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DIAGNOSTIC PLANNING IN JT-60 PROJECT

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The diagnostic plans of JT-60 were made along with design of the main machine. Basic requirements of the diagnostic program are (1) multiple measurement of respective plasma parameters, (2) efficient usage of the discharge, (3) capable data acquisition system, (4) high reliability of the diagnostic equipments, and (5) systematic development of new diagnostic techniques. Dimensions of the diagnostic ports were determined in detailed design of the vacuum vessel, anticipating the possible diagnostic methods. The proposed diagnostic systems and the plans are shown in table and figures respectively. Problems in the diagnostics are also described.

Keywords : Diagnostic Planning, JT-60 Project, Multiple Measurement, Plasma Parameter, Diagnostic Equipment, Data Acquisition, Diagnostic Port.

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JT－60におけるプラズマ計測計画
(臨界プラズマ試験装置設計報告・43)

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(1977年7月22日受理)

JT－60における予備的な計測計画を本体の設計と協調して立案した。計測計画立案における基本的要求事項は(1)プラズマパラメータの複数計測，(2)各放電の効率的利用，(3)データ収集の拡充，(4)計測器の高信頼化，(5)新計測法の組織的開発，である。本体の計測ポートは真空容器の詳細設計時にすべての計測法を考慮して寸法を決めた。整備すべき計測システムとそのスケジュールを図表にまとめた。最後に診断にともなう種々の問題点を提示した。

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Contents

1. Introduction

Emphasis has to be placed on diagnostics in the JT-60 program. This is not only because of their usual role of making measurements of plasma parameters for the understanding of plasma behaviors, but also due to the bearing they have on the plasma and the device control and especially on the safeguard of the device. Most of the conventional diagnostics on JT-60 will be extrapolated in scale and data-acquiring capability from equipments already in operation or under development for other tokamaks, especially JFT-2[1], DIVA[2], and JIPP T-II[3]. On the other hand advanced diagnostics should be developed systematically and effectively in cooperation with other laboratories according to demand.

In section 2 we discuss requirements in the diagnostic planning. In section 3 we explain all diagnostic ports of the main machine. In section 4 we show the proposed diagnostic plan and the schedule. In section 5 we describe some of the problems associated with diagnostics.

2. Requirements in Diagnostic Planning for JT-60

Basic requirements in the diagnostic planning for JT-60 are as follows:

(1) Multiple measurements for each plasma parameter
Crosschecking of plasma parameters by multiple diagnostic methods is needed to raise the reliability of measurements.

(2) Efficient use of each discharge
All parameters required should be obtained in one discharge as far as possible. This requirement will enhance the efficiency and progress of experiments. For example, basic diagnostic equipments should be consolidated as a diagnostic system capable of temporarily and spatially resolved measurement.

(3) Capable data acquisition system
A data acquisition system should be provided to acquire and process the output from diagnostic sensors. An efficient usage of a data acquisition system is required in the on-line plasma control and should expedite step-by-step progress of experiments.

(4) Reliable diagnostic equipments
Since a wide range of diagnostics should be employed it is necessary to make each diagnostic equipment highly reliable. Especially

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sensors for the plasma control system must be made highly reliable.

(5) Systematic development of advanced diagnostic methods
The plasma parameters to be measured in JT-60 are extended to a wider range than those established in the past. New diagnostic methods have to be developed and tested.

3. Arrays of Diagnostic Ports

Diagnostic ports of the main machine were preliminary decided in the process of the detailed design of the vacuum vessel considering possible diagnostic methods. The diagnostic ports are grouped into three types of access ports i.e. horizontal access ports, vertical access ports and oblique access ports. The outline of each type of port is described below.

(1) Horizontal access ports
Figure 1 shows a layout of horizontal access ports (S_1 and S_3), special vertical access ports (SP), and small oblique access ports (IN_3) through which we can measure plasma parameters in the region of magnetic limiter. Since the magnetic limiter will be set at the outer region of the vacuum vessel on the horizontal symmetry plane, there remains an access (S_1 port) to the plasma along horizontal lines of sight only in the upper or lower edge regions of the plasma.

(2) Vertical access ports
There must be an access to the plasma along vertical lines of sight. Figure 2 shows arrays of vertical access ports ($U_1 \sim U_6$). Most planar arrays, which are called as standard arrays in the following, will have 3 vertical lines of sight (U_2, U_4, and U_6) around the torus. U_1, U_3, or U_5 ports may be added to the standard arrays in some sections of the vacuum vessel. Another planar arrays of 2 or 3 elliptic tubes are shown in Fig. 3. Those will be set at 4 sections of the vacuum vessel and can be used as vertical access ports of 6 to 8 chords in cooperation with adjacent standard arrays.

(3) Oblique access ports
There is an access to the plasma along oblique lines of sight. The corresponding oblique access ports should be large so that the plasma can be viewed over a wide solid angle. Each port can be shared among heating systems, evacuating systems, or diagnostic equipments. Figure 4 shows oblique access ports for diagnostics (IN_2). We can fully measure spatial variation of a plasma parameter through IN_2

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port. It is desirable to have many large oblique access ports as possible, so as to maximize access to the plasma.

4. Proposed Diagnostic Plan

A list of the proposed diagnostics with an abbreviated statement of their purpose is given in Table 1. Figure 5 shows the time schedule of the diagnostic program. The program is aimed at producing a viable operating system of diagnostics connected up to JT-60 on April, 1981*). In the standard diagnostic methods, developmental or prior equipments are as follows :

(1) Submillimeter-wave interferometers
Electron densities of JT-60 plasmas will be mainly measured with these equipments. Figure 6 illustrates a preliminary design of the interferometer. We will use FIR laser (HCN or CH_3OH laser), photoconductive detectors and phase modulator of which modulation frequency will be employed several maga-hertzes.[4]

(2) Multipulse laser scattering equipments
Spatial and temporal variations of electron temperatures and densities of JT-60 plasmas are planned to be measured with these equipments. The spatial variation in the vertical direction can be measured at single shot by adoption of two dimensional photoelectric converter. The temporal behavior can be also measured by adoption of multipulse Nd or ruby laser from which 10 or more laser pulses can be emitted at arbitrary intervals of 1 msec to 1 sec.

(3) Super grazing incidence monochrometers[5]
Metal impurity content and its radiation power are planned to be measured with these equipments. The region of measurable wavelength may be one to some tens of angstroms.

(4) A high-counting rate pulse height analysis system
Soft X-ray detector, hard X-ray detector, and neutron spectrometer can be connected with this system. The measuring time interval and counting rate required would probably be 10 or less msec and 1×10^8 cps, respectively. It would be well founded that average counting rate of this system is above 100 fold for one of standard system. Therefore high-counting rate detectors must be developed in step with

*) For the present, the start-up time of the JT-60 experiments had been exchanged on September, 1981.

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In the new diagnostic methods, developments of a FIR laser scattering system and wall surface analysis systems should be started at an early stage, and developments of resonance scattering system and fluctuation analysis systems may be started at next stage. Finally, most precise measuring method of current density distribution will be selected from various proposed methods after experience in PLT tokamak machine[6] or others.

A conceptual layout of diagnostics is shown in Fig. 8.

5. Notes

Some of the problems associated with diagnostics are described below.

(1) Pumping

It is desirable to have a gate valve for each diagnostic equipment to be connected to the vacuum vessel in vacuum. Tests on the tightness and durability of all-metal gate valves should be made and the optimum baking temperature of the valves should be determined. The connections between the vessel and the vacuum diagnostic equipments have a reasonably large surface area. Care has to be taken to keep the outgas from the surfaces to a tolerable rate.

(2) Electrical safety breaks

There must be a provision for electrical insulations between the diagnostic equipments and the diagnostic ports or between the diagnostic equipments and the ground. This is necessary to protect personnel and the diagnostic equipments from high voltages that may appear on the vacuum vessel by the plasma or as a result of device malfunction.

(3) Alignment mechanisms of vertical access ports

The vertical access ports will be extended above the device to beyond the poloidal and toroidal field coils and below the device to the basement. The arrays above and below the vessel must line up, so that the plasma can be viewed through from the top on the basement. Therefore alignment mechanisms by which we will be able to adjust setting errors and thermal displacements of the ports must be employed to the vertical access ports.

(4) Limitation of the space available to diagnostic equipments

The space around the machine is occupied by apparata with high this system.

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The space around the machine is occupied by apparata with high

priority, such as neutral beam injectors and vacuum pumps. Care should be taken to leave as much space for diagnostics are practical and also to design the machine support structures to suit the diagnostic equipments.

(5) Radiation shielding

Diagnostic equipments must be shielded against hard X-rays which will be mainly produced at the magnetic limiter and limiter regions by runaway electrons and neutrons which will be produced from γ-n reactions.

(6) Magnetic shielding

Diagnostic equipments should be shielded against stray magnetic fields, as required to permit satisfactory operation. In turn, such magnetic shielding must not affect the field back at the plasma significantly. Expected maximum intensities of stray magnetic fields at the distance of 7 and 15 meters from the major axis of the device on the equatorial plane are about 500 and 30 gausses, respectively. In the vertical direction, its intensities at the distance of 7 and 15 meters from the minor axis are about 700 and 140 gausses, respectively. These values are much larger than in the present-day devices.

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4) Itagaki T., Matoba T., Funahashi A. and Suzuki Y. : JAERI-M 7121, "FIR-Interferometer for JT-60", (1977) (in Japanese)

5) Mori K. : private communication

6) Grove D. et al. : Princeton Plasma Physics Laboratory Report, PPPL-1302, (1976)

Table 1-a Proposed JT-60 diagnostic system. (part 1)

I. Standard Diagnostic Methods	
Diagnostic Name	Brief Description of Purpose
1. Electro-magnetic Method	
1-1) One-turn Loops	Loop volts
1-2) Rogowski Coils	Plasma current (Total ohmic current)
1-3) Magnetic Probe Coils	Plasma position and shape, gross fluctuations
1-4) Diamagnetic Loopa or Rogowski Coils for Toroidal Coil Current	Plasma pressure
2. Interferometry	
2-1) 4 mm μ-wave Interferometers	Electron density of initial breakdown and magnetic limiter plasmas
2-2) 2 mm μ-wave Interferometers Multichannel	Electron density in outer regions of plasma
2-3) Submillimeter-wave Interferometers HCN or CH_3OH laser, multichannel	Radial and temporal behavior of electron density
3. Thomson Scattering	
3-1) Ruby Laser Scattering Equipment Low stray light optical system	Spatial variation of electron temperature and density
3-2) Multipulse Laser Scattering Equipments Multipulse Nd or ruby laser	Spatial variation of electron temperature and density at several times
4. Spectroscopy	
4-1) FIR Spectrometers	Synchrotron radiation
4-2) Visible Spectrometers	Hydrogen atom density and impurity content close to plasma surface
4-3) V.U.V. Spectrometers Normal and grazing incidence monochrometers	Impurity content, power radiated, ion temperature close to plasma surface
4-4) Ultra-soft X-ray Spectrometers Super grazing incidence and crystal monochrometers	Impurity content, power radiated, ion temperature
5. X-ray	
5-1) X-ray Pulse Height Analysis Semiconductor detector, high counting rate electronic circuits	Electron temperature, electron velocity distribution, impurity concentration
5-2) Soft X-ray Detectors SSD or PIN detectors	Internal plasma fluctuations, hot plasma column
5-3) Hard X-ray Detectors NaI or plastic scintillators	Runaway electron effects

Table 1-b Proposed JT-60 diagnostic system. (part 2)

Diagnostic Name	Brief Description of Purpose
6. Neutron	
6-1) Neutron Spectrometer He^3 spectrometer	Ion temperature
6-2) Neutron Counters B^{10} counters or activation detectors	Neutron flux
7. Neutral Particle Analysis	
7-1) Charge Exchange Neutral Particle Analysers	Ion temperature in outer region of plasma
7-2) High Energy Neutral Particle Detectors SSD detectors	Ion temperature, beam thermalization
8. Boundary Layer Analysis 8-1) Thermal Flux Detectors Bolometers, thermocouples, IR TV 8-2) Neutral Gas Analysers Fast ion gauges, mass analyser 8-3) Plasma Position Detectors Fiber arrays, visible TV	Total power loss to limiter or wall

II. New Diagnostic Methods

Diagnostic Name	Brief Description of Purpose
9. FIR Laser Scattering CH_3F or D_2O laser	Spatial variation of ion temperature and Z_{eff}
10. Resonance Scattering High power tunable laser	Spatial variation of impurity content
11. Current Density Distribution One of following methods : Heavy ion beam, H beam (counter injection), α-particle, Zeeman splitting, laser scattering, second harmonic-wave generation	Current density distribution, $B_p(r)$, $q(r)$
12. Fluctuation Analysis	
12-1) Fluctuation CO_2 laser and μ-wave scattering	Spatial variation of fluctuations
12-2) Potential Tl beam	Spatial variation of plasma potential
13. Wall Surface Analysis Auger electron spectroscopy, secondary ion mass analyser, X-ray micro-analyser	Examine wall surface effects

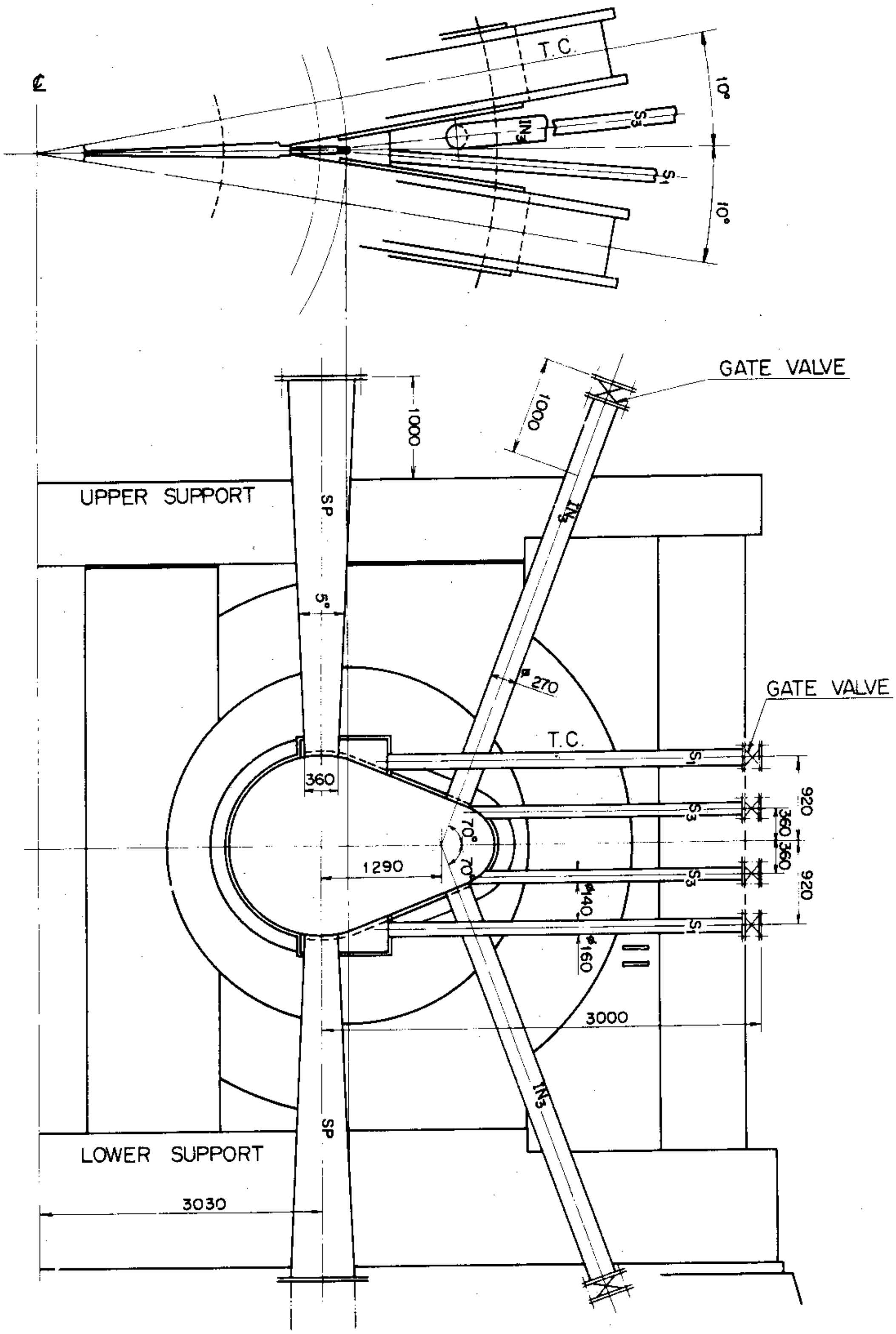

Fig. 1 Layout of horizontal access ports (S_1 and S_3), special vertical access ports (SP), and small oblique access ports (IN_3).

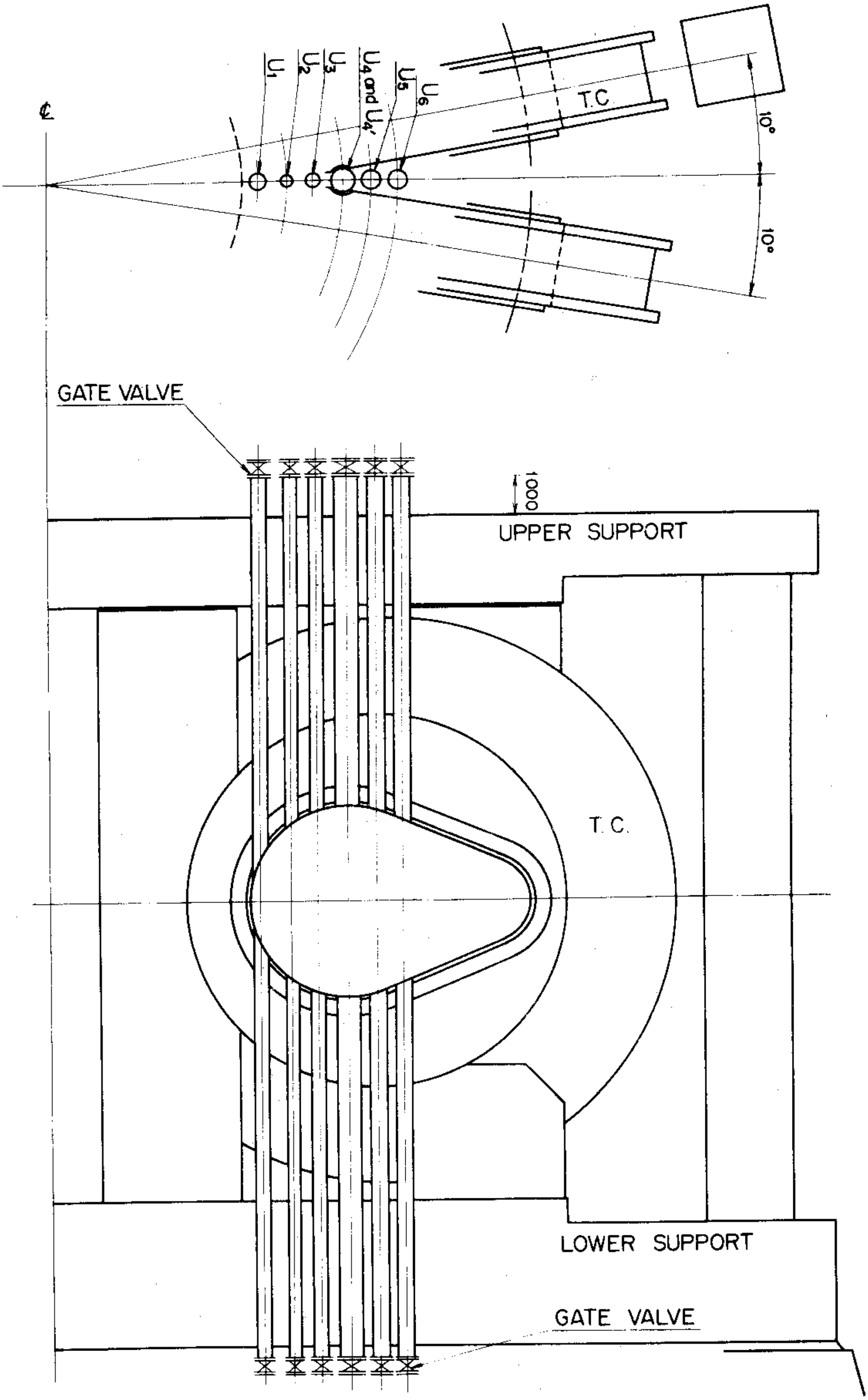

Fig. 2 Arrays of vertical access ports.

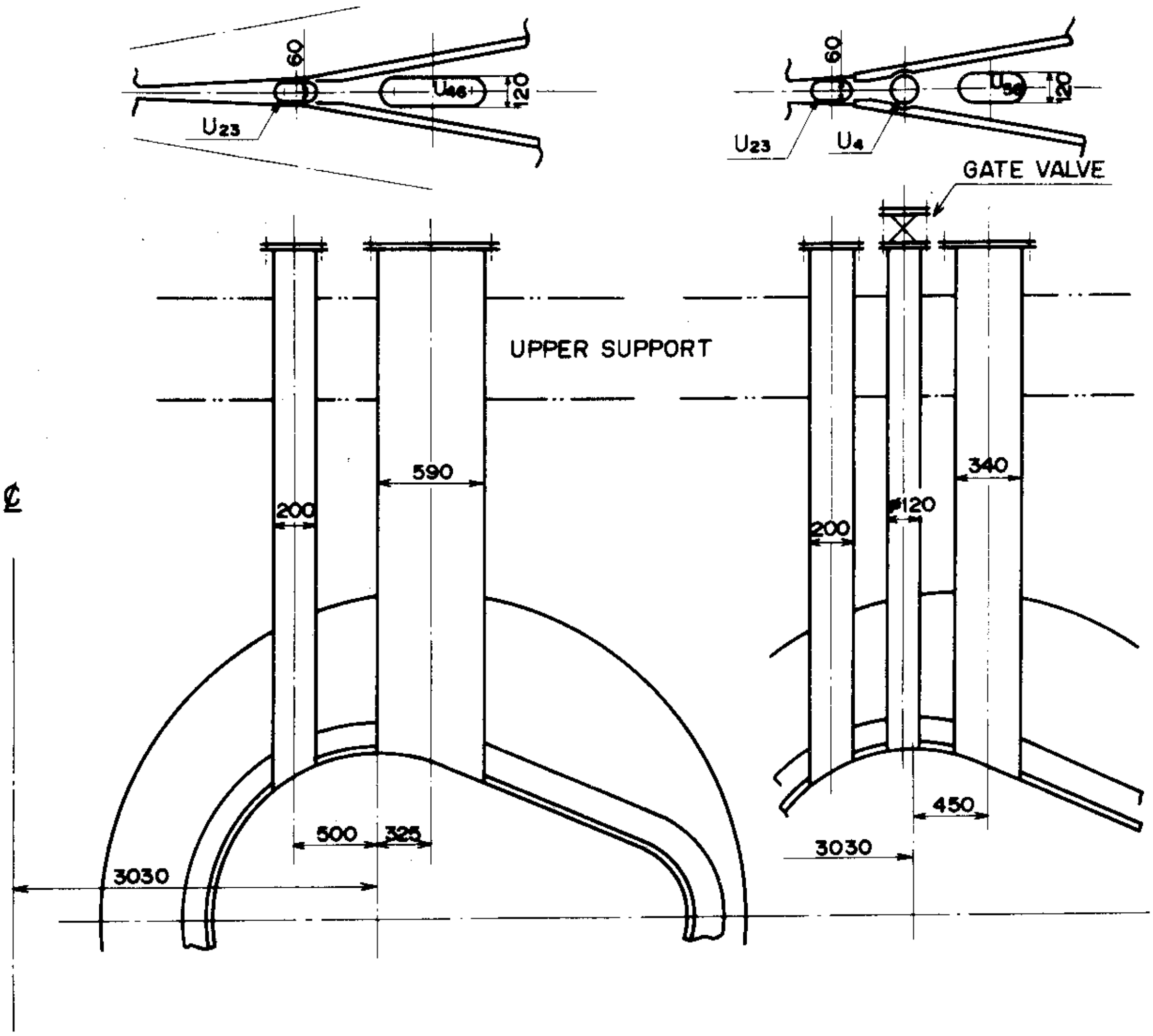

Fig. 3 Arrays of elliptic vertical access ports.

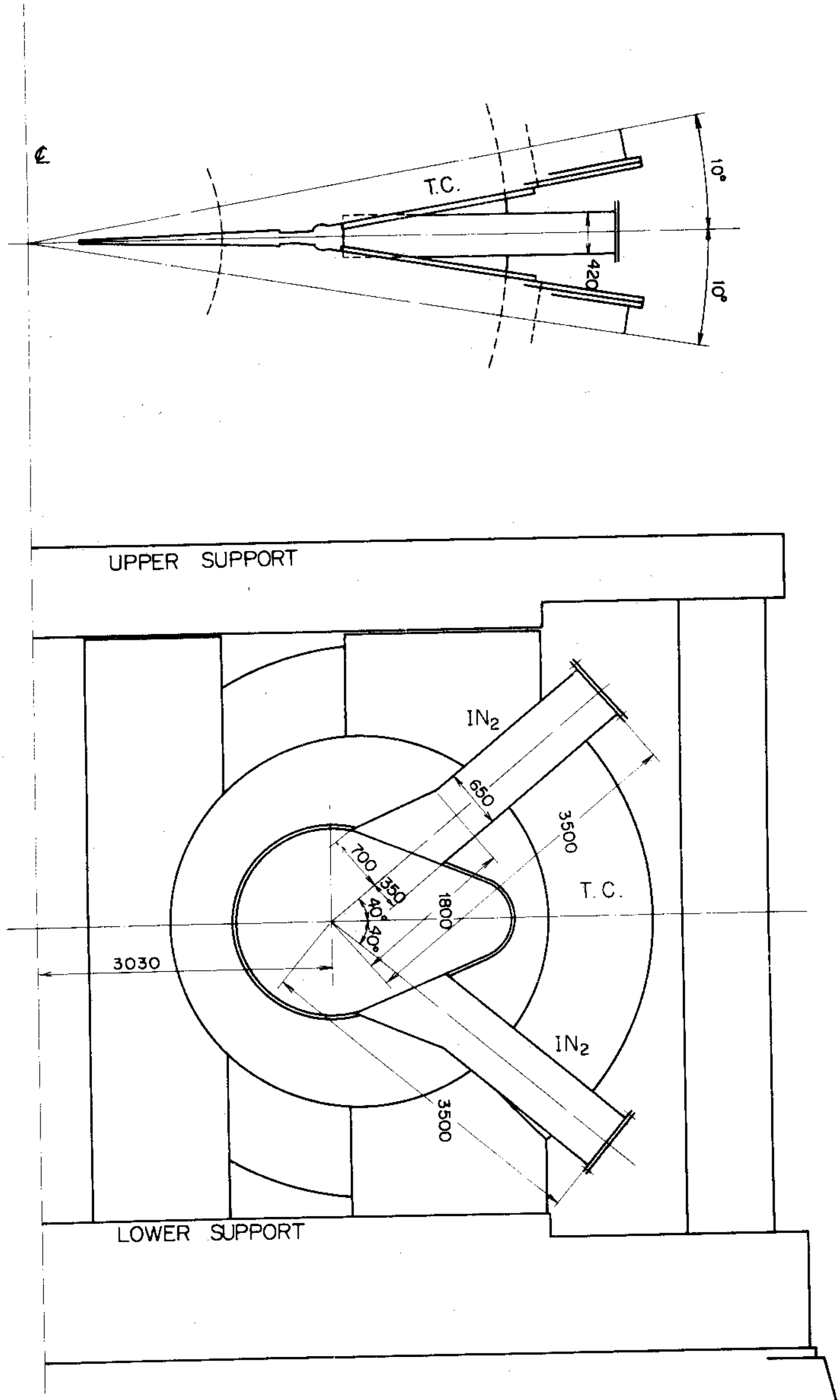

Fig. 4 Oblique access ports for diagnostics (IN_2).

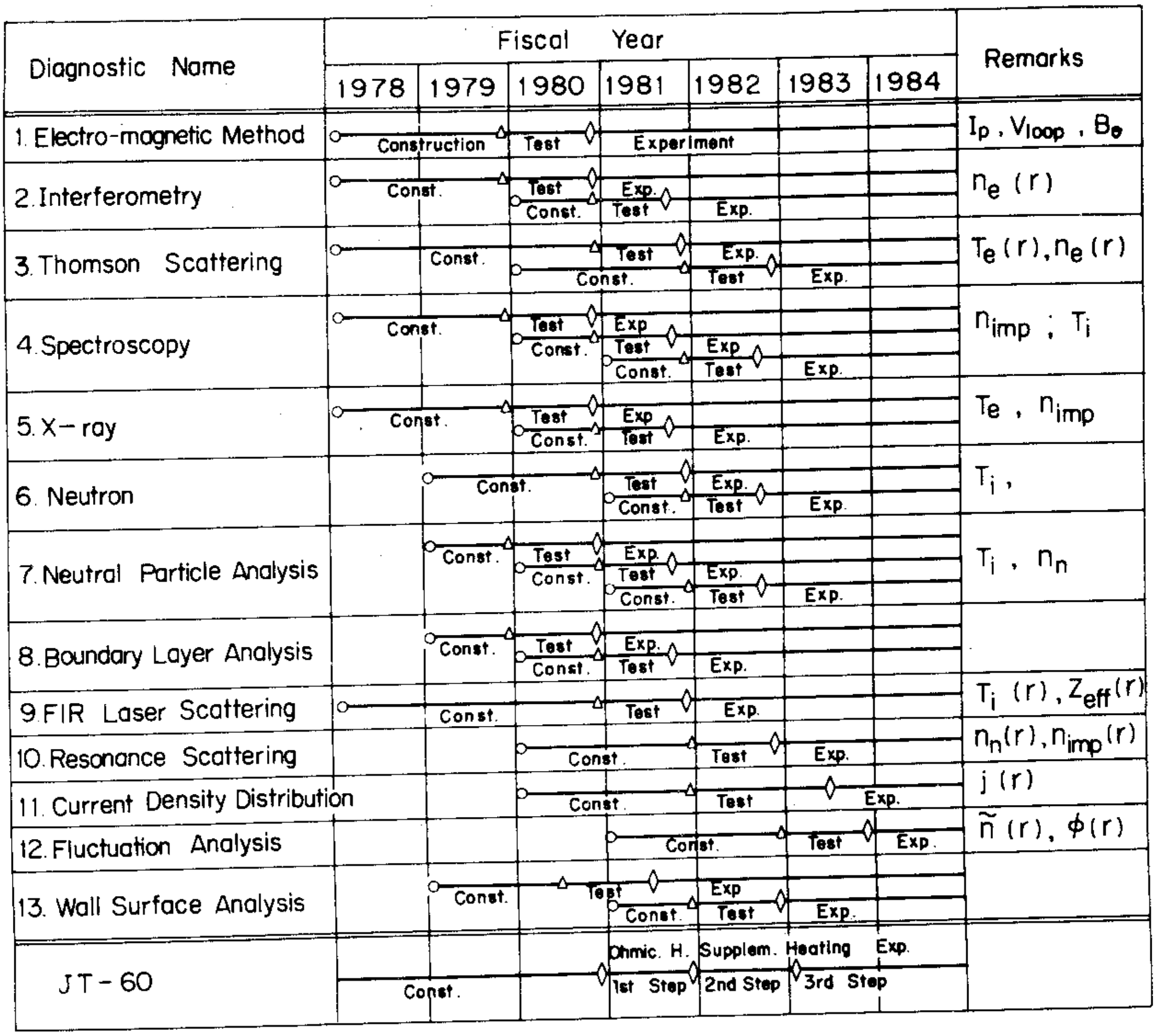

Fig. 5 Time schedule of the diagnostic program.

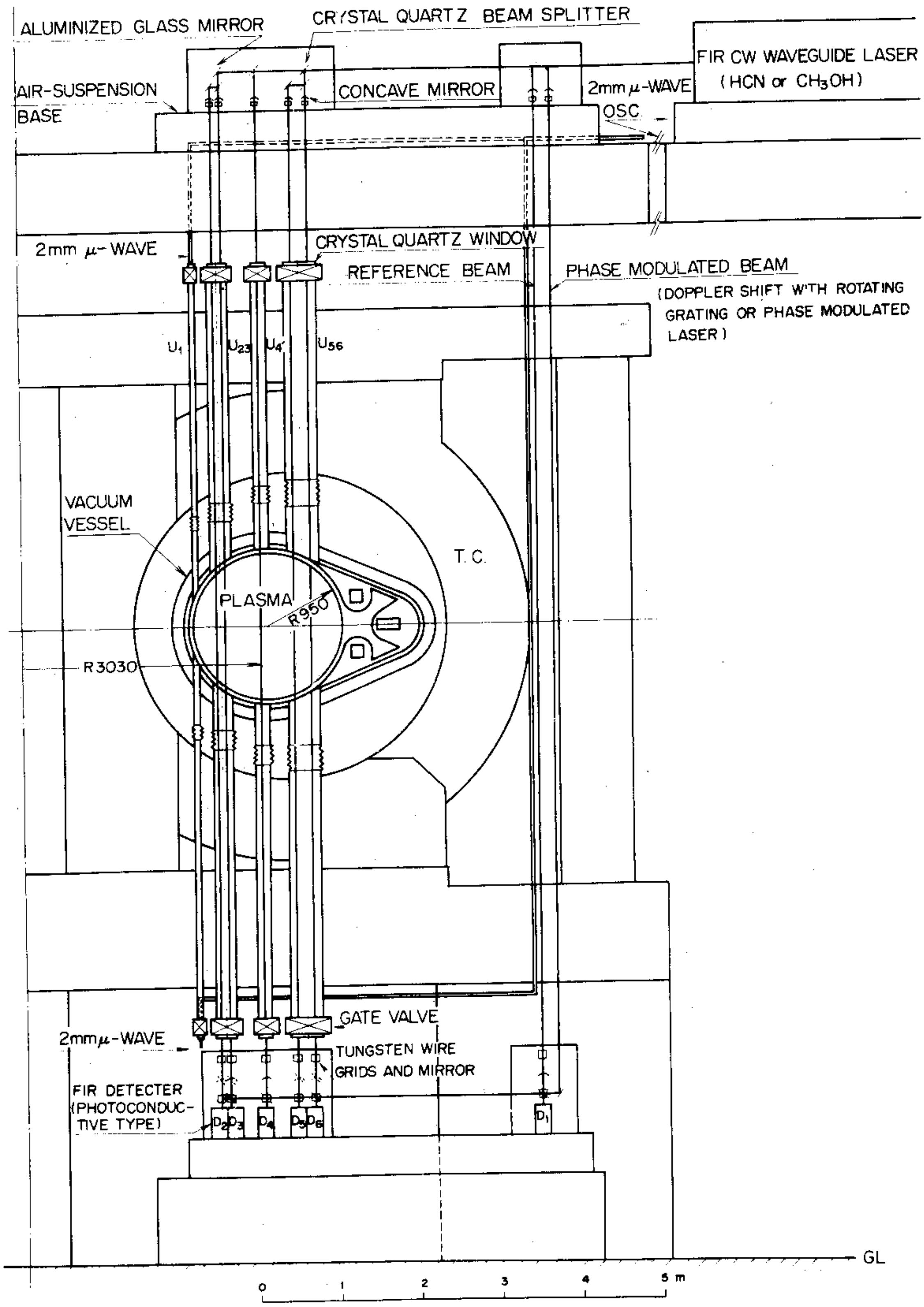

Fig. 6 Arrangement of FIR and mm-wave interferometer.

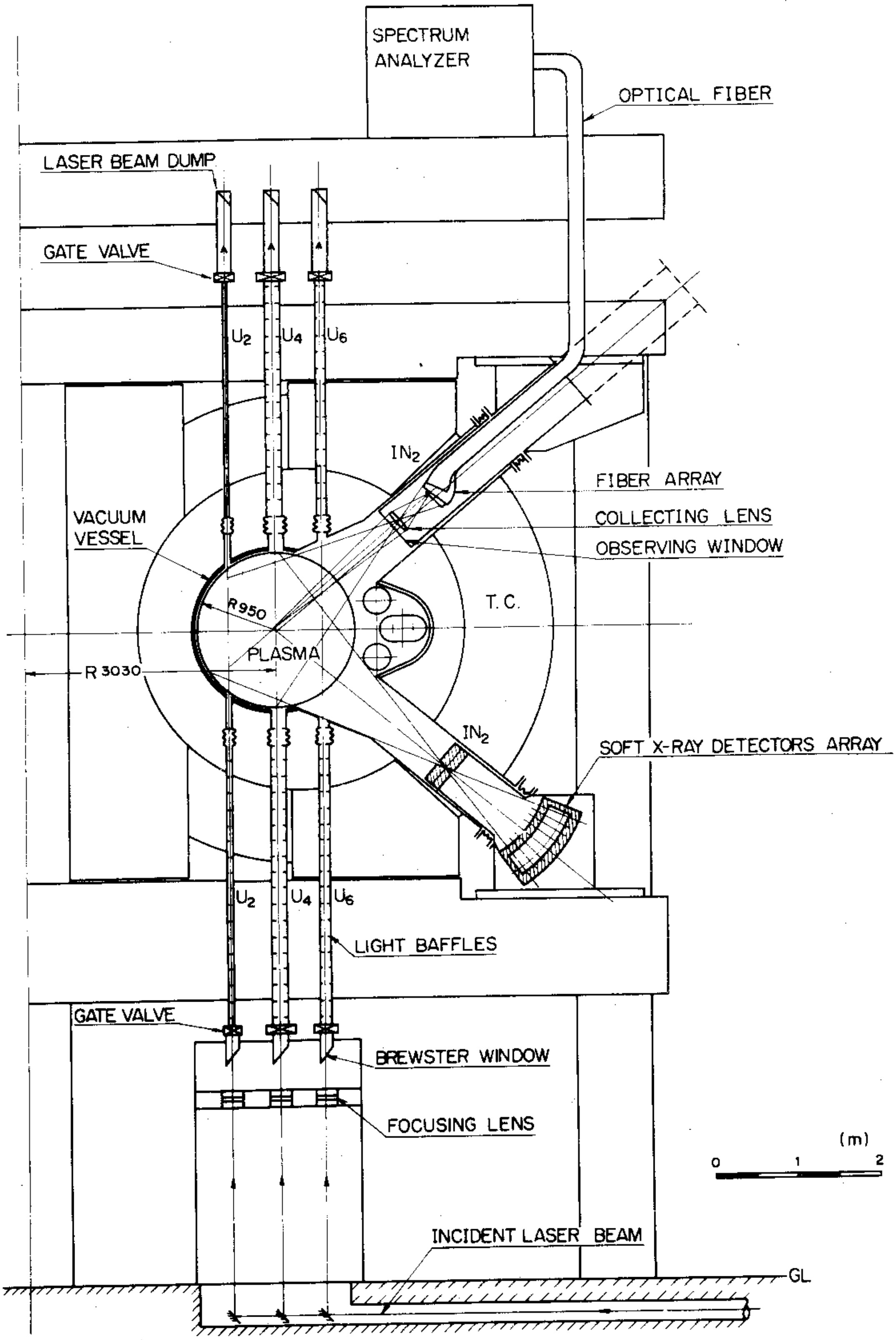

Fig. 7 Arrangement of multipulse laser scattering equipment.

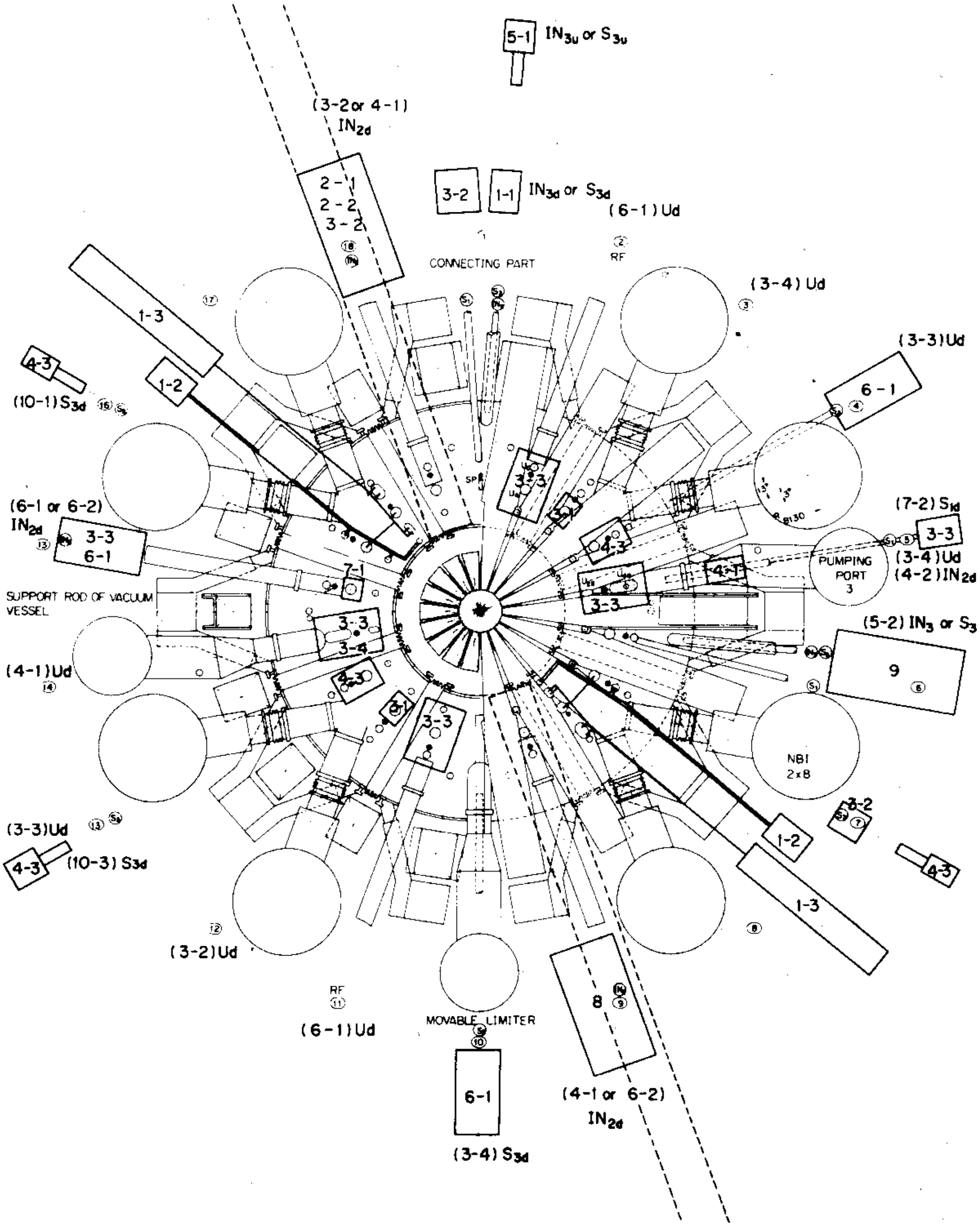

Fig. 8-a Conceptual layout of diagnostics.

DIAGNOSTIC NAME	SECTION NO.
1. INTERFEROMETRY	
1-1. 4 mm μ-WAVE INTERFEROMETER	①
1-2. 2 mm μ-WAVE INTERFEROMETER	⑦,⑧,⑯,⑰
1-3. SUB-mm-WAVE INTERFEROMETER	⑧,⑰
2. THOMSON SCATTERING	
2-1. RUBY LASER SCATTERING	⑱
2-2. MULTI-PULSE LASER SCATTERING	⑱
3. SPECTROSCOPY	
3-1. FIR SPECTROMETER	③,⑫
3-2. VISIBLE SPECTROMETER	①,⑦,⑫,⑱,⑱
3-3. V.U.V. SPECTROMETER	②,④,⑤,⑤,⑪,⑬,⑭
3-4. ULTRA-SOFT X-RAY SPECTROMETER	③,⑤,⑩,⑭
4. X-RAY	
4-1. X-RAY PULSE HEIGHT ANALYSIS	⑤,⑨,⑭,⑱
4-2. SOFT X-RAY DETECTOR	⑤
4-3. HARD X-RAY DETECTOR	④,⑦,⑬,⑬,⑯
5. NEUTRON	
5-1. NEUTRON SPECTROMETER	①
5-2. NEUTRON COUNTER	⑥
6. NEUTRAL PARTICLE	
6-1. CHARGE EXCHANGE NEUTRAL PARTICLE ANALYSER	②,④,⑩,⑪,⑮,⑮
6-2. HIGH ENERGY NEUTRAL PARTICLE DETECTOR (SSD)	⑨,⑮
7. BOUNDARY LAYER ANALYSIS	
7-1. THERMAL FLUX DETECTOR	⑮
7-2. NEUTRAL GAS ANALYSER	⑤
7-3. PLASMA POSITION DETECTOR	
8. COLLECTIVE SCATTERING (FIR LASER SCATTERING)	⑨
9. RESONANCE SCATTERING	⑥
10. WALL SURFACE ANALYSIS	
10-1. AUGER ELECTRON ANALYSER	⑯
10-2. SECONDARY ION MASS ANALYSER	
10-3. X-RAY MICRO-ANALYSER	⑬

Fig. 8-b Diagnostic name of conceptual layout.