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REMOTE OPERATIONS IN A FUSION ENGINEERING RESEARCH FACILITY (FERF)

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Abstract

The proposed Fusion Engineering Research Facility (FERF) has been designed for the test and evaluation of materials that will be exposed to the hostile radiation environment created by fusion reactors. Because the FERF itself must create a very hostile radiation environment, extensive remote handling procedures will be required as part of its routine operations as well as for both scheduled and unscheduled maintenance. This report analyzes the remote-handling implications of a vertical- rather than horizontal-orientation of the FERF magnet, describes the specific remote-handling facilities of the proposed FERF installation and compares the FERF remote-handling system with several other existing and proposed facilities.

Introduction

The Fusion Engineering Research Facility (FERF) is a small mirror-fusion reactor. Its purpose is to provide an intense source of 14 MeV neutrons for use in materials- and component-studies applicable to fusion-power-reactor design. The total-source strength will be 10^{18} neutrons/s with a flux in the test region of 10^{18} neutrons/$m^2 \cdot s$. (Ref. 1) FERF requires extensive remote-handling facilities because of the hostile radiation environment present throughout its containment volume. Hazards include a high neutron- and gamma-flux during operation, high gamma-flux after shutdown, tritium contamination and a nitrogen atmosphere. After machine shutdown, the gamma field in the reactor vault will be too intense to allow entrance by an unshielded person, requiring all maintenance and repair to be done remotely. This requirement influences the design to the extent that all equipment in the vault and all systems passing through the walls must be easily accessible and designed for remote maintenance and operation. The radiation field has the additional effect of limiting the list of materials available for use in the system to those sufficient radiation resistant to provide acceptably long operating lives.

The purpose of this report is to describe the impact of the proposed FERF facility design on the problem of remote handling. Included in a discussion of required remote-handling tools and sensing systems as well as a discussion of the feasibility of the proposed remote-handling configuration. Many of the concepts and techniques discussed in this report were originally described in Ref. 1, which should be consulted if further information is desired.

Remote Handling

Remote handling includes any operation that, for safety or logistical reasons, does not allow direct human contact with the components being handled. Under this definition, "remote handling" ranges from, say, the household use of a fire poker to the ground control of a space probe. As the "remoteness" increases, the availability of direct human sensory feedback diminishes. The lack of direct *sensing by the operator does not* rule out complex operations, but does greatly increase their cost in time and equipment. It is estimated that hot-cell type remote operations take 4 to 20 times as long as the same job done in a direct-contact mode.[2] Even where a "suited up" worker can do direct operations, there is a multiplication of required manpower by a factor of 3 to 5 (Ref. 3) mainly in proper administration of safe operations.

Clearly, the requirement for remote handling will have a significant impact on the design and cost of this facility. To minimize this impact, the number of components subject to remote handling must be as small as practical, and the "in-vault" components must be simple, reliable and accessible. In addition, adequate remote tooling and careful planning of maintenance and repair activities must be provided.

For a machine like FERF, remote activities can be divided into three categories, each having implications for the design process. The categories are:

- Remote Operations. This includes those functions normally involved in remote control, e.g., valve operation, control adjustments and diagnostics. These remote functions are required to actually operate the machine. They are highly specialized and obviously must be highly reliable.
- Scheduled Maintenance. This includes planned replacement or repair of units having a known, limited operating life. These are repetitive operations that justify extensive special tooling to minimize their total cost over the life of the machine.
- Unscheduled Repairs. This category includes repair or replacement of components suffering unanticipated failure. This class of operation is handled by general-purpose tooling. The costs of this type of operation can be kept down by careful design of components in order to make them compatible with the remote tooling available.

Facility Description

The facility described here differs from that described in the previous FERF proposal[1] in that the reactor axis is vertical rather than horizontal. This approach was chosen for the following reasons:

1. The magnet system is structurally stable when assembled with its

axis vertical. In the vertical position it requires a minimum of supporting structure.

2. A vertical magnet-orientation simplifies the handling of the most frequently replaced components.
3. A vertically mounted reactor is located symmetrically within the operating vault. This simplifies the connection scheme, maximizes the standardization of parts and reduces the number of different types of remote-handling operations.

The magnet system is shown in Figs. 1 and 2. While the total gravitational load of about 1500 tonnes requires a substantial supporting structure, this is a small force compared to the calculated 35,000-tonne attractive-force between coils. In a horizontal magnet configuration, a heavy supporting structure is required to sustain both the gravitational loads and the attractive forces. But with a vertical assembly of the magnet system, a reduction in structure can result because the gratitational loads are coaxial with the attractive force. Therefore, the gravitational load can be easily transmitted to the base of the magnet system by the same structure that handles the attractive force.

The magnet system is a simple stack of components that, at any stage of assembly, will stand alone without auxiliary support. The simplicity of this assembly eliminates the need for much of the supporting structure required for a horizontal assembly. It is assumed in this design that the magnet assembly will not be moved for the life of the coils and that no attempt will be made to repair failures internal to the coil cases.

The four injectors, Figs. 3 and 4, are the largest components that will be on a regular replacement schedule. They are approximately 2 m square, weigh 25 tonnes, and are scheduled for replacement every 6 months (one injector every 6 weeks). With vertical assembly, the four injectors are located near the midplane of the operating vault, thus making them readily accessible to manipulators and handling fixtures. Other orientations of the reactor place at least one injector in a difficult position for replacement operations. The symmetrical positioning of the reactor axis in the operating vault favors standardization of injector mechanical- and electrical-connections. This not only reduces the spares and special-tooling inventory but reduces the number of different remote operations that will be required for maintenance. The operational availability of the facility will be largely controlled by the down time necessary for injector replacement. Therefore, operational- or design-simplifications that reduce the difficulty in handling the injectors will have a direct impact on the effectiveness of the facility.

The most massive components to be handled remotely during the useful life of the reactor will be the two 50-tonne expansion-tank assemblies (Fig. 5) which include the first-wall sections. The first wall will be replaced when it has deteriorated to its safe-operating limit (estimated period: 2 years). The expansion-tank assemblies form reentrant sections that penetrate to the center-line of the machine. Although these assemblies could be inserted in a horizontal reactor, the long cantelivered first-wall and shield

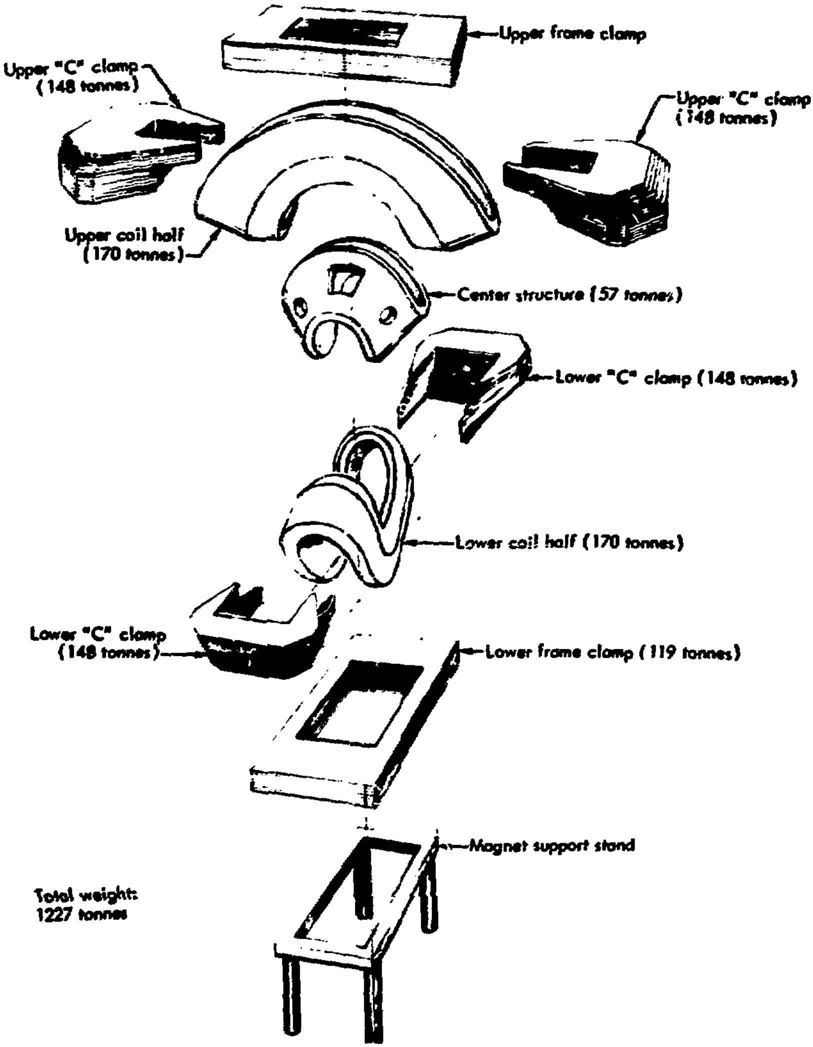

Fig. 1. Magnet system components.

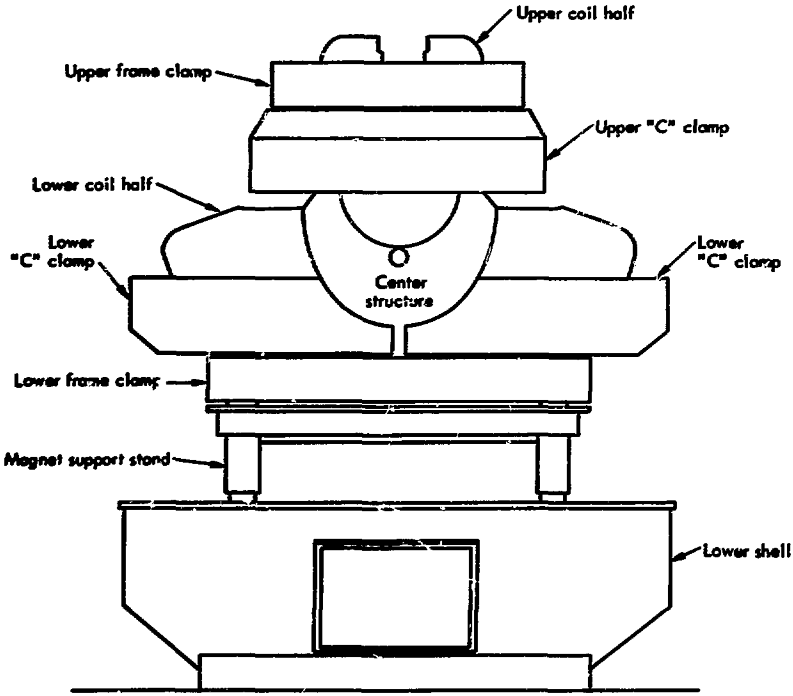

Fig. 2. Assembled magnet system.

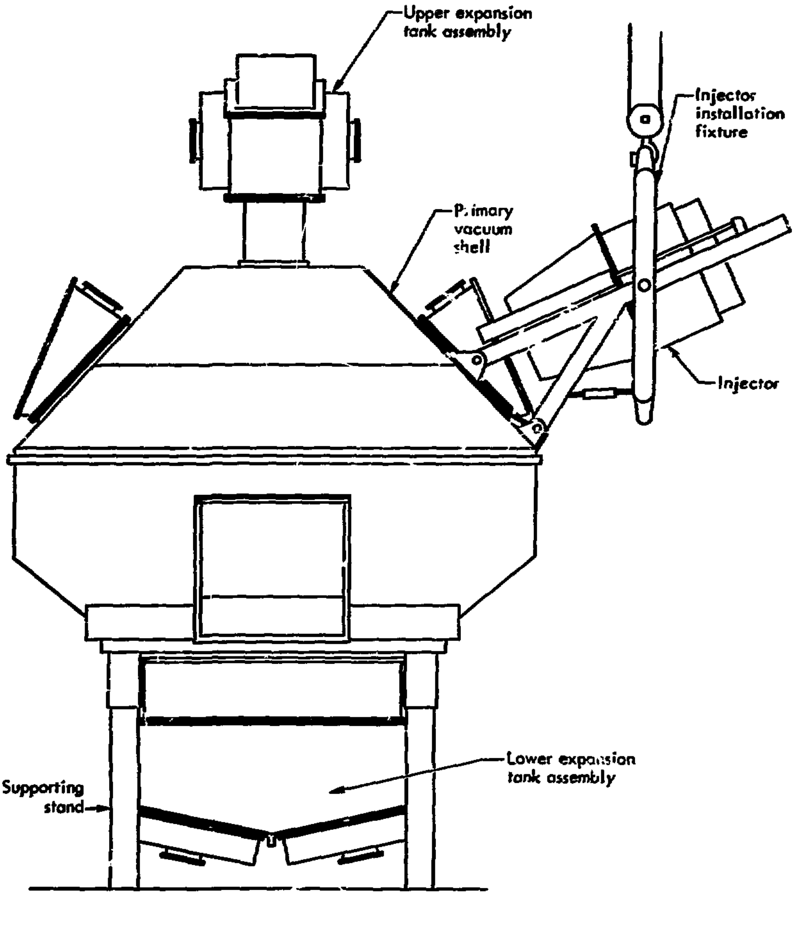

Fig. 3. Injector installation and removal.

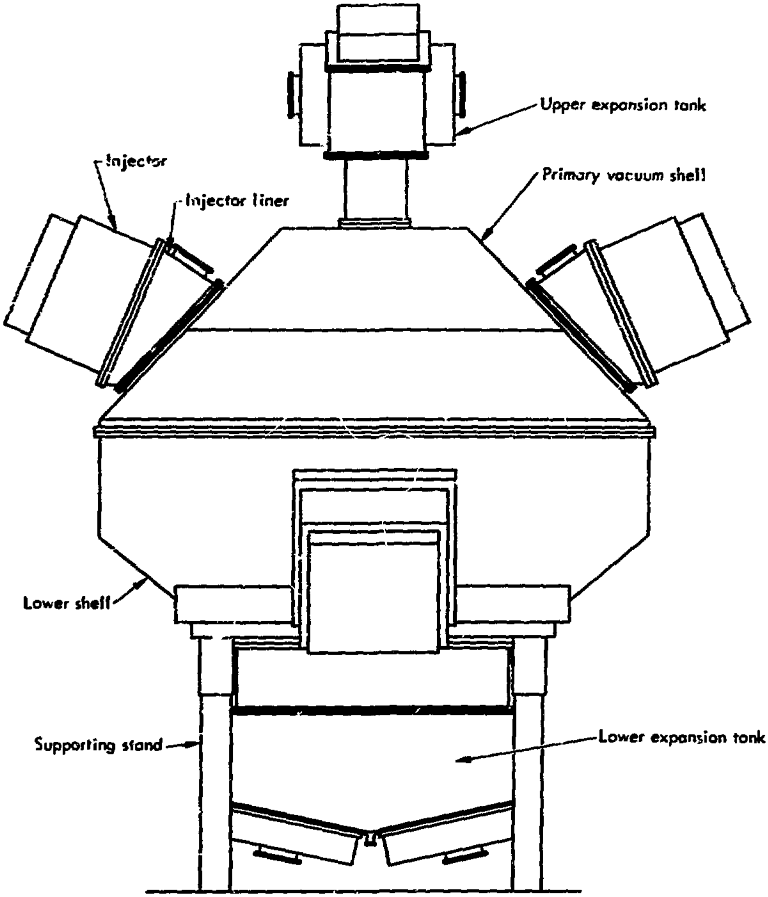

Fig. 4. Machine assembly showing injectors in place.

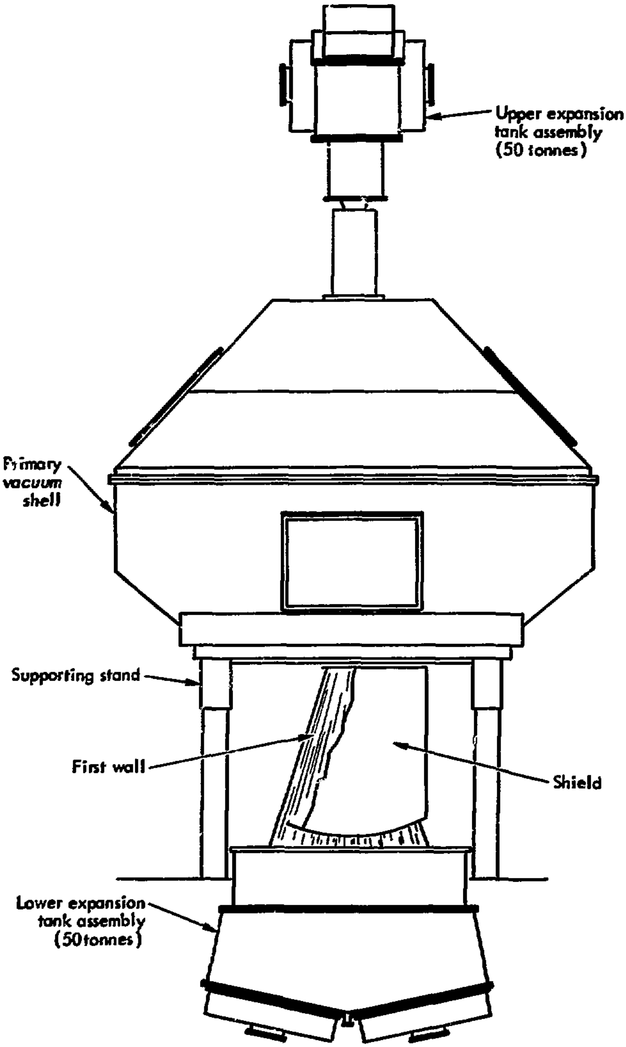

Fig. 5. Insertion and removal of lower expansion tank assembly.

portions of a horizontal system require highly precise control during assembly. This precise control is much more readily obtained with the free-standing or free-hanging assembly of a vertically oriented system.

Containment Structure

This discussion of the containment structure is limited to the biologically-shielded area since this is the basic area involved in remote operations. The shielded area (Figs. 6 and 7) is divided into two major areas: the operating vault and the hot-maintenance shops. The operating vault is 22 × 22 × 27 m high, has 3-m-thick concrete walls and ceiling and is sealed with a metal membrane. Penetrations are provided for windows, utilities, experimental facilities, controls and equipment access. The machine stands in the center of the room. Connections to the machine are grouped to minimize remote operations during routine maintenance. For example, when an injector is replaced, only those services directly connected with that injector need be handled. The vault opens into the hot maintenance shop through a 3 × 22 × 15-m-high main-shield door. The door size is dictated by the need to remove the overhead crane and manipulators from the vault during machine operation in order to prevent their activation by neutrons.

The main hot maintenance shop is 22 × 24 × 15 m high. The walls, ceiling, and floor are made of concrete and are sealed with a metal membrane contiguous with that of the operating vault. Adjoining the main hot shop are specialized hot cells, a storage area, and the main air lock. The hot-maintenance areas will be tooled for doing both routine and extraordinary maintenance and repair. The main bay will be equipped with general-purpose gear such as large manipulators, welding equipment, leak-checking instruments, and small tools. The hot cells will have specialized tooling for such jobs as injector rebuilding and test, and post-operational component inspection. The hot-maintenance shops will include a large storage area where activated or contaminated parts can be safely and conveniently stored until they reach a quantity sufficient to warrant operating the air lock. The main hotshop and the hot cells will be decontaminatable to the extent that a suited operator with breathing apparatus may enter to do direct maintenance.

Tools

The major tools necessary for FERF remote operations consist of a 228 tonne-total-capacity overhead crane and three large manipulators. The crane, a double 111-tonne-capacity unit with a 9-tonne auxiliary, serves both the hot shop and the operating vault. It will be equipped with a motorized rotating hook as well as mechanisms to allow retrieval in case of failure while in the operating vault. One

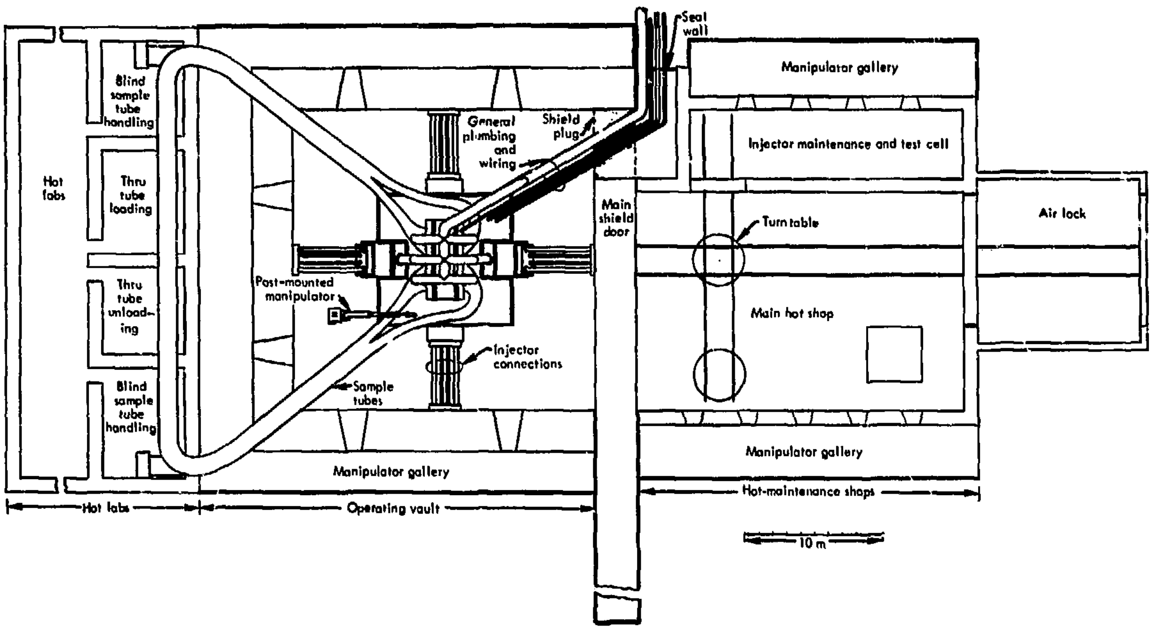

Fig. 6. FERF installation layout – plan view.

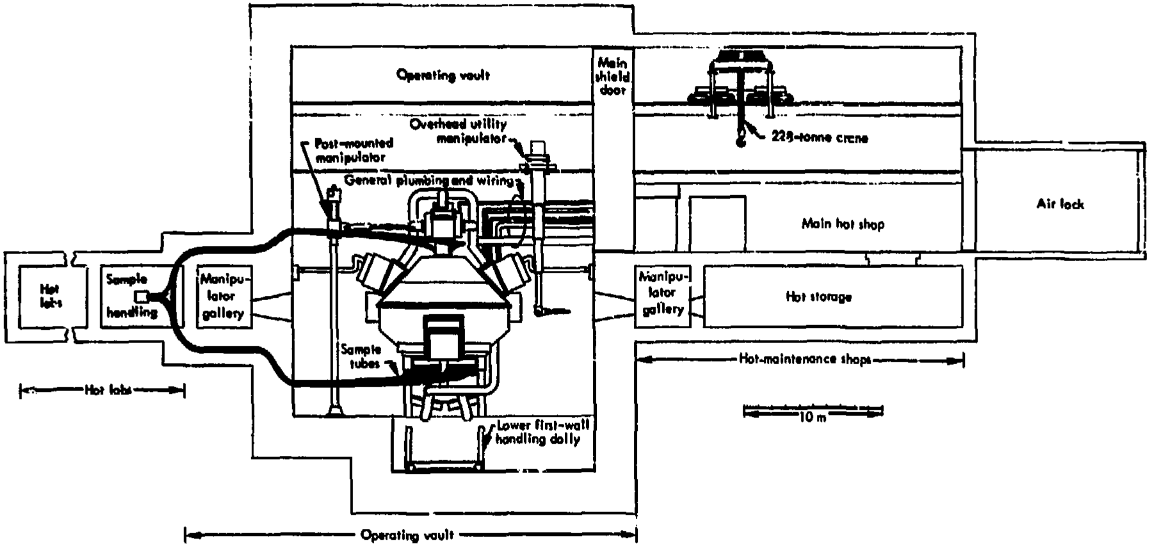

Fig. 7. FERF installation layout – elevation view.

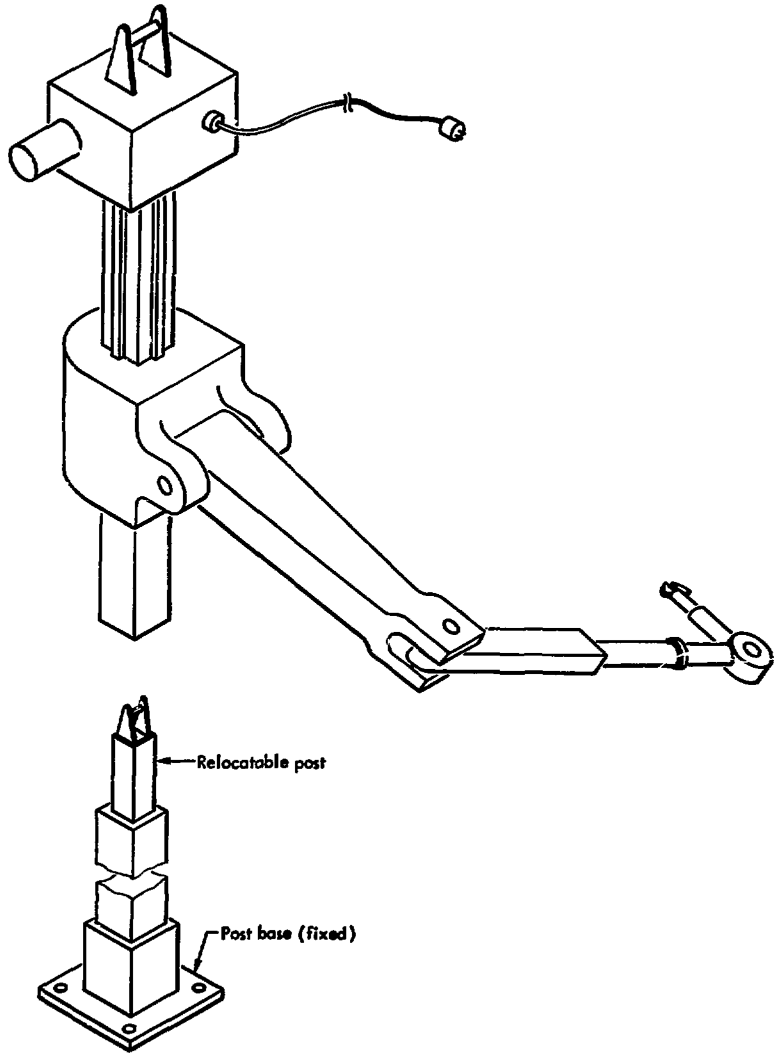

Fig. 8. Relocatable post-mounted manipulator.

of the large manipulators is an overhead type that travels on a bridge trolley below the overhead crane. It can reach the ceiling and the top half of the machine. Its purpose is to do light work such as assisting crane hookups, electrical connections, or lighting maintenance. The other two manipulators (Fig. 8) are mounted on posts adjacent to the machine. These two are the main-disassembly tools for heavy maintenance and repair operations. Each has a 6-m reach, a 182 kg-horizontal-load capability, and can traverse the full height of the machine. In order to give full room-coverage, the manipulator mounting posts can be moved to many alternate positions, as shown in Fig. 9. As with the overhead manipulator, these units are removed to the main hot shop during machine operation and are available there for remote work.

Sensing Systems

Sensing systems, which provide operators of remote-handling equipment visual-, "feel"-, and aural-feedback, will be required for both operation and maintenance. Listed in order of importance, the senses used in remote operations are vision, force-feedback (or "feel"), and then sound. Windows for direct viewing, binoculars, telescopes and periscopes form the primary visual system. Extensive use of fixed and mobile television will augment direct vision for viewing obstructed areas or for close-in work.

Large, overhead manipulators do not normally provide force feedback (i. e. "feel"). However, some heavy-duty industrial manipulators and some remote master/slave manipulators with force feedback are commercially available. For operations requiring "feel," this kind of feedback will be provided, either by means of some specific motions of the large manipulator or by using a smaller master/slave unit as an accessory.

Feasibility

In evaluating the feasibility of the proposed FERF remote-handling system, it is useful to compare it with other remote operations of comparable size and complexity. Table 1 compares gross dimensions and handling capabilities of four facilities: (1) FERF, (2) the proposed Two-Component-Torus (TCT) system, (3) Aircraft-Nuclear-Propulsion (ANP) Hot Shop, and (4) the Engine Maintenance and Disassembly building (E-MAD). TCT[4] and FERF are in the preliminary-planning and conceptual stages. The ANP Hot Shop[2] and E-MAD[5] were built in the 1960's and are presently operated in a standby- or minor-usage mode. FERF is slightly larger than any of the other three facilities, it requires a higher capacity crane, and its manipulators will have greater vertical travel. From a

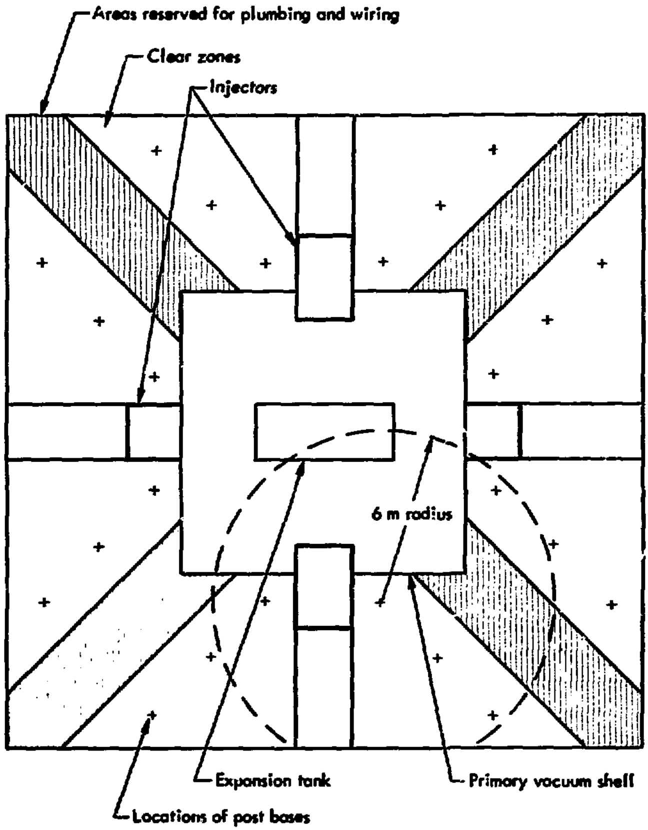

Fig. 9. Plan view of operating vault, showing locations of bases for post-mounted relocatable manipulators. Each manipulator can operate through a 6 m radius.

geometrical standpoint, FERF is well within the capabilities of present-day remote-handling equipment technology.

From the standpoint of complexity of operations, comparisons between these systems become less clear. The remote handling to be done in the operating vault of FERF is less complicated than that performed in many hot-cell installations. However, the parts to be handled by the FERF system are numerous, large, and heavy. With respect to weight, components no heavier than 18 tonnes have been handled remotely in either the ANP Hot Shop or E-MAD. However, in normal maintenance the heaviest FERF part to be handled remotely will weigh 50 tonnes and will be more complex and more delicate than those of the other systems.

Making and breaking fluid, electrical and mechanical connections comprise the majority of the remote-handling tasks in the FERF operating vault. There is ample evidence from many years of hot-cell work that fluid, electrical, and mechanical connections of the kind and quality required by FERF can be remotely handled successfully. Extensive development and test of the specific connectors for FERF will be required in order to optimize handling operations. The more complicated maintenance and repair will be done in the hot shop and adjacent hot cells. These areas will be equipped with conventional master/slave manipulators and special tooling to facilitate work that is more difficult and delicate than can be done in the operating vault.

Table 1. Comparison of remote-handling capabilities of four facilities.

Parameter	FERF proposal		TCT proposal[4]		ANP hot shop[2]		E-MAD[5]
Vault/shop dimensions:	Vault	Shop					
Length (m)	22	24	33		49		44
Width (m)	22	22	31		15		20
Height (m)	27	15	16		15		21
Total volume (m^3)	21 318		16 368		11 025		18 480
Bridge-crane capacity							
Primary/aux. (tonnes)	114, 114/9		91/9		91/9		36/9
Number of overhead manipulators	1		1		1		1
Travel L × W × H (m)	40 × 20 × 10		20 × 28 × 7		46 × 11 × 7		37 × 15 × 12
Arm reach (m)	6		3		2.1		–
Hand load capacity (kg)	181		181		227		–
Side-wall manipulators	2		1	2	2	1	2
Travel L × H (m)	0 × 16		24×6.5	0×5.1	46×6.7	46×4.6	37 × 6
Arm reach (m)	6		9.7	6	5.7	7	10
Hand load capacity (kg)	181		181	181	18	18	272

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