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## MASTER

### Proceedings of FED Remote Maintenance Equipment Workshop

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- D. Tobias
- N. Young

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**FUSION ENERGY DIVISION**

**PROCEEDINGS OF FED REMOTE MAINTENANCE EQUIPMENT WORKSHOP**

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## ABSTRACT

A workshop was convened in two sessions in January and March, 1981, on the remote maintenance equipment for the Fusion Engineering Device (FED). The objectives of the first session were to familiarize the participants with the status of the design of the FED and to develop a remote maintenance equipment list for the FED. The objective of the second session was to have the participants present design concepts for the equipment which had been identified in the first session. The equipment list was developed for general purpose and special purpose equipment. The general purpose equipment was categorized as "manipulators" and "other," while the special purpose equipment was subdivided according to the reactor subsystem it serviced: electrical, magnetic, and nuclear. Both mobile and fixed base manipulators were identified. Handling machines were identified as the major requirement for special purpose equipment.

## 1. INTRODUCTION

The major tokamak experimental machines currently under construction are being designed to demonstrate the scientific feasibility of fusion. The Fusion Engineering Device (FED) is being designed as the next major tokamak beyond the Tokamak Fusion Test Reactor (TFTR) and the Joint European Torus Tokamak (JET).

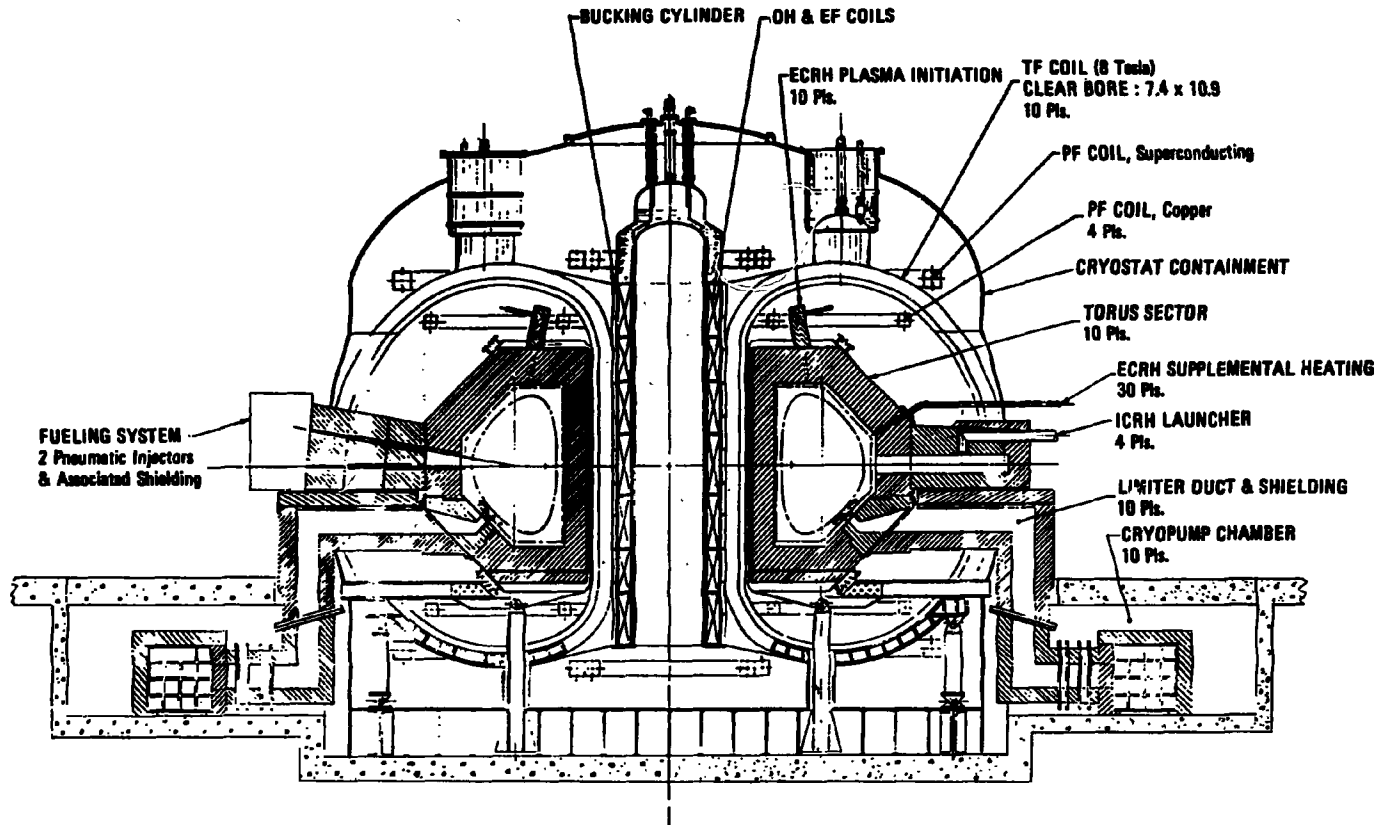
The principal mission of the FED has been identified as the integration of the engineering systems required for an operational fusion reactor. The remote maintenance system is recognized as a major component of these engineering systems. Accordingly, it was considered desirable to develop an initial definition of the remote maintenance systems when the characteristics and layout of the FED were adequately defined.

In order to obtain input from a broad spectrum of capabilities in remote maintenance equipment design, a workshop was organized. This workshop, which was held in Oak Ridge, was convened in two sessions. At Session I, convened on January 20-21, 1981, presentations were made on the current FED design and on the maintenance procedures associated with the design concept. On this basis, a preliminary list of the remote maintenance equipment requirements was developed. The participants were then requested to develop design concepts for specific items of remote maintenance equipment upon return to their home institutions.

At Session II, held on March 12-13, 1981, presentations were made by the participants on the design concepts that they had developed. Also, at this session a review was made of the equipment list, and several revisions were made on the basis of the information presented.

## 2. FED DESIGN

The design layout of the FED (Figs. 1-2) had been developed in sufficient detail at the time of Session I (January 1981) to provide information on the maintenance concept and on the scale of the maintenance operations. The principal design parameters reflecting the scale of the machine are summarized in Table 1. These parameters were



2

Fig. 1. FED reference design elevation view.

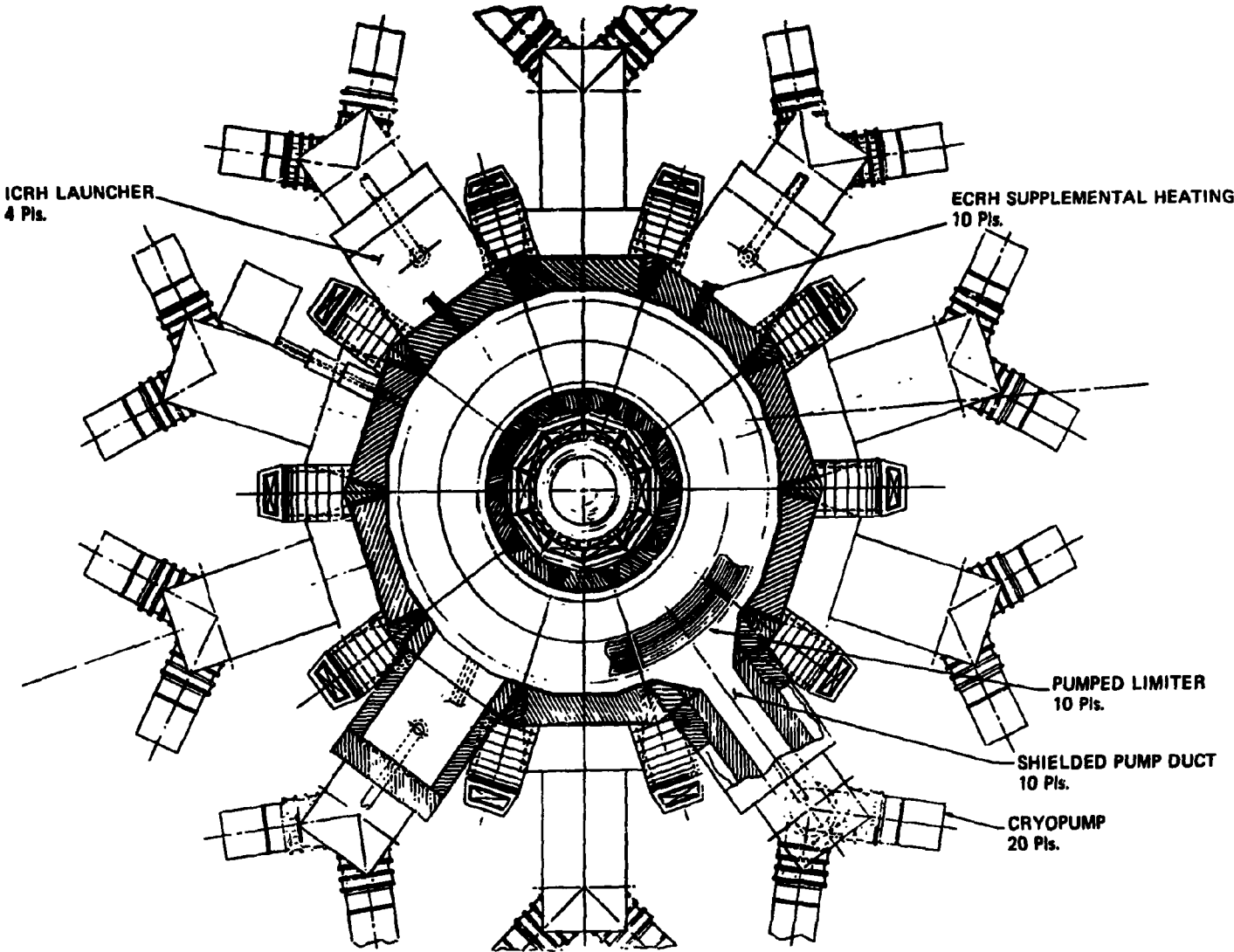


Fig. 2. FED reference design plan view.

Table 1. FED working parameters

Symbol	Description	Unit	Value
R	Major radius	m	4.8
$r_w$	Plasma chamber radius	m	1.5
a	Plasma radius	m	1.3
K	Plasma elongation	m	1.6
$\delta$	Plasma triangularity	-	0.5
A	Aspect ratio	-	3.7
-	Plasma volume	$m^3$	257
-	Plasma chamber area	$m^2$	366
$B_t$	Field on axis	T	3.6
$I_p$	Plasma current		
	Low $\beta$	MA	4.8
	High $\beta$	MA	5.4
$\langle\beta\rangle$	Beta (total)	%	5.5
$P_{th}$	Total D-T fusion power	MW	180
$t_{burn}$	Burn time	s	$\geq 100$
$t_{cycle}$	Cycle time	s	$\geq 152$
$t_p$	Pumpdown time	s	30
$t_{ss}$	Startup/shutdown time	s	12/10
-	No. of full-field pulses/lifetime	-	$3.5 \times 10^5$
-	Lifetime (D-T operation)	years	10

based on the plasma requirements to operate at an energy enhancement factor  $Q$  of about 5 for a maximum toroidal field (TF) at the coil of 8.0 T.

The design features ten TF coils and ten torus sectors. The sectors are inserted into a spool support structure, which, combined with the outboard faces of the sectors, forms an external vacuum enclosure for the plasma chamber. The enclosure is sealed by installing frame seals between the outboard faces of the sectors and the frames formed by the flanges and vertical posts of the support spool. With this arrangement a sector can be removed for repair or replacement of the first wall components by breaking the external sector frame seal and extracting the sector in a simple radial translation.

Penetrations are provided for the rf launchers, test modules, fuelers, and diagnostics. By removing the components in these ports, access can be gained to the interior of the plasma chamber for inspection and minor replacements and repairs. This feature should be especially useful for replacing a limited number of armor tiles, which are located on the top, bottom, and inboard walls of the plasma chamber in order to protect these surfaces from damage due to disruptions.

The current FED design also features a pumped limiter for impurity control. The limiter was installed on the lower 45° facet (January 1981)\* and extended completely around the plasma chamber in the toroidal direction. A vacuum pumping system incorporated two compound cryopumps, connected to the limiter base by means of a large pumping duct at each of the ten torus sectors. The ducting was designed so that the limiter can be extracted and replaced without removing the torus sectors.

A poloidal field (PF) coil system combining superconducting coils exterior to the TF coil bore and normal conducting copper coils inside the bore is reflected. By using normal conducting coils inside the toroidal bore, it is possible to segment the coils in such a way as to permit their extraction and replacement without disturbing the TF coil

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\* Subsequently relocated to the bottom of the torus.

assembly. The superconducting coils in the poloidal bore and above the TF coil assembly can be removed and replaced by a vertical lift. The PF coils under the TF coils have to be replaced by "jury rigging" temporary supports for the reactor and serially removing the main supports while shifting the coil laterally. Alternatively, redundant coils can be provided, or the conductor can be replaced by winding in place.

A common Dewar encloses all the superconducting coils. This Dewar is formed by a cylinder around the base, a dome over the top, and ligaments covering individual outboard legs of the TF coils. The apertures formed by these components of the Dewar provide access to the torus for installation of the rf launchers, vacuum ducts, test modules, fuelers, and diagnostics, as well as the basic torus sectors.

### 3. FED MAINTENANCE APPROACH

The maintenance approach adopted for FED emphasizes the requirements for remote operations but, in fact, is strongly based on the ability to perform contact operations on all components which are external to the plasma chamber (torus shield). The threefold approach which established the framework for developing the device configuration is as follows:

(1) In general, all major systems are designed to be maintained using fully remote procedures, but contact maintenance will be employed as a normal operation when savings in downtime can be confirmed. The ability to maintain all systems remotely covers cases of emergency when personnel could be prohibited from entering the reactor cell. Also, many routine operations that are thought to be more efficient by contact means may be done faster using remote means on a device which is designed at the outset for maintainability (i.e., the 24-h shutdown period can be waived). However, contact operations will be employed wherever they can be performed more quickly and more efficiently than remote procedures.

(2) Certain systems, which are relatively inaccessible, are classified as semi-permanent installations and must be designed to be very reliable since they are designed for the life of the device. However, the capability to accommodate their unexpected repair or

replacement will be a design criterion even though such an occurrence represents a prolonged downtime. Semi-permanent installations include, but may not be limited to, the TF coils, the bucking cylinder, and certain PF coils. They are analogous to the pressure vessel in a fission reactor and require the same degree of reliability.

(3) All components are designed at the outset to be maintained using existing or near-term remote maintenance equipment. This is not meant to imply that there is no need for development work in this area but that a technology base does exist which must be focused on the particular needs of next generation tokamak reactors. Remote maintenance equipment generally falls into three categories: manipulators, viewing systems, and transporters. Manipulators with integrated computer processors having feedback and programming capabilities are within the realm of near-term development, as are viewing systems using fiber optics and three-dimensional TV scanning. Also, the application of technology developed for transporting heavy components for military and space programs as well as that for heavy industry (i.e., fission reactor vessels, shipbuilding, mill work etc.) is already at hand and needs only to be extended to tokamaks.

Many of the problems associated with device maintenance and disassembly stem from the massive size and weight of the components. These considerations are in themselves formidable. Unfortunately, these engineering problems are further complicated by radioactivation of materials caused by high energy neutrons. For reasons of personnel safety, manned entry into the reactor cell is not permitted during D-T operation, and it is very likely that maintenance equipment also will not be permitted near the device in order to avoid induced activation.

The torus shielding is sized to meet the contact maintenance requirement stated earlier. After a 24-h shutdown period, the dose rate peripheral to the device is 2-1/2 mrem/h from induced gamma radiation, which is low enough to permit normal worker operations. This design approach permits manned access for major and minor maintenance tasks, allows for periodic inspection and/or testing in situ, and aids in setting up equipment for subsequent remote operations required after the

torus or other major components have been opened. The gamma radiation internal to the device is too high to permit contact operations in those regions. Dose rates may reach  $\sim 10^6$  mrem/h at the first wall immediately at shutdown. Depending on the dose rate level, the time required for a particular operation, and the availability of personnel, fully remote or semi-remote procedures will be used in these areas.

#### 4. WORKSHOP PROCEDURE

A primary objective of Session I of the workshop was to familiarize the participants with the status of the FED design. Presentations were made on the overall FED design, the basic maintenance approach, and the maintenance features of the principal subsystems (Table 2). In addition, presentations were made on related remote maintenance studies on the TNS and STARFIRE programs.

The participants in the first session (Table 3) were assigned to five working groups to examine the remote maintenance requirements and to identify the specific items of remote maintenance equipment required. Because of the relative importance of manipulators, the General Purpose category of equipment was broken into two working groups: one for "manipulators" and the second for "other" equipment. Three groups were formed to examine the special equipment requirements for the electrical, magnetic, and nuclear subsystems. These groups corresponded to the system branches having responsibility for the design of the various components and subsystems of the FED.

J. Garin chaired the General Purpose - Manipulators group, and D. Tobias chaired the General Purpose - Other group. E. R. Hager, H. Stevens, and N. Young chaired the Electrical, Magnetics, and Nuclear groups. Key Design Center personnel served as cochairmen.

The equipment requirements identified by these working groups are summarized in Sect. 5.

In Session II of the workshop, the participants who had generated input for the FED requirements convened (Table 4) and made presentations on the design concepts developed. These contributions were summarized and are included as appendices to this report.

Table 2. Agenda for the Remote Maintenance Equipment  
Workshop, Session I

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<u>January 20, 1981</u>		
0830	Welcome	D. Steiner/C. Head
0845	FED overview	P. Sager
0915	FED maintenance approach	P. Spampinato
0930	Torus system	G. Fuller
0945	Magnet systems	B. Hunter
1000	Heating system	D. Metzler
1015	Break	
1030	Fueler	G. Gorker
1040	Vacuum pumping system	W. Homeyer
1050	Instrumentation	D. Nelson
1100	TNS remote maintenance equipment	D. Madden
1130	STARFIRE remote maintenance	C. Trachsel
1200	Lunch	
1315	Working groups	
	General purpose	
	- Manipulators	
	- Other	
	Special purpose	
	- Nuclear	
	- Magnets	
	- Electrical	
1700	Complete working group deliberations	
<u>January 21, 1981</u>		
0830	General purpose, manipulators	
0900	General purpose, other	
0930	Special purpose, nuclear	
0950	Break	
1005	Special purpose, magnets	
1025	Special purpose, electrical	
1045	R&D requirements, discussion	
1145	Closing remarks	P. Sager

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Table 3. Participants, Remote Maintenance Equipment Workshop,  
Session I, January 20-21, 1981

---

E. S. Bettis, Lockheed Missiles & Space Company  
 K. W. Carboni, Combustion Engineering, Inc.  
 J. Daniel, Combustion Engineering, Inc.  
 B. A. Engholm, General Atomic Company  
 J. Evans, Oak Ridge National Laboratory  
 M. J. Feldman, Oak Ridge National Laboratory  
 C. R. Faltau, TeleOperator Systems Corporation  
 R. D. Fletcher, Exxon Nuclear Idaho Company  
 J. Garin, Oak Ridge National Laboratory  
 D. L. Grisham, Los Alamos Scientific Laboratory  
 E. R. Hager, General Atomic Company  
 R. H. Hagerman, Grumman Aerospace Corporation  
 D. B. Hagmann, Princeton Plasma Physics Laboratory  
 C. T. Harden, Combustion Engineering, Inc.  
 C. E. Head, Department of Energy  
 W. G. Homeyer, General Atomic Company  
 L. Lontal, Princeton Plasma Physics Laboratory  
 D. MacDonald, Oak Ridge National Laboratory  
 D. S. Madden, Kortech Engineering, Inc.  
 L. S. Masson, EG&G Idaho, Inc.  
 F. D. Michaud, Los Alamos Technical Association, Inc.  
 O. F. Rice, Honeywell Ceramics Center  
 G. Schukel, Combustion Engineering, Inc.  
 M. W. Sniderman, Westinghouse Electric Company  
 H. C. Stevens, Argonne National Laboratory  
 D. Tesar, CIMAR (Center of Intelligent Machines and Robotics)  
 D. A. Tobias, Argonne National Laboratory - West, Idaho Falls  
 C. Trachsel, McDonnell Douglas Corporation  
 H. L. Watts, Lockheed Missiles & Space Company  
 J. R. White, Remote Technology Corporation  
 R. W. Wiesener, PAR Systems Corporation  
 N. Young, EBASCO Services, Inc., Princeton Plasma Physics Laboratory

FEDC Personnel

R. J. Barrett	W. D. Nelson
R. W. Derby	R. E. Nygren
G. M. Fuller	P. H. Sager
G. E. Gerker	G. E. Smith
B. L. Hunter	P. T. Spampinato
J. Kirchner	D. Steiner
J. G. Murray	S. L. Thomson

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Table 4. Participants, Remote Maintenance Equipment Workshop,  
Session II, March 12-13, 1981

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C. Dillow, McDonnell Douglas Corporation  
 A. Ferrara, Grumman Aerospace Corporation  
 D. L. Grisham, Los Alamos Scientific Laboratory  
 E. R. Hager, General Atomic Company  
 D. MacDonald, Oak Ridge National Laboratory  
 D. S. Madden, Kortech Engineering, Inc.  
 L. S. Masson, EG&G Idaho, Inc.  
 J. T. McVey, Health Physics Systems, Inc.  
 O. F. Rice, Honeywell Ceramics Center  
 V. Scotti, Combustion Engineering  
 D. A. Tobias, Argonne National Laboratory  
 H. L. Watts, Lockheed Missiles & Space Company  
 R. W. Wiesener, PAR Systems Corporation  
 N. Young, EBASCO Services, Inc., Princeton Plasma Physics Laboratory

FEDC Personnel

R. J. Barrett	D. H. Metzler
R. W. Derby	J. G. Murray
G. M. Fuller	R. E. Nygren
G. E. Gorker	P. H. Sager
J. Kirchner	S. L. Thomson

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## 5. REMOTE MAINTENANCE EQUIPMENT REQUIREMENTS

A major focus of the workshop was the development of a list of remote maintenance equipment requirements for FED. This list (Table 5) describes the major items of equipment, together with an identification of the general types of tools, fixtures, lighting and viewing equipment, inspection systems, shields, and casks required. In some cases (e.g., Dewar leak detection system), major elements of the system may have to be integrated with the reactor component design.

### 5.1 GENERAL PURPOSE

#### 5.1.1 Manipulators

Maintenance activities on a fusion reactor will, by necessity, require remote activities for a number of situations. Some of these are: in situ inspection of highly activated components, disassembly or repair of components immediately after shutdown, and decontamination and cleanup after an accident or spill (i.e., a tritium leak, coolant spillage, or removal of activated particulate matter). All of these situations can be handled by general purpose manipulators. These devices are designed to simulate or duplicate wherever possible the dexterity of manned operations; in order for these devices to be used effectively, the tokamak configuration must be designed for accessibility.

The general purpose manipulators required to accommodate the basic maintenance needs for the FED configuration were identified as follows:

(1) An overhead bridge-mounted telescoping tube system was identified as having a 50-ft extension and a 10-ft reach. Two of these systems are required.

(2) A floor mobile manipulator system is required to provide access to the base of the reactor, which cannot be reached by the bridge mounted system or the fixed base manipulators. In addition, this manipulator system could be used to augment the capability of the fixed base system. Two floor mobile systems are required to provide for operations in two locations simultaneously.

Table 5. FED remote maintenance equipment list

Item	Remarks
<b>General Purpose</b>	
<b>Manipulators</b>	
Bridge mounted (2)	Interchangeable power manipulator and man-equivalent servo-manipulator. Power manipulator with force reflection. Unmanned. Independent arm-mounted stereo TV and lighting. Recovery capability or remotely maintainable.
Floor mobile (2)	(As above, except recovery capability only.) Free-roving umbilical control with multiple receptacle stations. Anchor stations at operating locations.
Pedestal mounted (4)	(Same as bridge mounted, except recovery capability only.) Ten pedestals located co-planar with TF coils.
<b>Other</b>	
Bridge crane	Five-hundred-ton capacity/25-ton auxiliary capacity. Recovery capability or remotely maintainable.
Modular maintenance vehicle	For handling limiter fuel injectors, test modules, rf launcher, shield plugs, component shield units, diagnostics.
Clamp installation devices	For large coolant lines, diagnostics, and smaller components.
Service connection devices	Adaptable to all service quick disconnects. Installed on manipulator.
Cutters	For Dewars, manifolds, and service lines.
Welders	For Dewars, manifolds, and service lines.
Area lighting and TV viewing	Provide adequate viewing capabilities, independent of building lighting.
Decontamination equipment	Manually and remotely controllable, high pressure, minimal fluid.

Table 5. (continued)

Item	Remarks
<b>Special Purpose</b>	
<b>Electrical</b>	
NBI transporter	Traction drive or cable drive. Track guided. Hydraulic ram or screw jack for breakaway and final positioning.
NBI special tools	For accelerator stack, source, cryopanel, direct recovery assembly, and gas cell.
ICRH handling fixture	
Optical diagnostics special tools	For removal of inside mirrors, vertical mirror assembly, horizontal mirror assembly of optical diagnostics such as the FIR interferometer.
Neutron detector handling tool	
Inspection tools	For various diagnostics.
<b>Magnetic</b>	
Coil handling tools	Slings/fixtures for TF and PF coils.
Coil positioning tools	
Dewar leak detection system	
Leak repair welder	To traverse through 5-cm annular clearance.
Coil fault isolation system	
<b>Nuclear</b>	
Plasma chamber inspection/maintenance machine	Fiber optics. Rapid changeout TV. Decon capability.
Shield sector transporter	

Table 5. (continued)

Item	Remarks
<b>Nuclear (cont'd).</b>	
Sector frame seal transporter	
Sector frame seal handling fixture	
Sector frame seal welder	Self-driven. Installed remotely and manually.
Sector frame seal cutter	Self-driven. Installed remotely and manually.
Limiter handling fixture	
Vacuum duct handling fixture	
Test module handling fixture	
Handling casks	For vacuum pumps, diagnostics, fuel injectors, limiters, rf launchers.
Shield plugs	For shield sector, NBI, fuel injector, C&I, and other plasma chamber penetrations.
Shield plug handling fixtures	
Plasma chamber leak detection system	Mass spectrometer.

(3) A pedestal four-degree-of-freedom articulated device was identified as having a 1363-kg (3000-lb) capacity along with a 4.6-m (15-ft) reach. Four of these would be provided so that operations could be carried out concurrently by two pairs at different reactor stations. They would be mounted behind the TF coils, with access to each sector through the TF coil/cryostat window.

All the manipulator systems would be designed to accommodate either a power manipulator or a man-equivalent servomanipulator interchangeably.

The power manipulator requires 182-273 kg (400-600 lb) of lift. It lacks the dexterity of the man-equivalent servomanipulator but can be used to complement its operations for a range of tasks.

The man-equivalent servomanipulator is the device which most closely duplicates the activities of a mechanic. It requires a lifting capability of 23 kg (50-75 lb).

End-effector devices which can be used in conjunction with the manipulator systems include, but will not be limited to, the following:

- shield block handler (shadow shielding),
- bolt torquer, out runner, impact wrench,
- welder,
- cutter,
- radiation monitor,
- leak detector,
- viewers.

Additional features which must be incorporated into these manipulator systems include obstacle avoidance, viewing systems with positioning control, and supervisory control. The supervisory control should include teach-playback and tool change capabilities. Radiation hardening will also have to be considered, since the manipulator systems will be exposed to high level sources upon removal of the shield sectors, test modules, and ancillary equipment requiring large penetrations.

Maintenance operations with these general purpose devices can be accomplished in conjunction with the other general purpose equipment and

the special purpose equipment which are described in the following sections.

#### 5.1.2 Other

In addition to manipulators, a wide range of general purpose equipment is required. A bridge crane with a 500-ton hoist capacity is required to move heavy reactor components, such as a shield sector. Either this crane should be capable of being recovered after being disabled, or it should be designed for being remotely maintained.

A modular maintenance vehicle is required for handling a variety of components in the intermediate weight range. Among the components for which this handling machine could be designed are the limiter, fuel injectors, test modules, rf launcher, shield plugs, component shield units, and diagnostics. This machine probably should be a free roving machine in order to interface with components installed in unanticipated locations. It should be equipped with local lighting and closed circuit television (CCTV) systems to provide adequate control of operations.

Diagnostics, large coolant lines, and many smaller components will be installed using clamps. Clamp installation devices are required to remove and replace these clamps remotely when the operations have to be performed while the reactor building is inaccessible. These devices should be adaptable to a manipulator-articulated arm and be capable of push, pull, and rotational motions.

A range of different size quick disconnects will be used for all electrical, instrumentation, cryogenic, hydraulic, and coolant service lines. For most requirements, these can be disconnected manually. For some situations (e.g., activities before 24 h after shutdown), however, it may be necessary to make or break connections remotely. Service connection devices are required for this purpose. Like the clamp installation devices, they should be designed for installation on a power manipulator-articulated arm and be capable of push, pull, and rotational motions. The manipulator lighting and CCTV system can be used to monitor the operations locally.

Automatic cutters and welders will have to be provided to cut and reweld the superconducting coil Dewars, manifolds, and service lines where sections not fitted with clamps or quick disconnects have to be removed. Normally, these tools can be set up manually, but they have to be designed for installation using a manipulator for those situations where the reactor building is inaccessible. These tools should be self-driven so that, once installed, the operations can proceed on an automated basis. Local lighting and CCTV for monitoring the operations remotely can be provided by the manipulator systems.

Area lighting and CCTV coverage are required at strategic points in the reactor building. Approximately six fixed stations will be required in the main bay of the reactor building. In addition, the lighting and CCTV system installed on the bridge crane can be used for mobile area coverage in places not adequately covered by the fixed stations.

Decontamination equipment which can be remotely controlled, as well as manually operated, is required to remove contamination in areas exposed to tritium and radioactive debris. A dry vacuum can be used for loose debris. High pressure Freon 113 and/or water spray with a vacuum pickup will be required where adhered material is encountered. For many operations, a manipulator with appropriate end effectors can be used to handle the decon equipment. It may also be desirable to develop a mobile system with controls permitting access to areas too restricted to accommodate a general purpose manipulator. In this case, the mobile system would have its own motive power and lighting and CCTV systems.

## 5.2 SPECIAL PURPOSE

### 5.2.1 Electrical

The electrical components include a neutral beam injector, a fuel injector, IRCH, ECRH, and control and instrumentation.

Wherever practicable, general purpose equipment should be used to maintain the electrical system components because of the range of uncertainties in component failure mode. Special purpose remote equipment should be planned only when justified by machine availability needs or

when required to allow work to be done in the contact or semi-remote mode. Electrical components will be maintained in situ whenever possible.

A transporter will be required for the neutral beam injector to remove it from the installation at the reactor and reinstall it. This transporter can be designed to employ either traction drive or cable drive. The NBI should be track guided to provide accurate positioning. A hydraulic ram and/or jack screws are required for breakaway and for final positioning of the NBI.

A variety of special tools for handling the components of the NBI is required. Among the components of concern are the accelerator stack, source, cryopanel, direct recovery assembly, and gas cell.

A handling fixture is required for removal and replacement of the ICRH assembly. It is assumed that either the modular maintenance vehicle (Sect. 5.1.2) or the bridge crane can be used for handling this component. In either case, the operation will have to be performed remotely, since it involves compromise of the torus shielding system.

Special handling and inspection tools are required for the various diagnostics.

### 5.2.2 Magnetic

Handling tools and positioning tools will have to be provided for both the TF coils and PF coils. In general, these slings and fixtures can be the same as those designed for the original construction. For normal maintenance operations, it is expected that the PF coils can be removed using contact procedures. To be consistent with the requirement to be able to perform maintenance operations if the reactor building becomes inaccessible, however, all the coils should be designed to be installed and removed using totally remote operations.

A Dewar leak detection system, which may have to be partially integrated with the Dewar design, is required to isolate the location of leaks so that they can be repaired. This system will most likely involve the local application of a tracer gas which can then be detected by a mass spectrometer at a Dewar pump-out location.

Once located, a welder can be used to overlay the suspect area. In the case where a leak is located in the annulus between the torus support spool and the central cylinder section of the Dewar, the welder will have to be designed to fit in a 5-cm clearance. Lighting and a miniature TV camera will also have to be designed to fit in this confined space.

A coil fault isolation system is required to determine the location of an electrical fault. This system will have to be built into the coil system in such a way as to permit remote control of the location of the fault.

### 5.2.3 Nuclear

Areas of prime interest in the nuclear systems remote maintenance review of the FED concept centered on in-vessel operations, sector module removal, limiter servicing, and vacuum system removal for access and system maintenance.

The plasma chamber inspection/maintenance system must incorporate numerous functional requirements. Systems discussed included electro-mechanical (power) arms, dexterous force feedback arms, and hoist systems. In general, an in-vessel system must be able to enter the vessel through an open port and access all interior surfaces within a specified portion of the vessel. The unit must have the capability of performing precise operations as well as handling relatively high loads. All systems discussed incorporated two dexterous force feedback systems capable of positioning, aligning, and handling small items with a high degree of flexibility and precision. Handling of heavy items can be accomplished with either electromagnetic (EM) manipulators or a simple jib hoist; however, the EM manipulator provides more versatility.

Large transporters will be necessary to install and retract the shield sectors and sector frame seals from under the Dewar canopy. The shield sector handling presents a particularly difficult challenge, since the shield sector weighs upward of 400 tons. It may be possible to integrate these two requirements into a single machine which could be equipped with special fixtures to perform the different operations.

Welding and cutting devices will have to be developed for the sector frame seal. Seal welding would be accomplished utilizing a standard mechanical TIG welder head mounted on a carriage which would align, clamp, and track the welded surfaces. A guide rail system should be incorporated into the design as a reference frame for the system. A roll shear, punch shear, or chipper could be used for the cutter. This device would mount on the same track system as the welder.

It is expected that a modular maintenance vehicle (Sect. 5.1.2) will be available to handle intermediate size components, including the limiters, test modules, and shield plugs. Handling fixtures will be required for adapting these components to the modular maintenance vehicle.

Handling casks will be required for various components, such as the vacuum pumps, diagnostics, fuel injectors, limiters, and rf launchers. The handling casks will limit contamination of the reactor building by tritium and radioactive debris. Further study may indicate the incorporation of shielding into the casks to provide more personnel access to the reactor building and accommodate off-site shipment. Shield plugs are also required to permit closure of the plasma chamber after removal of a component.

A plasma chamber leak detection system will be required to isolate the location of any leaks in welded joints or mechanically sealed closures. In general, this will require a means of applying a gas source locally and use of a mass spectrometer to detect when the gas has penetrated into the plasma chamber.

## 6. CONCLUSIONS

The FED Remote Maintenance Equipment Workshop was successful in bringing together a substantial number of specialists in the design of remote maintenance equipment to identify the remote maintenance equipment requirements for the FED and to develop design concepts for the equipment.

The identification of the remote maintenance equipment and the design concepts developed for this equipment indicates that the design philosophy adopted for the FED is valid. Where the remote maintenance

equipment can be set up prior to removal of radiation shielding, the maintenance operations will be substantially expedited. In the event of unexpected radiation exposure problems, however, it appears that with the mobile features provided with the manipulator systems it will be possible to perform all operations in a completely remote mode.

While the planned maintenance operations and the more obvious unscheduled maintenance operations are accommodated with the remote maintenance system conceived in this workshop, it is recognized that maintenance procedures not previously anticipated will be required. Accordingly, the maintenance system features a substantial number of a variety of manipulators to accomplish these unforeseen requirements.

The identification of the equipment requirements now permits a reevaluation of the FED design to establish compatibility of the design and the remote maintenance equipment. It is recognized that in some areas changes in the reactor component designs will have to be made, and special features will have to be provided to accommodate the remote maintenance equipment. As the reactor design further evolves, the remote maintenance system will have to be further developed to better define the capability, compatibility, and cost of the equipment.

The dual sessions used in this workshop were very effective in obtaining input with maximum usefulness from the participants. By briefing the participants on the status of the FED design in Session I and then allowing approximately 1-1/2 months for them to develop their ideas on equipment design concepts before Session II, we were able to obtain input directly related to the design under study. Such a procedure should be considered whenever the information to be obtained from the participants is highly dependent upon the reactor concept under development.

## RAIL-MOUNTED REMOTE MAINTENANCE VEHICLE

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The manipulator transporter concept is conceived as a self-contained floor-mounted system to perform remote maintenance tasks on large in-cell equipment assemblies. The transporter is equipped with servomanipulators mounted on an articulated telescoping boom on a rotating base. This floor manipulator system is used primarily to disconnect and reconnect component assemblies. The manipulators and television viewing also provide close-in support of overhead crane operations for removing and transport of large heavy equipment.

Floor Transporter

The system described in Figure 1 is a jib crane having both articulating and telescoping sections. This design offers the ability to reach throughout the spacial requirements of the cell equipment as well as the compactness for transport through work hatches as shown in Figure 2. Power screws are provided to individually actuate the different sections of the crane. The servomanipulators, service hoist, camera, lights, and stabilizer are all attached at the end of the crane arm to assist the repair operations.

A floor transporter with a rotating turntable provides the base for the crane arm. The transporter is powered along parallel rails. Band type electro-mechanical brakes are recommended for maintaining transporter position when stopped.

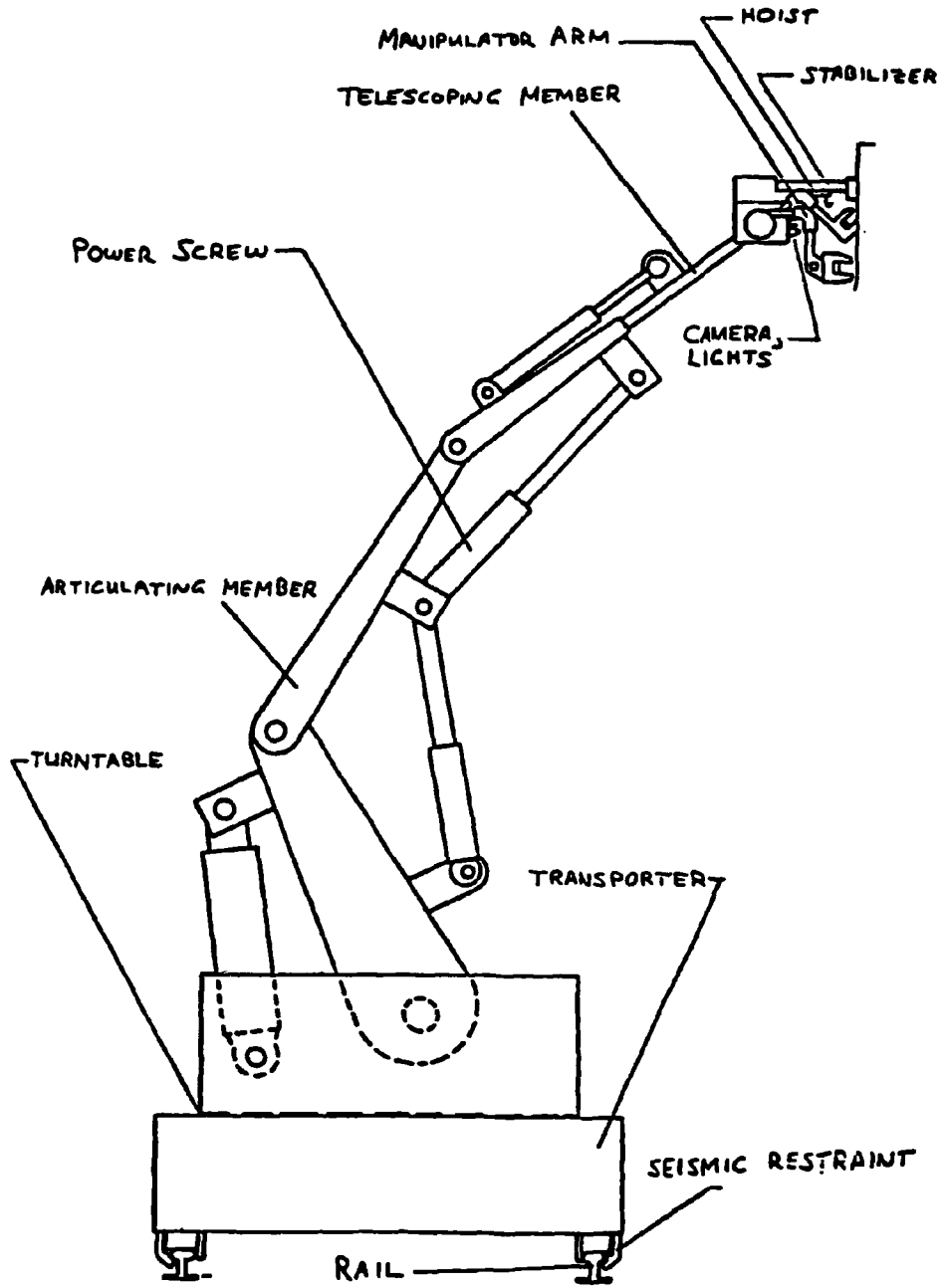
A power screw actuated seismic restraint/guide roller assembly is attached to the transporter at each wheel location. In addition, the seismic restraint/guide roller assembly is used to react the overhanging moment of the loaded crane arm under both static and seismic conditions. The stabilizer may be required for additional support at extreme boom extension and maximum load situations.

o The telescoping boom supports a hoist and a servo-manipulator/viewing package. A linear actuator is used to extend this boom.

o The servomanipulators and the viewing/lighting package are secured to an interface plate on the telescoping boom. The package has an umbilical interface connection which permits remote engagement/disengagement of manipulator control cables.

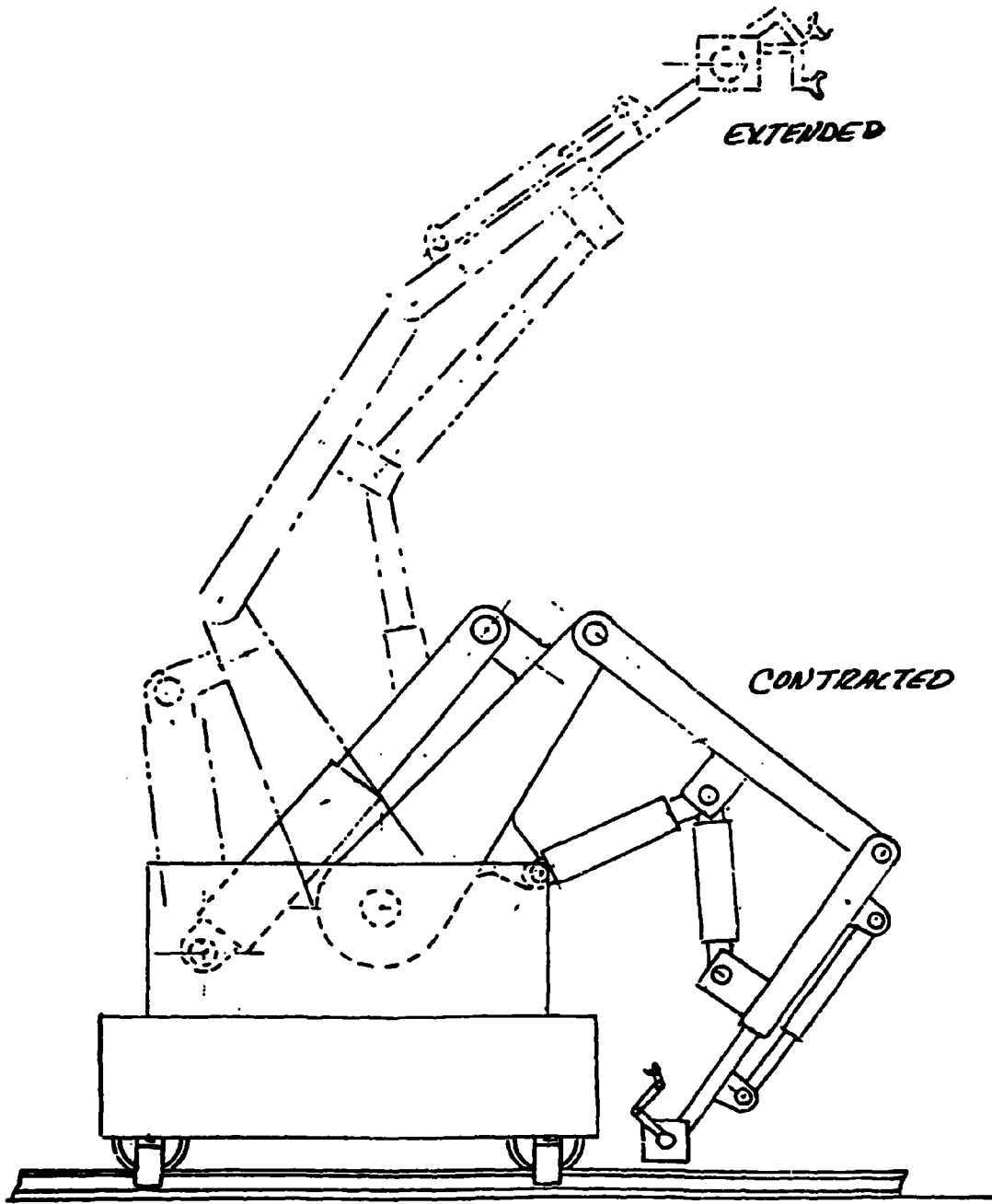
o The 1,000-lb capacity hoist is secured to an interface plate on the telescoping boom and features an electric power cable with quick disconnect terminals.

o The transporter is controlled from the maintenance control center. During transit to work stations, vehicle power and control signals are transmitted via busbar. At the work station, control signals to the vehicle for manipulator and television operation are via cable from plug-in stations.



*REMOTE MAINTENANCE VEHICLE*

Figure 1



*TRAVEL CONFIGURATION*

Figure 2

**APPENDIX B**



**FLOOR MOBILE MANIPULATORS**

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**INTRODUCTION**

Floor mobile manipulators will be needed in the FED to perform a variety of maintenance tasks. The design of these mobile manipulators will be based on the current technology and will include those design improvements expected to occur over the next few years. Future systems engineering analyses and mockup studies should be performed to establish the system requirements and design criteria.

**CURRENT USAGE**

Mobile manipulator systems have been used to replace man in hazardous environments. High energy propellant and explosive laboratories, for example, have used mobile manipulators to perform critical, hazardous procedures. The laboratory technician will perform the nonhazardous steps and then retire to a protected area to perform the hazardous tasks remotely using a mobile manipulator. The PaR column-mounted power manipulator has been operated on a tracked vehicle to perform laboratory tasks. This device operates at the laboratory bench height and can move from one location to another. Applications can utilize umbilical control and direct viewing or radio control with closed circuit TV.

A special mobile manipulator system was designed and fabricated at the U.S. DOE Rocky Flats Plant operated by Rockwell International. This system was designed to provide remote inspection and recovery capability in the event of an accident that would preclude manned entry into a plutonium fabrication facility. This device carries a power manipulator arm and has a TV camera for viewing. The machine is designed with a low height to permit maneuvering under glove boxes, tables, benches, etc., it is sized to fit through standard doors, has the capability to climb stairs, and can be either wireless or cable controlled.

If equipment has not been designed for operation by manipulators, it may be desirable to utilize a man-equivalent system. Several manufacturers produce servo systems which will simulate the motions of a man. At Rocky Flats a two-arm master/slave system was fabricated to replace a man at the glove ports of a glove box in an emergency situation. The manipulator slave arms are positioned remotely and then are operated from a safe location. The master arms are the exoskeleton type and are supported from a pack on the operator's back. The slave arms will follow exactly each movement of the operator's arms.

The man-equivalent manipulator systems are more expensive, less reliable, and have a lower load capability than the power manipulator systems. They do, however, provide the flexibility to perform special functions. All of the FED manipulator systems (bridge mounted, pedestal mounted, or floor mobile) should be designed around the use of power manipulator arms but should have the capability for interchangability with man-equivalent systems.

#### VEHICLE GUIDANCE

The vehicle on which the mobile manipulator is mounted can be either track-mounted or free-roving. Each option has some inherent advantages and disadvantages which should be considered in the design of the mobile manipulator system.

Track-mounted systems are especially applicable to repetitive operations. The motion of the vehicle minimizes the skill and concentration requirements of the operator. It is also possible to attach the vehicle to the rails to react any overturning moments. This will provide stability during seismic events and while lifting heavy, off-set loads. The obvious disadvantage of a track-mounted system is that it is constrained to operate only where the tracks are placed.

A variant of the track-mounted system is the vehicle which follows a wire imbedded in the floor. These vehicles are commercially available and are used in office buildings for unattended mail delivery, etc.

A free-roving vehicle is more versatile than one which is constrained to follow tracks. It permits access to areas where problems were not anticipated. The vehicle can approach a given point from any direction which may permit better positioning of the manipulator for a specific application. It also can provide viewing from different angles.

A free-roving vehicle must have a wide base and/or a low center of gravity to prevent overturning. Alternate approaches would be to design the vehicle with extendable outriggers or to provide attachment points on the floor of the facility.

A free-roving vehicle must have more complex control and viewing systems than a track-mounted system. It is also susceptible to operational problems where the vehicle gets stuck while trying to squeeze past obstruction, falls into floor openings, gets wedged under overhanging structures, etc.

One normally thinks in terms of free-roving vehicles which use wheels or tracks for their motive power. A magnet or suction cup drive concept can permit the vehicle to climb walls and ceilings. Magnet-drive systems have been used to position the ultrasonic inspection heads for the remote inservice inspection of reactor vessels. Suction cup systems have also been used in commercial applications. Although these two drive concepts require special surfaces, they should be considered for future special applications in the FED.

#### VEHICLE CONTROL AND POWER

The power and control input to a track-mounted vehicle is usually a relatively simple process. Options include: bus bars, cable reels, and festooned cables. Since the vehicle motion is constrained by the track system, a special purpose power and control input system can be designed.

A free-roving vehicle will normally utilize an umbilical cable, radio control, or some combination of both.

The use of an umbilical cable requires additional draw bar power to pull the cable but can eliminate the need for batteries in the vehicle. The cable can carry motive power, control signals, TV signals, and power for lighting. The cable creates the potential for hangup. The path should be planned and cable guides and guards provided.

The problems of a long umbilical cable can be eased by the use of parallel cables with strategically located receptables. The vehicle can "leapfrog" from one receptable to another and can pass through doors and air locks.

Radio control is not generally applicable to power transmission so that the vehicle must carry batteries. This requires additional weight and size and limits the vehicle range and/or operating time. A hybrid system using local receptables for power or battery charging might be considered.

Radio signals are quite applicable to control of a power manipulator system and have been used for many years for the remote operation of systems ranging from model airplanes to guided missiles. The technology is well developed. A man-equivalent manipulator system requires a more complex control circuitry and is not readily adaptable to radio control.

The transmission of TV signals requires a wide band width and is usually done with microwaves. Antenna alignment is quite critical and vibration can cause frequency shifts. The techniques used by the television networks to cover news and sporting events should be investigated for applicability.

#### VIEWING SYSTEMS

In general, it is much easier for an operator to operate a vehicle or a manipulator by use of fixed position viewing window, periscopes, or television cameras. The operator is afforded a perspective of the vehicle or manipulator relative to the surroundings and can maneuver the device more easily.

Operation of a free-roving vehicle using an on-board TV camera is particularly difficult because of the "tunnel vision" effect caused by the camera moving with the vehicle. This problem can be alleviated somewhat by placing a pan-tilt-zoom camera on a boom behind the vehicle. In this way, it is possible to scan the area in front of the vehicle and to watch the motion of the vehicle relative to the surroundings.

Vibration of the camera mount due to vehicle motion can also be a serious problem unless proper design is utilized.

It would be useful to have a TV camera on separate prehensile arm. This would permit the viewing of the manipulator operations from a wide range of angles.

#### RECOVERY FROM FAILURES

The design of a mobile manipulator system must provide a method for recovery from failures. In general, this recovery method would entail retrieval of the device and repair in a hot cell.

The retrieval system for a track-mounted vehicle can usually be designed into the facility. Manual overrides can be provided or the umbilical cables can be used to pull a disabled vehicle into a recovery area.

A free-roving vehicle should have multiple redundant systems to minimize the probability of a vehicle failure. In addition, a recovery vehicle should be provided which can retrieve a failed roving vehicle.

#### RECOMMENDED DESIGN APPROACH

The systems engineering approach should be applied to the design of the FED mobile manipulator. The design of the manipulator system should be performed concurrently with and made an integral part of the facility design. The tasks to be performed by the mobile manipulator should be established. The facility equipment should be designed for ease of remote maintenance and the mobile manipulator should be designed to perform the specific tasks. In addition, the manipulator design should include the flexibility to perform routine mechanical functions in order to accomplish unforeseen maintenance tasks.

A mockup facility incorporating a mobile manipulator should be designed and operated early in the program. This will identify potential design and operational problems at an early stage and permit relatively easy redesign to resolve the problems.

**APPENDIX C**

**POWERED MANIPULATORS**

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Based on the requirements defined for the powered manipulators during the workshop, it appears that commercially available systems can be provided which will provide the coverage and handling capacity required for FED remote maintenance. Large bridge mounted and pedestal mounted manipulator systems provided for other nuclear facilities can be modified to meet the special design requirements that will be developed for FED.

**Bridge Mounted Power Manipulator**

A typical system is illustrated in Figures 1 and 2. The system shown has a 108 foot bridge span and incorporates a Model 6000 manipulator which has a handling capacity of 400 pounds. The manipulator is mounted on a set of telescoping tubes which provides a total vertical travel of 30'-9" (25' telescoping tube travel plus 5'-9" of indexing travel). By indexing the tube set relative to the carriage, a larger volume coverage can be obtained. Tube travel can be increased to 50 feet.

The manipulator shown has a maximum reach of 128½ inches from the centerline of the telescoping tubes and has nine degrees of freedom. The Model 6000 manipulator is remotely removable at the interface between the shoulder pivot and shoulder rotate interface. A man-equivalent servo manipulator could be interchanged with the arm shown.

Located above the pivot boom rotate is a TV camera positioner which provides  $360^{\circ}$  of rotation and pivot motion from horizontal  $+75^{\circ}$ ,  $- 90^{\circ}$ . Camera positioning is independent of manipulator position.

A 5000 pound load hook is located on the centerline of boom rotate and can be used to handle and accurately position large fixtures and tools. Electrical and air tool power is located on the boom pivot housing.

The carriage, telescoping tubes, and manipulator can be remotely removed from the bridge as an assembly for maintenance with the facility bridge crane.

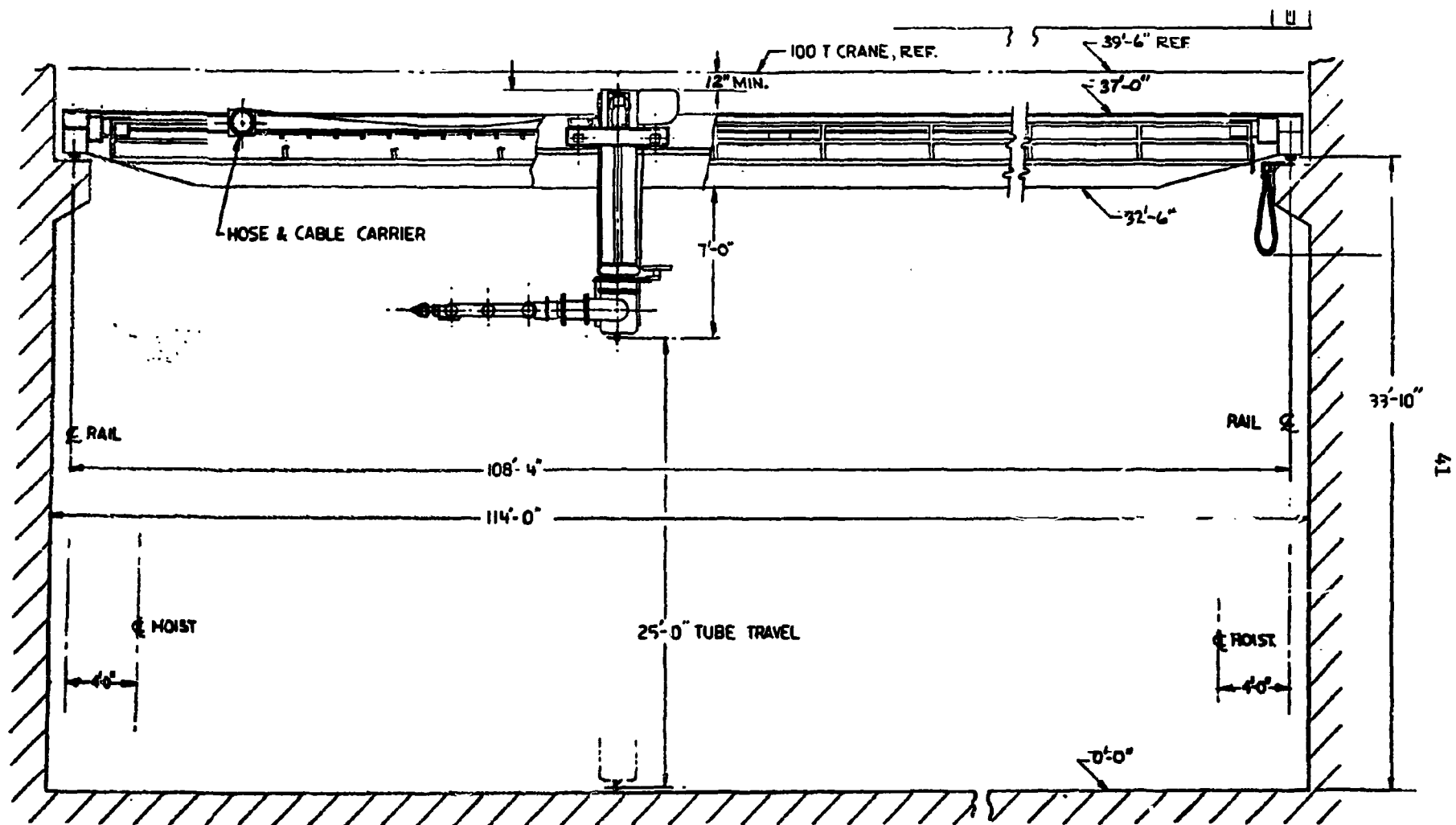
The control system provides variable speed control on all motions. Digital co-ordinate position readouts are provided for bridge, carriage, and telescoping tube travels. Semi-automatic position control and three dimensional obstacle avoidance are provided to assist the operator in positioning the manipulator at a specified work station.

#### Pedestal Mounted Manipulator

A typical system is shown in Figure 3. The system provides cylindrical remote handling coverage or approximately 28 feet in diameter by 50 feet high. The complete system can be remotely plugged into fixed base locations using the facility bridge crane.

The Model 6000 Manipulator arm is interchangeable with the arm shown on the bridge mounted system. A man equivalent servo-manipulator could be interchanged with the powered manipulator.

Motion specifications for the system are shown on Figure 3.



ELEVATION SECTION THRU TEST CELL

Figure 1 - Bridge Mounted Manipulator System

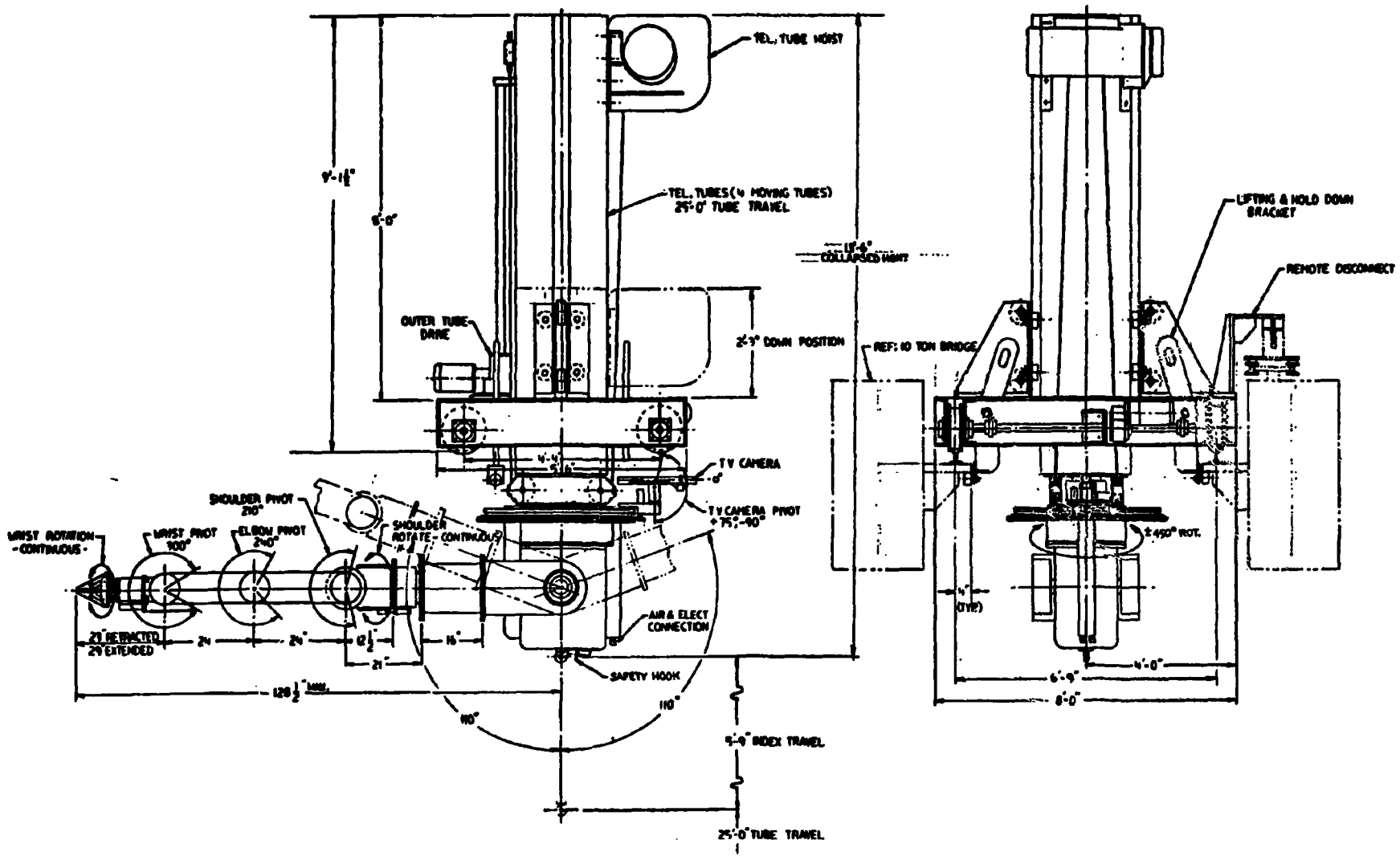


Figure 2 - Bridge Mounted Manipulator Carriage

**SYSTEM SPECIFICATIONS:**

**MANIPULATOR - LOAD CAPACITY - 200 LBS.**

• Base Swings	8 In.
• Force	0-200 Lbs.
• Velocity	35 In./Min.
• Base Swings	3 In.
• Force	0-2500 Lbs.
• Velocity	6 In./Min.
• Wrist Rotate Travel	Cont.
• Torque	700 In.-Lbs.
• Velocity	.7 to 2.0 RPM
• Wrist Extension Travel	6 In.
• Force	600 Lbs.
• Velocity	2.0 to 20 In./Min.
• Wrist Pivot Travel	200°
• Velocity	0.1 to 1.0 RPM
• Elbow Pivot Travel	240°
• Velocity	0.1 to 1.0 RPM
• Shoulder Pivot Travel	210°
• Velocity	0.1 to 1.0 RPM
• Rotate Travel	Cont.
• Torque	40,000 In.-Lbs.
• Velocity	0.1 to 1.0 RPM
• Max Load Rating	1,000 Lbs.
• Turret Rotate	360° Rev.
• Travel	0.00 to 0.35 RPM
• Velocity	
• Rev. Torque	25,000 In.-Lbs.
• Vertical Column	0.5 to 5.0 RPM
• Velocity	
• Capacity	5,000 Lbs.
• Base Pivot	200°
• Travel	
• Velocity	.00 to .25 RPM
• Torque	150,000 In.-Lbs.

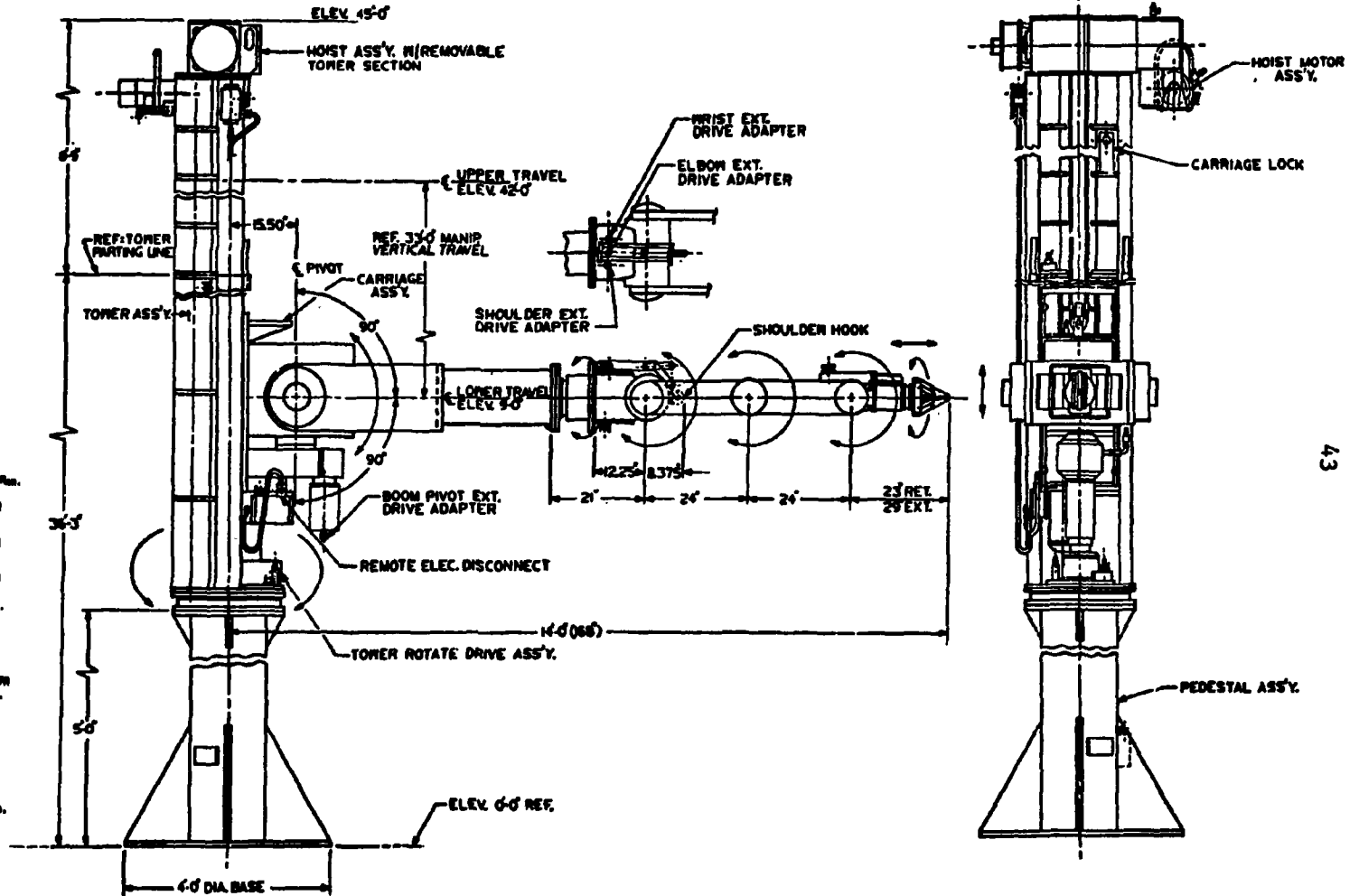


Figure 3 - Pedestal Mounted Manipulator System

**APPENDIX D**

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## MANIPULATOR TRANSPORTER AND PLANT CONFIGURATION

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The maintenance approach described in Section 4.5 of the July 1980 ETF Interim Design Description Document is well-written and consistent with the maintenance approach used at many other nuclear reactors and hot cell facilities. Basically, it states that radioactive components, such as the torus sectors, cyropump, injectors, etc. will be shielded to permit personnel entry and hands-on work within the reactor building after the shutdown decay period (estimated at 24 hours). It encourages the use of equipment modularization which will permit a high failure component assembly to be replaced without removing the large unit to which the assembly is attached. Further, it requires that all radioactive items be capable of replacement using remote means in case hands-on work is precluded.

The problem with applying this philosophy to the FED is that the FED does not have the same basic configuration features as either a fission reactor or a hot cell. The FED design is actually equivalent to a hot cell over a reactor and the maintenance approach should be more in this direction. The following discussion describes some specific features that would help provide the FED with a sound maintenance basis at minimal cost.

#### Plant Configuration

The current configuration will result in numerous operational problems and excessively high construction costs. It requires a very large vertical shield door, which must also be gastight, in the reactor containment/shield wall through which equipment is transferred. Highly radioactive items such as the torus sectors will have to be placed into shielded containers to be moved from the reactor building into the hot cells. This will result in the need for a set of different sized shielded

containers to service the FED. The transfer of these items is through an occupied area with no air-lock to the reactor building. It can be expected that tritium and particulate will migrate into personnel areas. The use of many small hot cells, each dedicated to a specific task, will be extremely expensive. Each cell requires dedicated handling, manipulation, viewing, storage, ventilation, and transfer lock equipment all of which are specialized designs.

An alternate plant configuration is shown on the attached sketches, Figures 1, 2 and 3. In this concept, the vertical reactor building shield and containment wall is penetrated only by a personnel air-lock. High radiation equipment, such as a torus sector, is remotely lowered into the shielded transfer cell. After the torus hole is remotely filled with either a new sector or a shield plug, people can re-enter the reactor building. The removed equipment can be remotely transferred into a large component cell for decontamination, storage, rework, or cutup for disposal. Shielded windows and mechanical M/S manipulators will be of little value in the large cell because of the size of equipment to be serviced. However, the small component cell should use this type of equipment.

New replacement equipment would be transferred into the reactor building through the shielded transfer cell which serves as an air-lock. It should be noted that large shielded openings are far less expensive in horizontal surfaces because existing cranes can lift out shield plugs and no large capacity drive systems are needed.

A major concern in the FED has to be recovery from failure of the remote handling systems. For example, if a torus sector is being transferred remotely within the reactor building and the bridge or trolley drive fails, there has to be a way to recover without personnel entry into the reactor building. The two trolleys shown on Figure 3 will help in this regard.

#### Reactor Maintenance

Work on the reactor components will include disconnecting modules, reconnecting modules, performing inspections, welding, etc. Equipment should be provided to help people do hands-on work quickly. This will

decrease exposure time as well as plant downtime. One approach would be to provide a mobile transporter system with a fully equipped work platform as shown on Figure 4. A hoist is also needed on the platform and should be capable of lifting components weighing up to 2 tons.

This same transporter can be used for positioning manipulators and performing work remotely as shown on Figure 5. The transporter may require more complex motions than are indicated in the sketches in order to reach into all maintenance areas.

#### Sector Removal

One of the most difficult tasks will be removing torus sectors. An inexpensive approach is shown on Figure 6. Basically it includes hands-on or M/S disconnection of the sector. The sector removal and replacement, or insertion of a shield plug would all have to be done remotely using the reactor building shield walls as a hot cell. A precision rail or guide system is needed for the final positioning of the sector within the torus. Outside of this position a more crude guide rail can be used.

The air bearing pad approach has a cost advantage over mechanical wheels and rails. A mechanical device to lift the sector enough to free it from the torus would be quite complex and expensive.

The tow machine shown on Figure 6 can be used to pull sectors and other equipment out from under the cryostat containment. The building crane can then be used to move the unit out of the reactor building. The electric M/S's can assist in remotely coupling the crane hook to the unit.

#### Injector Removal

The removal of injectors, launchers, and divertors is complicated because they extend under the cryostat containment. One low-cost approach, utilizing the tow vehicle and removeable rails is shown on Figure 7. It is expected that steps 2 through 4 of this operation must be remote with the reactor building evacuated.

#### Instrument Inserts

Standardized designs and maintenance approaches should be established for instruments and other equipment that are inserted into the beam area.

Figure 8 illustrates the kind of approach now used in reactors and hot cells. It is as complex and time-consuming as it looks. The FED has an advantage in that the reactor building can serve as a hot-cell. Hence the removal of these inserts can be more readily accomplished using a technique such as shown on Figure 9.

#### FED Remote Maintenance Equipment

The primary remote maintenance equipment needed within the reactor containment building include the following:

- 200 ton bridge trolley
- 50 ton bridge trolley
- Two floor transporters with man work platform and manipulator attachments
- Two tow vehicles (one spare)
- Air bearing pads
- Removeable rail sections (for injectors, etc.)
- Misc. tools (impact wrenches, cable slings, power tools, welders, leak detection, cutters, etc.)
- Equipment for remote recovery from failure of handling systems

#### Existing Manipulator Technology

These are commercially available power-manipulators (non-force reflecting) and electric M/S manipulators (with force reflection) that could be used to perform the FED remote maintenance work. It is essential that FED make an early selection as to which type will be used since the design of FED equipment will be affected by the choice. The best approach is to use both types. The electric M/S manipulators should be the primary system because they can do work faster and are more similar to the configuration of a man. This will result in less equipment design compromises for remote maintenance. If more advanced manipulator systems are developed they can easily be installed into the FED and will certainly improve the situation.

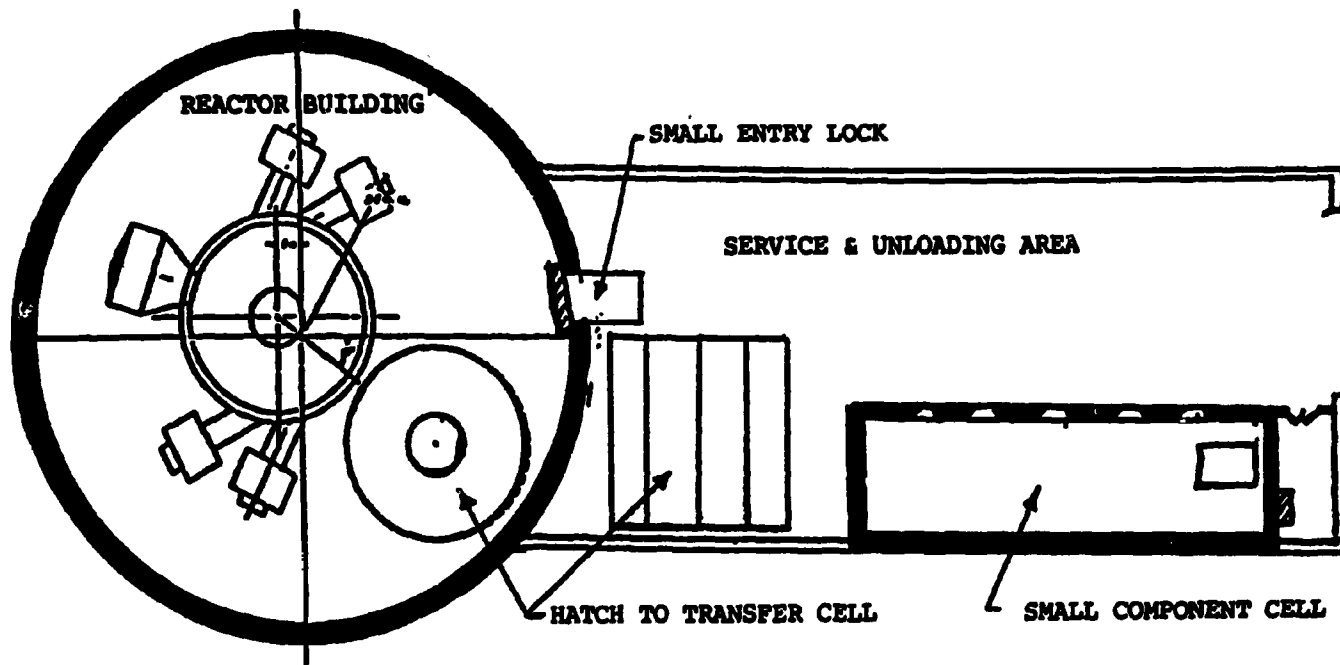


Fig. 1. Alternate reactor/cell arrangement, grade level.

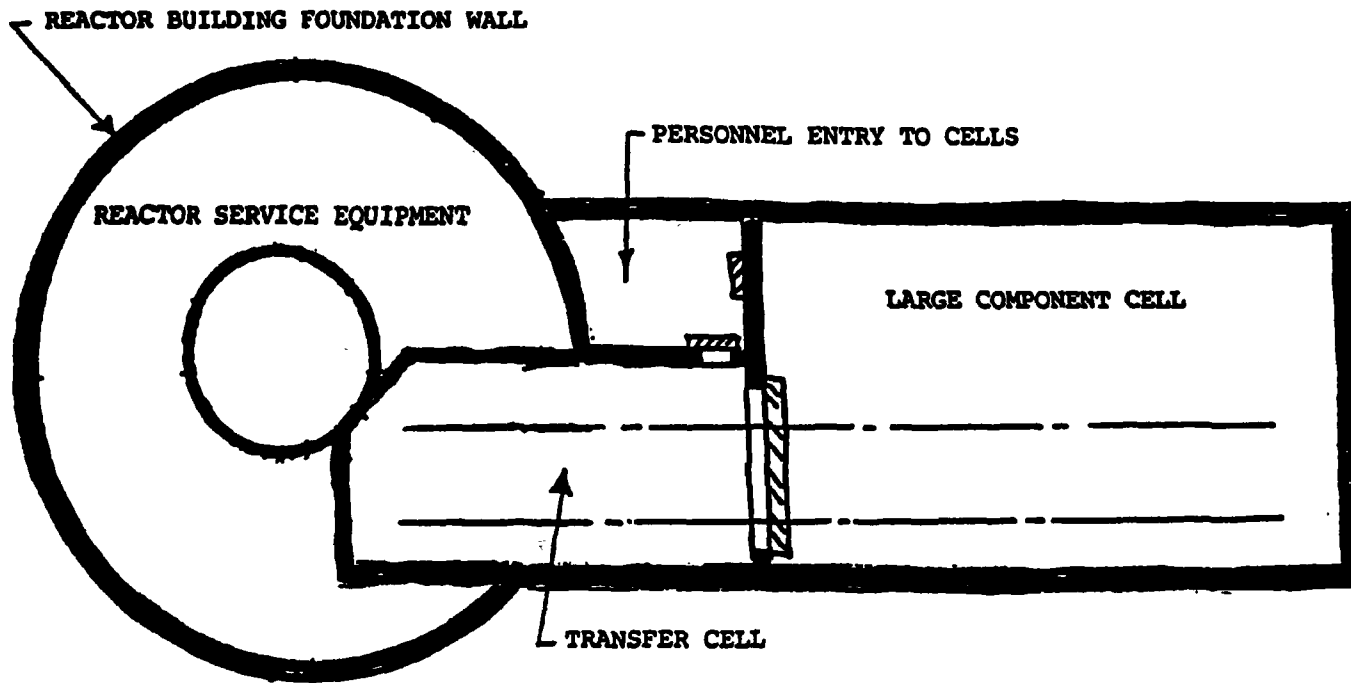


Fig. 2. Alternate reactor/cell arrangement, lower level.

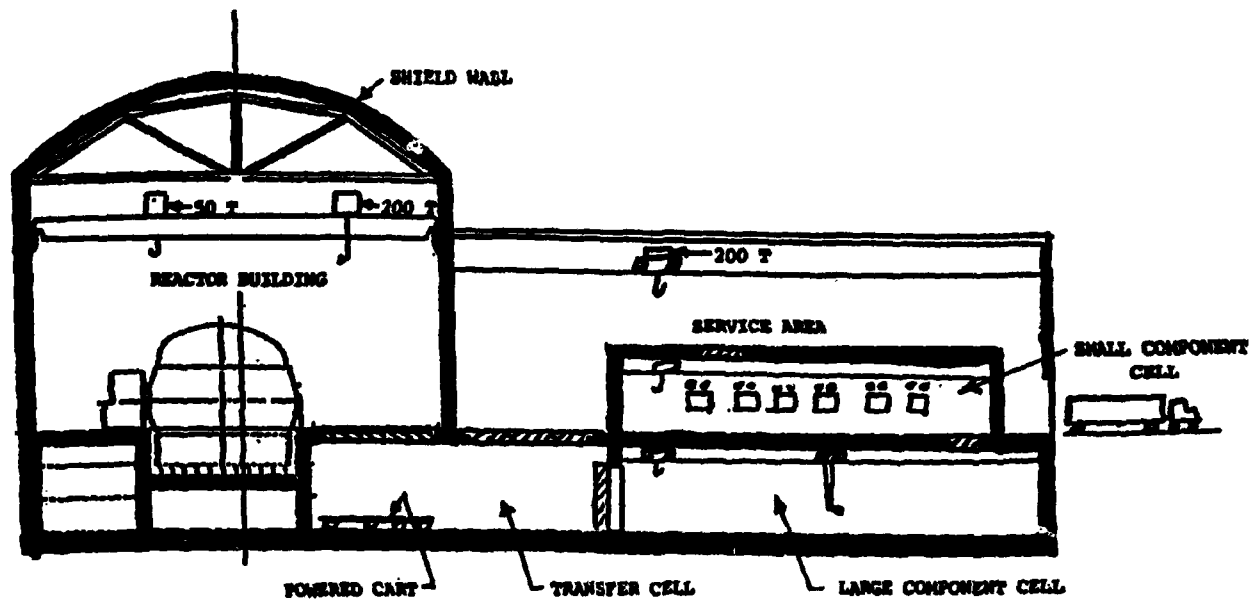


Fig. 3. Alternate reactor/cell arrangement, elevation view.

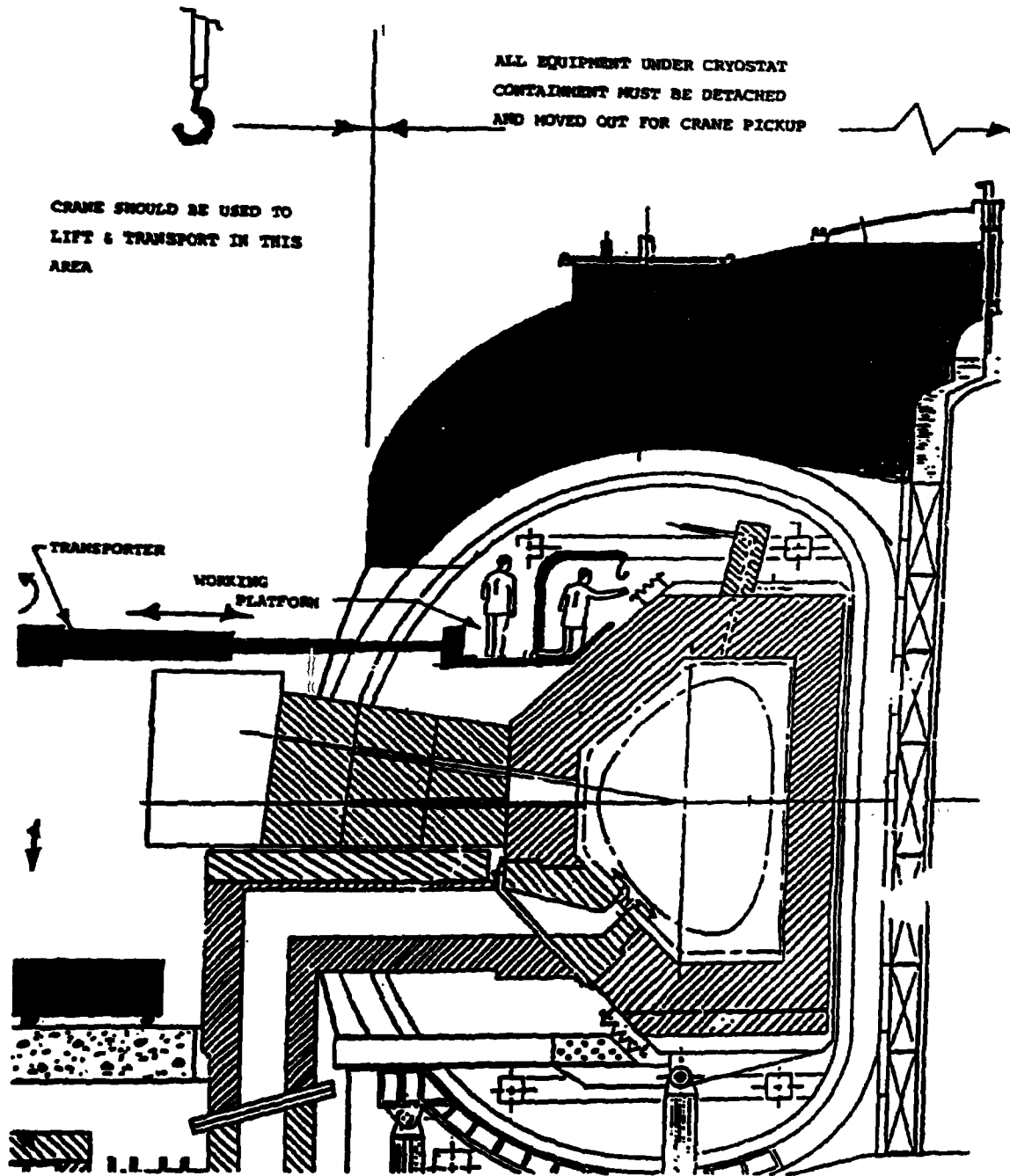


Fig. 4. Hands-on work under cryostat containment.

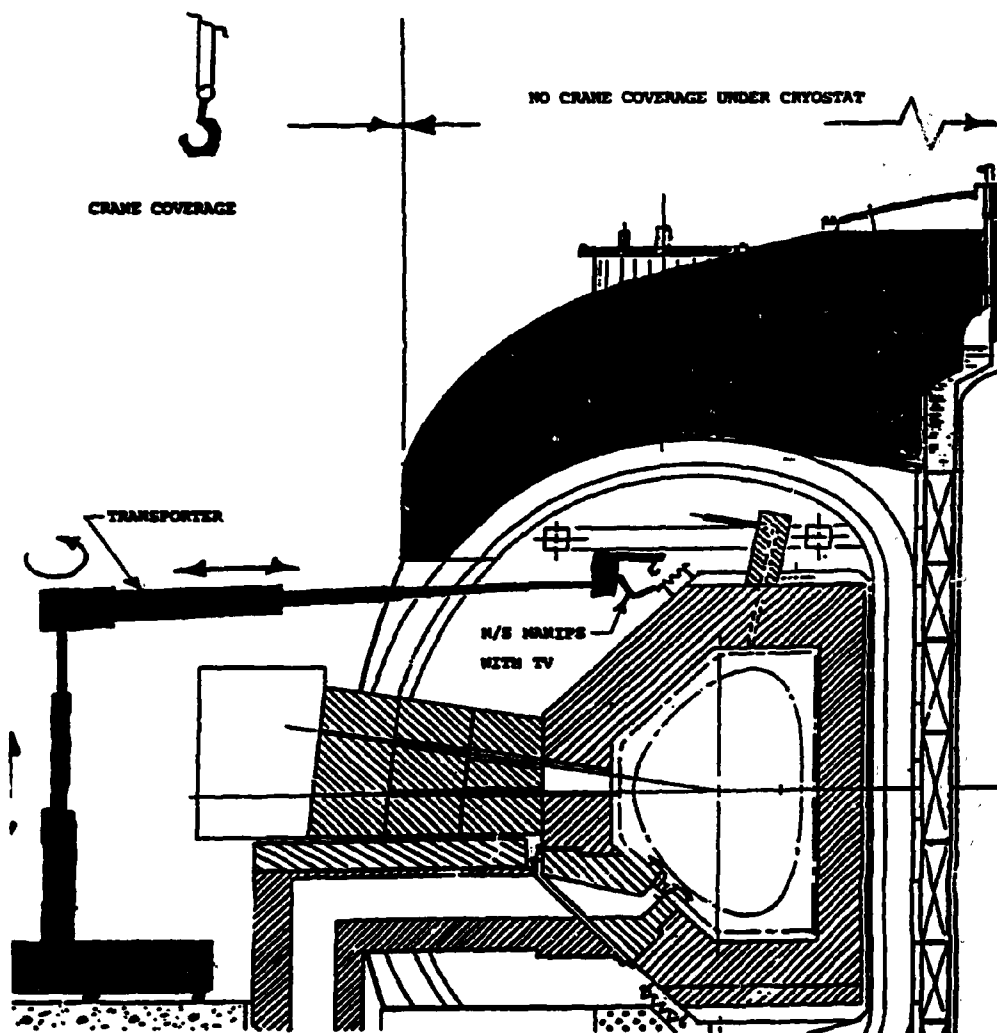
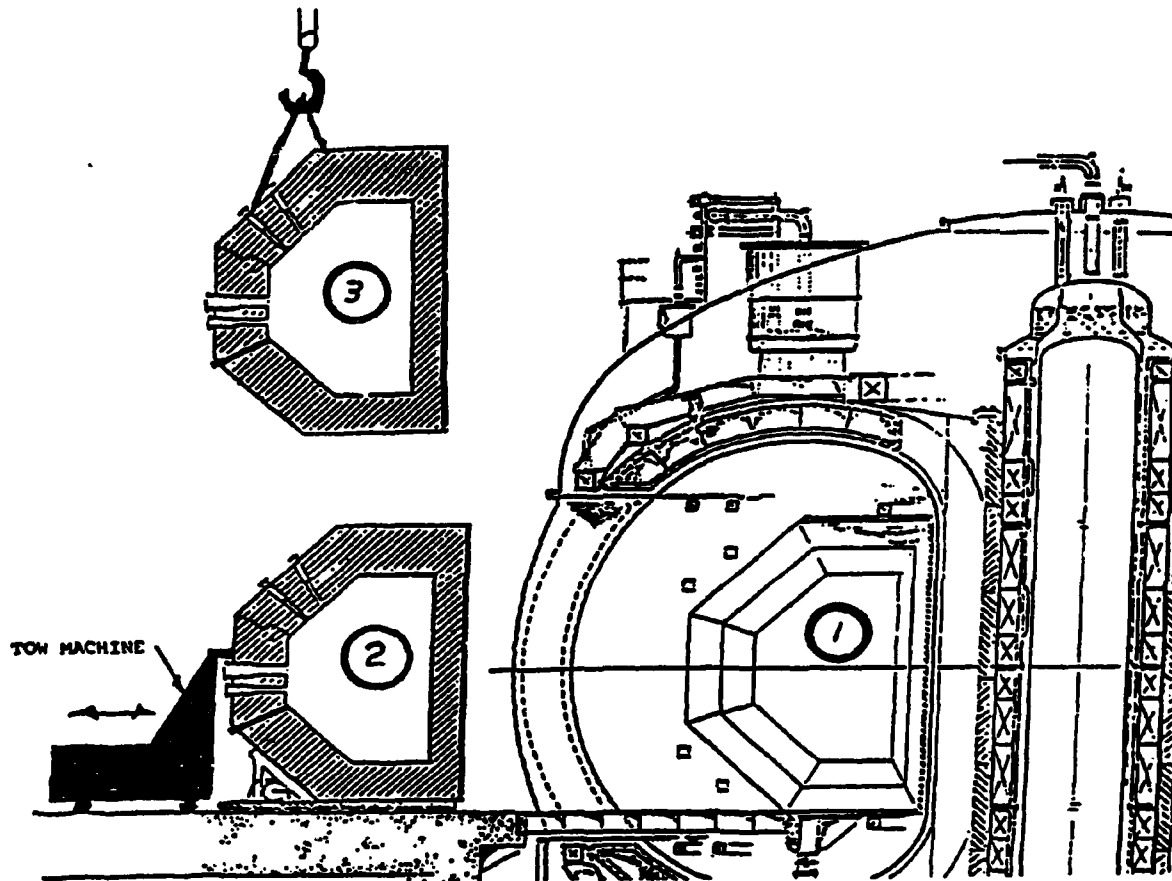


Fig. 5. Remote work using electric M/S's under cryostat containment.



1. Disconnect utilities and sector vacuum seal. Insert airbearing - connect tow machine.
2. Evacuate reactor building - Pull sector outside of cryostat containment remotely.
3. Remove sector from airbearing with reactor building crane and place into shielded transfer cell remotely.
4. Insert new sector or shield plug remotely, then enter reactor building.

Fig. 6. Sector removal.

1. Detatch utilities & vacuum seal.  
Install support & tow machine.
2. Evacuate building & tow injector to  
lift position.
3. Transfer unit to shielded transfer  
cell remotely.
4. Install new unit or shield  
plug remotely. Then enter  
building.

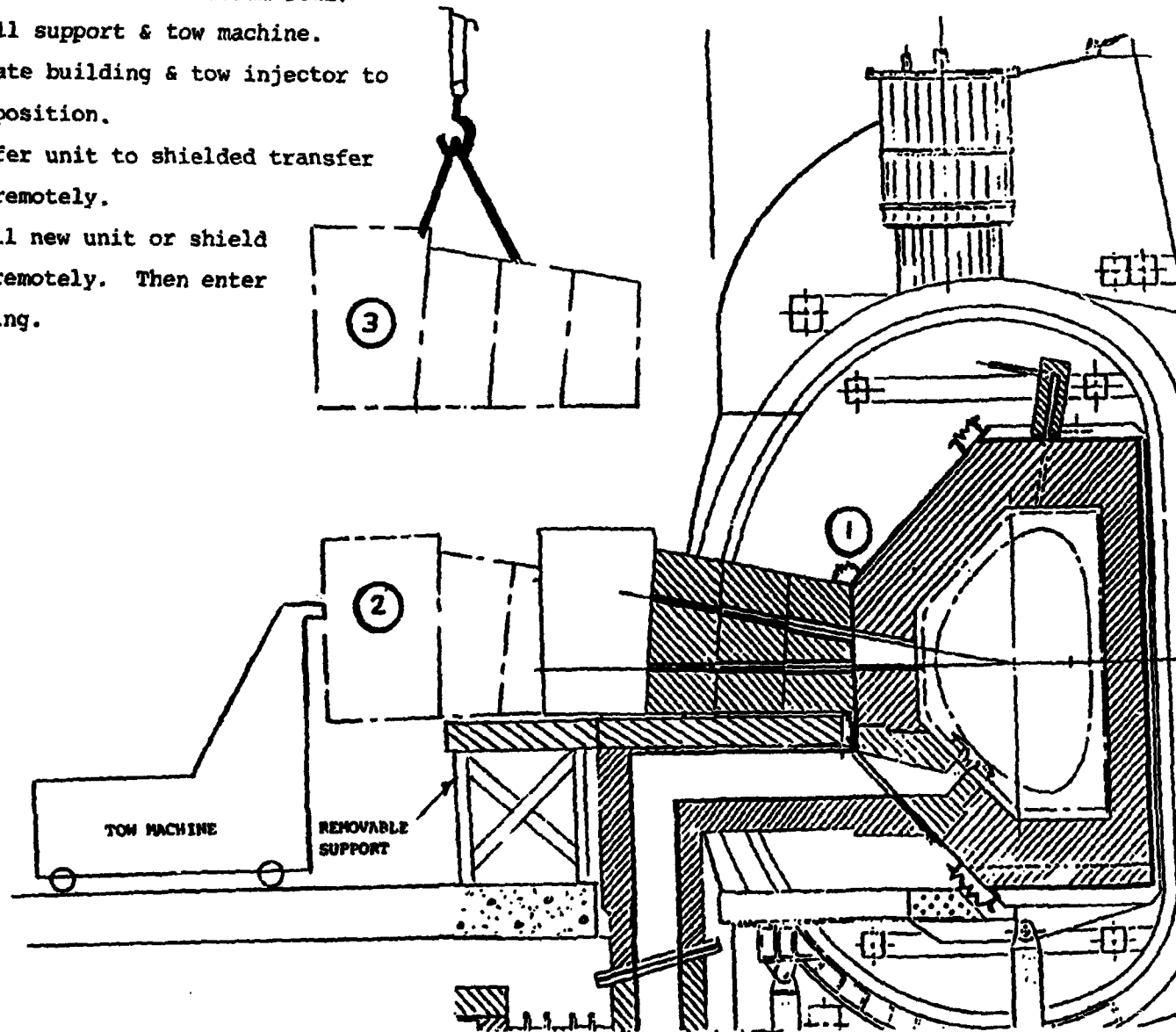


Fig. 7. Injector removal.

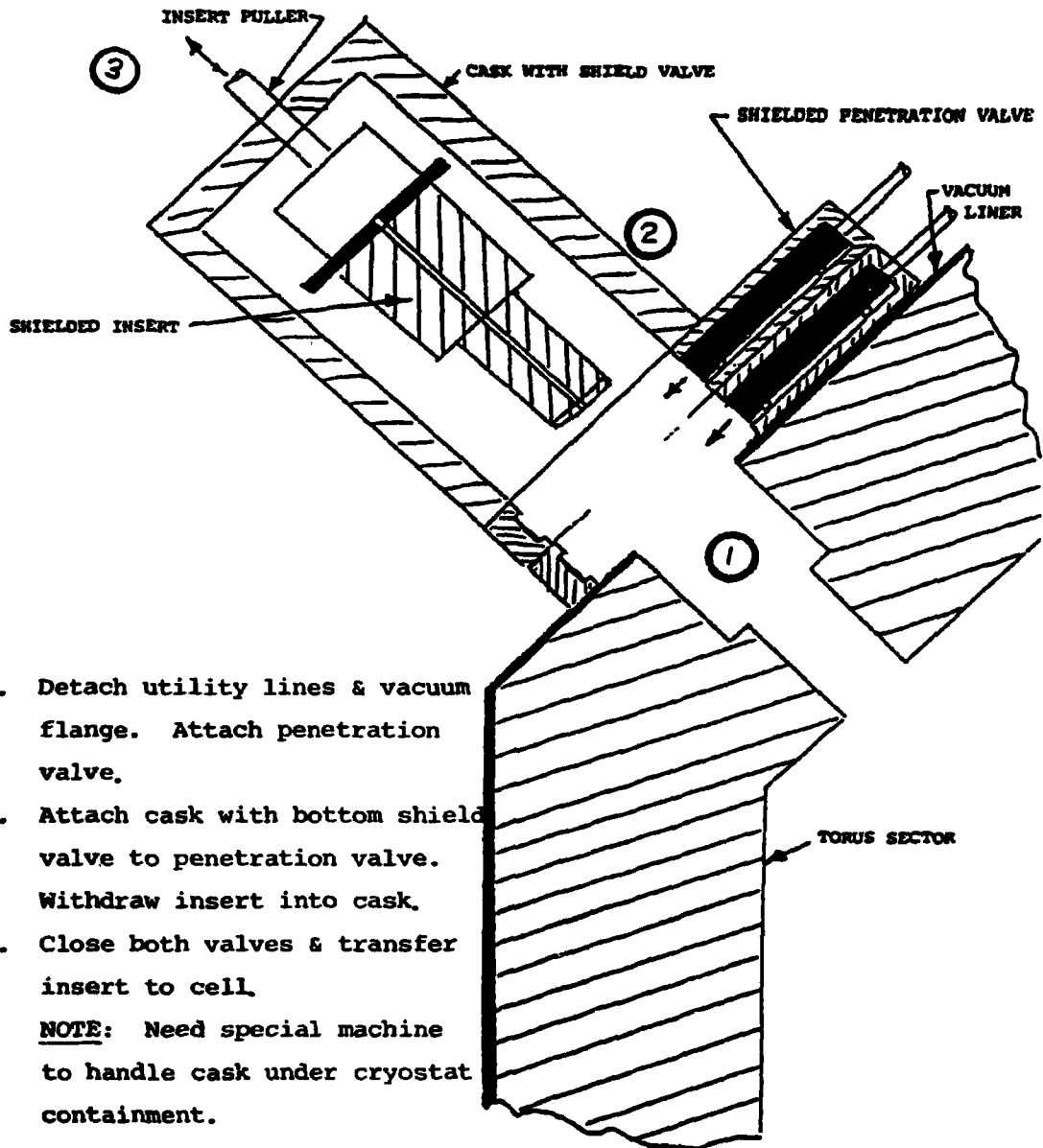
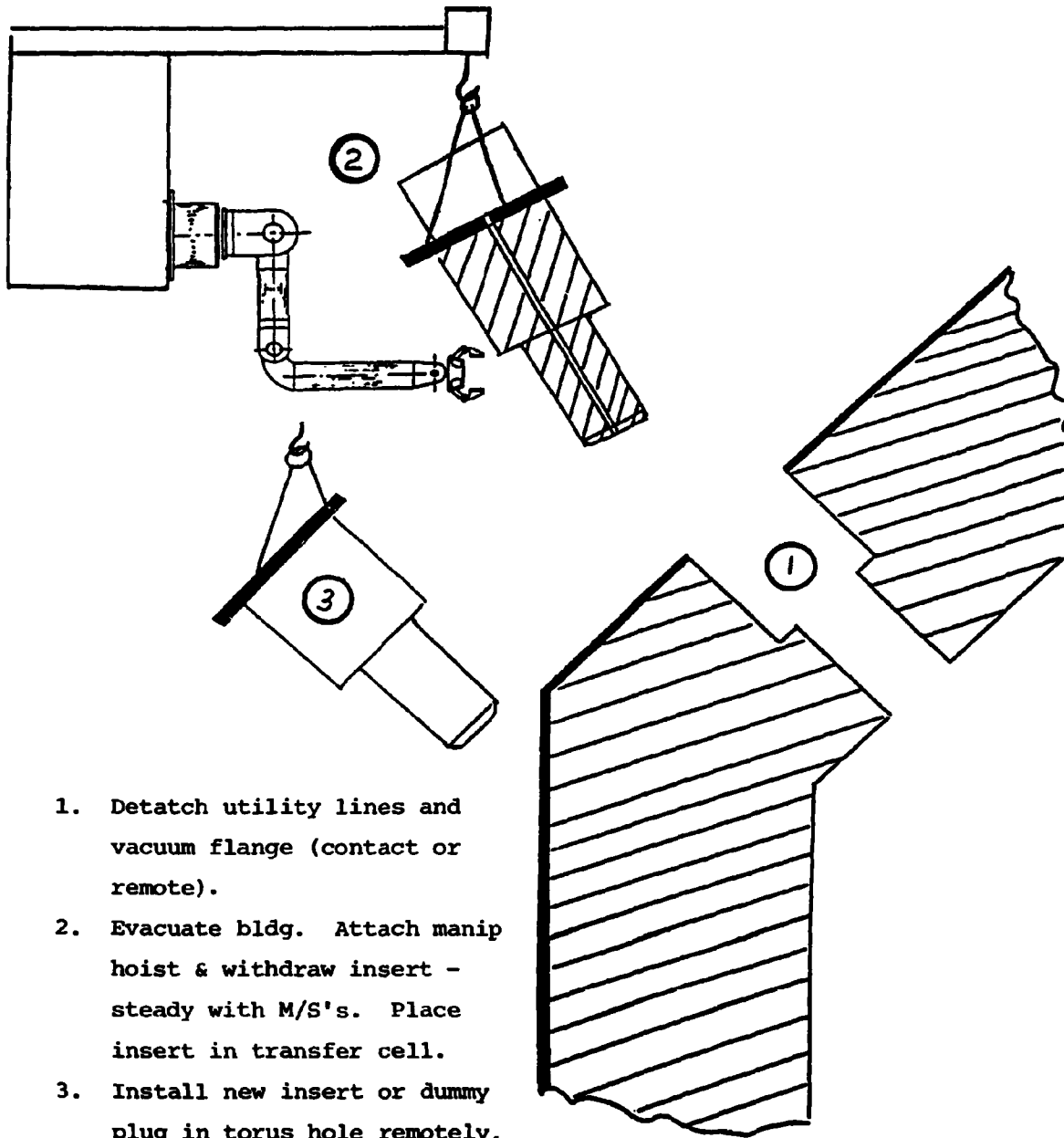


Fig. 8. Contact removal of insert.



1. Detatch utility lines and vacuum flange (contact or remote).
2. Evacuate bldg. Attach manip hoist & withdraw insert - steady with M/S's. Place insert in transfer cell.
3. Install new insert or dummy plug in torus hole remotely. Re-enter bldg.

Fig. 9. Removal of instrument inserts.

**APPENDIX E**

**REMOTE BRIDGE CRANE CONCEPT  
AND OUTLINE SPECIFICATIONS**

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UCC-ND Engineering, ORNL**

At least two remotely maintained 500T/25T bridge cranes are required in the FED. Lift ranges and spans are not defined at this time. Cranes are class D (heavy duty) service classification covered by CMAA Specification No. 70, "Specification for Electric Overhead Traveling Cranes."

Figure 1 shows the general bridge crane arrangement.

Cranes are designed for:

- (a) Interchangeability of parts and ease of maintenance.
- (b) Safe handling of critical loads. Hoist systems are designed single-failure-proof; the system is so designed that a single failure will not result in the loss of the capability of the system to safely retain the load.
- (c) Recovery from failure. Examples of recovery features are:
  - (1) Dual drive provisions for the main hoist, auxiliary hoist, trolley drive, and bridge drive. Single failure of any element of a dual-drive system will still permit the system to function at a reduced speed.
  - (2) Towing latch functions will allow a disabled bridge to be towed to an area where repair procedures may be initiated.
  - (3) Dual bus bar supply will allow a bridge to circumvent a faulty bus.
  - (4) Hoist reducers are equipped with external mating splines. A disabled hoist may be driven by engaging splines on the adjacent buddy bridge trolley to raise/lower a load at reduced speeds.

Features of the bridge system:

- o The bridge structure comprises two box section girders bolted to two box section end trucks.
- o All structure is painted, carbon structural steel.
- o Right angle wheel bearing housings are utilized for ease of removal of axle assemblies.
- o Two wheels are driven, one wheel at each end of the bridge. Each drive unit consists of a dc shunt-wound motor with dynamic braking, vertical!

mounted on a right-angle shaft gear reducer, which drives a pinion and gear on the bridge wheel. The motor has a C flanged mount, splined shaft, and electrical connector, for ease of removal.

- o The gear reducer and pinion are removable as one assembly. The gear reducer has a vertical flange mounting to the bridge with four conical head bolts and two tapered guide pins. Replacement units are jig-drilled to ensure wheel gear and pinion alignment when assembled.

- o Seismic restraints are provided on the end trucks. These restraints are retractable to permit bridge removal.

- o Emergency rollers are provided adjacent to each wheel. The function of these rollers is to support an end truck and permit bridge movement in the event of failure of a bridge axle bearing.

- o Spring bumpers are provided at each end of the bridge to limit trolley travel.

The trolley system features:

- o The trolley structure is fabricated from box section members to provide maximum strength and rigidity.

- o All structure is painted, carbon structural steel.

- o Right-angle wheel bearing housings are utilized for ease of removal of axle assemblies.

- o Two wheels on one side of the trolley are driven. The dual drive system is designed to allow one drive unit to drive the trolley in the event of failure of the other drive unit.

- o Each drive unit consists of a dc shunt-wound motor with dynamic braking, vertically mounted on a right-angle shaft gear reducer, which drives a pinion and gear on the trolley wheel.

- o The motor has a C flange mount, adapter, splind shaft, remote electrical connector, and lifting bail.

- o The gear reducer and pinion are removable as one assembly. The gear reducer is mounted and aligned in a similar manner to the bridge drive gear reducer.

- o Retractable seismic restraints are provided on the trolley.

- o Emergency rollers are provided adjacent to each wheel.

- o Lifting bars and trunnions are provided at the four corners of the trolley structure.

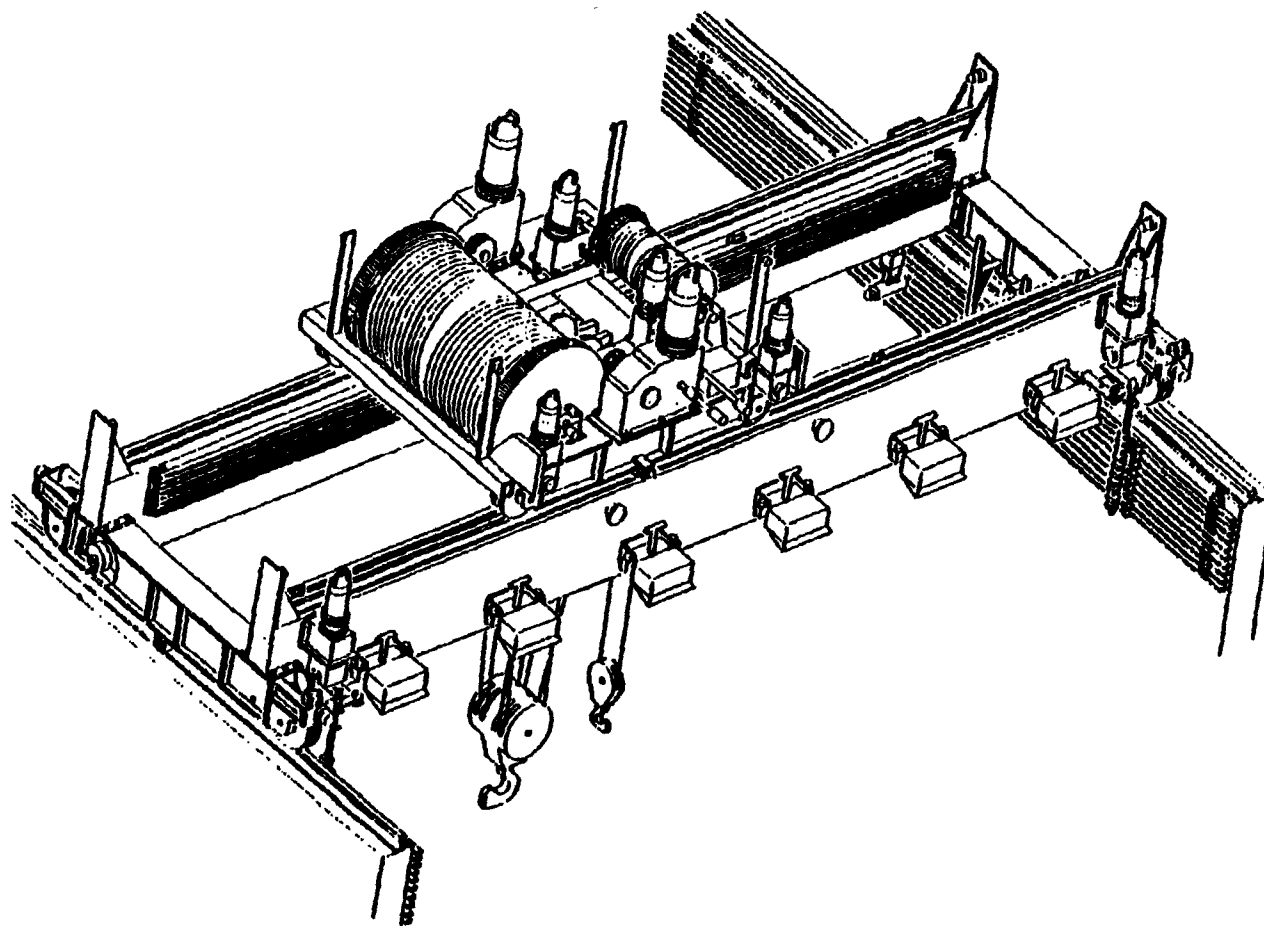


Fig. 1. Bridge crane.

**APPENDIX F**

**STEREO TELEVISION VIEWING SYSTEM****ORLEN RICE****Honeywell Ceramics Center****5121 Winnetka Avenue N.****New Hope, Minnesota 55428****INTRODUCTION**

We are all aware of the fact that we are able to perceive depth because our eyes are separated horizontally and each eye sees a slightly different view of objects in the field of vision. The brain notes the difference in the views perceived by each eye and interprets this difference as depth.

It follows from this, that in order to present a representative three dimensional image on the face of a flat CRT, it is necessary to provide two images which have been obtained from slightly different vantage points.

**SYSTEM CONFIGURATIONS**

Several different dual image systems have been devised for three dimensional television. All employ two cameras or one camera and a beam splitter, to provide two displayed images. Viewing has been accomplished in several different ways. One approach is to directly observe two adjacent monitors using binocular optics. Another provides a way to view two monitors using a half silvered mirror and a pair of passive, polarized glasses.

These dual monitor systems offer certain advantages but do require the viewer to hold his head on the center line separating the two monitors. These systems also do not lend themselves to video taping and a requirement for color complicates the dual monitor.

**SYSTEM USING STANDARD TV**

With the development of a fast acting, solid state optical shutter, another three dimensional television viewing system has been devised which is compatible with standard cameras, monitors and tape decks. This system makes use of the fact that broadcast and closed circuit television employs interlaced vertical scanning.

The nominal scanning rate for U. S. television is 15750 horizontal scans per second and 60 vertical scans per second. Each vertical scan, called a field, consists of  $262\frac{1}{2}$  horizontal scans (not all are visible). Figure 1 shows field 1 starting at the upper left hand corner of the screen and exiting at the lower center. Field two starts at the upper center and exits at the lower right corner and is interlaced between the horizontal lines of field 1. The presence of these interlaced fields, normally obtained from a single camera, lends itself to a straightforward three dimensional viewing system.

Referring to Figure 2, two synchronized cameras are separated horizontally and are angularly displaced to both view the same scene. The composite video signals are connected to a control box which extracts field 1 from the left camera and field 2 from the right camera. The control box combines these fields from the two cameras into a new composite video signal and feeds this to the monitor, thus presenting a dual image to the naked eye. A viewing hood is connected to the control box and is worn by the observer. The viewing hood contains optical shutters which are switched in synchronization with the field rate. The switching is such that the left eye sees only those fields from the left camera and the right eye sees only those fields from the right camera. The brain combines these angularly displaced views into a single three dimensional presentation.

This system uses standard, unmodified cameras and monitors and the video information can be recorded using any commercially available video tape deck or disc recorder. Either black and white or color equipment can be utilized. Also, if the situation so dictated, the three dimensional video information can be transmitted like any standard TV signal.

Figure 3 depicts the geometry of the 3-D image in relationship to the screen of the TV monitor.

#### ELECTRONIC SHUTTERS

The key to the operation of this 3-D TV viewing system is a transparent ceramic material - lanthanum-doped lead zirconate-titanate (PLZT). When electroded and placed between crossed polarizers this material can function as an optical switch. In Figure 4, unpolarized

light passes through a polarizer which transmits only that light in the  $45^{\circ}$  plane. With no voltage applied to the electroded PLZT this light, made up of components B and C, passes through unaffected as vector A, and is blocked by the  $135^{\circ}$  analyzer.

Applying a voltage to the PLZT has the effect of reversing the C component of the light to position -C. The resultant light is represented by vector D which will now pass through the analyzer. The speed of this switching action is dependent upon the PLZT material composition, thickness, and electrode configuration. In general, a switching speed of 100  $\mu$  sec is easily obtained.

#### SUMMARY

A stereo television viewing system has been assembled which is compatible with standard video equipment. Operators, wearing a PLZT viewing helmet, are able to move about in front of the monitor and still retain a three dimensional presentation.

# INTERLACED T.V. FIELD RELATIONSHIPS

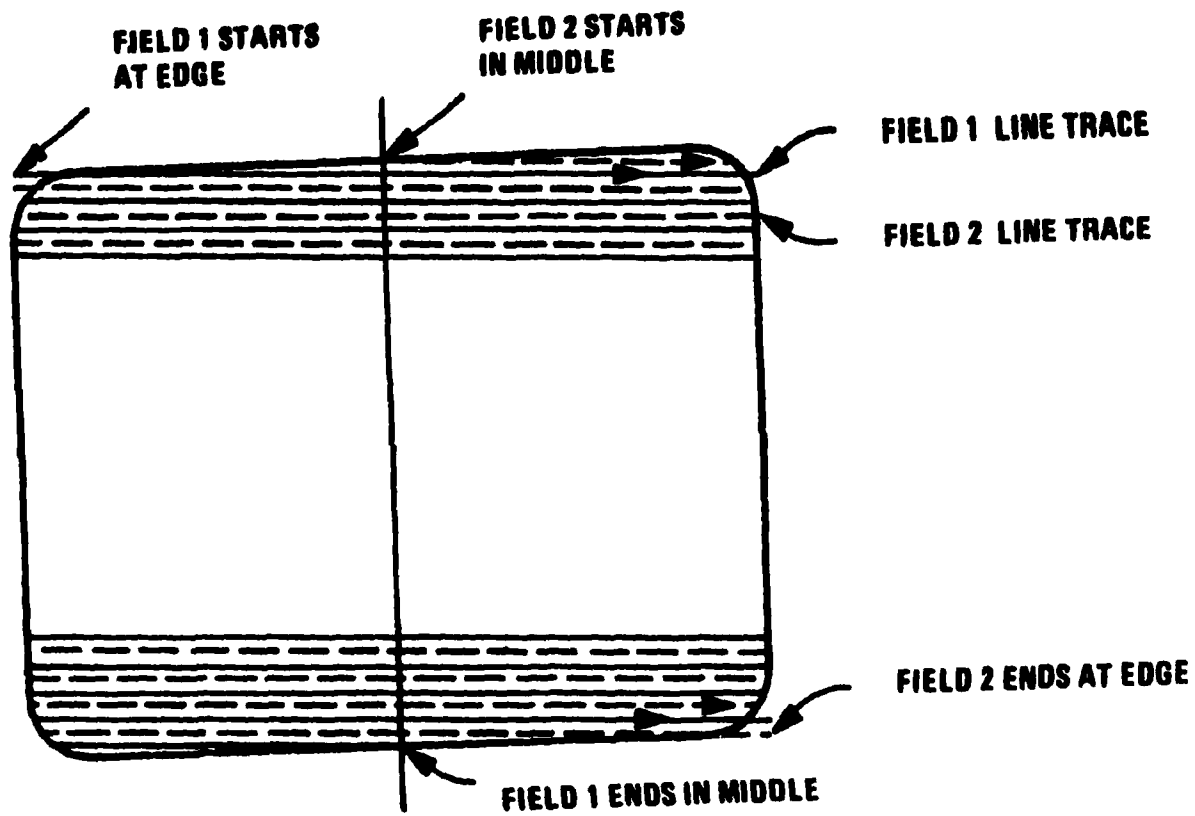
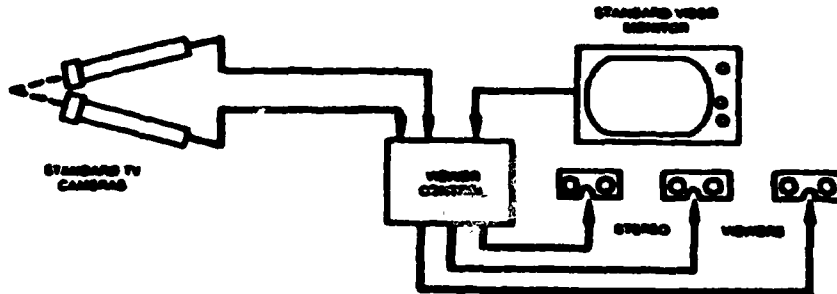


Fig. 1

# STEREO TV



The Stereo Television Viewing System consists of three viewing hoods and a control box. The control box takes the video signals from two angularly displaced cameras and, with synchronized signals, plays them on alternate fields of the television monitor, presenting a dual image to the naked eye. The stereo viewing hood, employing transparent ceramics as optical shutters, alternates the signal so that the left eye sees only what the left camera sees and the right eye sees only what the right camera sees. The brain then fuses the two angularly displaced views into a single three-dimensional presentation.

Fig. 2

## GEOMETRY OF 3-D IMAGE FORMATION

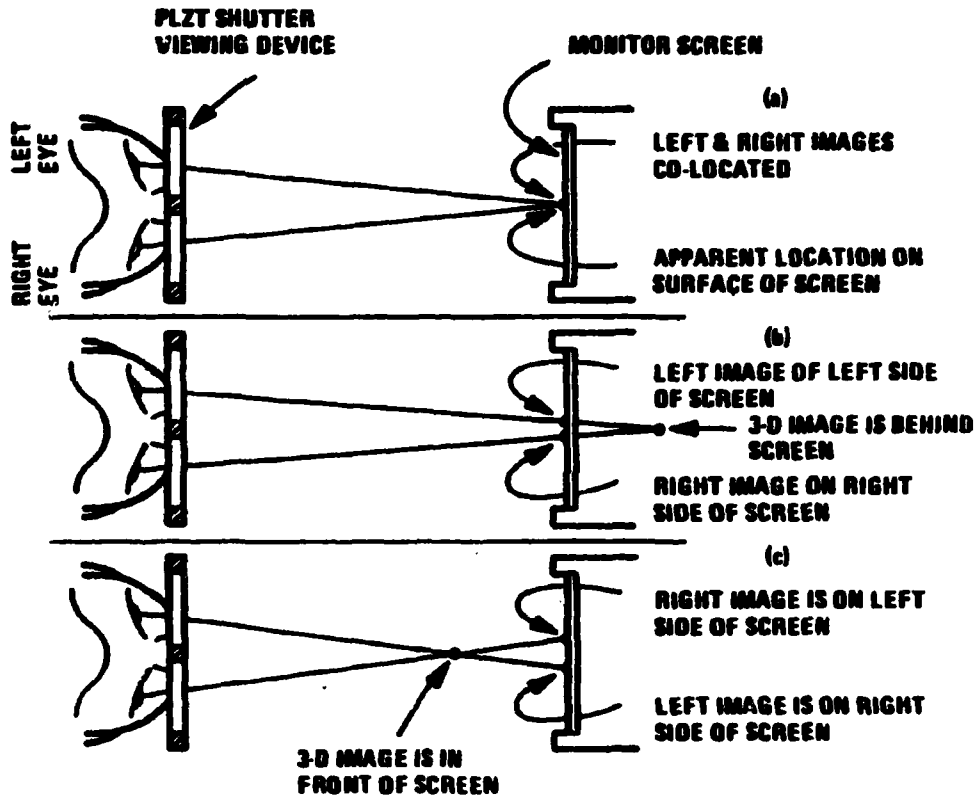


Fig. 3

## PLZT-TRANSVERSE ELECTROOPTIC MODE

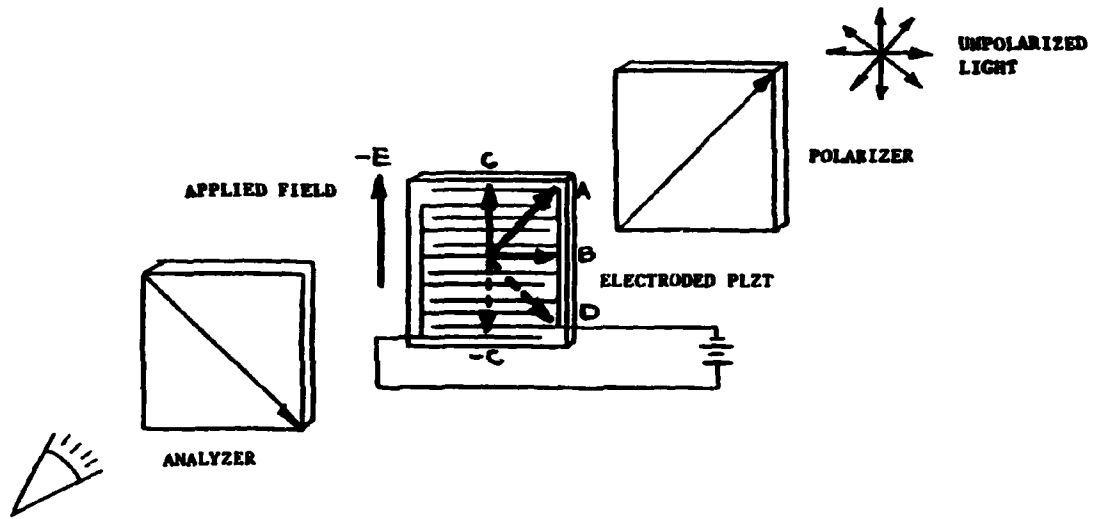


Fig. 4

**APPENDIX G**

**MANUAL/REMOTE DECONTAMINATION SYSTEM**

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**DECONTAMINATION**

A critical operation in the overall FED reactor maintenance program is the decontamination of the reactor components removed from the reactor. Localized predisassembly and postdisassembly decontamination operations will lower the exposure to radiation and prevent the spread of contaminated particulate matter as the component is removed from the reactor area for maintenance.

A vital consideration in overall reactor design is that the surfaces of the reactor building and reactor components are smooth and readily deconable with a high-pressure, low-volume decon fluid. The decon effluent should be locally reprocessed by equipment installed in facility systems, or by equipment in portable systems\* that could service other areas of the reactor building requiring decontamination.

The fluid recommended for general decon operations is a product known commercially as Valclene. It is known chemically as trichlorotrifluorethane or Freon 113. Table 1 lists the Freon 113 fluid specifications, advantages, and disadvantages for use as a decontamination fluid.

**Manual/Remote Decontamination Modes**

The FED reactor components external to the radiation shield can be decontaminated by personnel in appropriate anticontamination clothing and breathing apparatus. The decon system would involve an open loop system, where the decon fluid is pumped from the recovery process unit under high pressure (2200 psig) to a spray

\*Recommended decon system equipment such as supplied by Health Physics Systems Inc., Gainesville, Florida.

wand held by a technician. The effluent is then vacuumed from the floor retention basin as a liquid/gas and pumped back to the recovery unit where the radioactive particulate matter is removed from the fluid by direct filtering and a gaseous phase change. The Freon gas is recovered by a distillation process to condense it back to a fluid, which is then circulated to the holding tank of the process unit and recycled through the loop. In the event some of the decon wash Freon vaporizes because of very warm thermal temperatures, the gas will flow and collect at any depressed retention area of the floor, generally in the same location that the decon effluent will collect.

Whenever the reactor shielding is removed and the background radiation field is above human tolerance levels, the decon-system spray wand and vacuum pickup may be operated with electromechanical manipulators in a totally remote mode. Although the remote decon operation will be considerably more time-consuming, the overall cleaning efficiency of the system will provide a radiological condition that is conducive to contact maintenance work on the various reactor components in a separate maintenance area.

Table 1

## Freon 113 Decon Fluid Specifications

Du Pont Trade Name -- Valclene

Chemical Trade Name -- Trichlorotrifluorethane

Chemical Formula --  $C Cl_2 F - C Cl F_2$

Freon/Air Density Ratio	6.04
Freon/Water Density Ratio	1.57
PH	7
Boiling Point	117.6 °F @ SL
Freezing Point	-31 °F
Decomposition Temperature	570 °F
Dielectric Constant	2.41
Human Toxicity Level	4500 PPM

**Advantages:** Nonflammable, chemically and thermally stable.  
 Leaves < 1 PPB residual chloride or fluoride after cleaning.  
 Recoverable by distillation w/o decomposition.  
 Can be used for cleaning electrical equipment, glass, metals, teflon, and most plastics.

**Disadvantages:** High cost - \$14/gallon.  
 Violently reactive with sodium, potassium, or barium in free metallic state.

## REFERENCE

1. Freon Solvent Formulation Data, Bulletin No. FST-5, E.I. Du Pont de Nemours & Co. (Inc.), Wilmington, Delaware.

**APPENDIX H**

CONCEPTUAL DESIGN DESCRIPTION FOR  
FED FRAME SEAL WELDER AND CUTTER

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SCOPE

This section covers a condensed version of the conceptual design description for the equipment required to seal weld a torus sector to the FED vessel frame.

The complete design document entitled "Pre-conceptual Design Requirements and System Description for FED Frame Seal Welder and Cutter" dated March 1981 is available from the author.

DESIGN DESCRIPTION

The equipment required to install and remove the frame seal has been designed as an integrated system and is comprised of the following components: frame seal assembly; handling fixture; weld carriage; cutter carriage; remote operator console and fabrication-shipping fixture.

A brief description of each component follows:

Frame Seal Assembly

The function of the frame seal assembly is to provide a vacuum tight seal between the FED vessel frame and the individual removable torus sectors. Reference Figure 1.

The seal is constructed of five components; 2 weld flanges, 2 reinforcing flanges, and a common bellows which join these members. The geometry of the seal assembly will be identical to that of the vessel so that a continuous seal path around the torus vessel and sector(s) is effected.

The weld flange portion of the assembly will be constructed of approximately .030 thick stainless steel which necks up to a thicker

member suitable for welding into the reinforcement flange. The length of the weld flange will be sufficient to perform approximately five weld and cut operations. The bellows portion of the assembly will be constructed of approximately .060 thick stainless steel and will be seal welded to the inner and outer reinforcing flanges around the entire inner periphery.

The seal assembly will mate with flanges welded to both the vessel and torus sectors. These flanges, which also conform to the vessel geometry, will have weld flanges identical to the seal assembly flanges. When the seal assembly is mated to the vessel, the two weld flanges (inner and outer) will form the vacuum boundary.

#### Frame Seal Handling Fixture

The frame seal handling fixture (reference Figure 2) is the machine used to position the seal in the proper location on the FED vessel. To accommodate the anticipated misalignment between the FED vessel and the radial tracks (from which the shield sector is inserted), the handling fixture incorporates various mechanisms which will properly orient and hold the seal assembly in place on the vessel.

Guide rails, mounted on the inner and outer periphery of the handling fixture, are used to mount the welder and cutter carriage assemblies. These carriage assemblies are roughly positioned (relative to the seal weld joint) by the guide rails. Various roller, springs, slides, and actuators in the carriage assembly are used to accurately position the weld stinger or the cutter on the weld flange. A friction drive is employed to support and track the carriage assemblies on the guide rails.

The mechanism employed for securing the frame seal to the handling fixture is a set of vacuum cups located radially around the inner and outer periphery of the seal assembly. The basic advantage of the vacuum attachment concept is the relative ease of engaging and disengaging the seal assembly during remote operations.

### Weld Carriage

The welder carriage concept (reference Figure 3) utilizes a friction drive design whereby four contoured wheels engage guide rails mounted on the interior and exterior periphery of the handling fixture. Stepper motors, driving 2 wheels of this carriage, are used to track the carriage on the rail. The output from these motors is monitored to interrupt the welding operation in the event wheel slippage should occur. The welder head is mounted on an array of components which position the weld stinger in the proper relation to the weld flange. An electric actuator is utilized to engage and withdraw the weld head from the flange in order to initially install the frame seal on the vessel.

### Weld Cutter Carriage

The function of the weld cutter is to trim the two weld flanges after the seal flange assembly is installed on the vessel in preparation for the vacuum seal weld and also to sever the flanges, after welding, in order to remove the torus sector. The concept selected for this operation is a pneumatic powered roll shear (see Figure 4). The roll shear utilizes a serrated drive wheel and a shearing wheel both driven by a geared air motor. The cutter housing is mounted on a vertical, spring compensating slide which allows the unit to "float" for tracking around the seal flange profile. This slide is mounted on an electrically driven rotary table which is used to locate the cutter assembly in a position which allows the seal frame assembly to be installed on the vessel. After the seal assembly installation is complete, the rotary table is activated and the cutter assembly is rotated into the weld flange and the cutting operation is commenced.

The carriage frame which supports the entire assembly on the handling fixture guide rails is essentially the same as that employed for the welder assembly.

An unidirectional clutch is installed between the drive motor and wheel axle on each driven wheel of the carriage to compensate for different driving speeds of the carriage and cutter wheels. Both the cutter assembly and wheel drives can be reversed in the event that forward

motion of the units could not overcome a binding condition. It may be possible (as verified by operational testing) to stop the cutting sequence at selected intervals, reverse the cutter wheels and rotate the cutter assembly to sever the cut portion of the flange into "manageable" segments. This operation would alleviate the need for facility manipulators to handle the severed flange.

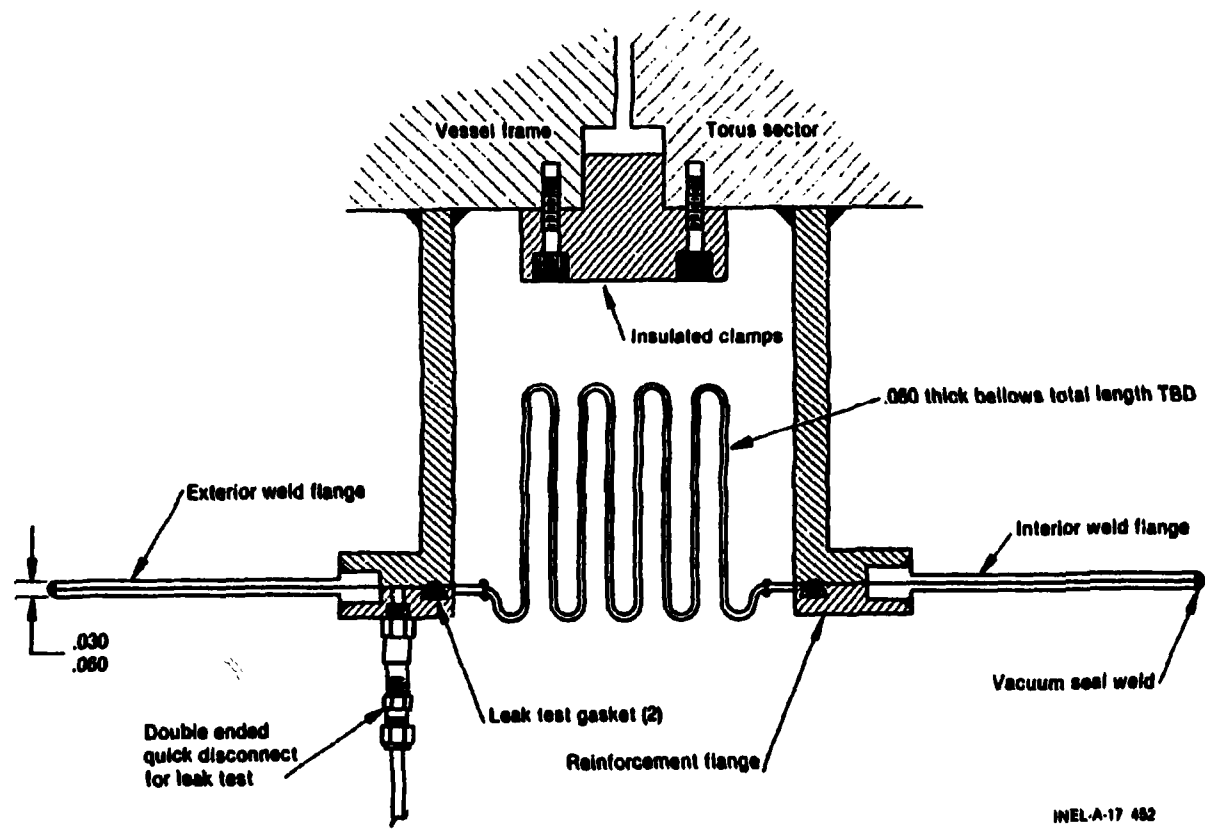
The roll shear cutting concept was selected due to its successful operating history in industry and the availability of the required equipment.

#### Remote Operators Console

The remote operators console is included as an integral part of the overall system. The console will include all controls, interlocks, displays, alarms, etc., required for system operation. The design of the control console will provide for a minimum of operator interface consistent with system operation.

#### Seal Frame Fabrication/Shipping Fixture

A special fabrication fixture for the seal frame assembly will be required. This fixture will be a male form of the seal frame geometry and will provide support for the seal during fabrication and shipping. Provisions will be included in the fixture to allow the bellows portion of the assembly to be welded in place between the reinforcement flanges. Special equipment will also be provided to verify the integrity of the fabrication welds so that a final leak test will only be required on the vacuum seal weld.



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Fig. 1

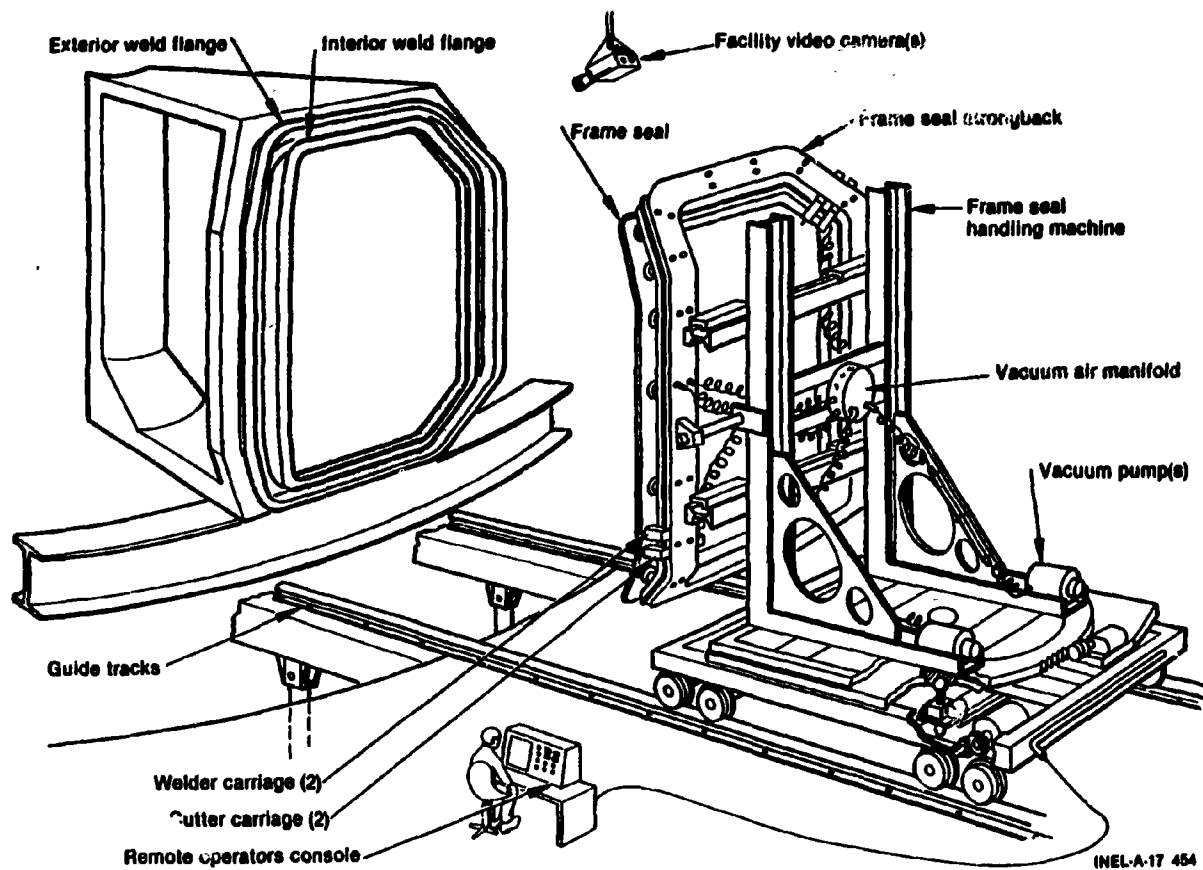


Fig. 2

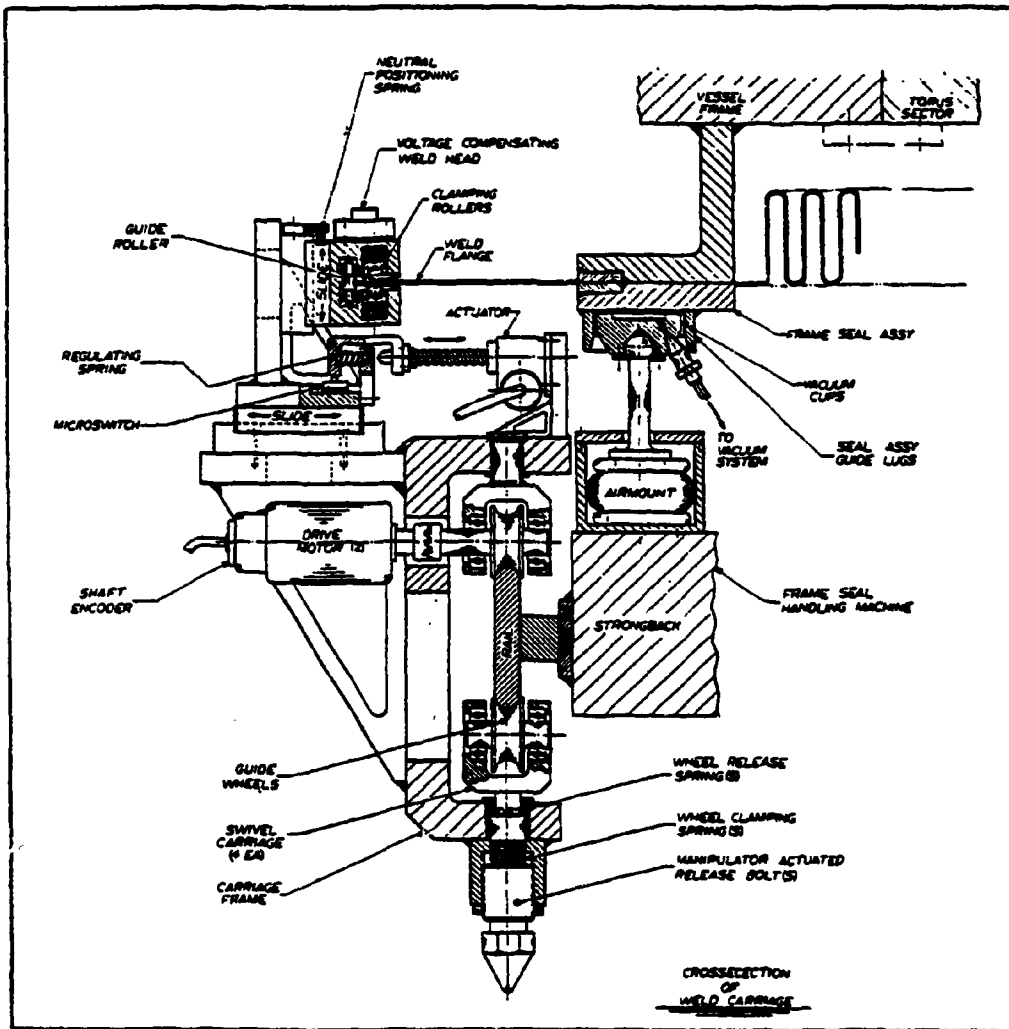
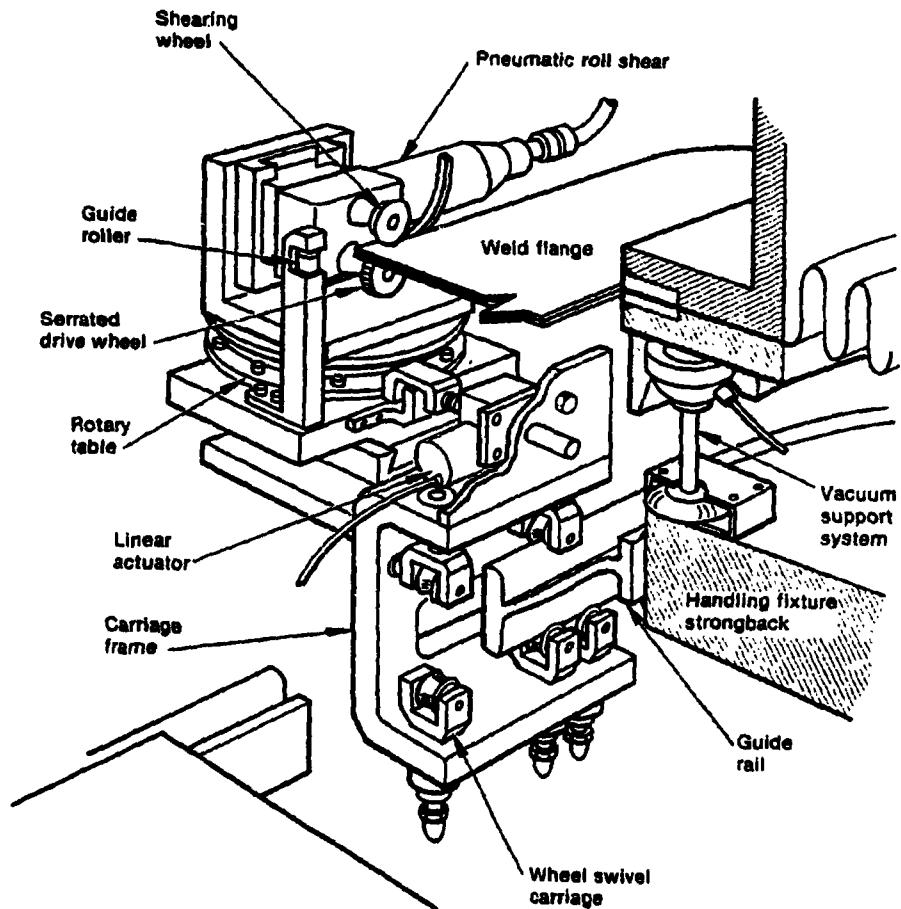


Fig. 3



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Fig. 4

APPENDIX I

11



## A CONCEPTUAL METHOD FOR TORUS SECTOR MODULE HANDLING

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Routine replacement of sector module assemblies utilizing remote methods will be the most significant task to be addressed in the design of a Fusion Engineering Device. Replacement of this subassembly involves first wall, blanket test modules and actively cooled shield walls. Extensive operations to disconnect and remove coolant headers, electric services and diagnostics must be performed prior to the actual removal of the sector module structures.

The method described herein addresses only the handling of the sector module. It involves removal of the module following disconnect of ancillary services and cutting of the sector module seal weld. The method addresses radial movement of massive (approximately 400 T) sectors as well as actual removal from the test cell to a maintenance facility.

Two methods of moving heavy sector modules are continually debated with regard to advanced machine modules. These include the use of high capacity bearings vs. air film bearings. High capacity roller bearings provide well controlled movement in one direction only while air bearings provide flexibility in all directions. Air bearings, however, require stringent requirements on floor surface first, which is extremely costly. In addition, the problems of controlling the inertia of massive structures on a virtually functionless surface provides significant problems for the module handling device.

A combination of the two methods was selected for use in the FED replacement method. High capacity roller bearings are utilized to move the modules radially out from the torus and clear of the cryostat containment. Upon replacement of the module, precise positioning of the structure is required in the last few feet of travel. This is accomplished by allowing the module to move laterally on an air bearing support while being guided into position by fixed positioners. This hybrid system is the basis of the suggested FED torus module replacement method.

### APPROACH SUMMARY

The method is based on lifting and moving the sector radially with a high capacity mobile jack system pulled by a transporter vehicle. The jack is similar to standard machine incline plane jacks with the addition of high capacity roller bearings.

The machine module design must be modified to include a jack interface under the module similar to fork lift slots. Additionally, a keyway for precise final positioning must be incorporated in the design.

The high capacity jacks will incorporate an air bearing on its upper surface to permit lateral movement during assembly for precise alignment.

Finally, the module will be handled with the overhead crane and rail car for final removal from the test cell.

### REMOVAL PREPARATION

Prior to module removal, a high capacity maintenance bridge must be installed (Fig. 1). This bridge spans the vacuum duct floor penetration as well as the area within the TF coils to the sector module. This bridge incorporates rails for the sector module transporter. In addition, imbedments for the module high capacity bearings must be set in the bridge at a precise level with the module base (See Fig. 2). An interface in the sector module for the module jacks must be incorporated in the sector design. This cavity must be plugged during machine operation with shield plugs to prevent streaming (See Fig. 1). These plugs must be removed and stored during preliminary operations. Also, a sector positioning bearing (See Fig. 2) or key must be incorporated in the module design.

### SECTOR RADIAL MOVEMENT

The module is moved radially with the sector transporter equipped with the higher capacity bearing/jack system (Fig. 3). The sector jack is positioned under the module in the jack interface. The entire module is lifted by activating the jack which works on the principle of a shallow-incline plane. Once raised on the jack, the module is attached to the vehicle upper stabilizer structure (See Fig. 4) with the sector raised and stabilized

### SECTOR RADIAL MOVEMENT (CONT'D)

it is moved radially outward with the transporter to a position clear of the cryostat.

### REMOVAL FROM THE CELL

All sector movement within the test cell outside the periphery of the cryostat is accomplished with the overhead crane. The sector is removed from the test cell to the maintenance area by rail car (Fig. 5). It is anticipated that the module would be removed to a maintenance area and a reconditioned module would be immediately returned to the test cell for installation.

### MODULE INSTALLATION

Installation of the sector module proceeds in a reverse mode from that described above. After the module is removed from the rail car, it is placed on the sector module transporter. The sector module is moved radially into proximity in the machine. Final placement of the sector module is accomplished by activating the air bearing system. The module is then moved into final position and the module becomes guided and laterally positioned by the keyway. The air bearing system permits lateral movements while the module is still completely under the control of the module transporter. Once positioned, the transporter is retracted and the shield plugs reinstalled.

### SUMMARY

A method for sector module replacement for the FED is possible utilizing present day technology as described above. Significant development work must be performed in the design of module transporters and in the design of FED to enable remote maintenance. Major movements of the sector module are accomplished with the overhead crane to preclude severe requirements on floor surfaces.

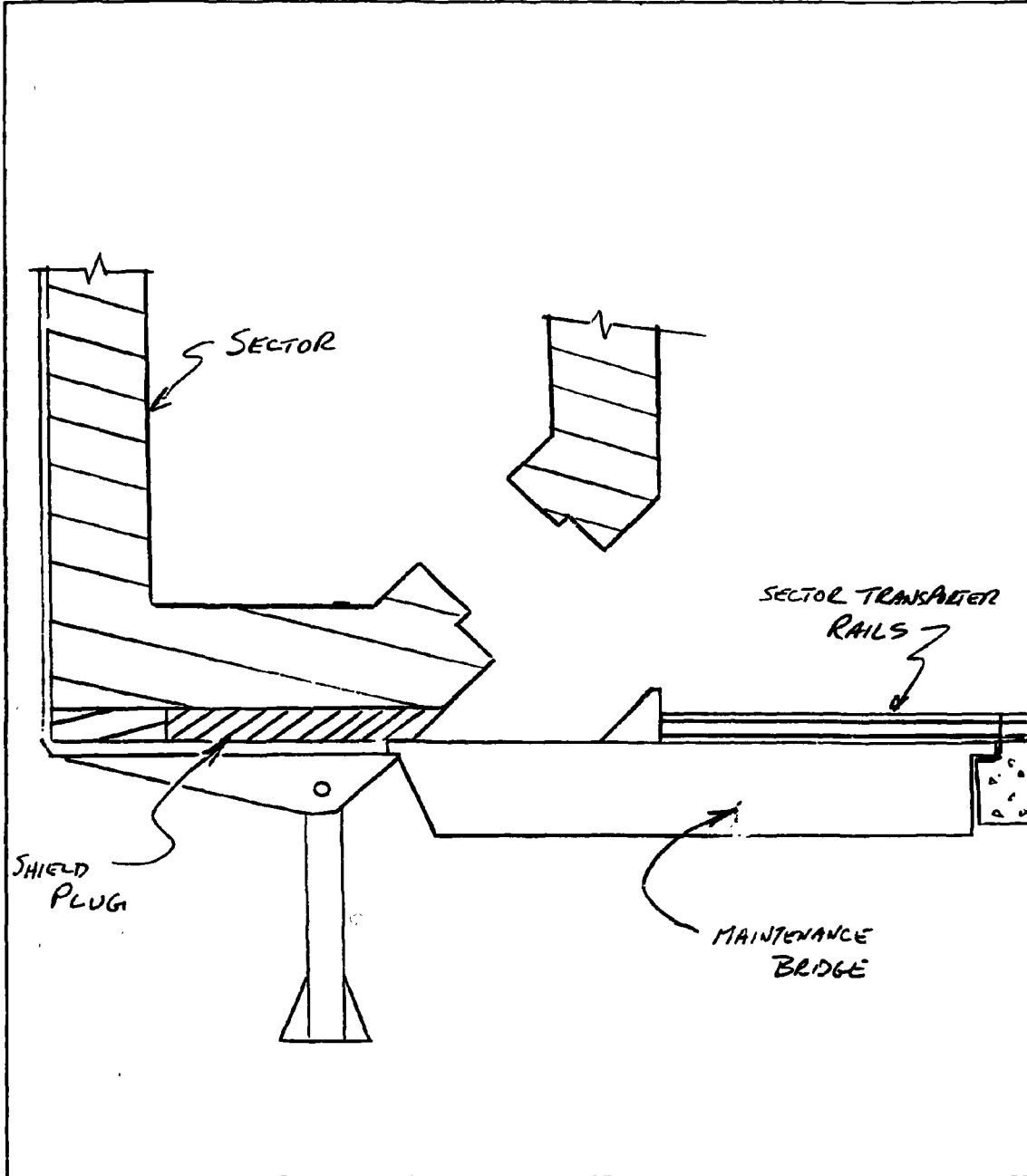


FIGURE 1

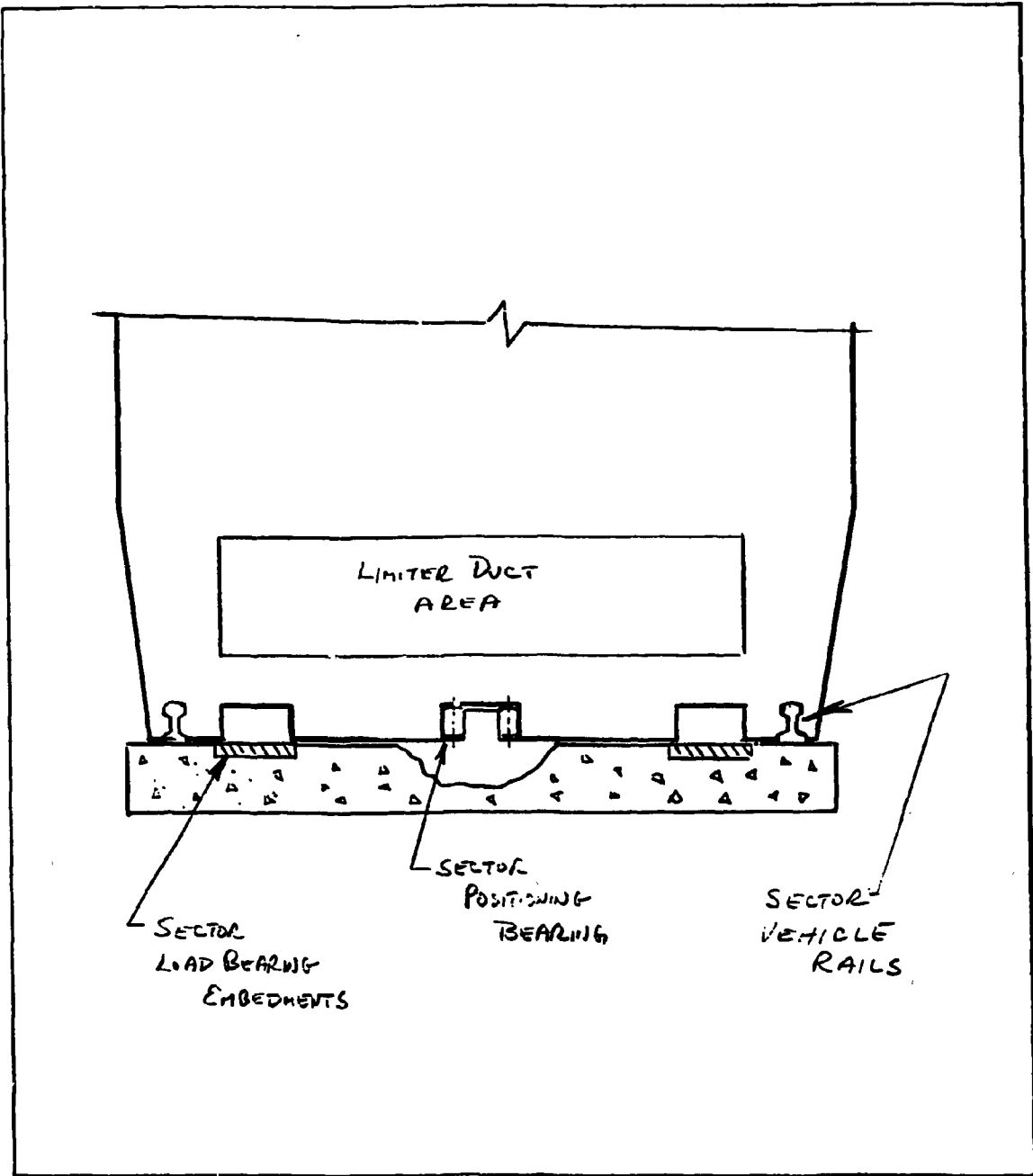


FIGURE 2

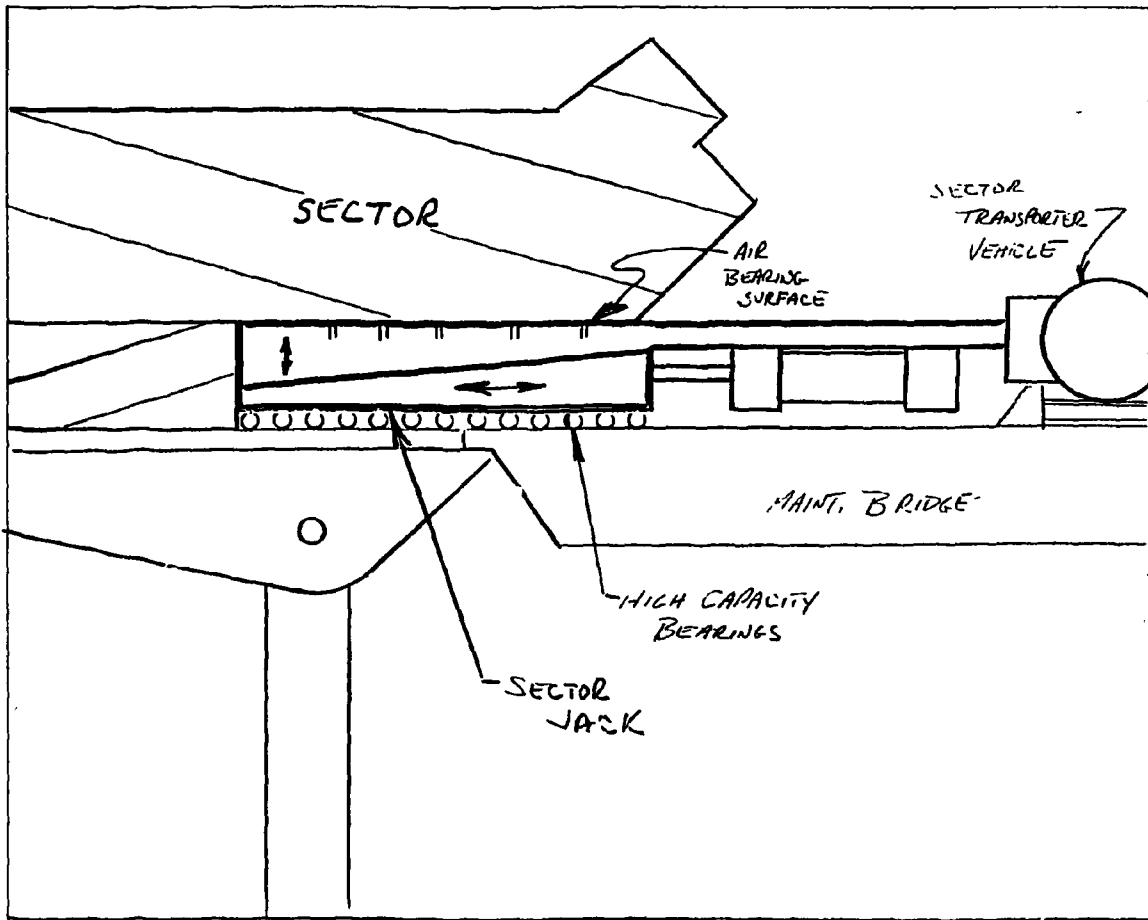


FIGURE 3

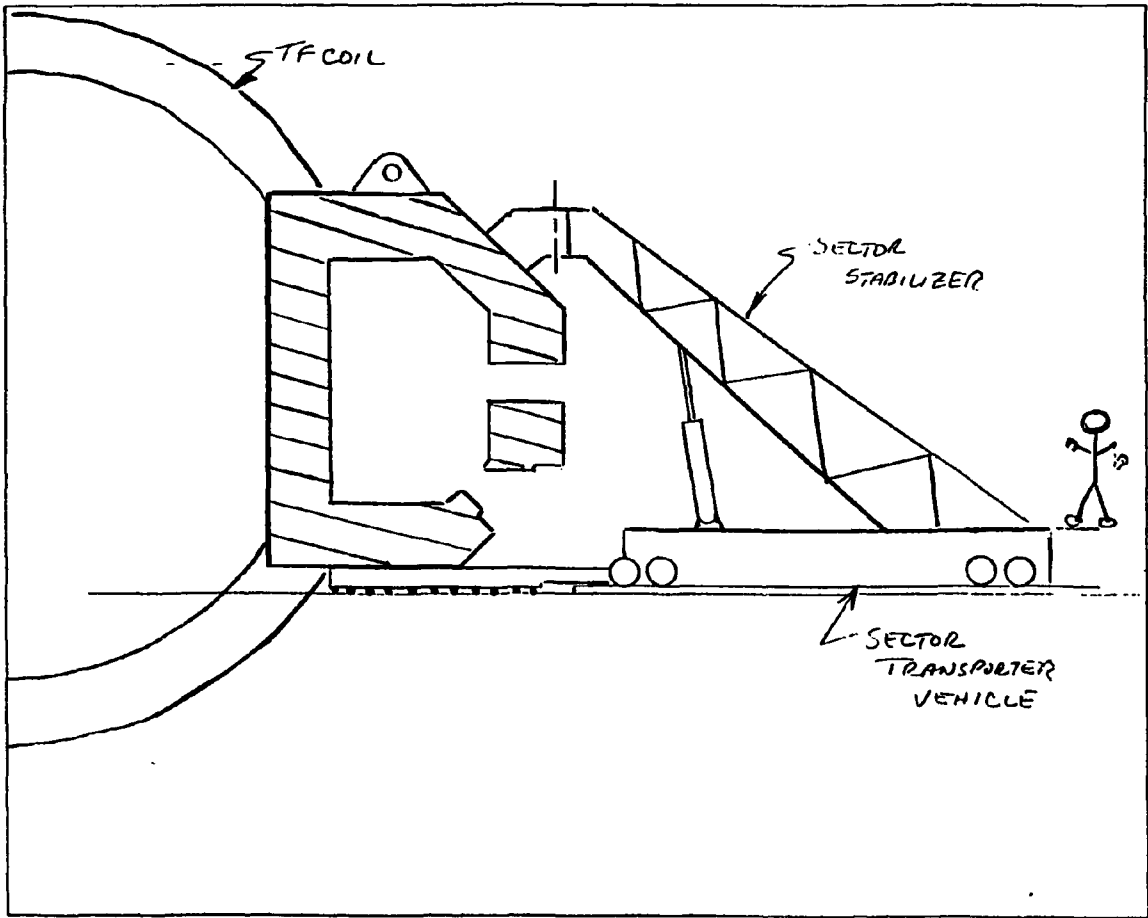


FIGURE 4

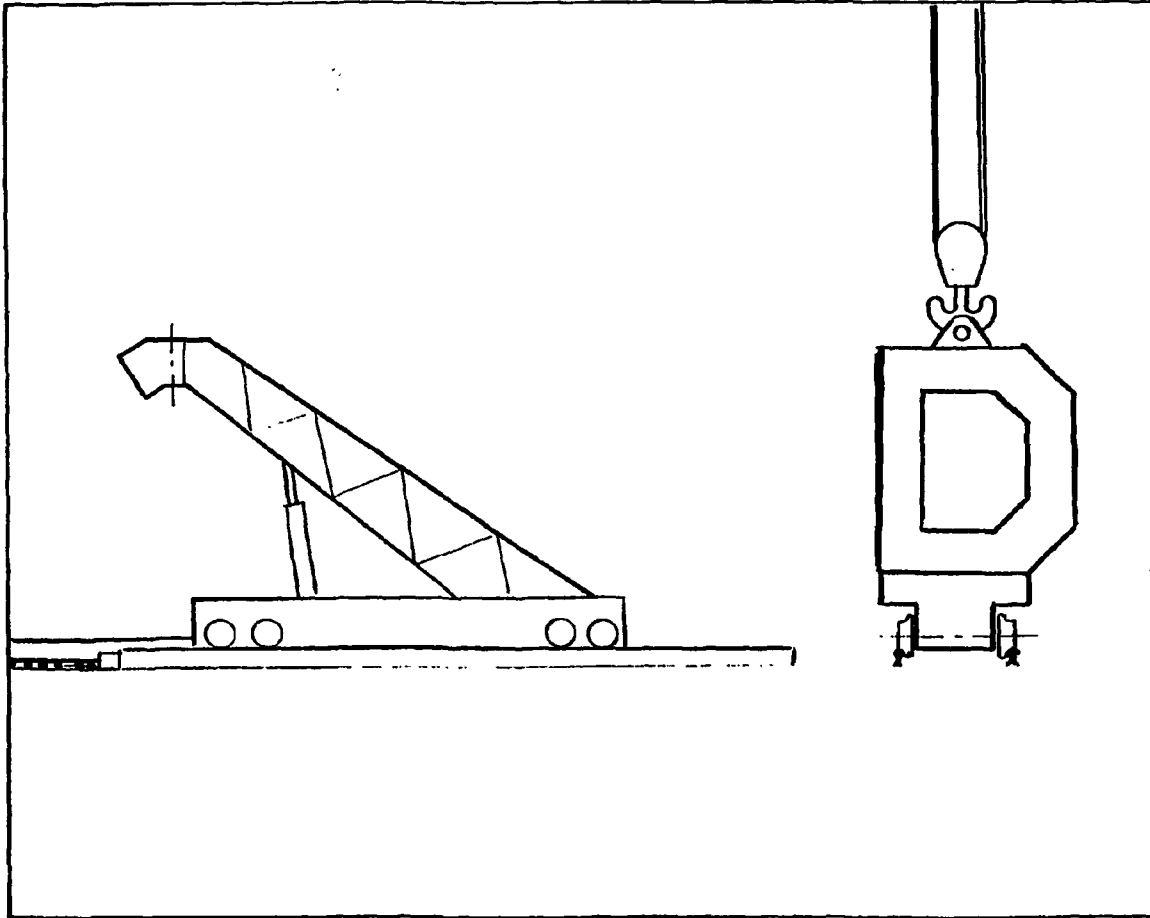


FIGURE 5

**APPENDIX J**

6



Sup

## TORUS SECTOR HANDLING SYSTEM\*

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## INTRODUCTION

This appendix will propose a scheme to move a torus sector from under the cryostat to a point where it can be handled by a crane and the reverse process for a new sector. Equipment recommendations will be presented, as well as possible alignment schemes. Some general comments about future remote-handling methods and the present capabilities of existing systems will also be included.

## SPECIFIC TASK

The specific task to be addressed is the removal and replacement of a 425-450 ton torus sector. This requires a horizontal movement of ~10 m (see Fig. 1) from a normal operating position to a point where its further transport can be accomplished by more conventional means (crane or floor transporter). The same horizontal movement is required for reinstallation, but a positional tolerance of 2 cm is required to allow reasonable fit-up for the vacuum seal from the radial frames to the torus sector. Since the sectors are not only heavy but rather tall and narrow, the transport system must provide a safe, stable, and repeatable method of sector movement.

## BACKGROUND

The access to the main experimental beam line at the Clinton P. Anderson Meson Physics Facility (LAMPF) of the Los Alamos National Laboratory is by horizontally transporting large shielding doors to expose the beam line. Since these doors weigh up to 1000 tons and are transported 4-6 m, the LAMPF scheme offers at least one solution to the torus sector transport problem. As shown in Fig. 2, the shielding doors

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\*Work performed under the auspices of the U.S. Department of Energy.

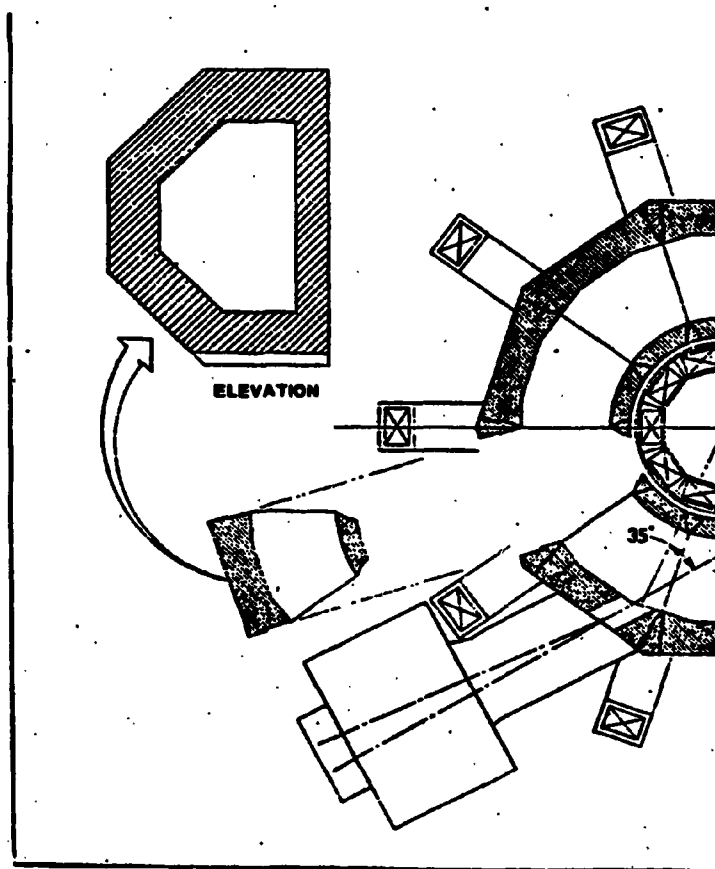


Fig. 1. Torus shield segmentation (plan view).

are "T"-shaped and fit in a similarly shaped concrete structure. The doors are lifted on hydraulic roller trucks (also shown in Fig. 2) and transported to the desired position by a hydraulic puller system. It appears that some of the features of the LAMPF system can be adapted for torus sector transport.

#### SPECIFIC RECOMMENDATIONS

Since the LAMPF roller trucks have a capacity of 150 tons each, four of that design could easily lift and transport a sector. In conjunction with the LAMPF door puller system, two of the three vital aspects of sector removal are available with existing equipment. The third vital element, guidance, could be achieved by utilizing carefully

aligned tracks in the floor to guide the roller trucks, which would be affixed to the sector. Figure 3 shows this process schematically.

A level-sensing and control system would be required to provide safe and stable operation of this system.

#### GENERAL REMOTE HANDLING

An existing remote-handling system, similar to Monitor at LAMPF (see Fig. 4) is able to remotely perform all the repair, modification, and replacement functions for a high-power proton beam line in an experimental facility. The tasks presently performed by Monitor (see Table I) are very similar to those required for FED, so further advances in remote technology will only make the task easier to accomplish in less time.

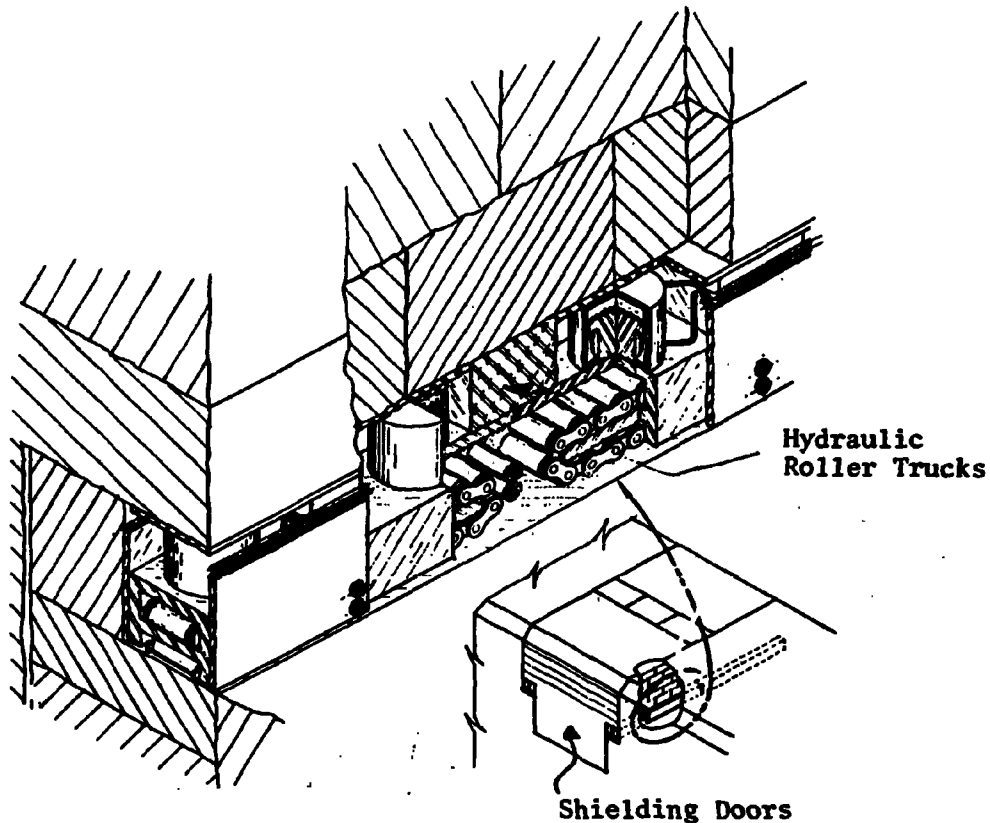


Fig. 2. LAMPF shielding doors and roller trucks.

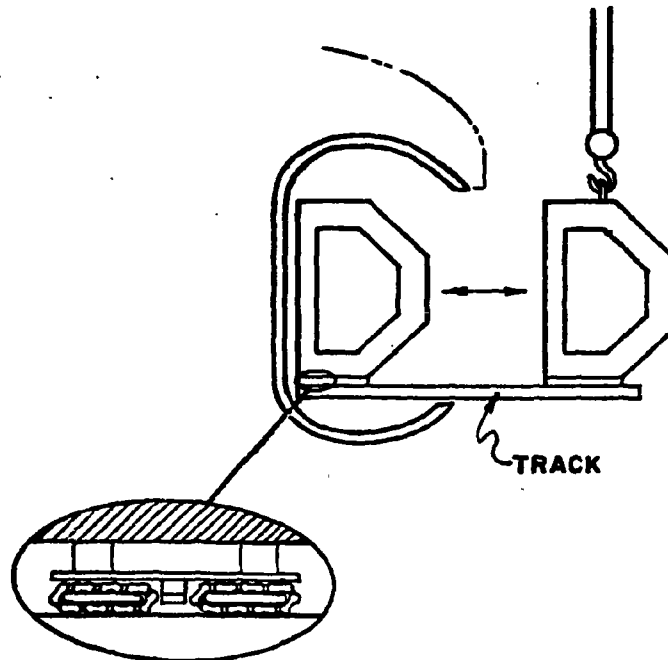


Fig. 3. Schematic sector removal.

TABLE I. PRESENT MONITOR CAPABILITIES

<u>Typical Operations</u>	<u>Basic Skills</u>
-Install eyebolts, slings, etc., for rigging various type/size cranes.	-Sawing (rotary, band, and reciprocating).
-General assembly/disassembly of large and small components, nuts, bolts, electrical connectors, etc.	-Drilling.
-Installation/removal of piping systems.	-Tapping.
-Repair leaks in piping systems.	-Grinding.
-General cleaning and surface preparation.	-Welding (MIG and MA).
-Replacement of pipe flange seals.	-Flame cutting.
-Installation, repair, and routing of electrical systems.	-Stud welding.
	-Soldering (resistance and torch methods).
	-Sanding.
	-Wire brushing.
	-Spraying of liquids.
	-Polishing.

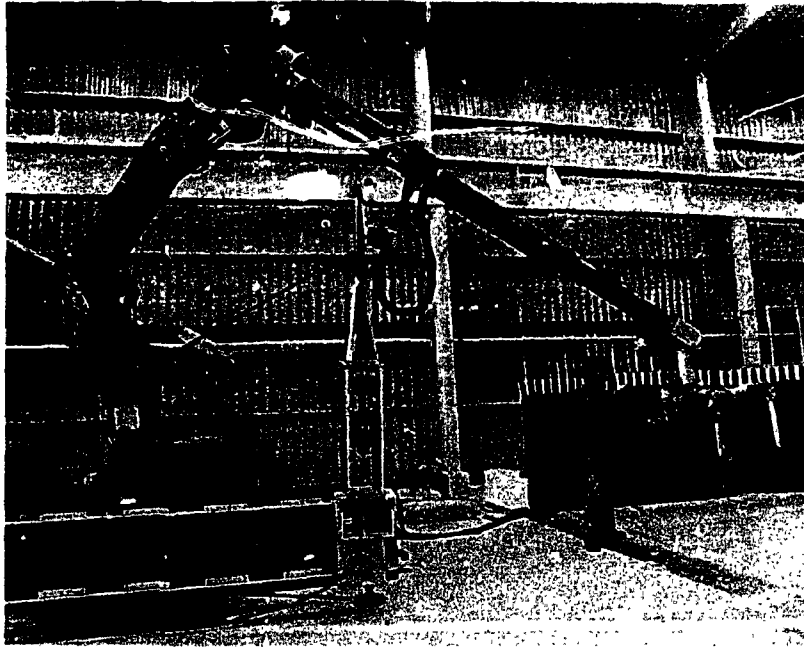


Fig. 4. LAMPF monitor system.

#### CONCLUSION

This limited study indicates that the LAMPF-based method of transporting torus sectors offers a proven method of moving heavy items. In addition, the present state of the art in remote equipment is adequate for FED maintenance.

**APPENDIX K**

## LEAK DETECTION APPROACH FOR FED MAGNETS AND FIRST WALL/SHIELD

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## MAGNET LEAK DETECTION SYSTEM

The superconducting magnet system configuration is defined in Figure 1. It consists of 10 TF coils, solenoid coils and poloidal coils. All superconducting magnets are located inside vacuum tanks and utilize a liquid helium coolant tank and a liquid nitrogen cooled shroud. A typical cross section through the outer leg of the TF coil system and through any external poloidal coils is shown in Figure 2. A cross section through the inboard TF coil leg is shown in Figure 3. The TF coils are enclosed in a common vacuum tank in this area and are located in an inaccessible area behind the shield. This cross section has been modified to add a secondary enclosure for leak detection that is discussed later.

For purposes of designing FED it should be assumed that periodic leaks will occur in the liquid helium dewar, liquid nitrogen shroud, or vacuum tank of the magnet during the life of the plant.

The magnet leak detection system should permit determining which magnet has developed a leak. This requires each magnet to be designed with manifolding that permits the liquid helium, liquid nitrogen and vacuum systems to be isolated to the smallest replaceable magnet. This may be individual TF coils or groups of center-post-ohmic-coils. Residual Gas Analysis (RGA) capability should be provided for the common vacuum tank and the vacuum tank of individual coils that are located outside the common vacuum tank. In the event a leak develops, a gas analysis can be performed to determine whether outside air, nitrogen, or helium is leaking into the vacuum enclosure. If a helium or nitrogen leak is detected each individual coil (or at least each set of removable coils) will be drained of helium or nitrogen. Next a tracer gas will be injected sequentially into each coil until the tracer gas is noted by the Residual Gas Analyzer. This will indicate which helium or nitrogen tank is leaking and will permit coil replacement. (Note: repair is not possible yet because the leak has not been

pinpointed.) This approach requires that each magnets helium and nitrogen manifold be designed with valving for independent injection of tracer gas. Vacuum leaks can be isolated to either the common vacuum tanks or coils that have separate vacuum tanks by spraying the vacuum tank exterior with tracer gas and monitoring the RGA. In areas where direct access is available to the common magnet dewar, progressive masking of areas can be used to locate the leak.

The area between the TF coil inner leg and the inboard shield requires a unique design to permit vacuum tank leak isolation to a single replaceable coil because access is limited. Two approaches are possible: 1) addition of 4<sup>+</sup> cm gap to permit lowering of an ion gauge or probe so the surface can be scanned, 2) addition of partitioned secondary vacuum enclosure to permit localization of leaks. The second option is considered best because of the limited access to the inner leg area.

The addition of a partitioned secondary vacuum enclosure is shown in Figure 3. Its purpose is to permit isolation of a vacuum dewar leak to a single zone. In addition it can provide redundancy in that a leak through the primary vacuum wall can be tolerated if the secondary wall is intact. The leak detection and isolation capability of the system is provided by noting a change of pressure in the secondary vacuum enclosure. A pressure increase indicates a leak in the primary vacuum boundary. Tracer gas can also be injected into the secondary enclosure for detection by the common dewar RGA as a further confirmation of the leak location.

#### FIRST WALL/SHIELD LEAK DETECTION

Leak detection of the First Wall/Shield is vital to a successful FED. Provisions for a remotely operable leak detection system that is capable of rapidly detecting and isolating leaks should be incorporated. The potential for leaks in the First Wall/Shield system falls into two basic categories. Leaks in the first wall or shield which result in coolant entering the vacuum vessel; or an atmospheric leak in the shield. These types of leaks are significantly different and each will be discussed.

### Coolant Leaks

Location of coolant leaks in the first wall/shield is complicated by the fact that it is inside the vacuum system. While it is conceptually possible to design a system to allow a leak to be pinpointed for repair, the complexity of such a system and the extreme environment in which it would be located seriously reduce its viability. For these reasons, location of leaks in the first wall/shield should consist of isolating the leak to the smallest replaceable component. The first wall/shield coolant design should include manifolding which permits isolation of the smallest replaceable component. In addition, residual gas analysis capability should be provided on the torus vacuum system.

The technique used to isolate a faulty first wall/shield segment will depend on the size of the leak. For small leaks, in which the high vacuum pumps are still operable, the pressurized coolant flow can be stopped sequentially in each of the segments and the pressure gauge and Residual Gas Analyzer (RGA) monitored. A decrease in vacuum system pressure or reduction in the mass-to-charge peak representing the coolant will identify the faulty segment.

Techniques for remotely isolating a larger leak, one in which the high vacuum pumps are not operable, are more complex. The technique described for isolating components with small leaks could be used, except that it could result in large amounts of coolant entering the vacuum vessel and complicate the clean-up problem. A design alternative is to remove all coolant and sequentially evacuate or pressurize each segment. The faulty segment would not achieve the same base pressure as the others.

### Atmospheric Leaks

Atmospheric leaks are most likely to occur at a vacuum seal or weld. Such leaks will normally be associated with the increased partial pressures of the atmospheric gases as determined by an RGA in the vacuum system. Leaks at welds will normally be small enough to permit use of RGA. The tracer gas would be applied to the weld by a movable nozzle or a spray bar with a series of nozzles until the leak is located by finding differences in response time. Location of leaks at replaceable seals

will not require precision pinpointing of the leak; identification of the faulty seal will suffice. A double vacuum seal with provisions for introducing a tracer gas between the seals should be adequate.

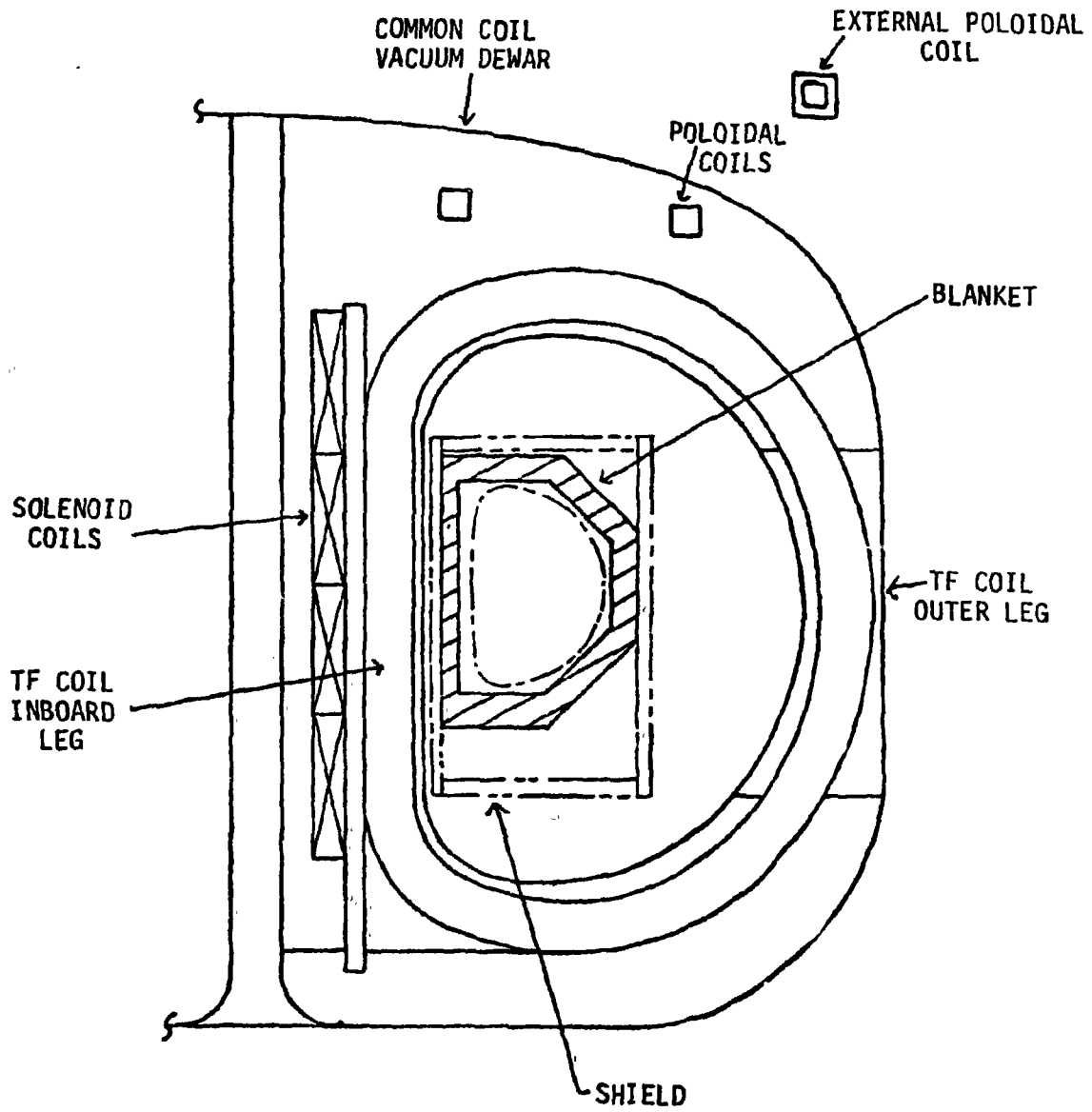


FIGURE 1 MAGNET CONFIGURATION.

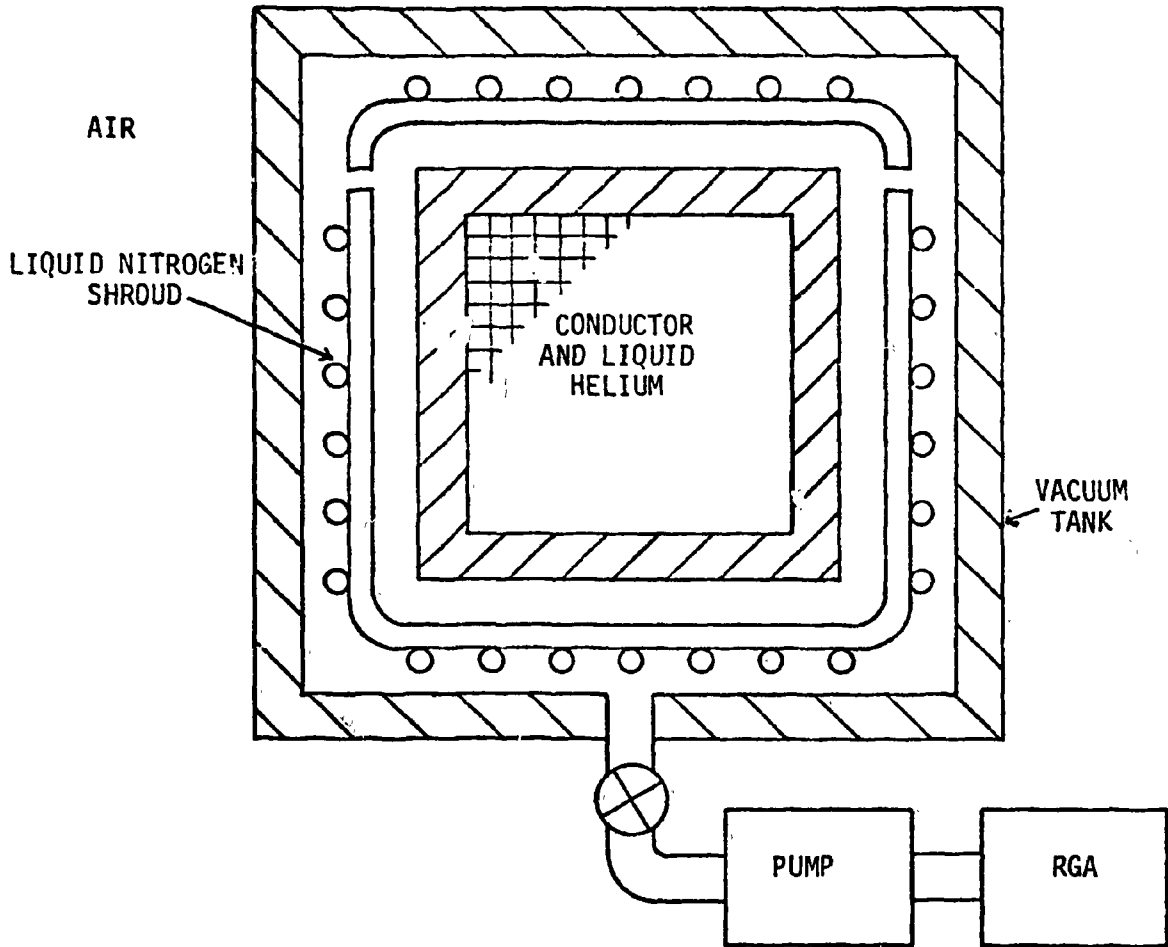


FIGURE 2 - TYPICAL SUPERCONDUCTING MAGNET DESIGN. HELIUM AND NITROGEN SYSTEMS MUST BE INDEPENDENTLY MANIFOLDED FROM OTHER MAGNETS

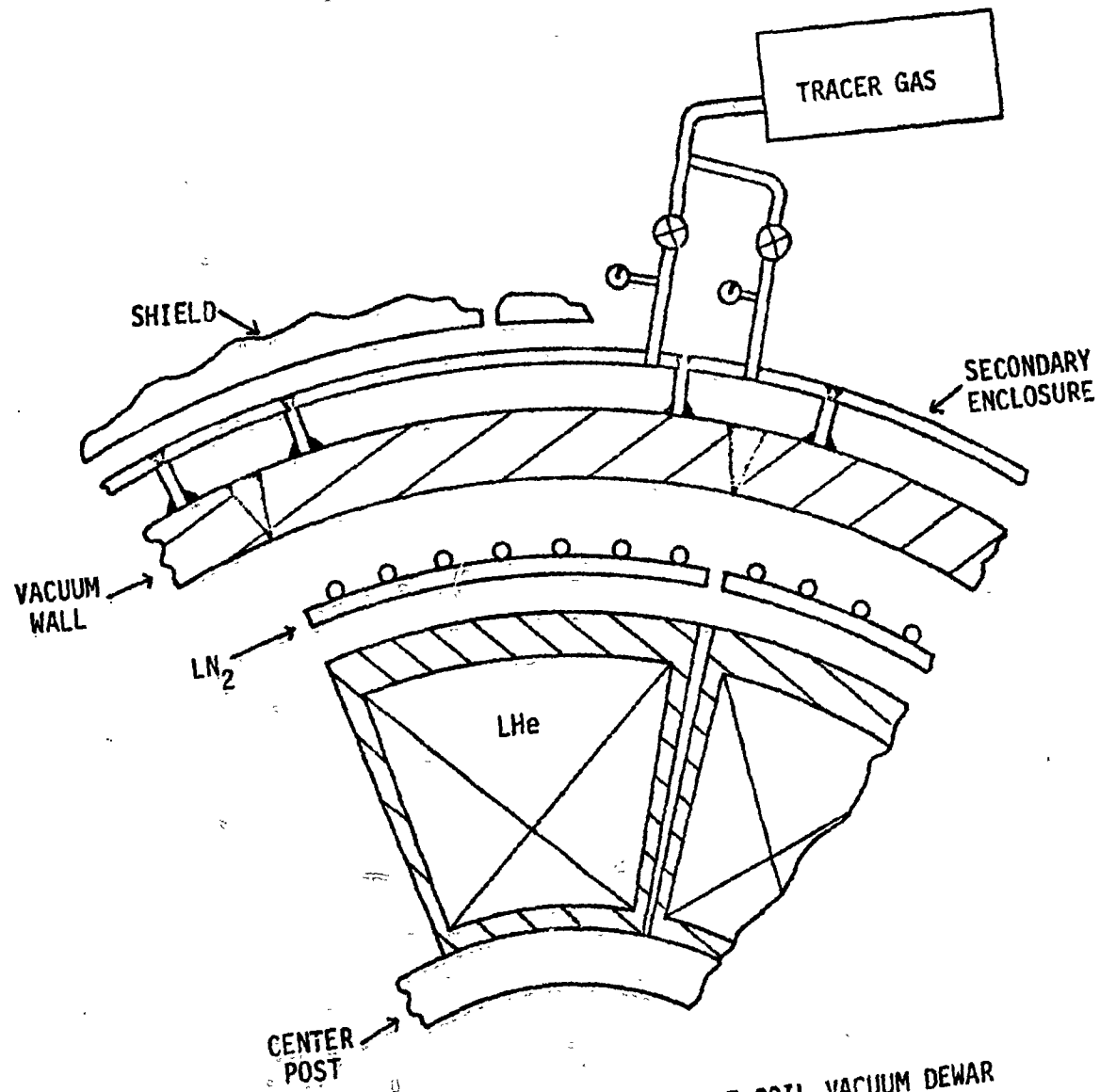


FIGURE 3 - CENTER REGION OF THE TF COIL VACUUM DEWAR

**APPENDIX L**

## NEUTRAL BEAM INJECTOR HANDLING SYSTEM

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## COMPONENTS REQUIRING MAINTENANCE

Maintaining the FED neutral beams requires two classes of work: (1) in-situ and (2) removal/replacement of the entire neutral beam assembly. In-situ repair or replacement is reserved for those components which are expected to have a high frequency of failure. Table 1<sup>1</sup> lists maintenance frequencies for major neutral beam components. Removal of the neutral beam assembly as a unit is required for repairs or replacement of components which have projected frequencies of failure greater than the FED machine operating life. For these repairs, the entire neutral beam is moved to the facility hot cell. Neutral beams must also be removed from their operating position to allow access to other machine components, such as ducting, torus sectors and magnets, which are covered or blocked by these units.

The beams require numerous electrical, control and instrumentation, and fluid services. These are listed in Table 2.<sup>1</sup> An important part of removal and replacement tasks is the ability to disconnect and reconnect these services. Contact work is utilized where possible.

## BEAM PULL BACK

Generally, movement of neutral beams in fusion reactor buildings has been discussed in connection with transporter traction units which push and tow the beam assemblies at least for a distance necessary to clear toroidal coils, vacuum shrouds, etc. An alternative considered here is a belt or cable drive which pulls the beam unit far enough back to allow the building crane to pick up and carry the unit to the hot cell. Figure 1 shows this scheme. Jack screws are shown as a method of positive disengagement of the vacuum seal area of the drift duct from mating surfaces on the machine.

The sequence of operations is as follows: (1) the vacuum seals are cut (if welded) or unbolted, (2) the drive cable unit is assembled and attached to the beam, (3) beam service lines are disconnected, (4) the jack screws push the beam out of contact with the machine and are disconnected, (5) the cable pulls the beam further away from the machine, and (6) the building crane lifts the unit (after drive cable disconnection) and removes it to the hot cell. Items (1) through (3) can be accomplished in the contact maintenance mode. It may be feasible to lift the beam unit out of its ~500 ton nuclear and magnetic shielding before transfer to the hot cell. Obvious handling benefits accrue at the expense of some additional complexity. The neutral beam is assumed to be supported and moved on linear bearings fitted to an accurately aligned radial rail system incorporating seismic restraints.

#### SOURCE-ACCELERATOR MAINTENANCE

As noted in Table 1, the most frequently maintained component of the neutral beam is the source. This frequency was shown to be a major component of overall machine availability in a previous study.<sup>2</sup>

The source and accelerator are removable as a unit and are gimbaled to the neutralizer. A removable shield cover is provided for the source-accelerator unit. Figure 2 illustrates the removal of the source shield cover utilizing the FED modular maintenance vehicle fitted with a special shield fixture. The fixture is then exchanged for a source handling tool and the vehicle is used to remove the source as shown in Figure 3. The procedure is outlined in Table 3.

#### DIRECT RECOVERY AND MAGNET SERVICING

One design alternative being considered for the neutral beams is to combine the source, neutralizer and direct recovery components as one unit. This unit would then be mounted on a pull-out drawer or rails which would facilitate its withdrawal. The modular maintenance vehicle will remove this unit with a specially designed manipulator tool as shown

in Figure 4. The procedure is outlined in Table 4. Removed components are stored in transfer casks so that contact work can be resumed as soon as possible.

If separate mounting of the source, neutralizer and direct recovery components is a more viable approach, the direct recovery unit and bending magnet can be removed through top of the neutral beam after the top shield has been separated as shown in Figure 5. Of course, removal of a bottom beamline unit requires that the units above it are lifted out first. This would not compromise scheduled maintenance but would penalize downtime for an unscheduled failure. A special overhead manipulator or crane fixture would be required. Figure 6 illustrates a removable side shield panel that would provide another alternative. The rear removal is preferred from the maintenance standpoint.

#### REFERENCES

- <sup>1</sup>Metzler, D. H., "Remote Handling Aspects of Auxiliary Heating on Fusion Engineering Device," a presentation given at Session I, FED Remote Handling Workshop, Oak Ridge, Tennessee, January 20, 1981.
- <sup>2</sup>Abdou, M. A., et al., "Shielding and Maintainability in an Experimental Tokamak," Proceedings of the 8th Symposium on Engineering Problems of Fusion Research, San Francisco, California, November 13-16, 1979.

TABLE 1. NBI HAS A FEW HIGH MAINTENANCE COMPONENTS

- Source (MTBF ~30 days)
  - Filament,
  - Arc chamber,
  - Accelerator stack.
- Direct Recovery Units (MTBF ~1 year)
  - Ion and electron collectors,
  - Bending magnet.
- Cryopumps
  - For full up operation (50% FED availability) regeneration is required every day.
  - Extra NBI allows regeneration in place.

TABLE 2. MANY DISCONNECTS ARE REQUIRED TO REMOVE THE NBI

- Electrical (6 sets) -
  - Filament - 2            10 V @ 4 kA
  - Arc                    200 V @ 5 kA
  - Grid #1                +20 kV @ 60 A
  - Grid #2                -50 kV @ 15 A
  - Grid #3                -152 kV @ 15 A
  - Grid #4                -150 kV @ 60 A
  - Collector              -145 kV @ 15 A
  - Magnet, source        5 V @ 30 A
  - Magnet, bending       20 V @ 500 A
- Control and Instrumentation
  - Fiber optics
- Liquids
  - LN<sub>2</sub>
  - LHe
- Gas
  - D<sub>2</sub>
  - Roughing pumps
- Drift Duct
- Shields
  - Nuclear igloo
  - Magnetic igloo

FIGURE 1. METHOD OF NEUTRAL BEAM PULL BACK

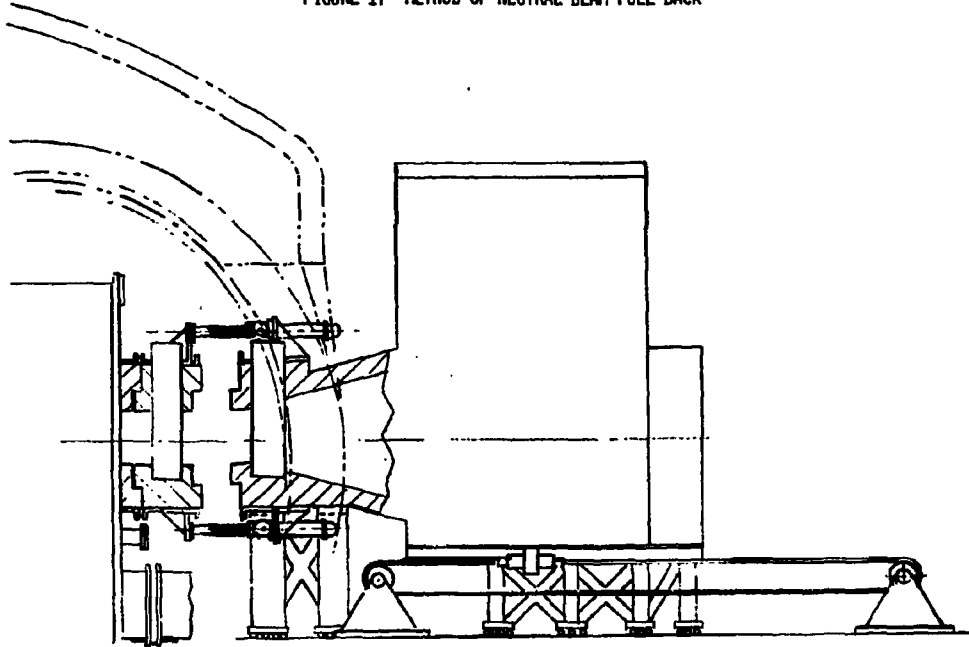


FIGURE 2. REMOVE/REPLACE SOURCE SHIELD COVER

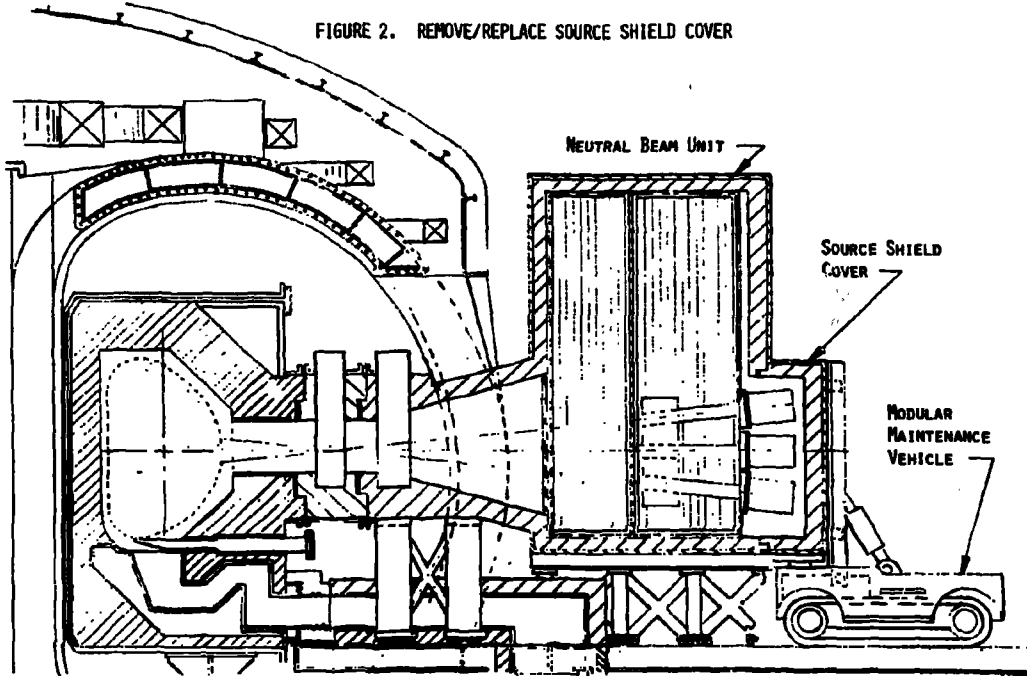


FIGURE 3. REMOVE/REPLACE SOURCE AND ACCELERATOR

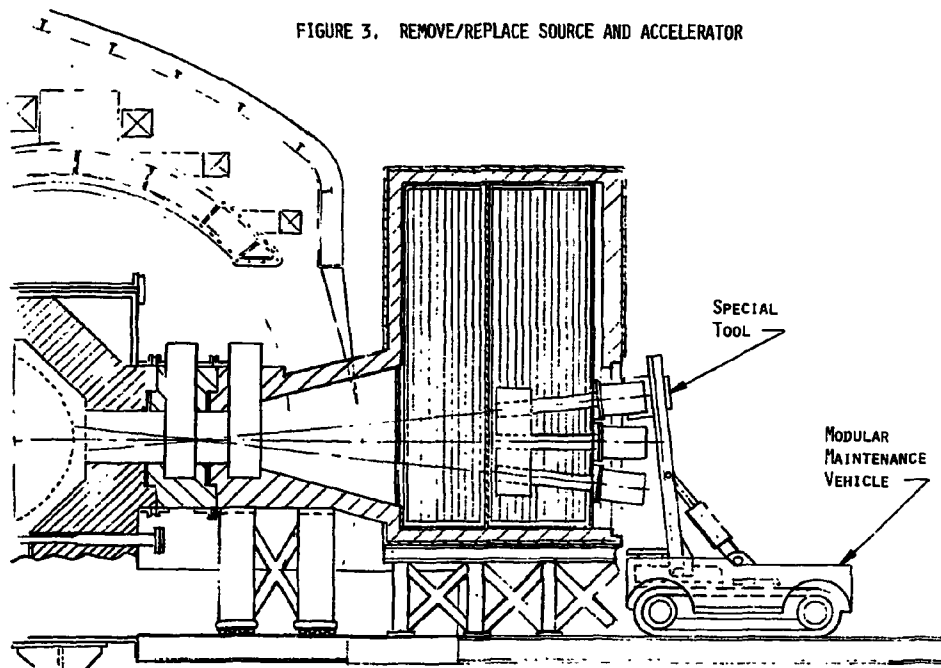


TABLE 3. REMOVE/REPLACE SOURCE AND ACCELERATOR

1. Disconnect structural, electrical and fluid lines as required externally using contact procedures.
2. Remove source shield cover using modular maintenance vehicle (MMV). Mobile servomanipulator and power manipulator assist as required.
3. Disconnect electrical and fluid lines as required internally using manipulators.
4. Remove source using MMV and special tool.
5. Place source in cask for movement to hot cell.
6. Install new source using MMV and special tool. Manipulators assist as required.
7. Reconnect electrical and fluid lines internally using manipulators.
8. Replace source shield cover using MMV.
9. Reconnect external structural, electrical and fluid lines using contact procedures.

FIGURE 4. REMOVE/REPLACE SOURCE, NEUTRALIZER AND DIRECT RECOVERY

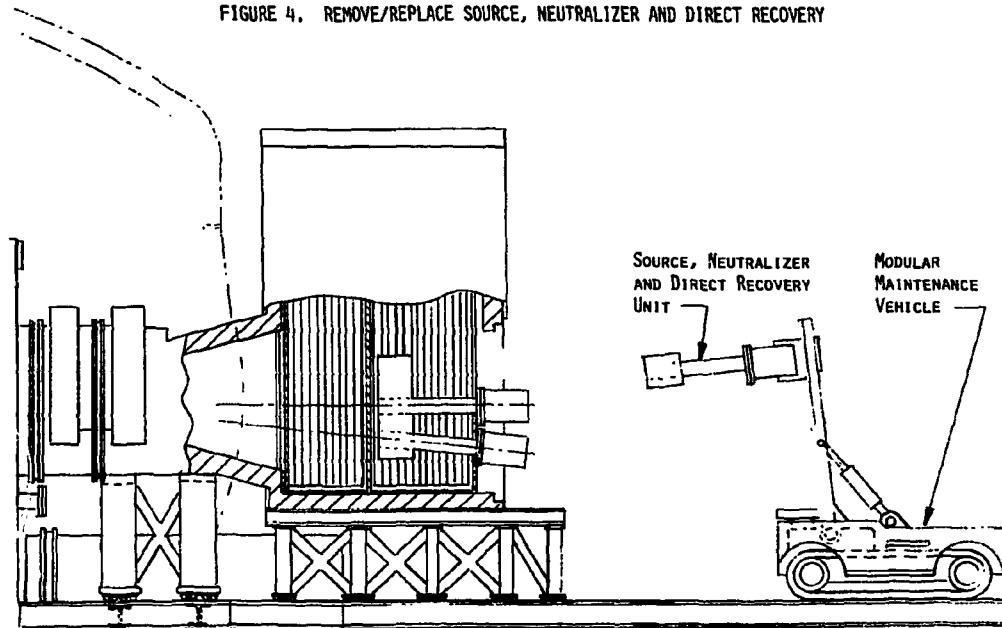


TABLE 4. REMOVE/REPLACE DIRECT RECOVERY UNIT AND MAGNET

1. Disconnect structural, electrical and fluid lines externally using contact procedures.
2. Remove source shield cover using MMV. Manipulator assist as required.
3. Disconnect electrical and fluid lines internally using manipulators.
4. Remove beam line module (includes source, accelerator, neutralizer, direct recovery and bending magnet) using MMV and special tool. Manipulators assist.
5. Repair or replace direct recovery unit and magnet. Manipulators assist as required.
6. Place any removed components in cask for movement to hot cell.
7. Replace beam line module using MMV. Manipulators assist.
8. Reconnect electrical and fluid lines internally using manipulators.
9. Replace source shield cover using MMV.
10. Reconnect external structural, electrical and fluid lines using contact procedures.

FIGURE 5. ALTERNATE METHOD OF ACCESS TO DIRECT RECOVERY UNIT

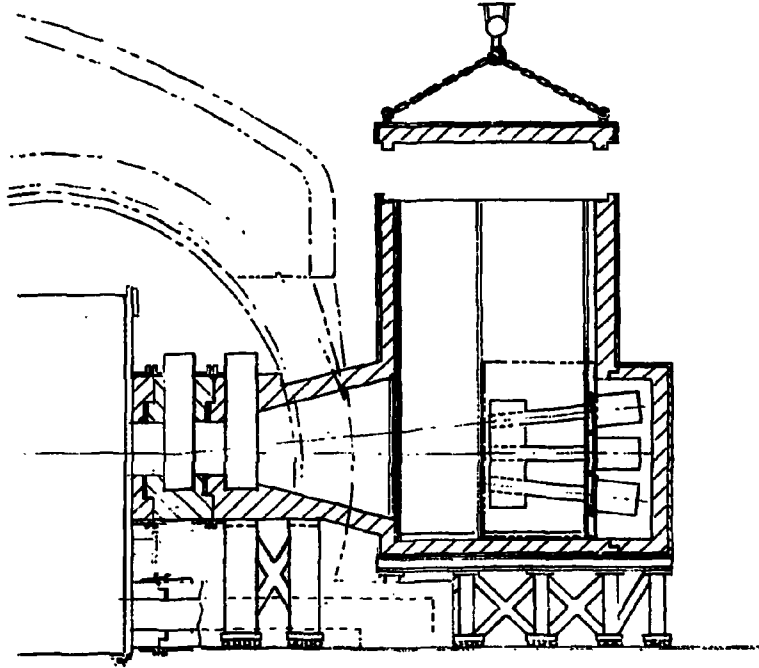
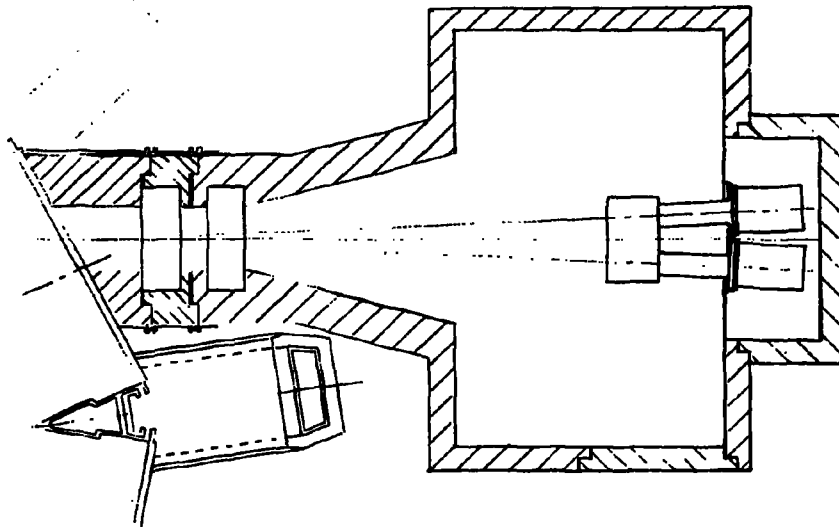


FIGURE 6. ALTERNATE METHOD OF ACCESS TO DIRECT RECOVERY UNIT



**APPENDIX M**



## SHIELDING REPLACEMENT DEVICES

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## SHIELDING REPLACEMENT DEVICES

The purpose of this paper is to present a systems concept for remote maintenance on the Fusion Engineering Device (FED) particularly in the area of shield separation and handling of the extremely heavy components.

Figure SRD-1 is the FED concept as presented at the March 1981 workshop.

To enhance maintenance, the following suggestions are made:

1. At the intersection of the torus and drift duct shielding extend the torus shielding outboard to allow room for the seal welds, (Figure SRD-2, View A).
2. Provide an interface joint between the neutral beam injector shielding and the drift duct shielding, (Figure SRD-2, View B).
3. At the vacuum duct:
  - o Incorporate the shield plug into the drift duct shield module, (Figure SRD-2, View C).
  - o Modify the bellows attachment to the vacuum duct for ease of cutting and rewelding, (Figure SRD-2, View C).
  - o Modify the vacuum duct shielding so it can be removed piecemeal.

Figures SRD-3 through SRD-10 show a gross pictorial sequence of operations which are required to penetrate the shielding to prepare the FED for maintenance operations.

1. Figure SRD-3 - The seal weld is cut at the interface between the neutral beam injector and the drift duct shield module. The 60-ton capacity lift truck is attached to the neutral beam injector in preparation for extracting it along the guide rails.
2. Figure SRD-4 - The neutral beam injector is extracted along the guide rail to provide a gap between it and the drift duct shield module for positioning of the shield support fixture using the overhead crane. The shield support fixture is actuated and the two shield covers are positioned and secured into the respective

openings of the neutral beam injector and the drift duct shield module.

3. Figure SRD-5 - The neutral beam injector is removed from the area. The 60-ton lift truck is attached to the vacuum duct shielding in preparation for its removal.
4. Figure SRD-6 - The vacuum duct shielding is removed piecemeal.
5. Figure SRD-7 - The bellows at the inboard end of the vacuum duct is cut remotely as is the external vertical section, and the vacuum duct is removed.
6. Figure SRD-8 - Shield covers are placed into the two sections of the vacuum duct. The seal weld at the torus shield/drift duct shield module interface is cut.
7. Figure SRD-9 - The drift duct shield module is extracted along the guide rails to provide a gap for positioning the shield support fixture by use of the facilities crane.
8. Figure SRD-10 - The shield covers are placed in the penetrations of the torus and the drift duct shield module.

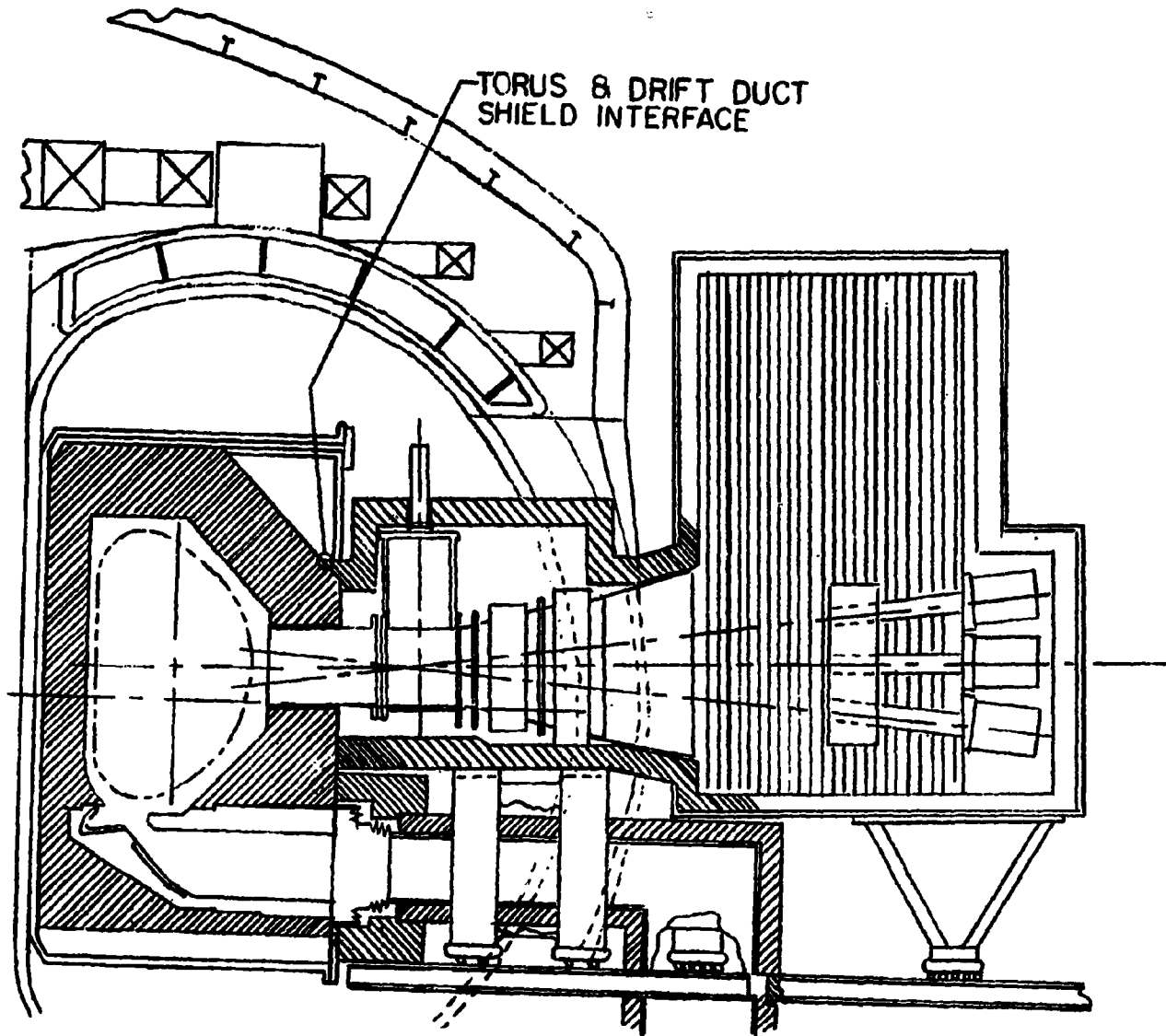
After suitable decontamination, selected maintenance operations may be performed.

The above brief study identifies several pieces of equipment that are required for shield penetration and replacements such as:

- o the 60-ton lift truck or other suitable means of power,
- o various seal weld cutters,
- o various remote seal welders,
- o attachment and handling fixtures to be used with the 60-ton lift truck for assembly and disassembly,
- o shield support fixture, ref. Figure SRD-4,
- o handling fixtures for the vacuum duct shielding,
- o shield covers:
  - (1) neutral beam injector,
  - (2) drift duct shielding at neutral beam interface,
  - (3) vacuum duct at drift duct shield module,
  - (4) vacuum duct for vertical section,
  - (5) torus shield,
  - (6) drift duct shield module at torus shield interface,
- o handling fixture for the torus shield and the inner shield

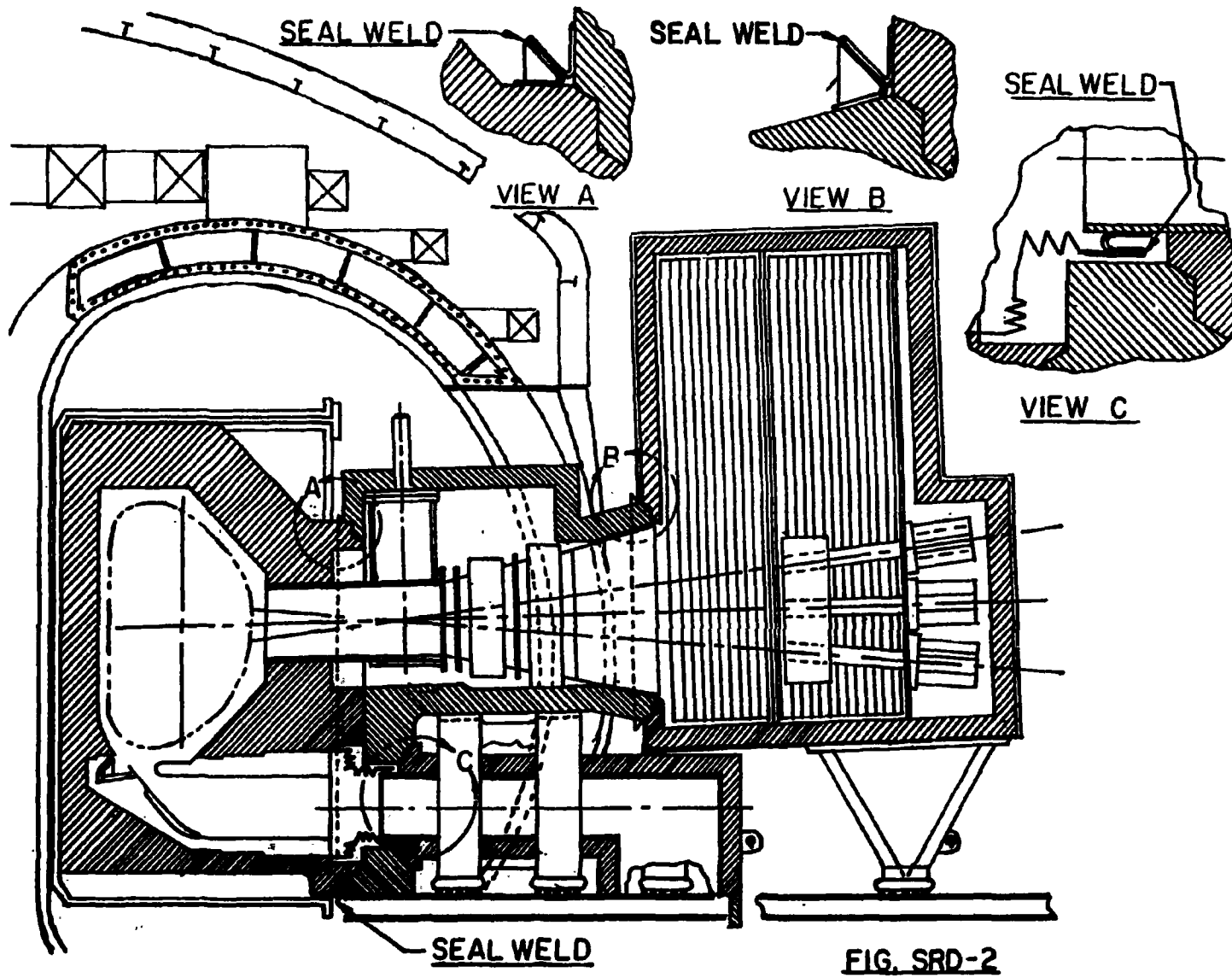
for the drift duct shield module.

It should be noted, when handling extremely heavy components, safety dictates that they be kept to a minimum altitude, (a matter of inches) in order to preclude massive damage should an accident occur. This in turn requires adequate clear floor space for their horizontal movements, very similar to the requirements of a guide rail system.



TORUS & DRIFT DUCT  
SHIELD INTERFACE

FIG. SRD-1



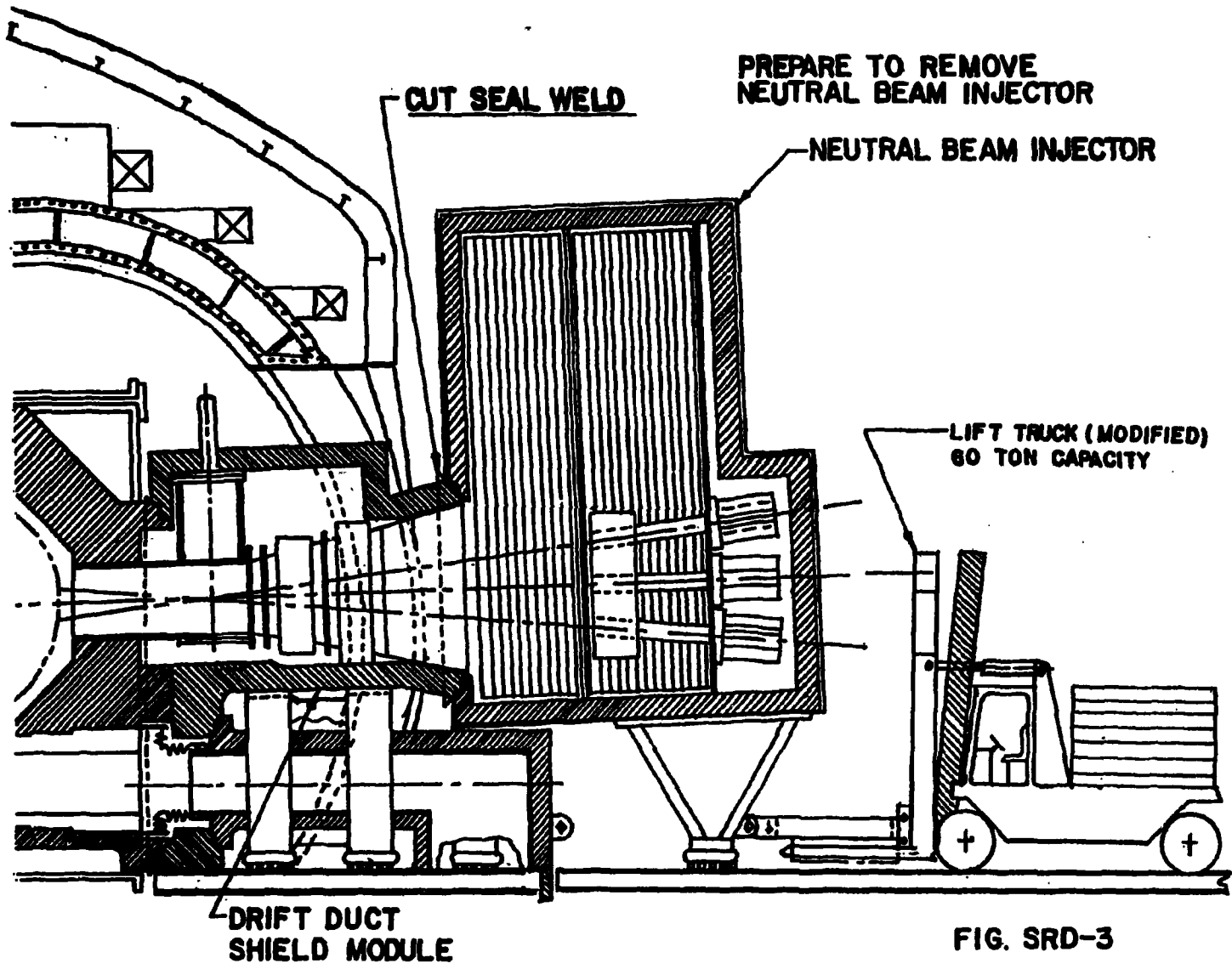


FIG. SRD-3

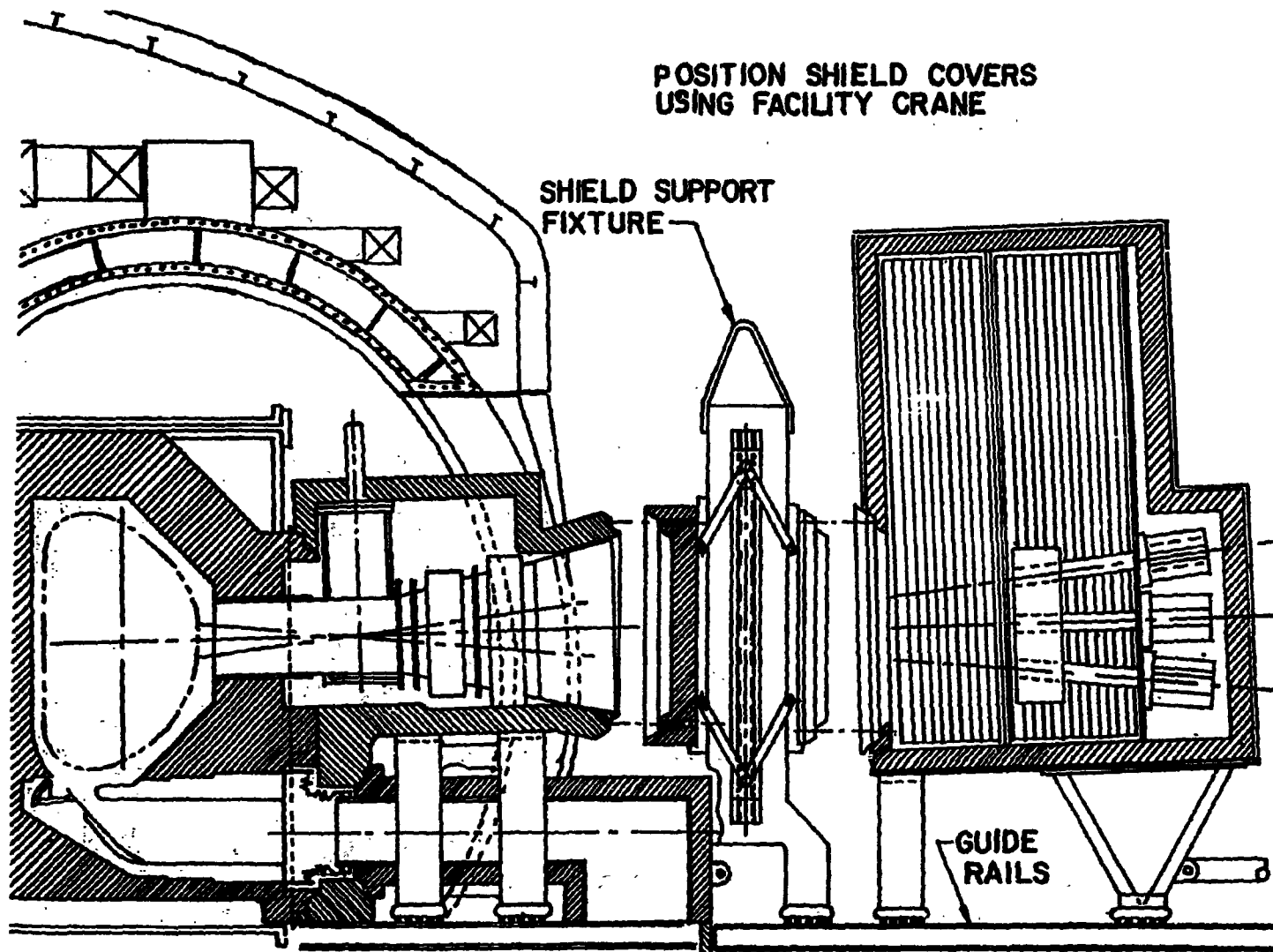
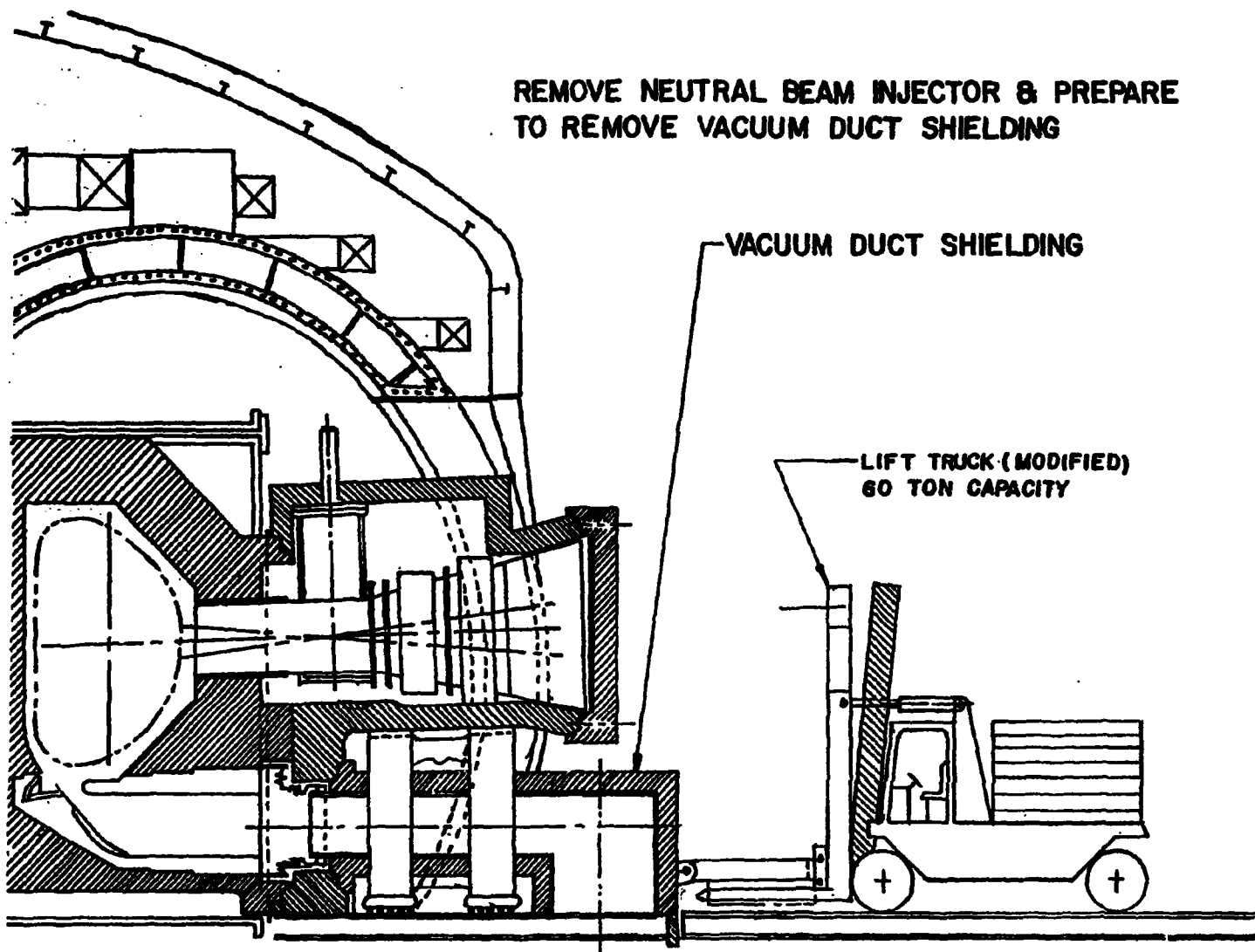


FIG. SRD-4



REMOVE NEUTRAL BEAM INJECTOR & PREPARE  
TO REMOVE VACUUM DUCT SHIELDING

VACUUM DUCT SHIELDING

LIFT TRUCK (MODIFIED)  
60 TON CAPACITY

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FIG. SRD-5

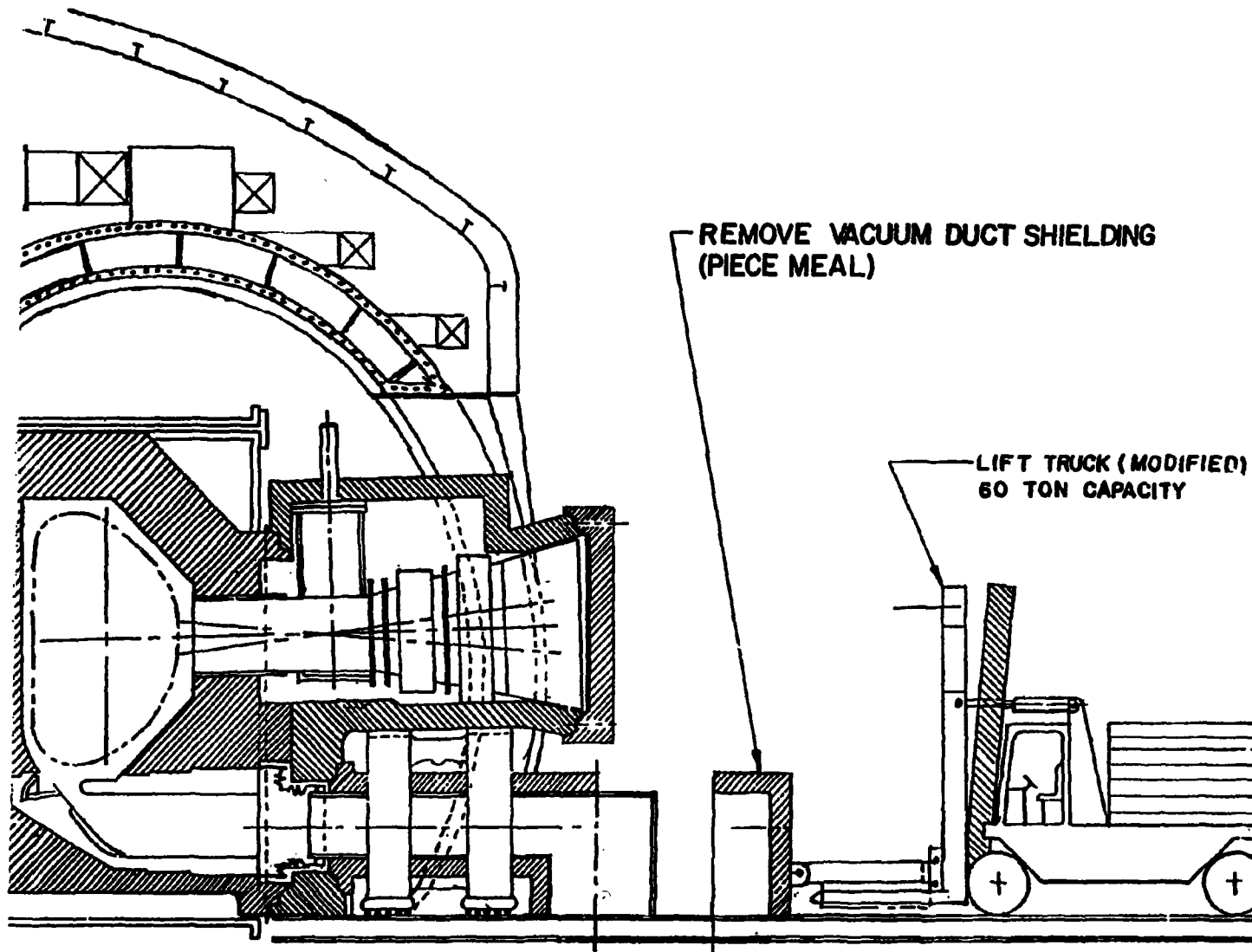
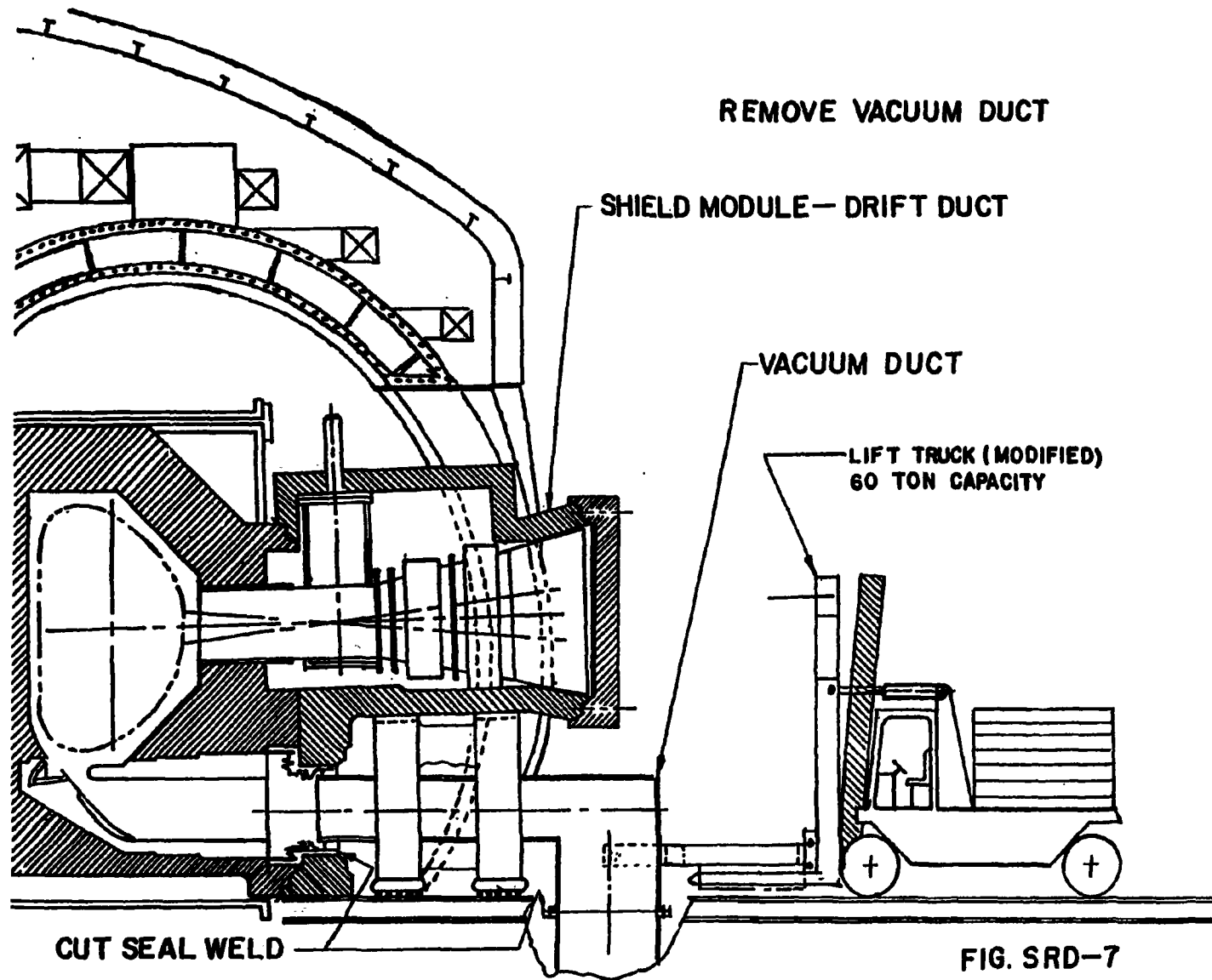


FIG. SRD-6



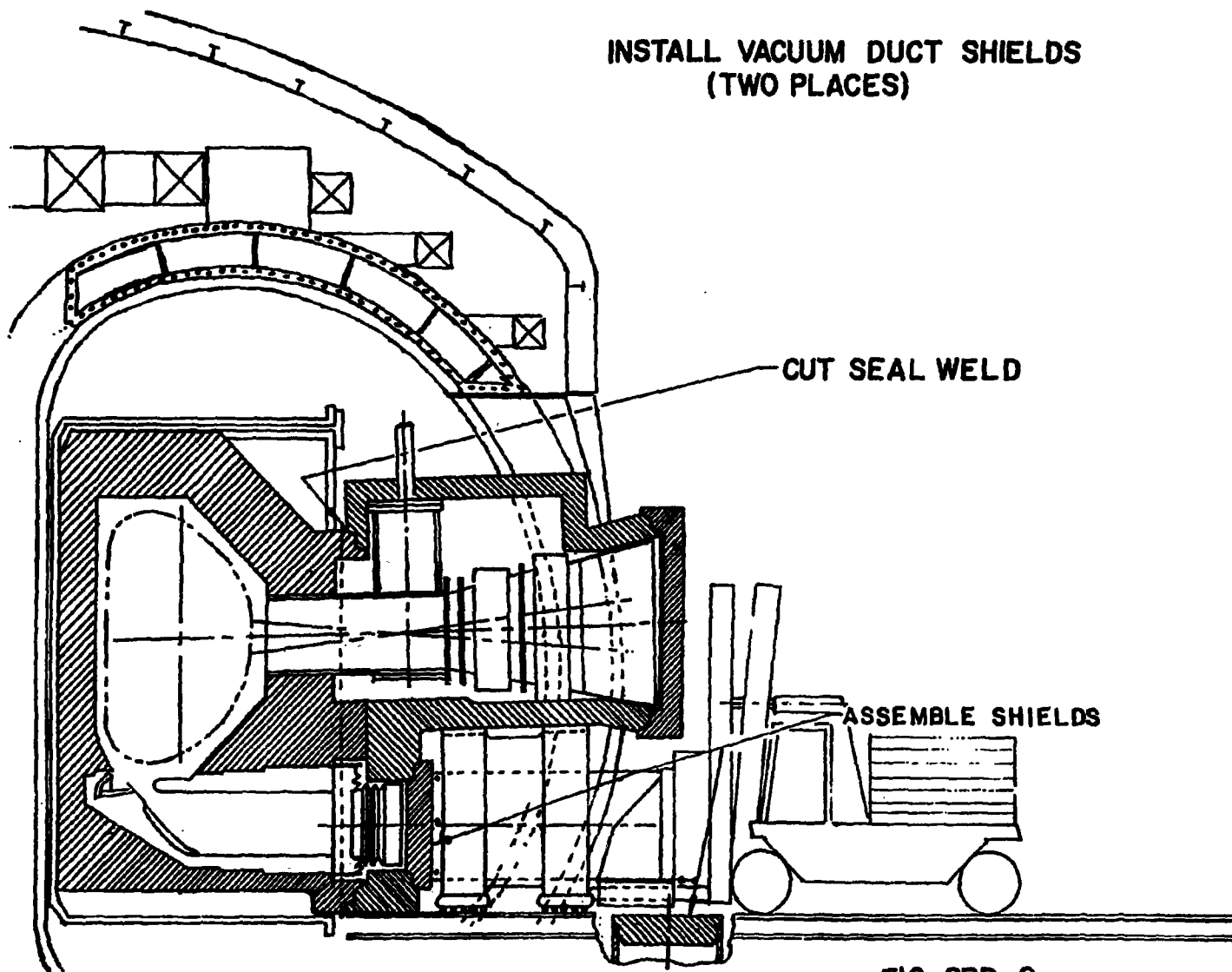


FIG. SRD-8

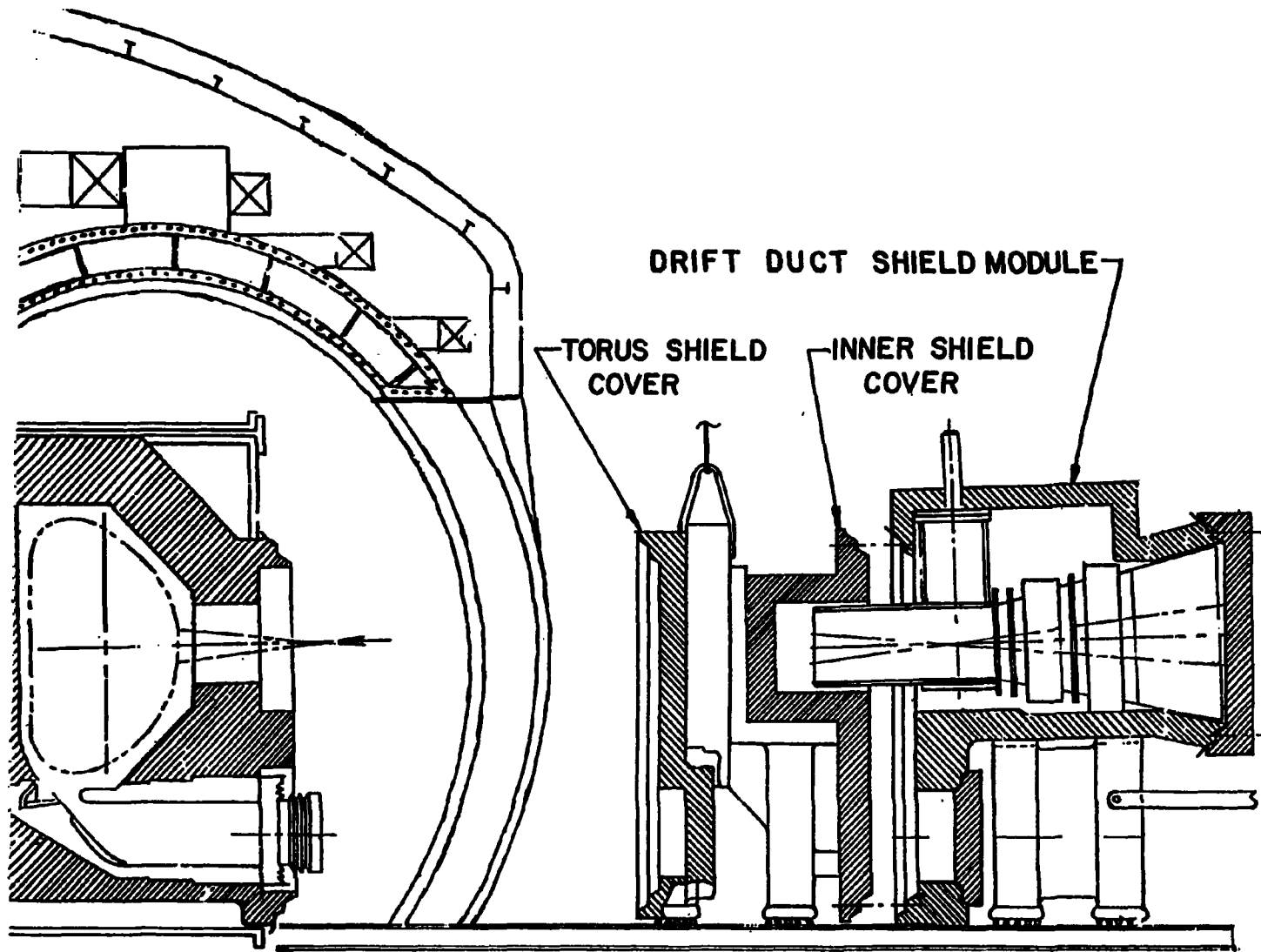
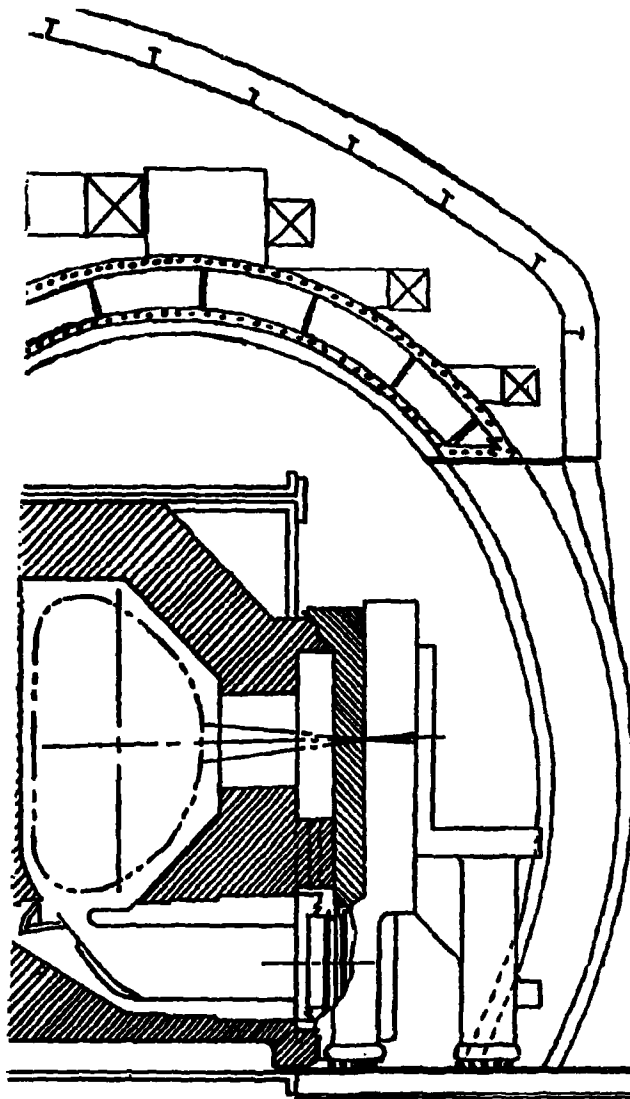


FIG. SRD-9



ASSEMBLE SHIELD COVERS TO:  
• NEUTRAL BEAM SHIELD MODULE  
• TORUS SHIELD

PERFORM MAINTENANCE AS REQUIRED

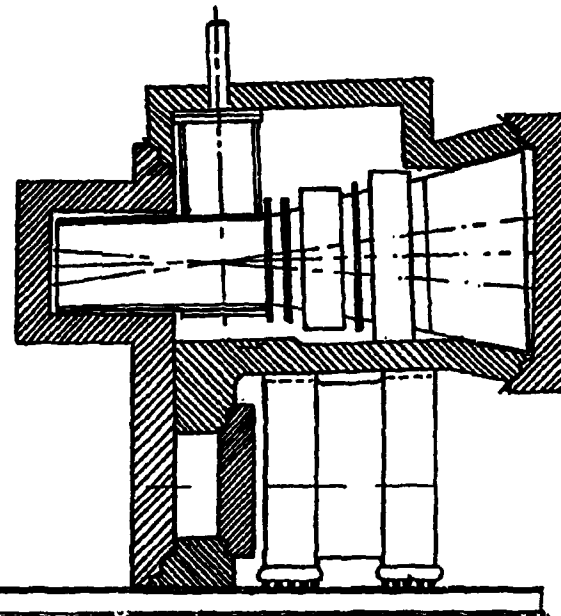


FIG. SRD-10

**APPENDIX N**

## REMOTE MAINTENANCE NEEDS FOR FED MAGNET SYSTEMS

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The magnet coil systems of the FED are all designed for the life of the reactor and for the most part are to be maintenance free. With the exception of the inner field shaping coils, all the toroidal field (TF) coils, poloidal field (PF), equilibrium field (EF) and ohmic heating (OH) coils are permanently fixed, also for the life of the reactor. Since these magnet systems are hopefully to operate on a maintenance free basis, a review has been made to determine what maintenance aspects can be foreseen and which of these requires remote equipment. Only a few repair/maintenance operations were identified and of these only one or two required special "remote" maintenance design considerations.

However, the issue of magnet failure or cryogenic cooling system failures will lead to unit replacement as in situ repair of TF, OH, EF and PF coils were determined to be at best impractical and high risk. Thus, the major consideration in this area becomes magnet replacement and the associated remotely operated equipment requirements. It is well known to all designers that the most difficult repair to a tokamak reactor is the replacement of TF coils and for this task, most all the original assembly equipment is needed along with some special equipment herein identified.

Another unique item addressed briefly herein is the replacement of the lower PF and OH coils trapped by the TF coil system array. Although there is no specific need for remote handling for radiation protection, the difficulty of replacement of these coils must be acknowledged and plans prepared.

In reviewing most all maintenance and repair scenarios for the reactor magnet systems, only one warrants description at this time.

TF Coil Repair

Only minor repairs are expected and the most difficult are associated with vacuum leaks. Attempts to internally repair a TF coil in situ have been reviewed and for the majority of cases, replacement was considered the only reasonable recourse. Most of the massive dewar/vacuum jackets are repairable without the need of remote maintenance equipment. However, some special equipment is needed, such as (a) diagnostic equipment for fault identification and general location and (b) vacuum leak location devices. These items are addressed elsewhere in this review. The only areas where repair of the TF coil vacuum jacket requires special equipment are located in the bore of the TF coil. Here in the inboard region, access for both leak location device and its repair will require removal of the blanket shield sections from the proximity of the leak. It is important to locate the leak within one or two shield sections or the reactor component removal process will easily escalate. Once the shield sections are removed and the inboard bore of the common TF coil vacuum jacket is accessible, the highly radioactive open ends of the plasma chamber will need to be shielded. Special designed end plugs are needed here as shielding to allow personnel access for repair. In addition, temporary lead sheet shielding may be needed to lower radiation levels from hot spots. A condensed listing of both special and major equipment required for the magnet systems maintenance/repair and replacement is given as follows.

TF Coil System

Maintenance - No special tools.

Repair - Special equipment

- . Fault diagnostic equipment
- . Vacuum leak location devices
- . Plasma chamber shield plugs

Replacement - Original assembly equipment

- . Plasma chamber shield plugs
- . OH and EF coil handling equipment
- . Torque frame handling equipment
- . TF coil lifting and transporter fixtures

- . Spare TF coil or material on hand (If the coils were fabricated on site, all equipment should be kept.)

OH Solenoid - No special tools.

EF & OH Ring Coil

Maintenance - No special tools

Repair - No special tools

Replacement

Upper Coils (lift off coils)

- . Handling slings
- . Lay down area
- . Spare coils (or extra materials and fabrication equipment)

Lower Coils (trapped coils)

- . Spare coils in situ
- . Coil winding space (provision for)

Summary

Very few additional or new remote handling equipment appears to be required for the magnet systems. However, most all of the very heavy original reactor assembly equipment must be kept available for repair/replacement requirements. This factor will significantly influence the reactor building design, with its access and cargo doors, lay down space, reactor support pedestal, crane and storage area. In addition, the ex-reactor building will be required to house the large and numerous dollies, lifting jigs, magnet coil materials and winding fixtures. Of the special equipment not available during assembly or for normal maintenance programs, only the following items are special:

- . Magnet fault diagnostic equipment
- . Vacuum leak location device
- . Plasma chamber end shield plug coils
- . Trapped coils (lower ring coil) replacement equipment

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