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REMOTE MAINTENANCE DESIGN ACTIVITIES AND RESEARCH AND DEVELOPMENT ACCOMPLISHMENTS FOR THE COMPACT IGNITION TOKAMAK*

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ABSTRACT

The use of deuterium-tritium (D-T) fuel for the Compact Ignition Tokamak (CIT) requires the use of remote handling technology to carry out maintenance operations. The remote operations consist of removing and replacing such components as first wall armor protection tiles, radio-frequency (rf) heating modules, and diagnostic modules. The major pieces of equipment being developed for maintenance activities internal to the vacuum vessel include an articulated boom manipulator (ABM), an inspection manipulator, and special tooling. For activities external to the vessel, the equipment includes a bridge-mounted manipulator system, decontamination equipment, hot cell equipment, and solid radiation-waste (rad-waste) handling and packaging equipment. The CIT Project is completing the conceptual design phase; research and development (R&D) activities, which include demonstrations of remote maintenance operations on full-size partial mock-ups are under way.

1. INTRODUCTION

The CIT, to be located at Princeton Plasma Physics Laboratory, will be the next experimental machine in the U.S. Fusion Program. Its use of D-T fuel requires the implementation of remote handling

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technology for maintenance and disassembly operations. The machine will be surrounded by a close-fitting nuclear shield designed to permit personnel access into the test cell 24 h after shutdown. Maintenance within the shield will be accomplished remotely with an overhead boom-mounted manipulator system and a floor-based mobile robot. Maintenance on components within the vacuum vessel will be accomplished by two ABM's operating within the vessel vacuum environment.

The machine will operate initially with hydrogen fuel for approximately one year. This will permit verification of the integrity of the total system and allow hands-on repair of any equipment that fails during early operation. In addition, the operation of maintenance equipment will be demonstrated. Once D-T operations begin, all maintenance to be accomplished within the shield will require remote handling techniques. Many of the envisioned remote maintenance tasks are part of ongoing R&D programs that will demonstrate the equipment and methodologies necessary to provide a complete and practical remote maintenance system for CIT.

2. MAINTENANCE APPROACH

The CIT is a compact, low-cost machine and, in this context, it was acknowledged that it would not be possible to remotely maintain every subsystem on the tokamak. The primary structure, the toroidal field (TF) and poloidal field (PF) coils, and the vacuum vessel are examples of subsystems that are not replaceable. They are designed to be permanent installations. The need for remote maintenance is still significant but will be limited primarily to components internal to the vacuum vessel and components external to the cryostat.

The in-vessel remote maintenance requirements include inspection of components, replacement of thermal protection tiles, leak detection, and repair welding activities. The ex-vessel maintenance requirements are limited to replacement and subsequent repair of those components outside the cryostat/thermal shield. The maintenance operations can be hands-on 24 h after shutdown in the test cell if the shield is intact, but must be performed remotely if a module of the shield is removed.

The shield is constructed of modules with permanent structural columns. Removal of a shield module exposes a segment of the machine for maintenance work. Figure 1 is an isometric view of the tokamak with the shield structure partially removed, and Fig. 2 is a plan view of the test cell with the top shield modules removed. A bridge-mounted master-slave manipulator system and an overhead crane will be used to replace equipment modules that interface with the machine. A floor-based mobile manipulator will be used for similar activities in the area underneath the machine.

An air-lock transfer area leads from the test cell to a decontamination cell. After decontamination, components will be evaluated for activation and/or contamination levels to determine the appropriate disposition. Nonradioactive components will be transferred to a warm cell in an unshielded containment area. Radioactive components will be transferred to a shielded hot cell, equipped with through-the-wall master-slave manipulation systems, where components can be repaired or packaged into waste containers for disposal.

3. IN-VESSEL MAINTENANCE

Experience has shown that component failures in the vacuum vessel will be a recurring event. The ability to provide rapid in-vessel inspection and maintenance will enhance machine availability. An ABM is used to transport maintenance equipment and parts within the vacuum vessel. A general-purpose servomanipulator end-effector is used for general maintenance operations, while special-purpose end-effectors are attached to the ABM for specific maintenance tasks. These include tile replacement, leak detection, and divertor module replacement. The general arrangement of the in-vessel remote maintenance systems is shown in Fig. 3.

Four dedicated ports have been provided on the vacuum vessel for in-vessel maintenance and inspection operations. These extend through the nuclear shield and contain moveable shield plugs and vacuum isolation valves. Two midplane ports, located 180 degrees apart, have attached antechambers, each housing a retracted ABM. Two top vertical ports provide access for inspection/viewing manipulators. These may be used in conjunction with the viewing systems on the ABM to provide additional information.

3.1. Articulated Boom Manipulator

Each ABM provides access to one-half of the vacuum vessel. The boom consists of a series of linkages that are folded onto one another to reduce space requirements in the stowed position. A similar system has been in operation for several years on the Joint European Torus (JET); another is now being tested for the Tokamak Fusion Test Reactor (TFTR).

The 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 ABM's access port. The carriage and telescoping mast sections 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 extend around the vessel during maintenance activities and fold into the antechamber for storage. Each link section is driven by a stepper motor, harmonic drive unit, and recirculating ball screw linear actuator. At its maximum extension, the ABM will support a 1000-kg vertical load with a deflection of less than 2.5 cm.

An interlocked material transfer port allows equipment and tools to be introduced or removed from the ABM antechamber during maintenance, and a separate port is provided through which a vacuum pumping system will evacuate the antechamber. A vacuum isolation valve and moveable shield plug are located just outside the vessel port to isolate and protect the antechamber during plasma operations and ABM removal. The antechamber functions as a transport carrier when the ABM is removed for decontamination and maintenance.

4. EX-VESSEL MAINTENANCE

4.1. Test Cell Operations

Shield modules must be removed to gain access to the peripheral equipment adjacent to the cryostat; therefore, all activities associated with the peripheral equipment must be done remotely. This equipment includes components for diagnostics, instrumentation, vacuum, etc.

Remote handling and manipulator transport systems have a major impact on the test cell configuration. During the conceptual design, various ways to provide manipulator coverage to the tokamak and associated cell equipment were studied. Alternatives included overhead systems, with either a telescoping boom or a rigid mast, and floor-based systems, including fixed mounted and mobile manipulators. The overhead system shown in Fig. 4 was selected because it provides full test cell coverage without interference from floor-mounted machine components and provides relatively quick access through the top shield for inspection. The basic manipulator system, shown in Fig. 5, consists of the manipulator arms, cameras, and an auxiliary hoist. The manipulator arms will be force-reflecting with real-time response and a 10-kg capacity. This combination of characteristics has been shown in controlled tests to enhance operator efficiency, thus reducing machine downtime.

Three television cameras are used to provide the operator with multiple views of the work area; one will be located between the arms and the others on either side of the arms. Each will be equipped with pan, tilt, and zoom so that operators can optimize their view of the work area. Other cameras located in the test cell will provide general overall coverage to assist the operators when moving the crane or manipulator bridge systems.

4.2. Decontamination Cell Operations

Disabled equipment coming from the test cell will be moved into the decontamination cell via a transfer cart. In-vessel components and other contaminated equipment items will be transferred in sealed containers to prevent spread of radioactive particles. The decontamination cell will be equipped with monitors to assess the condition of the equipment and with spray chambers to decontaminate components. Remotely operated equipment will handle the components. Personnel access to the decontamination cell may be permitted under very controlled conditions; routine access is not anticipated.

4.3. Repair Cells

The repair cells consist of a hot cell and a warm cell located adjacent to the test cell. Equipment coming from the decontamination cell will be transferred to either the hot (shielded) cell or the warm cell, depending upon the degree of contamination or activation. The warm cell includes 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 shielding window/master-slave manipulator stations, and appropriate in-cell tools and equipment. It has provisions for remote disassembly and repair operations and equipment for solid rad-waste processing, packaging, and storage. Commercially available equipment will be used to handle the rad-waste wherever possible.

5. RESEARCH AND DEVELOPMENT

The R&D activities for in-vessel and ex-vessel maintenance equipment have been under way for approximately one year. In some cases, this work is at the level of design studies; in others, the work includes prototype testing and the use of mock-ups.

Preliminary testing of a leak detection system using the leak telescope concept has been started. The purpose is to measure the sensitivity of such equipment under simulated tile and vacuum conditions. A vacuum vessel sector welding machine is under study; its design is based on commercially available equipment. The welder and the leak detection devices will be used in conjunction with the ABM. The ABM is in a concept design phase, which includes studies of the vacuum requirements, the operation of the boom and manipulator, and the need for radiation hardening of that equipment.

Manipulator systems for ex-vessel operation are undergoing use and comparison tests to establish CIT requirements. In addition, partial mock-ups of the CIT are being used to study manipulator operations and the machine configuration. An upper mock-up is investigating diagnostic ports and will be updated this year to reflect the increase in machine size, the elimination of the press frame, and the incorporation of Helicoflex/Cefilac vacuum couplings like those used on JET.

A mock-up of the midplane port, including a full-size rf module, is under construction and will be used to study rf replacement operations and midplane diagnostic replacements. A mock-up design of the area under the machine is planned for later this year. It will be used to study access and maintenance operations using a floor-based, mobile manipulator.

A collaborative testing program is under way at the Tritium Systems Test Assembly to study decontamination of tritiated remote maintenance tools from JET. The CIT project hopes to benefit from this testing when it begins designing tools and end-effectors.

6. CONCLUSION

The remote maintenance activities under way this year will focus on establishing equipment requirements, investigating commercially available equipment wherever practical, and providing input to the machine configuration and facility design. The use of mock-ups will continue to be a major tool for investigations. Most important will be the experience of others, particularly from our colleagues at JET and TFTR.

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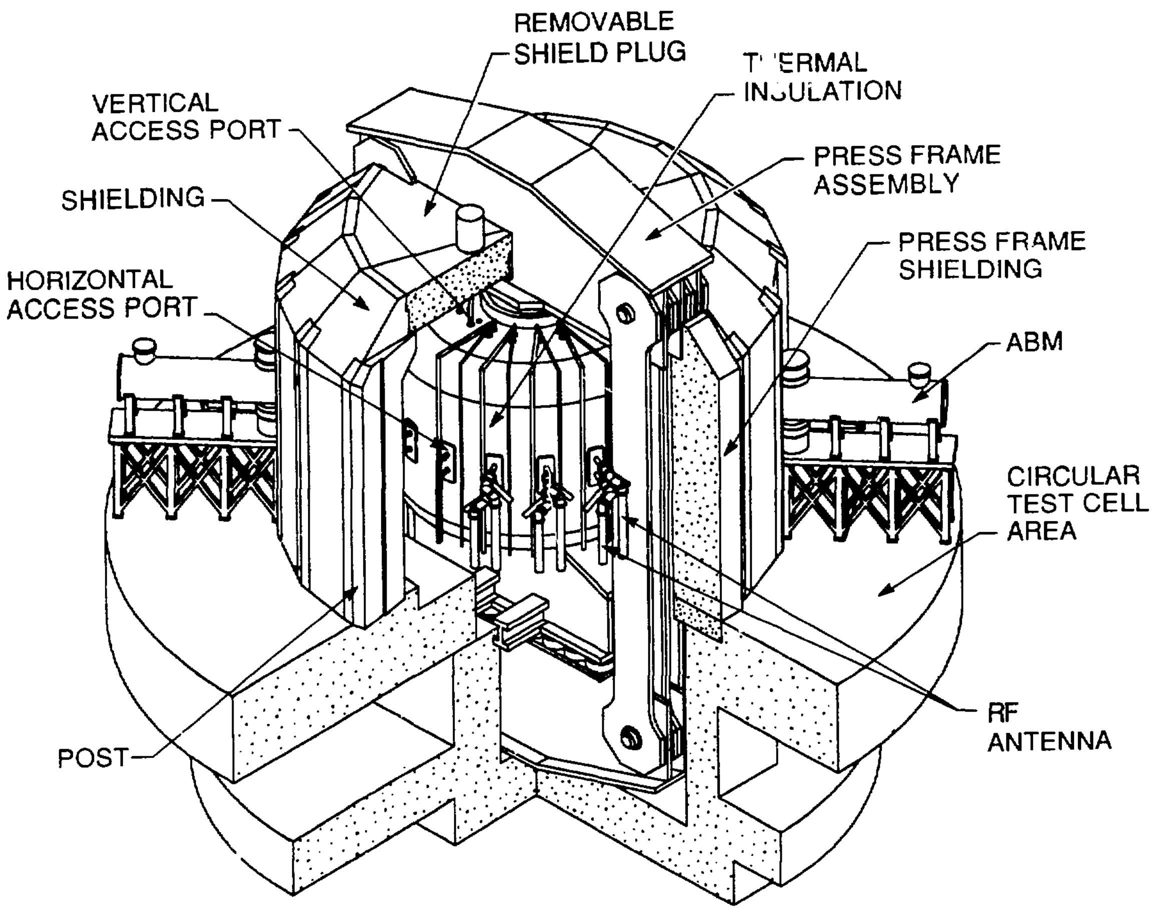
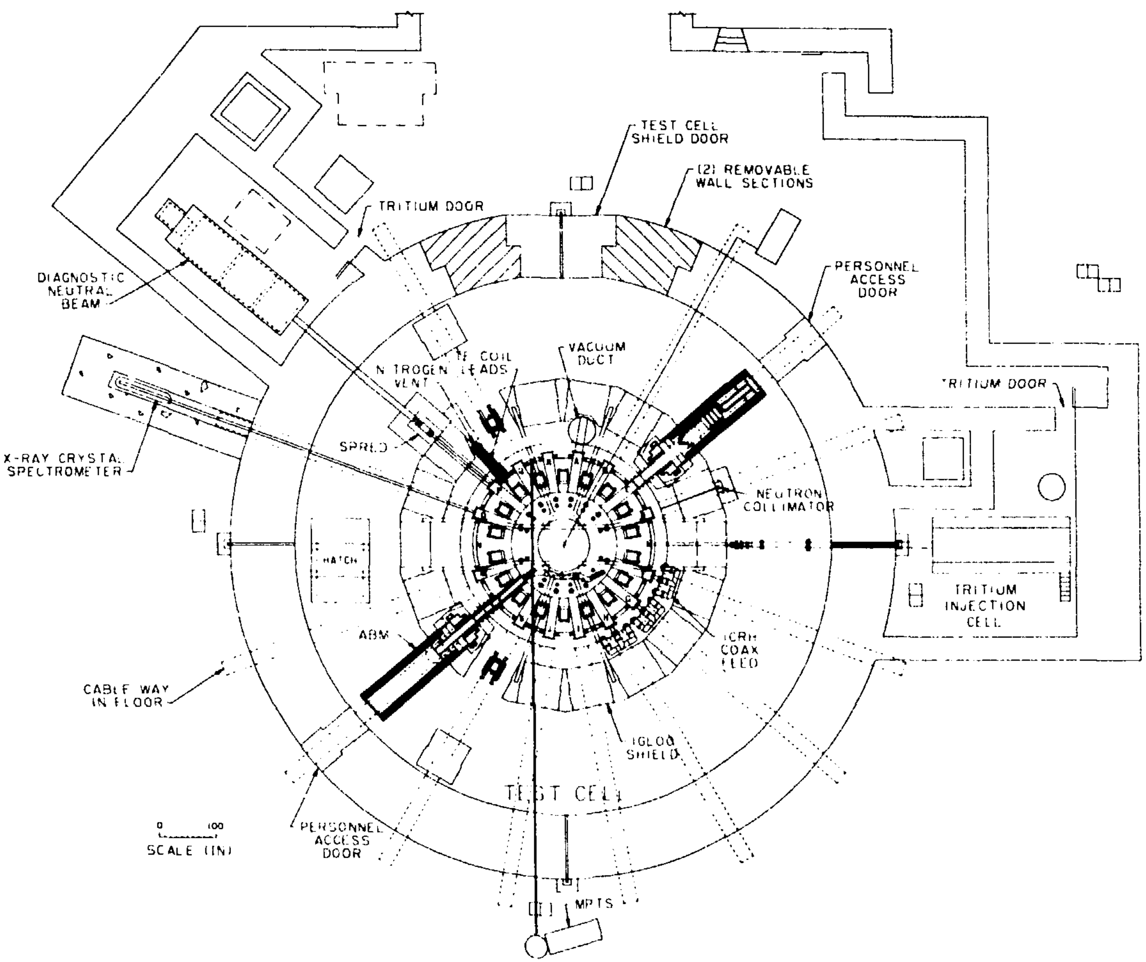


Fig. 1. The Compact Ignition Tokamak with part of the close-fitting shield removed.



TEST CELL SHIELD DOOR
(2) REMOVABLE WALL SECTIONS
TRITIUM DOOR
PERSONNEL ACCESS DOOR
DIAGNOSTIC NEUTRAL BEAM
COIL LEADS
VENT
VACUUM DUCT
X-RAY CRYSTAL SPECTROMETER
SPRED
TRITIUM DOOR
NEUTRON COLLIMATOR
HATCH
TRITIUM INJECTION CELL
ABM
ICRH COAX FEED
CABLE WAY IN FLOOR
IGLOO SHIELD
TEST CELL
PERSONNEL ACCESS DOOR
MPTS
0 100
SCALE (IN)

Fig. 2. Plan view of the test cell with the upper shield removed.

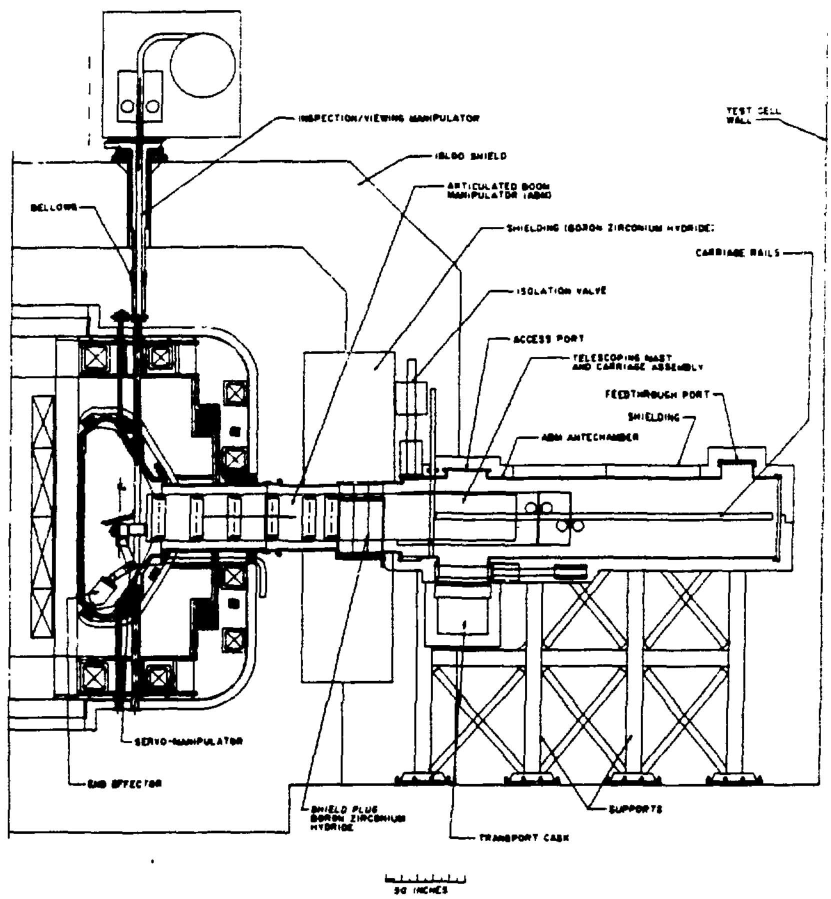
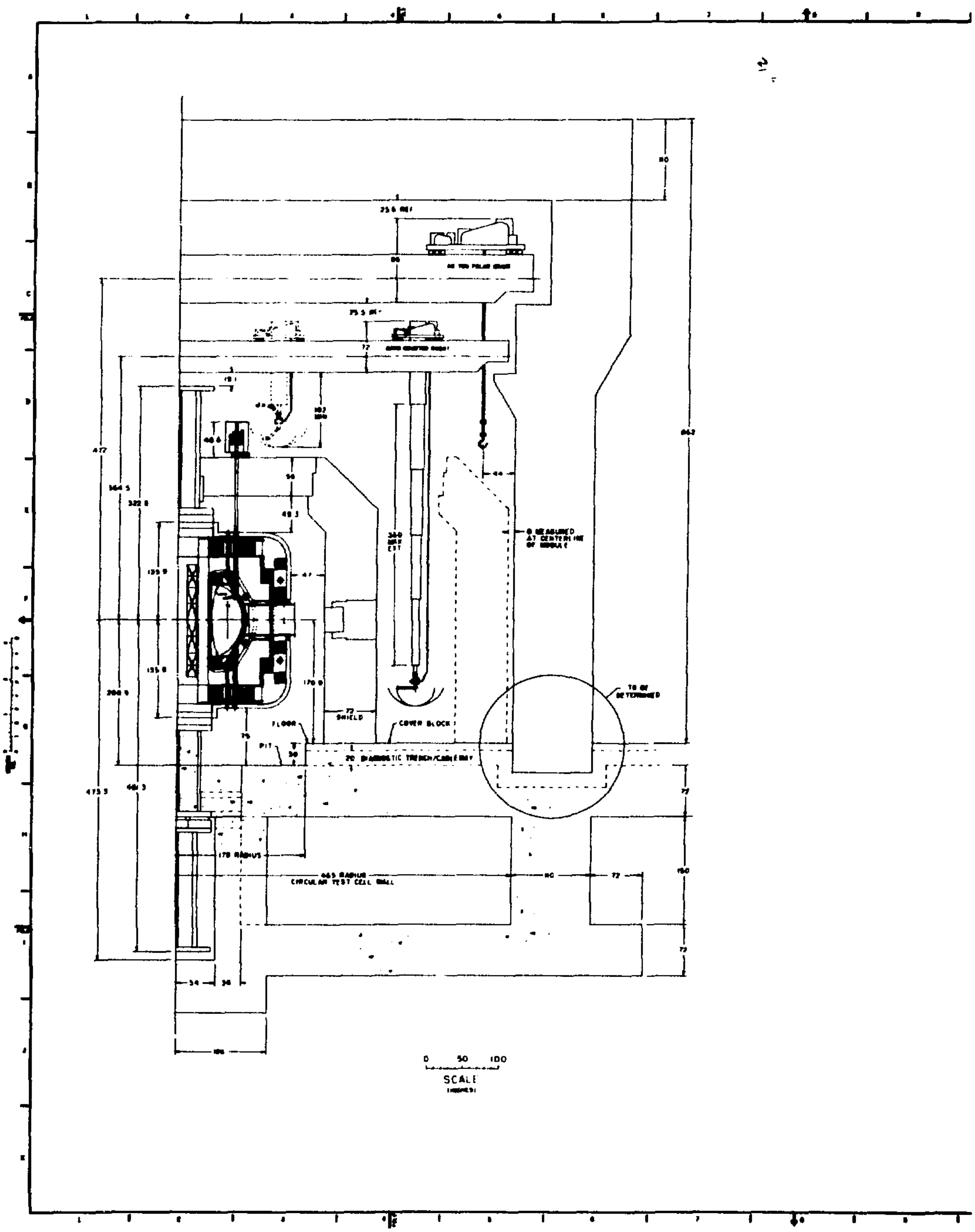

INSPECTION/VIEWING MANIPULATOR
TEST CELL WALL
IGLOO SHIELD
ARTICULATED BOOM MANIPULATOR (ABM)
BELLOWS
SHIELDING (BORON ZIRCONIUM HYDRIDE)
CARRIAGE RAILS
ISOLATION VALVE
ACCESS PORT
TELESCOPING MAST AND CARRIAGE ASSEMBLY
FEEDTHROUGH PORT
SHIELDING
ABM ANTECHAMBER
SERVO-MANIPULATOR
END EFFECTOR
SHIELD PLUG BORON ZIRCONIUM HYDRIDE
SUPPORTS
TRANSPORT CASK
50 INCHES

Fig. 3. The articulated boom manipulator and in-vessel inspection systems.



SHIELD
FLOOR
PIT
COVER BLOCK
170 RADIUS
CIRCULAR TEST CELL WALL
0 50 100
SCALE

Fig. 4. The bridge-mounted manipulator at various positions in the test cell.

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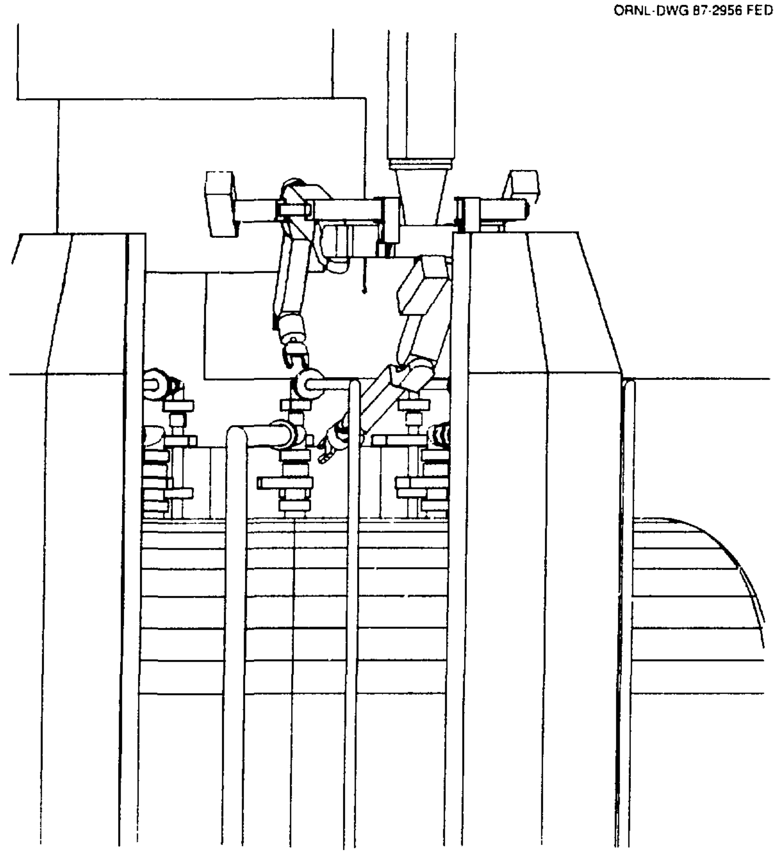

Fig. 5. CATIA model of the bridge-mounted manipulator operating on the upper diagnostic ports.