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TFTR REMOTE MAINTENANCE

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ABSTRACT

The Tokamak Fusion Test Reactor (TFTR) is the first tokamak designed to utilize tritium plasmas and achieve significant neutron yields. Tritium operations are scheduled for the early 1980's at the Princeton Plasma Physics Laboratory.

Complex operations of unprecedented scale must be performed remotely. The design of TFTR and the maintenance system supporting it are developing in parallel. The nature of the problem and a proposed set of maintenance tools are described.

INTRODUCTION

Tokamak, an acronym from the Russian words toroidal-chamber-magnetic, describes a form of experimental plasma physics research apparatus which has demonstrated relatively stable magnetic confinement of hot plasma. The Tokamak Fusion Test Reactor (TFTR) is the first device of this type designed to "burn" tritium using the reaction

$$D + T \rightarrow n\ (14.1\ \text{MeV}) + He^4\ (3.5\ \text{MeV}).$$

A substantial reaction rate is achieved by injecting energetic neutral deuterium beams (120 kV) into a colder (several keV) tritium plasma.

Design and construction are now underway leading to tritium experiments at the Princeton Plasma Physica Laboratory in the early 1980's. An initial experimental period of about one year using non-radioactive feed gases precedes the thermonuclear experiments. This phase will also serve as an engineering test period to demonstrate regular machine operations, determine and solve any problem areas that may arise and prepare with finality for remote operations.

Discussed here is the nature of the remote handling problem and the solutions proposed to date.

MECHANICAL ARRANGEMENT

An illustration of TFTR is shown in Fig. 1 and a plan view of the device with diagnostic apparatus and neutral beam injectors attached in Fig. 2. The toroidal reacting plasma is housed in a vacuum vessel surrounded by twenty toroidal field (TF) coils which mechanically trap the vessel. The ohmic heating, equilibrium field and variable curvature coils shown provide the magnetic field necessary to initiate the plasma current and control the position of the established discharge. All magnet windings use water cooled hollow or grooved cooper conductors. The TF coils are encased in circular box beams which, structurally, bear against segmented titanium compression rings within the central ohmic heating solenoid windings. The remaining superstructure is fabricated from austenitic stainless steel. The entire device is then shielded with a pillbox of borated concrete blocks. An array of four neutral beam injectors will be installed with provision for two additional units. Table I lists the major machine parameters.

RADIATION LEVELS

The calculated neutron yield for a reference full power, 0.5 sec. pulse is 3.6×10^{18}. D-T operations are limited to 1000 reference pulses per year or their neutraon equivalent by site boundary dose criteria. During pulsing, no access to the machine room is permitted -- the does exceeds 100 rem/pulse. After a series of pulses a wait of about one hour is required to reduce air activation and allow entrance. The machine shields are postulated to allow controlled access to their periphery. After a one day wait the contact dose at the vacuum vessel is about 4 rem/hour. The total radiation level at the shield surface from all major elements has not yet been determined since all component designs are not final.

DESIGN APPROACH

The machine is separable into ten segments, each containing two TF coils and a vacuum vessel sector. Any 60 ton segment may be removed individually. The upper coil structure is removable as a single 80 ton unit. Diagnostics are mounted on vacuum vessel port covers. All ports use remotely operable seals now under development. The machine room is large enough to accomodate all components of the disassembled machine.

To assure maintainability all details of the design are reviewed by a separate group having two main functions: (a) design of the maintenance tools, and (b) maintenance operations planning and procedures.

MAINTENANCE APPROACH

TFTR is primarily a physics experiment. Maintenance, as an engineering function, is a key element in assuring that the scientific objectives of the program are attained in an economical and timely fashion.

The nature of the experiment necessitates that certain maintenance operations be performeld remotely. Concerted effort is made to localize the need for remote maintenance to the Tokamak and components housed inside the device shield.

Some 200 remote maintenance tasks have been identified and categorized: routine operation, preventive maintenance, repair/replacement of components and major teardown. A number of critical tasks have been studied and explored in detail to define maintenance procedures and to establish the need for certain remote maintenance equipment and, where necessary, TFTR design changes. This is an ongoing effort.

The "maintenance group" has direct input at all stages of design by means of a Remote Maintenance Manual giving both design guidelines and specific details and by frequent design reviews. Final acceptance and approval of a design is embodied in the sign-off procedures.

PRESENT MAINTENANCE SYSTEM DESIGN

The presently envisioned maintenance system includes the following facilities and equipment:

Maintenance Facilities Adjoining TFTR Test Cell:

1) Repair/NB Test Cell - a 18.3m x 34.8m shielded hall where radioactive component maintenance and repairs will be performed in addition to neutral beam assembly, repair and testing activities. This facility is designed to provide fully remote maintenance capability.

2) Mock-up Area - a 25.6m x 44.5m building will house a full scale, one quarter mock-up of the reactor. This building will also provide space for storage of various maintenance equipment, a remote maintenance control room and a safety area. The initial use during TFTR construction will be for component preassembly and equipment staging.

3) Remote Maintenance Control Room - an equipment, video systems and communications control center for all remote operations in the TFTR Test Cell will be located in the Mock-up Area. Direct viewing by means of a shielding window is provided.

TFTR Mock-up:

A full scale mock-up of one quadrant of the final TFTR design configuration will be constructed. It will contain a section of the vacuum vessel, dummy coils and shielding. The mock-up will lend itself to being configured to give a true representation of any section of the machine. The primary purposes of the mock-up are the development and verification of maintenance procedures, establishing and proving capabilities of maintenance tools and systems, and training of personnel.

General Purpose Equipment

1) Remotely operable bridge cranes in both the TFTR Test Cell and the Repair Cell with special features, including slow motion capability for accurate control and motor driven rotating hook.

2) Heavy duty transfer car(s) for moving equipment between the Test Cell and the Repair Cell and/or the Mock-up Area will run on permanent, flush tracks and will be remotely operable.

3) Bridge mounted manipulator system (BMMS) using a 180 kg capacity, 3 m articulated electromechanical arm on a telescopic vertical boom mounted on a trolley. Both the TFTR Test Cell and the Repair Cell have an independent manipulator bridge running below the crane, while the Mock-up Area crane bridge has provisions for accepting the manipulator trolley. The manipulator system has the capability of being transfered (remotely) to any one of these bridges.

4) For in-vessel maintenance, a study program (RDAC 11.B.14) recommends the use of a 10 kg capacity bilateral servomanipulator in conjunction with a 100 kg capacity "power arm". Designs for these units and the device(s) to position them are not completed yet.

5) Thru-wall mechanical master-slave manipulators with shielding windows will be provided in the Repair Cell.

6) Shielded aerial platform with mechanical master-slave manipulator will be used for semi-remote operations.

Special Purpose Tools

1. Sector removal/replacement system consisting of the following major items:

   a) Sector handling fixture, which incorporates a six degrees of freedom (triaxial translation and rotation) short travel carriage, used for accurate movement and positioning of the 60 ton machine segment near its design location and for guiding the crane lift.

   b) Frame structure which attaches to the machine and establishes a precise reference and guiding mechanism for the handling fixture.

   c) Vacuum Vessel holding/spreading mechanism which controls the gross movements of the vessel and the clearances at the parting planes during sector removal/replacement.

2. Remote Welder/Cutter used to part the vacuum vessel and to reweld it. It is inserted into the vessel through a port opening and expands to a three-limbed structure carrying the individual welding and cutting heads, the welder is a programmable, automatic commercial unit with a modified head design. The cutter is a miller type design which simultaneously parts the vessel and prepares the joint for rewelding. The tool is guided by flanges which are integral with the vessel joint design.

3. Vessel seals for the different port configurations employed in the design are being developed for remote and/or semi-remote operation and maintenance. Both mechanical and welded seal designs are considered.

4. Leak detection system for remotely identifying the source of leaks will employ both permanently installed provisions at joints, seals and bellows, and mobile detectors to be positioned by manipulator.

Viewing Systems

The recommendations of a viewing study program (RDAC 11.D.15) are the following TV systems:

1) For manipulator support - A 3-D, normal resolution, gimbal mounted B & W system with helmet viewing and head control and a color surveillance system with pan and tilt control and console monitor.

2) For welder/cutter - Two fixed lens B & W cameras at 90° with remotely operable filters.

3) For Test Cell/Repair Cell surveillance - Two B & W cameras on each wall of each cell mounted on traversing carriages.

4) For restricted access areas - Articulated fiber optics probes and manipulator placed small B & W cameras.

5) For crane operation - Two B & W cameras on crane bridge and one near shoulder of BMMS arm.

Miscellaneous

1) General purpose small tools consisting of standard power tools and hand tools adapted for manipulator use.

2) Special purpose small tools designed for specific remote and semi-remote operations.

3) Lifting and handling fixtures, including turning and positioning devices, parking cradles and stands for movement, maintenance and temporary storage of various components.

4) Temporary radiation shields to permit controlled access to areas of the Test Cell and Repair Cell during maintenance activities.

CONCLUSION

The maintenance system for TFTR is still in an embryonic state. Details of many machine components are not yet available. Some 200 maintenance tasks have already been identified and only a few have undergone any procedural evaluation. The early work involves review of component designs and the conception of what can be adapted to successfully perform the required tasks. The essential tasks will be demonstrated on a full scale mock-up of a portion of the machine. A wood mock-up is already available and a limited set of maintenance activities will be evaluated this year.

TABLE I

Major radius, TF coils	2.8 m
Inside diameter, TF coils	2.8 m
Major radius, vacuum vessel	2.65 m
Inside diameter, vacuum vessel	2.2 m
Vacuum base pressure	1.33×10^{-6} Pa
Vessel in-site bake-out temperature	250°C
Maximum port size (approx.)	0.7 m x 0.85 m
Total vessel weight (approx.)	3.6×10^{4} kg.
Sector weight (approx.)	5.4×10^{4} kg.
Total weight of shields and structure	1.8×10^{6} kg.

Radiation level outside "igloo" shield (1 hr. wait) < 50 mrem/hr.

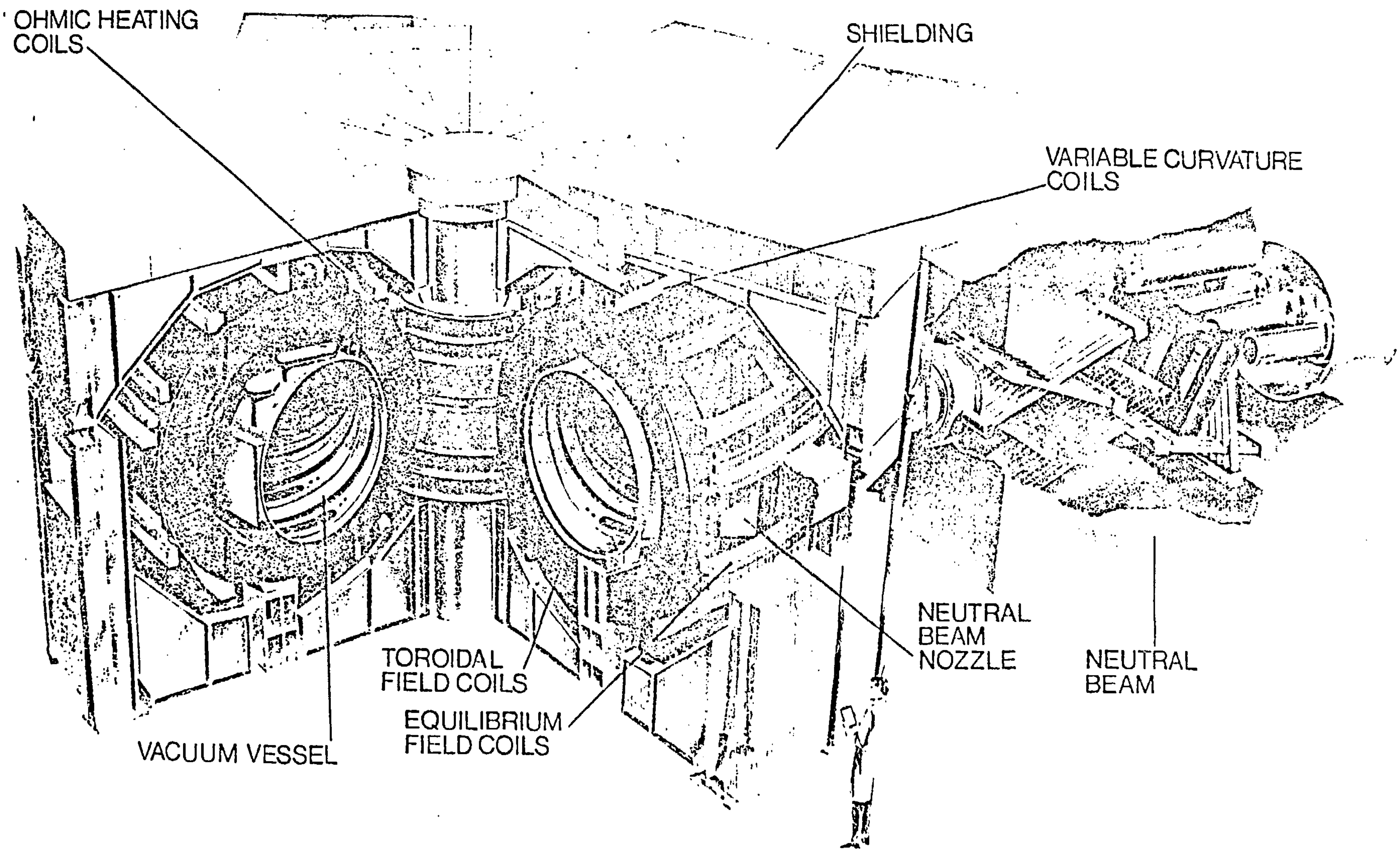
FIGURE CAPTIONS

<u>Figure 1</u>

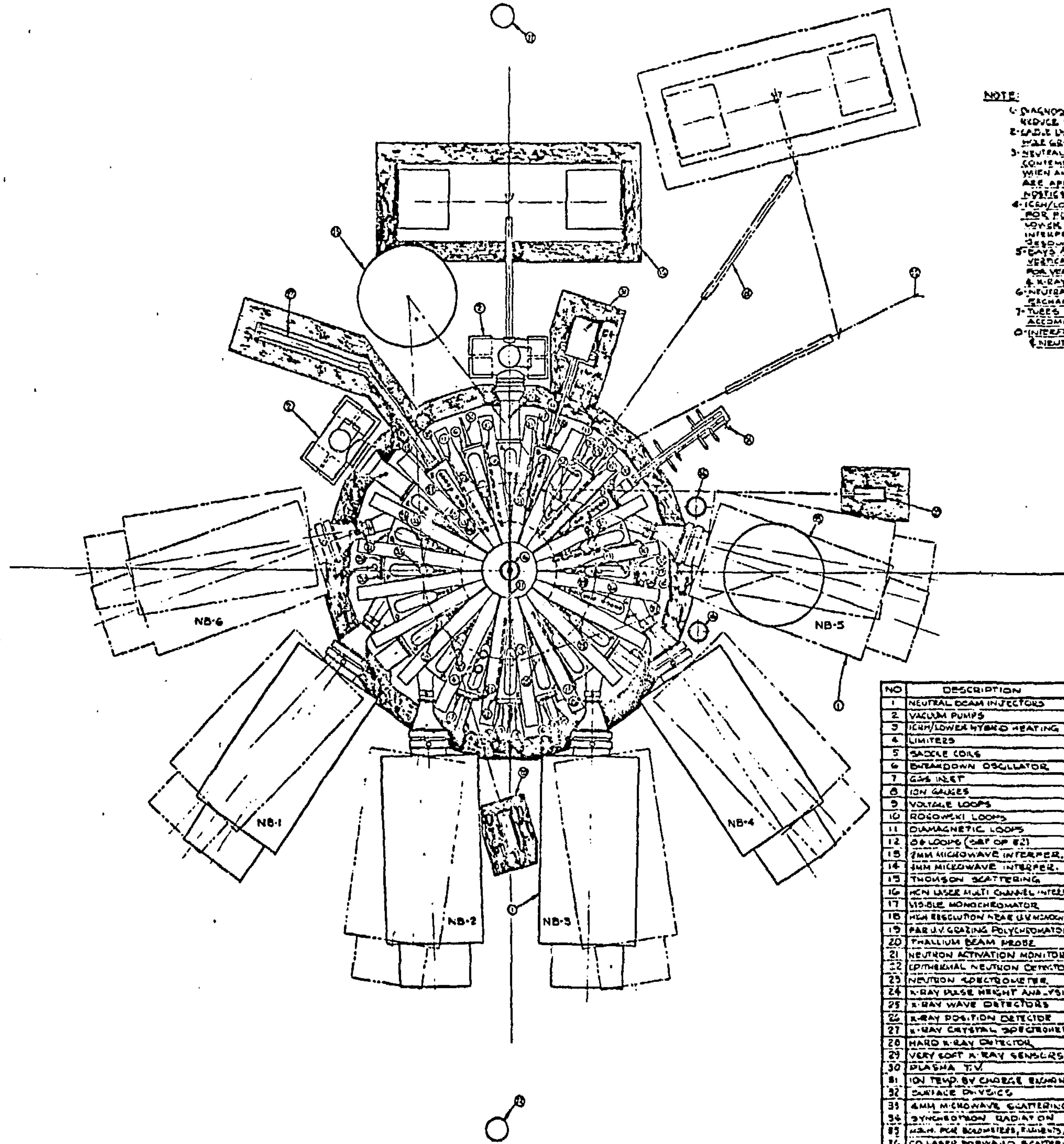
TFTR Assembly

<u>Figure 2</u>

TFTR - Plan View with Diagnostic Apparatus and Neutral Beam Installed.



OHMIC HEATING COILS
SHIELDING
VARIABLE CURVATURE COILS
NEUTRAL BEAM NOZZLE
NEUTRAL BEAM
TOROIDAL FIELD COILS
EQUILIBRIUM FIELD COILS
VACUUM VESSEL



NO	DESCRIPTION	QTY.	LOCATION
1	NEUTRAL BEAM INJECTORS	6	E,G,I,M,O,Q
2	VACUUM PUMPS	2	A,R
3	ICRH/LOWER HYBRID HEATING	24	[illegible]
4	LIMITERS	3	L
5	SADDLE COILS		NOT SHOWN
6	BREAKDOWN OSCILLATOR	4	D,J,K,T
7	GAS INLET	1	C
8	ION GAUGES	5	A,J,K,R,S
9	VOLTAGE LOOPS	6	NOT SHOWN
10	ROGOWSKI LOOPS	2	E,T
11	DIAMAGNETIC LOOPS	2	I,S,
12	δθ LOOPS (SET OF 82)	2	C,K
13	2MM MICROWAVE INTERFER.	2	C,S
14	1MM MICROWAVE INTERFER.	2	C,S
15	THOMSON SCATTERING	1	A
16	HCN LASER MULTI CHANNEL INTERFER	1	G
17	VISIBLE MONOCHROMATOR	4	B,C,J,L
18	HIGH RESOLUTION NEAR U.V. MONOCHROM.	2	B,F
19	FAR U.V. GRAZING POLYCHROMATOR	3	F
20	THALLIUM BEAM PROBE	1	N
21	NEUTRON ACTIVATION MONITORS	6	B,G,L,Q
22	EPITHERMAL NEUTRON DETECTOR	4	WALL
23	NEUTRON SPECTROMETER	3	E,H,T
24	X-RAY PULSE HEIGHT ANALYSIS	2	D
25	X-RAY WAVE DETECTORS	5	J,M,Q,T
26	X-RAY POSITION DETECTOR	1	Q
27	X-RAY CRYSTAL SPECTROMETER	2	S
28	HARD X-RAY DETECTOR	2	D,L
29	VERY SOFT X-RAY SENSORS	4	F,P
30	PLASMA T.V.	4	D,F,P,Q
31	ION TEMP. BY CHARGE EXCHANGE	2	B
32	SURFACE PHYSICS	2	C,H
33	4MM MICROWAVE SCATTERING	2	P
34	SYNCHROTRON RADIATION	1	T
35	M.M. FOR BOLOMETERS, FILAMENTS, ET.	6	A,C,F,K,R,S
36	CO2 LASER FORWARD SCATTERING	1	E
37	DIAMETRAL TUBE	1	CENTER OF MACHINE

NOTE:

1. DIAGNOSTIC OPENINGS TO BE SHIELDED TO REDUCE NEUTRON STREAMING.
2. CABLE DUCTS, ACCESS PLATES, AND THROUGH-WALL GRIDS TO BE CAST IN TEST CELL FLOOR (TO [illegible])
3. NEUTRAL BEAM INJECTORS AT BAYS E & Q ARE CONTEMPLATED FOR POSSIBLE FUTURE USE. WHEN AND IF THESE NEUTRAL BEAM INJECTORS ARE APPROVED, INTERFERENCES WITH DIAGNOSTICS AT BAYS E & Q WILL BE RESOLVED.
4. ICRH/LOWER HYBRID HEATING IS CONTEMPLATED FOR POSSIBLE FUTURE. WHEN AND IF ICRH/LOWER HYBRID HEATING IS APPROVED, INTERFERENCES WITH DIAGNOSTICS WILL BE RESOLVED.
5. BAYS A, F, J, M, P, Q, R, T MAY REQUIRE MULTIPLE VERTICAL ACCESS DURING TRITIUM OPERATION FOR VERY SOFT X-RAY, X-RAY WAVE DETECTORS & X-RAY POSITION DETECTOR.
6. NEUTRAL BEAM CALORIMETER AND CHARGE EXCHANGE DIAGNOSTICS TO BE ADDED.
7. TUBES & VALVES TO BE MOVED OUT TO ACCOMODATE DEVICE SHIELDING.
8. INTERFERENCE BETWEEN LASER TRIPOD LEGS & NEUTRAL BEAM TO BE RESOLVED.