REMOTE MAINTENANCE CONCEPTS FOR THE COMPACT IGNITION TOKAMAK

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F. C. Davis
Central Engineering
Oak Ridge National Laboratory*
Post Office Box X
Oak Ridge, Tennessee, USA 37831

E. R. Hager
GA Technologies, Inc.+
Post Office Box 85608
San Diego, California, USA 92138

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F. C. Davis
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, Tennessee 37831, U.S.A.

E. R. Hager
GA Technologies, Inc.
P. O. Box 85608
San Diego, California 92138, U.S.A.

ABSTRACT

Because deuterium-tritium fuel will be used in the Compact Ignition Tokamak (CIT), remote handling technology is needed to carry out some maintenance operations on the machine. In keeping with the compact, low-cost nature of CIT, remote maintenance is provided only for systems with the highest probability of failure. Remote operations include removing, repairing (if feasible), and replacing such components as thermal protection tiles on the first wall, radio-frequency (rf) heating modules, and diagnostic modules. For maintenance inside the vacuum vessel, major pieces of equipment under development include an articulated boom manipulator with servomanipulators, an inspection manipulator, and special tooling. For maintenance outside the cryostat, remote equipment includes a bridge-mounted manipulator system, equipment for decontamination and hot cell activities, and for handling and packaging solid radioactive waste. The conceptual design phase of the CIT project is nearing completion; research and development activities in support of the project include demonstrations of remote maintenance operations on full-size partial mock-ups.

1. INTRODUCTION

The Compact Ignition Tokamak (CIT), to be built at the Princeton Plasma Physics Laboratory (PPPL), will be the next major experiment in the U.S. fusion program. Because it will use deuterium-tritium (D-T) fuel, remote handling technology is required for maintenance and disassembly operations. The machine will be surrounded by a close-fitting nuclear shield designed to permit personnel access to the test cell 24 h after shutdown. Systems within the shield will be maintained with a manipulator system mounted on an overhead boom and a track-mounted mobile robot. Components within the vacuum vessel will be maintained by two articulated boom manipulators (ABMs).

The CIT will operate with hydrogen fuel for approximately one year. During this period, the integrity of the total system will be verified and the operation of remote maintenance equipment will be demonstrated. Hands-on repairs can be made on any equipment that fails during shakedown or early operation. Once D-T operation begins, however, maintenance of components

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within the shield will require remote handling techniques. Many of the remote maintenance tasks envisioned for CIT are part of ongoing research and development (R&D) programs that will demonstrate the equipment and methodologies needed to provide a complete, practical remote maintenance system.

2. MAINTENANCE OVERVIEW

The CIT was conceived as a compact, low-cost machine; in this context, it was acknowledged that remote maintenance for every subsystem of the device is not possible. For example, the primary structure, the toroidal field (TF) and poloidal field (PF) coils, and the vacuum vessel are considered permanent installations that are not replaceable. As a consequence, remote maintenance is limited primarily to components within the vacuum vessel and components external to the cryostat.

Remote maintenance tasks to be carried out in the vacuum vessel include inspection of components, replacement of thermal protection tiles, leak detection, and welding. Tasks to be performed outside the vessel are limited to replacement of components outside the cryostat/thermal shield and subsequent repair, when feasible, of the removed components. The shield is made of modules with permanent structural supports; modules can be removed to expose segments of the machine for maintenance, as shown in Figs. 1 and 2. Hands-on maintenance of components in the test cell can be performed 24 h after shutdown if the shield is intact; if a shield module is removed, however, remote maintenance is necessary.

A bridge-mounted master-slave manipulator system and an overhead crane are used to maintain and replace equipment modules that interface with the machine. A floor-based mobile manipulator is used in the area beneath the machine.

An air-lock transfer system leads from the test cell to a decontamination cell. After decontamination, activation levels in a component are evaluated. Nonradioactive components are transferred to a warm cell in an unshielded containment area. Radioactive components are transferred to a shielded hot cell, equipped with through-the-wall master-slave manipulator systems, where they can be repaired or packaged in waste containers for disposal. The cell arrangement is shown in Fig. 3.

3. IN-VESSEL MAINTENANCE CONCEPT

On the basis of past experience, recurrent failures of components within the vacuum vessel are expected. Rapid in-vessel inspection and maintenance capabilities will enhance machine availability. Two ABMs are provided to move maintenance equipment and parts into and out of the vacuum vessel. A general-purpose servomanipulator end-effector is used for general maintenance operations. Special-purpose end-effectors are attached to the ABMs for work on components that require frequent maintenance or replacement. Typical tasks requiring dedicated equipment include tile replacement, leak detection and repair, and diverter module replacement. The general arrangement of the in-vessel remote maintenance systems is shown in Fig. 4.

Four dedicated ports on the vacuum vessel support in-vessel maintenance and inspection. All four ports extend through the nuclear shield and contain movable shield plugs and vacuum isolation valves. The ABMs enter the vacuum vessel through two radial ports, located 180 apart on the vessel midplane. Beyond each port is an attached antechamber that houses the ABM when it is retracted from the vessel. Two top vertical ports provide access for the inspection/viewing manipulators from dedicated vacuum chambers. These manipulators are used for rapid in-vessel inspection and viewing. They can also be used in conjunction with the viewing systems on the ABM to provide additional information.

In this section, we describe the ABMs, the machine provided for installation and removal of thermal protection tiles, and the inspection/viewing manipulators.

3.1 Articulated Boom Manipulators

Two ABMs, each with access to half of the vacuum vessel, are provided. A similar system has been in operation for several years on the Joint European Torus (JET), and another is now undergoing tests for the Tokamak Fusion Test Reactor (TFTR) at PPPL.

Each ABM consists of a carriage assembly mounted on traversing rails, a two-piece telescoping mast, and five articulated link sections. The carriage assembly and telescoping mast travel on rollers into the vacuum vessel through the access port; they are actuated by a drive unit consisting of a stepper motor, gear reducer, wobble bellows rotary drive, and rack-and-pinion system. The five articulated link sections can be extended inside the vacuum vessel for maintenance activities and fold onto one another for storage in the antechamber. Each link section is driven by a stepper motor, harmonic drive unit, and recirculating ball-screw linear actuator. At its maximum extension, each ABM supports a 1000-kg vertical load with a deflection of less than 2.5 cm. In one design concept, load supports that expand against the vessel port are provided. The need for such supports will be reviewed in light of experience gained with the TFTR boom.

An interlocked material transfer port allows equipment and tools to be placed in or removed from the ABM antechamber during maintenance, and a separate port is provided for a vacuum system that evacuates the antechamber. The vacuum isolation valve and removable shield plug on the port protect the antechamber during plasma operations. The antechamber functions as a transport carrier for removal of the ABM when it requires decontamination or maintenance.

3.2 Tile Installation/Removal Machine

The interior of the vacuum vessel is covered with approximately 7000 tiles, made of graphite or a similar material, to protect it from high thermal loads. Tiles are attached to studs on the vacuum vessel wall. The tile height (distance between the tile and the wall) is adjusted to a close tolerance during installation.

Figure 5 is a conceptual design for a tile grappler used to attach a tile assembly to a vessel stud. The tile grappler is the front end of the tile installation/removal machine shown in Fig. 6. This machine is grasped by one arm of the in-vessel servomanipulator that is mounted on the ABM. The other arm supports a fixture containing replacement tiles, repair tools, and a container for removed tiles. The tile installation/removal machine is initially aligned in the vessel by computer positioning of the ABM and inspection/viewing manipulators. Final alignment is done by teleoperation of the manipulators. The size and weight of the machine have been minimized to meet the restrictive requirements of the working area within the vacuum vessel and the manipulator payload.

3.3 Inspection/Viewing Manipulators

The inspection/viewing manipulators permit routine viewing and inspection of the vacuum vessel interior with no alteration in vacuum quality. Each one provides a view of approximately half of the vessel interior. A small television camera and lights are mounted on a retractable boom, as shown in Fig. 7. During plasma operation, the booms are retracted into dedicated vacuum chambers outside the nuclear shield.

4. EX-VESSEL MAINTENANCE CONCEPT

The CIT maintenance concept calls for remote replacement and, in some cases, repair of the peripheral equipment within the nuclear shield. In addition, the solid radioactive waste (radwaste) generated during the machine lifetime must be remotely handled, packaged, and stored. Various inspections of machines and components are implicit in these functions. Considerations for ex-vessel maintenance include maintenance equipment and procedures for the test cell, the decontamination cell, the repair (hot and warm) cells, and for transport systems between these cells.

4.1 Test Cell

In the test cell, hands-on maintenance may be performed 24 h after shutdown if the nuclear shield is intact. If a shield module is removed, remote maintenance is required. Access to peripheral equipment adjacent to the cryostat requires removal of shield modules, so all activities associated with this equipment, which includes diagnostic devices, ion cyclotron resonance heating (ICRH) systems, instrumentation, and vacuum systems, must be performed remotely.

Because remote handling and manipulator transport systems have a major impact on facility configuration, the conceptual design included detailed studies of ways to provide manipulator coverage to the tokamak and associated test cell equipment. The alternatives included overhead systems, with either a telescoping boom or rigid mat, and floor-based systems, with either fixed or mobile manipulators. The overhead system shown in Fig. 8, which includes a polar 100/20-ton crane and a polar bridge for the manipulator system, was selected because it provides full coverage of the circular test cell without interference from floor-mounted machine components and relatively rapid access through the top shield to assess a failure condition.

The basic manipulator system (see Fig. 9) consists of the manipulator arms, cameras, and an auxiliary hoist. Each arm has a 10-kg capacity and is force reflecting with real-time response. Controlled tests have shown that this combination of characteristics enhances operator efficiency and thus reduces machine downtime. Because force reflection gives the operator a direct sense of feel and because action by the master manipulator creates an immediate response in the slave, the operator is much less likely to damage equipment by overstressing components.

The 225-kg auxiliary hoist is located just above and between the manipulator arms (see Fig. 9). It works in conjunction with the manipulators, lifting components such as valves and motors that are too heavy for the manipulator arms.

Three television cameras on the manipulator provide the operator with multiple views of the work area. One is located between the arms, and the others are located on either side. All are equipped with pan, zoom, and tilt so that the view of the work area can be optimized. Other cameras in the test cell provide general coverage to assist operators in moving the crane or the manipulator bridge system.

The overhead manipulator system cannot reach areas under the machine, where components such as valves and piping flanges may require remote maintenance or replacement. Two approaches for maintenance of these areas are being considered. On JET, a horizontal boom on the end of the vertical boom is used to reach similar areas. Experience with this approach will be evaluated for CIT. The other approach is a small track-mounted vehicle equipped with manipulators and cameras similar to those on the overhead system.

4.2 Decontamination Cell

Disabled equipment removed from the test cell is moved into the decontamination cell on a transfer cart. Components from inside the vacuum vessel and other contaminated items are transferred in sealed containers to prevent spread of radioactive particles. Monitors in the decontamination cell assess the condition of components, and spray chambers are provided for decontamination. All components will be handled with remotely operated equipment. Personnel access to the decontamination cell may be permitted under closely controlled conditions; routine access is not anticipated.

4.3 Repair Cells

A hot cell and a warm cell are located next to the test cell. Equipment from the decontamination cell will be transferred to one of these two cells, depending on its degree of contamination or activation.

The warm cells is a glove-box facility where equipment can be repaired or prepared for disposal in conventional glove boxes. The hot cell is a shielded facility equipped with a remotely operated crane, an overhead servomanipulator system, two master-slave manipulator systems with shielding windows, and in-cell tools and equipment. It provides for remote disassembly and repair and for solid radwaste processing, packaging, and storage. Commercially available equipment will be used wherever possible to handle the radwaste.

5. CONCLUSION

Existing remote maintenance technologies are being applied to CIT; new approaches are being developed only in areas where there is an absolute need. Conceptual design work to date indicates that maintenance of CIT after D-T operations begin can be carried out in a safe and timely manner. Continuous integration of the designs of components to be remotely maintained and the designs of remote maintenance systems is necessary.

6. ACKNOWLEDGEMENTS

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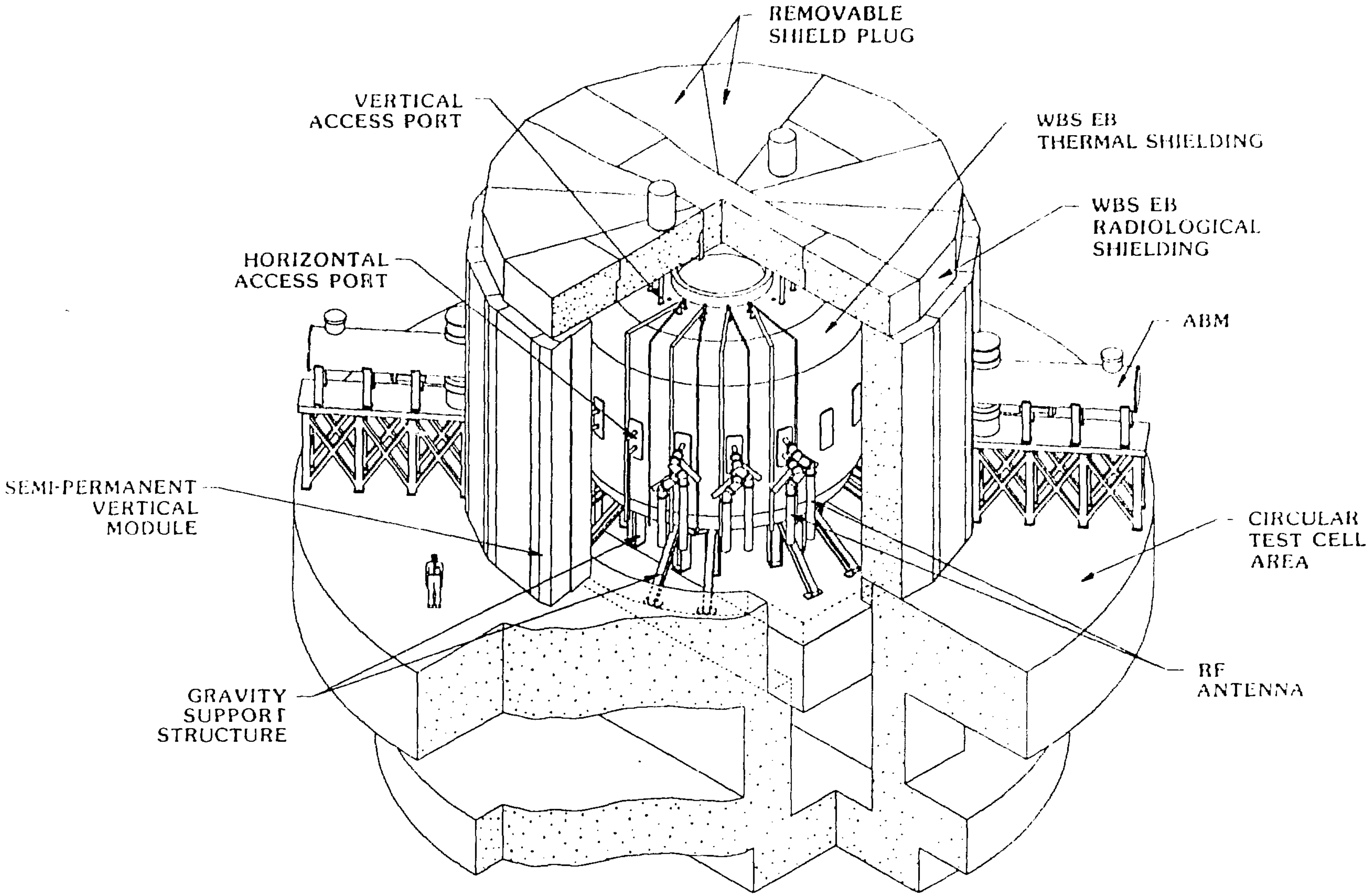
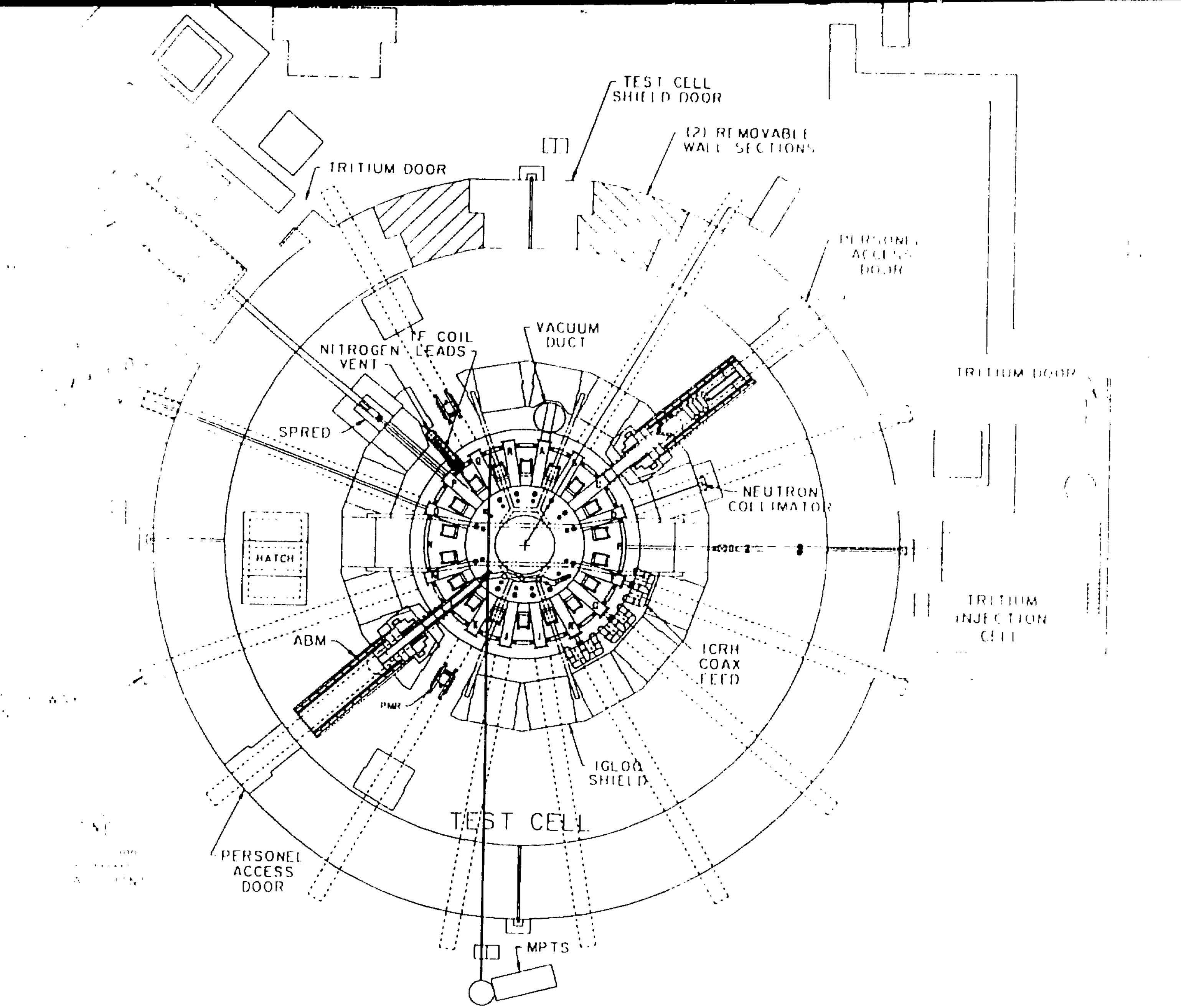
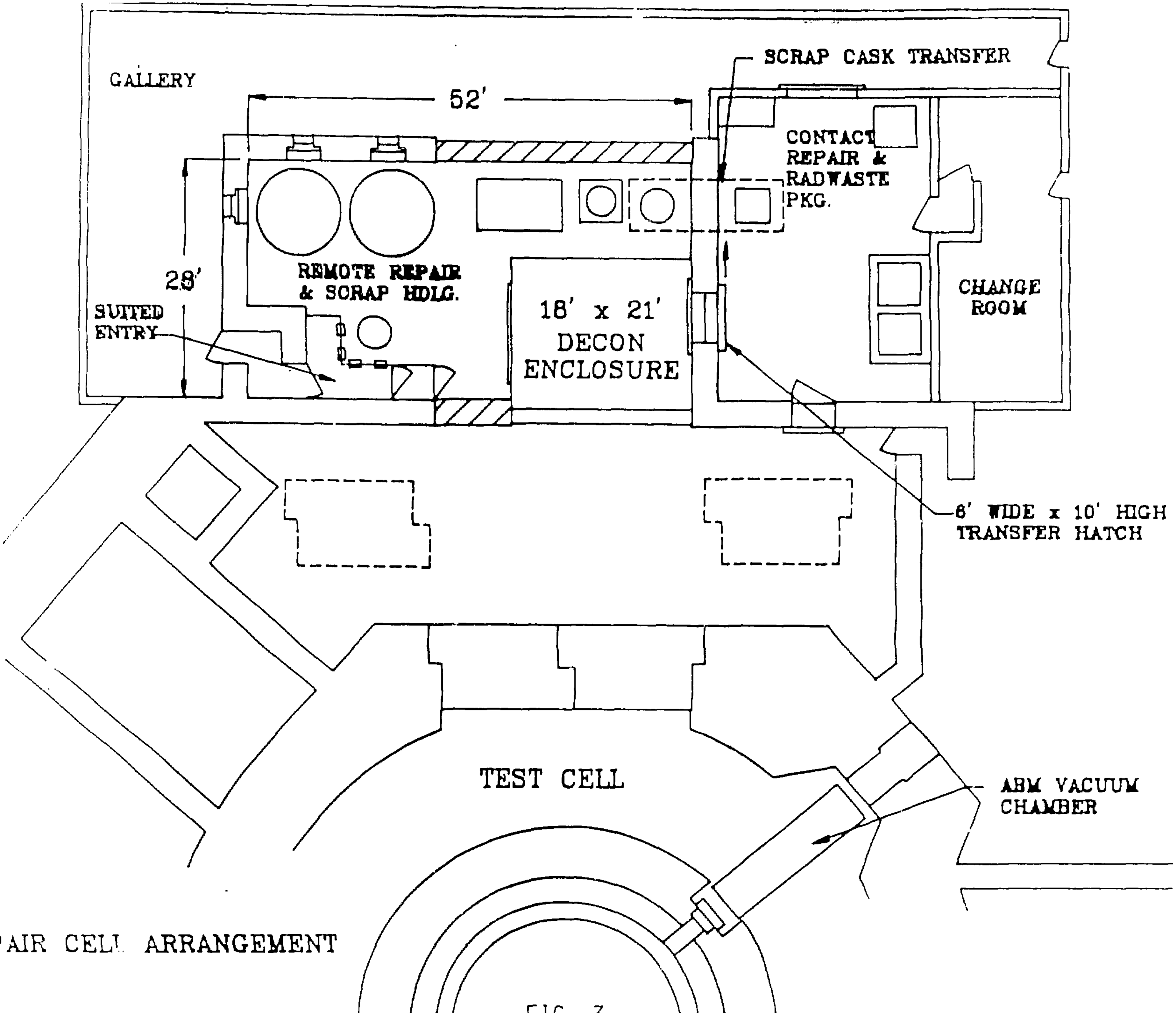


CIT DEVICE CORE

FIG. 1

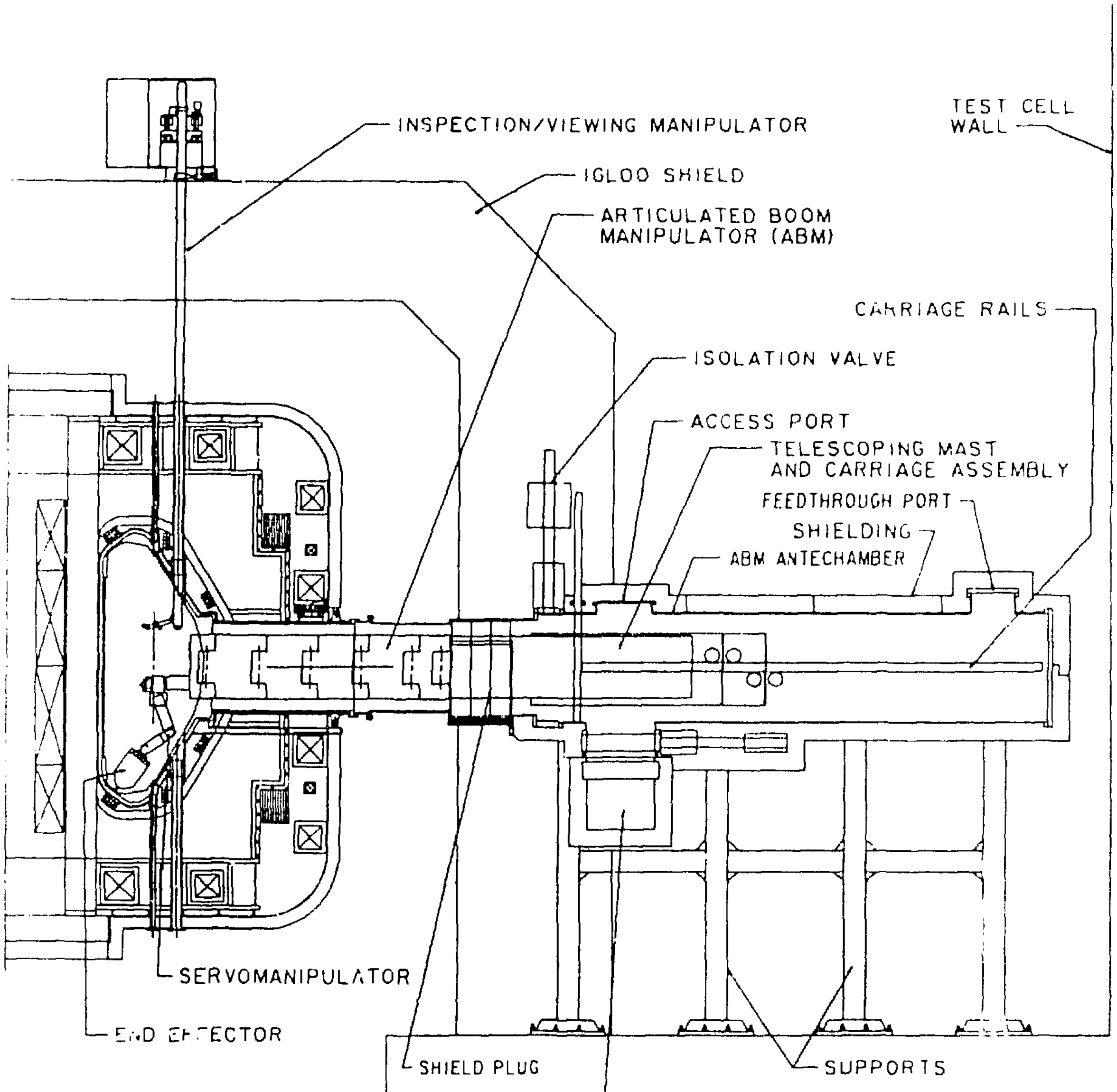


CIT DEVICE PLAN VIEW
FIG. 2

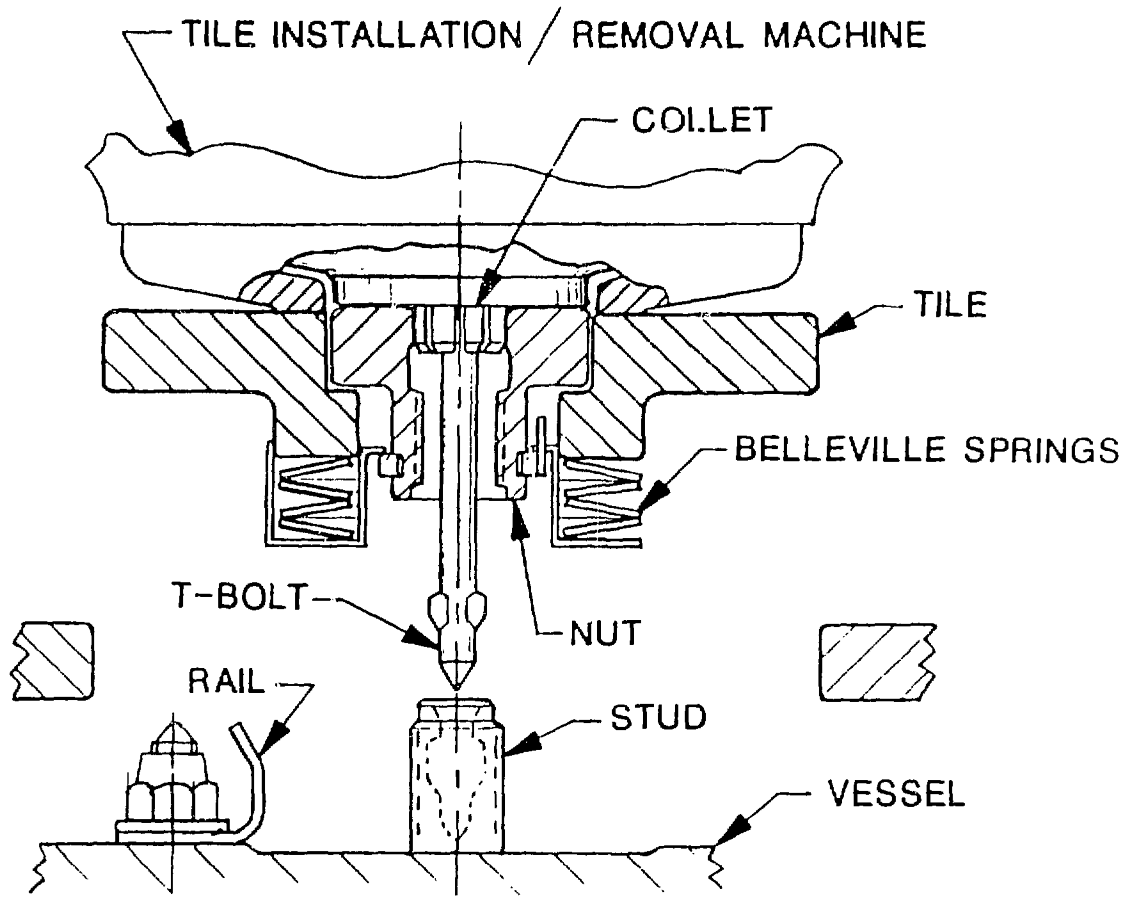


REPAIR CELL ARRANGEMENT

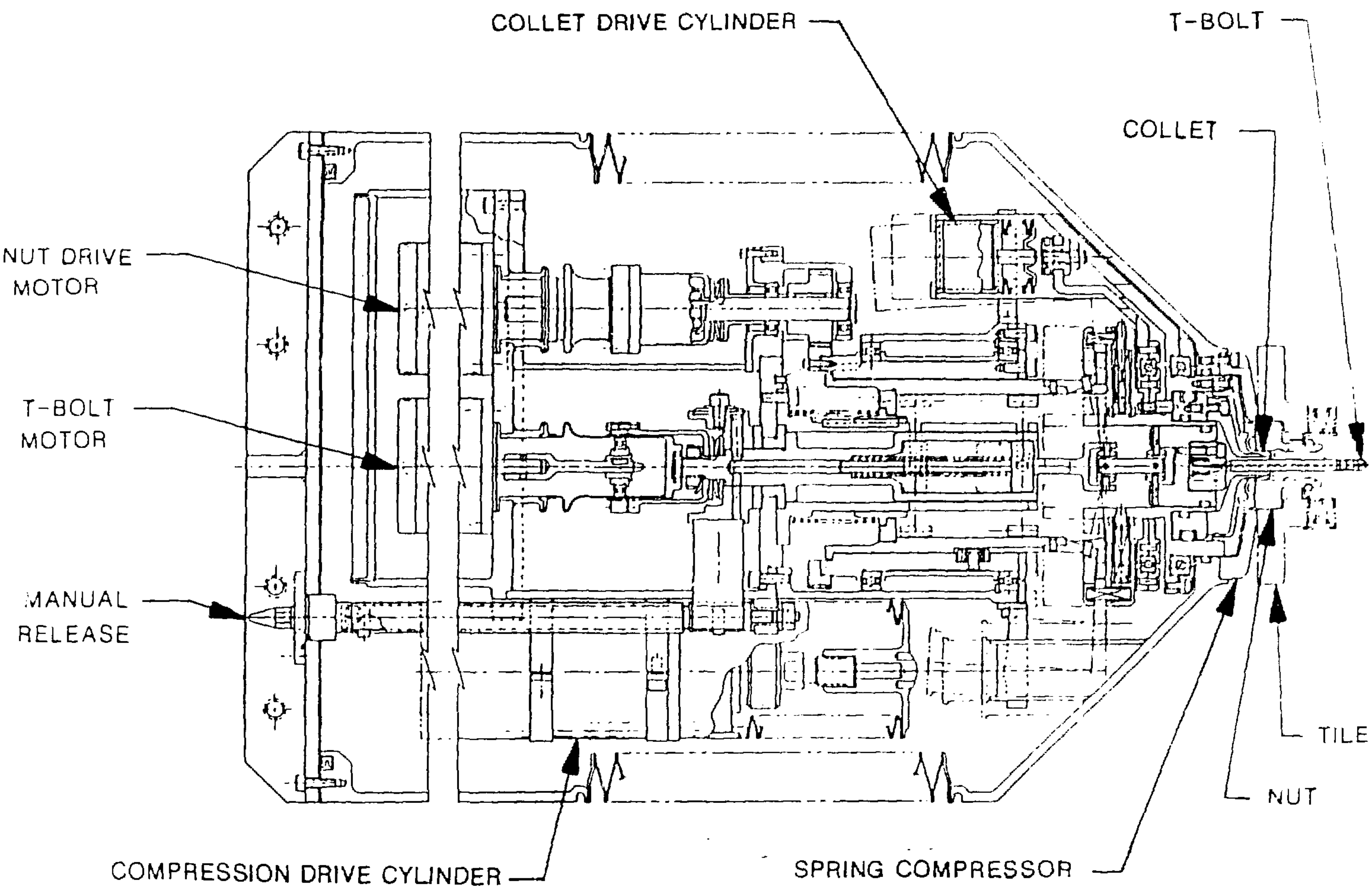
FIG. 3



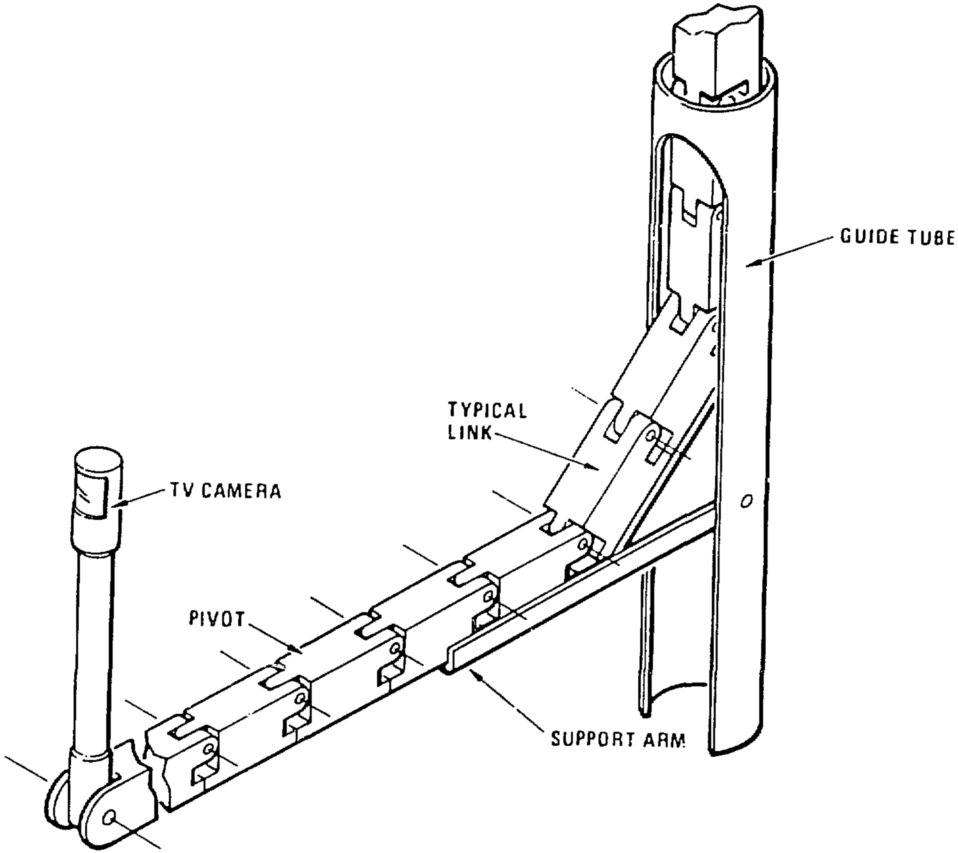
IN-VESSEL REMOTE MAINTENANCE SYSTEM
FIG. 4



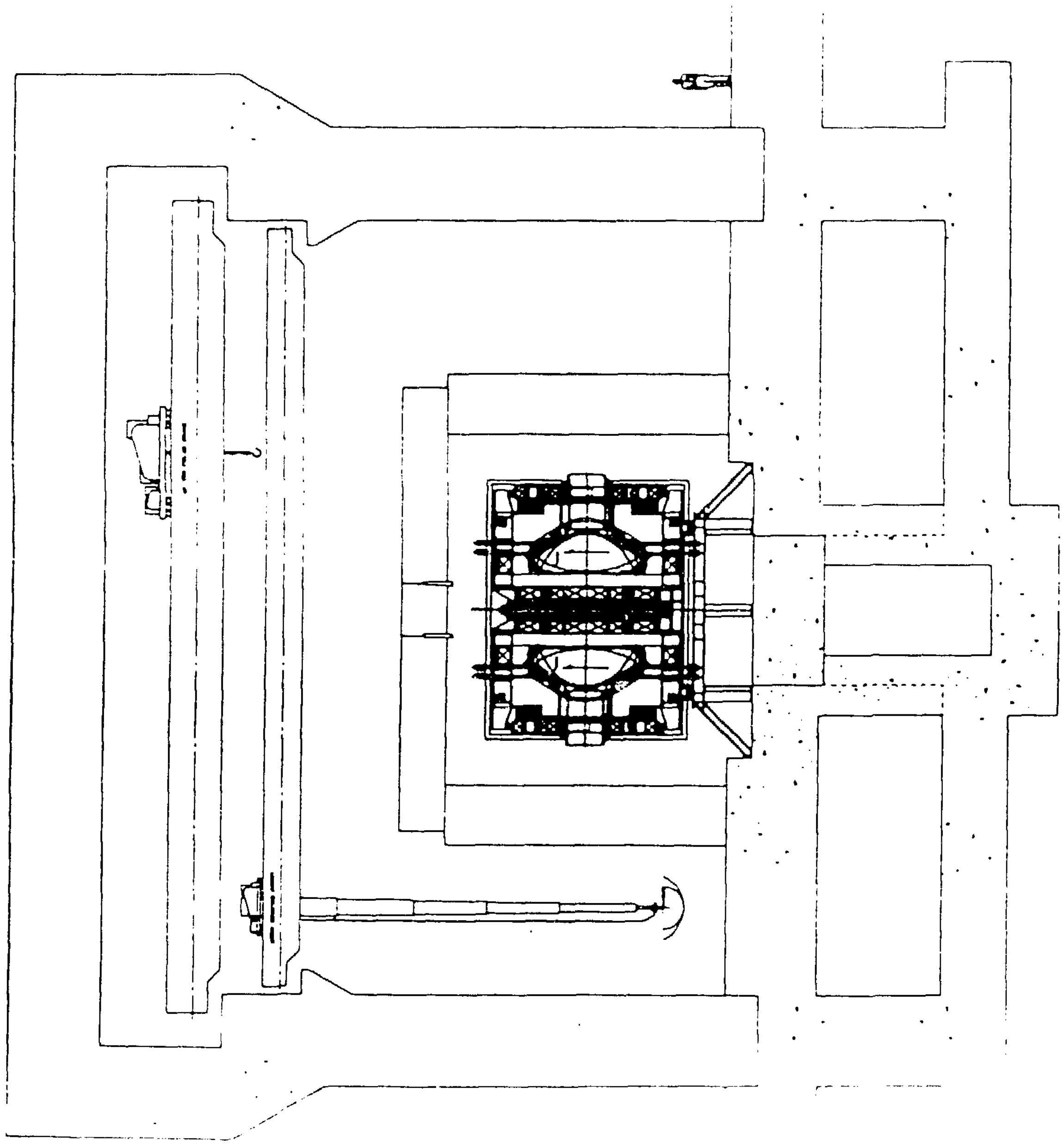
TILE GRAPPLER
FIG. 5



TILE INSTALLATION/REMOVAL MACHINE
FIG. 6



INSPECTION/VIEWING MANIPULATOR
FIG. 7



CIT MACHINE SECTION
FIG. 8

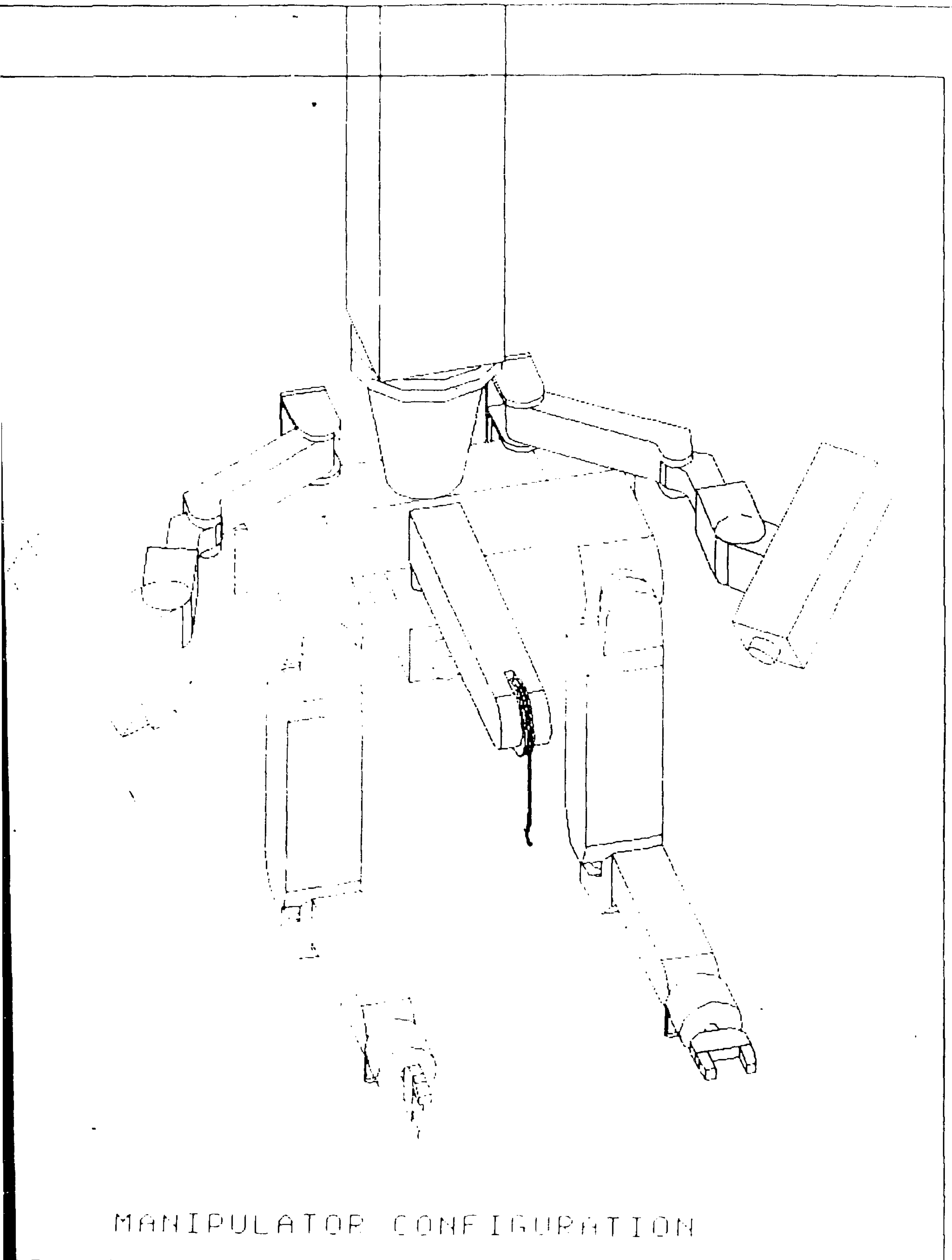


FIG. 9