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ISX—A Tokamak for Surface and Impurities Studies

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ABSTRACT

The ISX (Impurity Study Experiment) is a moderate size tokamak slightly larger than the ORMAK tokamak. ISX is being built explicitly for the study of impurities and plasma-wall interactions. Experiments are scheduled to begin in the spring of 1977. Several features have been deliberately designed into the ISX which make it particularly adaptable to surface studies. The first is a welded stainless steel vacuum system, bakeable to 400°C, with a projected base pressure $\geqslant 2 \times 10^{-9}$ torr. Another feature is that of "easy" demountability of the vacuum system; replacement of the entire vacuum system should take about two weeks. A third feature is diagnostic access to the edges of the plasma.

The initial surface physics question to be answered is how best to keep surfaces clean: by baking, by direct or indirect wall bombardment discharges, or by gettering. Later experiments will involve using wall materials other than stainless steel to determine their effect on the plasma.

1. INTRODUCTION

The ISX (Impurity Study Experiment) is a tokamak being constructed as a joint project between the Oak Ridge National Laboratory and General Atomic Company (GAC). It is being built for the dual purpose of studying primary impurity sources and subsequent impurity behavior inside plasmas. Experiments are scheduled to begin in the spring of 1977. The first of these studies lies in the realm of surface and vacuum science; the second

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is a plasma physics problem. Perhaps the most interesting experiments will combine both surface and plasma physics to determine how changes in wall conditions and materials affect the plasma.

The economic consequences of such studies are great for future tokamaks. In the near term, large savings can be realized if simple and effective wall cleaning methods can be found. In the longer term, there is great economic incentive to find ways other than divertors to control impurity influx and accumulation. In recognition of these facts, another tokamak, TEXTOR [1], has been proposed by the plasma group at Jülich, West Germany, to carry out plasma-wall and impurity studies similar to those in ISX.

A description of the ISX design is given in the next section. The third section describes expected plasma properties and wall fluxes, and proposed experiments are detailed in Sect. 4.

2. ISX MACHINE DESIGN

ISX is an iron core tokamak, quite simple in basic design. A cutaway side view of the overall device is shown in Fig. 1. This figure is deceptive, as the center line of the vacuum vessel stands 2.36 m above the floor for convenient access to diagnostic ports. ISX is about the same physical size as the presently operating tokamaks, ORMAK [2], TFR [3], and JFT-2 [4], with design features capitalizing on the experience gained from these devices.

2.1 Vacuum Chamber

The vacuum chamber is intended to be easily replaceable, as discussed below. Design of the first chamber is nearly completed; a top view is shown in Fig. 2. Construction is of welded 304L stainless steel, with nine box-shaped sections on which flanges for pumps and diagnostics are located. These box-shaped sections are constructed of half-inch thick slabs which are rigidly mounted to the machine frame and connected by nine 10-mil-thick bellows, each with a diameter of 26 in.

In a more recent version of Fig. 2, several port penetrations have been modified and more have been added. A bottom view would show a similar, but not necessarily identical port arrangement. Access to top and bottom ports is unencumbered by coils over most of the area of the diagnostic sections, allowing for ample diagnostic access. Top and bottom ports with an inside diameter of up to 6 in. are planned. All vacuum ports will have ultrahigh vacuum seals. Side ports vary in size up to an inside diameter of 14 in. for pumps and 8 in. for diagnostics.

The limiter is to be constructed of four electrically insulated molybdenum rods. The diagnostic section adjoining the limiter has been reserved specifically for surface physics experiments; other ports can also be used, depending on demand. The bottom side of the surface physics diagnostic section is shown in Fig. 3, and the top side is similar. The box-shaped design of diagnostic sections allows for the convenient installation of ports, with access to the plasma edge.

2.2 Vacuum Pumping and Wall Cleaning

The vacuum chamber will be pumped through three symmetrically placed pumping ports, as shown in Fig. 2. In order to ensure a clean system for surface physics experiments, no pumps using oil will be used. Roughing down will be accomplished by two Linde 140SN[†] cryosorption pumps. Once the system is roughed down to a few microns pressure, two air-bearing turbomolecular pumps will take up the pumping. Finally, two cryo-vacuum pumps will be employed to help draw the system down to base pressure and to absorb hydrogen gas during pulsed discharge operation. Assuming an outgassing rate of 10^{-11} torr ℓ/cm^2-sec, the ultimate pressure should reach 2×10^{-9} torr.

In order to achieve this outgassing rate, four surface cleaning techniques will be used. The first is baking. Provisions are being made to bake the entire liner to 400°C. Bellows sections will be baked

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[†]Linde Division, Union Carbide Corporation, New York.

by Ohmic heating currents, and diagnostic sections will have externally applied heaters. The second technique is discharge cleaning. As presently practiced in ORMAK, discharge cleaning involves either 120 Hz intermittent H_2 or O_2 cathode-less discharges, or 20-30 kA discharges, 4 sec apart. These discharges are run in the same manner as regular tokamak shots, but with no vertical field and much reduced toroidal field, current, and duration. The third wall cleaning method tested will be direct discharge ion bombardment [5]. In this mode the wall will act as a cathode and a wire down the center of the torus will act as the anode of a glow discharge. The fourth technique is titanium evaporation. Titanium coatings act to trap monolayers of adsorbed material and to chemically adsorb H_2, N_2, O_2, Co, and H_2O [6]. Titanium coatings will be applied over the lower 50% of the wall area in connection with the impurity flow reversal experiment discussed in Sect. 4.3. The principal parameters of the vacuum system are listed in Table 1.

Table 1. Vacuum system

Vacuum Chamber	
	1. UHV construction
	2. Metal port seals
Pumps	
	1. Two Linde 150SN cryosorption roughing pumps
	2. Two air-bearing turbomolecular pumps
	3. Two UHV cryo-vacuum pumps
Surface Desorption and Cleaning Techniques	
	1. Glow discharge cleaning
	2. Cathode-less discharge cleaning
	3. Titanium evaporation
	4. Baking to 400°C
Ultimate Pressure of 2×10^{-9} torr	

2.3 Toroidal, Ohmic Heating, and Vertical Magnetic Fields

The toroidal magnetic field coils will be cut from sheets of chrome-copper alloy material. Each of the 18 coils is to be self-supporting and edge-cooled by water. The maximum toroidal magnetic field will be 18 kG, limited by the power available from a Silicon Controlled Rectifier (SCR) power supply. Discharge rates are also limited to about one pulse per minute by the cooling of transformers associated with the SCR supply.

Each toroidal field coil is rectangular in cross section and has four joints, located at points of minimum stress. The lower two joints are included so that individual turns of the coils can be cut from a single sheet of chrome copper. Unbolting the upper two joints allows coil clearance so that the vacuum chamber can be lifted vertically free of the system. This demountable coil design has been tested successfully at GAC on Doublet IIA [7].

The Ohmic heating supply will use the capacitor and battery banks presently in use on ORMAK. Capacitors provide the voltage necessary during the initial breakdown of the discharge, and the slower-acting batteries hold the current steady at later times. The Ohmic heating supply will provide magnetic flux for a 0.9 V-sec iron core transformer with a single return leg. The turns ratio is 8:1, and all turns are wound on cylinders circling the iron core, beside the vacuum chamber. This design, coupled with the ability to lift off the top leg of the transformer, will keep the Ohmic heating system from interfering with vertical removal of the vacuum chamber. By working two shifts a day, it will take about two weeks to replace the vacuum vessel and resume operations.

The vertical field will also be provided by a capacitor-battery bank combination. The transistor-controlled battery bank portion of this system is presently used on ORMAK. A fraction of the vertical field arises from currents induced in the core by the plasma current. Coils have been arranged so than $n = -\frac{R}{B}\frac{\partial B}{\partial r} = 0.0$ to 0.5 over 85% of the plasma, to ensure vertical and radial equilibrium [8]. A feedback control system will provide active radial control over the plasma position.

The main magnetic field parameters are listed in Table 2.

Table 2. Magnetic field parameters

Toroidal Field	
1. Number of coils	18
2. Maximum field	18 kG
3. Power to coils	>30 MW
4. Power supply	SCR
Ohmic Heating System	
1. Primary-secondary turns ratio	8:1
2. Transformer flux swing	0.9 V-sec
3. Power supply	batteries and capacitors
Vertical Field	
1. Decay index n	0 - 1/2
2. Power supply	batteries and capacitors

3. PLASMA PARAMETERS

The projections of plasma parameters for new CTR test facilities are usually fraught with erroneous predictions, because plasma parameters do not scale as were supposed. The projected plasma parameters of ISX are on more certain ground, because its size and magnetic fields are very similar to tokamaks, such as ORMAK, which have been operating for some time. The major difference in plasma properties should arise from the presence of fewer impurities in ISX.

Assuming operation similar to ORMAK [2], central electron temperatures will reach 800-1800 eV for plasma currents of 150 kA, with a safety factor near 5. The corresponding peak ion temperatures will be 300-500 eV.

Gross energy confinement times should lie in the range of 5-15 msec. Particle containment times for electrons near the center of the discharge will be several times as long. For impurity transport studies it is important that the discharge remain in equilibrium for several impurity diffusion times. Assuming operation in the Pfirsch-Schlüter collisional regime [9], diffusion times scale as $\tau_d \sim T_e/Z_i$, where Z_i is the ionization state of species i. Thus for a given electron temperature, the lighter impurities have longer diffusion times. We have chosen a flat (equilibrium) plasma current length of ~ 250 msec. A short list of expected plasma parameters is given in Table 3.

Table 3. Expected plasma parameters

Major radius	93 cm
Minor radius	26 cm
Plasma current (at q = 5)	150 kA
Central electron temperature	800-1800 eV
Central ion temperature	300-500 eV
Shot repetition rate	1 per min
Flat (equilibrium) current duration	250 msec

The fluxes of particles and photons to and from the plasma-wall boundary are less certain. This is because these fluxes are not accurately measured in present tokamak experiments and so must be computed, based on models. Table 4 [1] presents computer predictions for ISX, TEXTOR,†† and JET.‡ Although the larger tokamaks, TEXTOR and JET, have much larger total power inputs than ISX, the power per unit area to the wall and the sputtered flux per unit area leaving the wall are remarkably constant for all three devices. This is a consequence of the fact that the boundary layer is effectively decoupled from the hot interior of the plasma.

††TEXTOR is a large technology-oriented tokamak proposed by the Institut für Plasmaphysik, KFA, Jülich, West Germany. It is to have a major radius of 175 cm, a minor radius of 50 cm, and a plasma current of 480 kA.

‡JET (Joint European Torus) is a large tokamak proposed for EURATOM. Its major radius is 296 cm, minor radius is 125 cm, and plasma current is 4.8 MA.

Table 4. Comparison of ISX, TEXTOR, and JET parameters
Hydrogen, $n = 4 \cdot 10^{13} cm^{-3}$, 2% Oxygen

	ISX	TEXTOR	JET
$T_e(0)$ [eV]	900	1,000	1,930
$T_i(0)$ [eV]	460	910	1,850
Plasma losses [MW]	0.17	0.50	2.3
Plasma wall loading [W cm^{-2}]	1.9	1.5	1.6
Conduction and convection losses [W cm^{-2}]	1.5	1.1	1.2
Charge exchange losses [W cm^{-2}]	0.33	0.26	0.34
Radiation losses [W cm^{-2}]	0.10	0.09	0.09
Flux of sputtered iron [$cm^{-2} s^{-1}$]	$1.51 \cdot 10^{13}$	$1.08 \cdot 10^{13}$	$1.02 \cdot 10^{13}$
Flux of hot neutrals [$cm^{-2} s^{-1}$]	$11.9 \cdot 10^{15}$	$5.6 \cdot 10^{15}$	$2.2 \cdot 10^{15}$
Ratio sputtered flux/ flux of hot neutrals	$1.3 \cdot 10^{-3}$	$2.2 \cdot 10^{-3}$	$4.7 \cdot 10^{-3}$

4. ISX EXPERIMENTAL PROGRAM

ISX will be primarily dedicated to studying two topics: (1) walls as impurity sources and (2) transport and control of impurities inside the plasma. Many of the diagnostics and computer codes necessary for these studies require further development before they can be applied on a shot-by-shot basis; the quality of these experiments will depend to a large extent on parallel efforts.

Because ISX is a versatile tokamak, it is tempting to suggest using it as a test bed. Diagnostic development, pellet refueling studies, and rf heating (particularly electron cyclotron heating) experiments have been proposed.

4.1 Program Schedule

A rough schedule of ISX experimental programs is given in Table 5. Details of these programs are given below.

Table 5. ISX program milestones

ISX Program Objectives	Year
Begin start-up experiments	1977
Begin impurity flow reversal experiment	1977
Begin wall and boundary studies	1978
Begin impurity transport studies (Run concurrently with wall and boundary studies)	1978
Advanced materials studies	1979

4.2 Surface Physics Experiments

Surface physics experiments during the start-up period will consist mainly of characterizing initial wall conditions and determining the relative merits of glow discharge cleaning, cathode-less discharge cleaning, and baking. The principal diagnostics are envisioned to be AES (Auger Electron Spectroscopy), SIMS (Secondary Ion Mass Spectroscopy), and SXAPS [10] (Soft X-ray Appearance Potential Spectroscopy), as adapted for tokamak use. AES and SIMS will require a sample transfer system from ISX to an UHV surface analysis chamber. A PDP-12[††] computer will record data from plasma and surface diagnostics. This computer is interconnected with larger computers for data storage and analysis, employing the software systems presently used for ORMAK data handling.

During the impurity flow reversal experiments described below, surface physics experiments will not be the primary work, except perhaps in the determination of wall effects on impurity flow. Of course, surface experiments can proceed in parallel, especially as regards the consequences of the titanium coatings necessary for the flow reversal tests.

[††] Digital Equipment Corporation, Maynard, Massachusetts.

After these tests and the resulting titanium contamination of the first vacuum system, a second stainless steel chamber will be installed. Attempts will be initiated to understand the origin of wall impurities; correlations will be made between contamination on the wall and limiter impurities in the plasma. Emphasis will be placed on determining the principal channels of plasma impurity release from the walls, i.e., by chemical reactions, sputtering, evaporation, or by electron, ion, neutral, photon, or thermal desorption. Of course, these measurements depend on knowing the particle, photon, and heat fluxes to the wall as a function of time during a discharge.

Present-day surface diagnostics are not adequate to make these measurements, so progress will depend on either developing new diagnostics or adapting proven techniques. Two suggested diagnostics are: (1) using surface reflection to determine contaminant thickness and (2) using laser or neutral particle bombardment, coupled with spectroscopy, to determine surface impurities.

Hopefully, by early 1979 these studies will have been completed and the experimental program can move to testing wall materials other than stainless steel. Materials tested will include low-Z wall candidates such as graphite and SiC, metals such as V, Nb, and Mo, and low-swelling alloys like PE-16 and LS-1. Low sputtering (honeycomb) wall configurations [11] will also be tried. Material for these tests will be inserted either as a liner inside the vacuum vessel or as wall coatings. These tests will involve several vacuum chambers and a full array of surface diagnostics.

In order to implement the surface studies program, provision is being made to provide a basic set of surface diagnostics, most likely including AES and SIMS, along with an UHV transfer system. These basic diagnostics will be operated by a local group, both for the benefit of plasma experimenters and as an aid to outsiders involved with related surface physics experiments. This group will also set up and operate a surface physics laboratory near ISX to provide facilities for visitors. These facilities will include a laminar flow clean bench, ultrahigh vacuum system, desks, tools, etc.

4.3 Plasma Experiments

The start-up period will constitute a shakedown period for plasma diagnostic systems. During this period measurements will be made to determine which wall cleaning technique results in the least plasma impurities. This time will also be used to work the "bugs" out of various plasma diagnostics. The original diagnostics will include those listed in Table 6. New diagnostics will also be introduced, including those described below.

Table 6. Plasma diagnostics

Diagnostic	Quantity Measured
Thomson scattering	$T_e(r)$, relative $n_e(r)$
Charge exchange analysis	$T_e(r)$, $n_o(0)$
Soft X-ray	Z_{eff}
PIN diode array	MHD location, implying $I_p(r)$
Ultraviolet and visible spectroscopy	Impurity identification and radial location
Radiometers	Power incident on the wall
Microwave interferometer	$\bar{n}_e$

Later in 1977 the impurity flow reversal experiment [12] will begin. The theoretical basis for this experiment is as follows: Calculations assuming neoclassical transport theory in the Pfirsch-Schlüter regime indicate that the radial impurity flux is coupled to the parallel component of the frictional (or collisional) force. If the relative parallel velocity between protons and impurities is changed, impurities can be made to flow outward rather than inward. This can be accomplished by introducing plasma in the top half of the torus, via a gas feed, and removing ions at the bottom, with a limiter and with simultaneous titanium gettering. Reversing the direction of the toroidal field reverses the direction of the impurity diffusion. It should be possible to verify these ideas by deliberately introducing impurities into ISX and observing their accumulation at the center, as a function of toroidal field direction and the amount of (asymmetric) gas feed.

There have been several other suggested ways to prevent impurities from getting into the hot part of the plasma [13,14]. Whether or not these methods will be tried in ISX depends on the outcome of further studies.

The goal of the impurity transport experiments, starting in the fall of 1978, will be to determine whether impurities accumulate and, if so, how quickly. Such detailed studies will require further development of existing diagnostics and the introduction of new ones. Two new techniques are being pursued at GAC. One uses neutral elastic scattering [15] to give time- and space-resolved measurements of the density and temperature of impurity ions. Another uses a tunable dye laser and resonant scattering [1] to detect heavy ion impurities in low ionization states near the periphery of the plasma.

During studies of advanced wall materials, plasma diagnostics will determine the effect of wall materials and wall configurations on plasma properties. Close interaction between surface and plasma measurements will be necessary throughout the life of the experiment.

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REFERENCES

[1] Report on the Planning of TEXTOR, Institut für Plasmaphysik, KFA, Jülich, West Germany (November 15, 1975).

[2] R. J. Colchin et al., "Impurity and Surface Studies in ORMAK" and references to ORMAK cited therein, to be published in the Proc. Intl. Conf. on Surface Effects in Controlled Fusion Devices (San Francisco, 1976).

[3] TFR Group, Plasma Physics and Controlled Nuclear Fusion Research, Vol. 1 (IAEA, Vienna, 1975) p. 127.

[4] N. Fujisawa et al., Plasma Physics and Controlled Nuclear Fusion Research, Vol. 1 (IAEA, Vienna, 1975) p. 3.

[5] A. G. Mathewson, Vacuum 24 (1974) 505.

[6] P. E. Stott, C. C. Daughney, and R. A. Ellis, Jr., Nucl. Fusion 15 (1975) 431.

[7] T. Ohkawa et al., Plasma Physics and Controlled Nuclear Fusion Research, Vol. 1 (IAEA, Vienna, 1975) p. 281.

[8] V. S. Mukhovatov and V. D. Shafranov, Nucl. Fusion 11 (1971) 605.

[9] P. Rolland and F. Werkoff, Proc. Seventh European Conf. on Controlled Fusion and Plasma Physics, Vol. 1 (Lausanne, 1975) p. 120 and references cited therein.

[10] R. E. Clausing et al., "Surface Impurities and 'Clean-Up' Techniques in ORMAK," to be published in the Proc. Intl. Conf. on Surface Effects in Controlled Fusion Devices (San Francisco, 1976).

[11] S. N. Cramer and E. M. Oblow, Nucl. Fusion 15 (1975) 339.

[12] T. Ohkawa, Kakuyugo Kenkyu 32 (1974) 67.

[13] D. W. Kerst, Bull. Am. Phys. Soc. 20 (1975) 1334.

[14] T. Consoli, R. Legardeur, and G. F. Tonon, Proc. Seventh European Conf. on Controlled Fusion and Plasma Physics, Vol. 1 (Lausanne, 1975) p. 139.

[15] K. H. Burrell and A. F. Leitzke, Bull. Am. Phys. Soc. 20 (1975) 1226.

FIGURE CAPTIONS

Fig. 1. Schematic of ISX showing jointed toroidal field coils, the iron core transformer, and the vacuum vessel.

Fig. 2. Preliminary drawing of ISX, looking down from the top. Top parts of toroidal field coils and the iron core have been removed for clarity.

Fig. 3. Drawing of the bottom side of the surface physics diagnostic section. The top side is similar.

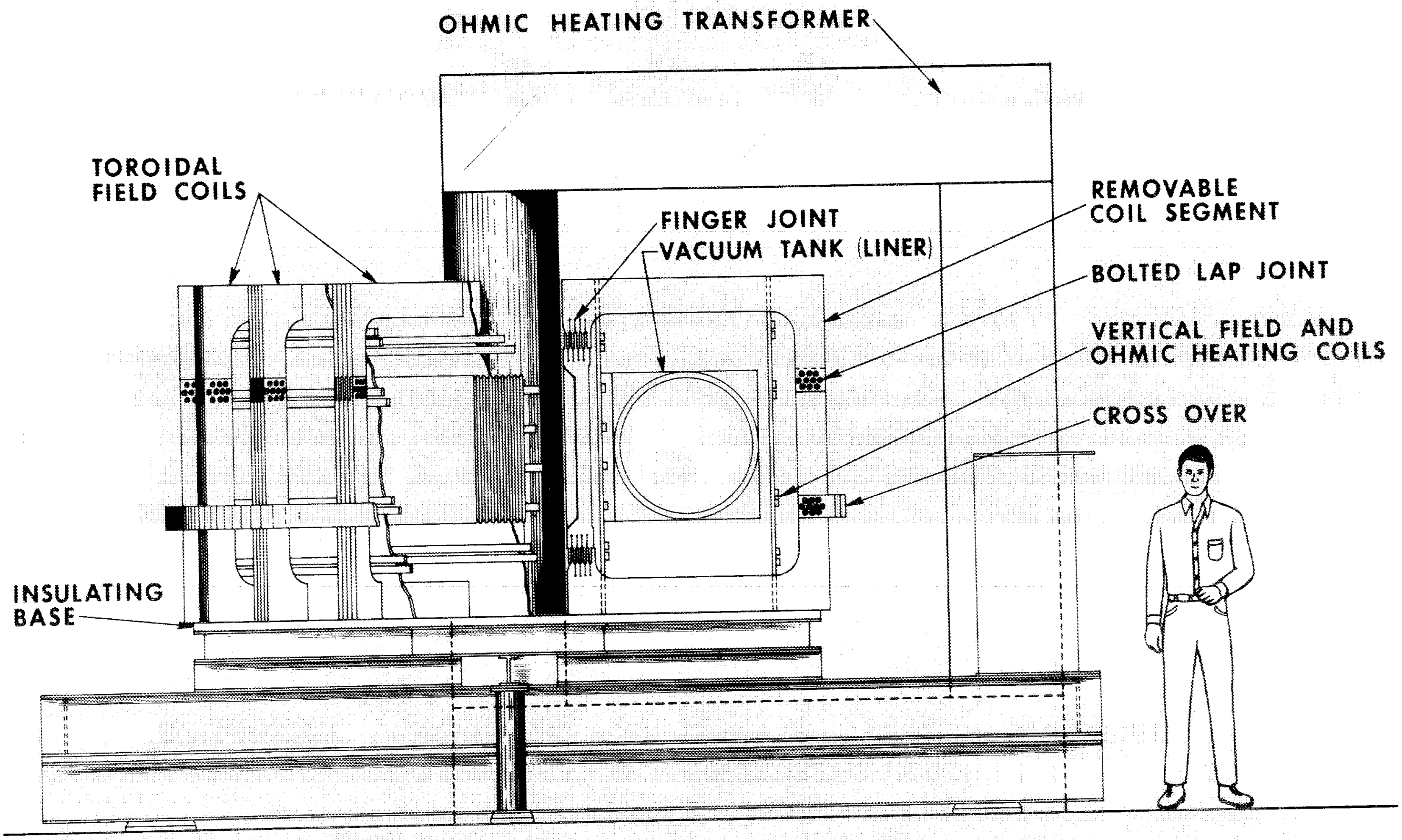
OHMIC HEATING TRANSFORMER
TOROIDAL FIELD COILS
FINGER JOINT
VACUUM TANK (LINER)
REMOVABLE COIL SEGMENT
BOLTED LAP JOINT
VERTICAL FIELD AND OHMIC HEATING COILS
CROSS OVER
INSULATING BASE

Fig. 1

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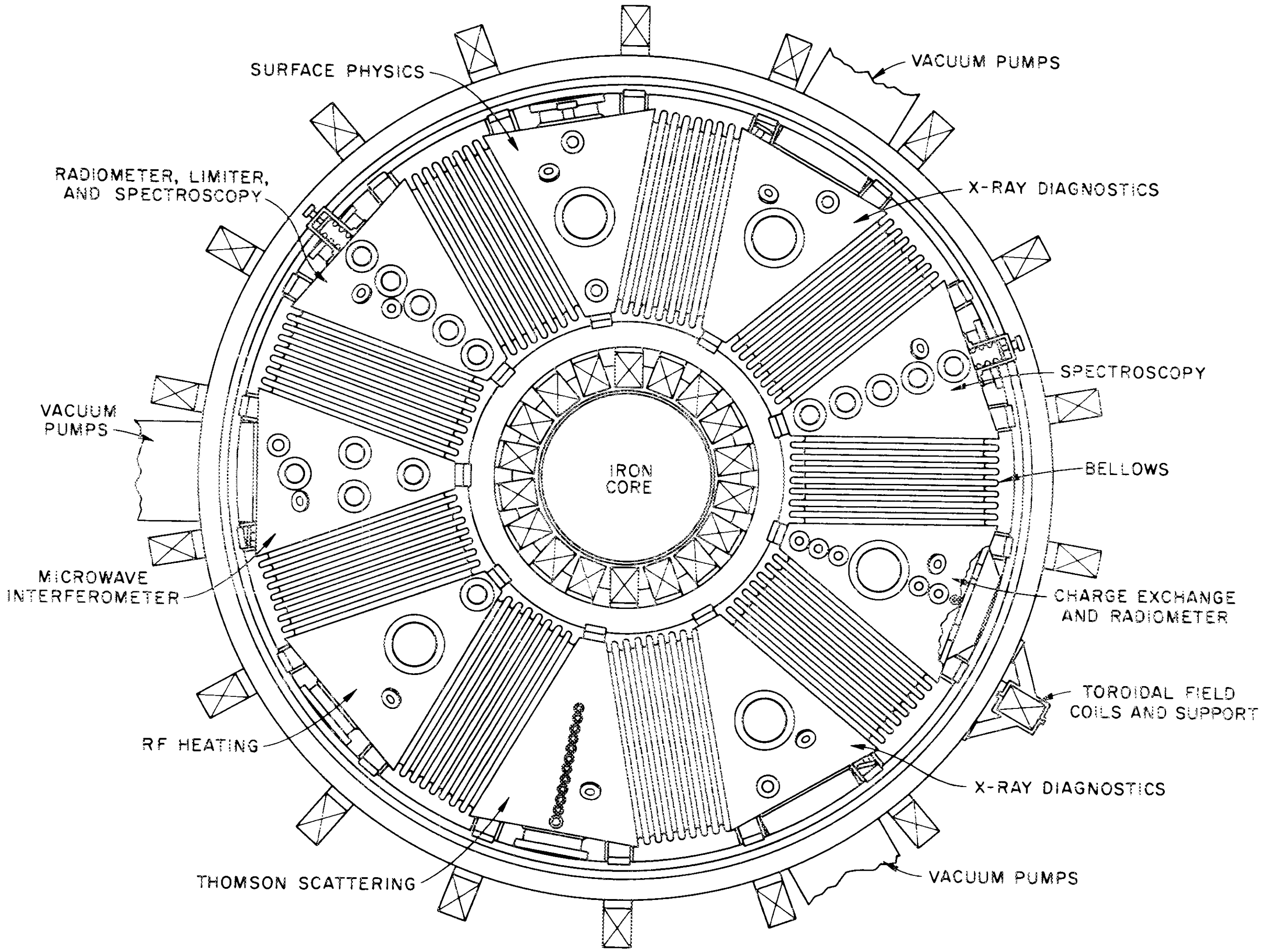

Fig. 2

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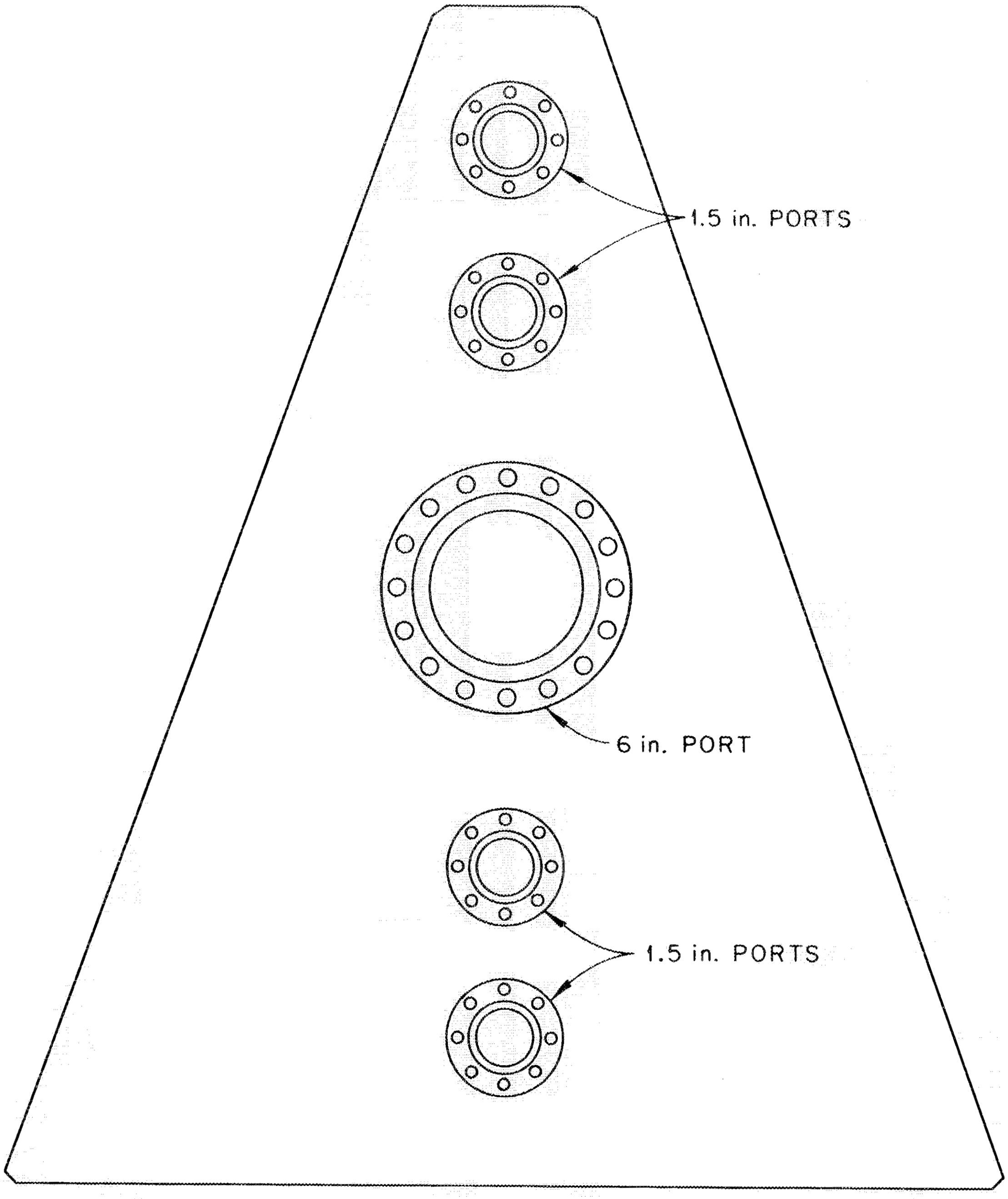

Fig. 3

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