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Westinghouse Electric Corporation
Fusion Power Systems Department

SEQUENCE OF OPERATIONS
TFTR ASSEMBLY AND DISASSEMBLY

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ABSTRACT

A conceptual sequence of operations necessary to complete initial assembly of the Tokamak Fusion Test Reactor (TFTR) are described along with subsequent disassembly operations and special techniques planned for use during radioactive disassembly. Special attention is given in this report to techniques, personnel exposure, and equipment needed to effect the opening and closing of a vacuum vessel port and the installation of the vacuum vessel seal weld cutting machine under radioactive conditions.

ACKNOWLEDGEMENT

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1.0 INTRODUCTION

1.1 PURPOSE OF REPORT

The purpose of this report is to present a conceptual assembly and disassembly sequence of operations for the Tokamak Fusion Test Reactor. In addition, a conceptual design relative to the handling techniques and a "model maintenance system" to be used in removing an activated component is also presented. The "model maintenance system" describes the operations, techniques, and handling equipment necessary to remove shielding, access port covers, and installation of the vacuum vessel (main parting plane) remote - operating, seal weld cutting machine.

The conceptual assembly and disassembly sequence of operations will be continuously upgraded during the development of the TFTR design. The sequence of operations will be used to functionally establish the need for special single-purpose equipment, special back-up systems and contingency equipment, areas of design interface, control of component installation/removal to assure space or envelope compatibility, identification of required procedures, definition of special training, testing, schedule development including parallel operations, and manning requirements (craftsmen as well as Engineers/Scientists). In general, the "Sequence of Operations Document" is the principal controlling "software" in the design, development as well as the implementation of a particular maintenance or servicing task.

It is the objective to utilize the subject "model maintenance system" as a reference design in the development of methods to handle, remove and/or assemble activated components. It should be recognized that the model scope considers man-rem exposure as well as handling techniques and equipment. Man-rem exposure considerations are necessary early in the conceptual design in that, unlike major nuclear-type facilities, manpower availability could be a limiting factor in the implementation of a servicing operation/tasks. For purposes of identification, the present system is considered a semi-remote handling system utilizing supplementary shielding for personnel protection.

1.2 FUNCTIONAL REQUIREMENTS; MAINTENANCE SYSTEMS

The design and development of a cohesive Maintenance/Servicing System requires the establishment of functional requirements which should be used as a design guide and also the means of measure to confirm that the various sub-systems are consistent with the overall system. Typical functional requirements for a maintenance/servicing facility are as follows:

a) System will be flexible with redundant design to assure that each maintenance operation can be accomplished remotely, if necessary, as a function of unexpected high radiation levels.

b) Hands-on conventional maintenance/servicing operations will be planned for each operation where expected radiation levels (as a function of maximum operating conditions) are less than 200 mr/hr at surface of components. Length of exposure (man-rem) should also be considered.

c) Shadow shielding of activated components and/or personnel will be utilized to reduce radiation levels and increase the hands-on conventional or semi-remote maintenance servicing capabilities.

d) Final design will include full remote handling features in selected areas where analysis has determined high radiation levels and shadow shielding is not feasible.

e) Minor preventive maintenance operations, inspection of components, adjustment of equipment will be accomplished in Test Cell.

f) Major maintenance operations will normally require removal of components/equipment to Hot Cells.

g) Initiation of Remote Servicing operations will be possible 15 minutes after the completion of a D-T experimental pulse.

h) Major design objectives are to assure safety of operation, maximize the use of existing technology, high reliability, low equipment cost and recognition of schedular considerations to preclude unnecessary delays in TFTR Operations.

i) In the event of a system malfunction, the equipment should be capable of recovery without significant perturbations.

2.0 INITIAL ASSEMBLY OF THE TFTR

2.1 INTRODUCTION

Assembly of the TFTR is planned in three phases. In each phase, the device will be assembled to the simplest configuration required to conduct experiments in that phase. This will simplify alterations to the TFTR required to correct deficiencies discovered during experiments. For example, Top, Upper Peripheral and Lower Peripheral Shields are not required until Phase 3. Installing these shields initially would interfere with modifications found necessary during Phase 1 experiments.

The three phases are:

Phase 1 - those operations necessary to prepare the device for Phase 1 experiments; i. e., low energy experiments involving use of hydrogen.

Phase 2 - prepare the TFTR for high energy, non-tritium experiments, using hydrogen and deuterium.

Phase 3 - complete final assembly required to conduct high energy experiments using deuterium and tritium.

2.2 ASSEMBLY OPERATIONS

2.2.1 Prerequisites

2.2.1.1 Construction of the Mockup and Assembly Bay and Test Cell is completed, cranes installed, and clean-room conditions established.

2.2.1.2 All utilities and services to the above areas installed, connected, and operating.

2.2.1.3 Mounting plate for Field Coil Support Pedestal in place in operating floor of Test Cell, together with nine rails for moving device half.

2.2.1.4 Cooling water lines and electrical bus have been installed to the device interface.

2.2.1.5 The following modules/assemblies have been preassembled outside of the Test Cell (in Mockup and Assembly Bay or in an outside area):

a. Lower, center, and upper sections of inner OH and EF Coils. Refer to this single assembly as the Inner Poloidal Field Coil Module. (Lower coils mounted on lower support arms, center coils on central cylinder, and upper coils on upper support arms.) See Subsection 2.2.5.1 for assembly procedure.

b. Stationary and movable parts of substructure without shielding. Twenty TF Coil Pedestals are in place, 10 on each half. To support the stationary substructure, 41 support pads are in place on Test Cell floor. As support for the movable substructure, 41 Roundway Bearings are attached to the substructure. (See Subsection 2.2.5.2 for assembly.)

c. Twenty TF Coils with shear panels in place. Holes for bolting outer Poloidal Field Coil brackets will be drilled at fabricator's plant.

d. 180° segments of outer EF and OH Coils. (Brackets for coils mounted on TF Coil case.)

e. Vacuum vessel in two halves with partial vessel shielding in place. (Each open face blanked for shipping and cleanliness.) Vessel weight is 30 tonnes (33 tons) while vessel shielding weighs 102 tonnes (113 tons). Total weight allowed for each vessel half and shielding is limited to 45 tonnes (50 tons); the capacity of the cranes in Mockup and Assembly Bay and Test Cell. Vessel shielding will be in crescent-shaped segments and will bolt to support brackets which are welded to top of vessel reinforcing rings.

f. Vacuum pumps (4).

g. 180° segments of cooling water headers complete with mounting brackets and hangers. (Forty manifolds will be attached on site.)

h. Gas injection system (for tritium, hydrogen, deuterium, etc.).

i. Major components of the Neutral Beam Lines.

j. Shielding segments for Top Shield, Upper Peripheral Shield, Lower Peripheral Shield, Inner Base Shield, and Outer Base Shield.

2.2.2 Phase 1 Assembly (Drawing Numbers identified where established)

2.2.2.1 Install Poloidal Field Coil Support Pedestal 1.6 m (5'2") in diameter by 0.7 m (2'3") high, weighing about 3.4 tonnes (3.8 tons) on mounting plate in Test Cell floor. This Pedestal bolts to the mounting plate with 8 - 3.2 cm (1.25") diameter bolts. (346867J)

2.2.2.2 Place Inner Base Shield segments. These blocks are ordinary concrete in pie-shaped segments with total weight about 4.5 tonnes (5 tons). (346867J and 346869C)

2.2.2.3 Place preassembled stationary portion of substructure 6.1 m x 12.2 m (20' x 40'), weighing 43 tonnes (47 tons) on 41 support pads which have been grouted into Test Cell floor. (346869C)

2.2.2.4 Install preassembled movable half of substructure. 41 Roundway Bearings attached to lower I-beams rest on 9 Roundway Rails which are recessed into Test Cell floor. Same dimensions and weight as above. (346867J)

2.2.2.5 Install four hydraulic cylinders for displacing movable half of substructure.

2.2.2.6 Bring two substructure halves together using hydraulic cylinders for trial fit. Separate prior to next step.

2.2.2.7 Install 132 outer Poloidal Field Coil brackets on TF Coil cases and 20 vacuum vessel support roller assemblies on the bottom inside diameter of TF Coil cases.

2.2.2.8 Place first preassembled TF Coil (18.3 tonnes (20.2 tons) each) on coil pedestal. Pedestals are 40.6 cm x 40.6 cm x 26.7 cm (16" x 16" x 10-1/2") high. Each circular channel section of the coil (2 sections) rests on half of a pedestal width. Provide necessary blocking. (346868J)

2.2.2.9 Place adjacent TF Coil on Coil Pedestals. Align and block. Insert and torque 13 - 5.1 cm (2") diameter high-strength bolts. (346868J)

2.2.2.10 Continue above process until 10 TF Coils are in place on each substructure half.

2.2.2.11 Bring two halves together, using hydraulic cylinders, for trial fit of TF Coils. Align holes at parting plane for 22 shear pins and 4 bolts. Insert 5.1 cm (2") diameter shear pins and bolts (11 pins and 2 bolts at each joint). Torque bolts.

2.2.2.12 Make electrical connections between TF Coils. There are 19 bolted electrical connections at top of the TF Coils, two of which will be at the parting plane. Make final connection (No. 20) between bus bar and last TF Coil assemblies. (346868J)

2.2.2.13 Install deflection gauges to measure movement of TF Coils, then pulse the coils to seat them. This assumes motor generator power is available. (Cooling water is not required if coils are allowed about a 30-minute cooling period between pulses.)

2.2.2.14 Break TF Coil electrical connections. Remove 4 bolts at parting plane and separate two halves using hydraulic cylinders.

2.2.2.15 Install Inner Poloidal Field Coil Module on Poloidal Field Coil Support Pedestal by loosening nuts on 4 - 5.1 cm (2") diameter thru bolts, rotating heads into slots in the Pedestal, and then retightening the nuts. Overall dimensions of the assembly are 4.9 m high x 6.1 m (16 ft. high by 20 ft.) outside diameter. (346870J) Total weight of assembly is about 33.6 tonnes (37 tons) distributed as follows:

Central Cylinder	-	11.8 tonnes (13 tons)
Inner OH and EF Coils	-	18.1 tonnes (20 tons)
40 Inner Support Arms Including Coil Connectors	-	3.6 tonnes (4 tons)
TOTAL	-	33.5 tonnes (37 tons)

2.2.2.16 Assemble 40 manifolds on water header assemblies using Marman Clamps (20 manifolds for each assembly half).

2.2.2.17 Install water header assembly on TF Coil assembly pads (fixed half of device). Overall dimensions with manifolds in place is 4.6 m x 10.1 m x 2.1 m (15 ft. by 33.2 ft. by 6.8 ft.) high. Assembly includes mounting brackets and hangers complete with inlet/outlet sections. Total weight of assembly is about 5.9 tonnes (6.5 tons). (346865J)

2.2.2.18 Concurrently with 2.2.2.17, install 180° segments of outer Poloidal coils in brackets mounted on TF Coil case (movable half). Overall dimensions are 5.1 m (16.5 ft.) by 10 m (33 ft.); total weight is about 7.2 tonnes (8.0 tons). There are three different size brackets and 22 of each size required - one per TF Coil plus 2 for the parting plane. Working from the bottom up, insert six 180° coil assemblies. Each 180° assembly slides into brackets located on TF Coil case at 11 locations. At 4 locations at each of the 6 levels, insert a radial guide pin 1.6 m (5/8") diameter. Make intercoil electrical connections. (346870J)

2.2.2.19 Place water header assembly on movable half.

2.2.2.20 Concurrently with 2.2.2.19, install six 180° coil assemblies on the fixed half.

2.2.2.21 Bring two halves together to check parting plane electrical connections for Poloidal field coils. Separate the two sections.

2.2.2.22 Bring one vacuum vessel half into Test Cell on special vessel removal rig which rests on a removal stand.* Out-to-out dimensions of each half is about 4.0 m x 7.9 m x 2.4 m (13' x 26' x 8') high; weight with partial shielding is 45.4 tonnes (50 tons). Assemble remaining vessel shielding to each half, bolting the segments to support brackets mounted on top of the vessel (approximately 20.9 tonnes (23 tons) additional for each half). See Subsection 2.2.5.3 for assembly and installation of Protective Plates which will be completed in Mock-Up and Assembly Bay prior to bringing vacuum vessel halves into Cell.

2.2.2.23 Align vacuum vessel support rollers. Remove end blanks and install half of vacuum vessel in stationary portion inside TF Coils. The built-in support rail at the vessel base engages and rests on the support rollers which are attached to the lower inside surface of the TF Coil case. Move the vessel onto the rollers by activating a gear drive on the vessel removal rig. Weight of each vessel half is about 66.2 tonnes (73 tons) with shielding in place. (346863J)

2.2.2.24 Repeat 2.2.2.22 and 2.2.2.23 for second half of vessel in movable portion.

2.2.2.25 Bring two portions together to check alignment of vessel halves. Determine by visual inspection that two halves of the parting ring match. Make adjustments, if necessary. (346863J)

2.2.2.26 Install neutral beam and vacuum pump adaptors to vacuum vessel. There are six neutral beam ports with rectangular flanges. Four Neutral Beam Lines will be installed, two on adaptors to receive diffusion pumps and two on single-purpose adaptors. (346777J)

*The vessel half will be placed on removal rig in Mock-Up and Assembly Bay and entire unit transported to Test Cell on transfer car. Test Cell crane will pick up vessel half with removal rig and place on removal stand which will be located between the two substructure sections.

2.2.2.27 Make water connections from header manifolds to TF and Poloidal field coils using flexible, quick-disconnect hose connections. (346868J and 346870J)

TF Coils: There are 44 cooling channels per coil, each channel with an inlet and outlet, or a total of 88 quick-disconnect couplings on each TF Coil, plus 88 similar couplings on the two manifolds which service each TF Coil (44 on inlet manifold and 44 on the outlet). Total couplings - 176 per coil.

Inner Poloidal Field Coils: Four inlet manifolds on the header feed 4 inlet submanifolds supported on the upper inner support arms.

The same arrangement holds for the outlet header manifolds and the outlet submanifolds which are supported on the lower inner support arms. There are 24 inlet connections from the submanifolds to the Inner Poloidal Coils and 24 outlet connections. Total number of quick-disconnect connections is therefore 56.

Outer Poloidal Field Coils: Twelve inlet manifolds and 12 outlet manifolds on the header have connections to a corresponding number of inlet and outlet submanifolds on the Outer Coils. There are therefore a total of 48 quick-disconnect connections.

At this point, the basic Tokamak System is assembled.

2.2.2.28 Install 4 vacuum pumps, 2 on Neutral Beam Adaptors, and 2 on Adaptors attached directly to the vacuum vessel. In all cases, the pump flange bolts to the adaptor flange with 8 - 2.1 cm (13/16") diameter bolts. (346777J)

2.2.2.29 Remove shipping covers (blanks) from vacuum vessel diagnostic port flanges and prepare ports for installation of diagnostics for Phase 1 experiments.

2.2.2.30 Install Phase 1 diagnostics.

2.2.2.31 Install limiters and breakdown oscillators. See Subsection 2.2.5.4 for assembly of limiters. (No data are available at present on breakdown oscillator installation.)

2.2.2.32 Connect 5 gas injection systems (for tritium, hydrogen, deuterium, etc.), and 2 tritium cleanup system lines (one inlet and one outlet).

2.2.2.33 Complete electrical connections between two halves for TF, OH, and EF coils. Make electrical continuity checks. Each Poloidal Coil winding has 2 parting plane electrical connections of the quick-disconnect type. Install and torque 4 bolts at TF Coil case horizontal centerline at parting plane.

2.2.2.34 Connect cooling water headers to incoming water lines. Pressurize the system and check for leaks.

2.2.2.35 Connect electrical busses to each coil system.

2.2.2.36 Install 12 band assembly halves on outer Poloidal field coil assemblies. (Each band half has a jacking mechanism.) Actuate the jacks to provide proper coil preload. (346870J)

2.2.2.37 Energize TFTR, pulse the coil systems using motor generator power source, and make complete system checkout (less gas injection and vacuum check).

2.2.2.38 Make final closure joints (2) using 2 ports at parting plane 180° apart. Present plan is to make the closure with a seal weld using special, automatic equipment.

2.2.2.39 Replace covers on 2 closure ports. X-Ray the weld and leak-test closure welds using a tracer gas in the annular space provided in the parting ring. (346863J)

2.2.2.40 Complete system checkout under local control. (Remote control checkout comes later.)**

**Basic device and support systems now operable for low-energy hydrogen experiments. This completes Phase 1 assembly.

2.2.3 Phase 2 Assembly

2.2.3.1 Install Neutral Beam Lines using components supplied by manufacturer and his assembly/installation instructions.

2.2.3.2 Install Phase 2 diagnostics. This completes Phase 2 installation and the device is ready for high-energy experiments with hydrogen and deuterium.

2.2.4 Phase 3 Assembly

2.2.4.1 Install Phase 3 diagnostics.

2.2.4.2 Install segments of Top Shield, Upper Peripheral Shield, Lower Peripheral Shield and Outer Base Shield. Weights are:

Top Shield	-	59.0 tonnes (65 tons)
Upper Peripheral Shield	-	42.6 tonnes (47 tons)
Lower Peripheral Shield	-	30.8 tonnes (34 tons)
Outer Base Shield	-	44.4 tonnes (49 tons)

This completes Phase 3 assembly and high-energy experiments with tritium can now be conducted.

2.2.5 Assembly of Modules (See Subsection 2.2.1.5)

2.2.5.1 Assembly of Inner Poloidal Field Coil Module (346870J, Sheets 1 and 2)

a. Install four 5.1 cm (2") diameter thru bolts, head down, in Lower Support Arm Ring.

b. Install three Split Rings in grooves on inside diameter of lower Support Arm Ring.

c. Bolt twenty Inner Support Arms to the Lower Support Arm Ring (bolts go into split rings).

d. Place ten poloidal coil assemblies on the Support Arms. These are 360° assemblies. Install four water manifolds on four designated Support Arms.

e. Install Retaining Plates on each coil assembly, place and torque 1.3 cm (1/2") diameter retaining bolts and nuts.

f. Concurrently with d. above (at different location) place four 3.8 cm (1-1/2") tie bolts through spacer and thread center support ring down over the tie bolts. Install inner poloidal coil assembly over the Center Support Ring. Place upper spacer over tie bolts and torque bolts.

g. Concurrently with d. and f. above, and at separate location, install three split rings in grooves cut on inside of Upper Support Arm Ring.

h. Bolt twenty Inner Support Arms on Upper Support Arm Ring (bolts go into split rings).

i. Invert subassembly of step h. above.

j. Place ten poloidal coil assemblies (360°) on Support Arms attached to Upper Support Arm Ring. Install four water manifolds on four designated Support Arms.

k. Install Retaining Plates on each coil assembly above, place and torque 1.3 cm (1/2") diameter retaining bolts and nuts.

l. Place Center Support Ring (with inner poloidal coils) subassembly on Lower Support Arm Ring, sliding the subassembly over four thru bolts in the process.

m. Invert subassembly of k. above, line up holes for four thru bolts, and place on top of Center Support Ring subassembly.

n. Place nuts on four thru bolts and snug up. Inner Poloidal Field Coil Module is now ready to place on the Poloidal Field Coil Support Pedestal.

2.2.5.2 Assembly and Installation of Substructure

a. Fabricator provides two substructure halves, including TF Coil support pedestals; Roundway rails; Roundway bearings; and support pads (for stationary portion).

b. At his plant, manufacturer assembles the complete structure, including testing of the movable half on Roundway rails. He match-marks each member before disassembly.

c. Fabricator prepares written assembly instructions and ships substructure to the Princeton site.

d. Installation contractor at TFTR site receives the substructure, installs Roundway rails in Test Cell Floor, and places support pads.

e. In Mock-Up and Assembly Bay, installation contractor assembles two substructure halves and transports them by crane and transfer cart into Test Cell where final installation is made.

2.2.5.3 Assembly and Installation of Vacuum Vessel Protective Plates (346863J)

a. Requirements

(1) At each of seven locations, three on one vessel half and four on the other, the circular reinforcing rings, including integral support rings, are in place.

(2) Horizontal braces, each 26.7 cm (10.5") long, are welded to the circular reinforcing rings. There are four braces at each location or a total of 28.

(3) For each of seven locations, the following three components are available:

2 Tungsten Protective Plates attached with bolts to vertical Molybdenum support bars.

1 hexagonal Protective Plug attached to a 63.5 cm (25") diameter flange cover by means of a bracket and bar assembly.

(4) Vacuum Vessel fabricator has made a trial fit of Protective Plates at his plant, match-marked the parts, and shipped with the vessel to the site.

b. Procedures (in Mockup and Assembly Bay)

(1) At each of seven locations, attach two Protective Plates (with vertical support bars) to the horizontal braces using two adjustable, quick-release fasteners for each plate.

(2) Insert a hexagonal Protective Plug in each of the seven 63.5 cm (25") diameter nozzles.

(3) In each nozzle flange, place 54 - 1.3 cm (1/2") diameter thru bolts, apply nuts, and torque.

2.2.5.4 Assembly and Installation of Limiters (346863J)

a. Requirements

(1) Four components of limiter assembly are available: the inner, upper and lower pieces which are fixed; and the movable outer limiter which is supported by a sealed and insulated positioning mechanism.

(2) For each fixed component, two attachment bars are welded to the reinforcing ring.

(3) Vacuum vessel fabricator has made a trial fit of the four components at his plant, match-marked the parts, and shipped with vessel to the site.

b. Procedures

(1) Attach three fixed components to attachment bars using two adjustable, quick-release fasteners per component. Accomplish in Mockup and Assembly Bay.

(2) In the Test Cell, position the movable limiter assembly with the bridge crane (using lifting lug attached to the assembly) and bolt to the 63 cm (25") diameter flange provided. About 48 - 1.3 cm (1/2") bolts are required.

(3) Connect electrical leads to actuator drive and position indicator.

3.0 RADIOACTIVE DISASSEMBLY AND REASSEMBLY

The term "radioactive disassembly" refers to the operations that will be required to disassemble the TFTR after D-T experiments have been conducted, thus producing radioactivity in the Tokamak hardware. These disassembly operations will be accomplished using remote methods (that is, without personnel being exposed to the Test Cell environment), semi-remote with the use of supplementary shielding, or by the use of hands-on method if radiation levels are acceptable. The method actually selected for a specific operation will be a direct function of the local radiation field during the operation.

In actual practice, the sequence of disassembly operations will be tailored to remove or repair a specific component that has malfunctioned. For the purposes of this report, radioactive disassembly is described as a sequence of operations reversed from the sequence given in Section 2.0. The disassembly sequence selectively utilizes the appropriate level of shielding and handling system that is compatible with the radioactivity expected to be encountered. Provisions will also be made for conducting all disassembly operations without exposing personnel to the Test Cell environment. Such operations are not described, however, except for operations where hands-on or semi-remote methods cannot be used because of expected high radiation levels. Hands-on and semi-remote methods are preferable because they are faster than remote methods and are therefore described in Section 3.2 of this report.

3.1 PREREQUISITES FOR RADIOACTIVE DISASSEMBLY

The equipment included in the Remote Handling and Maintenance System (SD No. TFTR-SD-5C) as installed in the Experimental Areas of the TFTR facility, is required to perform the radioactive disassembly operations described below. Figure 3.1-1 shows the installation of the more important remote handling and maintenance equipment planned for use. The equipment shown is "general purpose" equipment as opposed to the "specialized" equipment that must be designed to suit the handling needs of given components. Some of this specialized hardware is described in Section 4.0 of this report.

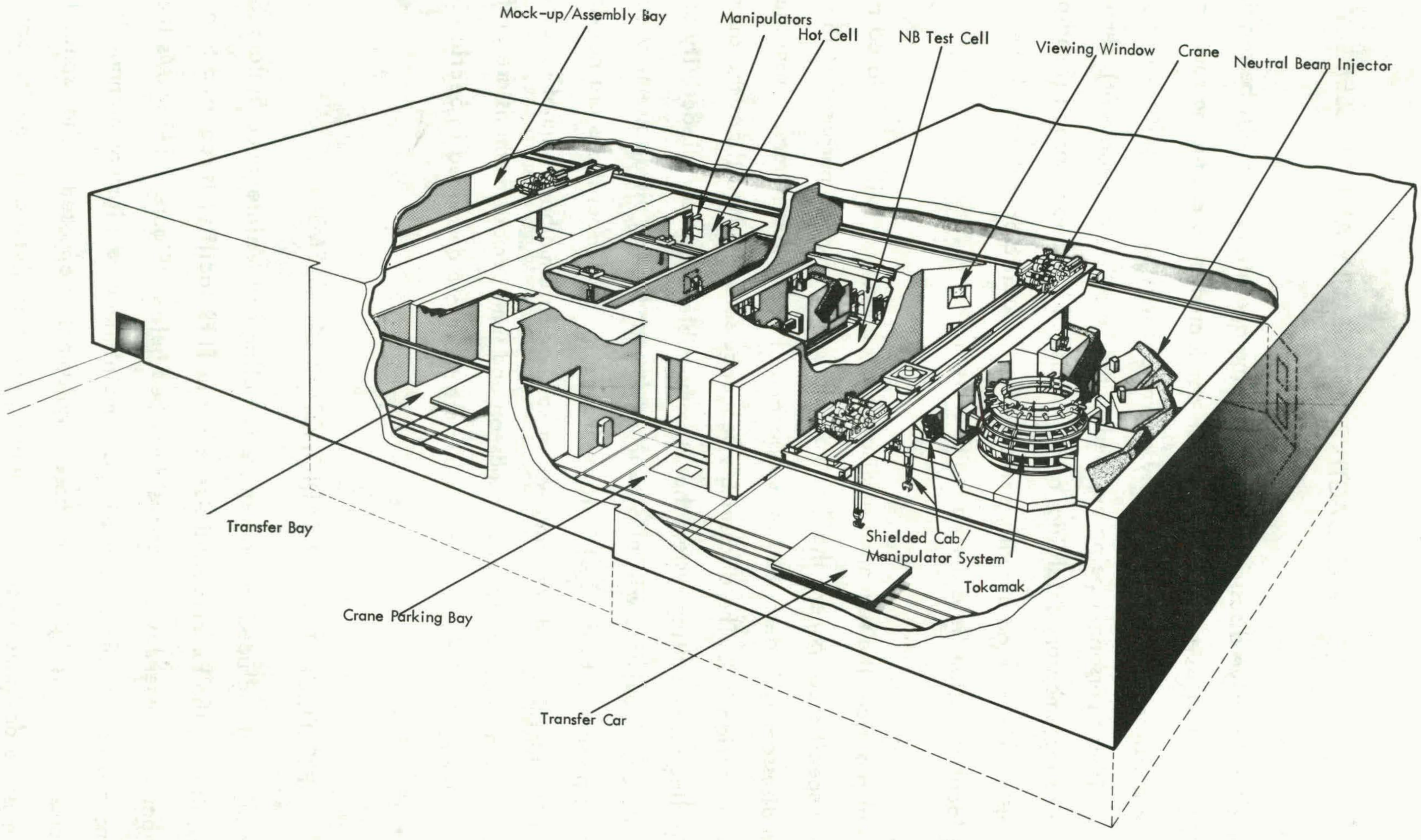

Figure 3.1-1 Installation of Remote Handling Equipment

3.2 DISASSEMBLY OPERATIONS

3.2.1 Remove Tokamak shielding selectively and concurrently with diagnostic apparatus and neutral beam lines. The shielding is selectively removed to minimize radiation levels encountered during removal of the diagnostic apparatus and neutral beam lines. The bridge crane, overhead manipulator and special handling frames are to be used where needed.

3.2.2 Remove two vacuum vessel access port covers and cut the vessel at two parting plane locations, using techniques and equipment similar to the "model maintenance system" described in Section 4.0 of this report.

3.2.3 Release and remove the bands around the outer poloidal field coil assemblies. This is accomplished by removing small sections of shielding to provide access to the 12 latches and manually unlatching each band. A "half-coil strongback" handling frame is used for holding each band after full shield removal.

3.2.4 Disconnect all coil systems (TF, EF, OH, and HY) from electrical busses by using manual operations and working through access paths that have been created by removing specific shielding sections.

3.2.5 Drain and disconnect cooling water headers from supply and return water lines. Drainage is accomplished by manual operations in the basement. A lift-stand will be used to bring operators into position near the elevated disconnect joint so that manual disconnection can be accomplished.

3.2.6 Disconnect all electrical coil systems (TF, EF, OH, and HY) at the parting plane using semi-remote techniques similar to those described in Section 3.2.4.

3.2.7 Disconnect gas injection and purging systems (for tritium, hydrogen, deuterium, helium and air) working manually from the basement area with long-handle wrenches.

3.2.8 Remove limiter, breakdown oscillators and any remaining diagnostic apparatus. This includes the operations from the basement area that sever the vertical port tubes from the vacuum vessel and operations similar to those described in Section 4.2.

3.2.9 Remove four vacuum pumps by working manually on the floor of the Test Cell and from above with the overhead manipulator, bridge crane and vacuum pump handling rig.

3.2.10 Disconnect marman clamps from water header manifold and outlet headers/inlet headers (20 places on outlet, 20 places on inlet), inner PF coils (56 places) and outer PF Coils (48 places) by using manual operations tailored to suit the existing radiation levels.

3.2.11 Remove the four neutral beam adaptors from the vacuum vessel by using the shielded booth, long-handled tools, the bridge crane, and a special lifting frame designed to handle the adaptor units.

3.2.12 Break loose the two vacuum vessel halves at the parting plane by activating the jacking screws (or equivalent mechanism) using the overhead manipulator or suitable semi-remote techniques.

3.2.13 Separate the halves of the Tokamak by activating the substructure roller system.

3.2.14 Rotate each vacuum vessel half 180° (2 separate and sequential operations) onto the vacuum vessel removal rig that has been brought into position on the vacuum vessel removal stand by using the bridge crane, overhead manipulator and vacuum vessel transfer rig. The rotational movement is accomplished automatically by a gear drive arrangement that is part of the vacuum vessel removal rig.

3.2.15 Remove shielding segments from vacuum vessel halves by using the bridge crane and overhead manipulator. The segments are positioned in a shield segment stand after removal.

3.2.16 Transport each vacuum vessel half onto the transfer car by using the bridge crane, overhead manipulator and vacuum vessel transfer rig. The self-propelled and remote controlled transfer car is then moved out of the Test Cell and into the Hot Cell.

3.2.17 Remove one 180° water header assembly from each Tokamak half by using the overhead manipulator, bridge crane and water header handling rig.

3.2.18 Remove twelve, 180° coil assemblies from the outer poloidal field coils (6 from each Tokamak half) by using the overhead manipulator, bridge crane and a "half-coil strongback" handling frame.

3.2.19 Remove the Inner Poloidal Field Coil Module from the support pedestal by using the overhead manipulator, bridge crane and inboard PF coil handling rig. This inner assembly consists of three subassemblies, namely the lower, center and upper sections of the Inner PF Coil Module.

3.2.20 Disconnect the electrical ties between all TF coils by working from above with the overhead manipulator and any special small tools required.

3.2.21 Remove bolts and shear pins between all TF coils by using supplementary shielding and semi-remote methods.

3.2.22 Remove all attachment bolts (if used) holding the TF coils to the support structure by using supplementary shielding and semi-remote methods.

3.2.23 Remove the TF coils individually by loosening each coil from the adjacent coils and lifting. The TF coil handling rig is used in conjunction with the overhead crane for this lifting operation. Each coil is placed on the transfer car for removal from the test cell.

3.2.24 Remove concrete shield slabs from substructure using cables attached to eyelets on each slab.

3.2.25 Lift both halves of substructure individually by using the bridge crane and handling slings as required to position each half on the transfer car for removal from the test cell. Each half must be in an inclined position on the transfer car in order to clear the doorways.

3.2.26 Remove concrete shield slabs from inner base region using the bridge crane and appropriate handling slings.

3.2.27 Remove the PF Coil Support Pedestal by using the bridge crane and transfer car. (This is the last operation needed to disassemble the TFTR.)

3.3 REASSEMBLY OPERATIONS

Reassembly operations will be required subsequent to any disassembly operation in order to get the TFTR back on-line. However, complete reassembly (starting from the bare Test Cell floor) will never be required since disassembly for maintenance will never be that complete. Reassembly operations that will be performed are not described in detail in this section since they are simply the reflection of prior disassembly operations that are described in Section 3.2.

Radiation levels for reassembly will be the same or somewhat improved from radioactive decay phenomena. This permits the use of the same tooling and techniques used for disassembly.

4.0 RADIOACTIVE PARTING OF THE VACUUM VESSEL

The toroidal vacuum vessel has been designed with several ports located at various positions around the equatorial circumference of the vessel. These ports are 63.5 cm (25") in diameter and provide access to the inside of the vessel for diagnostic equipment, internal inspection and insertion of equipment for welding and cutting the vacuum vessel at the parting plane. The system described in this section relates specifically to the port located adjacent to the parting plane of the vacuum vessel but should, in general, be applicable to other ports. Techniques and methods planned for use in opening a port, after the vacuum vessel has become radioactive, are described along with handling equipment to be used. The insertion and operation of equipment needed for welding or cutting the vessel at the parting plane is also described.

The system described is considered a "model maintenance system" and will be used as a reference in developing the overall maintenance system.

4.1 DESCRIPTION OF REGION AROUND ACCESS PORT

The center of the access port is located 9° or about 60 cm (23.6") from the parting plane of the vacuum vessel. As Figure 4.1-1 shows, the port is centered in the vertical 75 cm (29.5") space between the upper and lower outboard poloidal field coils and is also centered in the horizontal 90 cm (35.4") space between two adjacent TF Coils.

The cover plate itself is designed to be selfshielding and does not protrude beyond the periphery of the vacuum vessel shielding. Captive nuts and bolts are used for attachment of the cover plate to prevent the dropping of such items during opening and closing operations.

The Tokamak shielding forms a cylindrical wall 68 cm (26.8") thick approximately 98 cm (38.6") outboard from the port cover plate. A stepped cylindrical plug somewhat larger in diameter and in-line with the cover plate provides access for removal of the cover plate.

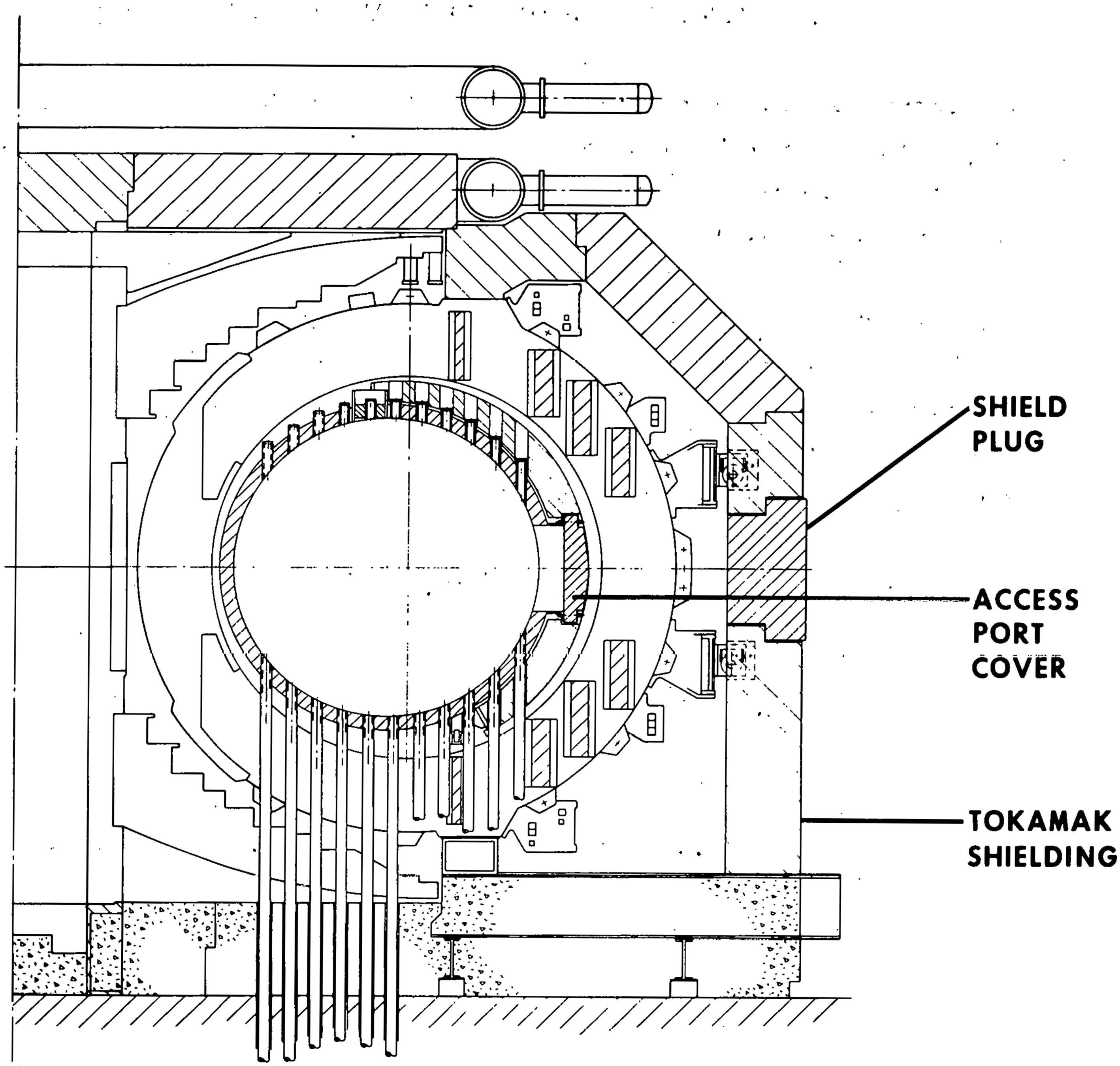

Figure 4.1-1 Parting Plane Access Port Region

Neutral beam injector units (ORNL type) are spaced to provide an access region approximately 3 meters (9.8') wide for remote maintenance and handling equipment needed for port cover removal.

4.2 REMOVAL OF ACCESS PORT COVER

Removal of a cover plate from one of the vacuum vessel access ports involves several operations that must be performed and controlled to assure a minimum of radiation exposure. The system established below describes tooling and operating techniques used to perform the operations with minimum radiation exposure.

4.2.1 Remove Plug in Tokamak Shielding

To gain visual and physical access to the vacuum vessel access port cover plate, a cylindrical plug in the Tokamak shielding must be removed. This is accomplished as shown in Figure 4.2-1 by crane-lifting the shield plug removal hanger into position next to the plug. After alignment, cap screws are manually threaded into appropriate holes in the plug, thus attaching removal hanger to the plug.

The hinged balance bar is then lowered and the shield plug manually unlatched from the Tokamak shielding. The shield plug can now be removed by moving the crane horizontally.

4.2.2 Remove Cover Plate from Vacuum Vessel Access Port

The access port cover plate is attached to the vacuum vessel by 48 bolts. To remove the plate, these bolts are disconnected by a man working through a rotary shield plug with a long-handled socket wrench as shown in Figure 4.2-2. The wrench is driven by a hand-held impact tool. The rotary shield plug has a lead glass window that permits

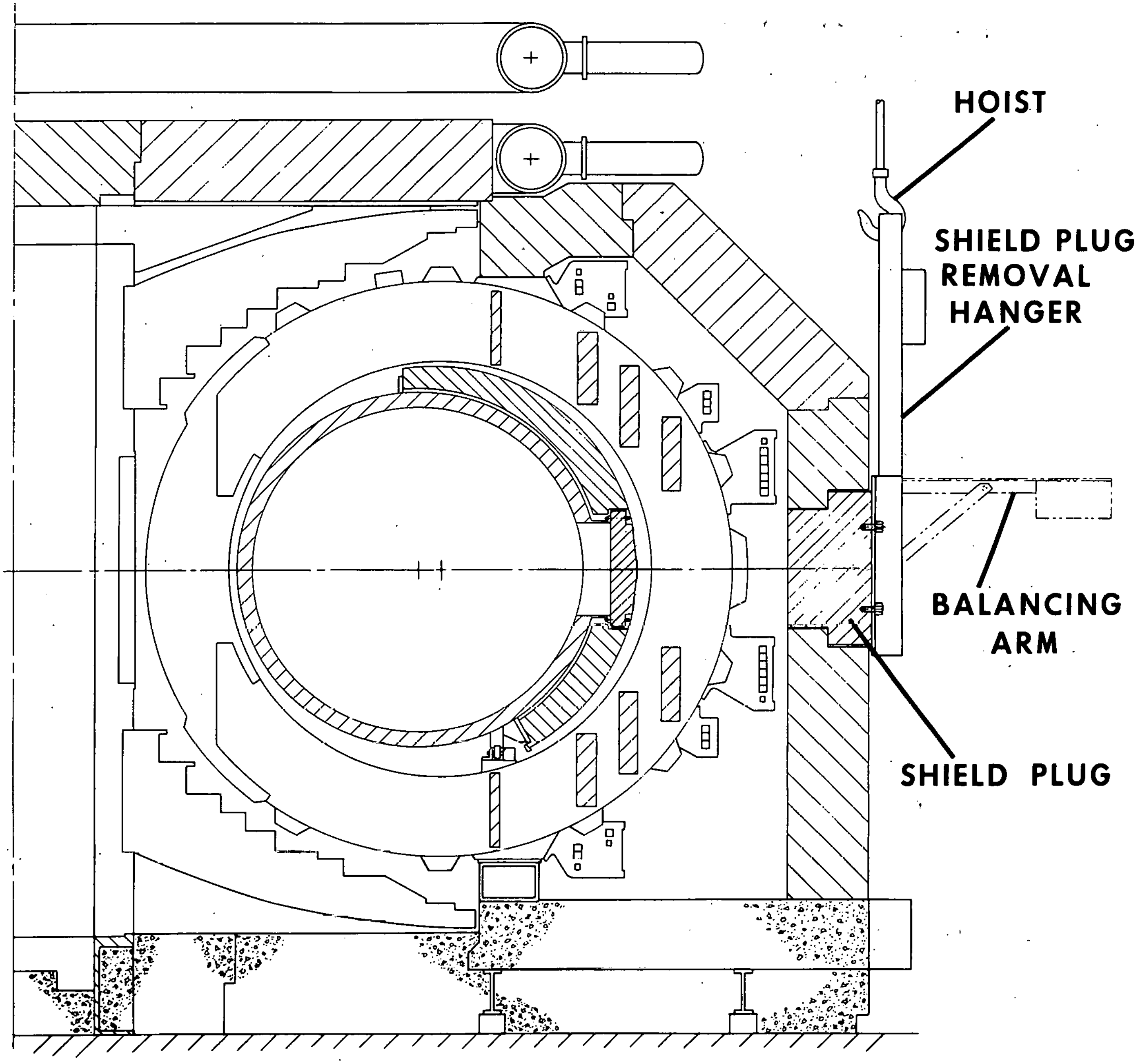

Figure 4.2-1 Removal of Tokamak Shield Plug

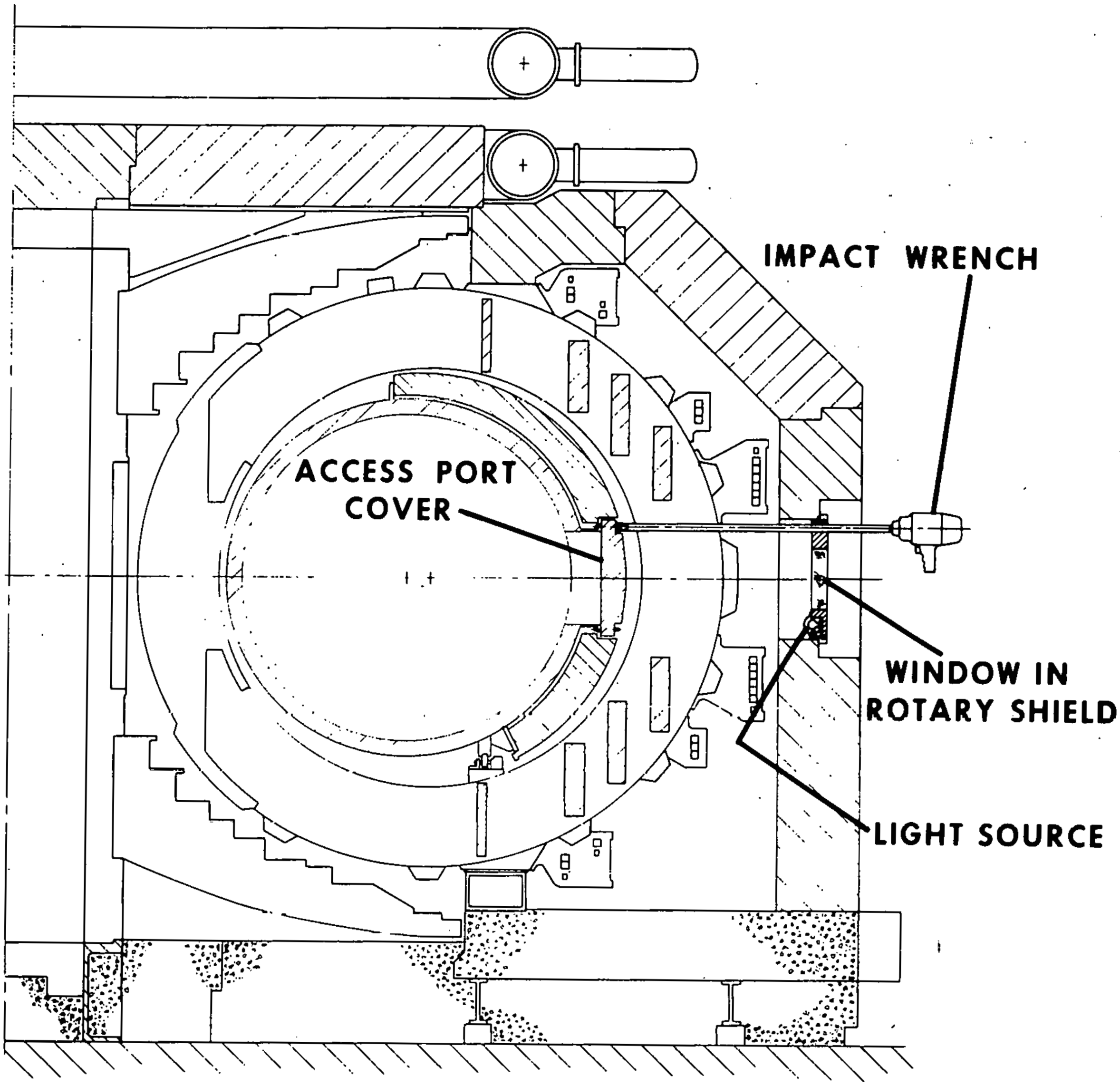

Figure 4.2-2 Removal of Access Port Bolts

the operator to actually see the attachment bolts. This is necessary for fast, positive operations. A light source is provided on the inner face of the plug to provide illumination for viewing. Jacking screws are provided to break-loose the plate from the vacuum vessel flange.

The cover plate is removed from the access port by pulling it along a monorail track that has been inserted through hangers that have been preassembled to the Tokamak hardware. Figure 4.2-3 shows this operation.

Final removal of the cover plate is accomplished by attachment of the plate to the shield plug removal hanger in a manner similar to that shown in Figure 4.2-1 for shield plug removal.

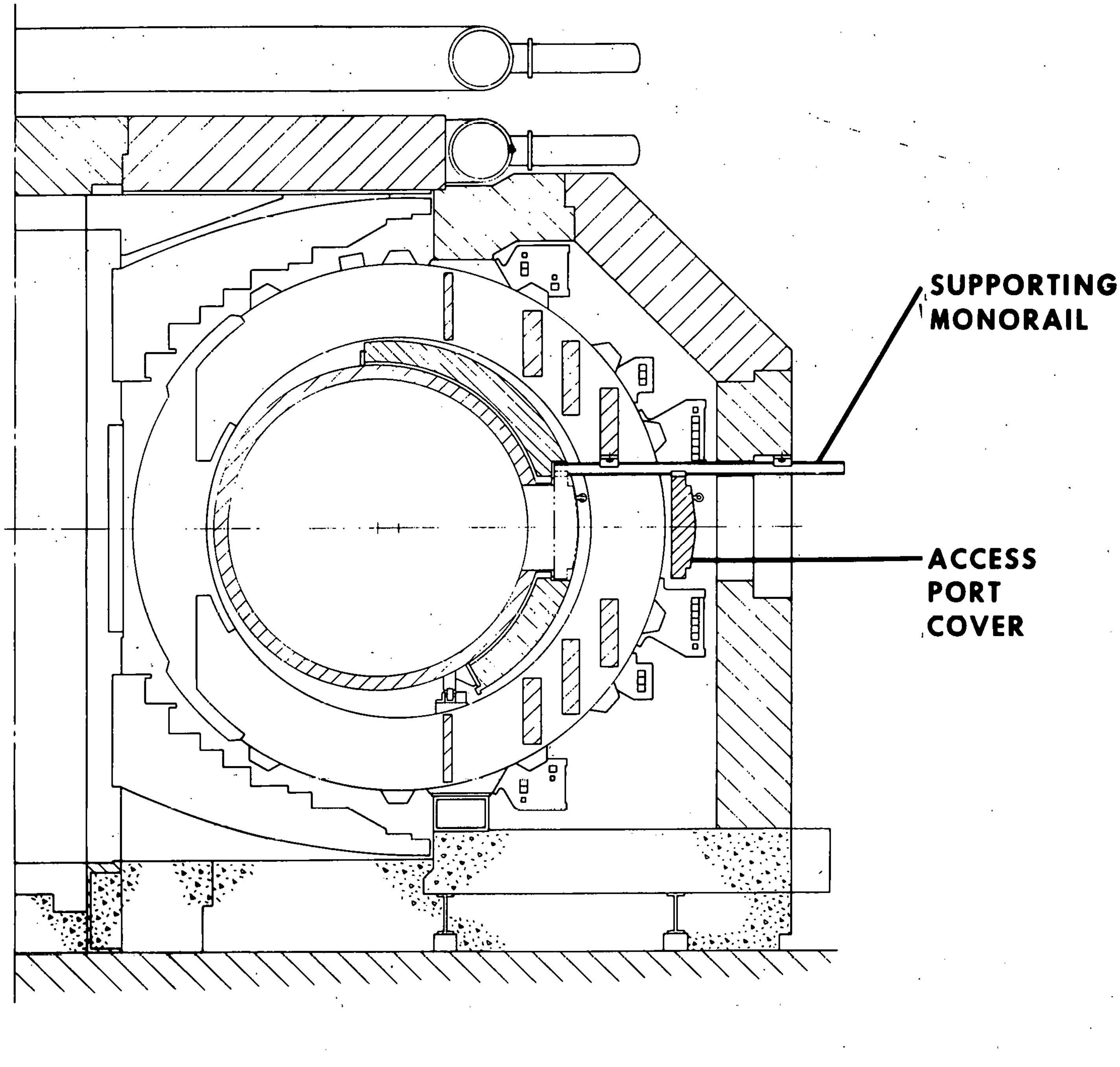

Figure 4.2-3 Removal of Access Port Cover

4.3 CUTTING THE VACUUM VESSEL AT PARTING PLANE

The vacuum vessel may require vacuum leak repair or other maintenance operations that must be done in the Hot Cell. The removal operation requires that the vessel be severed at two places, 180° apart, to permit separation of Tokamak halves and removal of either vacuum vessel half. The severing operation involves the insertion of cutting equipment through the appropriate access port, bringing it into position at the parting plane prior to performing the cutting operation. These operations are described in the following paragraphs.

4.3.1 Insertion of Parting Plane Cutting Equipment

Figure 4.3-1 shows the conceptual configuration of the special cutting equipment as it is being inserted through the vacuum vessel port. Insertion is accomplished by moving the support arm horizontally through a sliding arrangement on the support post. The equipment must be designed to fit through the 63.5 cm (25") port opening.

After the support arm has been fully inserted, the support post is rotated through 9 degrees and moved horizontally about 70 centimeters (27.6") in order to bring the pivoting arm into position with respect to the parting plane of the vacuum vessel.

4.3.2 Cutting Equipment in Operation

Figure 4.3-2 shows the equipment in the cutting position. The cutting operation needed to sever the vacuum vessel would now proceed after visual inspection and several dry runs were made to determine that a successful cut will be made. A small diameter (~8 cm) (3.1") milling cutter is fed into the metal to the proper depth while the pivoting arm is activated and turns through 360 degrees. Automatic controls maintain cutter travel in the proper direction. The milling cutter has been ground to a special contour so that the groove made by the cutter will serve as a weld prep for making a subsequent weld closure joint.

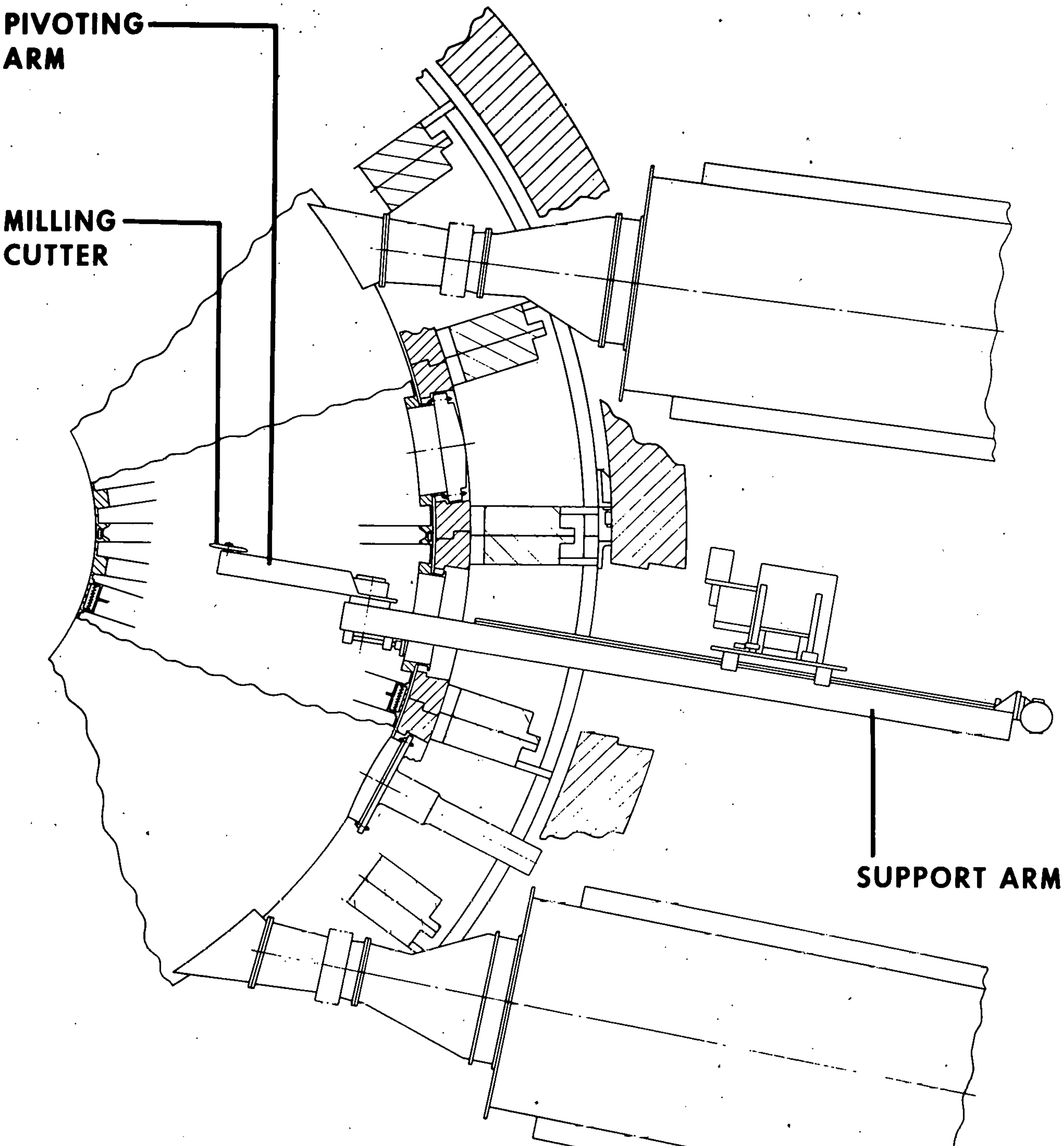

Figure 4.3-1 Insertion of Parting Plane Cutting Equipment

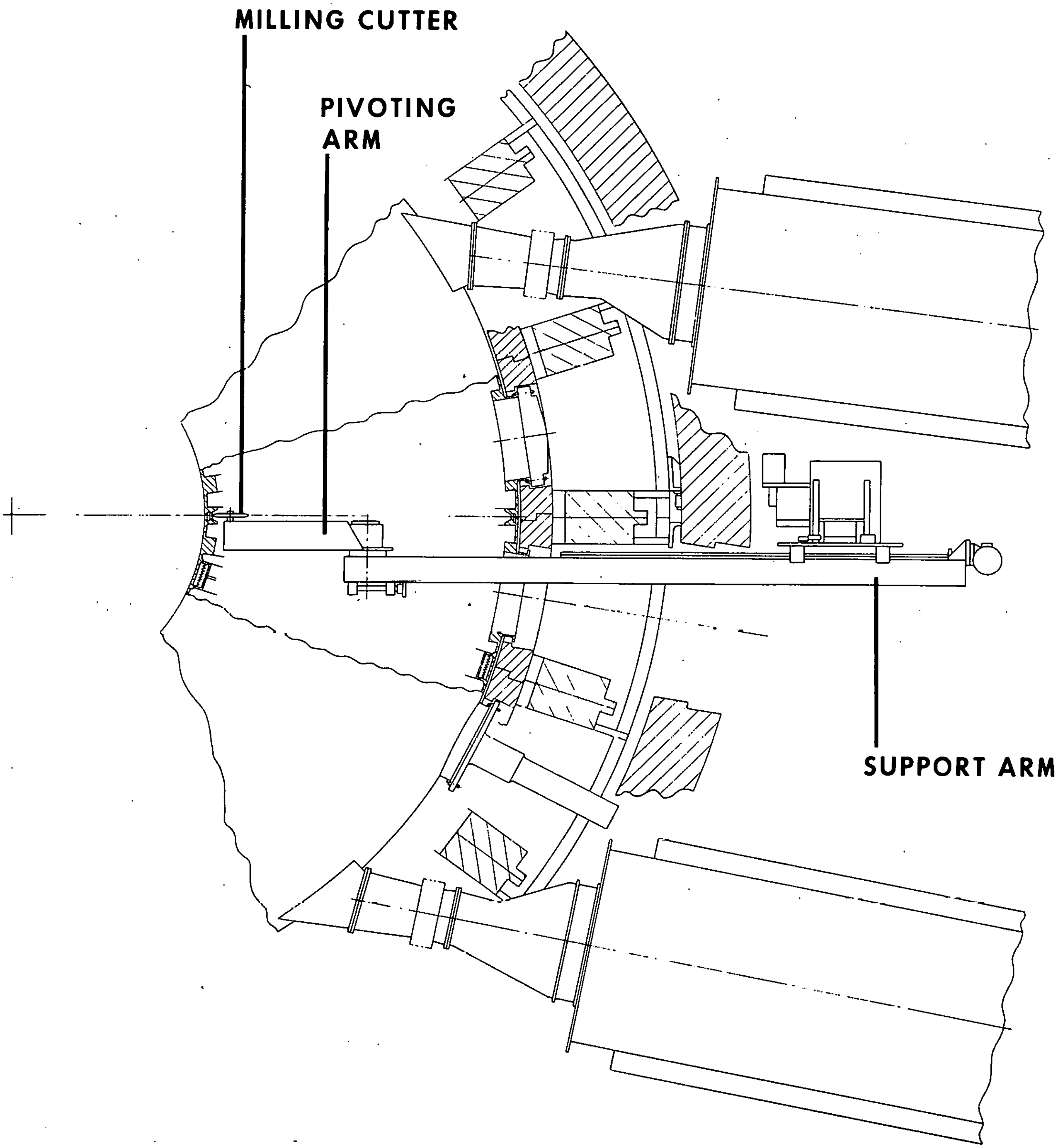

Figure 4.3-2 · Cutting Equipment in Operation

4.4 PERSONNEL EXPOSURE CONSIDERATIONS

Radiation exposure levels to be encountered by personnel working in the Test Cell will depend on many factors, such as TFTR operating time, decay time and shielding configuration. In order to arrive at quantitative estimates of personnel exposures, operating assumptions are made for these and other factors that influence radiation levels. Table 4.4-1 lists these assumptions that are thought to be realistic since they are based on current Tokamak design features and remote servicing plans.

TABLE 4.4-1

ASSUMPTIONS FOR ESTIMATING PERSONNEL EXPOSURES

1) Prior operation of TFTR was 1000 full power pulses at intervals of 5 minutes.

2) Decay time prior to personnel entry into Test Cell is 24 hours.

3) Effective thickness of vessel shield at location of access port is 7.6 cm (3.0") of lead loaded, boronated mortar (ρ = 4.2 g/cc) (262.1 lb/ft^3).

4) The effective thickness of the Tokamak peripheral shield is 55 cm (21.6") of lead loaded, boronated mortar (ρ = 2.5 g/cc) (156.0 lb/ft^3).

5) The exterior surface of the Tokamak peripheral shield is located 175.3 cm (69.0") outboard from the access port flange.

Using these assumptions, exposure rates at the exterior of the Tokamak peripheral shielding were determined for three shielding configurations associated with this study involving parting of the vacuum vessel. The rates were based on an estimated dose rate of 15 mrem/hour occurring just outside the peripheral shield with no openings (Configuration A). Rates for Configurations B and C were determined using techniques outlined by J. Faulkner for exposure rates outside of ducts through the peripheral shield (pages 102-109 of J. Faulkner's Record Book, dated November 11, 1975). These exposure rates are stated below:

	Shielding Configuration	Dose Rate
a)	Vacuum vessel shielding completely in place, Tokamak shielding completely in place. (Tokamak shield plug or rotary shield plug is in "plugged" position.	15 mrem/hr.
b)	Vacuum vessel shielding completely in place, Tokamak shield plug removed.	145 mrem/hr.
c)	Vacuum vessel access port open and Tokamak shield plug removed.	485 mrem/hr.

4.4.2 Personnel Exposure Information

Table 4.4-2 gives information relating to the exposure of personnel working in the Test Cell while performing the tasks needed to part the vacuum vessel at one place. It should be noted that complete separation of the vacuum vessel requires parting at two locations 180° apart. Time estimates given in Table 4.4-2 must be doubled if complete separation is considered. It should be recognized that manpower time estimates are for actual period of time in radiation area. The actual time to complete a specific task will be generally longer. No attempt has been made to establish overall period of time to complete the subject task.

TABLE 4.4 -2
PERSONNEL EXPOSURE INFORMATION

Task	Dose Rate (mrem/hr.)	Servicing Method	Duration (hrs.)	Personnel Involved	Dosage Each Man (mrem)	Total Exposure (man-mrem)
4.2.1 Remove Plug in Tokamak Shielding						
a) Crane lift shield plug removal hanger into position next to plug.	15	Remote	.3	0	0	0
b) Align holes and thread cap screws thru hanger into plug.	15	Manual	.3	2	4.5	9.0
c) Lower balancing arm and unlatch plug.	15	Manual	.1	2	1.5	3.0
d) Remove shield plug by moving crane.	15*	Manual	.3	2	4.5	9.0
4.2.2 Remove Cover Plate from VV Port						
a) Insert rotary shield plug into space vacated by Tokamak shield plug.	15*	Manual	.5	2	7.5	15.0
b) Remove bolts from access port cover plate using long-handled socket wrench and impact tool.	15	Manual	1.0	1	15.0	15.0

TABLE 4.4-2 (Continued)
PERSONNEL EXPOSURE INFORMATION (Continued)

Task	Dose Rate (mrem/hr.)	Servicing Method	Duration (hrs.)	Personnel Involved	Dosage Each Man (mrem)	Total Exposure (man-mrem)
c) Actuate jacking screws to loosen cover plate from mounting flange.	15	Manual	.3	1	4.5	4.5
d) Install monorail track on hangers provided.	15	Manual	.5	2	7.5	15.0
e) Pull access port cover plate along monorail to the inside edge of peripheral shielding.	15	Manual	.3	1	4.5	4.5
f) Attach rotary shield plug to hanger and crane lift away from peripheral shield.	15*	Manual	.6	2	9.0	18.0
g) Crane lift shield plug removal hanger into position next to cover plate.	485	Remote	.3	0	0	0
h) Align holes and thread cap screws thru hanger into cover plate.	485**	Manual	.3	2	145.5	291.0
i) Remove access port cover by moving crane.	485	Remote	.3	0	0	0
j) Install temporary shielding in peripheral shield opening.	145	Remote	.3	0	0	0

TABLE 4.4-2 (Continued)

PERSONNEL EXPOSURE INFORMATION (Continued)

Task	Dose Rate (mrem/hr.)	Servicing Method	Duration (hrs.)	Personnel Involved	Dosage Each Man (mrem)	Total Exposure (man-mrem)
4.3.1 Insert Parting Plane Cutting Equipment						
a) Crane lift cutting equipment into position and anchor equipment in place.	15	Manual	.8	1	12.0	12.0
b) Remove temporary shielding.	145	Remote	.3	0	0	0
c) Activate cutting equipment positioning cycle to automatically align arm, insert thru port, rotate 9° and move horizontally to bring in alignment with parting plane.	485	Remote (Surveillance from shielded cab)	.6	1	0	0
4.3.2 Operate Cutting Equipment						
a) Inspect position of milling cutter and control sensors. Make several dry runs to confirm operational characteristics.	485	Remote	2.0	0	0	0
b) Activate cutting equipment and monitor automatically controlled operation by using TV.	485	Remote	3.0	0	0	0

*Craftsman works outside of radiation beam to avoid high dose rate.

**Operation requires additional design effort. Radiation field and exposure is above desired levels.

5.0 SUMMARY

Assembly operations presented in Section 2.0 provide a logical sequence for initial assembly of the Tokamak. These operations will be continuously upgraded and expanded during development of the TFTR design, and will also be used to establish the need for special equipment, personnel training, and equipment testing. In addition, Section 2.0 permits preparation of preliminary scheduling and manning requirements.

Assembly operations emphasize the need for a multi-purpose work and staging area located outside of the Test Cell. The Mock-Up and Assembly Bay provides such an area and will be used to: (1) assemble TFTR modules and subassemblies; (2) stage these units and other TFTR components onto the Test Cell for final assembly; and (3) accomplish any required testing and checking of the above hardware prior to installation. Use of the Mock-Up and Assembly Bay as an assembly area will permit the TFTR assembly to proceed concurrently in both the Assembly Bay and Test Cell.

Maximizing the use of large modules as described in Section 2.0 will save time and dollars in TFTR assembly. The more important modules identified are:

Module	Dimensions	Weight
Inner Poloidal Field Coil	4.9 m high x 6.1 m diam. (16' x 20')	33.5 tonnes (37 tons)
Substructure Half	6.1 m x 12.2 m (20' x 40')	43 tonnes (47 tons)
TF Coil	4.0 m outside diameter (13')	18.3 tonnes (20.2 tons)

Planning can now proceed on crane lift requirements and sizing of door openings. There must be close coordination during the design stage to assure that door openings are compatible with module size. Present openings in the TFTR Experimental Area are adequate; e.g.:

Location	Size
Mock-Up and Assembly Bay to Transfer Bay (TB) No. 1	20' x 30' (6.0 m x 9.1 m)
TB No. 1 to TB No. 2	20' x 30' (6.0 m x 9.1 m)
TB No. 2 to Test Cell	20' x 30' (6.0 m x 9.1 m)

Conceptual Design facility drawings do not provide door dimensions for the exterior opening in the Mock-Up and Assembly Bay - this door must be at least 20' x 30' (6.0 m x 9.1 m) as above.

In general, the assembly sequence makes use of the same special equipment that is described in Sections 3.0 and 4.0; e.g., vacuum vessel removal rig, vessel shielding segment stand, TF Coil handling rig, and Poloidal Field Coil strongback. There will be a need also for a frame to support the substructure, at an angle on the transfer cart, during movement from the Mock-Up and Assembly Bay to the Test Cell.

In initial assembly of the TFTR, the major problem will be coordinating delivery of Tokamak modules, subassemblies, and other components to the Princeton Site. This makes preparation of schedules extremely important, especially those for the large modules described above.

The operations for radioactive disassembly of the TFTR and radioactive parting of the vacuum vessel are provided in Sections 3.0 and 4.0 respectively. These operations will be accomplished using remote, semi-remote, or hands-on techniques, the actual choice depending on environmental radiation levels existing at the time of servicing. Hands-on and semi-remote techniques are preferred for most operations since they are faster than remote methods. For this reason, parting of the vacuum vessel using hands-on and semi-remote techniques are planned for use and described in detail in Section 4.0.

Section 3.0 also lists prerequisites for radioactive disassembly and provides a sequence of disassembly operations, while Section 4.0 describes the region of the vacuum vessel adjacent to access ports, removal of access port covers, and the cutting operation at the vessel parting plane. Planning can now proceed on refining the requirements for special equipment, and, in addition, the disassembly operations can be expanded into detailed procedures.

The information given in Section 4.4 on personnel exposure is conceptual in nature and is based on estimates that are approximate due to the preliminary nature of the TFTR design. The information is presented primarily to serve as an example of how the exposure information can be organized into a useful tabulation. The total exposure value for parting the vacuum vessel, at one location, was found to be .396 man-rem. This value is related to the number of personnel working in the radiation environment and the duration of various exposures. It is a value that can be compared with values from other servicing methods in order to arrive at the most favorable method and to help in developing manpower requirements for servicing operations. The overall expected man-rem exposure, for a specific operation, is necessary to determine the staffing needed to complete the operation. As the TFTR design continues to progress, a fuller definition of each task can be established as well as a realistic schedule of work effort. The schedule of work will, in general, include parallel operations in the Test Cell; support operations in the Hot Cell, N.B. Test Cell and/or the Mock-Up Assembly Area; overall staffing requirement; Training Requirements and man-rem exposure considerations. It should be recognized that conceptual scheduling or staffing considerations have not been developed for this report but will be the subject of future studies.

Radioactive disassembly of the TFTR, as described in this report, is based on one half of the Tokamak being movable and the other half stationary. An alternate arrangement whereby both halves are movable has the following advantages:

a. disassembly of either half can be done independently of other half.

b. design and analysis effort on movable side is applicable to other side.

c. the inner side of TF coils is accessible if half of device is moved.

d. removal of a TF coil never requires removal of the upper inboard PF coils.

These advantages are significant and should receive an in-depth evaluation.

Access space requirements for equipment needed to part the vacuum vessel appear to be compatible with the N.B. Injector geometry as given in ORNL-CF-75-9-15 but not for an alternate unit as described in LBL-3296. Further study in this area is recommended.

The problems associated with containment and/or covering of removed components have not been considered in this report. Further development of the conceptual design will require containment evaluation and consideration. Special measures must be developed, for instance, to limit the spread of tritium contamination (flushing, bagging, baking, etc.).

This report conceptually describes how the Remote Handling and Maintenance System satisfies or partially satisfies the following functional requirements as stated in SD No. TFTR-SD-5C.

- Complete the initial assembly of the Tokamak and ancillary equipment.
- Perform diagnostic operations to inspect and locate malfunctions in the vacuum vessel.
- Remove major components from Tokamak System.

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