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**Westinghouse Electric Corporation
Fusion Power Systems Department**

**THE CONDITIONING OF THE
VACUUM VESSEL WALLS OF TOKAMAKS,
A PRELIMINARY LOOK**

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A PRELIMINARY LOOK

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ABSTRACT

The main features and operating characteristics of the primary vacuum system of many of the presently operating tokamak devices are presented. Particular attention is paid to the methods used to condition and clean the vessel walls in situ. For the devices discussed, a combination of a high-temperature bakeout and/or discharge cleaning is employed. In addition, discussions of the vacuum systems and wall conditioning methods anticipated for the next generation of tokamaks are presented. Since this report was written during a limited time period, it should be considered as preliminary and is not intended to be a general review. Much of the information that is presented was obtained by private communication and there is no bibliography. This study was initiated to aid in the design of TFTR. As presently envisioned, the TFTR vacuum system and methods for wall conditioning are consistent with what is presently practiced.

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INTRODUCTION

Within the plasma community there is considerable interest in techniques for the in situ conditioning of vacuum vessels and associated appendages on devices which magnetically confine plasmas. At this time there are several points of view on the subject of wall conditioning and even though experimental data do exist on a variety of conditioning methods and parameters it is often very preliminary and incomplete data. The devices on which data have been obtained are small when compared to a TFTR-type tokamak, and the plasma pulses generated in these machines are of short duration. Thus, it is difficult to predict what the results of a conditioning method would be on the next generation of tokamaks which will contain hotter discharges for longer periods of time. In general, two methods are considered as effective means for conditioning vacuum vessel walls: gas discharge cleaning to desorb surface gases on the wall surfaces, and a high temperature bakeout of the entire vacuum assembly in situ to release gases from the bulk of the vessel walls.

The purpose of this report is to present the present-day thinking on wall conditioning in tokamak devices and also to indicate expected design features of future tokamaks. The information and ideas given in this report were accumulated from many conversations with those in the field and from reviews of the written results of study groups designing D-T burning tokamaks which will begin operating in the early 1980's. There has been no attempt to give all of the details or to give a general review of the subject. If the information reported here provides any guidance in the design of future tokamaks, stimulates future work, or discussions on the subject, then this preliminary report will serve a useful purpose. The author hopes that the information within this report is a correct interpretation of ideas and results discussed in the various conversations with the people indicated in the acknowledgement.

Tokamak devices which are presently in operation in the U.S.A. and which are provided with in situ conditioning capabilities on the vacuum vessels include ATC, Doublet II A, Alcator, Microtor, ORMAK, and PLT. Devices expected to be built and operating in the next few years are PDX, Doublet III, JT-60, JET, T-20, and TFTR. The TFR project in France and the T-10 project in Russia have been operating successfully and recent results on these two devices as well as the U.S. devices will be discussed.

Of the fourteen tokamak devices discussed, eight are now in operation (two of them outside U.S.A.), and the remaining six are in the process of either being built or designed. As for in situ wall conditioning, 12 of the 14 machines now use or will use discharge cleaning methods. Roughly two-thirds of the devices incorporate in situ bake procedures which have been or will be carried out on an infrequent basis and followed by a period of discharge cleaning. A number of the devices have systems allowing the various ports and appendages communicating with the main vacuum system to be conditioned in situ. Of the devices now being built or designed only one (JT-60) will not, as presently conceived, have a vessel cooling system. From the discussions, it is concluded that the in situ conditioning of the TFTR main vacuum system as presently proposed is consistent with the present practice and thinking of those in the field.

ALCATOR

Vacuum Vessel and Pumping System

The Alcator vacuum vessel consists of 0.5 mm thick, 304L stainless steel bellows over ~90% of the vessel with the remainder being straight sections at which diagnostics and vacuum pumps are connected. The dimensions of the vessel are $R = 0.54$ m and $a = 0.125$ m for an enclosed volume of ~ 0.17 m³. The pumping system includes two Airco turbomolecular pumps (0.5 m³/s pumping speed each) which can evacuate the vessel to a base pressure in the 10^{-9} - 10^{-10} Torr range. Since the device has a LN₂-cooled magnetic coil system, the bellows walls are heated to near room temperature during normal operations by passing a current through these walls.

Bakeout of Alcator In Situ

A 300°C bakeout of the Alcator device in situ is performed on an infrequent basis, namely after the vessel has been let up to atmospheric pressure. For the bakeout, the walls are heated by passing 1000A of ac current through the bellows using the same system which heats the vessel during normal operations. Some, but not all, of the extensions of various diagnostic ports are baked using heating pads wrapped around their external surfaces. These pads are also used during pulsing operations to maintain the appendages at room temperature. Experience on Alcator has shown that without a bakeout or discharge cleaning, the plasmas contain large amounts of impurities as indicated by hard X-ray data. It was also found that a bakeout alone does not result in "clean" plasmas.

Discharge Cleaning of Alcator

After a bakeout, as well as at the start of a day's operation, Alcator is discharge cleaned. Following discharge cleaning, the device reaches a base pressure in the 10^{-9} - 10^{-10} Torr range and the discharges are low in impurity content, i.e., $Z_{\text{eff}} \approx 1$. The discharge cleaning operation consists of a number of 30-minute pulsing operations spaced by 30-minute periods when the pulsing is off. The 30-minute pauses allow the tungsten/tungsten-rhenium

limiters to cool. The discharge cleaning does not result in the bellows becoming hotter than room temperature. The toroidal field is held at 0.1 T; the cleaning pulses are ~ 7 msec in duration and occur at 140-msec intervals. A 20 kW power supply with a 2 kHz audio frequency is fed through a vertical field coil to break down in the gas, either H_2 or D_2 at a pressure of $\sim 10^{-4}$ Torr, in the chamber.

Studies have shown that carbon impurities are at a much lower level than in other tokamaks. These studies also indicate that following the cleaning schedule, a base pressure of 10^{-9} - 10^{-10} Torr is achieved and an average plasma density of ~ 3 - $5 \times 10^{14} \text{ cm}^{-3}$ can be obtained. If 2×10^{-6} Torr of O_2 is allowed to enter the torus along with the normal 2×10^{-4} Torr of H_2 gas, then the plasma density is typically lower by an order of magnitude; i.e., $5 \times 10^{13} \text{ cm}^{-3}$. It takes approximately three normal pulses to clean-up the O_2 impurities after the O_2 supply has been removed. The feeling is that the wall is being recoated with H_2 during the three subsequent pulses. Finally, it was found that with a base pressure of $\sim 10^{-8}$ Torr, there is some evidence that the discharges are not as "clean" as those formed when the base pressure is lower. It is not clear at this time if a low base pressure is necessary in the formation of "clean" plasmas. Experience at MIT has been that clean plasmas have been formed even when the base pressure is in the 10^{-7} Torr range. It should be noted that if the "high" base pressure is due to leaks to the atmosphere, then high impurity levels and unusually high electron temperatures exist. By repairing these leaks these problems have gone away.

DOUBLET II A

Vacuum Vessel and Pumping System

The Doublet II A vacuum system consists of a rectangular, double-walled structure (0.35 m x 1.05 m, mean radius 0.66 m) which is differentially pumped. The plasma chamber has a volume of $\sim 1 \text{ m}^3$, a surface area of $\sim 8 \text{ m}^2$, and is constructed of 0.25 mm 304 stainless steel. The vessel walls are cooled by a water-cooling system in which the water flows through tubes within the outer vacuum region. The D II A device is presently pumped out by a turbomolecular pump, having an effective speed of ~ 180 liters/sec, to a base pressure in the plasma chamber of $\sim 2 \times 10^{-8}$ Torr. The base pressure in the outer chamber is $\sim 3 \times 10^{-5}$ Torr.

Bakeout of Doublet II A In Situ

The 0.25 mm 304 stainless steel liner is baked to 300°C for periods of 8 hours per day for up to 5 days at a time. The liner can be heated to $\sim 300^\circ\text{C}$ in 10 minutes with a power input of 10 kW. The vessel liner is cooled down after a day of baking in a period of 30 minutes by allowing the pressure in the outer chamber to rise to 0.2 - 0.3 Torr so that the liner heat energy is convected to the cooling lines attached to the field shaping coils. The diagnostic appendages with vacuum systems which communicate with the chamber vacuum are baked using heating tape wrapped around the exterior surfaces. The bakeout of appendages and ports to remove water vapor is routinely carried out at a temperature of $\sim 100^\circ\text{C}$ for several hours after a pumpdown from atmospheric pressure. It has been found that bakeout of the appendages on a weekly basis similar to the main plasma chamber is not necessary. The surfaces which are not seen by the plasma are deemed to be not critical as far as in situ conditioning is concerned.

Discharge Cleaning Operations on Doublet II A

For effective wall conditioning the liner is discharge cleaned after bakeout for periods of up to 8 hours. For these operations a 2 kA plasma pulse of $\sim 300 \mu$ sec duration is created in a 0.1 T toroidal field at a 800 Hz repetition rate. The break-down voltage for discharge cleaning plasmas is 10 V peak-to-peak supplied by a 10 kW alternator. The chamber is filled to $\sim 10^{-4}$ Torr of Ar, He, or H_2 during discharge cleaning.

ORMAK

Vacuum Vessel and Pumping System

The ORMAK device is a double-walled structure and has cryogenic coils cooled by LN_2 . The inner vessel ($R = 0.795 \text{ m}$, $a = 0.254 \text{ m}$, $\text{Vol.} \approx 1 \text{ m}^3$) has a thin gold coating and is held at a constant temperature by inherent resistance heating. The constant temperature is desired from a structural point of view and to control/limit the desorption of gases from the vessel walls. Airco turbomolecular pumps evacuate the inner chamber and oil diffusion pumps evacuate the outer chamber. The base pressure in both chambers is approximately 10^{-8} Torr. The vessel does not have any bellows sections nor does it have any ceramic breaks.

In Situ Wall Conditioning of ORMAK

The conditioning of the ORMAK plasma chamber walls is done primarily by discharge cleaning the device nightly and on weekends. The vessel can be baked to 150°C , but such a bake has been found to be rather ineffective even for removing water vapor. After the device is let up to atmospheric pressure a one to two day conditioning period using plasma discharges is needed before good conditions are obtained. The discharge cleaning method employed uses pulses produced in the normal fashion, but at a higher repetition rate and without the aid of the vertical magnetic fields to position the plasma pulses. For this 100 to $200 \mu\text{sec}$, 40 V, 140 A pulses are created. Discharge cleaning is limited to a rate such that the vessel walls do not get hotter than 100°C . The working gas is either H_2 or O_2 . Oxygen is not normally used to discharge clean tokamaks, but O_2 has been found to be effective in removing carbon in ORMAK. Argon has been found to be effective in cleaning the ORMAK device.

There are approximately fifty diagnostic ports and four neutral beam injection ports on ORMAK. Because diagnostic appendages must penetrate the LN_2 -cooled outer shell region the surfaces are at a much lower temperature than the plasma chamber. In a few special cases, e.g., surface appearance probe, the cold surfaces are heated to avoid any cold trapping

effects. The main requirement on any appendage which communicates with the main vessel vacuum system is that it have a low leakage rate to assure that it does not contribute more than an acceptable amount of impurities. There are a number of appendages on which oil diffusion pumps and elastomer seals are used, and even though it would be desirable to eliminate such pumps and seals and to replace them with turbomolecular pumps and hard seals, the cost is found to be prohibitive.

MICROTOR

Microtor is an Alcator-like device with plasma parameters of $R = 0.3$ m, $a = 0.1$ m, and $I = 40$ kA. The toroidal magnetic fields at the plasma are ~ 1 T. The Microtor device is operational and is being used in surface interaction studies of tokamak discharge cleaning operations. A larger device called Macrotor is in the planning stages at the UCLA Tokamak Laboratory.

Recent results on Microtor are still being analyzed and will be presented in the near future. The experimental work is concentrating on the high energy bombardment by plasma ions on various wall materials; e.g., stainless steel and nickel. The work is being conducted in cooperation with Bechtel who are making the Auger electron measurements. The studies are indicating the importance of both the interaction energy of the ions and the ion bombardment dose per unit area of wall. The latter parameters are of particular importance in light of the fact that the large devices of the future may not be able to develop the high ion dose fluxes at the walls that the present-day smaller devices can develop. It is believed that the processes involved in discharge cleaning involve etching of the surfaces and sputtering. "Good" results are obtained at bombarding energies ≥ 300 eV and it is expected that energies of 2-3 keV may be the most effective as far as discharge cleaning is concerned.

ATC

The ATC device has been in operation for several years. The vacuum vessel is a welded stainless steel bellows structure in which O-ring seals are employed. The pumping system presently consists of an oil diffusion pump and a refrigerated baffle which has a hydrogen pumping speed of ~ 1000 liters/sec and evacuates the vessel to $\sim 1 \times 10^{-7}$ Torr.

The walls are discharge cleaned after the vessel has been up to atmospheric pressure. The discharge cleaning involves short pulses every 1 to 2 seconds for a minimum period of 5-6 hours. The pulses have a duration of ~ 2 m sec and a peak current of ~ 15 kA. The toroidal magnetic field is reduced to 0.3 T and is not pulsed.

In one series of experiments titanium was evaporated onto the interior surfaces of the ATC vessel. The titanium was found to suppress the gas influxes normally observed in ATC during normal pulsing. These influxes are due to the bombardment of the vessel walls by plasma particles. A, Z_{eff} close to unity was observed as well as reduced levels of oxygen and iron in the plasmas. There were no signs of the desorption of trapped impurities from the titanium layers.

PLT

Vacuum Vessel and Pumping System

The PLT vacuum vessel is a 305 stainless steel structure with bellows sections as well as two ceramic breaks. The toroidal vacuum vessel has a major radius of 1.30 m and a minor radius of 0.50 m (volume = 7.4 m^3 and surface area $\approx 50 \text{ m}^2$). The components were pre-baked at 400°C and the vessel assembly employs gold seals. PLT has been operating for only a few months, and so far the base pressure has been as low as 1×10^{-8} Torr. Presently only two of the four Torr Vacuum 25-cm diameter mercury diffusion pumps are being used. These two pumps have a hydrogen pumping speed of 2360 liters/sec.

Discharge Cleaning of PLT

The in situ wall conditioning of PLT consists of carrying out discharge cleaning operations for periods of time as found necessary to allow "clean" discharges to be formed. In general, a cleaning operation is done for an 8-hour period followed by normal pulsing mixed with discharge cleaning operations until a satisfactory result is obtained. For purposes of cleaning, a steady state toroidal magnetic field of between 0.25 T and 0.60 T is used. The vessel is filled with H_2 (and sometimes He) to a pressure of $\sim 3 \times 10^{-5}$ Torr. Pulse discharges having currents of 100-200 kA and durations of $\sim 40 \text{ m sec}$ are then created every 14 to 15 seconds. The voltage drop is from 5 to 10 V depending on the wall conditions, and the average power to the walls is 5-6 kW. A substantial amount of the power is deposited on the limiters.

TFR

The TFR device has been operating in France for a number of years. The TFR vacuum vessel is an all-welded structure made of 0.5 mm thick Inconel bellows ($R = 0.98$ m and $a = 0.20$ m). The pumping system includes two turbomolecular pumps rated at 600 liters/sec and 70 liters/sec in parallel with a titanium pump to exhaust the vessel to a base pressure of $\sim 5 \times 10^{-10}$ Torr.

A system is used to bake the TFR vessel in situ to 450°C and to bake the eight diagnostic ports to 300°C in situ. Experience has shown that discharge cleaning after bakeout is necessary to effectively condition the walls. It has been found that following a 400°C bake of the toroidal vessel with the diagnostics at 200°C and subsequent discharge cleaning a "remarkable" outgassing rate of $\sim 2 \times 10^{-13}$ Torr liter/sec cm^2 is observed.

T-10

Vacuum Vessel and Pumping System

The T-10 machine is a double-wall, stainless steel structure having a copper shell between the two walls. The device is constructed in quadrants with the diagnostic ports located between the quadrants. The ports allow viewing in the perpendicular direction, but not in the parallel direction, so that a system to inject tangential neutral beams is impossible to incorporate. The outer wall consists of bellows around approximately half of the major circumference, and the inner wall is a thin liner which developed a hole during the initial stages of operation. The hole has not been repaired. The vessel is provided with a water cooling system, but this system was not properly sized and is found to be inadequate.

Each of the four vessel quadrants has an associated vacuum pumping unit, and the outer vacuum region has two additional units. Each unit consists of a modular arrangement of a large number of turbomolecular pumps and ion pumps. Because there is a hole in the inner liner the base pressure is not as low as expected, but it is $\sim 1.5 \times 10^{-7}$ Torr.

Discharge Cleaning T-10

The vacuum components on T-10 were prebaked before final assembly, and the completed assembly was designed to be baked in situ. The initial operation on T-10 was an in situ bake and it was at that time that the inner liner developed its leak. Thus, there is no bake of T-10 at the present time. There is no bake of the diagnostic ports or appendages other than a prebake before assembly.

Discharge cleaning is employed on a nightly basis in order to condition the vessel walls. The discharges for a cleaning operation are carried out for an eight hour period during which time parts of the vessel will heat up to approximately 100°C . The discharges which are primarily hydrogen, although krypton has also been used, are 200 kA, 30 m sec pulses created in a 0.5 T toroidal magnetic field at a repetition rate of two to three per minute. After a discharge cleaning operation, a period of three hours is required to cool the vessel.

DOUBLET III

Vacuum Vessel and Pumping System

The construction of the large Doublet III noncircular tokamak is now underway. The vessel has a cross section of $0.45 \text{ m} \times 1.50 \text{ m}$ and a major radius of 1.40 m , and has a volume of $\sim 17 \text{ m}^3$. The shell is an all-welded, corrugated sandwich structure with gas cooling and has an inner hot liner made of silicon carbide shingles. The corrugations are made of 1.57 mm Inconel 718 and form the integrated gas-cooling channels. The pumping system is envisioned to be three turbomolecular pumps (each at 1500 liters/sec) with the addition of cryopumping if necessary. With an assumed outgassing rate of $< 10^{-11} \text{ Torr liter/sec cm}^2$ a base pressure of $\leq 3 \times 10^{-9} \text{ Torr}$ can be obtained where the hydrogen pumping speed is $\sim 2700 \text{ liter/sec}$ for the turbomolecular pumps. Total internal surface area is $\sim 70 \text{ m}^2$.

In Situ Wall Conditioning of Doublet III

The vessel will be baked to $\leq 400^\circ\text{C}$ for periods of time on the order of 10 hours and discharge cleaning will be used to help remove impurities. The Doublet III neutral beam system which is now being developed is envisioned as being capable of a 250°C bakeout.

PDX

Vacuum Vessel and Pumping System

The PDX device will be a large tokamak, now under construction at PPPL, which will develop and test techniques for reducing impurity levels via magnetic limiters. The vacuum vessel is a stainless steel structure which will be lined with a thin layer of material to shield the vessel from the plasma. As presently designed double elastomer seals will be incorporated and there will be no bellows sections. The liner will probably be made of titanium bonded to aluminum, but the final decision on the liner material has not been made at this time. The vessel has a major radius of 1.45 m and non-circular cross section in the shape of a race track with a full height of 3.05 m and a full width of 1.50 m. The vessel has a volume of approximately 30 m^3 . The pumping system includes twenty titanium evaporator compartments, each with two titanium pumps, to provide the pumping inside the magnetic limiters. It is expected that fresh titanium evaporation will be required after each pulsing operation. In addition to the limiter pumps, a system of cryopumps (at 4 K) and turbomolecular pumps is expected to be employed. This cryo-turbo system will have a pumping speed of $\sim 10^4$ liters/sec and will provide a base pressure in the chamber of $\sim 10^{-8}$ Torr. Large mercury diffusion pumps are being considered as an alternative system. The SS vessel and its liner will be water-cooled through stainless steel lines attached to the exterior of the vessel.

Wall Conditioning of PDX In Situ

The in situ conditioning of the walls on the PDX vacuum vessel will be via discharge cleaning. The possibility of in situ baking of PDX is being considered, but it is presently believed that with an aggressive discharge cleaning operation the walls will reach temperatures of several hundred $^{\circ}\text{C}$ so that a bakeout will not be necessary. The discharges for the cleaning operations will have a repetition rate of one every second at a pulse length of 50 m sec and a current of $\sim 100 \text{ kA}$. An energy of approximately 50 kJ will be deposited on the vessel wall per pulse.

JOINT EUROPEAN TORUS (JET)

Vacuum Vessel and Pumping System

The JET vacuum vessel is a non-circular, double-wall structure composed of a series of thick box sections and bellows. The vessel will be made of Inconel (600 and 625) and will be completely welded. The main vessel has a major radius of $R = 2.99$ m and a D-shaped cross section with internal radii of 1.32 m (horizontal) and 2.1 m (vertical) for a volume of 190 m^3 and internal surface area of 780 m^2 . The vessel components will be fabricated under "clean conditions".

A base pressure of 2×10^{-10} Torr is expected for the main vacuum chamber and 10^{-4} - 10^{-5} Torr for the interspace chambers. The main vessel pumps will have an effective pumping speed of 4×10^4 liter/sec. These pumps will be four cryopumps backed with turbomolecular pumps and vane-type rotary pumps. The shell vacuum system will also be pumped by a cryopump, but there will be only one of them and it will be backed by a Roots pump and a single-stage, vane-type, rotary pump.

The In Situ Bakeout of JET

In order to achieve the 2×10^{-10} Torr base pressure indicated above, the outgassing rate of the vessel walls must be $\leq 10^{-12}$ Torr liter/sec cm^2 . To accomplish this, the JET device will be baked at a temperature of 300° to 500°C for a "soaking" time of between 10 and 15 hours. It will require 10 hours at a 1 MW power capacity to reach 500°C and a 0.5 MW power capacity to maintain 500°C . This will be accomplished by circulating a hot inert gas at a velocity of ~ 10 m/s through the shell chambers, either through the full cross section of the chambers or through ducts welded inside the box-type structure adjacent to the bellows protection shields. The vacuum vessel will be thermally isolated with 25 mm of insulation on its external surfaces and will expand ~ 30 mm during the bakeout at 500°C . The hot circulating gas will be heated on the primary side of a conventional multi-pass tubular heat exchanger of ~ 1 MW capacity.

A possible alternative to the aforementioned scheme is to pre-bake the vessel components prior to final assembly at a very high temperature; i.e., 800° to 1000°C , under vacuum conditions. After assembly the vessel will be baked in situ to $\sim 350^{\circ}\text{C}$. As a general note, it should be indicated that one of the written objectives indicated for JET is the study of plasma-wall interactions so that in situ conditioning must be carefully planned to fulfill this objective. At the present time JET will not be discharge cleaned.

The JET Cooling System

The vessel walls will experience a change in temperature per pulse of $\sim 10^{\circ}\text{C}$ so that cooling is required. The vacuum chamber interspace or the ducts through which the hot gas circulates during a bakeout will also be used for cooling the device. The heat exchanger for the cooling gas will have a 0.5 MW capacity and the gas is expected to flow at a high rate. The exact position of the cooling ducts is not defined until it is determined whether the temperature rise will occur primarily in the limiters, or the vessel walls, or both. The cooling system may also be used in the cool-down of the vessel after a bakeout in order to speed the process. The operating temperature during normal pulsing will be 20° to 50°C .

TOKAMAK-20 (T-20)

Vacuum Vessel and Pumping System

The T-20 vacuum vessel will consist of two concentric toroidal systems of circular cross section - a discharge chamber and an intermediate chamber. The discharge chamber ($R = 5$ m and $a = 2.1$ m) will enclose a volume of 435 m^3 and have a surface area of 410 m^2 . It will consist of a thin walled corrugated toroid protected from the plasma by shielding diaphragms. The intermediate chamber is a reinforced structure integrated with the nuclear radiation shielding and cooled by passing water through cooling pipes. The wall of the intermediate chamber will be maintained at 50° to 100°C in order to minimize the permeation of tritium through the walls and into the atmosphere surrounding the device. The temperature of the discharge chamber during operation is expected to be between 100° and 500°C .

The discharge chamber will be maintained at a base pressure of $\sim 2 \times 10^{-8}$ Torr which will require a pumping system providing a pumping speed of $\sim 10^5$ liter/sec (D_2). This system will include turbomolecular pumps in combination with surface action pumps. An experimental evacuation unit using cryosorption will also be used. In order to prevent local overheating of the wall, an inert gas is introduced after each plasma pulse. The intermediate chamber will be evacuated to a base pressure of $\sim 10^{-6}$ Torr by pumps having an effective speed of 5×10^3 liter/sec.

Wall Conditioning On T-20

Specific outgassing rates of $10^{-12} - 10^{-13}$ Torr liter/sec cm^2 at room temperature for the discharge chamber walls and of 10^{-10} Torr liter/sec cm^2 for the preliminary degassed stainless steel of the intermediate chamber are desired. To accomplish the low rate for the discharge chamber, a bakeout at 600°C during technological preparation for experiments will be carried out. Additional conditioning of the walls will be carried out by discharge cleaning the walls using 1.5 - MA plasma pulses in an inert gas.

JAPAN TOKAMAK-60 (JT-60)

The JT-60 vacuum vessel will have an elliptical cross section which accommodates a magnetic limiter/divertor and will have a major radius of 3 m and a minor radius of 1.2 m. The vessel has a volume of 100 m^3 and a surface area of 1200 m^2 . The pumps evacuating the vessel will have a speed of $20 \text{ m}^3/\text{s}$, so that if the desired base pressure of 10^{-9} Torr is to be reached, the outgassing rate of the vessel walls must be $\sim 2 \times 10^{-12}$ Torr liter/sec cm^2 . The vessel will be lined with molybdenum (or possibly SiC or carbon), and will be made up of Inconel 625 bellows sections. The device is expected to operate at temperatures ranging from room temperature to 500°C and will be baked in situ to 500°C . A large effort will be required to solve the engineering problems associated with the expansion and motion of the vessel during operations. In addition to an in situ bake of the main vessel, the various diagnostic ports will also be baked in situ to 250°C . The bakeout schedule for JT-60 has not been considered in any detail at this time. During normal pulsing, JT-60 is expected to operate at a wall temperature of approximately 300°C since there will be no vessel cooling system. At this high temperature, it is felt that the walls will recycle H_2 at a high rate such that there will be no build up of hydrogen on the walls of the device. An important objective of JT-60 is to study wall-plasma interactions as well as impurity behavior and control. The JT-60 device will not be used to form D-T plasmas.

TOKAMAK FUSION TEST REACTOR (TFTR)

Vacuum Vessel and Pumping System

The TFTR vacuum vessel will be a 305 stainless steel structure having twelve bellows sections separated by straight sections reinforced with stiffening rings. The vessel ($R = 2.65$ m, $a = 1.10$ m) will have a volume of 63 m^3 and a surface area of $\sim 1000 \text{ m}^2$, and will be evacuated to a base pressure of $\sim 3 \times 10^{-8}$ Torr by 61-cm diameter mercury diffusion pumps. The mercury pumps will be backed by mechanical pumps and a zirconium-aluminum alloy getter and hot filament "cracker" pumping system. The effective pumping speed of the high vacuum pumps is $\sim 3.3 \times 10^4$ liter/sec for hydrogen. The base pressure indicated above assumes a specific outgassing rate of 10^{-10} Torr liter/sec cm^2 . Each bellows section will include an outer cover plate with the region between the plate and the bellows evacuated to $10^{-3} - 10^{-4}$ Torr by a mechanical pump/gettering pump system.

It is anticipated that the main vessel will be cooled so that it will be maintained at a temperature $\leq 50^\circ \text{C}$ during normal pulsing operations. The 50°C limit will allow the amount of tritium permeating through the vessel walls to remain below 1 Ci/year and prevents excess thermal expansion so that the motion of the many diagnostic appendages is ≤ 2 mm. An expanding vacuum vessel could result in alignment problems and because of the number of appendages the motion must be minimized. To maintain the vessel at these low temperatures, the possibility of incorporating either a forced-air cooling system or a water-cooling system has been studied in detail.

Bakeout of TFTR In Situ

Current studies of the TFTR device includes a system to heat the vessel to 250°C by passing electric currents through the vessel walls; i.e., 6 kA at 13 V ac in the toroidal direction and

34 kA at 1 V dc in the poloidal direction. It is anticipated that the various ports and extensions leading to diagnostic appendages will also be baked out since the associated surface area is 16% of that of the main vessel. The appendages will probably be heated by a combination of methods; e.g., external heating sleeves and/or direct applications of current. Each appendage will require individual attention to the method used to heat it as well as to the optimum bakeout temperature. A bakeout is expected to take two days and to be administered only infrequently, namely, after a pumpdown from atmospheric pressure or after changing working gases. It should be noted that in addition to the possibility of baking in situ, the vacuum system will be prebaked for 60 hours before final assembly. The final assembly will take place under "clean room" conditions and will be followed by several days of baking of the entire vacuum assembly before the initial start-up of TFTR.

The Discharge Cleaning of TFTR

Aggressive discharge cleaning of TFTR will be carried out on a weekly basis in addition to the infrequent bake of the vacuum vessel in situ. This cleaning operation will take from a few hours to several days and the cooling system will be used to maintain the walls at $\leq 250^{\circ}\text{C}$. The high temperatures are not critical, or even desired, during discharge cleaning, but must be limited because of mechanical/structural considerations. The working gas will more than likely be hydrogen or deuterium and the discharges will be ~ 300 kA in a ~ 0.7 T toroidal magnetic field. The pulses will last ~ 150 msec and occur every 1.5 seconds for an anticipated power to the walls and limiters of about 0.8 MW.