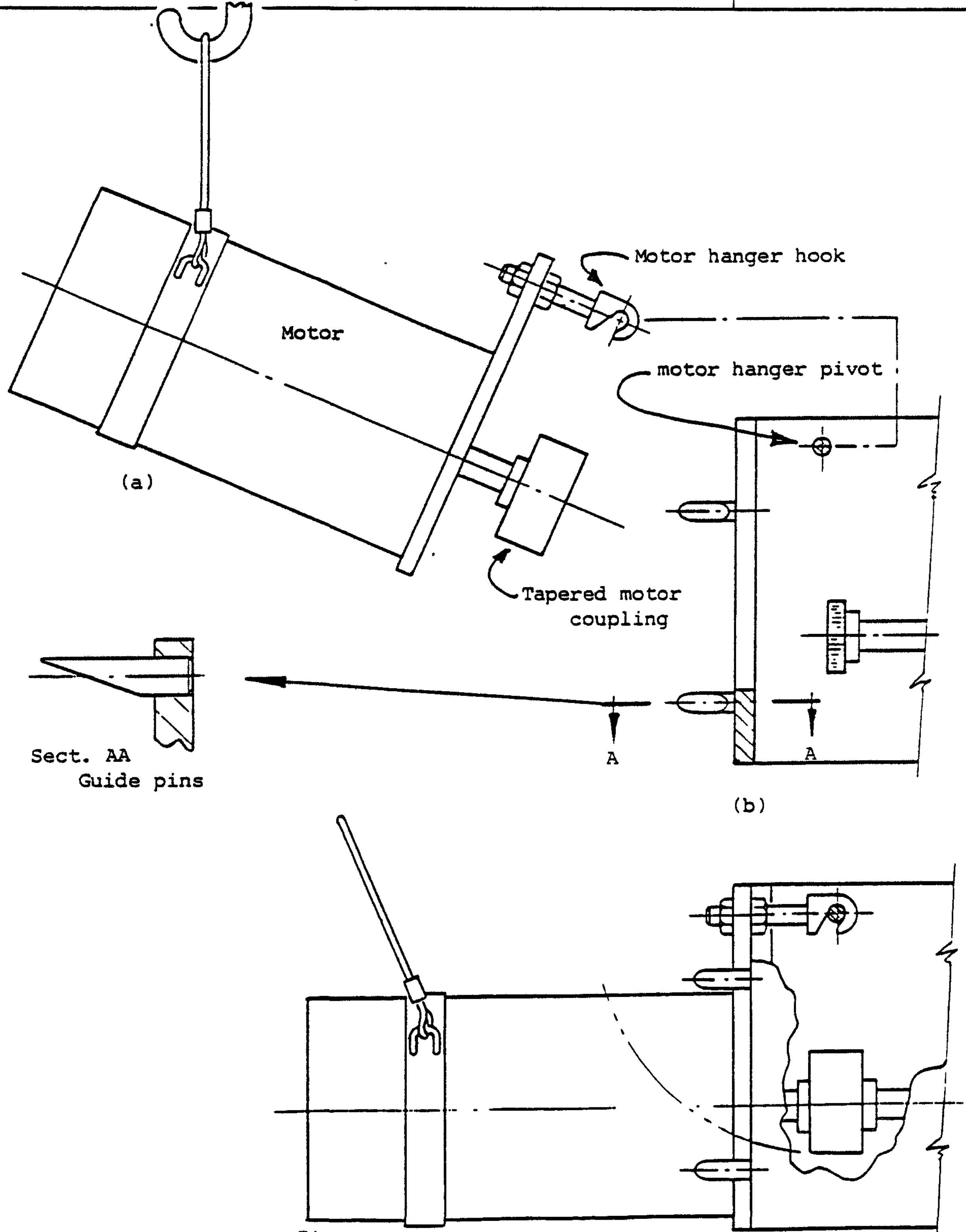


Fig. 4.1-8 Swing Motor Mount.

4.1.6 Heavy Components — A unique requirement for fusion reactor maintenance is that large, heavy components must be remotely removed and replaced. This includes sectors of the vacuum vessel, blanket modules, magnets, etc. Some of the principles described herein can be applied to the guiding and positioning of these components. However, it is generally expected the special equipment with a high degree of positioning accuracy coupled with sensing instrumentation will be required as discussed in Chapter VI. A

The location and type of handling attachments strongly influence the success of remote-handling operations. Much consideration should be given in the design of the handling and set-down points. Flanges, trunnions, lifting eyes, hooks, bails, flats, and projections have all been used as handling attachments. The design must be based on the handling equipment which will be provided in the facility. Several general design requirements for handling attachments are listed in Table 4.2-1. During maintenance operations, components have to be set-down during transfer operations. This may be on special support fixtures or flat surfaces. The component must be designed such that adequate set-down points are provided. The requirements are listed in Table 4.2-2.

Table 4.2-1 General Handling Attachment Guidelines

1. The handling attachment must have both physical and visual accessibility for the mating device.
2. Clearance is required for the handling device.
3. Straight-line motion by the handling device to the attachment point is desirable.
4. The attachment point should be designed with a safety factor of 5 based on material ultimate strength and should be load tested at 150% of the load. A
5. The attachment point should be designed for permanent attachment to the component, if possible (i.e., installation prior to handling is not required).
6. It is desirable to add the lifting attachment to small components in the field by the installation/check-out crew and not at the vendor's shops in order to locate the center of gravity and provide adequate handling clearances. A

Table 4.2-2 Component Set-Down Guidelines

1. Stability of the component must be provided during the set-down operation, that is, the component must not tip or fall over and it must stay orientated so that the handling equipment can re-engage the handling attachment.
2. Avoid the use of special set-down support fixtures if at all possible.
3. Make sure that the component is designed for the set-down loads.

4.2.1 <u>Crane Handling Attachments</u> — There are a number of crane handling attachment systems that can be used remotely. Examples of such systems are bails (see Figs. 4.2-1 and 4.2-2), trunnions and eye bolts.

All of the general design requirements in Table 4.2-1 apply for crane handling attachments along with the items listed in Table 4.2-3.

CAP	"A" MIN.	"B" MIN.	"C" MAX.
1 TON	3 3/4	1 1/4	3/4
2 TON	4	1 1/2	3/4
5 TON	6 1/2	2 3/4	1 1/4
10 TON	10	4	2
25 TON	13	6	3 1/4
50 TON	18	8 1/8	4 1/2

*Dimension, in inches

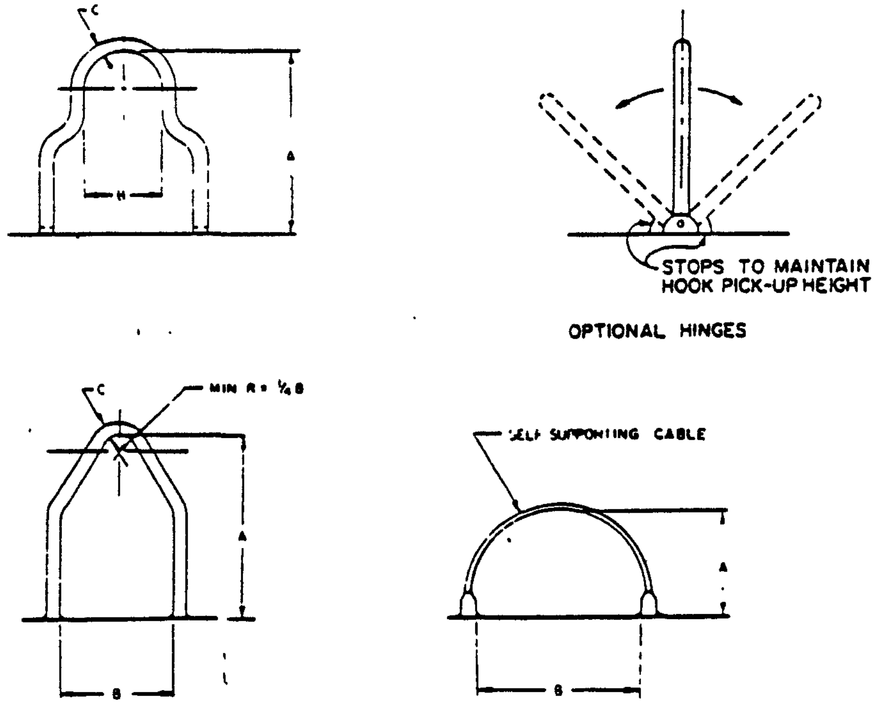


Fig. 4.2-1 Light Duty Lifting Bails.

CAP	A	B	C	D	E	F
1 TON	1	2 1/2	1	1	6	4
2 TON	1	2 1/2	1	1	6	4
5 TON	1 1/2	3	1 1/2	1 1/2	8	6
10 TON	2	5	2	2	10	8
25 TON	3	8	3	3	12	10
50 TON	3 1/2	10	5	4	14	12

*Dimension in inches

A

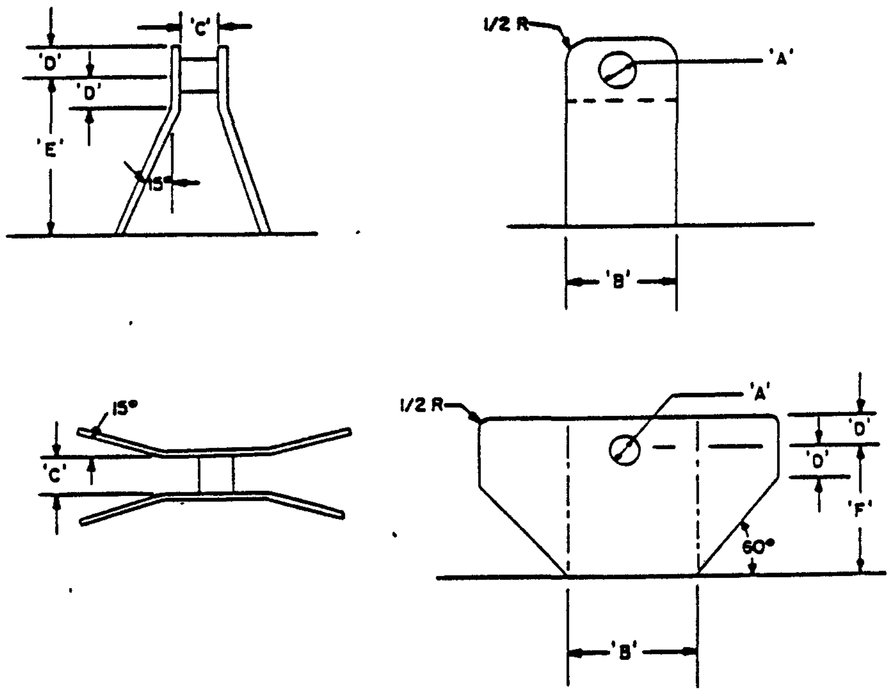


Fig. 4.2-2 Heavy Duty Lifting Bails.

Table 4.2-3 Crane Attachment Requirements

1. If the component is to be handled with both the crane and manipulator, the attachment method (e.g., bail) should be designed to accommodate both handling methods (Fig. 4.2-3). A
2. The lifting point must be located directly over the center-of-gravity of the component being handled. If not, weights should be added to assure that it hangs plumb. Large counter-weights often hamper handling operations and should be avoided if at all possible.
3. Pivoting or cable bails must be positioned so that the crane can be attached to the bail without the assistance of a manipulator, i.e., the bail must stand off from the component far enough to allow the crane hook to engage.
4. Some facilities may have requirements which mandate the use of safety devices on crane hooks. This requirement has been eliminated from most remote facilities requirements because of operational difficulties. Bails should be designed to limit motion of the crane hook once it has been engaged with the bail. This must be a passive restriction, i.e., not requiring the use of a manipulator or special actuators.
5. Special fixtures are normally required to pick up components which utilize trunnions as a support and pick-up method. Stops must be provided on the trunnions so that the lifting fixture cannot inadvertently slide off (Fig. 4.2-4).
6. Eyebolts are one of the least desirable methods of attaching handling equipment remotely. Eyebolts, slings and shackles usually require installation just prior to use. This type of installation is very time-consuming (Fig. 4.2-5).
7. If permanent eye-rings are installed in the correct orientation, special fixtures, as shown in Fig. 4.2-6, can be used for handling operations.

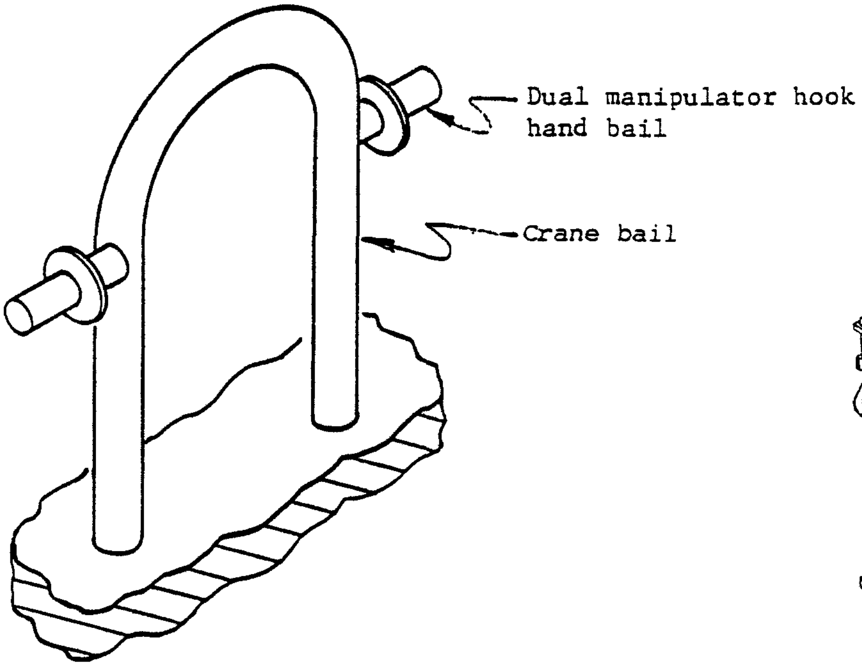


Fig. 4.2-3 Dual Purpose Handling Bail.

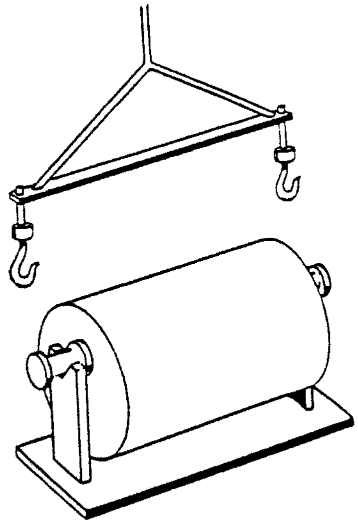


Fig. 4.2-4 Trunion Handling.

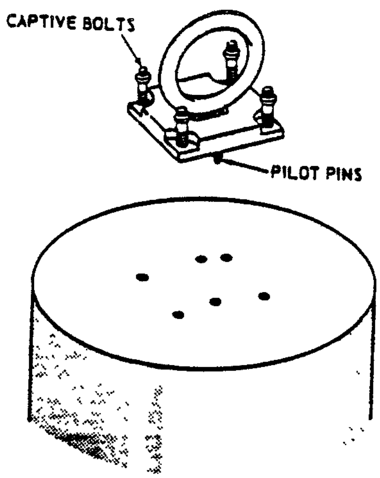


Fig. 4.2-5 Detachable Ring.

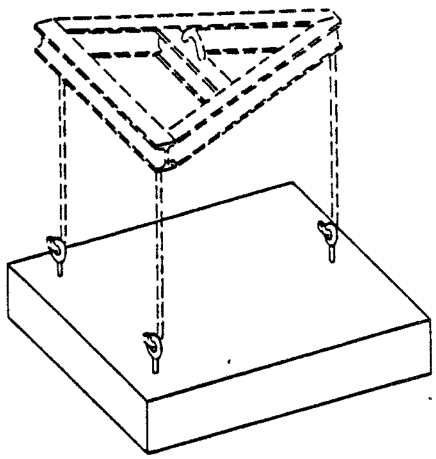


Fig. 4.2-6 Three Eyebolts and Lifting Fixture.

4.2.2 Power Manipulator Handling Attachments — Current market power manipulators range from 50- to 400-lb. capacity with the hand in any position. Figure 4.2-7 shows a typical manipulator configuration.

Figure 4.2-8 shows a number of typical power manipulator hands. Hands in A&B are the type normally in use today. The items listed in Table 4.2-4 must be considered.

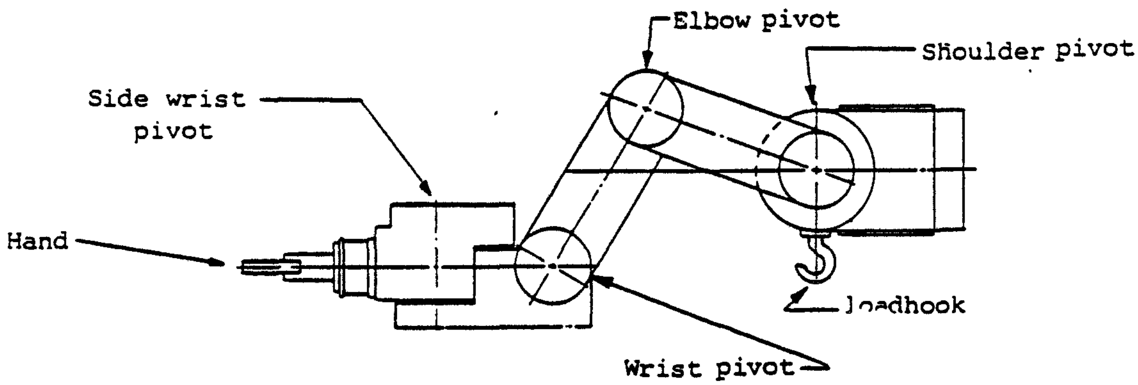


Fig. 4.2-7 Typical Power Manipulator Configuration.

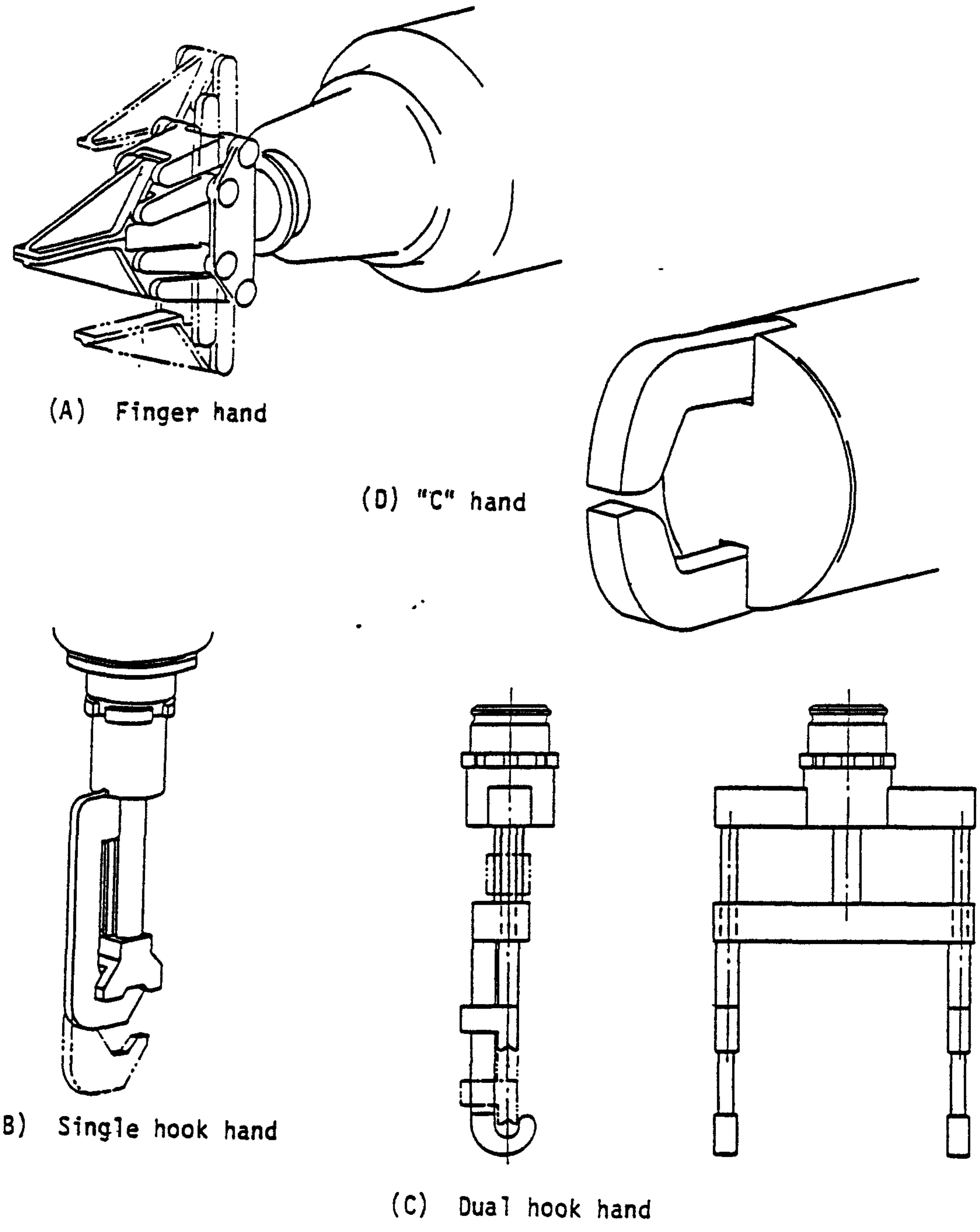


Fig. 4.2-8 Typical Power Manipulator Hands.

Table 4.2-4 Power Manipulator Guidelines

1. Round objects, such as pipes and rods, tend to roll in the finger hand unless flats are provided (Fig. 4.2-9).
2. The location of the load center-of-gravity must be considered during the design process (Fig. 4.2-10).
3. Figure 4.2-11 shows a typical configuration for a dual hook attachment fixture. This type of assembly can be permanently attached to a component, or it could be installed in a threaded hole each time it is used.
4. Since the manipulator can grasp components tightly (if within the rated load capacity), component attachment points do not need to be directly over center-of-gravity as required for cranes.

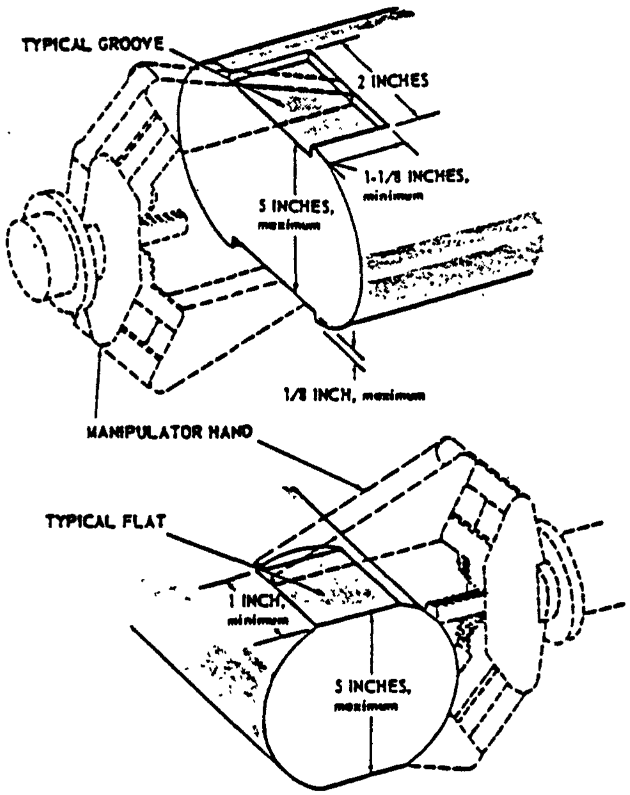


Fig. 4.2-9 Typical Grooves and Flats for Finger Hand.

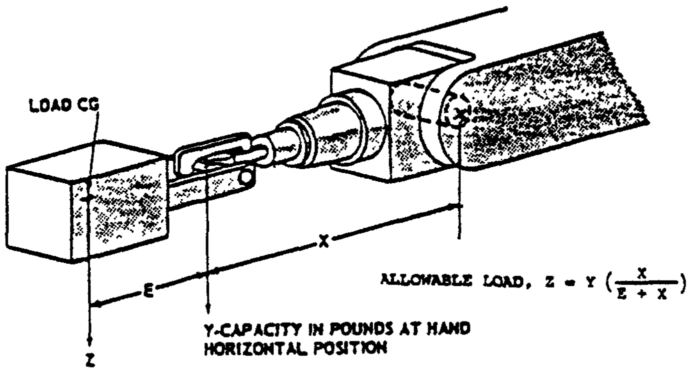


Fig. 4.2-10 Component-Manipulator Load Relationship.

Typical Bail Dimensions

		DIMENSIONS (INCHES)					
BAIL CAP	HOOK MOUNTING EQUIPMENT	'A'	'B'	'C'	'F'	'D'	'E'
150 LBS.	PAR 3000 AA	8 ± 1/16	4 1/2 ± 1/32	0.75 ± .01	5	3/4	1/2
400 LBS	PAR 6000 AA	8	5 1/4	0.75	5 3/4	3/4	1/2

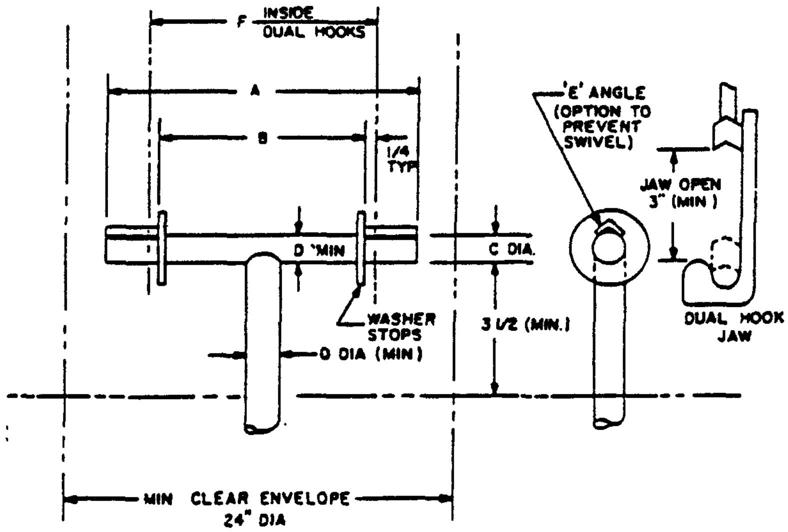


Fig. 4.2-11 Typical Dual Hook Bail.

4.2.3 Master-Slave/Servo Manipulator Handling Attachments — A typical master-slave (MS)/servo manipulator hand is shown in Fig. 4.2-12. Operations with these types of manipulators require a minimum amount of special fixturing to make handling operations possible. The following items should be considered:

- Round items are hard to hold with this type of hand. Special "V" fingers can be provided for the hand if numerous operations are to be performed on round items.
- Flat items are hard to pick up with this type of hand; therefore, some type of handling aid should be provided, if possible (Fig. 4.2-13).

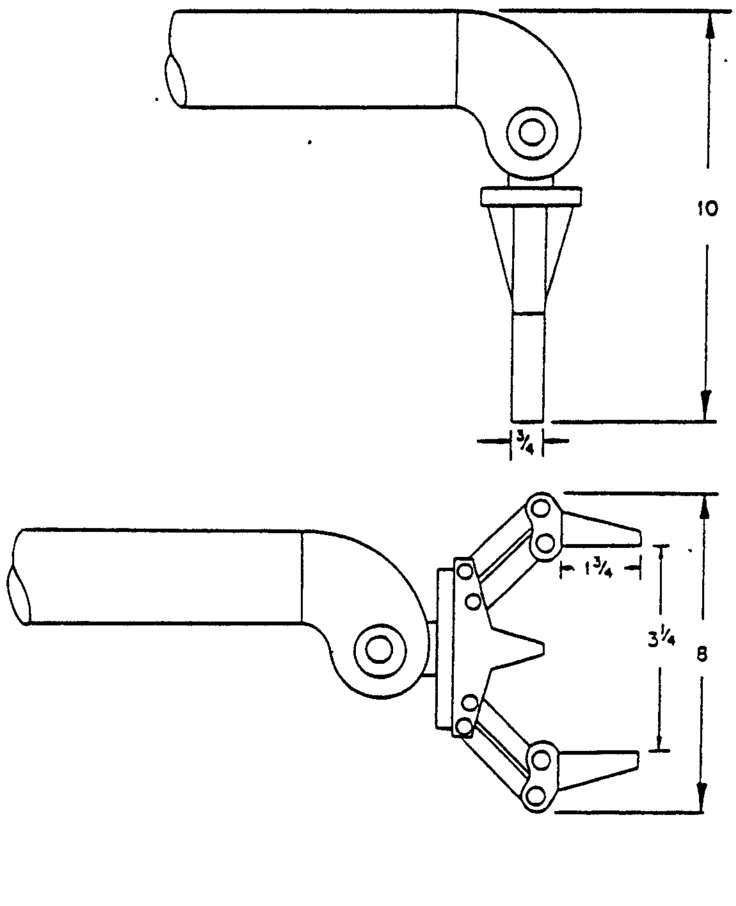


Fig. 4.2-12 Typical M/S or Servo Manipulator Hand - Dimension in Inches.

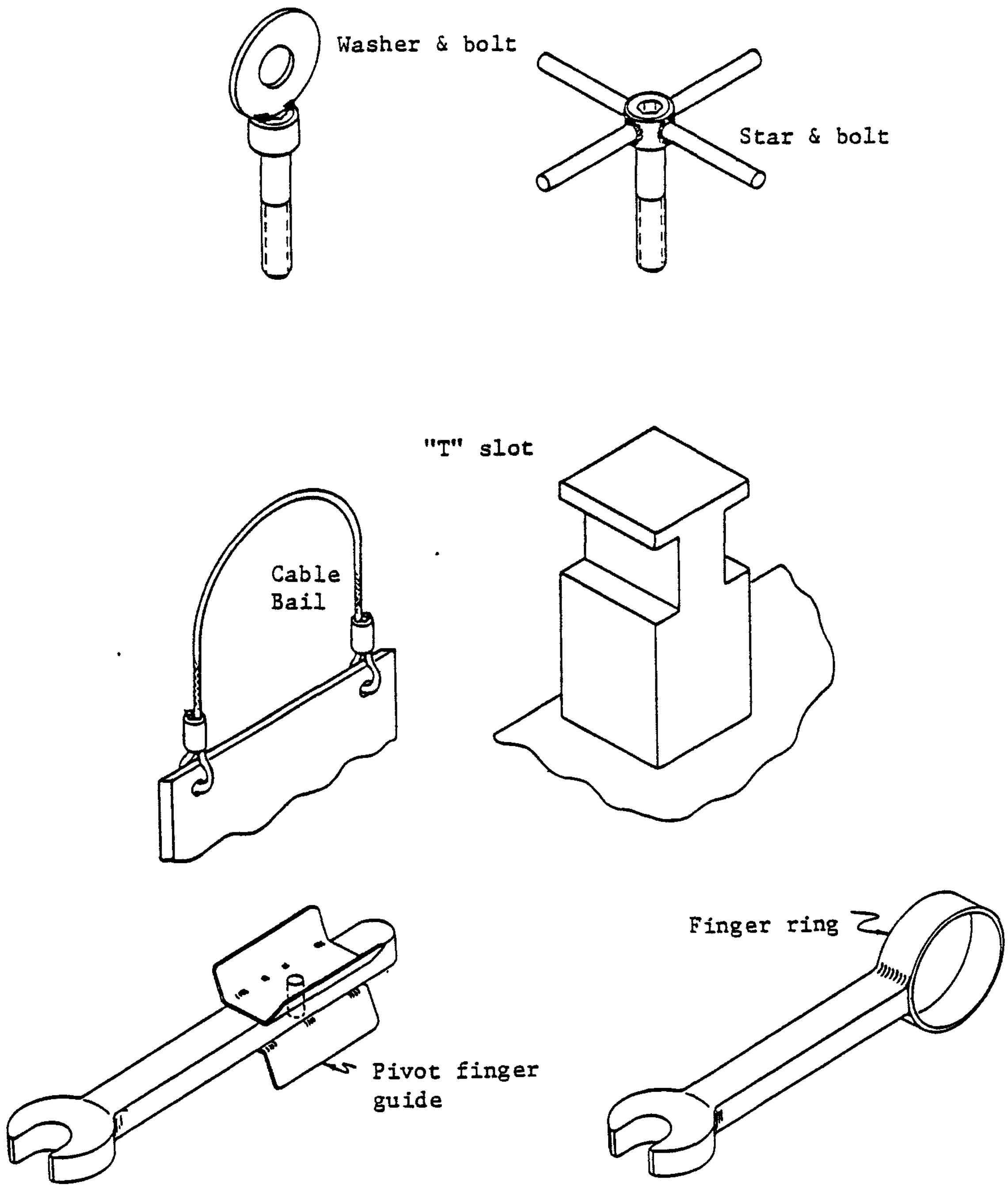


Fig. 4.2-13 Manipulator Handling Aids.

4.2.4 Special Attachments — There have been many special handling attachments designed and used over the years. Although they are all somewhat similar, each one has a special design and purpose.

1. A typical collet application is shown in Fig. 4.2-14.[3] The collet nut is rotated on the threaded portion of the shank. As the nut is moved down on the thread, it forces the jaws of the shank to come in contact with the items to be supported. A

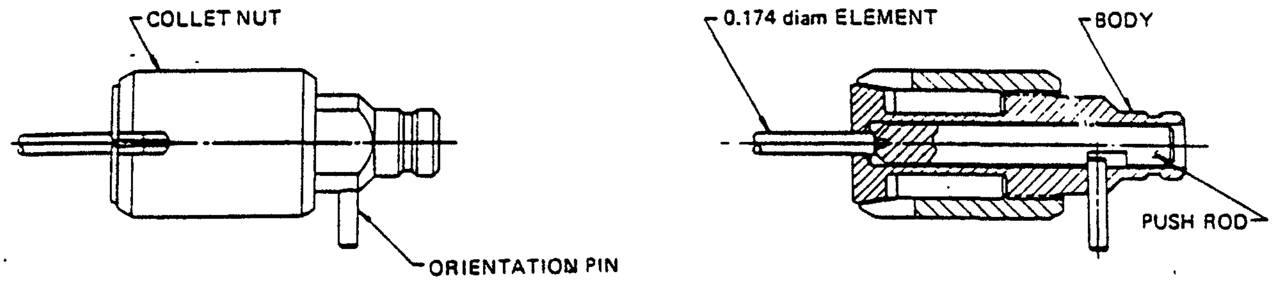


Fig. 4.2-14 Typical Collet Handling Attachment.

NOTE: Additional items will be added here.

(3) *White, J. R., et. al., "Handling of Irradiated Elements and Capsules in HFEF/N," American Nuclear Society, Proc. of 23rd Conf. on Remote Systems Technol., 1975.* A

The design of fastening systems for remote operations is one of the most time-consuming and costly parts of the entire remote maintenance design process. Normal fastening systems cannot be used, and on occasion, very unique techniques must be devised. Conventional fasteners, such as threaded bolt and nut assemblies, present a potential problem in remote operation since the bolt or nut may be irretrievably lost or the threads may be damaged during handling operations.

Special fasteners are required for the following reasons:

- Fastening devices may be lost during maintenance operations if they are not attached to the component.
- Operations are speeded up when fastening devices are attached to the component.
- Proper fastening device design will limit damage to the fastener thereby shortening maintenance downtime.
- Remote operations are much more time consuming than contact operations and the large number of fasteners required demands more rapid operation.

Some general requirements that must be considered are listed in Table 4.3-1. If the Table 4.3-1 requirements are applied along with the usual considerations such as selection of sizes, materials, heat treatment, and additive finishes, satisfactory fasteners systems will be obtained. Fastener systems that are normally used include bolts and nuts, toggle clamps, detent pins, bayonet pins and slots, and ball-lock mechanisms.

Table 4.3-1 General Captive Fastener Requirements

1. Fastener parts must be "held captive" so that they are not dropped when unfastened. An example of a typical captive screw application is shown on Fig. 4.3-2. The design shown has widespread use.
2. Fasteners should be accessible by a straight-on motion of a manipulator, torque wrench, or impact wrench.
3. Fasteners should be operated by a straight line motion of the manipulator or by simple rotation about a fixed axis. A
4. Fasteners should be made in such a way that mating parts are guided together.
5. The number of fastener sizes should be minimized.
6. Fasteners should be overdesigned, if (economically) feasible.
7. When possible, an indicator should be incorporated to indicate proper engagement or operation.
8. The design and fabrication of special fasteners should be avoided.

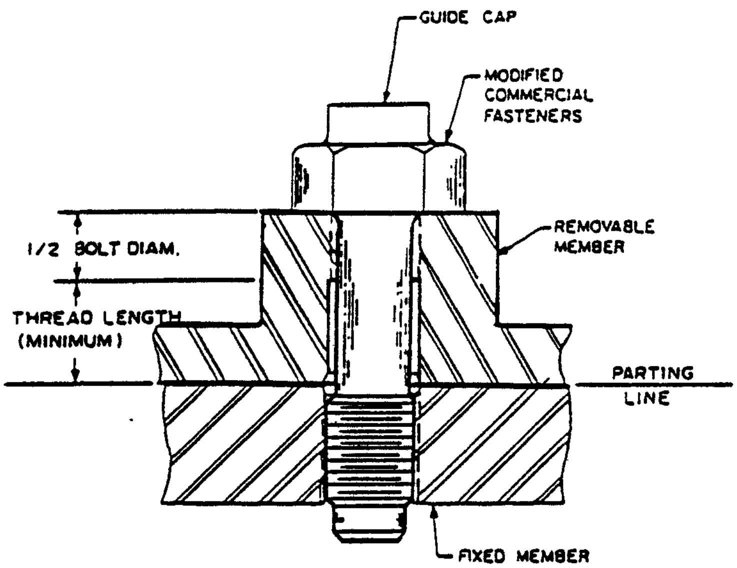


Fig. 4.3-2. Typical Captive Screw Application.

A

4.3.1 Bolts and Nuts — Consider the guidelines shown in Table 4.3-2 for selection of bolts and nuts.

Table 4.3-2 Guidelines for Selection of Bolts and Nuts

1. Use the coarse series of threads.
2. Use the largest bolt diameter feasible.
3. Remove the first two threads to the root diameter, as a minimum, to act as a guide to align the bolt and prevent damage from cross-threading. A
4. The bolts and nuts should be captive wherever possible.
5. The captive bolt should usually be mounted on the component being removed.
6. Captive nuts are preferred over tapped holes.
7. The nuts should have a lead-in taper to guide the bolt into engagement.
8. Alloy steel or stainless steel heat-treated to 38-42 Rockwell C[(1)] are the most desirable bolt and nut materials.
9. In many cases it is desirable to apply a dry-film lubricant to the bolt threads.
10. Avoid the use of slotted head bolts. A

V FW/B/S DESIGN GUIDELINES

*Not available at this time.

A

There currently exists a wide variety of designs and proposed design concepts for the FWBS components. Because the tokamak and mirror designs are currently of greatest interest, the FWBS for these concepts will be given precedence. However, other concepts will be included wherever possible. The purpose of this chapter is to present a very brief description of the design approaches and some comparison between those approaches that indicates how they influence maintenance and how the design is influenced by maintenance requirements. Design guidelines for FWBS assemblies, subassemblies and components will be included to assist in designing these elements for maintenance. This information provides a basis for defining and selecting the specialized maintenance and inspection equipment guidelines set forth in Chapters VI through X. Only one subsection of this chapter has been completed.

First wall, blanket and shield joints and closures which affect maintenance are primarily those which provide for assembly/disassembly of components that must be removed and replaced during the life of the reactor. These will include the sector concepts which have large sealed joints in the vacuum wall, frequently as part of the shield, and joints between sectors which have no direct attachment. Most joints are of specialized design, such as for the blanket breeder cavities, but many also utilize standard commercially available joints, such as for coolant lines. All joints and closures in these areas must be remotely assembled/disassembled. Each type of joint will be the subject of a separate subsection. The joints to be included are listed in Table 5.2-1. A

Table 5.2-1 FWBS Joints and Closures

- Conducting First Wall Joints
- Shield Door, Vacuum Seal Joints
  - Latches
  - Weldments
- FWBS Sector Joints
- Coolant Joints
  - First Wall
  - Blanket
  - Shield
  - Manifolds

  } { Water, Helium, Liquid Metal
- Fuel Line Joints
- Diagnostic Feedthroughs
- Modular Joints
  - Blanket Modules
  - Shield Modules
- Shield Door Closures
- Seals
  - Vacuum
  - Water
  - Helium
  - Liquid Metals

A

5.2.1 Conducting First Wall Joints - The first walls of some tokamak concepts are currently requiring the capability to conduct the induced current caused by the changing magnetic fields during operation or the current induced by a plasma disruption. Since many FWBS concepts utilize toroidal sectors which are not physically attached to each other except through the reactor base or roof structure at the back of the shield, specially designed joints are required. These joints must be disconnected without direct remote access, i.e., no tools are used to operate the joint actuator, because access, except from within the reactor, is impractical. The key components of these electrical connectors is the actuator system and the electrical contacts used. These will be treated separately.

5.2.1.1 Joint Actuators - Many actuator concepts have been devised but none are yet proven in their operating environment. These are either actively actuated from an outside power source, or are passively actuated as a function of their design. Figures 5.2-1 and 5.2-2 show the active and passive concepts, respectively, for a number of these devices. A

Guidelines for the design of these actuators and contacts include:

- Maximum spacing is established to reduce forces between sectors to prevent any permanent structural distortion during a plasma disruption.
- Contact spacing and size is defined to provide a low resistance current path in preference to the vacuum/plasma gap between sectors.
- Contact actuation must be remote or from within the plasma chamber.
- A positive opening action is required.
- The actuator must be protected from plasma thermal radiation and cooled, if necessary.
- A minimum of mechanisms is desired to provide reliability.
- Failsafe opening of the contact is necessary in the event the contact points are welded during reactor operation.

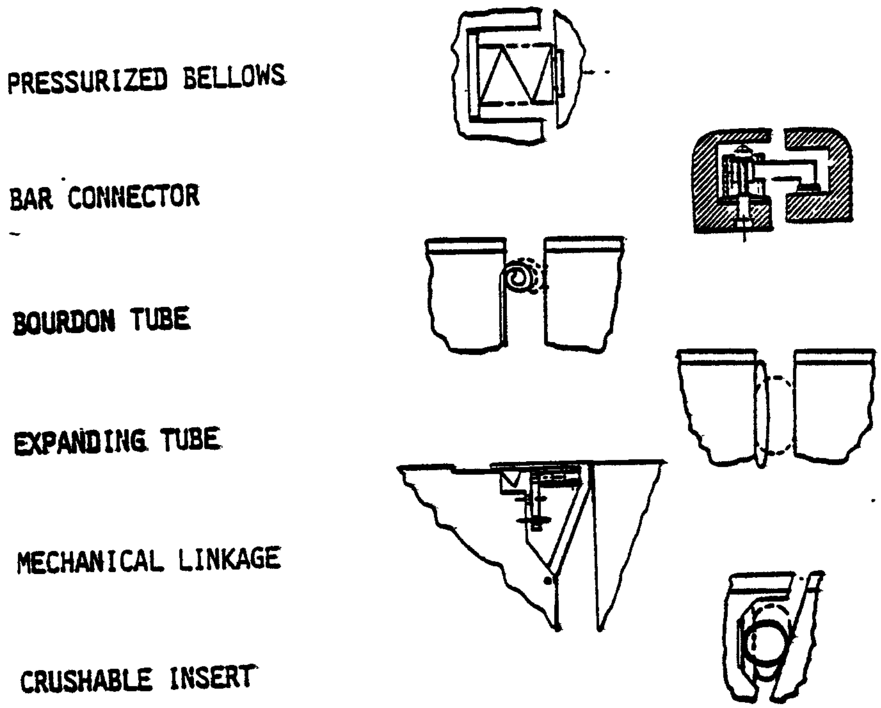


Figure 5.2-1 First Wall Connector Options (Active Concepts)

A

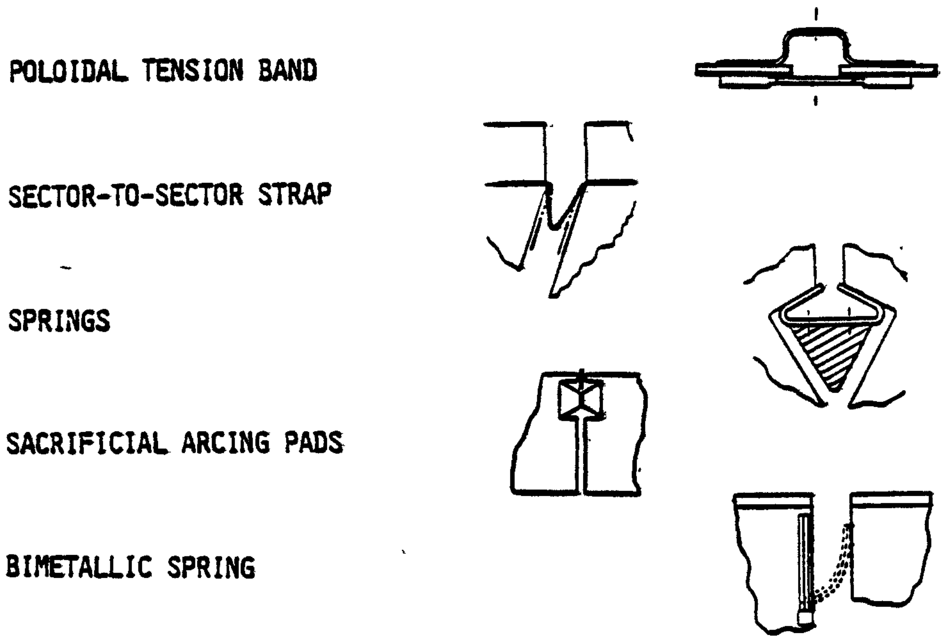


Figure 5.2-2 First Wall Connector Options (Passive Concepts)

A

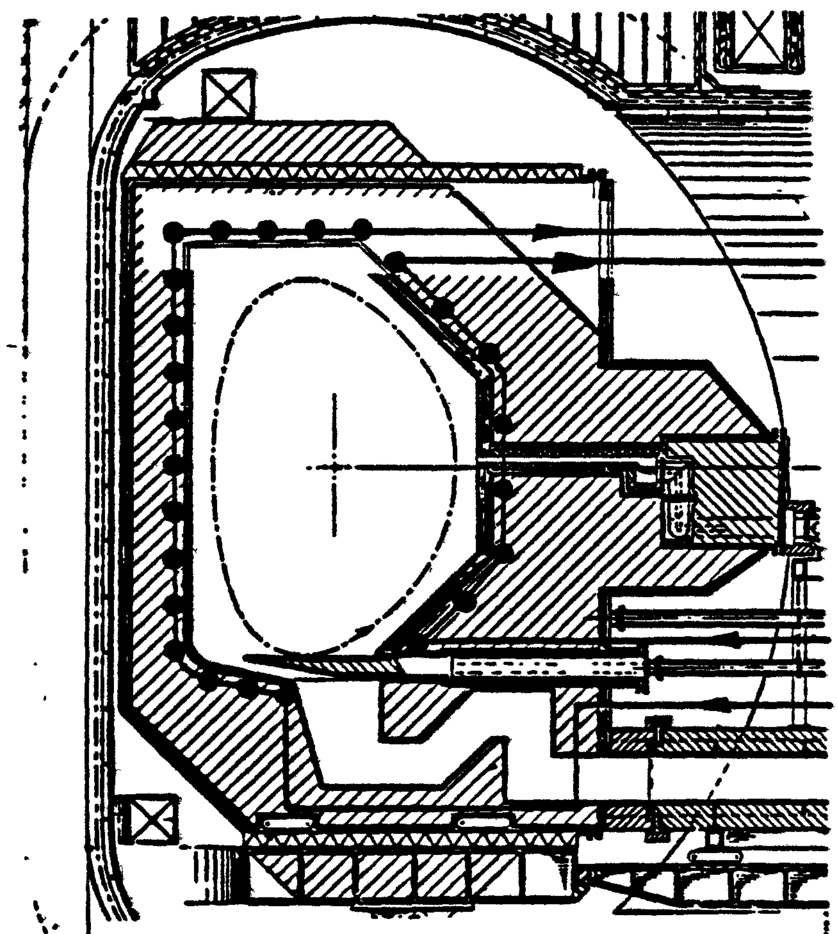
- The actuator must maintain contact during thermal expansion and contraction of the FWBS sectors while the reactor is operating.
- Springs are generally undesirable for devices near the first wall or unprotected from neutron radiation because of relatively rapid deterioration of spring resiliency from radiation damage.

Pressurized Bellows - The bellows concept utilizes a series of individual contacts spaced around the periphery of the first wall between sectors as shown in Figure 5.2-3.[1] Each contact is located on the side of each sector immediately behind the first wall and recessed to reduce radiation damage and heating. The bellows requires a pressurized coolant to cool the bellows and provide a positive pressure which moves the contact across the gap between sectors and provides pressure to mate the electrical contacts. Contact pressures are discussed in Section 5.2.1.2. The contact is opened by reducing the coolant pressure below atmospheric and bringing the plasma chamber to atmospheric pressure. The internal electrical conductors also act as a weak spring to retract the contacts. A

Bar Connector - A series of concepts have been devised which employ a bar that is pivoted across the gap between sectors and makes contact.[2] This

(1) *Kirchner, J., "Sector-to-Sector Electrical Contacts," Fusion Engineering Design Center, FEDC-M-82-RE-093, May 21, 1982.*

(2) *Gorker, G. E. and Kunselmann, M., "Torus Sector Electrical Connecetors," Fusion Engineering Design Center, FEDC-M-81-ES-101, December 11, 1981.*



200 KA SECTOR-TO-SECTOR ELECTRICAL CONTACT SPACING AND COOLANT SCHEMATIC

Figure 5.2-3 FW Electrical Connector Locations - FED

A

mechanism is located at points around the first wall periphery and recessed for protection. The bar is activated by either rotating it physically from within the plasma chamber after the sectors are in place or by the magnetic field. Pressures between the electrical contacts are very light with field actuation. The bar is retracted by a spring when field actuation is employed or by direct mechanical forces from within the plasma chamber. Cooling and failsafe provisions are limited.

Bourdon Tube - This is one of several concepts that use an internally expanded tube. The fluid used for expansion can also be used for cooling. Contact areas and conductor areas can be provided by making these more continuous around the first wall periphery between sectors than the individual contacts previously described.

Mechanical Linkage - The actuating force for this linkage is provided by a continuous cable or series of links around the periphery of the sector first wall. This cable is fed through the shield and the contacts are mated or opened by pulling on either end of the cable from outside of the shield while the sectors are in place. The cable or links are spring loaded to maintain contact while the gap width changes because of thermal expansion. The contact area can be made of linear sections around the first wall periphery. The contact plate would require internal cooling. A

Crushable Insert - This concept uses a replaceable insert that is deformed when the second of the mating sectors is emplaced. As the sector moves into place, the protruding insert makes contact across the gap between sectors. Further movement crushes the insert and rolls or slides it slightly. Sufficient resiliency is required to accommodate the change in gap width with thermal expansion and contraction of the sectors. The contacts are disengaged when the sector is withdrawn.

Poloidal Tension Band - This band is considered a passive concept because there is no active forcing mechanism operating once it is installed. The contacts are joined by a flexible conductor strap that is continuous around the periphery of the first wall between sectors. This strap is fed into a slot in the shield behind the first wall after the sectors are in place and then clamped by a takeup mechanism behind the shield. Disassembly occurs by removing the strap from behind the shield. The strap is cooled by radiation and conduction.

Sector to Sector Strap - This strap is attached from within the plasma chamber and, in the particular case illustrated in Figure 5.2-2, it is installed behind the graphite armor tiles.[3] The conductor strap is provided with thermal protection by a refractory metal alloy cover strap attached with the conductor. This strap accommodates the change in intersector gap dimensions caused by thermal expansion and contraction. However, installation and removal requires an in-vessel manipulator system. A

Springs - Springs can be designed to be affixed to the reactor sector framing structure, as shown in Figure 5.2-2, or to the sectors. These mate with the sectors when the sectors are emplaced and require no further actuation. The spring action maintains contact during thermal expansion and contraction. These devices are difficult to locate near the first wall. Because of this, large forces may be induced in the sectors when the current moves from the first wall to the contact and back again.

Sacrificial Arcing Pads - The pads are designed to produce local charge concentrations and present a preferred path to the next sector through a small gap. This would result in arcing during a plasma disruption and destroy a pad. This passive concept requires no actuation and has no cooling. However, sector construction and emplacement tolerances must be less than considered for the foregoing concepts.

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[3] *Kirchner, J. "Sector-to-Sector Electrical Strap Design," Fusion Engineering Design Center, FEDC-M-82-RE-096, June 10, 1982.*

Bimetallic Spring - This concept provides contact only after the reactor heats up, e.g., during bakeout. When the reactor is cooled, the contact would be opened. Contact pressures are expected to be light. The radiation damage effect should be small because the spring action is caused by thermal expansion coefficient differences. Contact metals must be attached to the bimetal spring to provide sufficient contact area to prevent welding. Radiation/thermal protection and cooling may be required.

5.2.1.2 Electrical Contact Materials - The selection of materials for the conducting first wall electrical contacts and the design of those contacts is crucial for remote maintenance. The contacts should have the following characteristics:

- Very high conductivity to provide a preferred current path for plasma disruption paths. A voltage drop across the entire contact assembly of less than 10 volts is the goal at this time. A
- The capability to carry the maximum current per unit area without welding the contact surfaces. This is affected significantly by the surface configuration as well as by the material.
- Minimum weld strength for ease in separating the contacts if a weld does occur.
- The contact surfaces should provide maximum contact surface area per unit area of the contact. This recognizes that all of the area of a particular contact surface does not mate with the other part of the contact.
- Contact pressures should be uniformly distributed across the contact surface.

Table 5.2-2 lists the characteristics of materials that are candidates for electrical contacts.[4] Those which appear to have the best characteristics for

[4] Banker, D.C., "FWBS Engineering Technology Program, Assembly, Maintenance and Repair, Test Program Element IV, Annual Report-1982, Volume III, Electrical Contact Materials Survey," McDonnell Douglas Astronautics Company, prepared for Argonne National Laboratory, January 1984.

PRELIMINARY

Table 5.2-2 Properties of Selected Metals and Alloys

	RESISTIVITY (Ω - CM)	CONDUCTIVITY Ʊ - CM	HARDNESS (PSI)	WELD STRENGTH	MELTING POINT °C	OUTGASSES?	% MIX	RESISTANCE TO ARC EROSION	RESISTANCE TO OXIDATION
ALUMINUM	2.66×10^{-6}	3.76×10^{5}	40×10^{3}	STRONG AS ORIGINAL METAL	660	NO	100% PURE	LOW	LOW
CARBON	1.37×10^{-6}	7.27×10^{2}	20×10^{3}	↓	3000	YES	↓	LOW	HIGH
COPPER	1.67×10^{-6}	5.98×10^{5}	60×10^{3}	↓	1080	NO	↓	LOW	LOW
MOLYBDENUM	5.7×10^{-6}	1.8×10^{5}	350×10^{3}	↓	2620	↓	↓	HIGH	HIGH <800°F
TUNGSTEN	5.5×10^{-6}	1.8×10^{5}	700×10^{3}	↓	3410	↓	↓	HIGH	HIGH <800°F
SILVER	1.59×10^{-6}	6.29×10^{5}	60×10^{3}	↓	960	↓	↓	LOW	HIGH
COPPER/TUNGSTEN	5.77×10^{-6}	1.73×10^{5}	N/A	0 → 1,000	1080*	↓	25/75	HIGH	LOW
SILVER/MOLYBDENUM	3.0×10^{-6}	3.3×10^{5}	135×10^{3}	0 → 500	960*	↓	40/60	HIGH	HIGH <800°F
SILVER/TUNGSTEN CARBIDE	4.3×10^{-6}	2.33×10^{5}	245×10^{3}	N/A	960*	↓	40/60	HIGH	HIGH
SILVER/LEAD	N/A	N/A	N/A	0-45	920	↓	94/6	N/A	LOW
SILVER/TUNGSTEN	3.05×10^{-6}	3.28×10^{5}	142×10^{3}	0 → 500	960*	↓	40/60	HIGH	HIGH
SILVER/CADMIUM OXIDE	2.3×10^{-6}	4.3×10^{5}	78×10^{3}	0-10	960*	YES	88/12	LOW	HIGH
SILVER/COPPER	2.65×10^{-6}	3.77×10^{5}	145×10^{3}	N/A	788	NO	72/28	LOW	LOW
SILVER/BISMUTH	N/A	N/A	N/A	0 → 100	940	↓	97/3	LOW	LOW
SILVER/TELLURIUM	N/A	N/A	N/A	0-550	N/A	↓	99/1	N/A	N/A
COPPER/CARBON	1.2×10^{-4}	8.3×10^{3}	N/A	N/A	N/A	YES	27/73	HIGH	HIGH
COPPER/LEAD	N/A	N/A	N/A	130-990	1070	NO	99/1	LOW	LOW
COPPER/THALLIUM	↓	↓	↓	45-990	N/A	↓	97/3	N/A	N/A
COPPER/BISMUTH	↓	↓	↓	10 → 40	1050	↓	90/10	LOW	LOW
COPPER/TELLURIUM	↓	↓	↓	N/A	N/A	↓	95/5	N/A	N/A
LEAD/ALUMINUM	↓	↓	↓	0-400	N/A	↓	4/96	LOW	LOW

N/A = NOT AVAILABLE

* = MELTING POINT OF NON-REFRACTORY CONSTITUENT (I.E. SILVER OR COPPER)

A

electrical contacts include mixtures of a refractory metal or alloy and a highly conductive metal, such as Copper Tungsten, Silver Molybdenum or Silver Tungsten Carbide. These are made of a compacted powder and scintered refractory metal infiltrated with the conductor. Silver Lead also appears to have excellent characteristics.

Test data defining the maximum current achievable without welding the contacts at varying contact pressures from 0.069 MPa (10 psi) is plotted in Figure 5.2-4.[5] Very little difference was found among the three metals. The most significant difference in current carrying capability appears to be a function of the surface characteristics. The smoothness of the surface and possibly the amount of oxide buildup may be critical. The current carrying capability also increased with contact pressure but the maximum current density decreased with the larger area contacts tested. No appreciable gain appeared when using dissimilar metal mixes for contacts. More detailed characteristics are found in Reference 5.2-5. A

[5] Zahn, H. S., "FWBS Engineering Technology Program, Assembly, Maintenance and Repair, Program Element IV, Final Report, Volume II. Electrical Contact Materials Test Report," McDonnell Douglas Astronautics Company, prepared for Argonne National Laboratory, January 1984. (to be published)

VI INTERFACE EQUIPMENT GUIDELINES

A

*NA - Not available at this time.

This chapter provides guidelines for designing specific FWBS interfacing systems and components for remote AMR. The manipulation, viewing, handling, inspection, and general purpose tools that are used to actually perform the remote work are described in Chapters VII through X.

In this issue, only the remotely operable connectors that are required to interconnect FWBS systems with coolant lines, vacuum ducts, and electrical lines are included. These components are discussed under the applicable subsystems in Sections 6.1, 6.3, and 6.8. A

6.1.1 Pipe Connectors — There are many types of pipe connectors and it would be impractical to list all of them here. However, some of the connectors suitable for remote maintenance consideration are listed below.

6.1.1.1 Hanford-Purex Connector — The connector is shown in Fig. 6.1-1. It resembles a three jaw gear puller. The separation line contains a wedge type compressible packing on a spherical seat. An interrupted guide funnel aligns the horizontal pipe section with the vertical pipe hub. The jaw legs pass through the funnel notches to reach a flange. The jaw legs are pivot mounted in a threaded collar which receives the operating bolt. A cam ring below the threaded collar forces the jaws radially into engagement when the connector is drawn tight. An inner cam surface on the cam ring forces the jaws open to release the connector. The bolt operation presses the horizontal jumper against the vertical hub compressing the packing.

The Hanford-Purex connector has been used satisfactorily on many two and three inch low pressure applications. Hands on maintenance is required to change the packing. Piping strains are absorbed in the packing. The coupling/decoupling operation is fast using an overhead vertical center line impact wrench and a crane to lift the jumper/equipment section.

6.1.1.2 Remote Grayloc Connector — The Remote Grayloc connector is shown in Fig. 6.1-2. The symmetrical hubs have short tapered flanges which mate with a three sectioned clamp. The clamp sections have internal faces tapered to draw the hubs together as the clamp is tightened. The seal is located between the hubs. It is tee shaped with an external center post and tapered arms which wedge in the slightly greater taper of the hub. As the hubs are closed the lips of the arms are deflected elastically inward forming a narrow sealing band of contact. Contact surface remains at the outer edges of the seals thus providing a radial differential pressure across the seal which increases the seal area contact pressure as the internal pressure rises. Over-compression of the seal arms is prevented by the hubs bottoming on the seal rib.

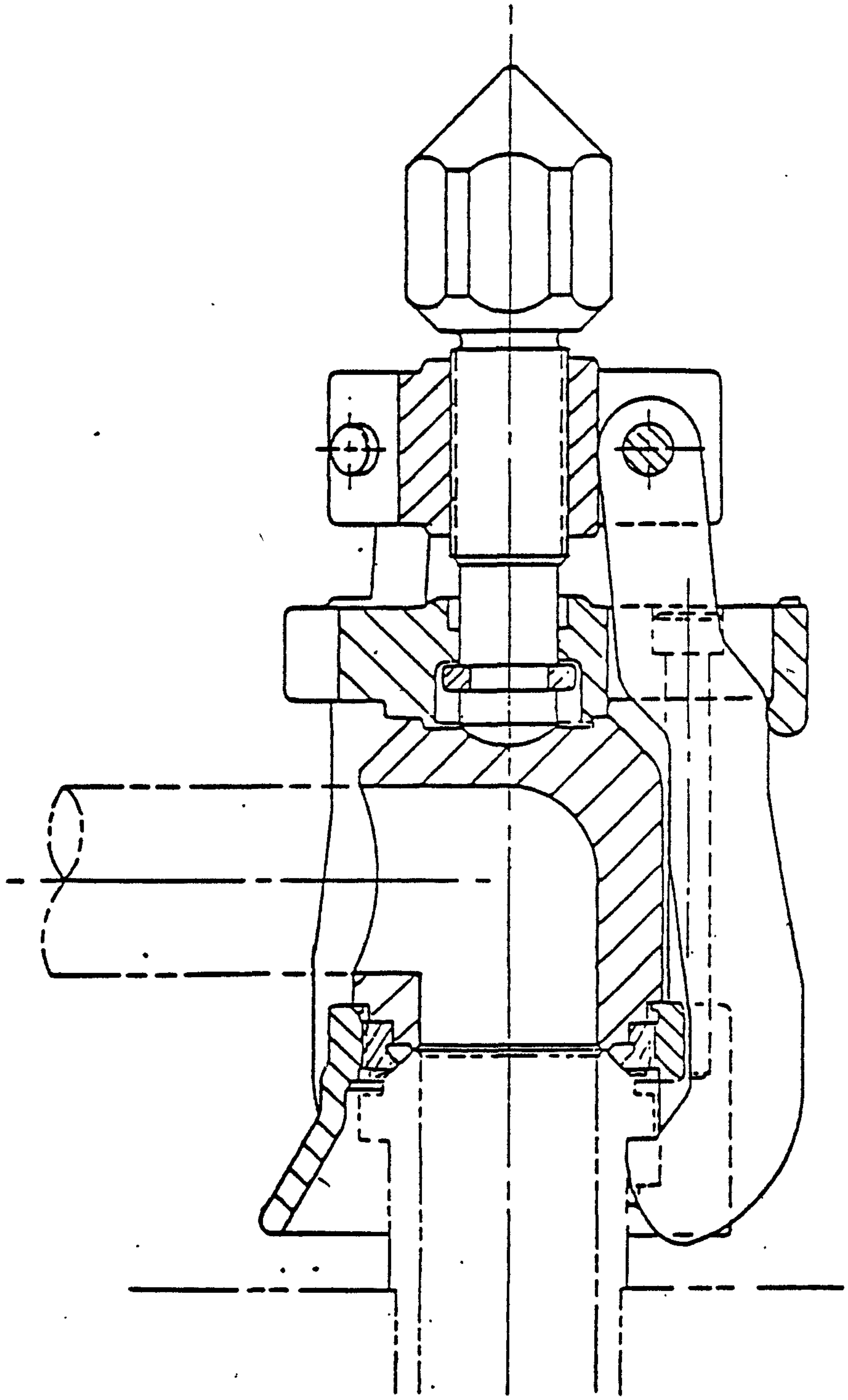
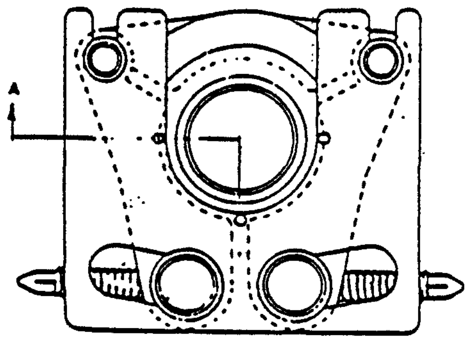


Fig. 6.1-1 Hanford-Purex Connector.



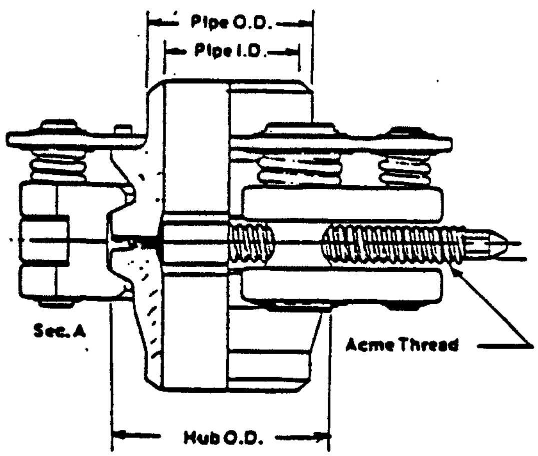


Fig. 6.1-2 Remote Grayloc Connector.

The Remote Grayloc clamp has an Acme screw and two pivot points to hinge the three piece clamp. The Acme screw is mounted in two barrel nuts. These nuts and the pivots are passed axially through a mounting plate secured to one hub. Axial springs on the pivots and nuts allow the clamps to find their center on the gapped or closed hubs. The ends of the barrel nuts and the pivots follow cam tracks in the mounting plate which spreads the clamp sections evenly as the clamp operates. This action provides balanced squeezing as the clamp is closed and also pulls the clamp sections free of the hubs on opening.

6.1.1.3 Rocky Mountain Nuclear Remote Connector — This connector, shown in Fig. 6.1-3, is almost an exact copy of the Remote Grayloc connector. The principle difference is that the hubs butt against each other around the seal instead of butting on opposing sides of the seal flange. Remote maintenance of the clamping mechanism is claimed to be simpler than with the Grayloc connector.

6.1.1.4 Walker Remote Connector — The Walker connector shown in Fig. 6.1-4 is designed for a pipe jumper with a vertical pipe rise to the bottom hub and a horizontal pipe run from the top hub. A yoke is mounted on the bottom hub. The yoke is open at the center line and on the side of the horizontal pipe run to permit a straight vertical lift of the upper hub through the yoke. The bolt is connected to the upper hub by two pins engaging a circumferential groove in the bolt. The bolt is equipped with a barrel nut having two trunnions which engage two ears on the yoke when the nut rotates 90°. Rotating the bolt further raises the barrel nut up into the socket. When the trunnions bottom in the sockets, the bolt presses the upper hub down on the lower hub clamping the seal between them. When the bolt is untorqued the barrel nut descends until it clears the ears on the yoke. It is then free to rotate 90° aligning the trunnions with the open vertical passages thus permitting the upper butt and horizontal line to be lifted clear.

6.1.1.5 TRU Connector — The TRU connector shown in Fig. 6.1-5 uses an offset single bolt to apply clamping and sealing force through a swing clamp. Sealing is accomplished by use of an all-metal, conical-seating seal arrangement.

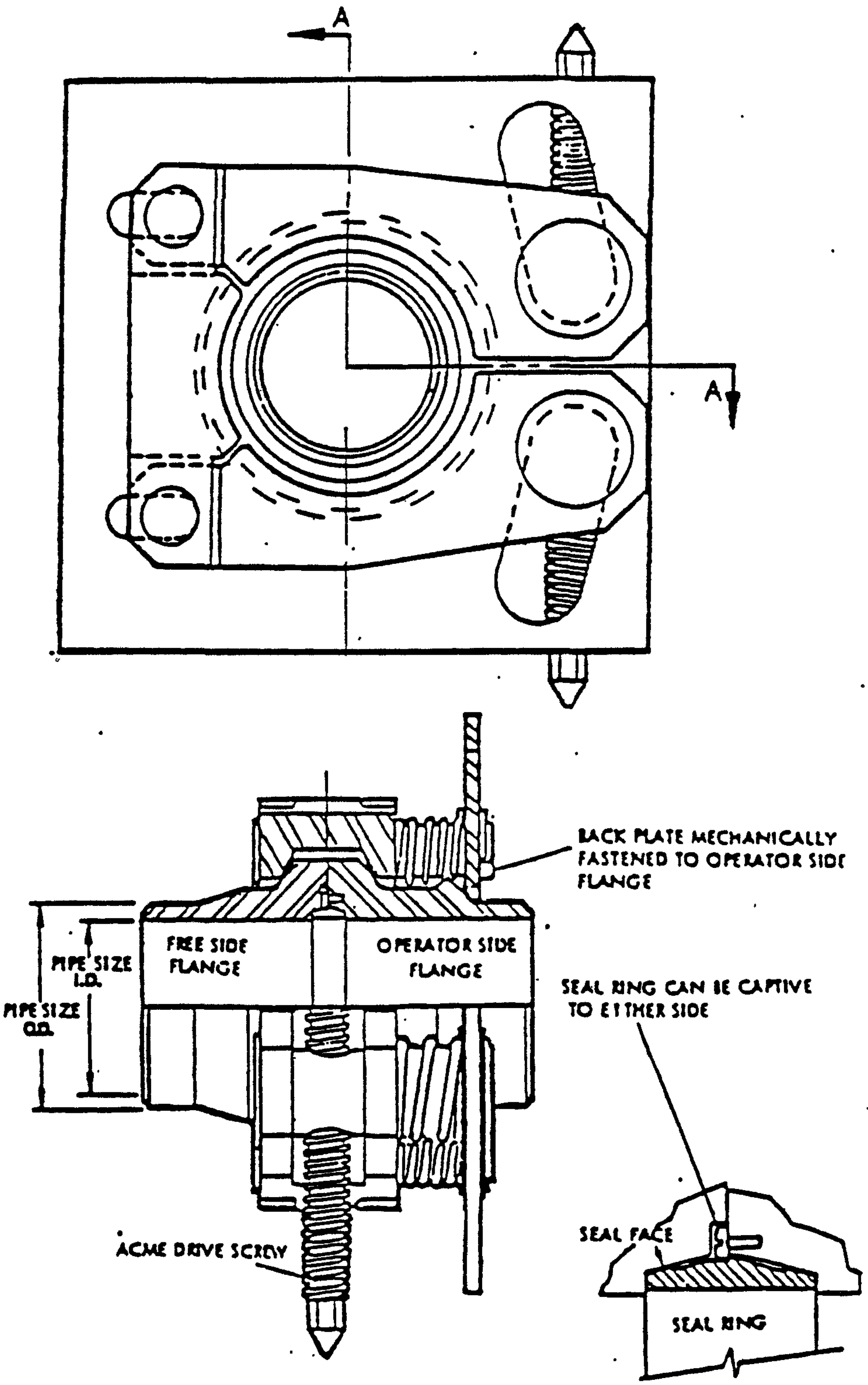


Fig. 6.1-3 Rocky Mountain Nuclear Remote Connector.

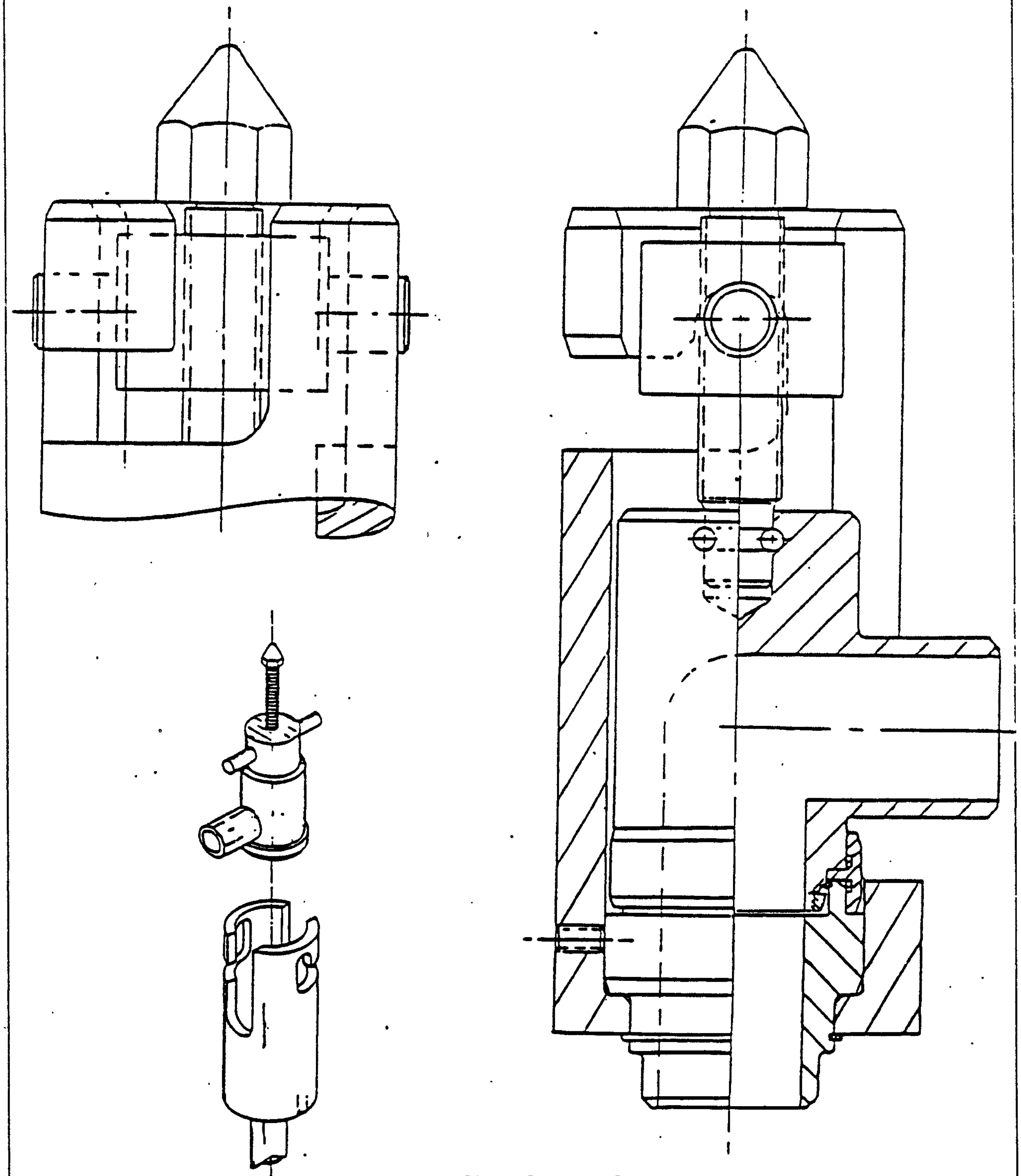


Fig. 6.1-4 Walker Remote Connector.

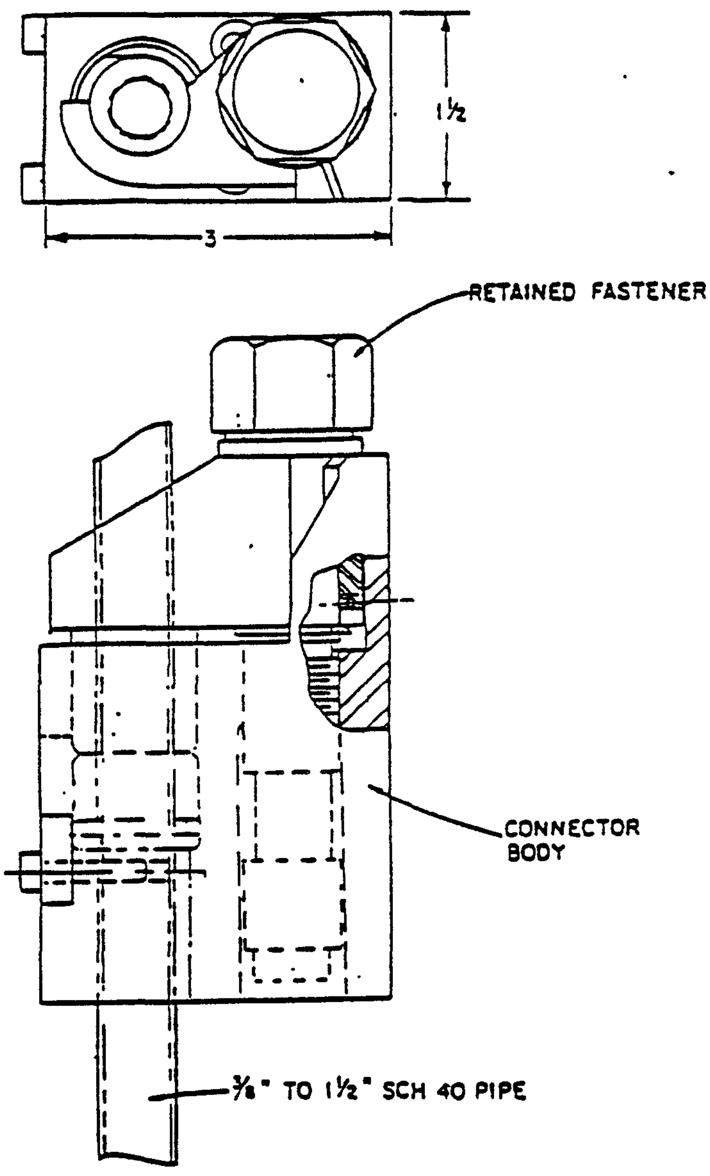


Fig. 6.1-5 TRU Connector.

6.1.1.6 REMOTEC Swing Clamp Connector — The connector shown in Fig. 6.1-6 is available for tubing sizes up to 0.75-in. dia. and is an improved, single-bolt type similar to the TRU. The connectors differ in that the REMOTEC version offers the capability to easily change the sealing element, and the simplified design is less expensive to fabricate.

The body portion of the connector can be affixed to any given structure, and a stationary portion of tube or pipe to be joined is clamped within the body. The body provides for axial alignment of the second removable portion of tube or pipe and carries the C-shaped swing clamp. The swing clamp engages the removable portion moving it axially towards the stationary portion to effect the seal. A

The motion of the swing clamp is accomplished by a left-hand threaded bolt that engages the threads of the swing clamp and mounts in the body as the pivot element. Frictional engagement between the swing clamp and bolt provides the movement of the swing clamp between mechanical stops as the bolt is rotated. Upon engaging one of the stops, the swing clamp moves axially with respect to the removable portion of tube or pipe by further rotation of the bolt.

A replaceable metallic or elastomeric seal is carried by the removable portion so the joint may be refurbished and reused as necessary.

6.1.1.7 Modified Commercial Flanges — Commercial flanges can be modified as shown in Fig. 6.1-7.[1] The modified flanges are especially effective for larger pipe sizes or where infrequent removal is required.

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[1] *Hager, E. R. and R. E. Field, "Remotely Maintainable Connectors for Fusion Development," American Nuclear Society Proceedings of the 30th Conference on Remote Systems Technology, 1982.*

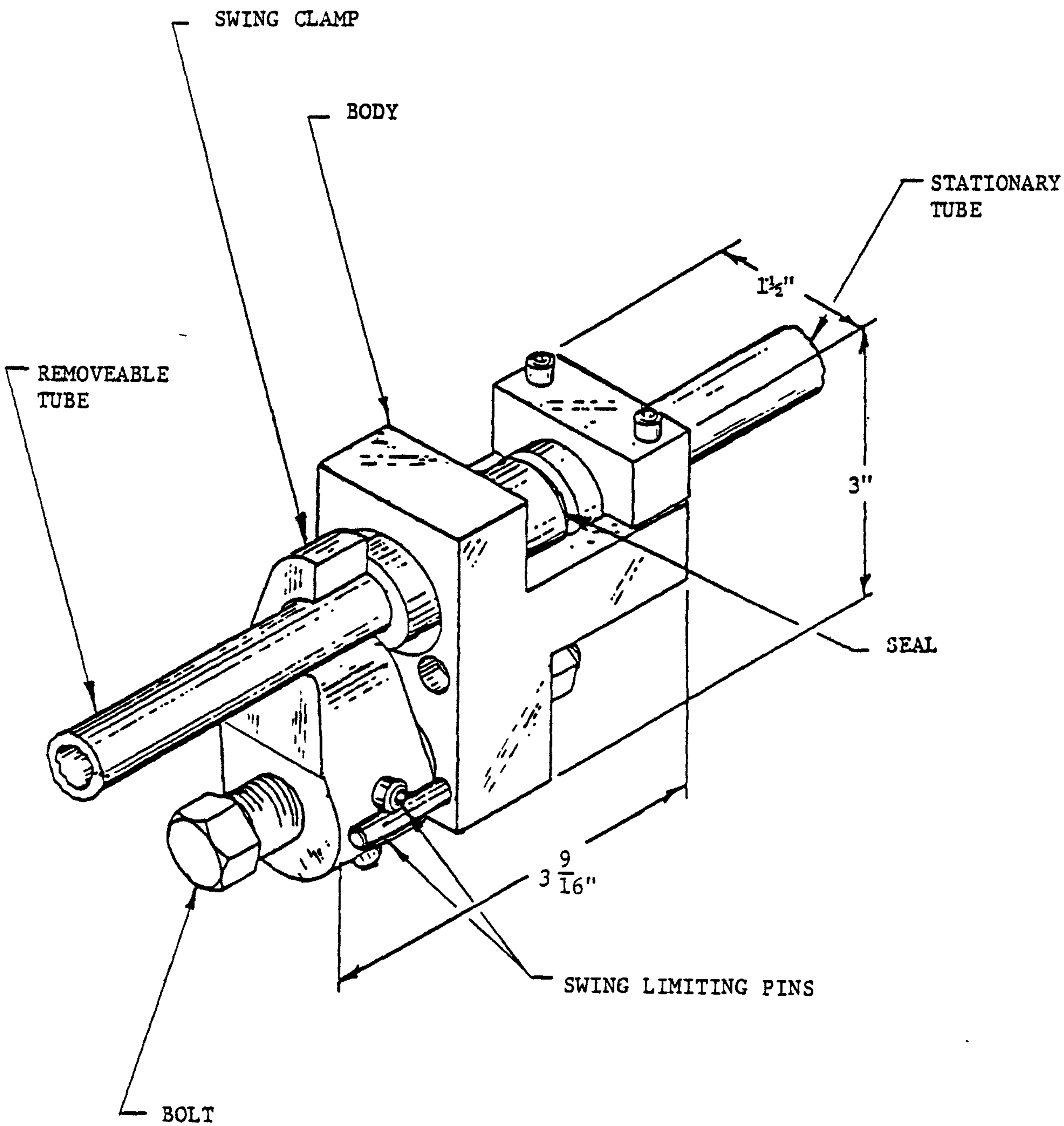

Fig. 6.1-6. REMOTEC Swing Clamp Connector.

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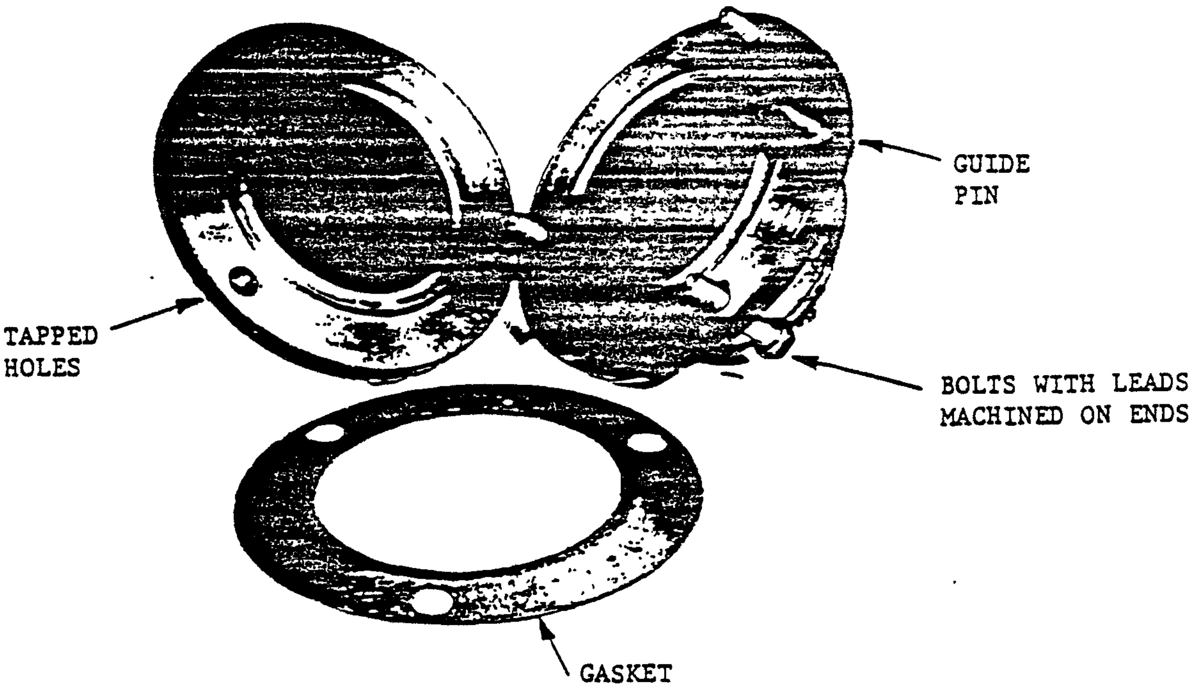

Fig. 6.1-7 Modifications to Typical 3-Bolt Flange.

A

6.1.1.8 Modified Commercial Quick Disconnects — Commercial quick disconnects can be modified as shown in Fig. 6.1-8. The modified quick disconnects are convenient for applications requiring frequent removal such as flex lines, air operated tools and sampling equipment. A

6.1.1.9 Commercial "Off-the-Shelf" Hardware — Commercially available hardware items such as tube fittings, pipe unions, and etc., can be used remotely without modification if in-cell maintenance systems provide adequate dexterity and proper tool clearance is provided. A

Table 6.1-1 is a list of manufacturers that provide connector joints that have been used in remotely operated cells.

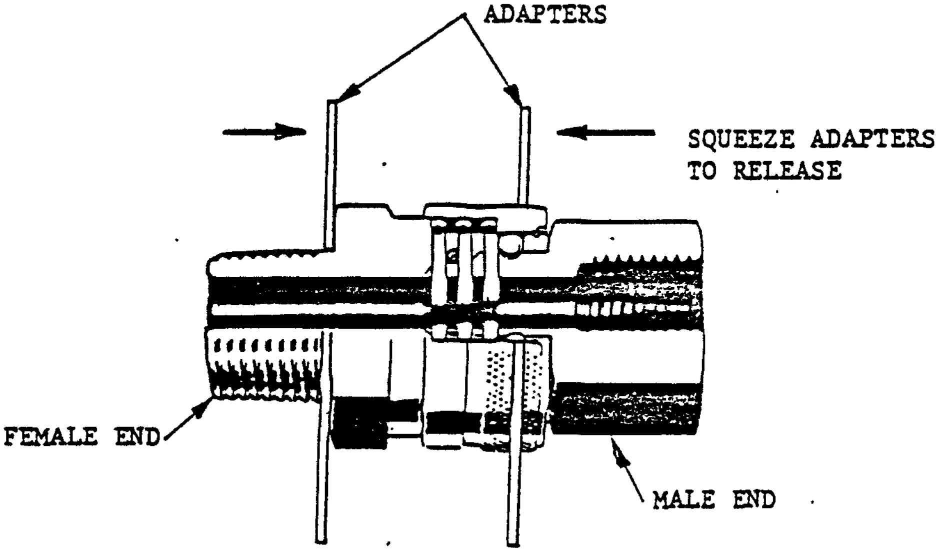

Fig. 6.1-8 Modifications to Typical Quick Disconnect.

A

Table 6.1-1 Connector Suppliers

Product	Company
Tube Fittings and Quick-Connects	Swagelok Crawford Fitting Company 29500 Solon Road Solon, OH 44139
High Pressure Tubing Fitting	Sno-Trik 32550 Old South Miles Road Solon, OH 44139
Pipe and Tube Fittings	Gamah Division of Stanley Aviation Corporation P.O. Box 20308 Denver, CO 80220
Quick-Connects	Hansen Couplings The Hansen Manufacturing Company 4050 West 150th Street Cleveland, OH 44135
Pipe and Tube Joints	Marman Clamps Aeroquip Corporation 300 South East Avenue Jackson, MI 49203
Tube Fittings and Quick-Connects	Parker-Hannifin 17325 Euclid Avenue Cleveland, OH 44112
Tube Fittings	Hoke, Incorporated One Tenakill Park Cresskill, NJ 07626
Hanford-Purex Connector	No commercial supplier - drawings available, fabrication required.
Remote Grayloc Connector	Gray Tool Company 7135 Ardmore Street P.O. Box 2291 Houston, TX 77001
Rocky Mountain Nuclear Remote Connector	Rocky Mountain Nuclear Manufacturing and Engineering, Inc. 2230 South 2000 West Salt Lake City, UT 84119
Walker Remote Connector	Remote Technology Corporation 114 Union Valley Road Oak Ridge, TN 37830
TRU Connector	Remote Technology Corporation 114 Union Valley Road Oak Ridge, TN 37830
REMOTEC Swing Clamp Connector	Remote Technology Corporation 114 Union Valley Road Oak Ridge, TN 37830

A

6.3.1 Pipe Connectors - There are numerous pipes in a fusion plant that are used to interconnect support and diagnostic equipment to the primary vacuum system. Many maintenance operations require that the pipes be disconnected and reconnected for replacement of failed equipment. In some cases, the pipes will be radioactive or located in a high radiation area necessitating the use of remotely operable connectors. Some of the remote pipe connectors described in Section 6.1.1 can be used for high vacuum and possibly the very high vacuum (1×10^{-8} torr) service required in the vicinity of the FWBS.

The American Vacuum Society defines vacuum as follows:

High vacuum:	1×10^{-3} to 1×10^{-5} torr
Very high vacuum:	1×10^{-6} to 1×10^{-8} torr
Ultrahigh vacuum:	1×10^{-9} torr and below

A

Tokamak and mirror reactors require only very high vacuum with ultrahigh vacuum being limited to such concepts as heavy ion inertial confinement systems.

The designer should give consideration to radiation levels, temperatures, and the frequency of actuating the connectors when selecting seals for the pipe connectors. The metallic seals are superior to elastomer seals in a high radiation and temperature environment. Also, the outgassing rate of materials to be used as seals must be considered when choosing a connector and seal, refer to Table 6.3-1. Outgassing provides a particular problem during bakeout cleaning of the plasma chamber. In addition, materials must withstand bakeout temperatures (specified as 250°C [482°F] for TFTR). Elastomers tend to lose resiliancy. Radiation dosages on the order of 10^4 to 10^8 Rads deteriorate most elastomeric materials.

On the other hand, remotely achieving a vacuum-tight connection with metal seals is very difficult. Metal seals in very high vacuum environments can rarely be reused. Any movement of the seals with respect to the flange or seal support cannot be permitted, even when assembling or positioning the flanges. Remote assembly of a joint must lead it into mating the seal without touching until positioning is precisely correct except for applying seal pressure. Seal

Table 6.3-1 Outgassing Rate of Materials[1]

Outgassing rate, after being pumped on for the noted times (in torr-liters/sec. per cm^2), at average room temperature.

Material	1 Hr.	4 Hrs.	10 Hrs.	24 Hrs.
Kel-F	4×10^{-8}	1.7×10^{-8}		
Neoprene	8×10^{-6}	5×10^{-6}		
Viton A				2×10^{-8}
Teflon	4.7×10^{-7}	2.8×10^{-7}	2.1×10^{-7}	
Silicone Rubber (Wacker R-60)	7.0×10^{-6}	1.7×10^{-6}		
Stainless Steel	9×10^{-8}	3×10^{-8}	2×10^{-8}	
Mild Steel	5.4×10^{-7}	1.4×10^{-7}	5×10^{-8}	
Aluminum	1.5×10^{-6}	3.7×10^{-7}		
Copper	2.3×10^{-6}			
Cast Brass	1×10^{-6}	2.5×10^{-7}	1.1×10^{-7}	

A

pressures must be carefully controlled to produce the required deflection or seal deformation. Stops of some type are usually used to control this and are designed into the flange/seal interface. Achieving a remote vacuum-tight connection with metal seals is, at best, very difficult. Remote cleaning or preparation of the metal seals must be accomplished without any seal face damage, even a slight scratch, in order to achieve a high vacuum. Elastomeric seals are more readily handled remotely but have a shorter life in the severe environment. A

(1) *Veeco Industrial Equipment Division, Plainview, N.Y., Unnumbered Data Sheet, Personal Communication with H. Harvey, REMOTEC.*

6.3.1.1 Remote Grayloc Connector (see 6.1.1.2) - The Remote Grayloc connector will provide adequate sealing for the very high vacuum with the selection of the proper seals. This connector is being utilized in the Fusion Materials Irradiation Test (FMIT) facility in Hanford, Washington. It has been tested in high vacuum and demonstrated a leak rate of less than 10^{-6} cc/sec. A

6.3.1.2 Rocky Mountain Nuclear Remote Connector (see 6.1.1.3) - Comments are the same as for the Remote Grayloc except this connector is also available with a "Helicoflex" seal. This should provide adequate sealing for high vacuum applications. A

6.3.1.3 Walker Remote Connector (see 6.1.1.4) - The Walker connector utilizes a metallic seal and should provide adequate sealing for the very high vacuum requirements, however, reuse of the metallic seal may derate the sealing capabilities. No data is currently available on the use of this connector in a high vacuum environment. A

6.3.1.4 TRU Connector (see 6.1.1.5)

6.3.1.5 REMOTEC Swing Clamp Connector (see 6.1.1.6)

6.3.1.6 Modified Commercial Flanges (see 6.1.1.7) - The 3-bolt flange configuration has limited sealing capabilities in pipe sizes above 1" and should be considered for high vacuum applications only on small pipes. Standard commercial flanges are available for larger pipe sizes and higher vacuum applications. The manufacturing agencies are referenced in the latter portion of this section. A

6.3.1.7 Modified Commercial Quick-Disconnects (see 6.1.1.8) - Quick-disconnects require the use of elastomeric seals and friction sealing forces, therefore, they should not be considered for the very high vacuum ranges. A

6.3.1.8 Commercial "Off-the-Shelf" Hardware - Table 6.3-2 is a list of manufacturers that provide connector joints adequate for various vacuum applications. A

Table 6.3-2 Connector Suppliers

Product	Company
Flanges, Seals, and Fittings	Varian Industrial Products 58 Cummings Park Woburn, ME 01801
"Cefilac" Seals	Joints Fargere Industries St, Etienne, France
Seals	Helicoflex Company 400 Myrtle Avenue Booton, NJ 07005
Flanges and Fittings	Cajon Company 32550 Old South Miles Road Solon, OH 44139
Fittings and Quick-Connects	Swagelok Crawford Fitting Company 29500 Solon Road Solon, OH 44139
Pipe and Tube Fittings	Gamah Division of Stanley Aviation Corporation P.O. Box 20308 Denver, CO 80220
Pipe and Tube Fittings	Remote Technology Corporation 114 Union Valley Road Oak Ridge, TN 37830
Quick-Connects	Hansen Couplings The Hansen Manufacturing Company 4050 West 150th Street Cleveland, OH 44135
Pipe and Tube Joints	Marman Clamps Aeroquip Corporation 300 Southeast Avenue Jackson, MI 49203
Tube Fittings and Quick-Connects	Parker-Hannifin 17325 Euclid Avenue Cleveland, OH 44112

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6.3.2 Rectangular Duct Joints - Two design concepts for a remotely operable joint attachment system for the large rectangular vacuum ducts required on advanced fusion machines are presented in this section. These concepts provide for more rapid assembly/disassembly than is possible with captive bolt systems currently in use. The designs were developed by Remote Technology Corporation (REMOTEC) and GA Technologies, Inc. (GA).[2]

6.3.2.1 Design Requirements - The design basis was the outer vacuum duct joint nearest the tokamak shield (Fig. 6.3-1) of the Fusion Energy Device (FED). Table 6.3-3 is a list of the design requirements for the joint attachment system.

6.3.2.2 REMOTEC Design - Existing, commercially available fastening methods that could be used, or modified and used, to meet the duct-joint system design requirements were surveyed[3], and no off-the-shelf- fastening system was found to be available. The options for this type of application fall into three general categories: A

- o clamping
- o latching, and
- o threaded fasteners

Evaluation of the options within the categories resulted in the design of the captive-screw clamp module for attaching duct sections. Fig. 6.3-2 illustrates the concept. One clamp half has tapped holes; the other half has mating clearance holes that provide a guiding fit with the screws. When the screws are torqued, the clamp halves are drawn together on the joing flanges to apply

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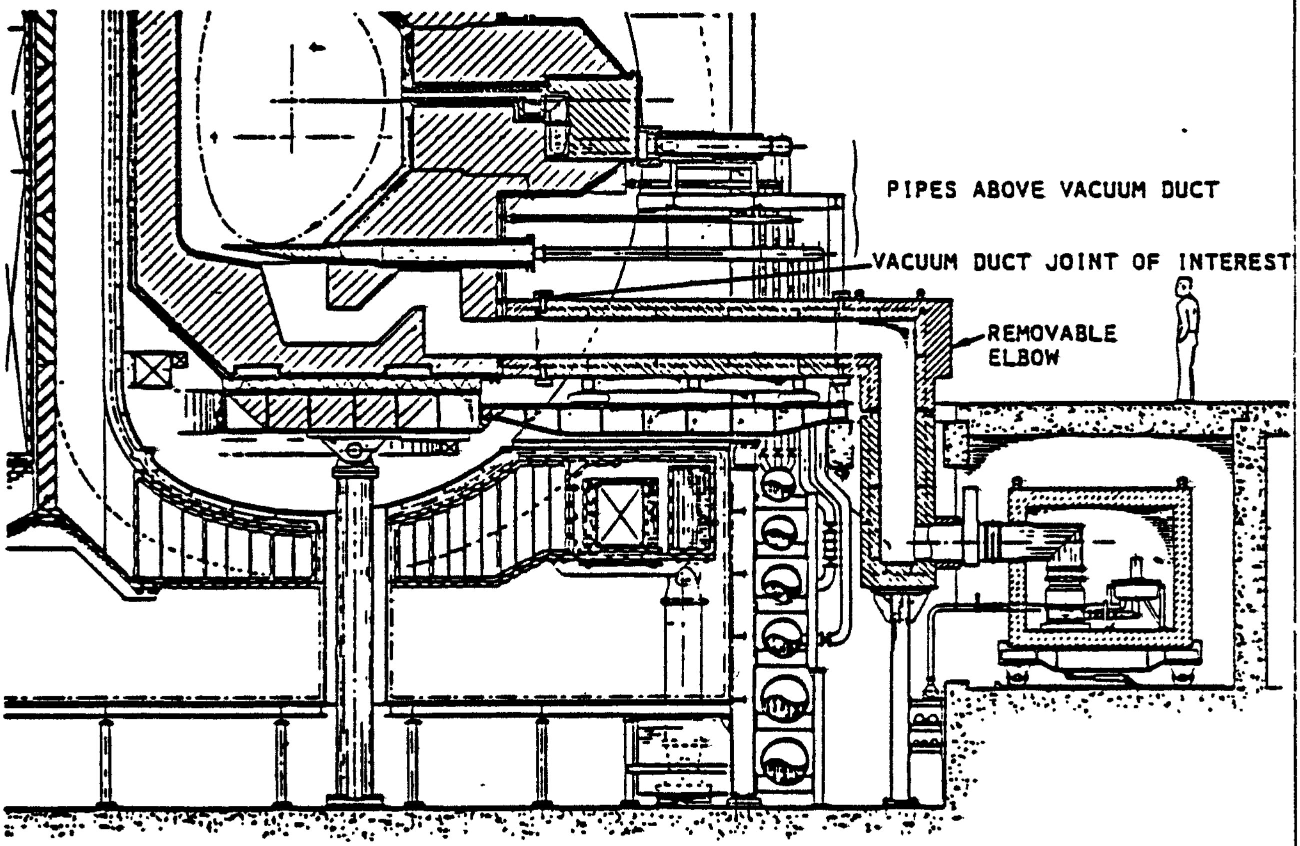
(2) *Zahn, H. S., Hagmann, D. B., Hager, E. R., et.al., "FWBS Engineering Technology Program, Assembly, Maintenance and Repair, Test Program Element IV, Phase 1 Annual Report-1982, Volume II, Seal Joint Systems," McDonnell Douglas Astronautics Company, prepared for Argonne National Laboratory, January 1983.*

(3) *Hagmann, D. B., and J. B. Coughlan, "A Remote Joint System for Large Vacuum Ducts," American Nuclear Society Fifth Topical Meeting on the Technology of Fusion Energy, 1983.*



A

Fig. 6.3-1. FED Vacuum Duct.

Table 6.3-3 Joint System Design Requirements

Parameter	Requirement
Duct Size	2.6 m x 0.4 m cross section opening. (1.0 m x 0.4 m for developmental designs)
Duct Access	Clearance around duct shield limited to: ≈ 0.5 m above duct, ≈ .13 m to 1.0 m laterally, ≈ 0 m below duct, and unlimited along duct axis. Duct is surrounded by shielding 0.4 m thick.
Duct Design	1" thick walls, 316 SS, with truss supports to limit deflection to 0.2".
Loads on Duct	Vacuum loads, duct weight, shielding weight. (Duct and shield weight not supported through joint.)
Joint Assembly/Disassembly	Mechanical operation (i.e., no welding).
Seal Design	Helicoflex, Dual Seal, .3" dia, Ag liner.
Loading Across Seals	8000 #/in. including 2280#/in limiter preload. A
Leak Check	Joint to be individually leak checkable.
Life	100 operations in 30-year life.
Temperature	250°C maximum at inner seal during bakeout 18 temperature cycles/year maximum.
Joint Handling	Fully remote, position to within .25" before engaging attachment system.
Axial Attachment System Takeup	0.75 inches.
Joint Adjustments	Maintain seal loads within tolerances.
Operational Interfaces	Joint mechanically demountable. Electrical, mechanical or pneumatically powered. Power unit integral or separable from joint.
Failure Constraints	Fail safe (fail closed). No single failure shutdown. Lock in closed position. Remote recovery from all failures.
Degree of Automation	Operable with remote tooling.

PRELIMINARY

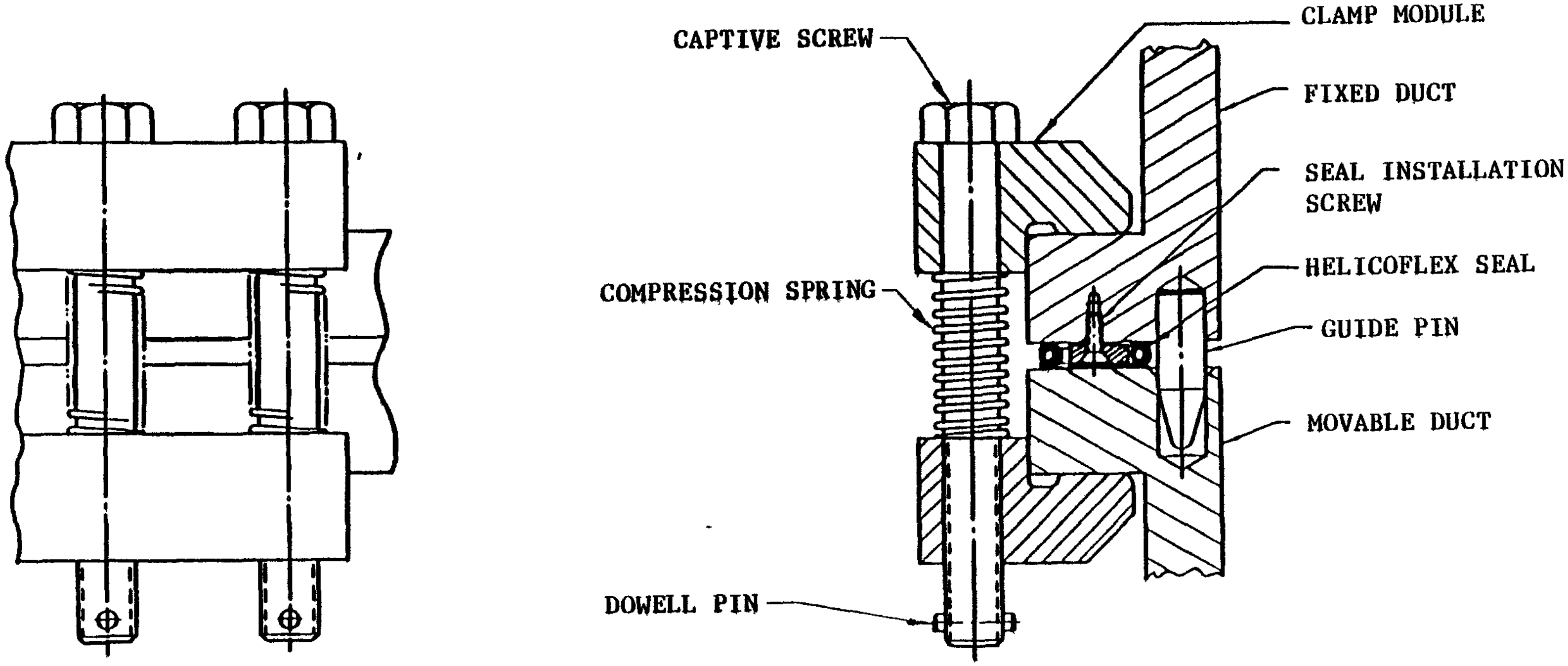


Fig. 6.3-2. Captive Screw Clamp Assembly.

PRELIMINARY

sealing pressure to the surfaces of the seal. Clamp removal is performed by rotating each screw to its mechanical stop. The compressed-spring force separates the clamp halves to relieve the sealing pressure.

Figures 6.3-3 and 6.3-4 show a typical vacuum duct joint where the internal flanges of the duct sections are joined together using the captive screw clamp modules. Modules are installed using a manipulator attached to the end of a telescoping boom. The clamps used on the upper half of the joint hang from pins that protrude from the flanges. Clamp screws are operated by a socket-equipped impact wrench gripped by the manipulator.

The internally clamped flange was chosen for the following reasons:

- The internal volume of the duct can be used for equipment operating space eliminating external access problems. A
- No joint shielding removal is required.
- Duct and shielding can be of unitized construction.
- A smaller size seal can be used.

The conclusions identified for the captive screw clamp concept are as follows:

- Clamping forces are applied directly over the seal.
- Very few operations are required to assemble/disassemble a joint.
- Fabrication and installation costs are low.
- Design is simple, tending to yield high reliability.
- Double seals can be easily leak checked.
- Modular design of clamp provides for rapid replacement during maintenance operations.
- The design concept can be used on other joint configurations such as round pipes and sector flanges, either on internal or external flanges.

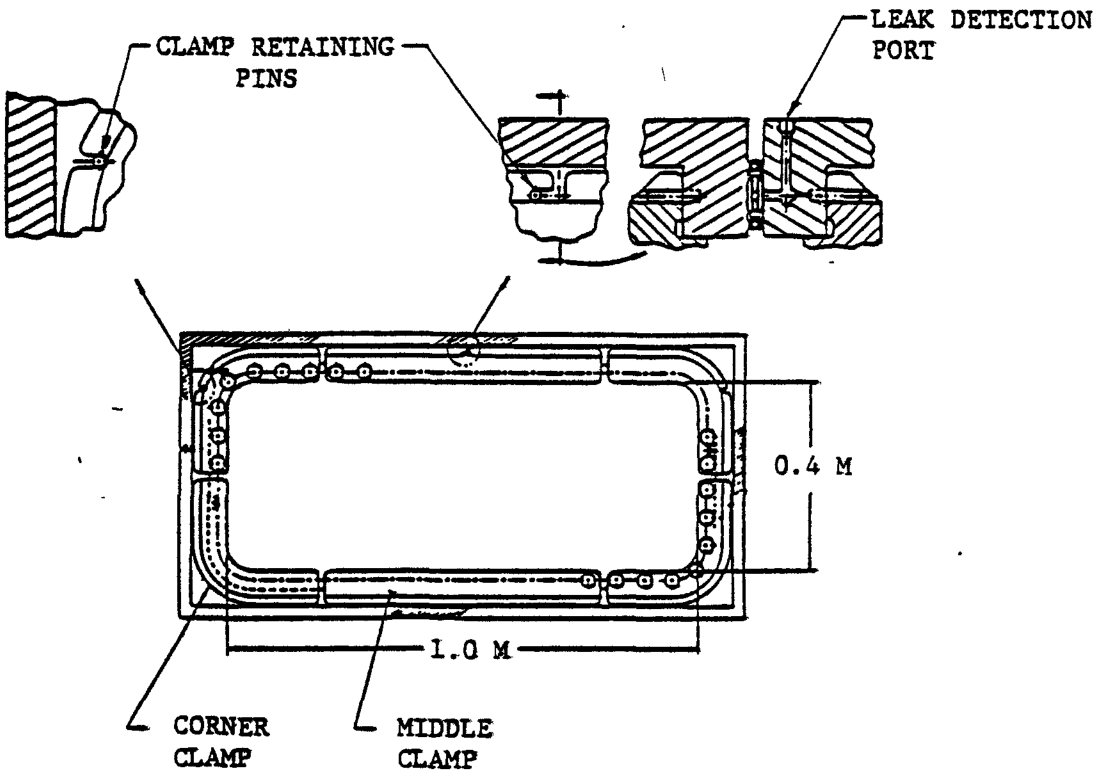


Fig. 6.3-3. Internal Flange Joint Arrangement.

A

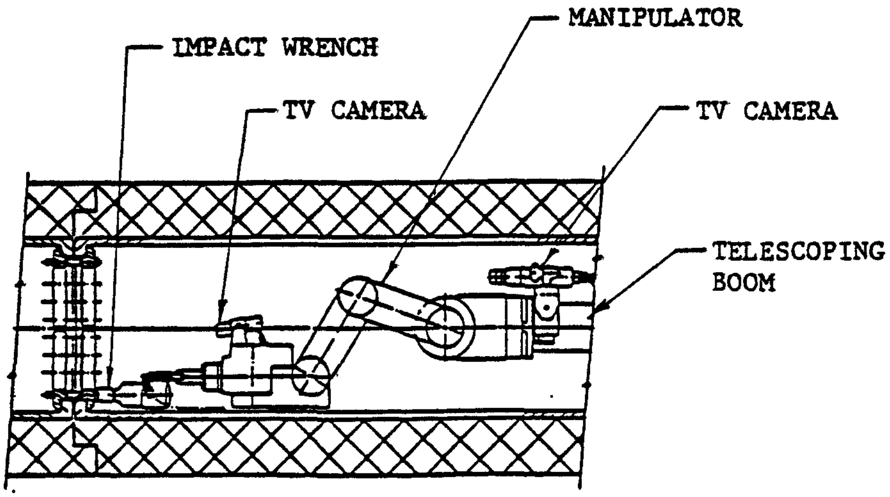


Fig. 6.3-4. Captive Screw Clamp Assembly/Disassembly.

6.3.2.3 GA Design - The GA design is a mechanical latch system.[4] The basic design concept consists of adjacent-mounted latches and opposing compression snubbers (Fig. 6.3-5). Figure 6.3-6 shows an assembly (set) of five or six latch hook/snubber combinations driven by two separate shafts and linkages. The snubbers provide an axial force against one joint flange which is reacted by the latch mechanisms that engage the mating flange. The latch hooks are operated first to engage the fixed flange; the snubbers are then engaged forcing the movable flange to complete the sealing process. These separate actions have individual drive shafts actuated by an impact wrench handled by a remote manipulator. The screw heads on the end of the drive shafts are tapered for easy engagement with the wrench socket drive unit. The over-center linkage design provides a positive lock for each action. A

Figure 6.3-7 shows the peripheral arrangement of the latches around the duct joint. The latches are grouped in six separate sets to make up an entire joint assembly. Each set is individually operated and removable as a unit for remote replacement.

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[4] *Doll, D. W., and E. R. Hager, "Remote Vacuum Joint Concept for Fusion Reactors," American Nuclear Society* ***Fifth Topical Meeting on the Technology of Fusion Energy****, 1983.* A

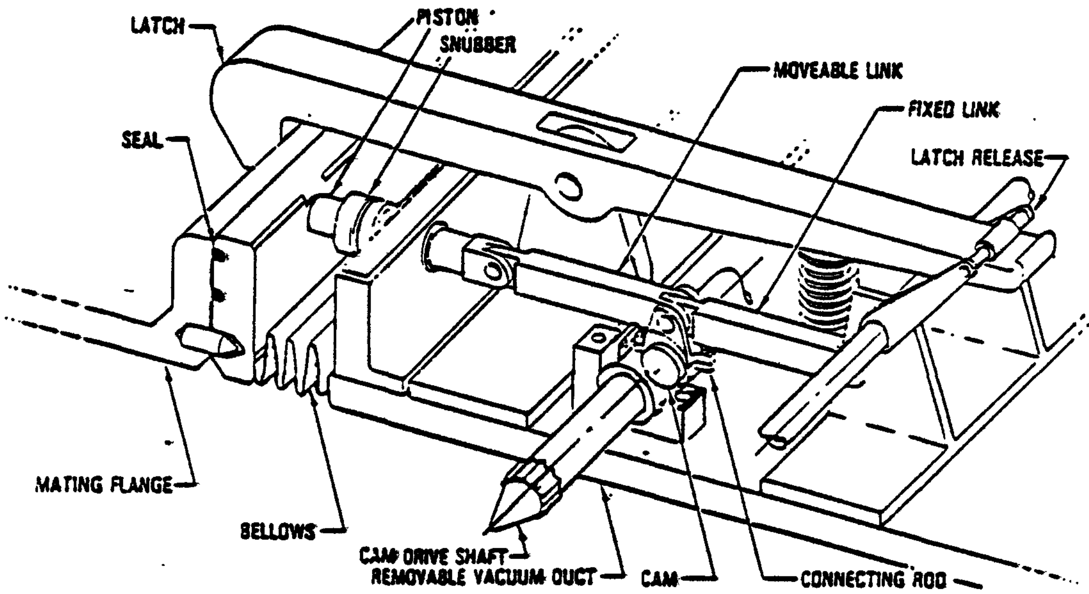

Fig. 6.3-5. Typical Latch and Snubber.

A

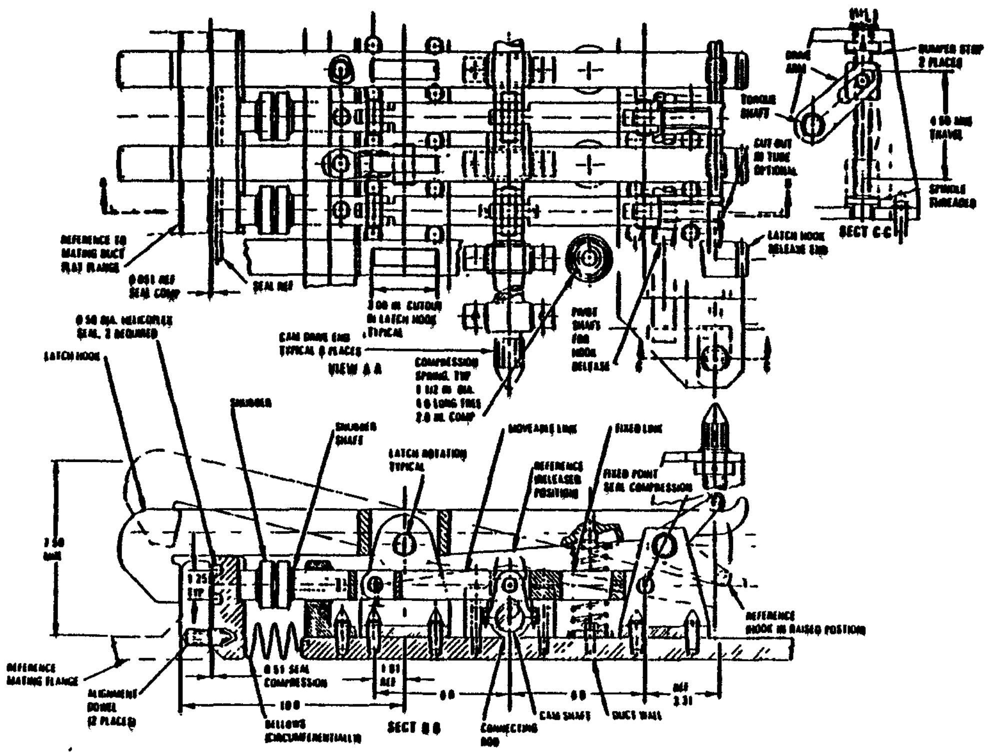

Fig. 6.3-6. Latch Set Assembly.

PRELIMINARY

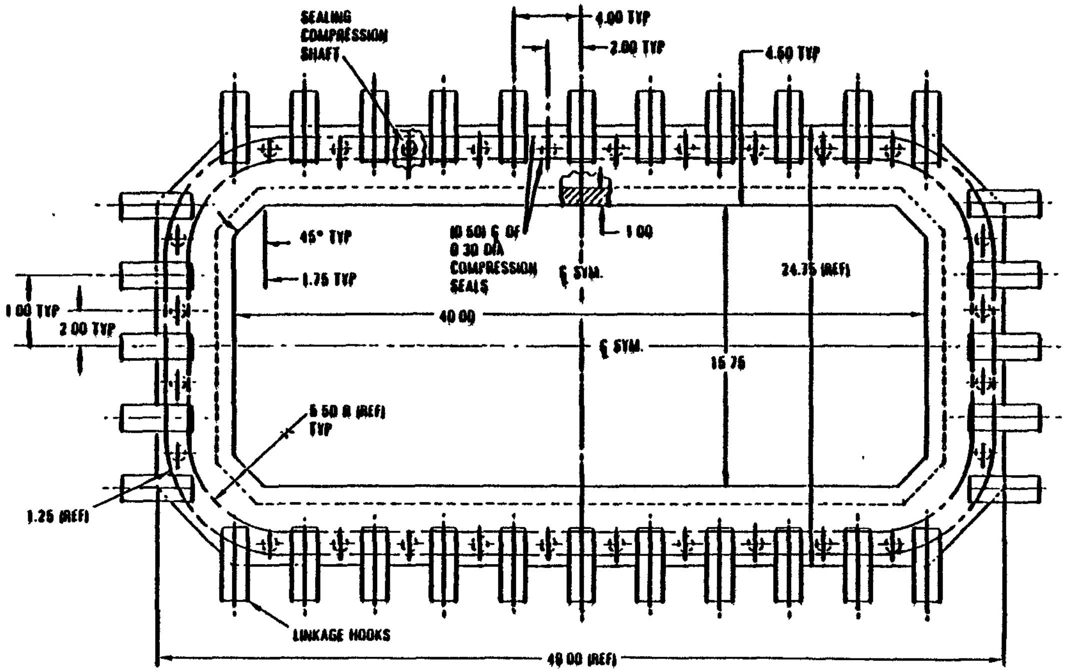

Fig. 6.3-7. Latch Arrangement Around Joint.

PRELIMINARY

The maintenance equipment required to assemble/disassemble this joint includes a standard power-arm manipulator, a telescoping support to increase reach, and two right-angle pneumatic impact wrenches.

The conclusions identified for this joint concept are as follows:

- It meets the requirements of a FED vacuum duct using the Helicoflex seal.
- Clamping forces are applied directly over the seal.
- Double seals are easily leak checked.
- Extremely high flange compression (8,000 lb./in. seal) is generated.
- The design takes advantage of existing technology to achieve the required clamping force. A
- Manufacturing costs are justified when compared to downtime costs of an experimental device.
- Modular design of the assemblies provides for rapid replacement during maintenance operations.
- The operations required to assemble/disassemble a joint are reduced since the operating shafts can project through the shield and operate multiple latches.
- There is possible application of the concept to other large service ducts.
- Further work is recommended to optimize the linkage and test a prototype unit.

6.8.1 Electrical Connectors - Power — The availability of electrical power connectors suitable for remote handling applications is limited when compared with fluid connectors. The design requirements for electrical connectors are as follows:

- Remote electrical connectors should be self-aligning through the incorporation of socket guide pins, polarized socket guides or socket geometry, or the incorporation of tapered keys and keyways into the socket design.
- All remote electrical process connectors should be environmentally sealed when assembled.
- All remote electrical process connectors should be self-locking or equipped with a locking mechanism to prevent accidental disconnects.

  Note: Pin friction is often adequate for small jumpers or for connecting to equipment in a stationary position.

- Whenever possible, voltage should not exceed 220V. If higher voltages are required for equipment such as furnaces, welders, and etc., special connectors should be designed (see Fig. 6.8-1).[1] A
- Electrical connector assembly and disassembly sequences should be simplified to straight line paths or single independent manipulator operations. Compound interdependent assembly motions should be simplified to single independent operational sequences, i.e., straight line insertion.
- Electrical process connectors must be operable by the utilization of standard remote tooling or multifunction manipulator end effectors.
- Execution of the operational assembly sequences should be limited to the utilization of a single robot or manipulator.

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(1) *Hampson, D. C., et. al., "Operating Experience With an Argon Atmosphere at the Fuel Cycle Facility," American Nuclear Society Proceedings of the 16th Conference on Remote Systems Technology, 1969.* A

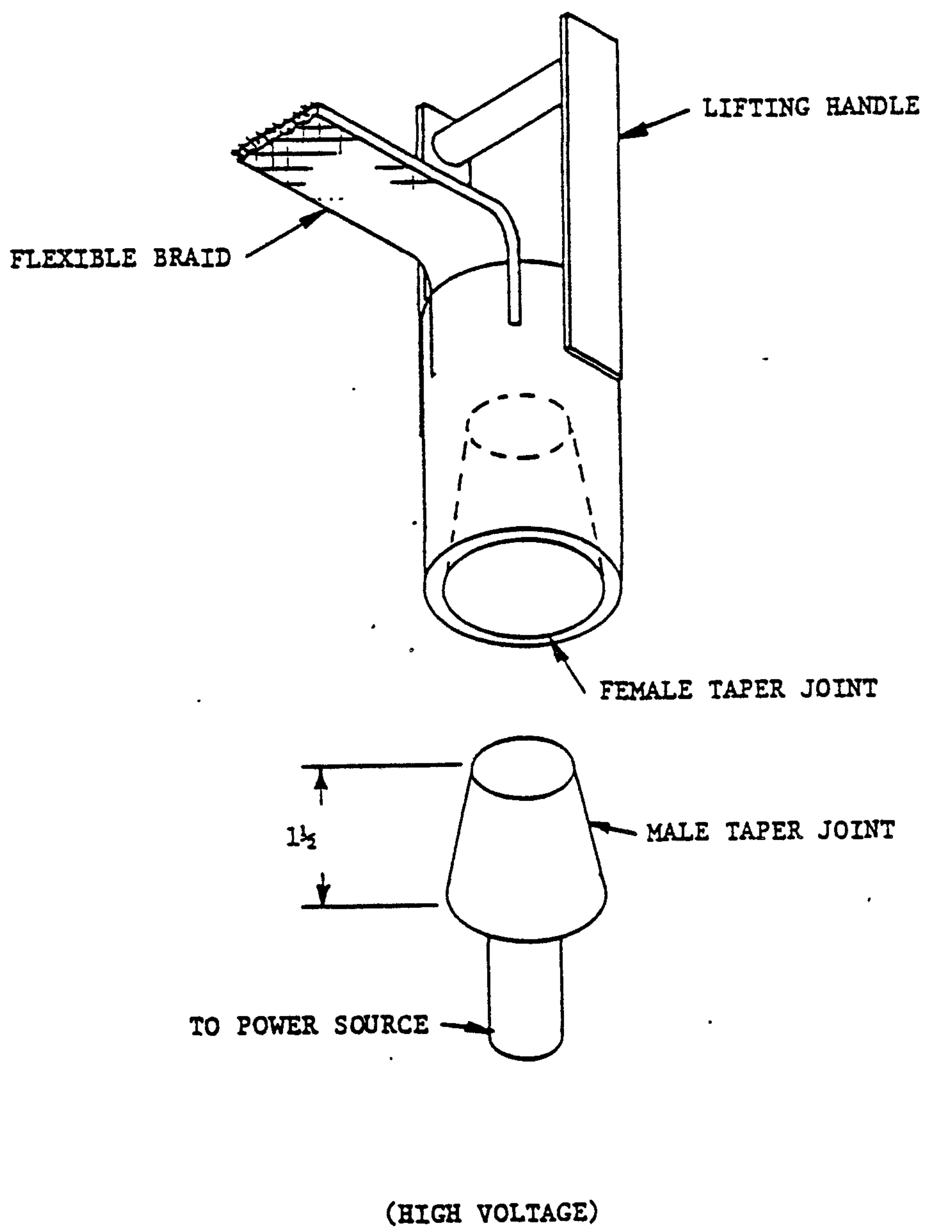

Fig. 6.8-1. Taper-Joint Electrical Disconnect.

- Remote electrical process connectors must be designed so that all parts are captive, eliminating loss of unrecoverable loose parts.
- For voltages to 220V in an argon or vacuum atmosphere, a "D" rating spacing(2),(3) would be used (normally good for 700V in air). Since nitrogen has basically the same rating as air, no derating is required.
- Bare conductors, such as busbars, should have 5/16-in. spacing.
- The energized portion of a connector should be the female (socket) half of the connector.

The following connectors have been successfully used in remote facilities and are candidates for applications in fusion plants.

6.8.1.1 Hanford-Purex Connector — The Hanford-Purex Connector shown in Fig. 6.1-1 can be adapted for use as an electrical connector by modifying the connector housing to receive an insert fitted with button-type contacts. The contacts are spring-loaded and complete the circuit through face-to-face contact.

6.8.1.2 Walker Remote Connector — The Walker Remote Connector shown in Fig. 6.1-4 can be adapted for use as an electrical connector by making the same modifications as indicated in Item 6.8.1.1 above.

6.8.1.3 HFEF Electrical Connector — One of the standard electrical connectors used in the Hot Fuel Examination Facility (HFEF - Idaho) is an Amphenol MS-type, straight pin connector (see Fig. 6.8-2). The coupling nut is discarded to make it suitable for handling by MSM's or Electrical Master/Slave Manipulators (EMM's) and utilizes pin friction and the weight of the wiring to hold the two

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(2) *Ludlow, et. al., "Glove Box" Proceedings, 13th Conference on Remote Systems Technology, RSTD.*

(3) *Military Specification, MIL-C-5015 C, "Connectors Electrical," and "Type," May 16, 1983.*

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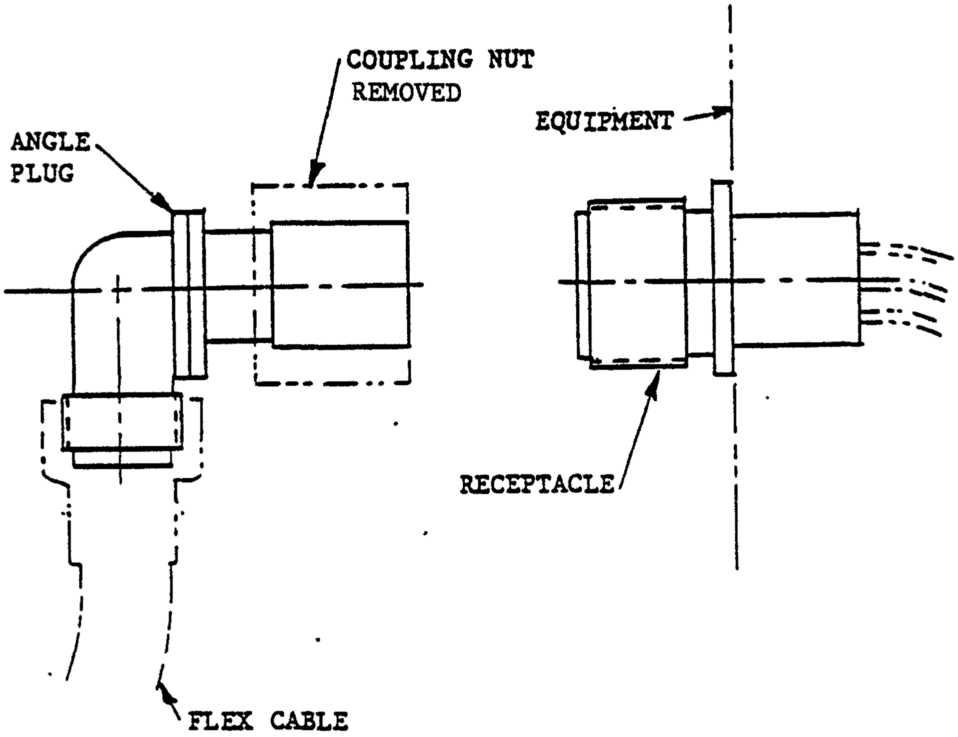


(Modified MS connector)

Fig. 6.8-2. HFEF Electrical Connector.

halves together. This connector is always positioned in either a vertically down or horizontal attitude at the HFEF. A

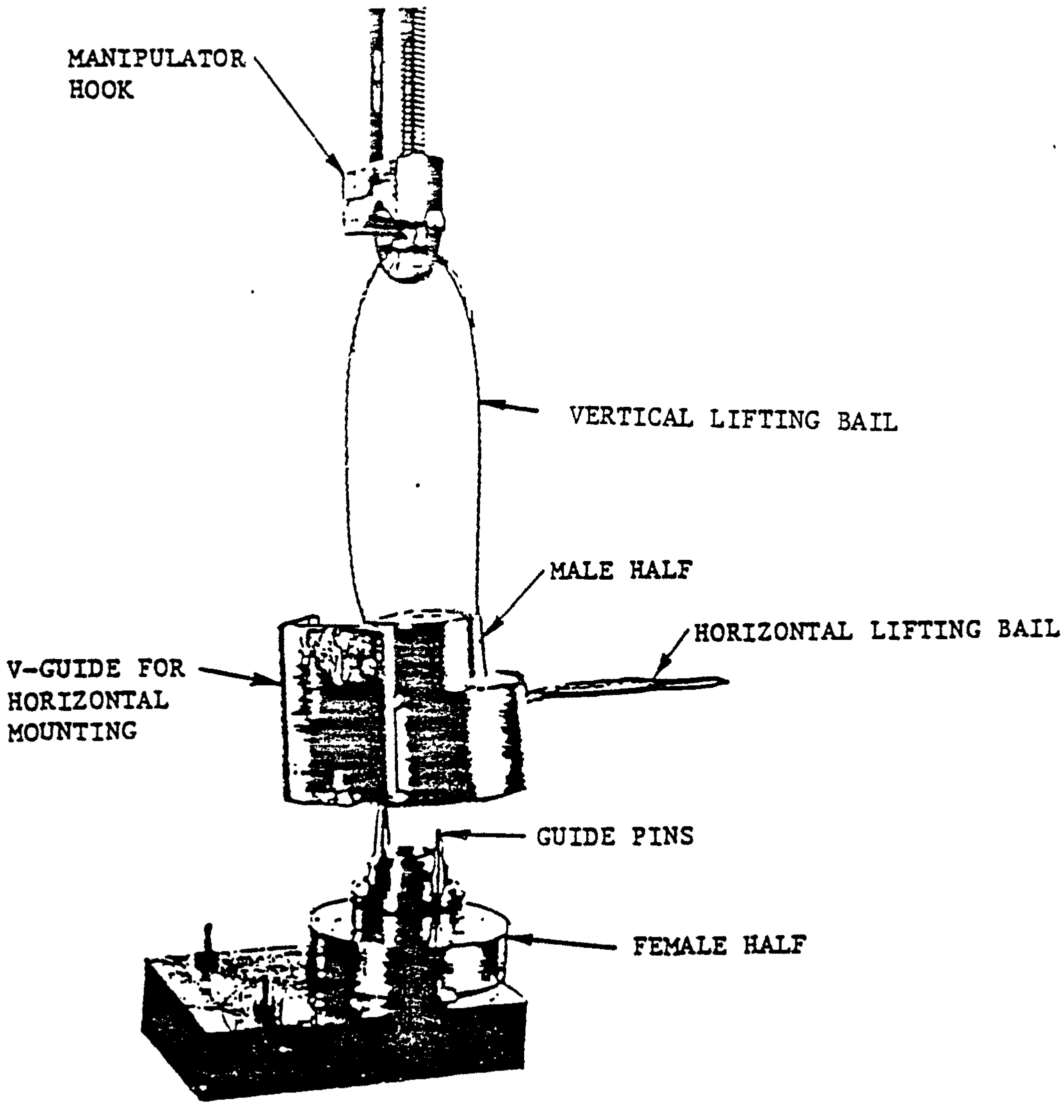
6.8.1.4 NWCF Electrical Connector (Gulton - LORMEC) — The New Waste Calcining Facility (NWCF) connector shown in Fig. 6.8-3 is a commercially available connector using straight-pin, Amphenol MS-type inserts in outer shell sections arranged to facilitate remote assembly and disassembly of the connector.

6.8.1.5 PaR "Cole" Electrical Connector — The Cole connector uses a pin with a ball-shaped end and a spring-loaded split socket which makes it unusually adaptable for remote electrical connector applications. The Cole connector has successfully been attached to motors and lights requiring only a crane lift-off for removal and installation (see Fig. 6.8-4).

6.8.1.6 REMS Electrical Connector (Gulton) — The Remote Electrical Manipulator System (REMS) electrical connector shown in Fig. 6.8-5 is a commercially available connector designed specifically for remote manipulator operation. The connector is basically a straight-pin type constructed from radiation resistant materials. The connector contains special built-in guides, alignment sight-targets, and automatic self-locking mechanism.

6.8.1.7 Wiggins Electrical Connector — The Wiggins electrical connector utilizes Bendix Pigmy electrical inserts which are available in shell sizes 8 through 24. A variety of pin configurations is available with 2 to 61 pin connections. This unit is designed as an extra rugged, lightweight, remotely operated push/pull miniature connector. A

6.8.1.8 Suppliers — Table 6.8-1 lists power connector suppliers discussed in this section. A



(GULTON-LORMEC)

Fig. 6.8-3. NWCF Electrical Connector.

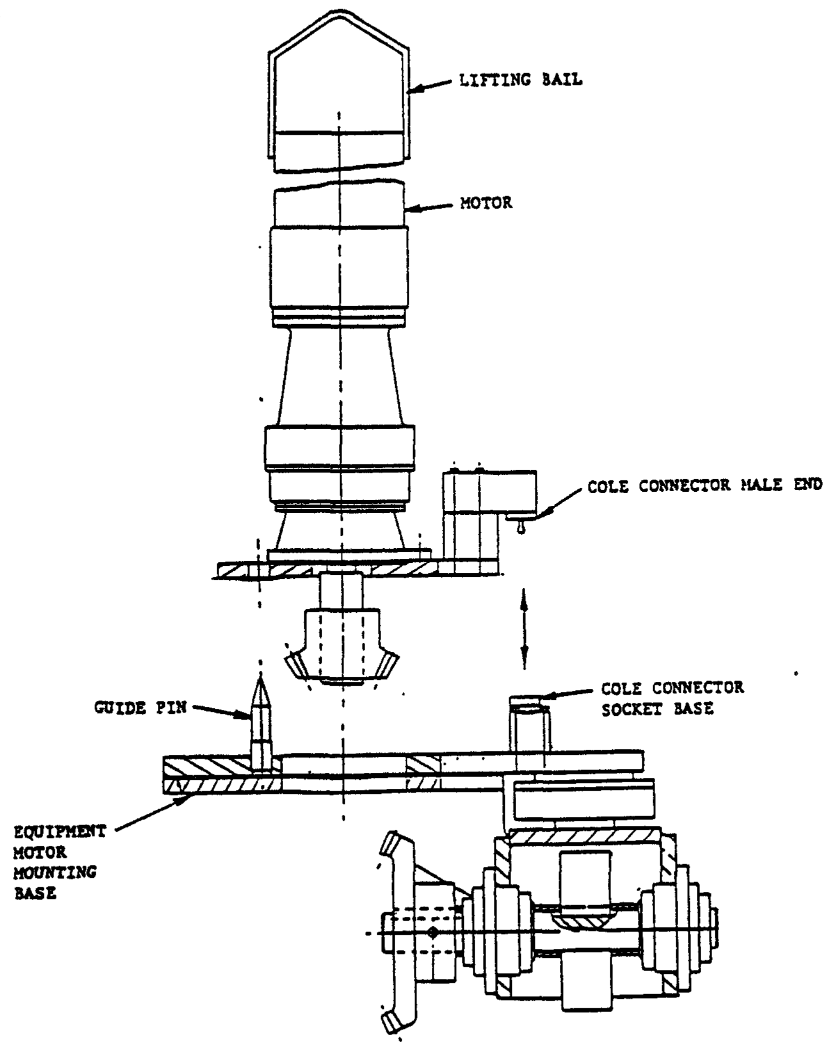


Fig. 6.8-4. Typical Cole Connector Mounting.

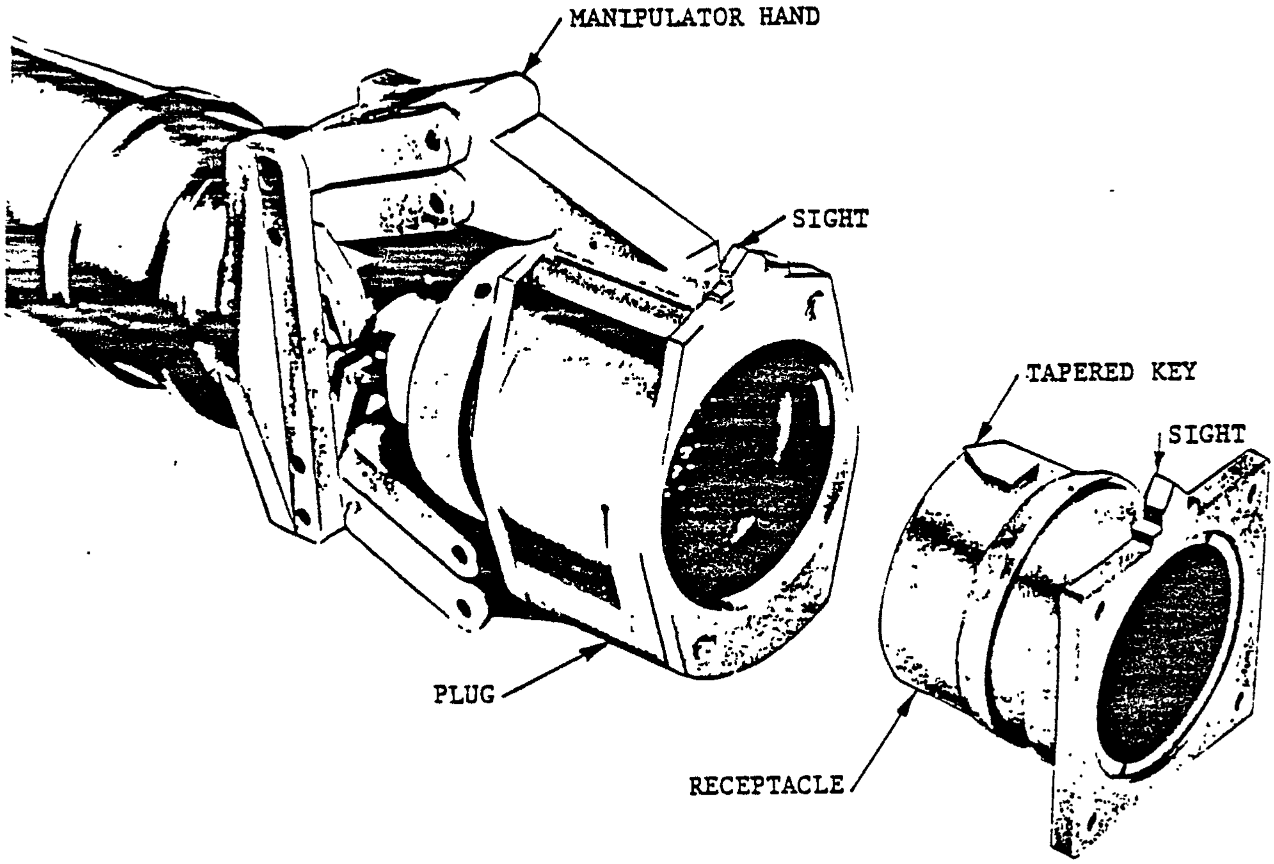


Fig. 6.8-5. REMS Electrical Connector.

Table 6.8-1 Power Connector Suppliers

Connector	Company
Hanford-Purex Electrical Connector	No commercial supplier - special design and fabrication required.
Walker Remote Electrical Connector	Design modification required. Remote Technology Corporation 114 Union Valley Road Oak Ridge, TN 37830
HFEF Electrical Connector (MS Connectors and Inserts)	Cannon ITT 666 East Dyer Road Santa Ana, CA 92702 Amphenol North America Division Bunker Ramo Corporation 2122 York Road Oak Brook, IL 60521
NWCF Electrical Connector (LORMEC)	Gulton Industries, Inc. S•C Division 1644 Whittier Avenue Costa Mesa, CA 92627
PaR "Cole" Electrical Connector	PaR Systems Corporation 3460 Lexington Avenue, North St. Paul, MN 55112
REMS Electrical Connector	Gulton Industries, Inc. S•C Division 1644 Whittier Avenue Costa Mesa, CA 92627
Wiggins Electrical Connector	Transamerica Delaval, Inc. Wiggins Connectors Division 5000 Triggs Street Los Angeles, CA 90022

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VII FAULT ISOLATION AND INSPECTION

*NA - Not available at this time.

The inspection and isolation of faults in the FWBS and the interfacing equipment and subsystems associated with fusion devices and reactors utilize many specialized devices and is of concern in the required inspection operations. The rapid detection and isolation of faults by remote means is one of the most critical operations in assembly, maintenance, and repair operations. The devices available for consideration are described in this section even though very few have been applied to remote operations. Most of these are suitable for adaptation to remote maintenance in fusion devices. The devices requiring manual operation are included for completeness and as an aid to the designer. Inspection functions characteristic of fusion reactors are described in the appropriate parts of Chapter I - Section 1.4, Chapter II and Chapter IX. Inspection devices encompass those instrumentation and diagnostic systems required to remotely detect, locate, or measure the extent of faults. Those conditions which occur or are evidenced by conditions within the plasma vacuum vessel of a reactor and its interconnected vacuum cavities are denoted as In-Vessel faults. Inspection to detect and isolate these faults frequently requires inspection equipment or systems which are located partially inside and partially outside of the vessel. These are the systems most directly associated with fault isolation and inspection of the FWBS and these systems will be discussed in this chapter. In most cases, the generic system and its operation will be described and then its potential application to the FWBS maintenance will be briefly discussed. The system operation is of importance to the remote maintenance system designer in addition to knowledge of the equipment characteristics in order to understand which equipment to select, how to emplace the equipment for remote maintenance and the effect of failure of the equipment on reactor operation. The most important maintenance function for a fusion FWBS system is to provide for maintaining a vacuum. This maintenance must, in most cases, be done remotely. This function will be given primary attention in the following sections.

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The related documents providing for these inspections and the operating requirements imposed on the equipment will be:

- The ASME Boiler and Pressure Vessel Code Section III
- (NRC Applicable Regulations as developed)
- Applicable Local Jurisdiction Ordinances and Regulations
- Other documents developed by responsible agencies
- Manufacturers and Suppliers Manuals
- The specific fusion device Maintenance Manuals

7.0.1 Inspection Objectives - FWBS inspection operations are conducted to provide data which permits rectification of any faults determined through the inspection process. The failure modes or conditions indicating incipient FWBS failures that would be examined and the data necessary for their correction are summarized in Table 7.0-1. This chapter will describe the inspection systems capable of developing the detailed FWBS data for each objective. A

Table 7.0-1 Inspection Objectives for FWBS Fault Conditions

FAULT	INSPECTION OBJECTIVE(S)
First Wall Surface Cracks	Locate cracks Measure extent, direction of crack
Vacuum Vessel Leak	Determine that leak exists Locate leak and record position
Blanket and Shield Coolant/Fuel Leak	Determine that leak exists Locate leak and record position
Weld Failure	Determine that weld failure exists Measure extent and direction of failure
First Wall, Armor, etc. Surface or Coating Erosion	Observe location Measure amount of erosion
First Wall, Limiter, etc. Coating Thickness	Measure coating thickness
First Wall Surface Pitting	Locate Pitting Measure wall thickness/pitting depth

A

Table 7.0-1 Inspection Objectives for FWBS Fault Conditions (Continued)

FAULT	INSPECTION OBJECTIVE(S)
Impurity Deposits	Determine existence of impurities in wall Quantify impurities and effect on wall materia
Missing Parts in Plasma Chamber	Observe location Locate debris (if in vessel)
Loose Parts in Plasma Chamber	Measure attachment loading/position Measure part deflection
Misalignment of Parts or Wall	Measure part location from reference Measure part orientation from reference
Discoloration of Parts or Wall	Locate discoloration and record Determine cause of discoloration

A

7.0.2 Inspection Capabilities — The detection and measurement systems which are available for fault isolation and inspection of the FWBS failure modes listed in Table 7.0-1 are listed in Table 7.0-2. These involve techniques and equipment for inspection, and detection and measurement of faults that have wide application in AMR for all subsystems of the fusion reactor. The application of a particular technique is dependent on the type of fault that is suspected or for which an inspection is being made and also on the reactor configuration. The configuration determines the type of access available to the inspection region. The potential application to each type of fault to be located or to each type of inspection to be made is indicated in Table 7.0-3. A

Table 7.0-2 Detection and Measurement Systems

Code	Device
1	X-ray
2	Ultrasonic
3	Magnaflux
4	Eddy Current
5	Television
6	Infra Red
7	Thermal Conductivity
8	Particle Count
9	Spectrometry
10	Gas Chromatography
11	Halogen Detectors
12	He or H_2 Detectors
13	Gauges
14	Residual Gas Analyzer
15	Periscopes
16	Optical Systems
17	Photographic Systems
18	Force Gauges
19	Audio Devices
20	Crack Penetrants

A

Table 7.0-3 Inspection Device Potential Applications

TYPE OF FAULT	TYPE OF DEVICE (For Code - see Page 7.0-5)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Surface Cracks	X	X	X	X	X		X								X	X	X		X	X
Subsurface Cracks	X	X	X	X															X	
Vacuum Leak		X				X	X	X	X		X	X	X	X					X	
Coolant Leak					X	X			X	X			X	X					X	
Fuel Leak						X	X	X	X	X		X	X	X						
Surface or Coating Erosion		X			X	X	X	X	X							X	X			
Surface Pitting (Galling)		X			X	X	X	X	X				X		X	X	X			
Impurity Deposits		X			X				X		X	X	X		X	X	X			
Missing Parts					X										X	X	X			
Loose Parts													X					X	X	
Misalignment of Parts					X								X		X	X	X			
Discoloration of Parts					X	X			X						X	X	X			

In conducting inspections with the equipment listed, it is imperative to satisfy each objective listed in Table 7.0-1 with either detection of some item or phenomena and measurement of equipment size, location, erosion, forces, composition, or other measurable parameter. These measurements incorporate the following types of inspections:

- Crack Detection/Measurement
- Vacuum Vessel Leak Detection
- Coating Detection/Measurement
- Deflection Measurement

- Dimensional Location Mapping (see also Chapter IX)
- Force Measurement
- Material Analysis - Physical
- Material Analysis - Chemical
- Surface Roughness Measurement
- Optical Measurement (see also Chapter IX)

The following sections describe specific equipment and the general operations required to apply it to detecting and locating faults in fusion machines. Specific examples of applications in fusion machines will be added as they become available. The principal problems encountered in detection and isolation of faults in fusion machines are:

- Gaining remote access to the fault. This is the cause of many design characteristics of fusion configurations. Some solutions use an in-place system instead of one that must be moved into place when required.
- Location of the fault once it has been detected. The machines are so large that the area to be investigated requires considerable time. A
- Modularization. Faults need only be located to the replaceable module in which they occur. Repair in situ is seldom considered for FWBS modules because of the time required.
- Entrapment of maintenance equipment. Maintenance system design for remote operations must consider how the equipment is to be removed from the reactor in the event of a failure. Failure to consider this can cause excessive down time.

7.2.1 Vacuum Vessel Leak Detection - Fusion reactors which have vacuum vessels are subject to leaks. Even small leaks are detrimental to plasma burn and the achievable burn time. Therefore, rapid and precise leak detection is important for achieving a high plant availability and low cost electricity. Areas where leaks are most likely to occur are the first wall/blanket/shield coolant loops, vacuum vessel, and tritium containment devices. The first wall/blanket and vacuum vessel present the most difficult leak detection task because of the relative inaccessibility and the harsh environment in which leak detection must be accomplished. Leaks in these areas will let impurities stream into the plasma and either quench the plasma or reduce plasma burn time. Leaks arise from such sources as failure in welds or seals, virtual leaks (i.e., pockets of gas trapped within the vacuum wall but not sealed from the vacuum), or faulty valves and similar failures. Small leaks can also propagate from flaws in the basic material at a rate dependent on the stresses present and the materials' toughness. The behavior of crack growth, the resultant leak and shutdown of the vacuum system before ultimate fracture is discussed in the section on crack detection (Section 7.1). The integration of a leak detection capability into the vacuum vessel design and the use of specific leak detection devices is dependent on:

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- The access to potential leak sources as limited by the design of the vacuum vessel and the internal components or the external components adjacent to it.
- The proximity of the leak detection sensor to the leak necessary for detection as well as location to a specific accuracy.
- The size of the leak detection components.
- The capability of the components to withstand the vacuum vessel environment during the leak detection operation and the impact of this environment on the performance of the leak detection system.
- The requirement imposed on the system by the design either to only detect the leak or to both detect and locate the leak.
- The need to isolate individual leaks when many, both small and large, are present.

Table 7.2-1 lists available leak detection devices which may be adapted to remote operations. The more usable of these devices employ instrumentation which analyzes the exhaust gases from the evacuated fusion device or reactor vacuum vessel and adjacent passages. This type of device will detect the existence of leaks. The determination of the location of the leak usually requires additional equipment such as helium wands, thermal sensors, built in valving or other auxiliary devices which must be emplaced remotely with the necessary gas or power supplies. The ability to repair the leak detection system requires access to each of these devices and the ability to replace or repair it. The overall sensitivity of available leak detection devices is listed in Table 7.2-1. The specific characteristics of each device will be discussed in the following sections. A

Table 7.2-1 Vacuum Leak Detection Capability

	Method	Minimum Detectable Leak, Std CC/Sec (Approx.)	Potential for Application to Remote Operation
1.	Particle Counting	10^{-4}	Good
2.	Vacuum Gauges and Ion Pumps	10^{-8}	Good
3.	Vacuum System Pumping Speed	10^{-5}	Good
4.	Pressure Rise	10^{-3}	Good
5.	Pressure Decay	10^{-3}	Good
6.	Bubbles	10^{-4}	Poor*
7.	Thermal Conductivity	10^{-5}	Good
8.	Ultrasonic	10^{-1}	Fair
9.	Halogen Detectors	10^{-8}	Excellent
10.	Residual Gas Analysis	$10^{-10}/10^{-9}$	Excellent
11.	Helium or Hydrogen Detectors	$10^{-10}/10^{-8}$	Excellent

*Potentially useful only in very specialized configurations such as the SPTR (Section 2.2.6).

A

7.2.I.1 Residual Gas Analyzers[1] — Residual gas analyzers provide a convenient method of leak checking. Gas analyzers are basically mass spectrometers which distinguish gas species or mass fractions and their partial pressures in the residual atmosphere of the vacuum vessel. Although residual or partial pressure gas analyzers are normally not thought of as leak detectors, this is one of the most versatile methods for performing leakage evaluations on certain types of specimens and vacuum systems. Figure 7.2-1 shows an Ultek, Quad 250 Residual Gas Analyzer being used to evaluate gas composition. This gas analyzer has the capability of a mass scan from mass No. 1 to mass No. 500. An actual recording of the analyzer's output made during the evaluation illustrated in Figure 7.2-1 appears in Figure 7.2-2. This record covers a mass range from 1 to 46. A A A A

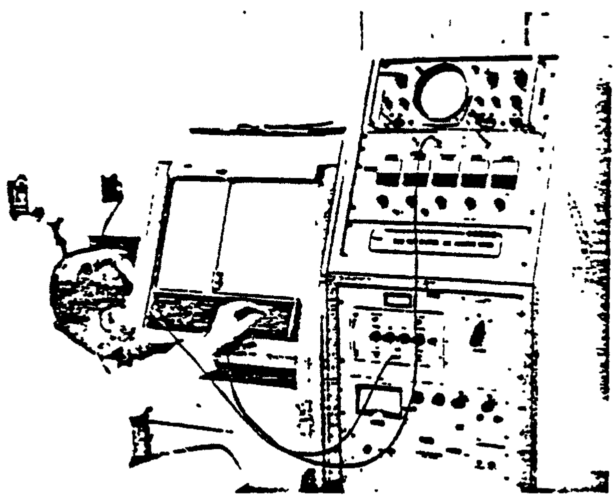

Figure 7.2-1. Analysis Within a Space Chamber Using a Residual Gas Analyzer.

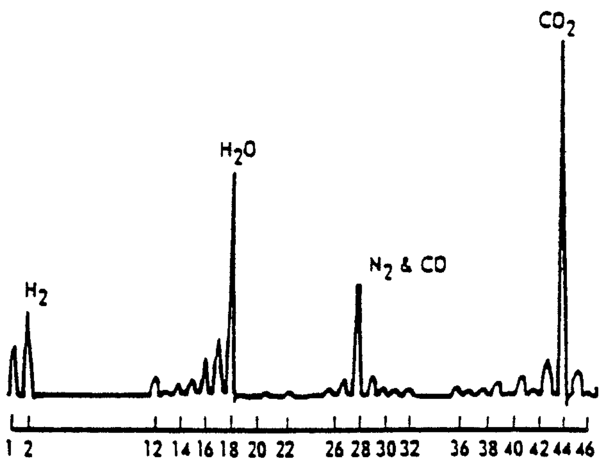

Figure 7.2-2. Partial Analysis of Residual Gases Detected in a Space Chamber. A

(1) *McKinney, H. F., "Practical Application of Leak Detection Methods," Presented at the 14th Annual Institute of Environmental Sciences Technical Meeting, 29 April - 1 May 1968.*

Residual Gas Analyzer Applications -- Gas analyzers have been used for qualitative leakage analysis of various systems.

One application was to identify gases from a specimen under test in a 30-foot diameter vacuum chamber. The test specimen in this case was a complete spacecraft. During the test program, system leakages occurred and were readily identified with the aid of the gas analyzers. A

Some conceptual instrumented applications for remote operations in fusion systems include the use of exhaust sampling from each vacuum pumping station or each sector of a tokamak or tandum mirror system. The gas analyzer has the capability to measure concentrations of various gases in addition to helium used in many leak detector systems, thereby determining impurities arising from leaks into the vacuum vessel from other inert atmospheres, from outgassing, from coolant lines, etc. Thus the source of the leak may be identified during reactor operation, thereby decreasing the time required to locate the fault and correct it. The possibility of correcting the fault without interruption of reactor operation also exists when the configuration permits, such as when redundancy exists in the leaking components. In addition to leak detection, these gas analyzers find applications in trouble shooting operations, checking gas composition such as in fuel or purge lines, and checking pumping problems such as by determining contaminants in pumping outputs. A

In other applications, such as leak detection in cryogenic shrouds or cryo panels, tne gas analyzer is capable of identifying the leakages and serving as a very useful leak detector. Also, working in conjunction with constant pumping speed techniques, a reasonable approximation of the amount of leakage present and a clear definition of the source of the gas present can be determined.

Gas analyzers may be used with low level ionizing radiation if the reduced sensitivity is acceptable. In general, protection from such radiation should be provided in the sensor installation. A

Residual gas analyzers are produced by several manufacturers. Some of these are listed in Table 7.2-2. For additional applications data, these or other manufacturers should be contacted. A gas analyzer system manufactured by Balzers is illustrated in Figure 7.2-3. A general description of this unit and its capabilities are given in Table 7.2-3. Varying sensitivity levels are available. A typical example of the output is shown in Figure 7.2-4. This output may be compared with the reading in Figure 7.2-2.

Table 7.2-2 Gas Analyzer Equipment Sources*

A

Manufacturer	Address
Balzers Corporation	8 Sagamore Park Rd. Hudson, NH 03051

*List is incomplete

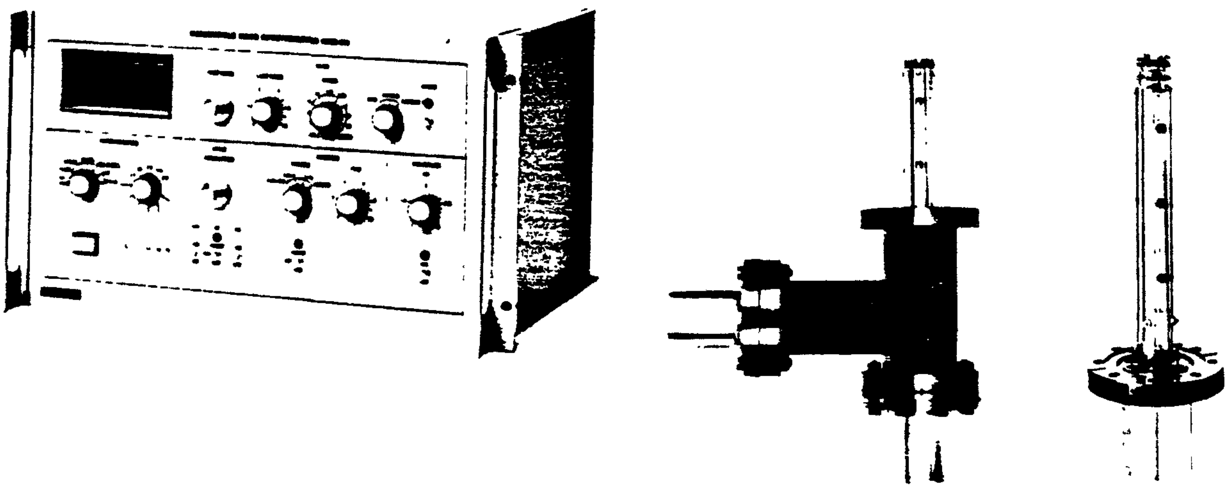

Figure 7.2-3 QMG 311 System (Balzers Quadrupole Mass Spectrometer)

Table 7.2-3 Balzers Quadrupole Mass Spectrometer Characteristics

Description: The quadrupole mass spectrometer system consists of the electronic control unit and the Analyzer with or without a secondary electron multiplier (SEM) and a separate electrometer amplifier. The electronic control unit is mounted in a 19" rack module with controls for mass scan, function control, RF generator, emission current contact and SEM supply allowing readout of important parameters.

The analyzer consists of the ion source, the mass filter and the ion collector assembled on an Ultra High Vacuum CF Flange. A

Capabilities:

- Mass ranges of 1 to 100 and 4 to 300 amu
- Unit resolution available in both mass ranges
- Stability allows monitoring single mass peak over long periods
- Either anolog or digital display
- Analyzer bakeable to 400^{0}C without connector plate
- High gain SEM with sensitivity up to approximately 1000 A/mbar
- Detection limit to 10^{-16}mbar range
- Random selection of quadrupole reference potential allowed for:
  - high spectrum energy of ions to reduce influence of the fringe
  - prevention of electron emission to surroundings with source at positive voltage with respect to ground.

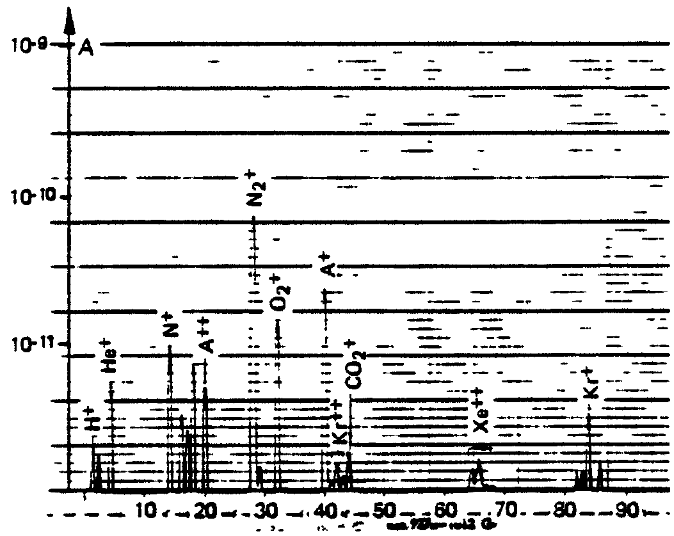

Figure 7.2-4 Example of Partial Pressure Analysis (Courtesy Balzers) (Mass range of 1 to 100 amu for a gas mixture of helium, nitrogen, oxygen (air), argon, krypton, xenon.)

A

7.2.1.2 Helium Leak Detectors[1] - The principle of operation of this class of leak detectors is basically the same as for the residual gas analyzer, except that they are normally sensitive to only one or two gases, usually helium or helium/hydrogen. This class of leak detector continuously monitors, at the sensing element, the partial pressure of a gas to which it is sensitive. Most of the leak detectors in use are sensitive to helium gas. A

The three general methods of applying helium leak detection systems are pressure, pressure-vacuum, and vacuum testing. A

Pressure Method — In the pressure testing method, the chamber to be leak-tested is pressurized with helium gas, and the exterior of the chamber is examined with a "sniffer" probe as shown in Figure 7.2.5. The "sniffer" probe is connected to the detecting instrument by means of a flexible hose, and a helium supply is used to pressurize the test specimen. It is desirable to keep the hose that connects the "sniffer" probe to the instrument as short as possible in order to improve response time of the instrument. Also, the connecting hose should be clean and made of a material that has a minimum absorption for helium. A high background indication shows this line is becoming contaminated and needs to be cleaned or discarded. A

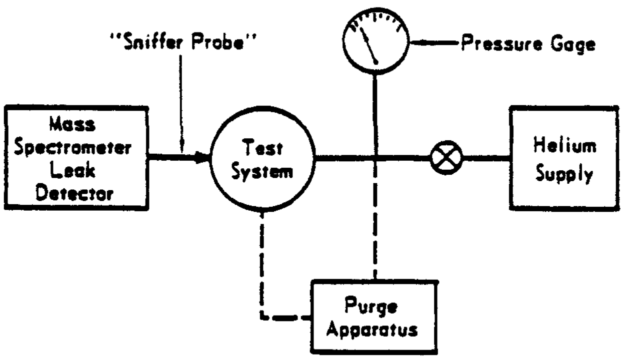

Figure 7.2-5. Pressure Test Method Using a Mass Spectrometer Leak Detector. A

(1) See page 7.2-3.

When employing this method of leakage detection, the following guidelines should be observed:

- The evaluation should be performed in an area that is well vented,
- Keep excessive air currents away from the test chamber, A
- The speed with which the probe is moved over the test area should be slow and governed by the response time of the detector and associated connection hose,
- The distance between the end of the probe and the suspected leak area should not be greater than approximately 1/8 inch,
- On many occasions, to aid in isolating a small leak, a small piece of surgical tubing may be attached to the "sniffer" probe and placed in direct contact with the surface of the chamber under test, A
- A precaution that should be taken when using the "sniffer" probe is to ensure that the areas being evaluated are clean.

If the surface is dirty, the probability of detecting a leak when it does exist is decreased. Also, the "sniffer" probe may become plugged with dirt and rendered inoperable. Since the possibility of the probe becoming plugged exists, it is a good practice to have a helium supply available to periodically check probe operation.

Leakages on the order of 10^{-6} Std. cc/sec have been detected with this method, but it normally requires an experienced person to consistently detect them. To obtain maximum sensitivity using this method, it is necessary to purge the test chamber to obtain an undiluted helium environment within the chamber. A This is usually accomplished by evacuating or blowing helium through the chamber. Also, if design of the chamber permits, the pressure may be increased thereby increasing the probability of leak detection.

Test requirements exist involving chambers with excessive leakages where it is desirable to use diluted helium gas when employing the pressure test method. A common diluted mixture, commercially available, is 10 percent helium and 90 percent nitrogen. Using this diluted gas, it is possible to isolate leaks as large as 10^{-3} Std. cc/sec. If undiluted helium was used with a system that has leakages of this magnitude, the ambient background reading would become quite high, and instrument contamination would result because most mass spectrometers saturate when experiencing leakage greater than 10^{-5} Std. cc/sec of pure helium. A

The pressure method for qualitative evaluation also has been used on a variety of items, including pipes and tubing that in actual service carry liquids or gases, and on complete vacuum systems. The latter leakage evaluation is often conducted during testing to enable immediate correction of problems. A

Pressure-Vacuum Method - With the pressure-vacuum method of evaluating leakage, the test chamber is within another vacuum chamber, and the mass spectrometer detector is connected in parallel with the outside chamber roughing or foreline pumps as shown in Figure 7.2-6. This method is applicable to systems where quantitative leakage evaluations are desirable and is capable of directly analyzing leakages as small as 10^{-9} Std. cc/sec. The procedure followed when using the pressure-vacuum method varies somewhat with the test chamber. When the inner chamber does not contain helium, it is necessary to purge the inner chamber until a helium environment exists within. This purging process is normally accomplished by evacuating the inner chamber and backfilling two or three times with helium. Restrictions with respect to differential pressure across the test chamber must be respected. A

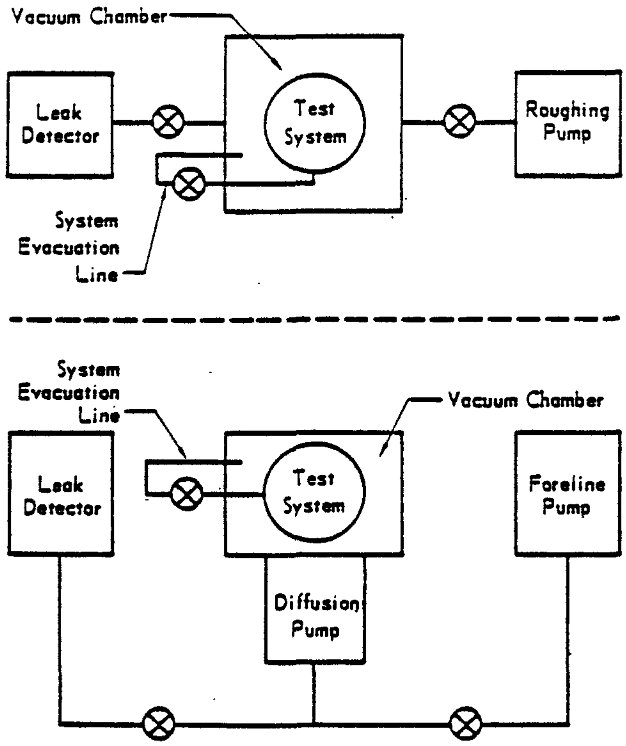

Figure 7.2-6. Pressure-Vacuum Test Methods Using a Mass Spectrometer Leak Detector. A

One of two calibration conditions must exist if an accurate quantitative analysis is to be obtained using this method. An accurate calibration of the instrument must be performed at an instrument system pressure equivalent to test conditions. This means that the combined gas load from the test system and the outer vacuum chamber must be a small enough quantity that the instrument can pump without significant change in instrument pressure. For the first condition shown in Figure 7.2-6, if instrument pressure changes but is still within a working range, calibration is performed under the instrument's pumping load pressures. The second condition shown is that, if the instrument pressure change is not within its working range, it becomes necessary to use a parallel vacuum pump, and a calibrated source must be introduced into the outer vacuum chamber to obtain an accurate calibration. Calibration can become quite tedious with this method. However, if careful consideration is given to the test being performed, repeatable and accurate data can be obtained even though calibration problems may occur.

Following instrument calibration, the test specimen is pressurized to the desired differential pressure and the leakage evaluation is performed. With some specimens, the leakage is too great to measure. Alternate methods may be used if this situation exists. In one alternate, a parallel pump can be installed to "rob" some of the gas load from the instrument. In another, the helium may be diluted using either 90 or 50 percent nitrogen. Recalibration is required if the "robbing" technique is employed, but if diluted helium is used, instrumentation calibration may be calculated.

Vacuum Method — The vacuum test method involves attaching the system under test to the leak detector and utilizing the detector's pumping system to maintain a vacuum in the system. On large systems, initial evacuation is normally performed by parallel pumps of large capacity as shown in Figure 7.2-7. In high vacuum systems where diffusion pumps are used to attain low pressures within the chamber, the leak detector and its associated pumping system are placed in series with the diffusion pump and this pump provides the required foreline pumping. A

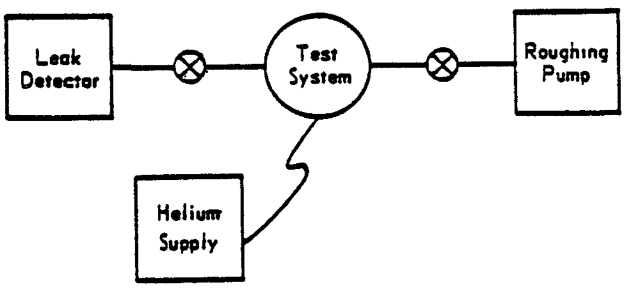

Figure 7.2-7. Vacuum Test Method Using a Mass Spectrometer Leak Detector. A

Helium gas is sprayed over possible leak areas on the surface of the chamber. If heavy gas loads are experienced using this procedure, parallel pumping or the previously discussed "robbing" technique is employed. This method allows both quantitative and qualitative leakage analysis to the ultimate capability of the mass spectrometer detector being used. This capability is normally 10^{-9} Std. cc/sec. Also, calibration of the instrument is normally quite simple when using the vacuum test method.

Experience on Doublet III has shown that a combination of these methods is adaptable to remote operation. This method uses a double wall vessel that permits evacuation of the inter-space through a mass spectrometer. A helium source on either side of the vessel double wall will locate the leak thus employing the vacuum method or the vacuum-pressure method. By reversing the arrangement and using a suction cup from the outside, the exact location can be spotted. Few other methods are adaptable to remote operation. Double seals with intermediate pump-out spaces can be used in a similar manner at mechanical seal joints.(2) A

Mass spectrometer manufacturers are listed in Table 7.2-4. These should be contacted for additional information than illustrated herein. A

Table 7.2-4 Mass Spectrometer Leak Detection Equipment Sources*

Manufacturer	Address
Varian Associates, Lexington Vacuum Division	Lexington, MA 02173
Laybold Heroeus Vacuum Products, Inc.	5700 Mellon Road Export, PA 15632
Veeco Vuco Instruments, Inc.	Terminal Drive Plainview, NY 11803
Alcatel Vacuum Products Division Atcom Systems, Inc.	6 Sharp Street Hingham, MA

*List is incomplete

(2) Hager, E. R., Personnel Communication Review Comments, Ed.

Figure 7.2-8 illustrates a mass spectrometer. The instrument illustrated is mobile (weighing approximately 160 kg) and is used in conjunction with the spectrometer tube illustrated in Figure 7.2-9. A general description of this equipment and its capabilities are summarized in Table 7.2-5. These indicate the capabilities to be found in this class of equipment. Many arrangements are available. The equipment is useful for vacuum system leak detection and trouble-shooting. The presence of residual helium in the vacuum chamber and of ionizing radiation may reduce the system sensitivity depending on the installation characteristics. The effect of ionizing radiation has been briefly discussed in Section 7.2.1.1. A

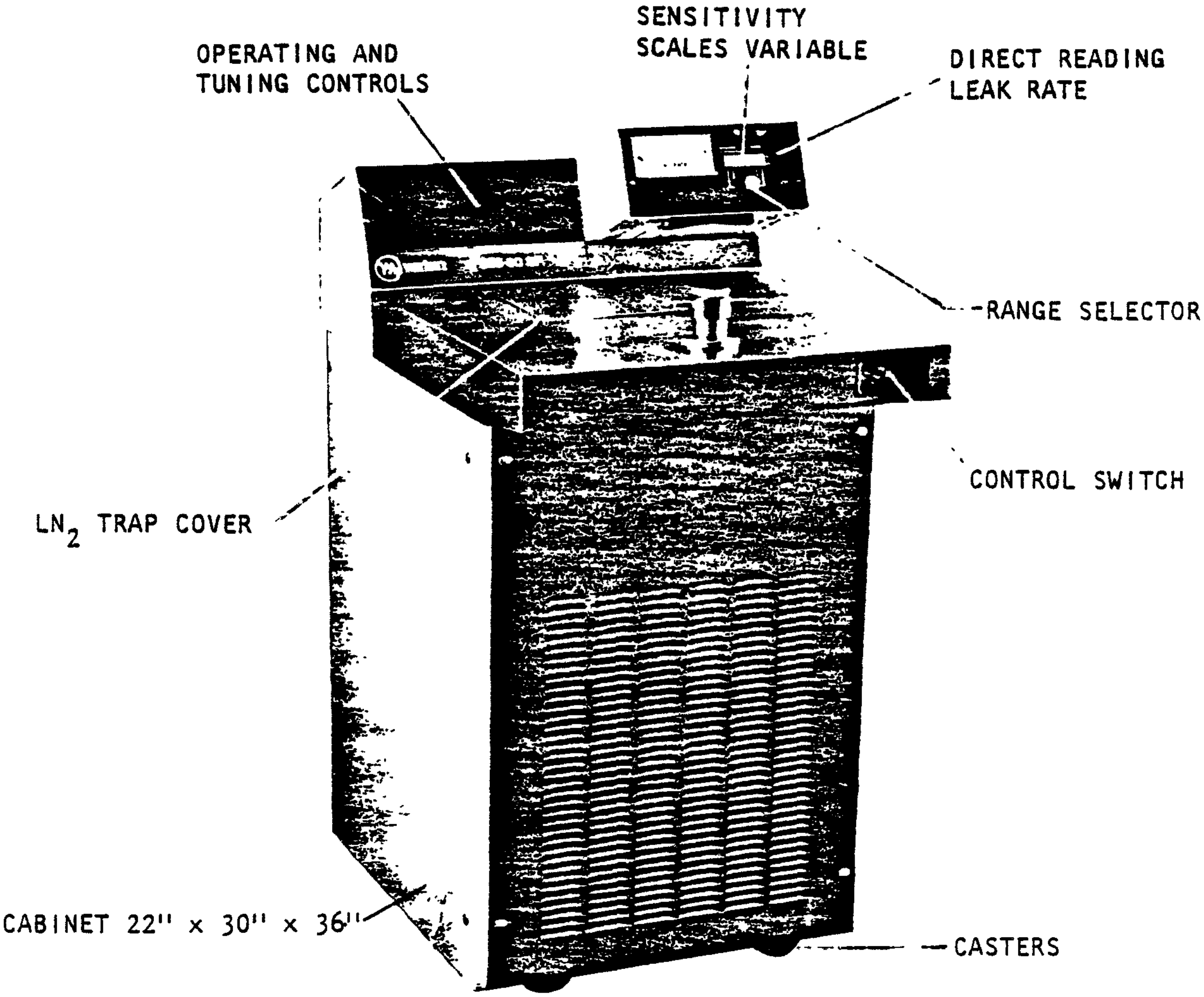

Figure 7.2-8. Varian 936-60 Helium Leak Detector. A

Figure 7.2-10 shows the actual spectrum from the spectrometer illustrated in Figure 7.2-8. This spectrum shows the separation of the helium peak (mass 4) achieved with this spectrometer. A

The flow diagram depicted in Figure 7.2-11 illustrates the operation of the spectrometer. The object to be tested is connected to the test port and evacuated. Helium entering through a leak diffuses into the foreline of the specially designed diffusion pump. The spectrometer tube generates an electrical output proportional to the amount of helium in the tube. This output is amplified and displayed on the leak rate meter. When the helium source is removed from the leak, the helium remaining in the system is rapidly pumped away. Thus, the effect is a rise and fall of the leak rate meter indication. A

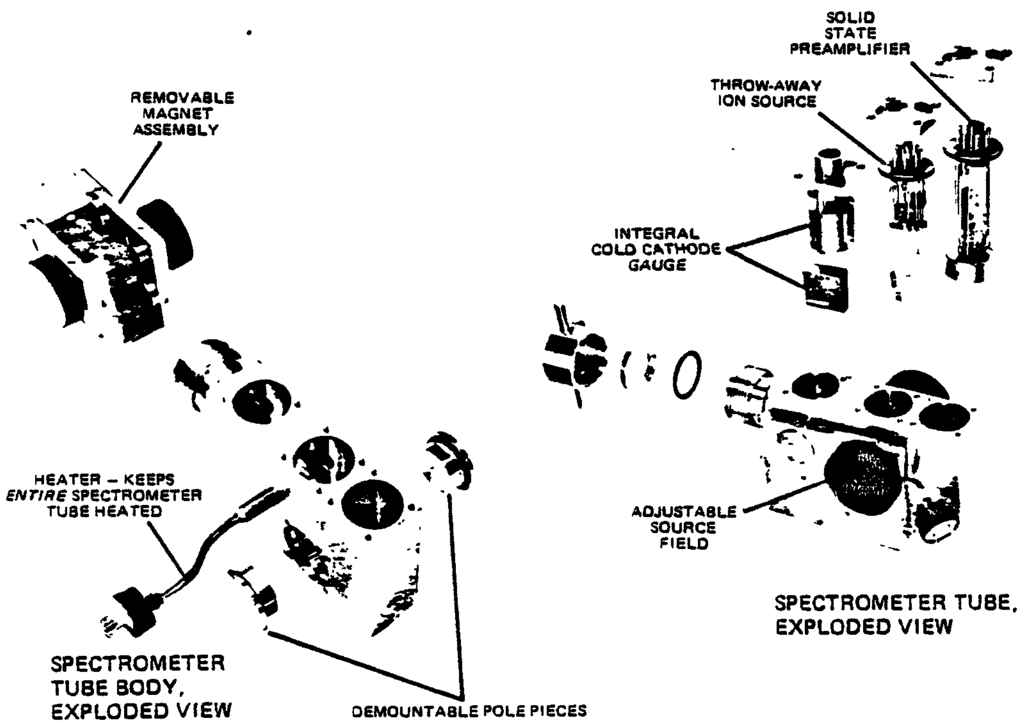

Figure 7.2-9. Spectrometer Tube - Varian 936-SP Series Helium Leak Detectors. A

Table 7.2-5 Varian 936-60 SP Helium Leak Detector Capabilities | A

Description: The composition and operation of the 936-60 leak detector is depicted in Figure 7.2-11. This unit is an example of a helium leak detector even though many special features are present and others found in similar devices are not present in this unit. A

Capabilities: The performance characteristics of the Varian 936-60 leak detector are: A

- Sensitivity: 8×10^{-11} atm cc/sec range for helium,
  3×10^{-11} atm cc/sec range for air,
  Minimum detectable leak is 2% of full scale deflection on most sensitive range,
- Response time: 3 seconds for helium @ high sensitivity,
- Pump rate: Nominal 3.2 cfm pump to attain specified sensitivity,
- Diffusion pump: Stainless steel, air cooled, A
- Automatic manifold valves
- Test port with 1-1/8" ID quick coupling
- Mass peak separation: (see Figure 7.2-10)
- Spectrometer tube: (see Figure 7.2-9)
- Remote use with extension cable.

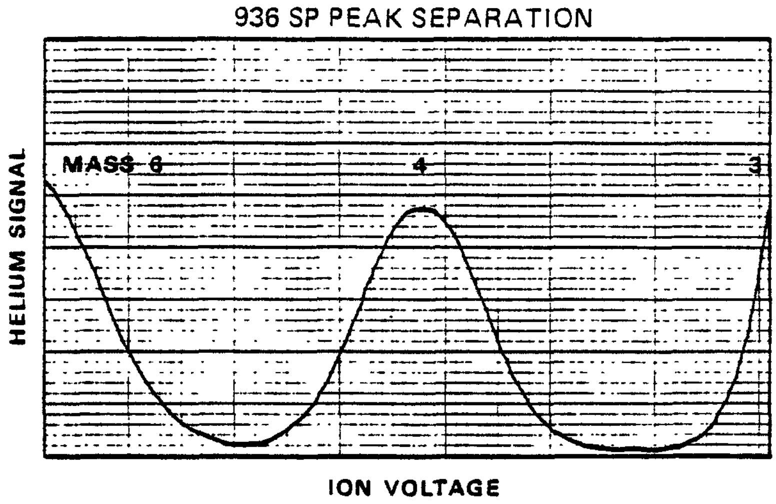

Figure 7.2-10. Varian 936 SP Series Helium Leak Detector Mass Peak Separation.

A

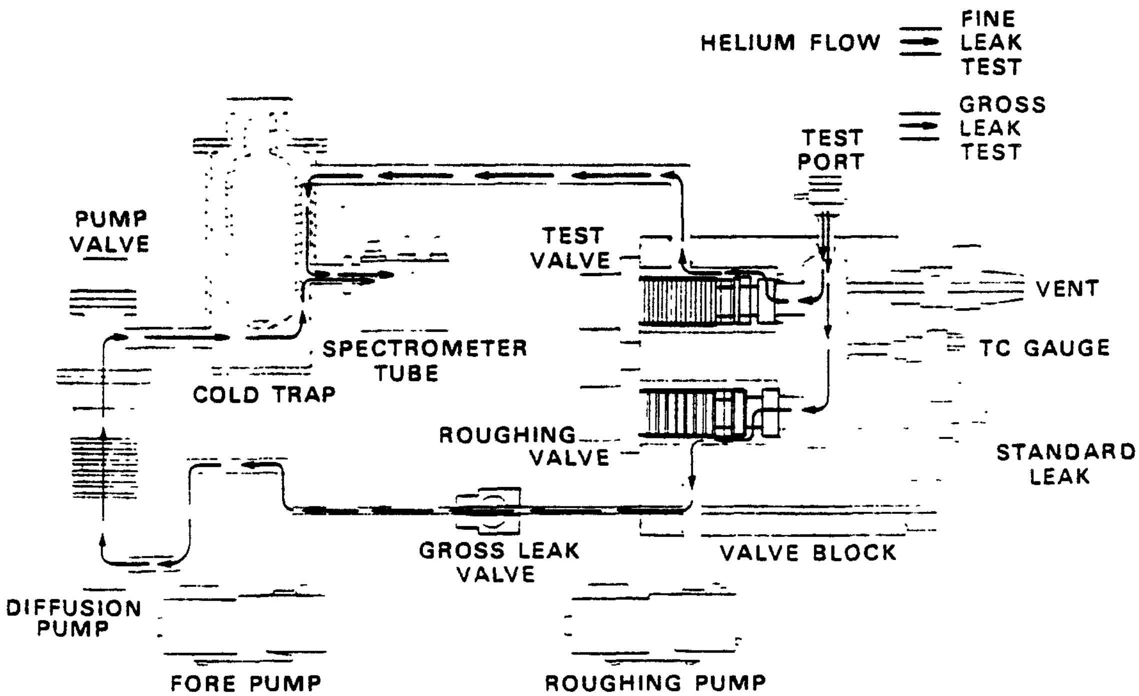

Figure 7.2- 11. 936-60 Leak Detector Flow Diagram.

VIII MATERIAL HANDLING SYSTEMS

*NA - Not available at this time.

This chapter provides the designer with a reasonably comprehensive list of specific handling equipment that has been used successfully or is proposed for use in non-fusion nuclear facilities and other remote handling operations. Much of the equipment is commercially available, however, some modification of this equipment is generally required for remote handling.

There are a number of different types of remote manipulator/viewing systems that have been successfully used in non-nuclear facilities. There are also a number of advanced systems (such as robots) that have recently been made available commercially. This chapter incorporates the results of a comprehensive technology survey and provides guidelines for the use of available handling systems in fusion AMR work.

In addition to manipulators, robots, and other related equipment, there are many transporters for materiel required by fusion reactors. These range from transporters for large FWBS sectors to dollies. Also, some very specialized component handling systems have been conceived. All of these are included under the subject of materiel handling.

 A

Numerous maintenance operations encountered in fusion can and will be performed utilizing general-purpose mechanical master-slave manipulators (MSM). These general-purpose manipulators are capable of performing a wide variety of operations with speed, accuracy, and dexterity relative to other methods available for remote handling (Fig. 8.1-1). This development of diversity in manipulative devices was initiated in the late forties by Argonne National Laboratory (ANL).[1,2] The ANL Model M1 (1948) was the first in a family of mechnical MSM's to evolve in about a six-year period. In 1954, ANL introduced the Model 8 which was to become the standard hot-cell manipulator. Since the mid-1950's, the addition of many refinements, upgrades and improvements has resulted in many versions of the Model 8. It is interesting to note, however, that the basic concept and features of the Model 8 design have remained virtually the same (Fig. 8.1-2). A

The MSM's that are commercially available today are listed in Table 8.1-1. They have a broad variety of features as listed below:

- Capacity 5 to 100 lbs.,
- Up to seven degrees of freedom,
- Air or inert atmosphere operation,
- Force-feedback,
- Low friction, and
- Indexing to extend area coverage.

The most advanced U.S. version of the MSM is currently the CRL System 50 (Fig. 8.1-3) which has the unique features and advantages listed in Table 8.1-2. A

The major drawback of this species of manipulators is its lack of mobility. MSM's require a support structure which normally takes the form of a shielding

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(1) *Ray Goertz, "Manipulator Systems Developed at ANL," Proceedings of the 12th Conference on Remote Systems Technology, ANS, pg. 117, Nov. 1964.*

(2) *NASA SP-5047, Teleoperators and Human Augmentation (1967).*

	LASL*	MIT	NASA	MBA	CEA
TWO ARMED MAN (UNSUITED)	1	1	1	1	1
TWO ARMED MAN (SUITED)	---	---	---	8	---
TWO ARM MECHANICAL MSM	8	8-10	8	8	2-8
POWER MANIPULATOR (POSITION CONTROL)	80	40-50	64	55	10-30
POWER MANIPULATOR (SWITCH CONTROL)	480	80-100	640	---	50-100
CRANE (IMPACT WRENCH)	> 500	> 100	> 600	> 500	> 100

| A

*LASL - LOS ALAMOS SCIENTIFIC LABORATORY
MIT - MASSACHUSETTS INSTITUTE OF TECHNOLOGY
NASA - NATIONAL AERONAUTICS & SPACE ADMINISTRATION
MBA - MB ASSOCIATES
CEA - COMMISSARIAT A L'ENERGIE ATOMIQUE

Fig. 8.1-1. Time Comparison to Perform Remote Tasks.

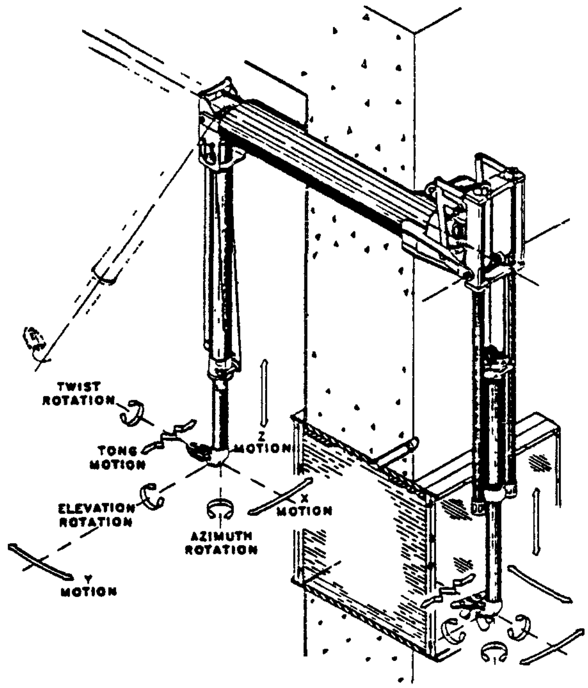

Fig. 8.1-2 ANL Mod. 8 Mechanical Master-Slave Manipulator.

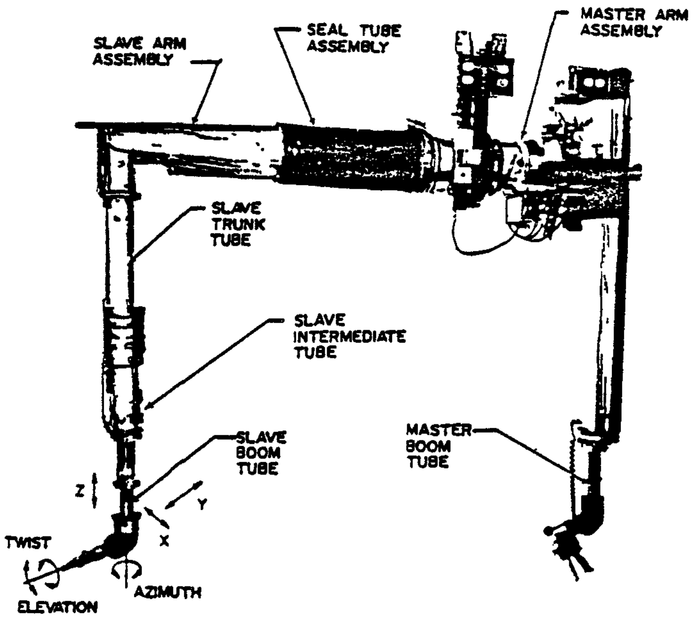

Fig. 8.1-3 CRL System 50 Manipulator.

Table 8.1-1 Commercially Available Mechanical MSM's

Company	Model	Capacity (lb.)	Coverage ft.^{3}	Atmospheric Containment	Mounting
Sargent Industries	7	10	70	Booting	Over-wall
Central Research	G	10	80	Booting	Thru-wall
	H	10	70	Booting	Thru-wall
	L	10	135	Sealed	Thru-wall
	8	20	270	Booting	Thru-wall
	E	20	800	Booting	Thru-wall
	A	20	220	Sealed	Thru-wall
	J	20	600	Sealed	Thru-wall
	8HD	50	270	Booting	Thru-wall
	EHD	50	800	Booting	Thru-wall
	D	100	250	Booting	Thru-wall
	F	100	660	Booting	Thru-wall
	50	50	660	Sealed	Thru-wall
Drath & Schroeder	K20	44	≈600	Sealed	Thru-wall
Walischmiller	A100 Series	44	≈200 to 600	Available in Sealed and Unsealed Versions	Thru-wall
	A200	33	≈70 to 100	Booting	Thru-wall
GEC Reactor Equip., Ltd.	REL11	100	≈270	Booting	Thru-wall
VNE (Nuclear), Ltd.	9	100	≈270	Booting	Thru-wall
	9ER	100	≈600	Booting	Thru-wall
	9SM	100	≈270	Sealed	Thru-wall
	11	100	≈270	Booting	Thru-wall
	GT2000 MK II	100	≈270	Sealed	Thru-wall
	VNE 80	50	≈600	Sealed	Thru-wall
Toshiba Seiki	UD	33	≈270	Booting	Thru-wall
	UER	110	≈600	Booting	Thru-wall
	UERGA	110	≈600	Sealed	Thru-wall
	HB	11	≈70	Booting	Thru-ceiling
GCA/PaR	Mini-Manip.	5	30	Booting	Thru-wall
	Light Duty	10	≈80	Booting	Thru-wall

A

Table 8.1-2 CRL System 50 - Features and Advantages

Feature	Advantage
Power-assist tong system	Amplified tong gripping force
Designed for 50-lb. handling capacity	Increase scope of work
High reliability	Increased availability
Remotely replaceable and interchangeable wrist joint assembly	Decontamination effort reduced, maintenance downtime reduced
Replaceable and interchangeable master- and slave-end assemblies (Fig. 8.1-4)	Work station downtime minimized, reduced installation and removal space
Reduced tape and cable loads	Longer tape and cable life, reduced friction/increased feel, high reliability
Sealed thru-wall tube assembly - interchangeable with standard (8, D, F, J, etc.) sealed and unsealed MSM's (Fig. 8.1-5)	Existing facilities for sealed and/or higher capacity operations

A

A

wall which limits the area that can be serviced. Under certain maintenance conditions, this area of coverage can be extended by mounting the MSM's on a movable wall section, that is, shadow shield or shielded cab.

The mounted height and centerline separation for MSM's varies with the specific style arm and intended use. Standard duty (CRL Mod. 8, F, 50, etc., styles) normally are mounted 10 ft. (120 in.) from the floor with light duty (L) at 8 ft. (96 in.) and special service (H style) at 6 ft. and 3 in. (76 in.). Centerline separation distances are generally the same for all styles MSM's with the minimum distance being 28 in. and maximum distance being 40 in. The required viewing coverage and intended use will be the primary drivers in

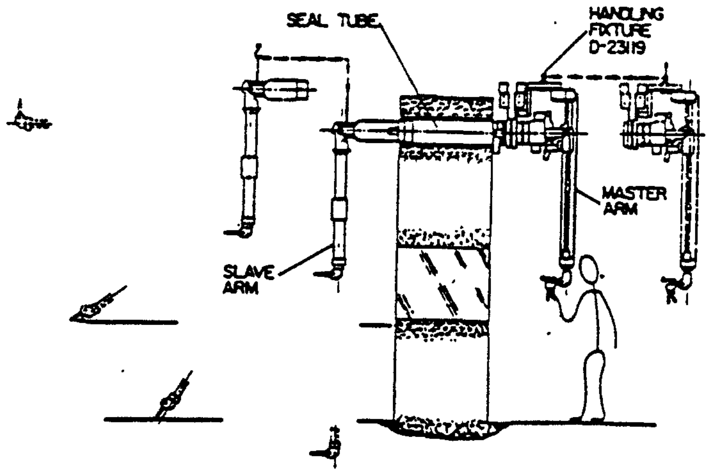

Fig. 8.1-4 Interchangeable MSM's.

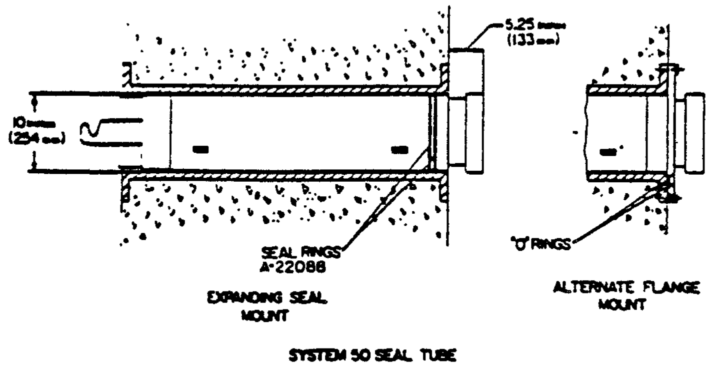

Fig. 8.1-5 Thru-Wall Seal Tube.

setting the centerline spacing. Note, however, that the counterweight envelopes on some arms, such as the F, require a minimum of 40-in. centerline spacing.

The facility should allow sufficient room for installation and removal of MSM's. The requirements for installation will vary depending on the MSM system under consideration. Figure 8.1-6 illustrates how to calculate the amount of room.

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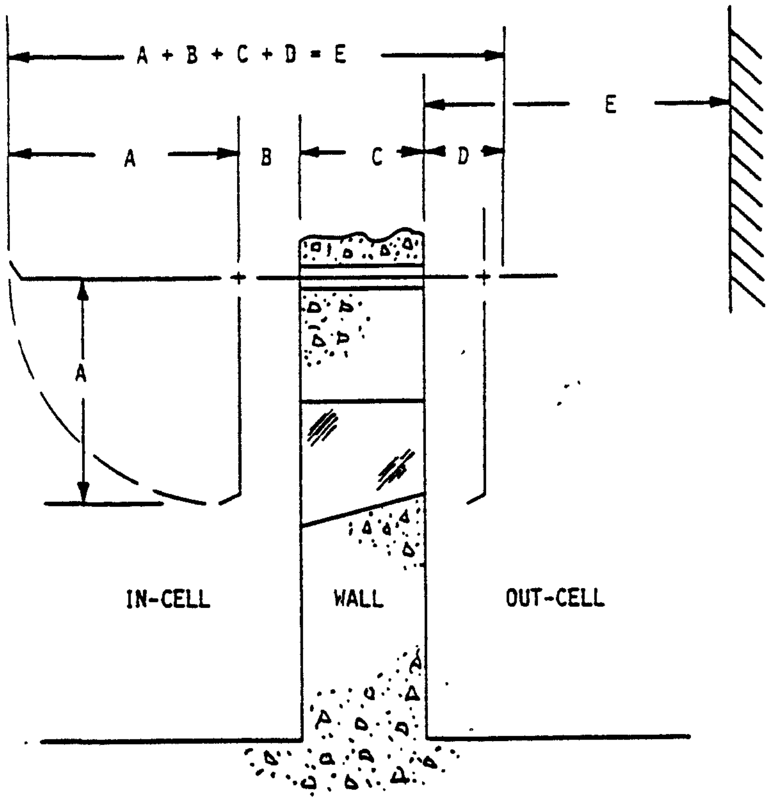

Fig. 8.1-6 Manipulator Installation and Removal Space Requirements (Unsealed Type).

A

Extra distance should be added to "E" to allow for clearance and maneuvering of the installation and removal equipment.

Since the MSM's are tied to a fixed wall position, it is advantageous to have the equipment being serviced movable. This enables the operation to fully utilize the dexterous reach area of the MSM's. Equipment mobility can be achieved in a number of ways such as turntables, carts, lift tables or a combination of these approaches.

Facilities should be designed to allow adequate space in and around the MSM installation to provide access for installation, removal, and maintenance servicing equipment. Manipulator service carts need maneuvering room. In most

A

installations when MSM's are removed from the hot cell, they must be "bagged out" which requires room for service platforms for technicians and health physics personnel. Sealed installations utilizing A's, J's, and Sys 50's must allow for the in-cell removal of the slave arms. This usually means crane hook access must be within 18 in. of the inside hot-cell wall.

The facility should provide adequate viewing and illumination for the type of work to be performed. Depending on the operations at the specific work station, the use of windows, TV, periscopes, binoculars, or a combination of systems with appropriate lighting may be required. All manipulation requires some form of overview viewing (window, TV) which keeps the operator cognizant of the work area as a whole and prevents equipment damage. When intricate operations are to be performed, specialized magnifying (closeup) systems such as periscopes, zoom TV or binoculars may be useful. When using specialized viewing systems, it is often advantageous to provide supplemental lighting to augment and enhance the work area.

Equipment to be serviced by the MSM's should be positioned to take full advantage of the reach and dexterity characteristics of the manipulators. As the angle of the slave arm changes from vertical to horizontal (Fig. 8.1-7), the dexterity and effective degrees of freedom are reduced. When the slave arm reaches the horizontal position, very simple tasks can be performed only with difficulty. Tasks requiring dexterous frequent manipulations should be placed in the A area of manipulator coverage while the B area is reserved for the less frequent simple operations.

The majority of MSM's are not protected from overloading and are, therefore, frequently overstressed, which results in cable or tape failures. Careful operator training and sizing of equipment components with the selection of proper capacity MSM's can appreciably reduce equipment downtime. Providing lifting handles, rings, cables or bails on components to be handled by MSM's will reduce operator fatigue, equipment failure, and repair time. Typical examples are shown in Fig. 8.1-8. A

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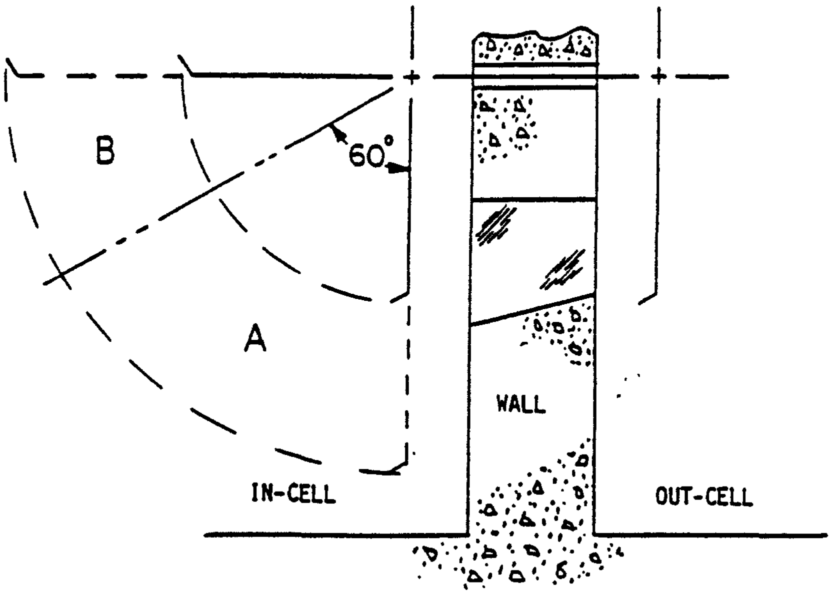

Fig. 8.1-7 Master-Slave Working Area.

A

A listing of current MSM's suppliers along with addresses and telephone numbers is provided in Table 8.1-3.

A

| A

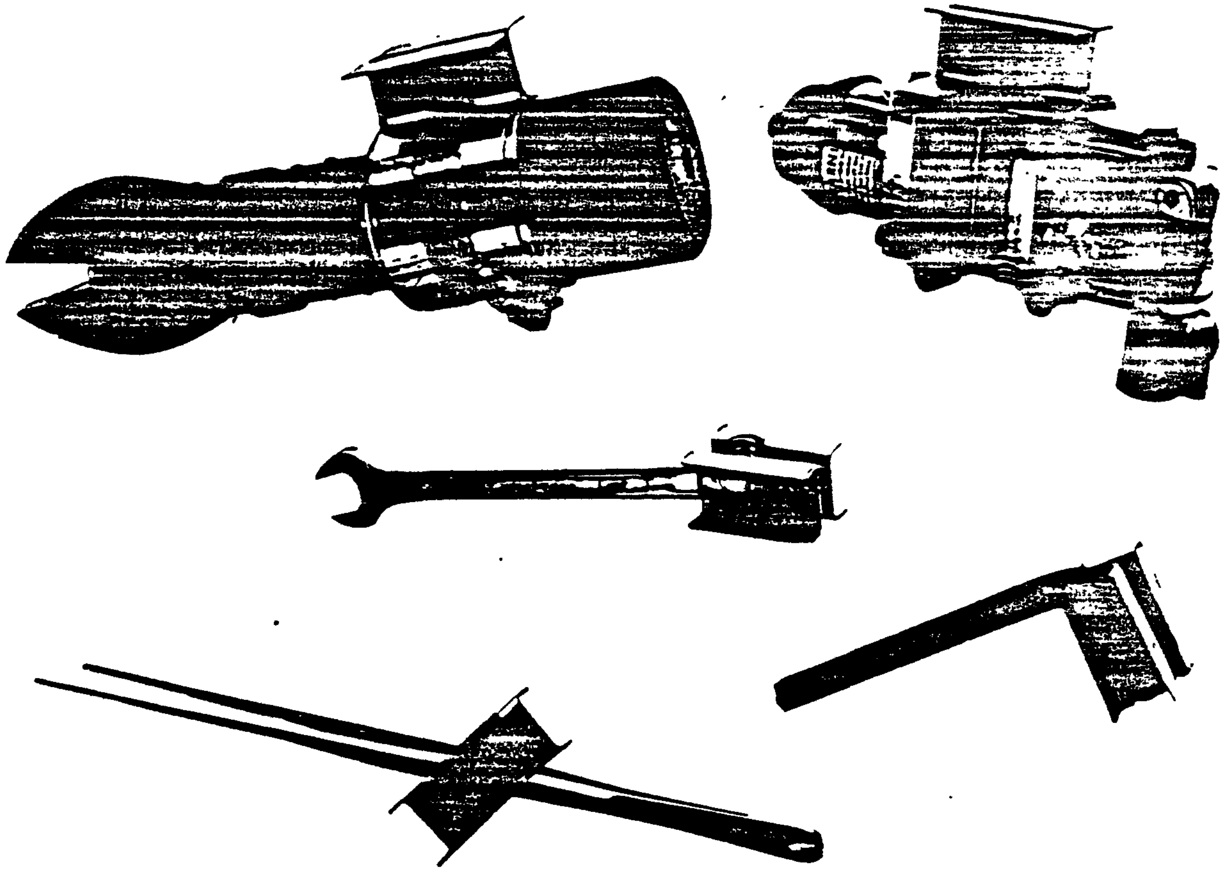

Fig. 8.1-8 Typical Tool Modifications.

| A

A

Table 8.1-3 MSM Suppliers

Central Research Laboratories Div.
Sargent Industries
Red Wing, MN 55066
USA
(612) 388-3565

Darth & Schrader
Maidammstr. 234/5 - Postfach 1140
D-2814 Bruchhausen-Vilser
Germany
(04252) 2206

PaR Systems
GCA Corporation
3460 Lexington Avenue, North
St. Paul, MN 55112
USA
(612) 484-7261

GEC Reactor Equipment, Ltd.

Toshiba Seiki
13-12 Mita 3 Chome
Minato-ku Tokyo 108
Japan
03-454-7111

HWM
Hans Walischmiller Gmbh Markdorf
777E Markdorf/Bodensee
Germany
(07544) 3027

VNE (Nuclear), Ltd.
South Marston Industrial Estate
P.O. Box 33
Swindon SN3 4RA
Wiltshire, United Kingdom

During 1948 General Mills produced the Model A unilateral manipulator in which the arms and hands were driven by switch-controlled motors rather than by direct mechanical or electrical linkage to the operator (as in the true master-slave). The Model A became a "workhorse" of the nuclear industry in tasks requiring more strength and working volume than possible with MSM's,[1] see Fig. 8.2-1. Since this early date power manipulators have developed to the point where they may have many degrees of freedom, see Fig. 8.2-2. A

Numerous maintenance operations encountered in fusion facilities can and will be performed utilizing power manipulators. These general purpose manipulators are capable of performing a wide variety of operations but usually with less speed, accuracy and dexterity than that achievable with master-slave manipulators. However, the above statement only applies when the manipulator is switch controlled. Computer control can be added to a power manipulator which speed up operations and increase the degree of accuracy. Computerized manipulators are called robots. The Robot Institute of America defines a robot as "a programmable, multifunction manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks."

[1] *NASA SP-5047, "Teleoperators and Human Augmentation," pg. 6, (1967).*

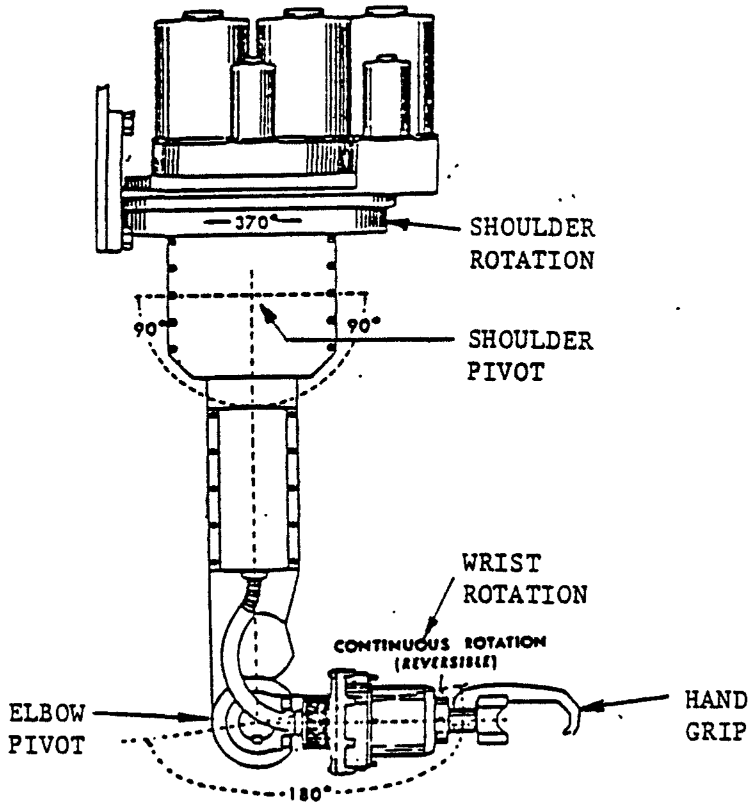

Fig. 8.2-1 Early "General Mills" Power Manipulator.[2]

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[2] *Nucleonics, pg. 99, Nov. 1950.*

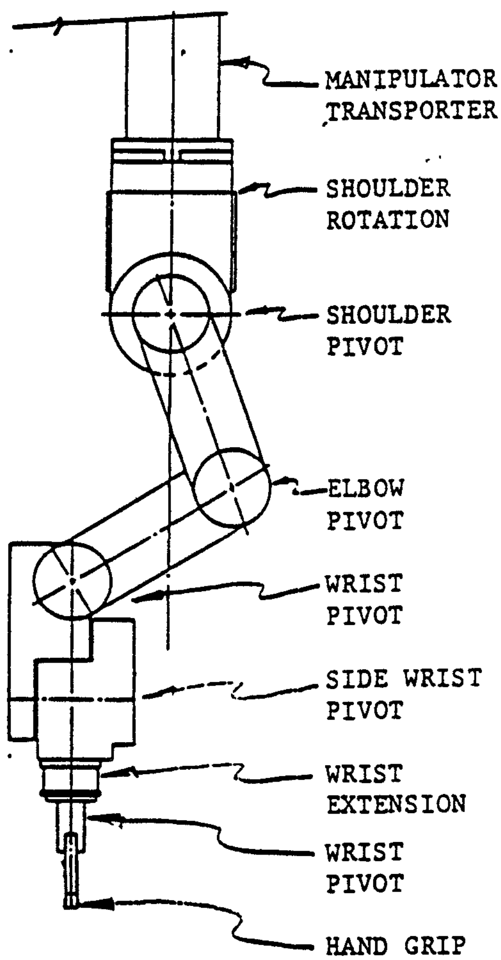

Fig. 8.2-2 Typical Power Manipulator.

8.2.1 Manipulators — Power manipulators are switch controlled and driven by electric motors, at least for nuclear purposes. In addition to one standard design of the basic kinematic systems, there are numerous types of designs with very different performance characteristics. As a rule, a complete unit consists of an arm and mounting arrangement to move the arm to the work place discussed in Section 8.5. Arms with one to three (often two) pivots have between four and eight (often five) motions including the tongs and the mounting arrangements have between one and eight (mostly three) motions.

Most types of arms are simplifications compared with Fig. 8.2-2, with between one and four motions missing. If only two pivots are available, the first pivot viewed from the tong is called the elbow pivot. If the arm has only one pivot, this is called the elbow pivot. Unlike Fig. 8.2-2, there are also some designs with upper arm rotation and upper arm extension motions instead of other motions. Standard arm designs have the five motions of shoulder rotation, shoulder pivot, elbow pivot, wrist rotation and gripping.

The arms are between 18 in. and 225 in. long (in most designs, 40 to 55 in.). In the horizontal position of the arms, depending on the design, the tongs may hold and manipulate objects weighing between 50 and 2000 lbs. (in most cases, between 100 and 600 lbs.).

Usually the parallel jaw hands are used as the end effector, however, there are many types of hands in existence, see Fig. 4.2-8. The hands are usually remotely changeable with the aid of a hand change fixture. A

Some manipulators allow for the replacement of the hand by a special tool such as an impact wrench. This practice is only recommended if the special tool is to be used for extended periods of time since considerable operating time is lost changing tools.

Table 8.2-1 lists all of the power manipulator suppliers currently available and a representative listing of the equipment they supply. Table 8.2-2 lists these same suppliers with their address and phone numbers, if available.

Table 8.2-1 Available Power Manipulators

Company	Model	Capacity (lb.)	Mounting
ACB	2050 B	100	Bridge
	3025 B	100	Bridge
	2100 B	200	Bridge
	2100 AE	200	Bridge and Wall
	1100 B	300	Bridge
	3050 B	100	Bridge
	3050 AE	100	Bridge
	2150 AE	300	Bridge
	2150 B	300	Bridge
	2250 AE	500	Bridge and Wall
	2050 TB	100	Bridge and Wall
	2100 MAE	200	Bridge
	3050 TAE	50	Wall
Drath & Schrader	ELMA 60-1000-1	123	Bridge
	ESMA 300-3000-1	511	Bridge
	ELFAM 1000-4000-1	1,637	Bridge
	SM3-A	100	Bridge
	SM3-13	100	Wall
GEC-Elliott	Mark 1	164	Bridge
	Mark 2	164	Bridge
PaR	Model 3000 Standard	100	Bridge and Wall
	Model 1000 Standard	75	Bridge and Wall
	Model 2000 Standard	150	Bridge, Wall, Pedestal
	Model 3500 Standard	100	Bridge and Wall
	Model 6000	400	Bridge and Wall
	Model 3800	600	Bridge and Wall
	Model 7000	700	Bridge and Wall
	Rigid E/M Manip. 3000US-H	100	Undersea Vehicle
Vickers, Limited	750	100	Bridge
	350	100	Wall
Toshiba Seiki	TP 050-8	100	Bridge
	TP 050-10	100	Bridge
Walischmiller	A 1000	265	Bridge
Weserhvtte	SM5-C	600	Bridge
	SM5-B	600	Wall
	SM5-D	400	Wall
	SM5-E	1,500	Bridge
ATCOR	4001	400	Bridge
Cunnington & Cooper, Ltd.	No standard unit specialty items		
Taylor Hitec, Ltd.	Specially designed in-reactor manipulators		
Perry Controls Group	5F	150	Submersible
	6F	150	
	7F	110	
International Submarine Engineering, Ltd.		Up to 350	Submersible

Table 8.2-2 Power Manipulator Suppliers

ACB
29 rue du Faubourg
Saint-Honore 75008
Paris, France
266-51-71

ATCOR
270 Farmington Avenue
Farmington, CT 06032
USA
(203) 677-0457

Cunnington & Cooper, Ltd.
Wall Hill, Dobcross
Oldham, Lancashire OL3 5RB
United Kingdom

Orath & Schrader
Maidammstr 234/5 - Postfach 1140
D-2814 Bruchhauser - Vilsen
Germany

GEC - Elliott

PaR/GCA Corporation
3460 Lexington Avenue, North
St. Paul, MN 55112
USA
(612) 484-7261

Taylor Hitec, Ltd.
77 Lyons Lane
Chorley, Lancashire PR6 0PB
United Kingdom

Toshiba Seiko
13-12 Mita 3 Chome
Minato-ku Tokyo 108
Japan

Vickers, Ltd.
Nuclear Engineering Div.
South Marston Works
Swindon, SN 3 4RA
Wiltshire, United Kingdom

Hans Wallischmiller Gmbh
D-7778 Markdorf/Bodensee
Germany
(07544) 3027

Weserhutte
Germany

Perry Oceanographics, Inc.
P.O. Box 10297
Riviera Beach, FL 33404
USA
(305) 842-5261

International Submarine Engineering, Ltd.
2601 Murray Street
Port Moody, B.C. Canada V3H 1X1
(604) 931-2408

8.2.2 Robots - The industrial robots were designed primarily for operation in fully automated manufacturing and assembly lines. Their programming capabilities are utilized in a fixed frame of reference where the robot operates from a predetermined stationary axis and services individual or multiple work stations, performing a series of preprogrammed tasks.

Incorporation of a programmable multi-task robot into a fusion facility for remote maintenance requires mobility of the robot and an aptitude for performing a vast array of work tasks. There are three possible modes of operation: a full manual "man-in-the-loop" operator teach mode, a computer monitored and controlled mode, and a hybrid computer vision and computer control mode. Both the manual teach mode and the computer controlled mode are available on existing robot systems. The technology exists to develop a hybrid system. A

Operation of the programmable robot in only the full manual "man-in-the-loop" operator teach mode allows the operator to perform an entire array of work tasks in a canyon or on a production line relying primarily on television feedback for process monitoring and control. In this mode, the robot would function as a power manipulator with an operator controlling all process functions. Restriction of robot operation to the teach mode or operator control relieves any requirements for precision robot location or fixturing. All maintenance and repair tasks are performed through video feedback with the operator closing the feedback loop. This provides much greater utilization of the robot for unstructured repair operations. With the development of suitable software, the computer can be utilized to function as a safety backup system to prevent collision or encroachment into areas of exclusion. A

In the second mode of operation, the operation of a programmable robot in the programmable mode requires robot position monitor control. A large CPU memory capacity is needed to log the major component locational coordinates and the appropriate operational sequence procedures. In addition, the robot has to be monitored for accurate ordinate positioning relative to the component being worked on. Inaccurate positioning of the robot relative to the component being repaired renders the programmed operational sequences inoperable. Incorporation of a complete automated repair system imposes strict dimensional and alignment tolerances on facility construction, fabrication, and component installation.

The third mode of operation, a hybrid system consisting of a computer vision system in conjunction with a programmable robot, could provide a highly sophisticated automated remote maintenance system. Developments in the field of vision and video technology have advanced the state-of-the-art in remote alignment using a video camera to a feasible concept. Current commercial video machine perception systems are capable of computing component centroids, component recognition, parts inspection and component dimensioning. Incorporation of such a system would establish a reference datum from which the robot would perform its programmed repair functions. The object recognition function would dictate or identify the appropriate program function to be selected.

There is little doubt that robotics is a rapidly advancing technology and will have application within hostile environments. However, caution should be exercised in the application of robotics to fusion plants at this time.

Much of the remote manipulation work that is performed will be unstructured which means that a pre-planned program could not be established. Also, the repair of an individual component (motor, pipe jumper, filter, etc.) will be performed infrequently, perhaps only once in 5 or 10 years. The value of funding software programs for each of these tasks is questionable. The electric master-slave manipulator, with a human mind in the loop, appears to be a more cost-effective solution for this work. There are, however, many other tasks which may be repetitive and could better be performed by a teachable robotics system. This could include the control of the maintenance system on its way to a specific work place, the automatic changing of tools, etc.

Work previously performed at MIT,[3] JPL,[4] and currently under study at ORNL[5] has shown that current state-of-the-art electric master/slave manipulators can be interfaced with computer systems and operated as a programmable/computer controlled manipulative device. This would allow an operator to teach a manipulator a task that proves to be repetitive and then direct the computer to repeat the task as required. The concept of real time computer control can place the manipulator under the direct real time control of the operator and still employ safeguard limits or computer controlled feedbacks which are preprogrammed into the control system computer. A

The results of robotic device survey is provided in Table 8.2-3. Only those systems for which information was available and which have potential for use in Fusion AMR, are listed.

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[3] *Sheridan, T. B., "Supervisory Control of Remote Manipulators for Undersea Applications," Proceedings Int. Conf. Cybern Soc., 1977.*

[4] *Hamel, W. R., "Robotics-Related Technology in the Nuclear Industry," Society of Photo-Optical Instrumentation Engineers Technical Symposium, 1983.* A

[5] *Bejczy, A. K., "Allocation of Control Between Man and Computer in Remote Manipulation," JPL, Calif. Institute of Technology, 1976.*

Table 8.2-3 Robotic Survey

Company	Potential	Products/Comments
ACB Prairie-av-Duc-B.P.165(44) Nantes - France	Yes	Power Manipulators
Action Machinery Company P.O. Box 3068-T Portland, OR 97208	Maybe	Heavy Duty Backhoe Type Material Handling Equipment
Admiral Equipment Company 305 West North Street Akron, OH 44303	Maybe	Robots
Andromat CSEE 17, Place Etienne - Pernet 7573E Paris Cedex 15 France	Maybe	Founding & Welding Robots
ASEA, Inc. 4 New King Street White Plains, NY 10604	Maybe	Robots
Astrosystems, Inc. 6 Nevada Drive Lake Success, NY 11042	Maybe	Robotic Controls & are Developing a Robot
ATCOR Engineering Sys., Inc. 270 Farmington Avenue Farmington, CT 06032	Yes	Power Manipulator

Table 8.2-3 Robotic Survey (continued)

Company	Potential	Products/Comments
Baer Automated Systems Lakeland Industrial Park Route 4, Box 1200 Lakeland, FL 33803	Maybe	Gripping Hand
The Bendix Corporation Robotics Division 21238 Bridge Street Southfield, MI 48037	Maybe	Robots
Blocher-Motor GmbH & Co. KG Dieselstr 4 7430 Metzingen Federal Republic of Germany	Yes	Servo Master-Slave Manipulator
Brown, Boveri & CIE AKTIENGESELLSCHAFT Postfach 10 16 80 6900 Heidelberg 1 Germany	Maybe	Workpiece Recognition
Canadian Gen. Elec. Co., Ltd. 107 Park Street North Peterborough, Ontario Canada K9J7B5	Maybe	U.S. Licensee for Andromat Robots
CEE VEE Engineering, Ltd. Cooden Sea Road Bexhill on Sea Sussex TN 39 4SL United Kingdom	Maybe	Tongs & Tong Type Manipulators

Table 8.2-3 Robotic Survey (continued)

Company	Potential	Products/Comments
Central Research Lab. Sargent Industries Redwing, MN 55066	Yes	Master Slave & Servo Manipulator
Cincinnati Milacron 4701 Marburg Avenue Cincinnati, OH 45209	Maybe	Robots
CONCO Mendota, IL 61342	Maybe	Man Assist
Copperfield Steel Company 1401 East Fourteen Mile Road Troy, MI 48084	Maybe	Pick & Place Robots Vision Recognition Systems
Daido Steel Company, Ltd. 1-11-18, Nishiki, Naka-ku Nagoya, Japan	Maybe	Heavy Duty Man Assist
Dainichikiko Company, Ltd. KOSAICHO NAKAKOMAGUN YAMANASHI 400-04, Japan	Maybe	Wide Range of Robots
Dojen Robotics, Inc. Blueberry Hill Industrial Park Woburn, MA 01811	Maybe	Rotary Joint
Drath & Schrader Maidammstr-234/5 - Postfach 1140 D-2814 Bruchhausen - Vilsen Germany	Yes	Power Manipulators

Table 8.2-3 Robotic Survey (continued)

Company	Potential	Products/Comments
General Electric Company 12850 Boston Avenue Bridgeport, CT 06602	Maybe	Many Robot Models
Grasp, Inc. RD 3, Box 233A Troy, NY 12180	Maybe	Robot Simulation Program
Herr-Voss Corporation Callery Pennsylvania 16024	Maybe	Heavy Duty Material Movers
Hodges Robotics Intern. Corp. 3710 North Grand River Avenue Lansing, MI 48906	Maybe	Several Robot Models
International Submarine Engineering (I.S.E.), Ltd. 2601 Murray Street Port Moody, B.C. Canada V3H 1X1	Maybe	Hydraulic Manipulator
International Robomation 2281 Las Palmas Drive Carlsbad, CA 92008	Maybe	Air-Servo Motor Robot
Kernforschungszentrum Karlsruhe GmbH Weberstr. 5 - Postfach 3640 D-7500 Karlsruhe 1 Germany	Yes	Developed Many Types of Manipulative Devices Which are Licensed to Others

Table 3.2-3 Robotic Survey (continued)

Company	Potential	Products/Comments
KUKA Welding Systems & Robot Corporation 24031 Research Drive Farmington Hills, MI 48018	Maybe	Universal Robot
La Calhene 5, rue Emile-Zola 95870 Bezons France	Yes	Servo Manipulator
Lord Corporation 1635 W. 12th Street P.O. Box 2051 Erie, PA 16512	Maybe	Centering Compliance & Tactile Sensors
Machine Intelligence Corp. 1120 San Antonio Road Palo Alto, CA 94303	Maybe	Machine Vision System
MAN Kerntechnik Katzwanger Strabe 101 Postfach 440100 D8500 Nurnberg 44 West Germany	Maybe	Specially Designed Remote Systems
Marol-Nagata Company, Inc. 2759 Higgins Road Elk Grove Village, IL 60007	Maybe	Man Assists & Heavy Duty Factory Manipulators

Table 8.2-3 Robotic Survey (continued)

Company	Potential	Products/Comments
MB Associates Bollinger Canyon Road San Ramon, CA 94583	Maybe	No Product Line - Have Developed Manipulators for Special Applications
Mefferd Industries, Inc. Walnut Street & Rush Lake Road Laurens, IA 50554	Maybe	Man Assist Positioning Arm
Meidensha Elec. Mfg. Co., Ltd. 2-1, 2-Chome, Ote-machi, Chiyoda-ku Tokyo 100, Japan	Yes	Servo Manipulator
Milwaukee Cylinder 5877 South Pennsylvania Ave. Cudahy, WI 53110	Maybe	Power Lifts
MOBOT 980 Buenos Avenue San Diego, CA 92110	Maybe	Several Manipulator Devices
Moog, Inc. Industrial Division Jamison Road East Aurora, NY 14052	Maybe	3-Axis Robot Wrist
Morfax, Ltd. Willow Lane, Mitcham Surrey CR4 4TD United Kingdom	Maybe	Several Remote Defense Systems

Table 8.2-3 Robotic Survey (continued)

Company	Potential	Products/Comments
MTS Systems Corporation Ind. Systems Division P.O. Box 24012 Minneapolis, MN 55424	Maybe	Many Robotic Systems
Nachi America, Inc. 223 Veterans Boulevard P.O. Box 373 Carstadt, NJ 07072	Maybe	Many Industrial Robot Models
NPS Robotic Systems, Inc. Daily News Building 220 East 42nd Street New York, NY 10017	Yes	Roving Robot With 150# Manipulator
PaR Systems GCA Corporation 3460 Lexington Avenue, North St. Paul, MN 55112	Yes	Power Manipulators/Robots
Picker Corporation Picker Nuclear Division 12 Clintonville Road Northford, CT 06472	Maybe	Ultrasound & Diagnostic Equipment
Positech Corporation Rush Lake Road Laurens, LA 50554	Maybe	Man Assist
Reis Machines 1450 Davis Road Elgin, IL 60120	Maybe	Several Robotic Models

Table 8.2-3 Robotic Survey (continued)

Company	Potential	Products/Comments
RTD Quality Services Delftweg 144 3046 NC Rotterdam Holland	Maybe	Automatic Ultrasonic Inspection
Taylor Hitec, Ltd. 77 Lyons Lane, Chorley Lancashire PR6 OPB United Kingdom	Yes	Special Manipulators & Devices for Nuclear Reactor Repair
Teledyne Readco Welding Equipment Division 903 S. Richland Avenue York, PA 17403	Maybe	Weld Positions - Same as Used at Princeton
TeleOperator Systems Corp. 45 Knickerbocker Avenue Bohemia, NY 11716	Yes	Servo Manipulators & Power Manipulator
Tetra-Tech., Inc. 11777 Sorrento Valley Road P.O. Box 2528 San Diego, CA 92112	Maybe	Underwater Vehicles & TV Systems
Toshiba Corporation 72, Horikawa-cho, Saiwai-ku Kawasaki, Japan	Yes	Master/Slave Manipulators & Other Special Equipment for Nuclear Industry
Towa Corporation of America 1711 South Pennsylvania Avenue Morrisville, PA 19067	Maybe	Materials Handling Equipment

Table 8.2-3 Robotic Survey (continued)

Company	Potential	Products/Comments
Unimation, Inc. Shelter Rock Lane Danbury, CT 06810	Maybe	Large Variety of Pick & Place Robots
Vickers, Limited South Marston Works Swindon, Wiltshire England	Yes	Master/Slave & Power Manipulators
Walischmiller GMBH Markdorf 7778 Markdorf/Bodensee Germany	Yes	Master/Slave & Power Manipulators - Will Soon Have Servo Manipulator

The most recent advancement in the field of remote maintenance equipment is the electric master-slave manipulator. These manipulators have dexterity and force-reflection capabilities similar to those of the mechanical manipulators. However, the master and slave units are electrically connected but not mechanically connected. This allows the electric slave unit to be transported throughout a large volume cell and to replace failed components in-situ.

The electric manipulators were actually developed and tested in the 1950's.[(1),(2),(3),(4)] However, they were not made commercially available until the early seventies.[(5)] There were a number of reasons why application took so long. One was the high cost of the electronic control system in the current design. Solid state circuitry developments have greatly reduced this cost. Also, remote facilities prior to 1970 were not extremely large and could be serviced using windows and mechanical manipulators. New requirements have arisen in the 1970's; namely, accelerators, fusion reactors, waste repositories, refabrication plants and fuel reprocessing plants. All of these have high plant operating efficiency as a requirement and need the large volume coverage that is provided by the electric MSM system.

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(1) *"Electronically Controlled Master-Slave Manipulator (ANL Model 2)," Hot Laboratory Equipment, Second Edition, Brookhaven National Laboratory, 1958.*

(2) *NASA SP-5047, "Teleoperators and Human Augmentation," 1967.*

(3) *NASA SP-5070, "Teleoperator Controls," 1968.*

(4) *Ray Goertz, "Manipulator Systems Developed at ANL," Proceedings of the 12th Conference on Remote Systems Technology, pg. 117, 1964.*

(5) *John Simon, et. al., "Design of the Fermilab Neutrino Remote Target Maintenance System," Proceedings of 23rd Conference on Remote Systems Technology, 1975.*

A

Reliability of a new system has to be a concern especially in the hostile environment of a fuel reprocessing cell. In comparison to the mechanical manipulators, the electric appear to be more reliable. Experience at one hot cell facility in the U.S. has shown that mechanical manipulators (all types) can perform an average of 25 hours[6] actual work between repairs while the electric manipulators at Los Alamos Meson Physics Facility have "been in operation approximately 4,000 hrs. each, with an availability above 95%."[7] However, operation in an intense radiation environment for long periods requires special attention to the design of insulators, lubricants, etc. which are subject to radiation deterioration. A

When good force-reflecting servos are provided, the performance of electric master-slave manipulators are quite similar to that of mechanical manipulators. The electric master-slave manipulator has the following advantages over its mechanical counterpart:

- Mobility of slave and master arms
- Force amplification
- Different sized master and slave arms

The chief advantage to be gained in having the master and slave arms connected with an electric cable instead of mechanical linkages is that the slave arm can be made mobile so that it can work anywhere in a large volume facility. Figure 8.3-1 is an elementary diagram of such a system, and Fig. 8.3-2 illustrates a typical installation. Figure 8.3-3 shows the slave portion of the Model SM 229 manipulator provided by TeleOperator's System. Figure 8.3-4 is a conceptual layout for a manipulator control room utilizing the electric force reflecting manipulators and TV viewing.

Table 8.3-1 provides a listing of currently available electric master-slave manipulators. A

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(6) *Private Communication J. R. White and D. A. Tobias, ANL-W/HFEF, 1972.*

(7) *Grisham, D. L., Monitor Update - 1979, Proceedings of the 27th Conf. on Remote Systems Technology, pg. 268, 1979.*

A

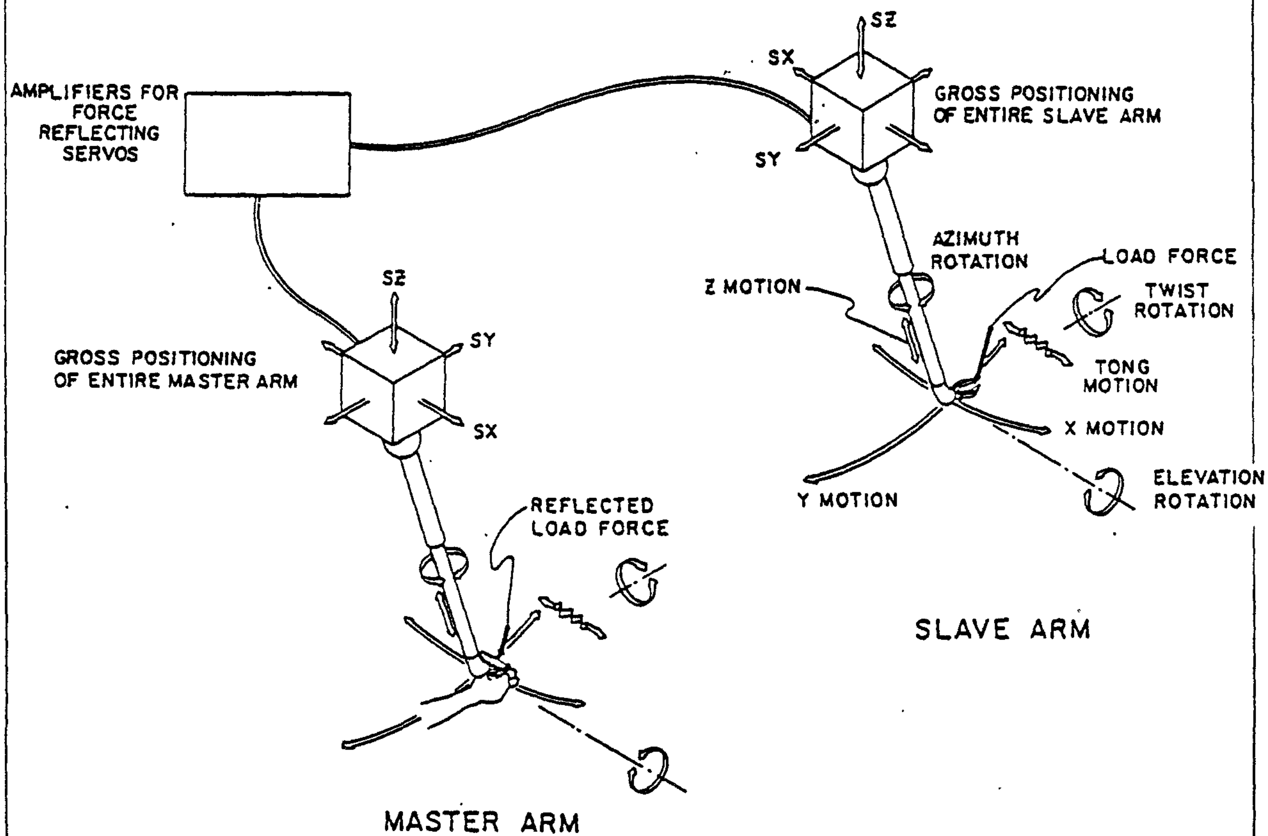


Fig. 8.3-1 Elementary Diagram of an Electric Master-Slave Manipulator.

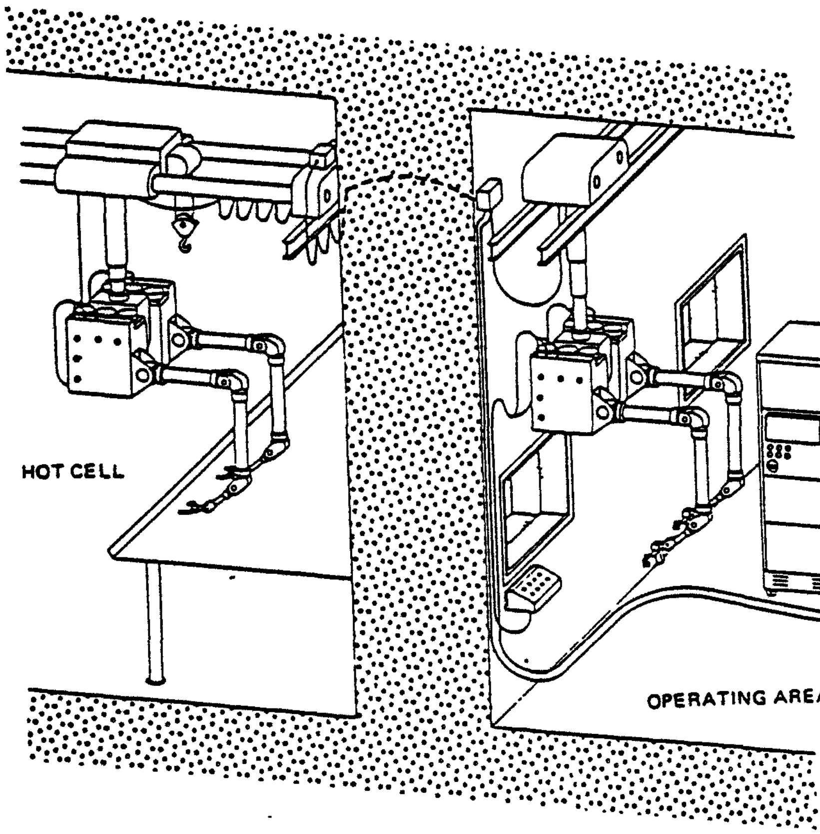


Fig. 8.3-2 Typical Electric Master-Slave Hot Cell Installation.

A

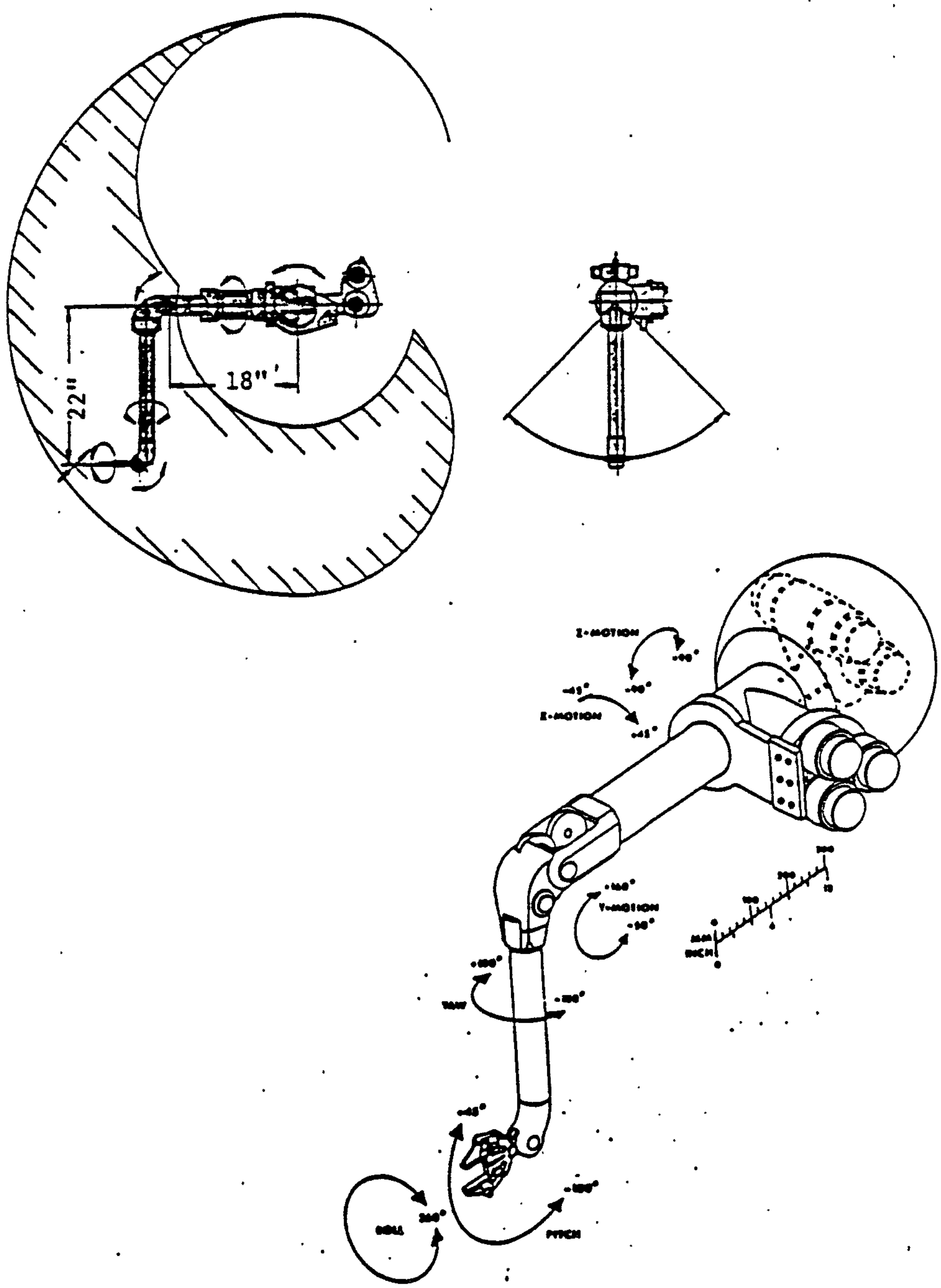


Fig. 8.3-3 Model SM 229 TOS Slave Arm.

A

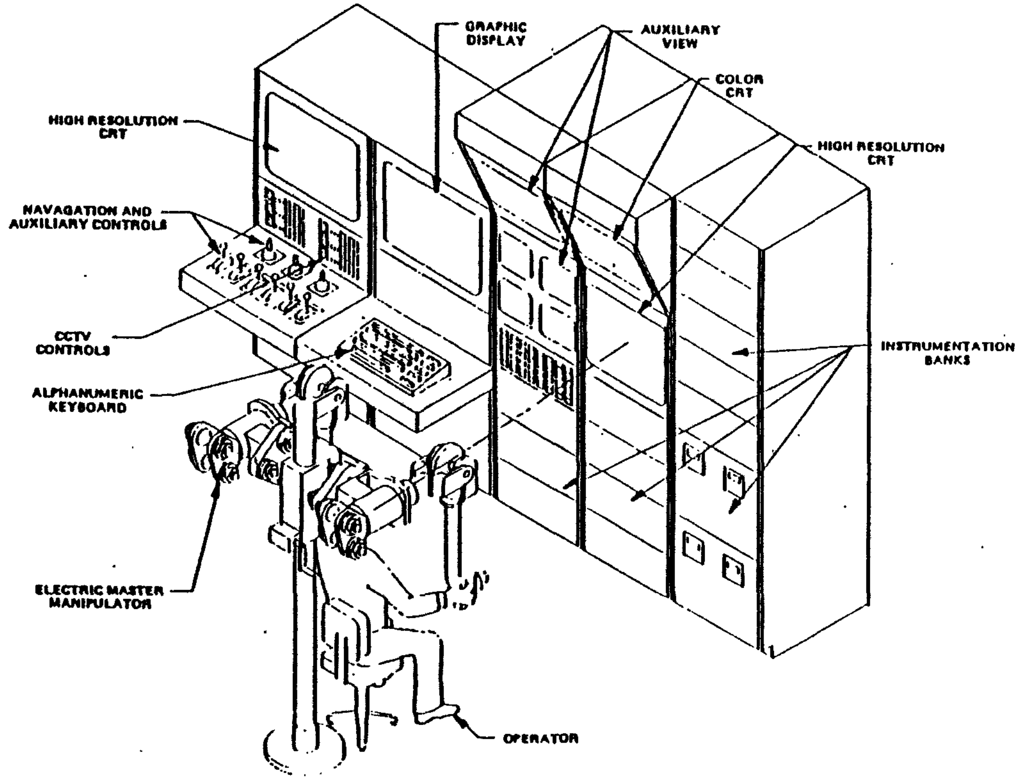


Fig. 8.3-4 Manipulator Control Station.

A

Table 8.3-1 Current Available Electric Master-Slave Manipulators

Manufacturer	Model	Capacity (lb.)	Address	Comments
Central Research	M	50	Sargent Industries Red Wing, MN 55066	Electric
TeleOperator Systems	SM-229	22	45 Knickerbocker Avenue Bohemia, NY 11716	Electric
Blocher	EMSM1 EMSM2	50 50	Dieselstr 4 - Postfach 129 D-7418 Metzinger, Germany	Electric
LaCalhene	MA23	50	Cedex 328, La Ville aux Clercs, Cedex, France	Electric
Selenia	*Mascot	45	Italy	Electric
Remote Technology Corp.	RM-10	22	114 Union Valley Road Oak Ridge, TN 37830	Electric
Meidensha		22	Meidensha Electric 1-17, 2 Chome, Ohsaki, Shinagawa-ku, Tokyo, 141, Japan	Electric
Toray	EMSM-II	55	Toray Engineering Nihonbashi Muromachi Bldg. No. 6, 3 Chome Nihonbashi-Hongoku-cho Chuo-ku, Tokyo, 103, Japan	Electric

*JET Manipulator System - Selenia no longer manufactures this item.

A

There are many different manipulator transport systems. Twelve typical configurations are presented here. The configuration of special purpose transporters are only limited by the imagination of the designer.

8.5.1 Telescoping Transporter — Figure 8.5-1 illustrates the telescoping tube transporter. This manipulator transporter is a standard configuration used in almost all hot cells throughout the world. Bridge travel (x-motion) moves the manipulator the length of the facility while the carriage travel (y-motion) traverses its width. The telescoping tubes (z-motion) raises or lowers the manipulator to the correct working elevation. The manipulator is attached to the end of the telescoping tube.

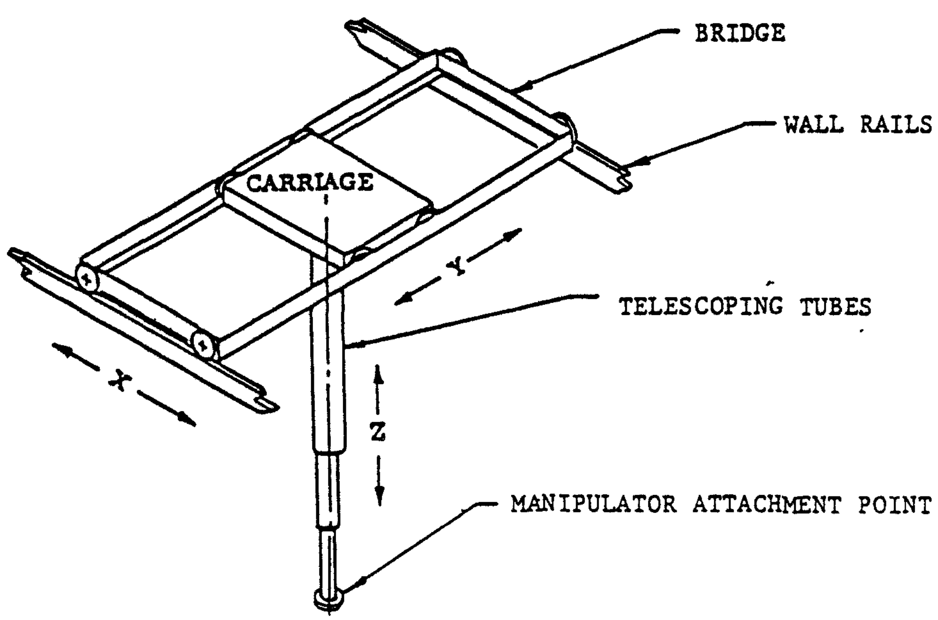


Fig. 8.5-1 Telescoping Tube Transporter.

8.5.2 Rigid Tower Transporter - Figure 8.5-2 illustrates a rigid tower transporter. The bridge and carriage in this concept provides the same functions as in Fig. 8.5-1. A rigid tower is provided vertically. The tower carriage may be equipped with a boom which is equipped with a pivot motion. The manipulator would be attached to this boom. This type of transporter has the advantage of being able to be able to cover larger vertical distances than the telescoping tube transporter as there are practical distances that tubes can be designed and built to cover. A

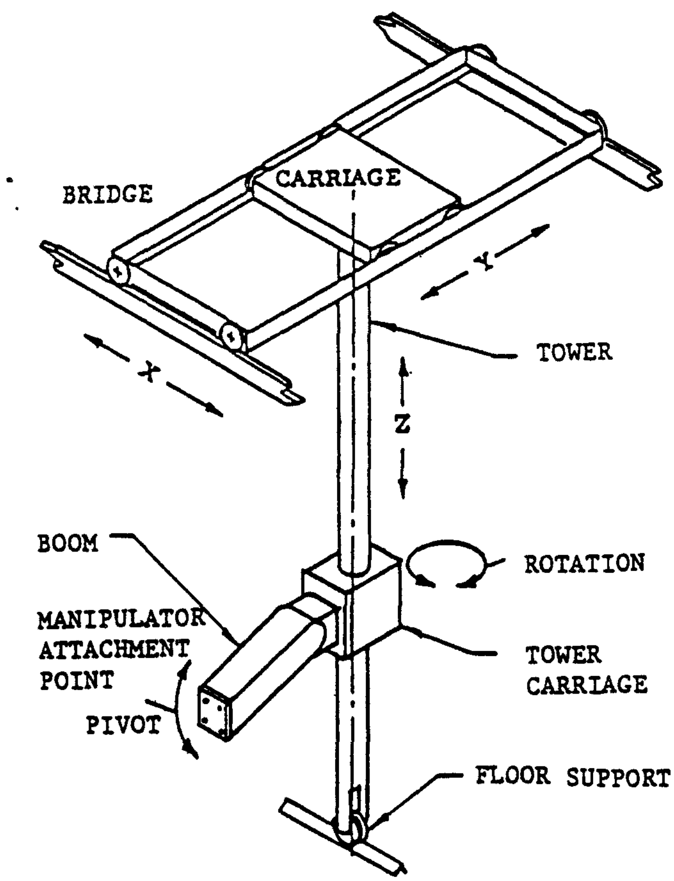
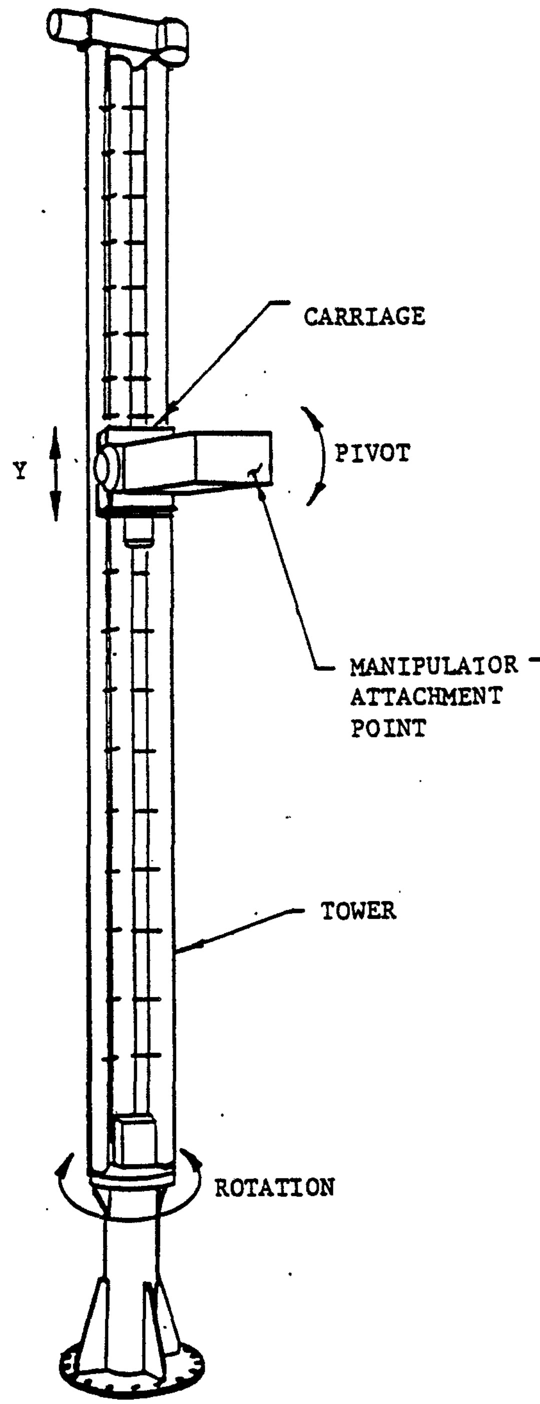


Fig. 8.5-2 Rigid Tower Transporter. A

8.5.3 Pedestal Transporter — Figure 8.5-3 illustrates a typical pedestal manipulator transporter. The specific model shows a fixed location pedestal which is mounted to the floor. However, models have been developed where the base is a large turntable and the pedestal may be moved to different work locations by a facility crane. The basic pedestal usually has vertical (y) and rotation motion. The pedestal carriage may be equipped with a telescoping boom if desired. The manipulators would be mounted to the end of the boom.



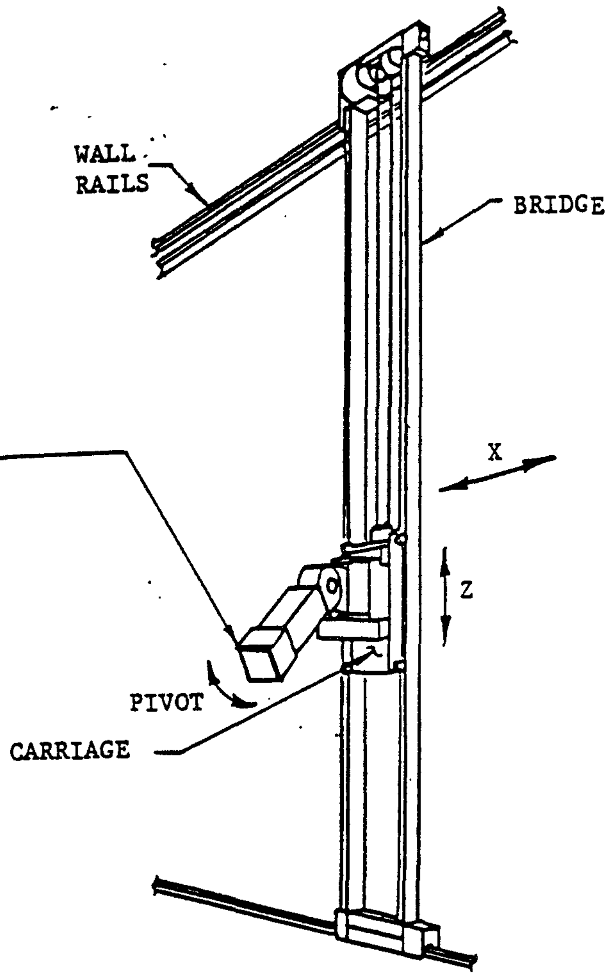


Fig. 8.5-4 Wall Mount Transporter.

Fig. 8.5-3 Pedestal Transporter.

8.5.4 Wall Mounted Transporter — Figure 8.5-4 illustrates a typical wall mounted manipulator transporter. This system would be utilized with a facility where one wall was to be free from obstructions and the items to be worked on were to be a fixed location from that wall.

8.5.5 Tracked Vehicle Transporter — Figure 8.5-5 illustrates a typical tracked vehicle manipulator transporter. This type of vehicle would usually be applied to a situation where heavy loads and rough surfaces were to be encountered.

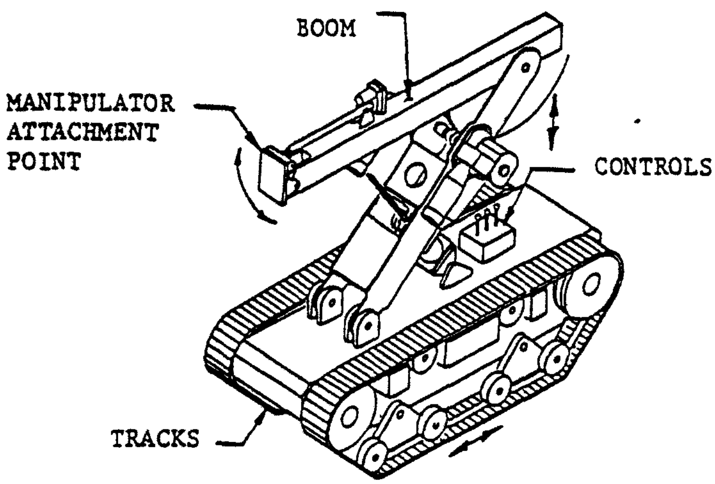


Fig. 8.5-5 Tracked Vehicle Transporter.

8.5.6 Backhoe Transporter — Figure 8.5-6 illustrates a typical backhoe manipulator transporter. This type of transporter would be especially useful where the manipulator must reach over the top of items or down into a pit type situation.

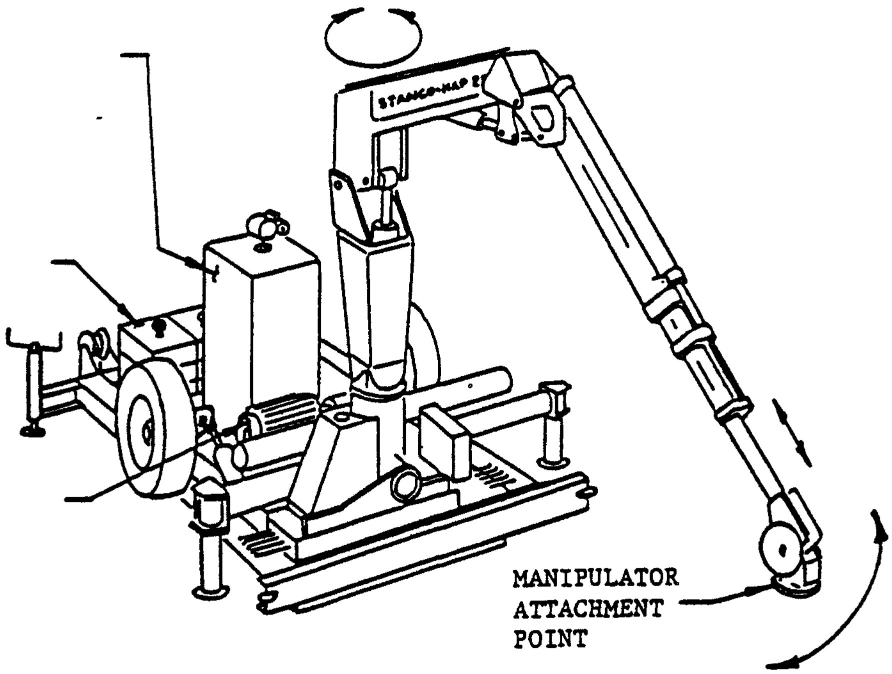


Fig. 8.5-6 Backhoe Transporter.

8.5.7 Floor Mounted Trolley Transporter - Figure 8.5-7 illustrates a typical floor mounted trolley manipulator transporter. This type of transporter would be used where the work is going to be a fixed location from the floor mounted track.

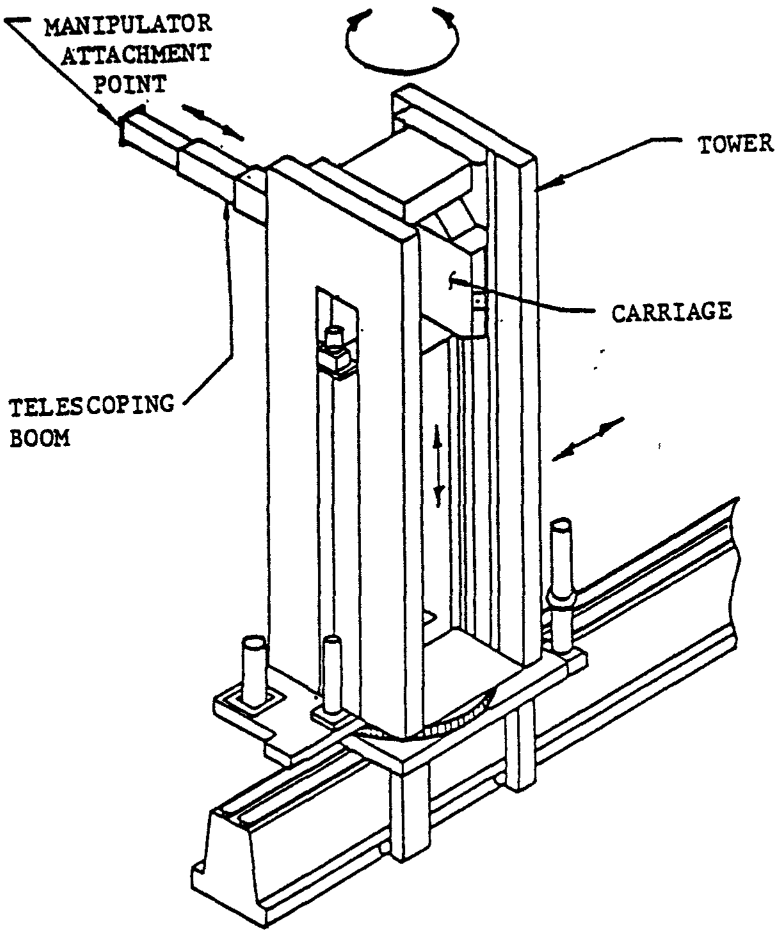


Fig. 8.5-7. Floor-Mounted Trolley Transporter.

8.5.8 <u>Fixed Position Mount</u> - Figure 8.5-8 illustrates a typical fixed position manipulator transporter. This type of transporter is typical of that used for most of the current robotic applications. A

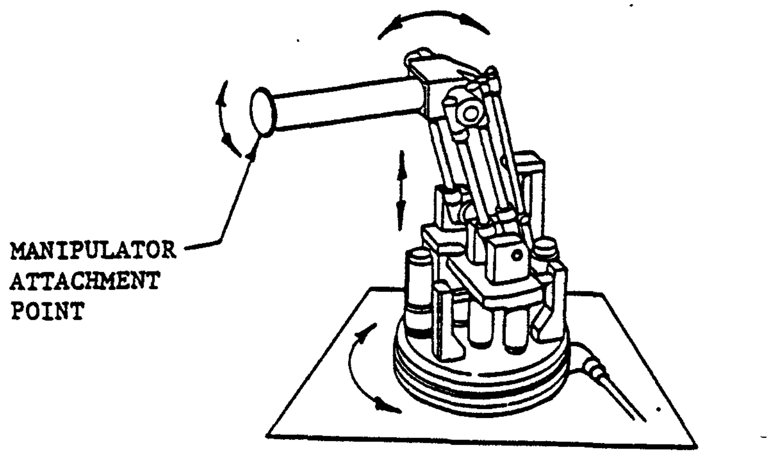


Fig. 8.5-8 Fixed Position Transporter.

8.5.9 Boom Transporter — Figure 8.5-9 illustrates a possible configuration for an extending boom manipulator transporter. The boom would extend and articulate into the work location.

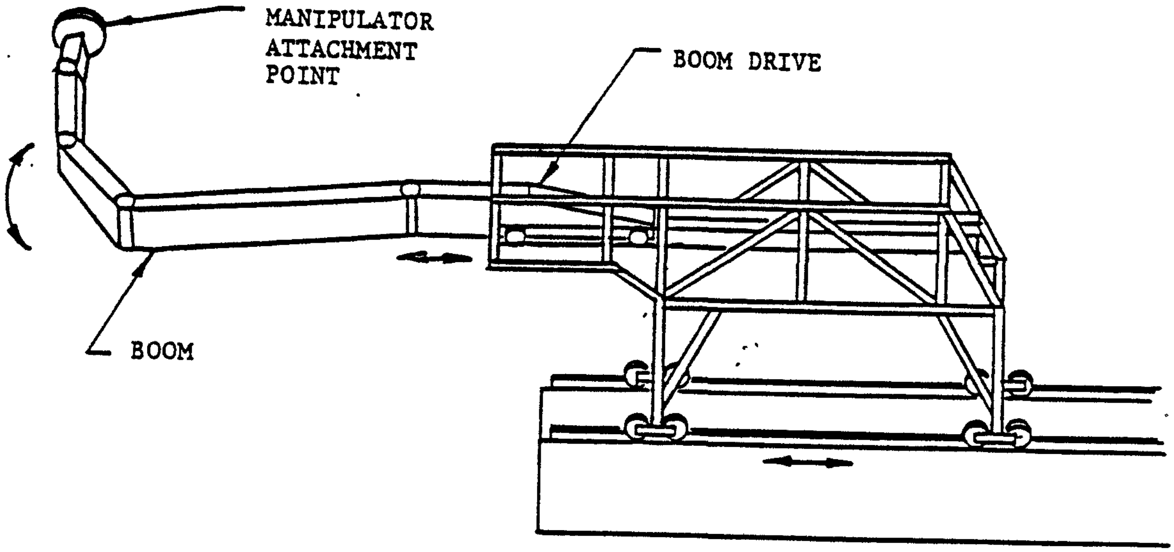


Fig. 8.5-9 Boom Transporter.

8.5.10 Wheeled Vehicle Transporter — Figure 8.5-10 illustrated a typical configuration for a wheeled vehicle manipulator transporter. The vehicle can be guided to the work location by a driver or it can be radio controlled.

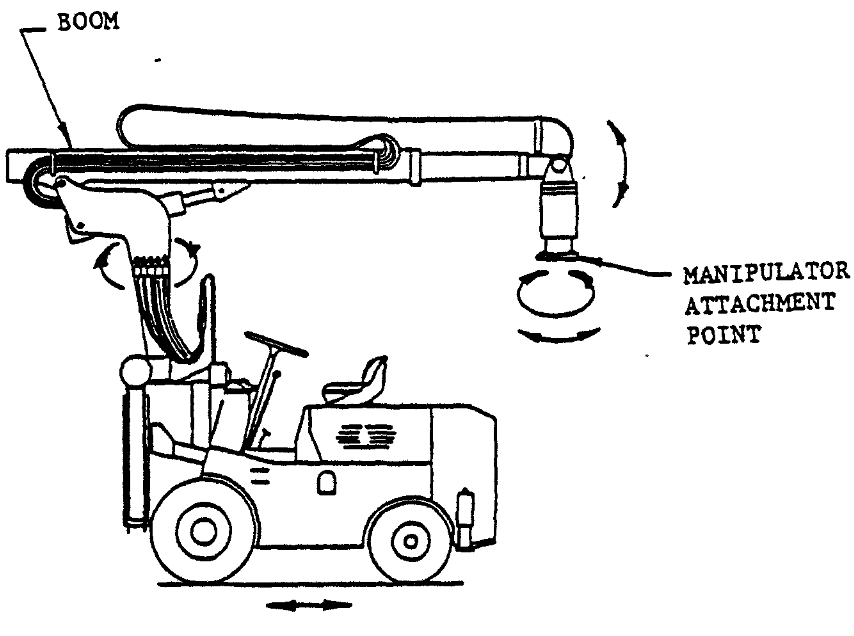


Fig. 8.5-10 Wheeled Vehicle Transporter.

8.5.11 Rigid Link Transporter — Figure 8.5-11 illustrates a rigid chain link manipulator transporter. This transporter is designed to lower the manipulator thru a penetration and reach large distances to the side of the penetration center line.

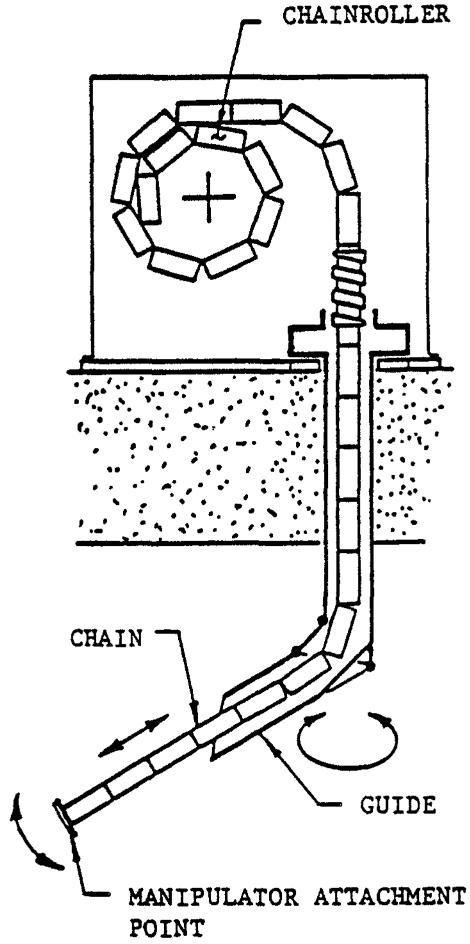


Fig. 8.5-11 Rigid Link Transporter.

8.5.12 Special Penetration Transporter — Figure 8.5-12 illustrates a special penetrator manipulator transporter. This device would be designed for specific application where the work location is close to the penetration centerline.

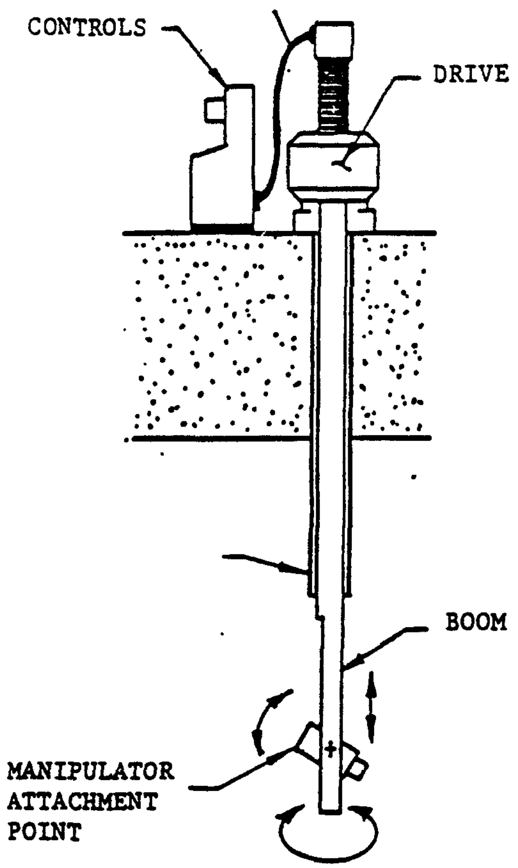


Fig. 8.5-12 Special Penetration Transporter.

The purpose of this section is to suggest material handling crane systems other than and as an alternate to bridge cranes. A

8.8.1 Gantry Crane — Figure 8.8-1 illustrates a typical gantry crane which is similar to an overhead crane except that the bridge for carrying the trolley or trolleys is rigidly supported on two or more legs running on fixed rails or runway. A

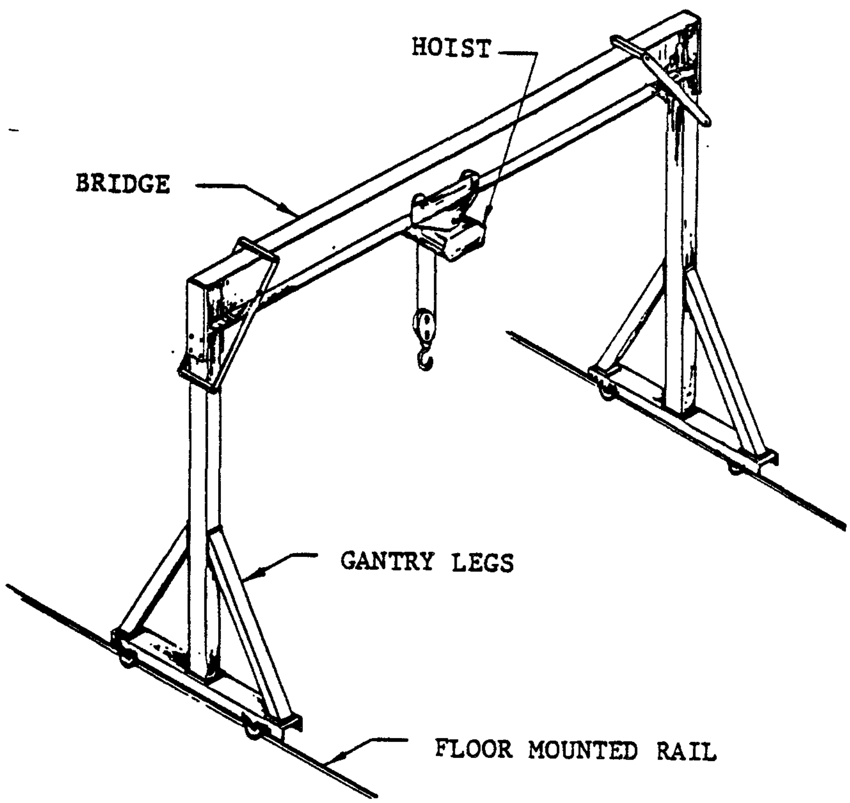


Fig. 8.8-1 Gantry Crane. A

8.8.2 Jib Crane — Figure 8.8-2 illustrates a typical jib or wall-mounted crane. This type of crane is cantilevered from a side wall or line of columns of a building or mounted on a free-standing pedestal. Normally a 180 degree radius of coverage is provided by this fixed position crane. A

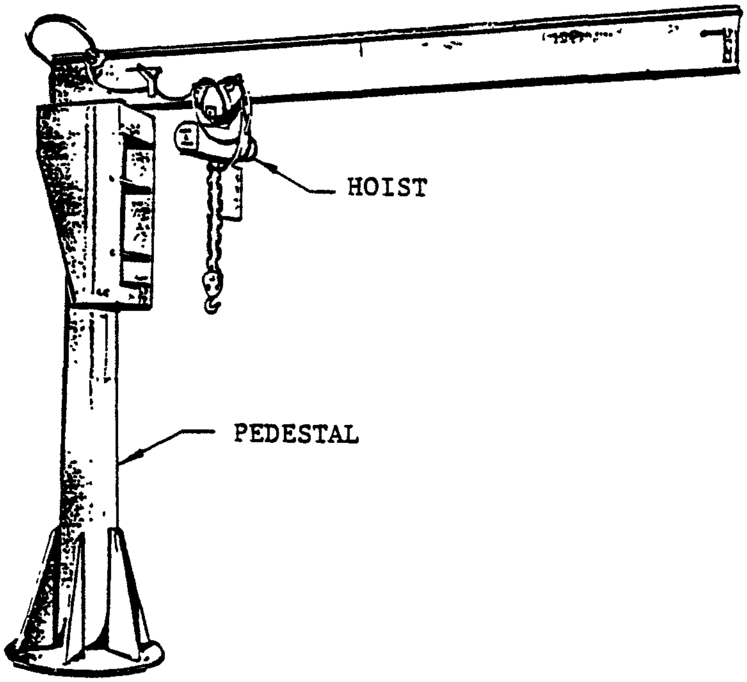


Fig. 8.8-2 Jib Crane. A

8.8.3 Mobile/Portable Cranes — These cranes are illustrated and described in Sections 8.5.6 and 8.5.10. A

8.8.4 Stacker Cranes — Figure 8.8-3 illustrates a typical stacker crane. This type unit is typically suspended from an underhung track, and in many cases, can transfer from one crane bay to another via a transfer track section. The mast, which extends down, can be either fixed or telescoping depending on the application. Stacker cranes work well in narrow aisles while raising, lowering, inserting, and retrieving material at heights in excess of fifty feet with no danger of tipping and a high degree of accuracy. Another advantage of the stacker crane is its ability to make 360 degree turns in an area no larger than a circle enclosing its major dimension. A

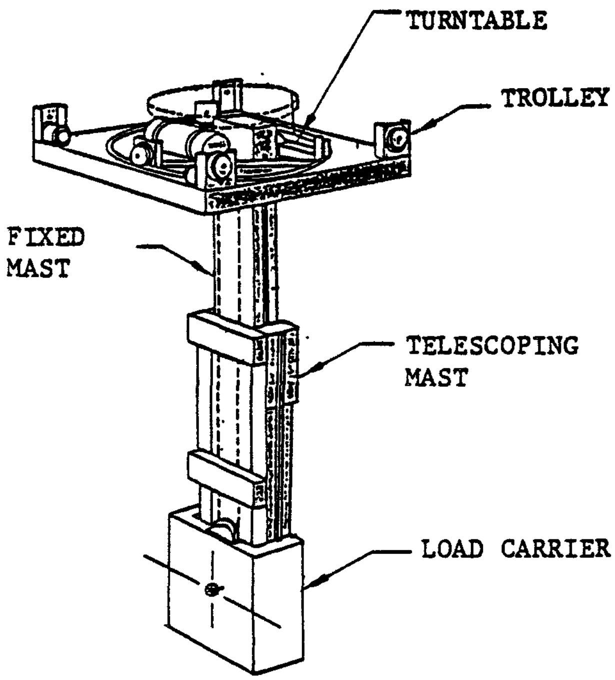


Fig. 8.8-3 Stacker Crane. A

IX VIEWING SYSTEMS

A

*NA - Not available at this time.

This chapter provides a list of maintenance equipment used successfully in viewing systems in non-fusion nuclear and other facilities. Guidelines for its use will also be provided. Much of the equipment is commercially available, however, some modification of this equipment is generally required for assisting in remote handling. Therefore, the special purpose equipment that has been developed for fission reactors, fusion reactor concepts and other remote viewing systems will also be included. Television equipment will include all types such as Change-Coupled-Device (CCD) Television and the various forms of Vidicon Television. This chapter will incorporate the results of a survey of available equipment and technology and provide guidelines for the use of all available systems in conjunction with fusion reactors and devices.

A

X SPECIFIC EQUIPMENT

A

*NA - Not available at this time.

This chapter provides the designer with a list of specific maintenance equipment that has been successfully used in non-fusion nuclear and other facilities. The equipment described is classified in groups other than the main remote maintenance equipment classifications found in Chapters VI through IX. Much of this equipment is commercially available. However, some modification is generally required to allow remote operation using manipulators or cranes.

Contact maintenance equipment has been included to assist in providing appropriate advance planning for contact maintenance operations. The guidelines included for the use of constact maintenance equipment items should be helpful in alleviating the problems of inadequate space for maintenance, access to the work site, high personnel radiation exposure and extended maintenance outage periods.

An inherent part of remote maintenance operations is to provide the manipulators with an adequate tool box. Guidelines for the design and use of remote tools and fixtures will be provided to aid in selecting and designing tools to conduct many simple operations remotely through manipulators.

Similarly, the remote use of general purpose cutting and welding equipment will probably require modification to operate as tools in conjunction with remote manipulators. Guidelines for the use of this equipment will be provided.

Scrap cutup and packaging is usually conducted in hot cells. The equipment available for these operations will be described and guidelines for its use and selection will be provided.

XI FACILITY GUIDELINES

A

*NA - Not available at this time.

To achieve success in the remote AMR of fusion reactors, the necessary facility configuration features, remote equipment, and support features must be provided in the reactor plant. The purpose of this section is to define the basic requirements and guidelines for the buildings to house and support a remotely maintainable fusion reactor. Where applicable, provisions needed for the contact and semi-remote maintenance options described in Chapter II will be discussed in addition to the fully remote maintenance provisions. The flow of materials during repair operations and techniques for remotely recovering from failure of the remote maintenance equipment will be included. The sections on cranes, transporters, viewing, and hatches, for example, will include building features and guidelines associated with these topics. Specific equipment is described in Chapters VI through X as appropriate.

A

XII CONTROL SYSTEMS

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Chapter: Remote Maintenance Control System Section: Contents	Chapter: XII Section: 12.0

A

*NA - Not available at this time.

Remotely operated maintenance systems require manual, semi-automatic, or totally automated control systems for each piece of remote maintenance equipment and, potentially, for the overall system. The purpose of this chapter is to discuss the control variants available and provide guidelines for their application to a remote maintenance system for fusion reactors. A multi-level control system is required with the supervisory control as a top level to manage the interface between the reactor, building utility system, and the maintenance equipment. Available control equipment will be described. The use of man-in-the-loop and the human engineering aspects of the man/machine interfaces applicable to maintenance control systems is included to provide guidelines in the relationship between contact and remote maintenance.

A

XIII MAINTAINABILITY ANALYSIS

A

A

*NA - Not available at this time.

The requirement for this chapter stems from the need to treat the maintenance system as another subsystem of the machine when remote maintenance operations are required in order to achieve an economically viable fusion machine. This requires, in turn, that the maintenance system be thoroughly integrated with the design of the fusion machine. The techniques for accomplishing this objective during all phases of the fusion machine development are to be included herein. A

Definition of maintenance systems early in fusion reactor design programs is essential. This chapter will define the capabilities of analytical, simulation, and mockup techniques appropriate for consistently defining maintenance systems together with their influence on reactor design. Initially during the development of a fusion system the achievement of a maintainable FWBS system can be defined by analytical techniques which establish the maintenance system equipment requirements and the achievable availability. These analyses will utilize the techniques defined in Section 13.2. They rely on MTTR and MTBF data banks which should be included as appendices to this guidebook. Maintenance simulator systems are useful to define the MTTR for unique FWBS or maintenance equipment using either analytical or test devices. Mockups are frequently A A key to the development and evaluation of maintenance capabilities and are included to define mockup levels of detail and their potential utility. Their usefulness in equipment development and training will also be included. MTTR evaluations using mockups are techniques that will be illustrated. A

The capability to define MTTR and MTBF of both reactor and maintenance equipment is essential in early design trade studies. The methods appropriate to fusion will be discussed together with guidelines for their application.

A

Assembly, Maintenance and Repair (AMR) has a major influence on reactor or experimental device effectiveness. For commercial power plants the relative effectiveness of different designs is largely evaluated by the Cost of Electricity (COE) which can be produced. The COE is a function of capital costs, operating costs, plant output capacity and availability.[1] The cost of research data derived from an experimental device is also a function of the capital and operating costs of the device and its availability to conduct experiments. In both of these applications availability is defined as: A

$$\text{Operating Availability} = \frac{\text{Available Hours X 100}}{\text{Period Hours}}$$

Available Hours is the time during which a unit (major equipment, reactor, device, plant, etc.) is capable of service, whether or not it is in service. Period Hours is the clock hours in the period under consideration (generally one year or 8760 hours). This availability definition by Edison Electric Institute (EEI) is used in most studies of fusion devices.[2] Other definitions of availability and of other factors applied to availability, such as the Capacity Factor, have been accepted by EEI, Electric Power Research Institute (EPRI) and the Nuclear Regulatory Commission (NRC) for use in various power plant economic analyses. A

Available hours are directly a function of the machine downtime required for maintenance. The need for scheduled replacement of the FWBS is a major element

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(1) *Schulte, Steven C., Willke, Theodore L. and Young, John R., "Fusion Reactor Design Studies - Standard Accounts for Cost Estimates," Battelle Memorial Institute, PNL-2648, May 1978.*

(2) *"Report on Equipment Availability for the Ten-Year Period - 1967-1976," Equipment Availability Task Force of the Prime Movers Committee, Edison Electric Institute, EEI-77-64, December 1977.*

A

of this downtime. The influence of the ability to maintain as well as replace the FWBS on the available hours must be analyzed continuously as the fusion machine design progresses. More detailed discussions of these factors and availability are found in References (1), (2), and (3). A

The COE is evaluated by:

$$COE = \frac{\text{Total Period Operating Costs}}{\text{Plant Capacity for Period X Operating Availability}}$$

The period is usually taken as one year elapsed time. Operating costs include Return on Investment (based on total capital costs), cost of spares, maintenance labor and fuel. The plant capacity is the total generation output (MWe) if the plant is operated at its rated capacity for the period. This is reduced by Capacity Factors as needed for the analysis. However, for conceptual design evaluations, these factors are usually taken as unity.

The foregoing equations show how strongly the plant economics are affected by availability. The Available Hours can be written as:

Available Hours = Period Hours - (Scheduled Outage Hours + Forced Outage Hours)

Outage Hours are a direct function of time-to-release or repair, failure rates and equipment life. Time-to-replace or repair is frequently defined as the cumulative time required to perform maintenance functions. It is affected by both the device or reactor design and the maintenance system. The failure rate and life of device or reactor equipment determines the frequency with which these functions are performed. Thus, the COE for a power plant is a direct function of the effectiveness of the design for maintenance as well as the system reliability.

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(3) *Sharif-Homayoun, A., Koppe, R. H., et. al., "Basic Techniques in Availability Engineering," Electric Power Research Institute, EPRI NP-2166, RP1391-2, May 1982.*

13.1.1 Availability Economics Influence on Commercial Reactors - The effect of operating availability on the COE for commercial fusion reactor concepts is illustrated in Figure 13.1-1. This data was taken from the STARFIRE tokamak reactor plant study.[4] This cost data was derived by using the characteristics of a baseline design concept and varying its size (output) with attendant variations in cost. The resultant scaling exponent, based on electrical output capacity, was .78. Other study data for Tandem Mirror Reactor (TMR) and Elmo

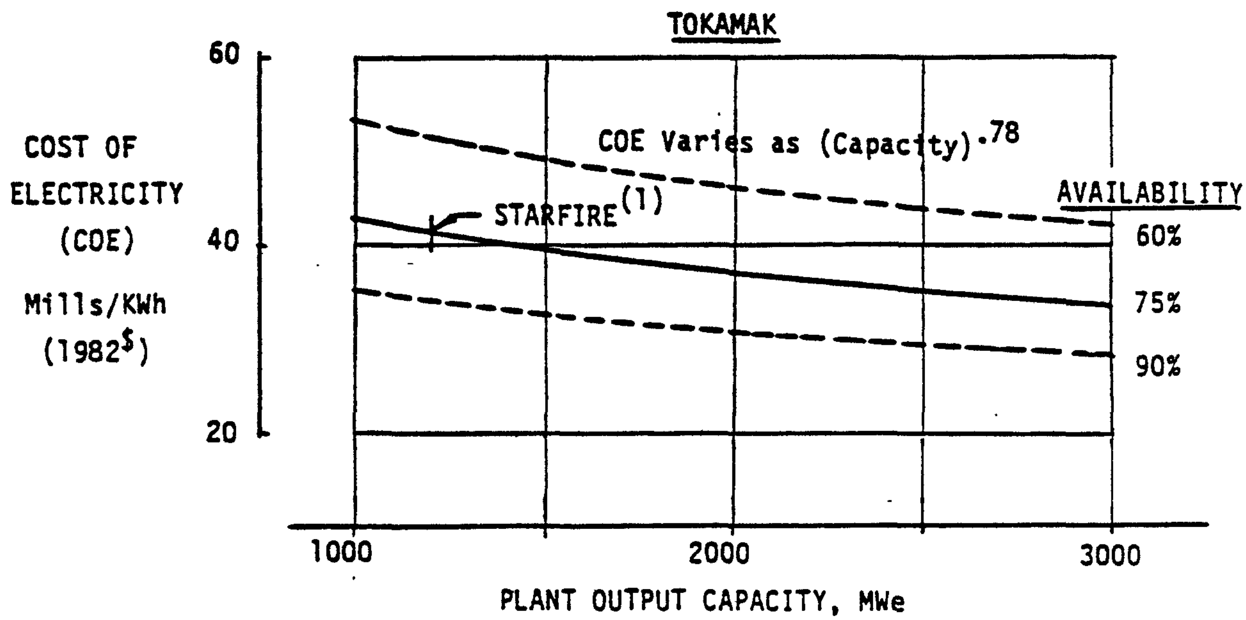

Figure 13.1-1 COE as a Function of Plant Capacity and Availability.

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[4] "STARFIRE - A Commercial Fusion Power Plant Study," Argonne National Laboratory, ANL/FPP-80-1, 1980.

Bumpy Torus Reactor (EBTR) conceptual designs[5],[6] exhibits similar characteristics.

Scaling exponents of COE to a function of plant capacity varied between .38 and .78. The STARFIRE study reactor parameters are shown as a specific data point on the Tokamak reactor curve.

Figure 13.1-1 shows that the COE can vary significantly over a range of availability for each type of reactor. A nominal availability goal of 75% was adopted for the STARFIRE commercial reactor. Seventy-five percent is considered an acceptable goal for design and 90% is probably close to a maximum achievable over extended periods. The general impact of increasing availability on COE is defined in Figure 13.1-2. In the event that a design achieves an initial availability of 75%, revisions in design or operation that increase this to 90% result in a decrease in COE of 17%, provided that no overall increase in total operating cost occurs. A A

Usually, the achievement of increased availability or lower operating costs results in higher capital costs. These are incurred either as reactor equipment costs or as the cost for increased quantities or advanced design of maintenance equipment. Figure 13.1-3 shows the increase in total capital cost that may be allowed to achieve an increase in the operating availability of 1% for the plant characteristics indicated, assuming that the COE will remain constant. The amount that may be spent is shown to be greater at low availabilities, such as at 60%, than at high availabilities. The variation among reactor concepts is A

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(5) *"Impact of Confinement Physics on Fusion Power Station Design and Economics and the Utility Interface,"* McDonnell Douglas Astronautics Company - St. Louis Division, EPRI RP547-1, 1978.

(6) *"Elmo Bumpy Torus Reactor and Power Plant,"* Los Alamos National Laboratory LA-8882-MS, 1981.

also indicated based on data from References (4) through (6). Present conceptual designs with capacities of approximately 1200 MWe may spend up to $40 million to achieve a 1% increase in availability. When the cost of achieving the increase in availability is less than the amount indicated, the COE is reduced because of the increased availability.

The data shown in the figures in this section provide a measure of benefits for design changes that affect availability. The influence of component and system failure rates and life is a related parameter and vies for the same capital improvement funds as changes in time-to-replace or repair. Therefore, a balance between these two design characteristics must be attained for the most effective plant design.

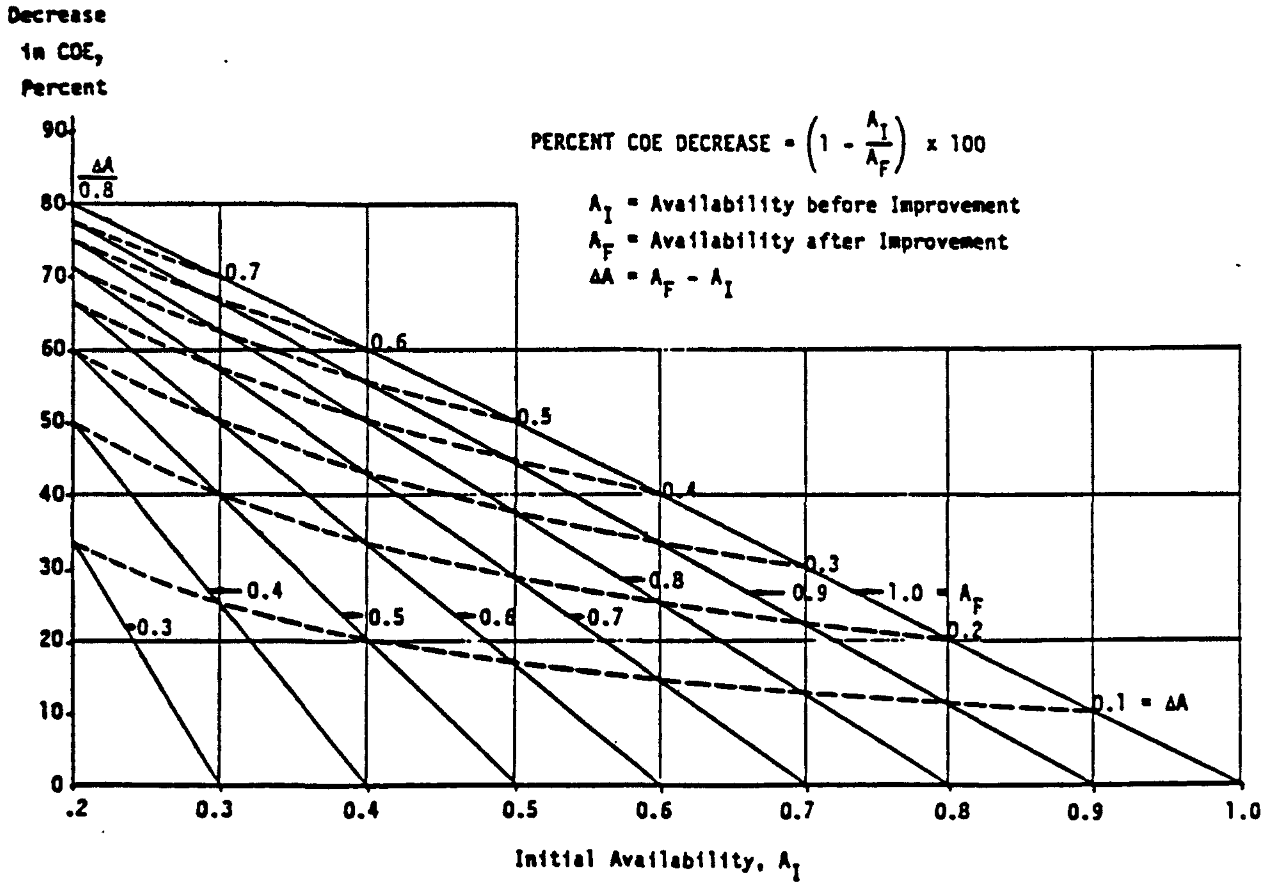

Figure 13.1-2 Effect of Increase in Availability on Cost of Electricity.

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Chapter: FWBS Maintenance System Definition Analyses Section: Influence of Maintainability on Availability Economics	Chapter: XIII Section: 13.1

A

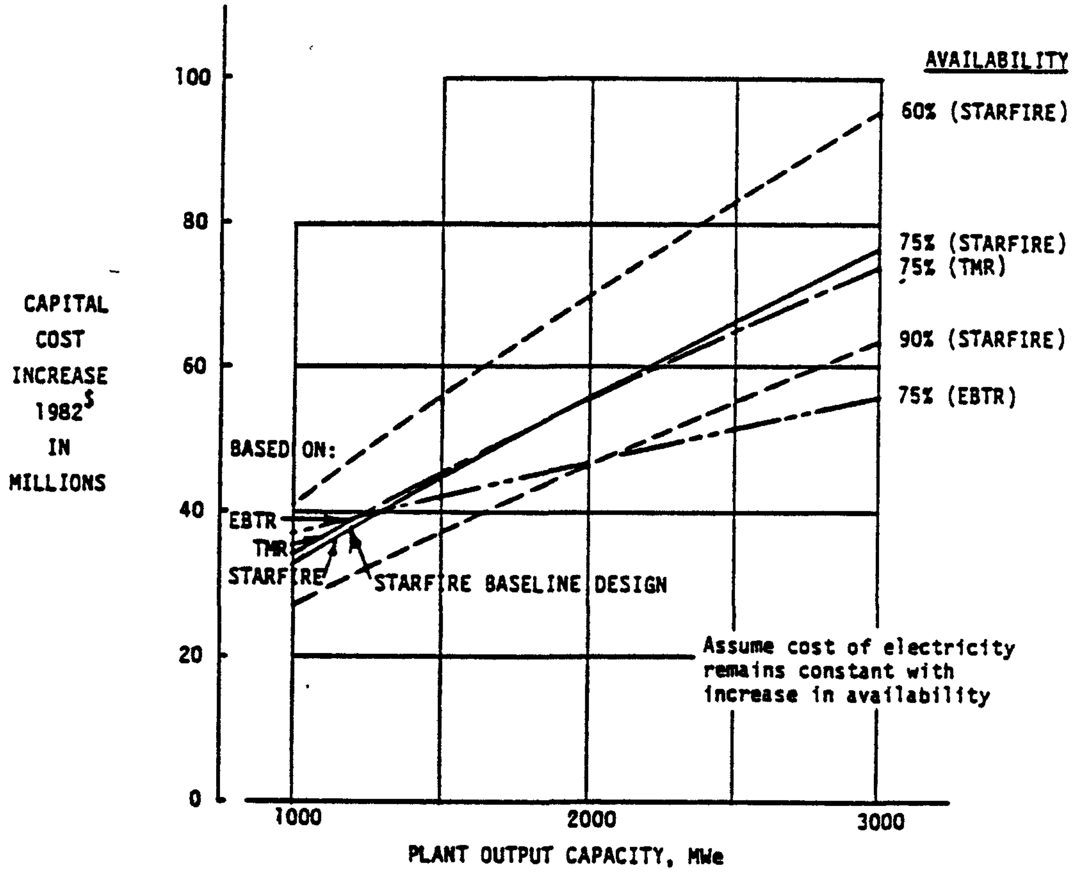

Figure 13.1-3 Allowable Increase in Capital Cost for One Percent Increase in Availability. A

13.1.2 Availability Economics Influence on Experiental Devices - Experimental devices usually are designed for obtaining specific data without any requirement for producing economical electrical power. Therefore, COE is unacceptable as a measure of the maintainability of these devices. The time available for experiment is insufficient as the only criterion for use in design. An acceptable criterion must consider total capital cost, operating costs and availability. A criterion for experimental devices which is analogous to the COE used for commercial devices would be:

$$\text{Cost/Experiment Hour } (COE_X) = \frac{\text{Capital Return on Investment + Operating Cost}}{\text{Period Hours X Operating Availability}}$$

Experiment Hours are defined as the hours during the total period being evaluated which are available for use in conducting experiments whether or not they are actually used. The Capital Return on Investment is a time dependent cost of the capital investment over the period used for evaluation and measures the impact of the capital cost of the device on the total operating cost of the system. This cost includes the cost of all equipment, including maintenance equipment, the cost of the facility, and other construction costs. The Operating Cost includes the costs of supporting services, utilities, spares and the experimental staff personnel.

The recommended use of the Cost/Experiment Hour (COE_X) provides a criterion for evaluating design tradeoffs. Experimental devices tend toward low operating availabilities since the experimental capabilities are given more weight during design than the time required to complete the experimental program. The sensitivity of the COE_X to the device operating availability at low availabilities is illustrated in Figure 13.1-4. This is an extension of Figure 13.1-2 but in the low availability range. Typical reductions in COE_X are 60% for an availability increase of 3% when going from 2% to 5% availability or a reduction of 50% for an availability increase of 10% when improving availability from 10% to 20%. Such high sensitivity is indicative of the importance of achieving effective AMR even in experimental devices.

A

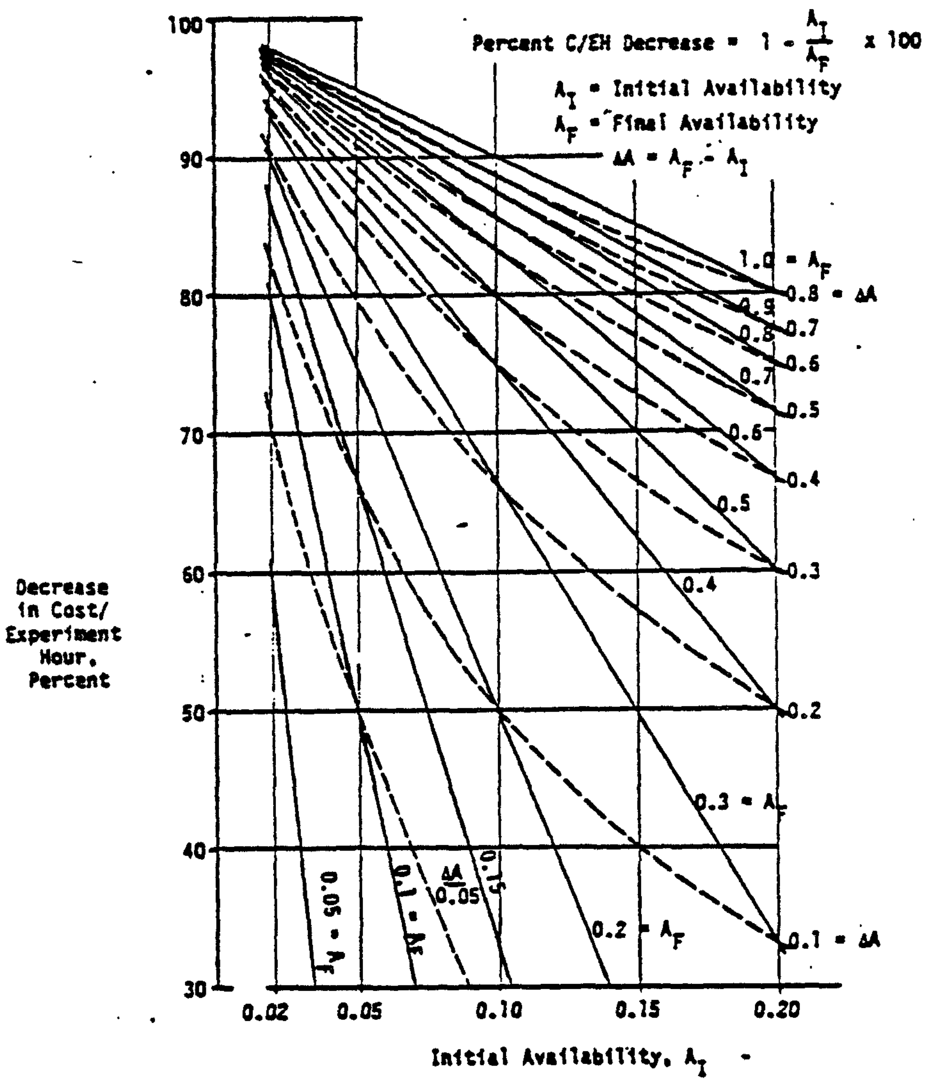

Figure 13.1-4 Sensitivity of Cost/Experiment Hour (COE_X) to Availability Increase at Low Availabilities.

A

Another example of the application of this criterion is shown in Figure 13.1-5. These plots show the capital costs that may be justified to increase availability 1% above the operating availability assuming that the COE_x is unchanged. Lower additional capital costs than indicated to achieve the 1% improved availability will result in a decrease in COE_x. Thus, a low availability experimental device, e.g., at 20%, can afford to spend as much as $75 to $100 million to improve availability 1%. Higher availability devices can afford to spend less. The plots in Figure 13.1-5 will differ for the conditions applicable to each experimental device or device modification.

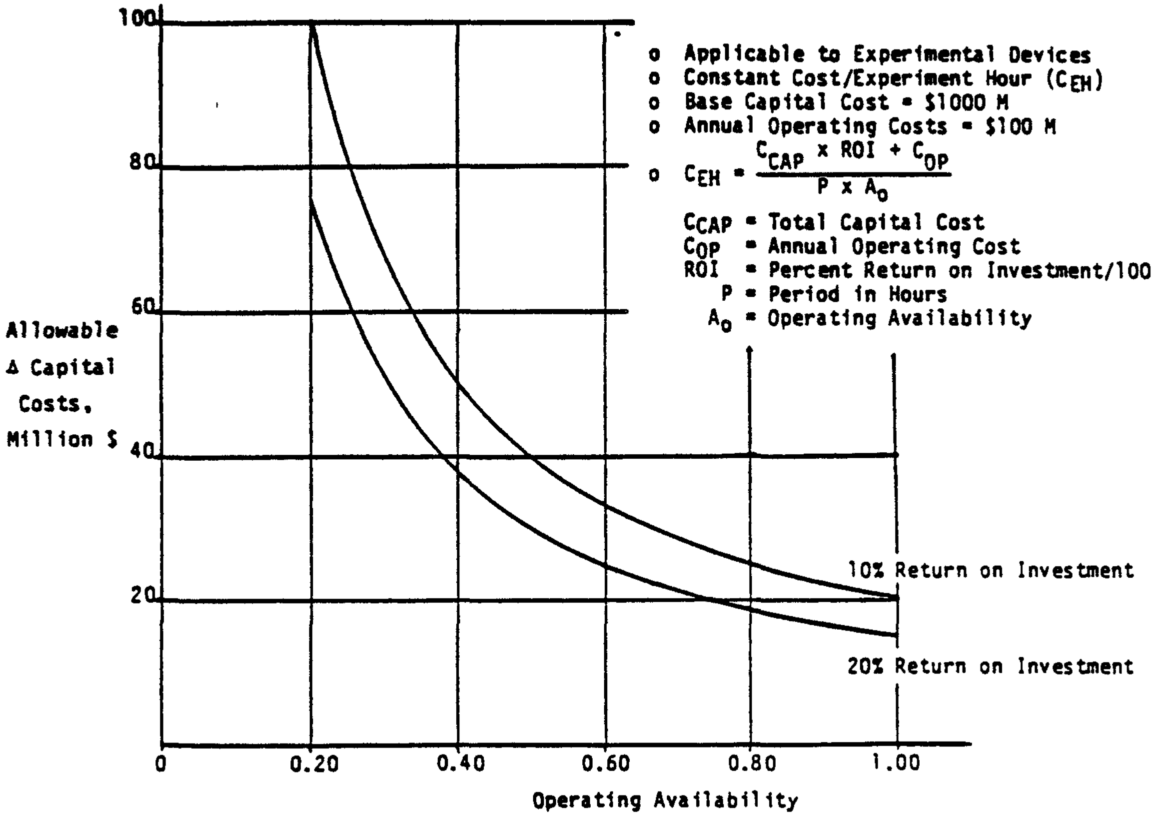

Figure 13.1-5 Example of Allowable Capital Cost Increase to Gain 1% Availability Increase.

The capability to make experiment modifications during maintenance shutdowns is ignored by this criterion. This capability could significantly increase the effective operating availability but it is not readily quantified during the initial design of the device. The planned exchange of experiments can be included in original design evaluations. However, experiment modifications are considered to be unplanned changes in the basic device design that are conceived subsequent to building the device. These changes are difficult to evaluate.

Once the experimental device is in being, the total capital cost may be deemed unimportant in evaluating availability. At such a time a different criterion may be used. For example, once the primary missions of a device such as TFTR are achieved, the costs of experimentation are only staffing and operating consumables. Then the cost base may be reduced to operating costs and additional capital costs for experiment modifications. These incremental operating costs can provide a tool for evaluating new experiments and their impact on reactor shutdown and delays.

Two types of changes may be proposed in experimental devices. These are (1) modifications to increase operating availability and (2) modifications to add experimental capability. Each type will increase the total capital cost of the device. Adding experimental capability (Type 2) usually justifies an increased cost per experiment hour based on total capital cost or redefines this parameter based on the cost of the additional capability alone. In either case, the evaluation is related to a new availability analysis and the design should be evaluated only by cost per experiment hour with the additional capabilities. When modifications of both types are being made simultaneously, the justification of changes becomes difficult. Therefore, it is suggested that the total capital cost is retained in the cost base, even though it is not chargeable to the new experiments, to provide a consistent base for comparison of the impact of Type 1 modifications either with or without Type 2 modifications included.

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Chapter: Guidebook Supporting Information Section: Contents	Chapter: XIV Section: 14.0

A

*Not available at this time.

It is the purpose of this chapter to present the instructions, procedures, information, and other supporting information, to aid the user of the Designer's Guidebook.

The Guidebook Index will be an alphabetically arranged locator index for all subjects covered in the guidebook.

The Guidebook Procedures will define the methods used for updating, publishing revisions, adding data from additional sources and incorporating newly issued revisions or data into the book. The method of registration and control of the document will be described. A

Abbreviations and Acronyms will be a complete list of all abbreviations and acronyms included in the guidebook.

Technical definitions will be a glossary of technical terms used in the guidebook. These will be coordinated with the Glossary of Fusion Energy (DOE/TIC 10192).

The List of References will be a complete alphabetical bibliography of all documents referenced in the guidebook by title, subject and author with locator information.

The List of Figures will list all figures included in the guidebook by section. A

The section on Facilities will eventually list all facilities involved in fusion programs.

The section on Affiliations will eventually list all organizations involved in fusion programs.

Alcator-A, -C: Tokamak, MIT

CFE: Center for Fusion Engineering

CTHR: Commercial Tokamak Hybrid Reactor

DITE: Tokamak, Great Britain

DIVA: Tokamak, Japan

Doublet-III (D-III): Tokamak, General Atomic

DTHR: Demonstration Tokamak Hybrid Reactor

EBT-P: Elmo Bumpy Torus - Proof-of-Principle

EBT-S: Elmo Bumpy Torus, ORNL

ETF: Engineering Test Facility

FED: Fusion Engineering Device

FERF: Fusion Engineering Research Facility

FMIT: Fusion Materials Irradiation Test Facility, HEDL (under construction)

FRM: Field Reversed Mirror

HYLIFE: High Yield Lithium Injection Fusion Energy

ISX: Impurity Studies Experiment, ORNL

ITR: Ignition Test Reactor

JET: Joint European Tokamak, Euratom (under construction)

JT-60: Tokamak, Japan (under construction)

LCP: Large Coil Project, ORNL

LFR: Laser Fusion Reactor

MFR: Mirror Fusion Reactor

MFTF: Mirror Fusion Test Facility, LLNL

MFTF-B: Expansion of MFTF to a large tandem mirror

ORMAK: Oak Ridge Tokamak

PDX: Poloidal Divertor Experiment, tokamak, PPPL

PLT: Princeton Large Torus, PPPL

PWR: Pressurized Water Reactor

ST: Stellerator Tokamak

T4: Tokamak, USSR

TFTR: Tokamak Fusion Test Reactor, PPPL

THR: Tokamak Hybrid Reactor, France

TMR: Tandem Mirror Reactor

TMX: Tandem Mirror Experiment, LLNL

TSTA: Tritium Systems Test Assembly, LANSL (under construction)

UWMAK: University of Wisconsin Tokamak

2XIIB: Mirror machine, LLNL

Aerojet — Aerojet Electrosystems Co.
Airco — Airco Central Research Laboratories
Alsthom (France) — Alsthom-Atlantique (France)
Ames Lab. — Ames Laboratory - US DOE
ANL — Argonne National Laboratory
Aydin — Aydin Energy Division
Aydin-Transrex — Aydin-Transrex

Bechtel — Bechtel National, Inc.
BNL — Brookhaven National Laboratory
Burns & Roe — Burns & Roe, Inc.

Cambridge U. — Cambridge University (England)
Canatom — Canatom, Inc. (Canada)
Chicago Bridge — Chicago Bridge & Iron Co.
Cornell U. — Cornell University
Corps Engr. — Corps of Engineers (Oregon)
Cox — Cox Engineering Corporation
Culham Lab. — Culham Laboratory (EURATOM/UKAEA Fusion Association)

DOE — Department of Energy
Draper Lab. — Charles Stark Draper Laboratory

Ebasco — Ebasco Services, Inc.
Ecole Polytech. (France) — Ecole Polytechnique (France)
Ecole Polytech. (Swiss) — Ecole Polytechnic Federal (Switzerland)
Ecole Royale — Ecole Royale Militaire-Koninklijke Militaire Sch. Lab. of Plasma Physics
EG&G — EG&G
Electrotech. — Electrotechnical Laboratory (Japan)
Energiteknik — Studsvik Energiteknik AB (Sweden)
Exxon — Exxon Nuclear Co.

EURATOM-CEA — Association EURATOM-CEA sur la Fusion

EURATOM-CNR — Centro di Studio sui Gas Ionizatti (Assoc. EURATOM-CNR)

FBNML — Francis Bitter National Magnet Laboratory

Federal Inst. — Swiss Federal Institute for Reactor Research

Fujifacom — Fujifacom Corporation

Fujitsu — Fujistu, Ltd.

Furukawa — Furukawa Electric Company

GA — General Atomic Company

GE — General Electric Company

General Dynamics — General Dynamics/Convair

Georgia Tech. — Georgia Institute of Technology

Giffels Assoc. — Giffels Associates, Inc.

Grumman — Grumman Aerospace Corporation

HEDL — Hanford Engineering Development Lab.

High Energy Lab.-Japan — National Lab. for High Energy Physics (Japan)

Hitachi — Hitachi, Ltd. (Japan)

Hitachi Cable — Hitachi Cable Co.

Holec — Holec, Machines & Systems

ILC Corp. — ILC Corporation

Industrial Plating — Industrial Plating Corp.

INESCO — International Nuclear Energy Systems Company, Inc.

INRS-Energie — Institut National de la Recherche Scientifique, Universite du Quebec

Intermagnetics — Intermagnetics General Corporation

Iowa St. U. — Iowa State University

IPCR — Institute of Physical & Chemical Research

IPP (Garching) — Max-Planck Institut fur Plasmaphysik, Garching

IPP-Julich — Institut fur Plasmaphysik der Kernforschungsanlage, Julich GmbH. Association EURATOM-KFA

IREQ — Institut de Recherche d'Hydro-Quebec (Canada)
Ishikawajima — Ishikawajima-Harima Heavy Industry Co. Ltd. (Japan)
ISPRA — Commission of European Communities Joint Research Center, ISPRA

JAERI — Japan Atomic Energy Research Institute
JAYCOR — Jaycor (VA)
JET — Joint European Tokamak
Jones — J. A. Jones Construction Co.
JPL — Jet Propulsion Lab. (Cal.)

Kaiser — Kaiser Engineers
Kawasaki — Kawasaki Heavy Industry Co., Ltd. (Japan)
KfK — Kernforschungszentrum Karlshuhe (Germany)
Kobe Steel — Kobe Steel Ltd. (Japan)
Kyoto U. — Kyoto University (Japan)
Kyushu U. — Kyushu University (Japan)

LANL — Los Alamos National Laboratory
LBL — Lawrence Berkeley Laboratory
Leybold — Leybold-Heraeus GmrH (Germany)
LLNL — Lawrence Livermore National Laboratory

Magnetic Corp. — Magnetic Corp. of America
Math Sciences — Mathematical Sciences Northwest, Inc.
Maxwell — Maxwell Laboratories, Inc.
MDAC — McDonnell Douglas Astronautics Co.
Michigan Tech. — Michigan Technological University
MIT — Massachusetts Institute of Technology
MITRE — MITRE Corporation
Mitsubishi Atomic — Mitsubishi Atomic Power Industry, Inc.
Mitsubishi Electric — Mitsubishi Electric Company
Monsanto — Monsanto Research Company
MPB Tech. — MPB Technologies, Inc.

N. Carolina St. U. — North Carolina State University
Nagoya — Nagoya University (Japan)
NASA-Lewis — NASA-Lewis Research Center
NBS — National Bureau of Standards
Nihon U. — Nihon University (Japan)
Nilsson — Nilsson Engineering, Inc.
NJ Tech. — New Jersey Institute of Technology
NRL — Naval Research Laboratory
Nuclear Data — Nuclear Data, Inc.
NUKEM — NUKEM GmbH, Hanan (Germany)

O'Donnell — O'Donnell and Associates
ORNL — Oak Ridge National Laboratory
Osaka U. — Osaka University (Japan)

Pacific — Pacific Northwest Laboratory
Parsons — The Ralph M. Parsons Company
Penn. St. U. — Pennsylvania State University
PG&E — Pacific Gas and Electric Co.
Politech. Milan — Politechico of Milan (Italy)
PPPL — Princeton Plasma Physics Laboratory
Princeton U. — Princeton University
Purdue U. — Purdue University

R&D Assoc. — R. & D. Associates (Va.)
RCA — RCA Corporation
REMOTEC — Remote Technology Corporation | A
Robicon — Robicon Corporation
Royal Tech. (Sweden) — Royal Inst. of Technology (Sweden)
RPI — Rensselaer Polytechnic Institute

Saitama U. — Saitama University

Shawinigan — Shawinigan Consultants, Inc.

Siemens — Siemens AG, Forschungslaboratorien (Germany)

SNL — Sandia National Laboratories

Swiss Inst. — Swiss Institute for Nuclear Research

TU Braunschweig — Technische Universitat Braunschweig

Thomson-CSF — Thomson-CSF, DRT, DRE (Fontenay-Aux-Roses) (France)

Toshiba — Toshiba Corporation

Transrex — Transrex Facility

TRW — TRW

U. Cal.-Berkeley — University of California-Berkeley

U. Cal.-Davis — University of California-Davis

U. Cal.-Los Angeles — University of California-Los Angeles

U. Illinois -- University of Illinois at Urbana-Champaign

U. Mich. — University of Michigan

U. Missouri-Columbia — University of Missouri at Columbia

U. Missouri-Rolla — University of Missouri at Rolla

U. Montreal — Universite de Montreal

U. Padova — University of Padova, Italy, Instituto di Constrizioni

U. Texas — University of Texas-Austin

U. Tokyo — University of Tokyo (Japan)

U. Toronto — University of Toronto

U. Wisconsin — University of Wisconsin-Madison

Unibus — Unibus, Inc.

Union Carbide — Union Carbide Corporation, Nuclear Division

United Tech. — United Technologies Research Center

Varian — Varian Associates, Inc.

W — Westinghouse Electric Corporation