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Impurity and Recycling Control with Gettering in ATF*

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The vacuum vessel of the Advanced Toroidal Facility (ATF) is Ti-gettered with a surface coverage of 70%. The major effects of gettering are: (1) reduction of the oxygen, carbon, and nitrogen content in the plasma and (2) improved density control due to wall pumping of the working gas hydrogen. The overall leak rate in ATF is 2×10^{-4} Torr-l/s which is too high for successful plasma operation. Ti-gettering is routinely employed every morning prior to operation and compensates for this shortcoming by reducing the partial pressure of nitrogen and other residual gas components to the low 10^{-9} Torr range which is close to the RGA background pressure. Rate-of-rise measurements at this stage show only argon and some methane. The argon is used to monitor the leak rate. In addition to impurity reduction, gettering leads to low recycling of the working gas which appears to be crucial for density control in ATF. The capacity of the gettered surface is large enough to show a strong effect even after 24 hours. An extensive data base on the short-term and long-term effects of gettering on the residual gas composition and its effects on plasma performance has been established over the past three years and will be discussed in this paper.

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I. INTRODUCTION

The Advanced Toroidal Facility (ATF) is a device which has many features similar to a tokamak, but because of its stellarator geometry, it has the additional possibility to operate in a very long pulse or steady state mode. Energy confinement and operational space are roughly the same as for tokamaks of similar size and fields.[1]

The toroidal vacuum vessel consists of some 1200 individual pieces of stainless steel welded together. This method of construction was chosen because of the complex shape of the vessel which was required to maximize the plasma size for a given system of magnetic field coils, optimize diagnostics access, and provide access for tangential neutral beam injection. Due to the large number of welds, this fabrication technique had the inherent potential for a large cumulative leak rate. The initial total leak rate of the vessel was ~ 1 x 10^{-5} Torr-l/s, but rose to 2 x 10^{-4} Torr-l/s after some operation and several baking cycles between room temperature and 150 °C. At this point, efforts to reduce the leak rate were unsuccessful due to the limited access to the vacuum vessel which was almost totally enclosed by the coils and the structural shell. Glow discharges and baking cleaned the walls sufficiently to allow plasma operation with ECH alone, whereas NBI plasmas collapsed within 50-70 ms.[2] To overcome this behaviour, chromium gettering, which was developed at this laboratory[3] and first used on the ISX-B experiment[4], was initially employed on ATF. Using either two or four getter sources accomplished a reduction of the total radiated power losses by a factor of 1.4[5].

While chromium gettering improved plasma operation by reducing the impurity radiation to some extent, the uncontrollable increases in the density, a problem experienced before gettering, continued even after chromium gettering. This was not surprising since the hydrogen pumping capability of a chromium film is limited to approximately one monolayer on its surface, in contrast to titanium which pumps hydrogen by surface adsorption and consequent diffusion into the bulk of the film[6]. Hence, titanium films represent a hydrogen pumping capacity of many monolayers, depending on the film thickness. To investigate the effects of this hydrogen pumping capability, the chromium sources were replaced with titanium sources with the goal to control the plasma density by reducing the hydrogen recycle coefficient. At the present time, seven titanium sources, providing ~ 70% wall coverage, allow plasma pulses of 20 second duration (the limit of present hardware capabilities) without collapse and plasma densities of up to $10^{20}m^{-3}$ (not simultaneously). This article describes the use of a quadrupole mass spectrometer to analyze the effects of gettering on the residual gas and the working gas and the improvement of plasma performance.

II. EXPERIMENTAL DETAILS

The residual gas analyzer (RGA)[7] is connected to the vacuum vessel header via an isolation valve and is differentially pumped by a 50 l/s turbomolecular pump. A capacitance manometer, calibrated with a spinning rotor gauge, is utilized to calibrate the system. A retractable orifice valve, in series with the isolation valve, can be used to reduce the pressure in the RGA. This is necessary when data are taken during operating modes in which the pressure in the main vessel is higher (mTorr) than the RGA operating range can accommodate, e.g. during glow discharge cleaning.

The system is computer-controlled and extensive software has been developed which allows operation in a number of modes. Mode 1, the scan mode, measures the peak heights from 1-50 atomic mass units (AMU). Mode 2, the monitor mode, records the values of up to 16 pre-selected AMUs every 20 seconds for extended periods of time. And mode 3, the fast transient mode, follows the behavior of a single mass at the rate of 100 Hz. Data output consists of logarithmic graphs of pressure in Torr as a function of AMU (mode 1), a family of curves with identifying mass numbers as a function of time (mode 2), or the partial pressure in Torr of one selected mass as a function of time (mode 3). Additional software enables the operator to locate the top of the peak precisely and to set control voltages on the quadrupole to the required values. This is important since only one reading is made during each cycle in the monitor and fast transient modes.

The normal sequence of events for a gettering cycle is: (1) an RGA scan of masses from 1 to 50 AMU is performed and the RGA background subtracted, (2) the rate-of-rise for the vacuum vessel is determined by isolating the vessel from the pumps and recording pressures as functions of time for each gas of interest, (3) the valves are re-opened, the getter sources are driven to the midplane of the torus and current is applied for 30 minutes which deposits a film of approximately 5 monolayers (minimum) over ~70% of the surface of the vacuum vessel wall, (4) the vessel is isolated again and another set of rate-of-rise measurements is made. This procedure is usually followed once each day prior to plasma operations. The rate-of-rise measurements before and after the getter cycle determine the total leak and outgassing rate of the vessel.

In an ungettered vacuum system, the leak rate may be measured with an ion gauge by observing the rate-of-rise in total pressure or by the rate-of-rise in the nitrogen partial pressure, utilizing a residual gas analyzer. In a system such as ATF, neither of the above methods can be used as long as the getter material is active, since nitrogen and oxygen, the main components in air, are pumped by the getter. The noble gas argon, however, is not pumped by the titanium film and can provide a measure for the leak rate by measuring the rate-of-rise of argon Vdp(Ar)/dt and inferring the leak rate of nitrogen from the equation

$$Q = \frac{\%N}{\%Ar} \times \frac{Vdp(Ar)}{dt} \qquad (1)$$

where Q is the nitrogen leak rate, %N is the volume percent of nitrogen in air, %Ar is the volume percent of argon in air, V is the volume of the ATF vacuum vessel and dp(Ar)/dt is the change in the argon partial pressure as a function of time.

III. EXPERIMENTAL RESULTS

1. Effects on the Residual Gas

The nitrogen leak rate inferred from argon rate-of-rise measurements and equation (1) is shown in FIG. 1(a). Very little difference is observed between the argon data taken before and after gettering. The actual nitrogen leak rates, measured immediately after gettering and before gettering the next day, are shown in fig. 1(b). The inferred nitrogen leak rate matched the measured nitrogen leak rate when the getter was inactive, e.g. on day 268 in FIG. 1(b), following a long shut-down of the machine. The leak did vary by a factor of ~ 2 regularly which was associated with baking of the Thompson scattering diagnostics. The long-term downward trend of the leak rate was the result of locating and repairing several leaks.

A nitrogen leak rate of 2×10^{-4} Torr-l/s corresponds to 17.2 Torr-l or 5.5×10^{20} particles during a 24 hour period. If all these particles were pumped by the wall with 70% getter coverage, the nitrogen coverage of the getter film would be ~ 1×10^{19} m^{-2}, or ~ one monolayer. This also assumes a roughness factor of unity. The data presented in FIG. 1(b) show that after a few days of uninterrupted gettering, the values of the rate-of-rise taken on the next day before gettering are observed to become smaller than the actual value of the leak, indicating the continued pumping of nitrogen by the titanium. After machine vents, the getter was fully saturated and the total nitrogen leak became apparent as depicted in event 10 of FIG. 1(b), which indicates the start of the pump-down, preceded by a 40 day air vent and followed by event 11, hydrogen glow discharge cleaning. Event 12 was the first titanium gettering cycle with 7 sources since the shut-down. Event 13 followed a short shut-down and event 14 followed a weekend of hydrogen glow discharge cleaning. The figure indicates that all of these events represent the vacuum vessel in the ungettered state, displaying the full leak rate of 2×10^{-4} Torr-l/s.

The rate-of-rise of mass 18 (H_2O) for the same time period is shown in FIG. 2(a). The rate-of -rise at event 11 demonstrates that the water adsorbed on the wall has been reduced by glow discharge cleaning, while the nitrogen leak rate displayed in FIG. 1(b) is, of course, not effected. The rate-of-rise starting at event 12 demonstrates that water and oxygen are pumped very efficiently by titanium getters. The partial pressure of water after gettering, as indicated in FIG.2(a), approaches the RGA background generated by interactions of atomic hydrogen with the walls around the filament. Initial sticking coefficients of oxygen on titanium approach unity[2] and more than one monolayer has been observed to be adsorbed at room temperature[9]. The pumping of oxygen-bearing molecules can further be extended by displacing other, previously adsorbed gases with lower binding energies on the titanium surface.[10] Since oxygen-bearing molecules have much higher sticking coefficients than nitrogen, partial pressures of oxygen and water are more representative of wall cleanliness while nitrogen partial pressures are more representative of leak rate and surface pumping speed.

The rate-of-rise of mass 44 (CO_2) displays a similar pattern and is shown in FIG. 2(b). Immediately after gettering the rate is often below our measurement capabilities of 1×10^{-9} Torr-l/s. Some increase is observed 24 hours later due to the decreased pumping capability of the titanium film.

2. Effects on Plasma Operation

Immediately following a discharge with gettered or ungettered walls, the partial pressure of water was recorded in the RGA fast transient mode which is shown in FIG. 3. In the ungettered case, the background partial pressure of water before the discharge is almost an order of magnitude higher than in the gettered case and then rises by a factor of 5 after the discharge, as a consequence of plasma-wall interactions. In the gettered case, the initial level of water pressure is much lower and very little change is seen after the discharge. This behaviour is reflected in the oxygen content of the plasma discharges related to these residual gas measurements, which is shown for two corresponding discharges in FIG. 4 (b). The difference is obvious. For the ungettered case, the oxygen radiation starts high and continues to rise throughout the discharge until the plasma collapses at about 0.25 s. The gettered case, on the other hand, shows an initial oxygen radiation which is more than an order of magnitude lower and remaining at this low level until the end of the discharge. The densities for these two shots were similar and are shown for comparison in FIG. 4 (a).

In addition to impurity control, gettering has also provided an efficient technique for controlling the density. FIG. 5 shows an example of a 25-shot sequence with nominally constant density. The densities just before and during neutral beam injection are depicted. The ECH plasma density just before beam injection is a good measure for the shot-to-shot reproducibility of recycling and particle control. The neutral beam phase has a more intense wall interaction and usually a somewhat larger variation of the data points. The gas puffing rate for these discharges was pre-programmed and varied by approximately 5%. For the neutral beam phase, the observed drift of the maximum plasma densities due to the increased particle load on the getter film is not larger than 10%. FIG. 6 shows that the maximum deuterium pressure evolution in the vessel obtained immediately after each discharge is also fairly reproducible and constant within ±5 %. There was no additional gettering during the sequence which lasted for more than two hours. The relation between deuterium gas puff, plasma density, and neutral edge pressure during the discharge is shown in FIG. 7. The indicated neutral pressure at the time of plasma breakdown, during the discharge, and immediately after the discharge, displayed in FIG. 7 (c), are very low because of the strong effect of gettering on the neutral density. This effective recycling control, in combination with programmed gas puffing, has improved density control in ATF substantially.

IV. CONCLUSIONS

Titanium gettering has been successfully employed to overcome the deleterious effects of a 2×10^{-4} Torr l/s leak rate in ATF. The effective leak/outgassing rates of the most abundant gaseous impurities except methane, which is not gettered by titanium, have been observed to be as low as 10^{-9} Torr l/s after gettering. Spectroscopic analysis of the radiated power during discharges has determined that before gettering between 50% and 75% of the input power was radiated and after gettering this fraction was reduced to 15 - 20%.[2] The pumping capacity of the gettered surface is large enough to continue pumping of nitrogen, the most abundant gaseous impurity, as much as 24 hours after the getter film has been deposited. It is assumed that pumping of oxygen-bearing gases is even better[3]. In addition to impurity control, the titanium layer also provides an effective method for density control by reducing wall recycling. The combination of impurity and density control has enlarged the operating space of ATF considerably. Before gettering, achievable electron densities were in the range of several 10^{18} m^{-3}, while after extensive gettering it was possible to operate with densities up to 10^{20} m^{-3}.

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REFERENCES

[1] M. Murakami, et. al., Phys. Fluids B3, 2261 (1991).

[2] R. C. Isler, et. al., Nuclear Fusion **31**, 245 (1991).

[3] J. E. Simpkins, P. Mioduszewski and L. W. Stratton, J. Nucl. Mater. **111-112**, 827 (1982).

[4] P. Mioduszewski, et. al., J. Nucl. Mater. **128-129**, 884 (1984).

[5] R. C. Isler, et. al., J. Neucl. Mater. **176-177**, 332 (1990).

[6] J. E. Simpkins and P. Mioduszewski, J. Vac. Sci. Tech., **20**, 1321 (1982).

[7] UTI 100C, UTI Instruments Company, Sunnyvale, CA.

[8] M. Cabrera and V. F. Mott, Report on Prog. in Physics **12**, 168 (1949).

[9] J. E. Simpkins, et. al., J. Vac. Sci. Technol. A, **1**, 1306 (1983).7

FIGURE CAPTIONS

FIG. 1 (a). The nitrogen leak rate inferred from the rate-of-rise of mass 40, before and after gettering. (b). The actual rate-of-rise of nitrogen before and after gettering. Event 10 indicates the start of the pump-down, getter inactive. Event 11 indicates hydrogen glow discharge cleaning and event 12 marks the first titanium getter cycle. Event 13 indicates a short shut-down and event 14 a weekend of hydrogen glow discharge cleaning.

FIG. 2 (a). Rate-of-rise of mass 18 before and after gettering. The behavior of this mass is related to the behavior of oxygen in the vacuum vessel. (b). Rate-of-rise of mass 44 before and after gettering. After gettering, the partial pressures of this gas were often too close to the RGA background to measure.

FIG. 3. The behavior of mass 18 following a discharge with gettered and ungettered walls. The higher mass 18 partial pressure before the shot and the increase following the discharge are due to plasma-wall interactions.

FIG. 4(a) Density scans of a gettered and an ungettered discharge. (b). Oxygen radiation from the same discharges.

FIG. 5. Values of the density at 0.20 s (before NBI) and at 0.26 s (during NBI) for a 25 shot sequence.

FIG. 6. Maximum deuterium pressure evolution after the discharge during the 25 shot sequence of constant density.

FIG. 7. Gas puff , plasma density and edge neutral pressure during a gettered discharge.

ORNL-DWG 91M-3476 FED

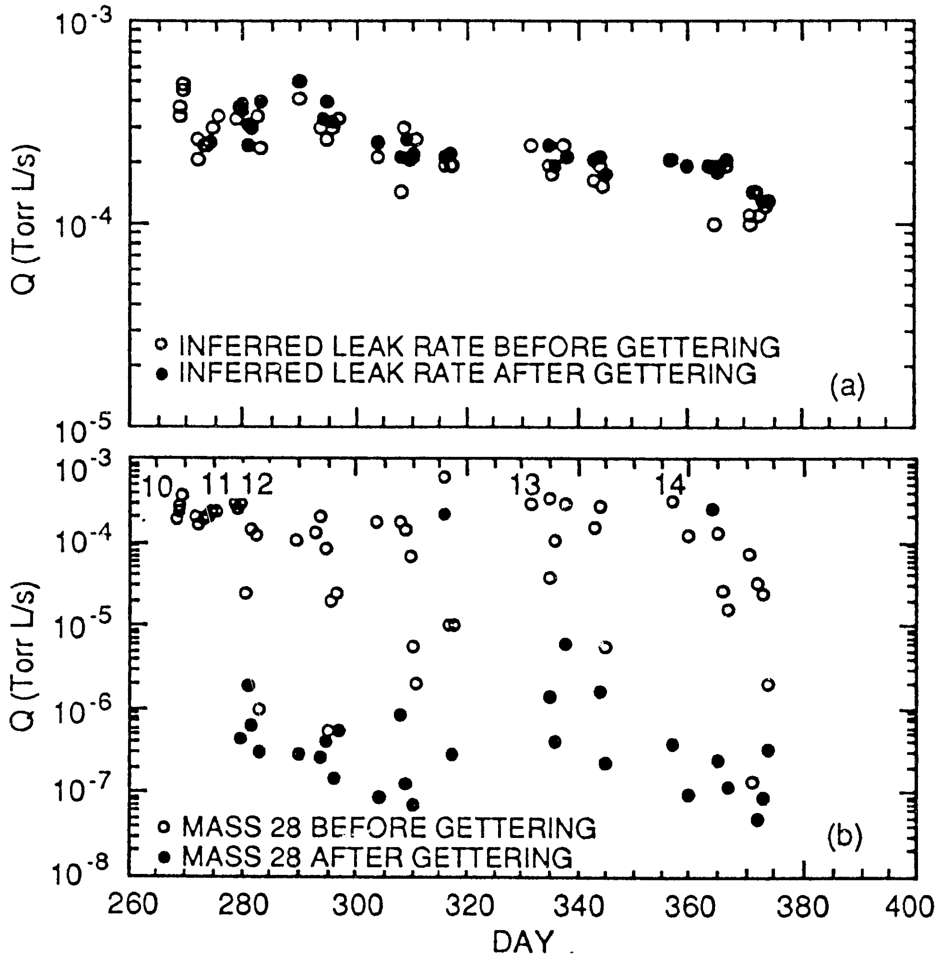


Fig. 1

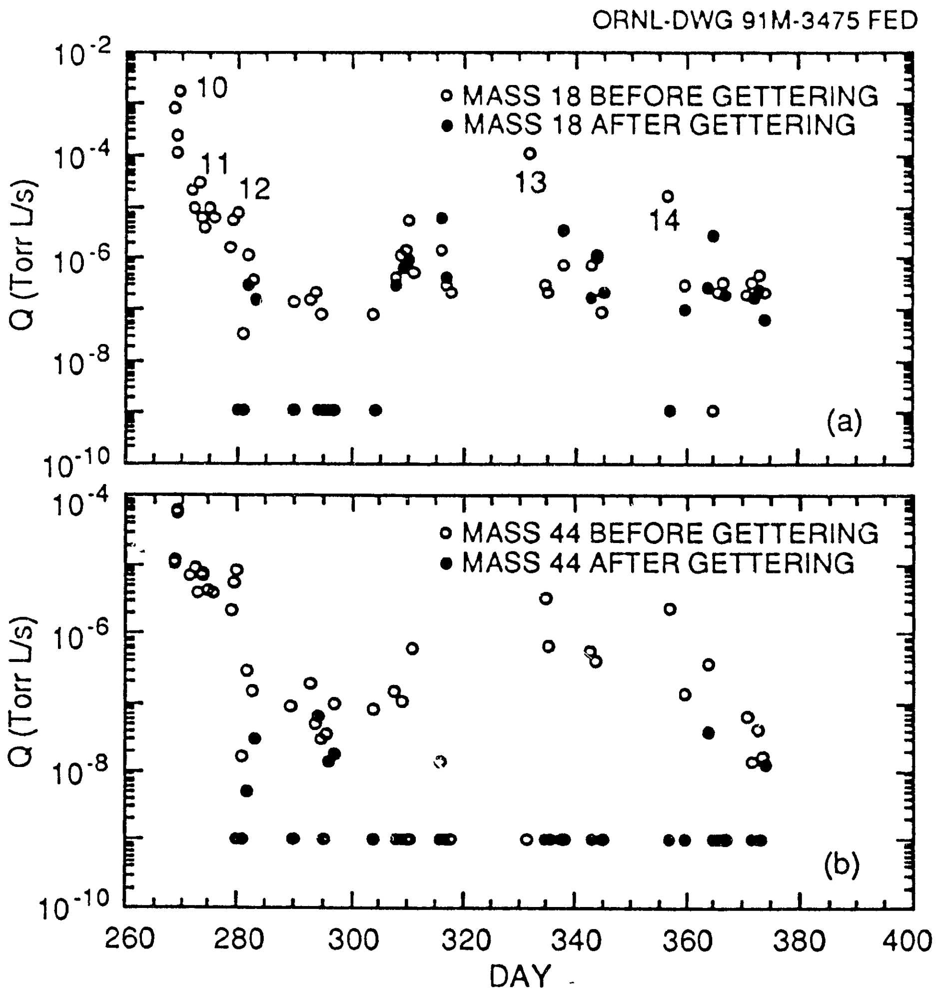
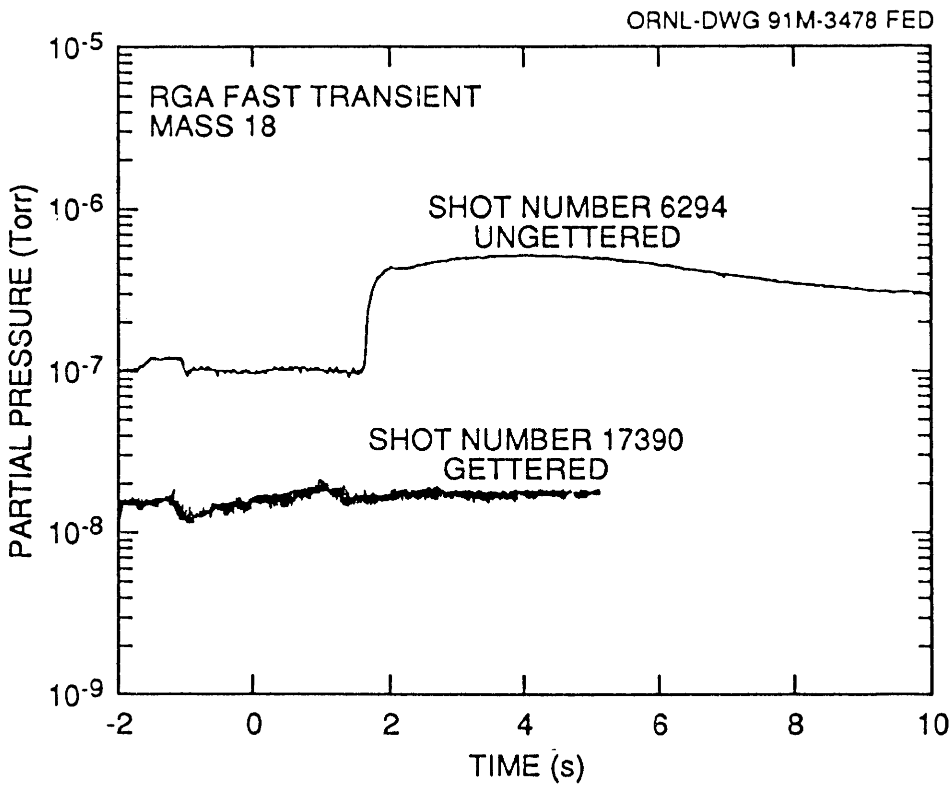

ORNL-DWG 91M-3475 FED
MASS 18 BEFORE GETTERING
MASS 18 AFTER GETTERING
10
11
12
13
14
(a)
MASS 44 BEFORE GETTERING
MASS 44 AFTER GETTERING
(b)
Q (Torr L/s)
DAY
260 280 300 320 340 360 380 400

Fig. 2



ORNL-DWG 91M-3478 FED
RGA FAST TRANSIENT
MASS 18
SHOT NUMBER 6294
UNGETTERED
SHOT NUMBER 17390
GETTERED
PARTIAL PRESSURE (Torr)
TIME (s)

Fig 3

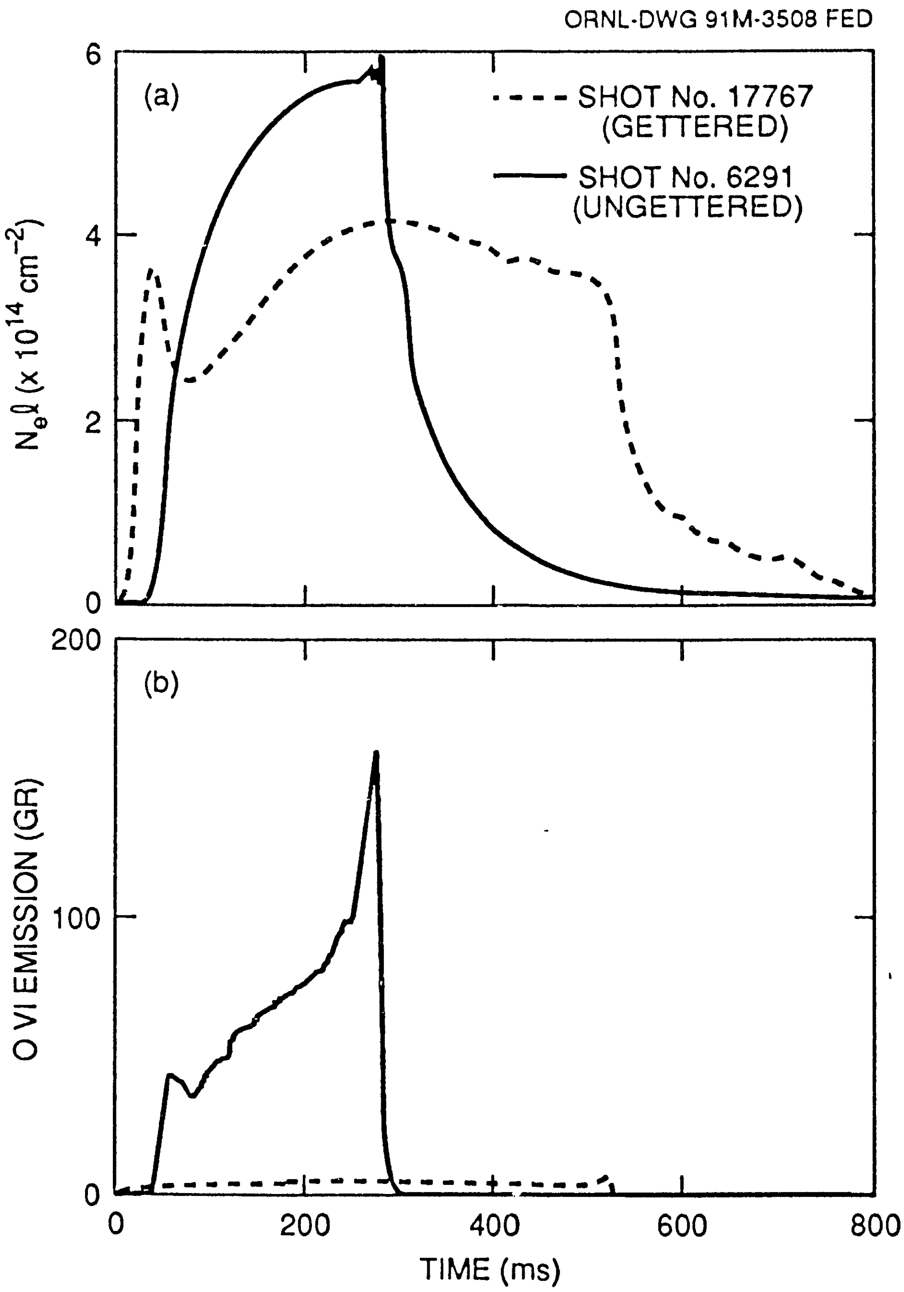
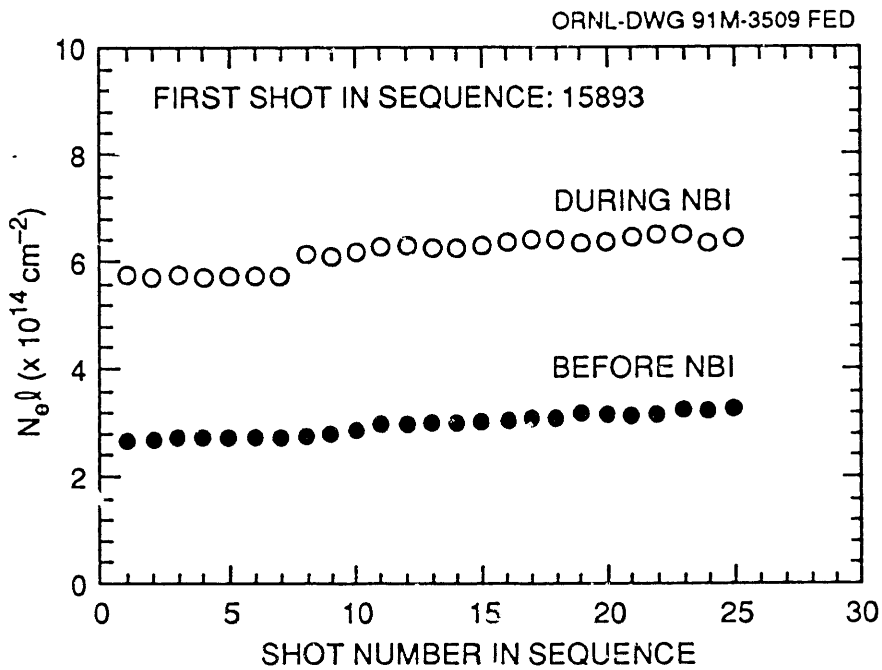

ORNL-DWG 91M-3508 FED
(a)
SHOT No. 17767
(GETTERED)
SHOT No. 6291
(UNGETTERED)
$N_e \ell$ (x 10^{14} cm^{-2})
6
4
2
0
(b)
200
100
0
O VI EMISSION (GR)
0
200
400
600
800
TIME (ms)

Fig 4



ORNL-DWG 91M-3509 FED
FIRST SHOT IN SEQUENCE: 15893
DURING NBI
BEFORE NBI
N$_e$l (x 10^{14} cm^{-2})
SHOT NUMBER IN SEQUENCE
0
2
4
6
8
10
0
5
10
15
20
25
30

Fig 5

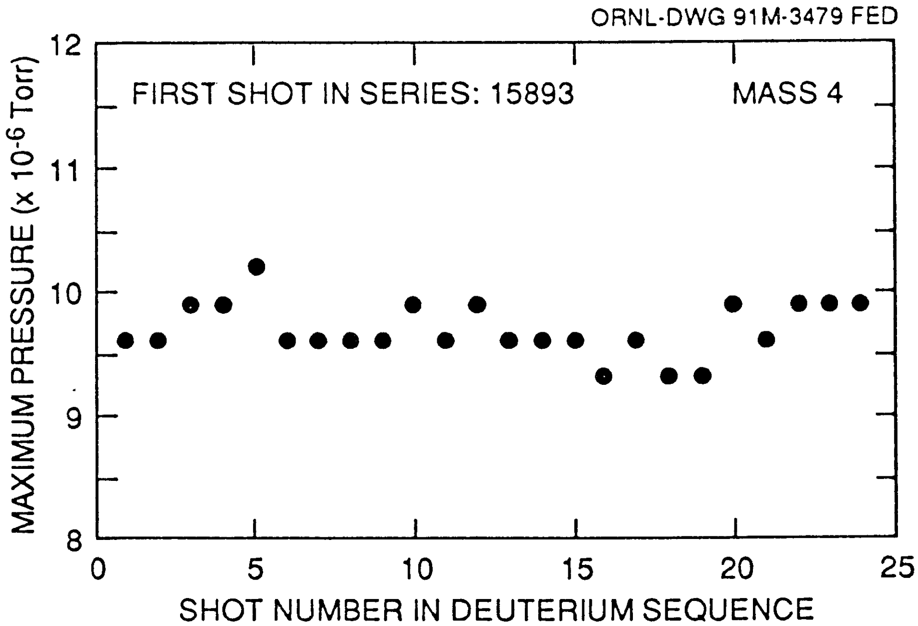

ORNL-DWG 91M-3479 FED
FIRST SHOT IN SERIES: 15893
MASS 4
MAXIMUM PRESSURE (x 10-6 Torr)
12
11
10
9
8
0
5
10
15
20
25
SHOT NUMBER IN DEUTERIUM SEQUENCE

Fig 6

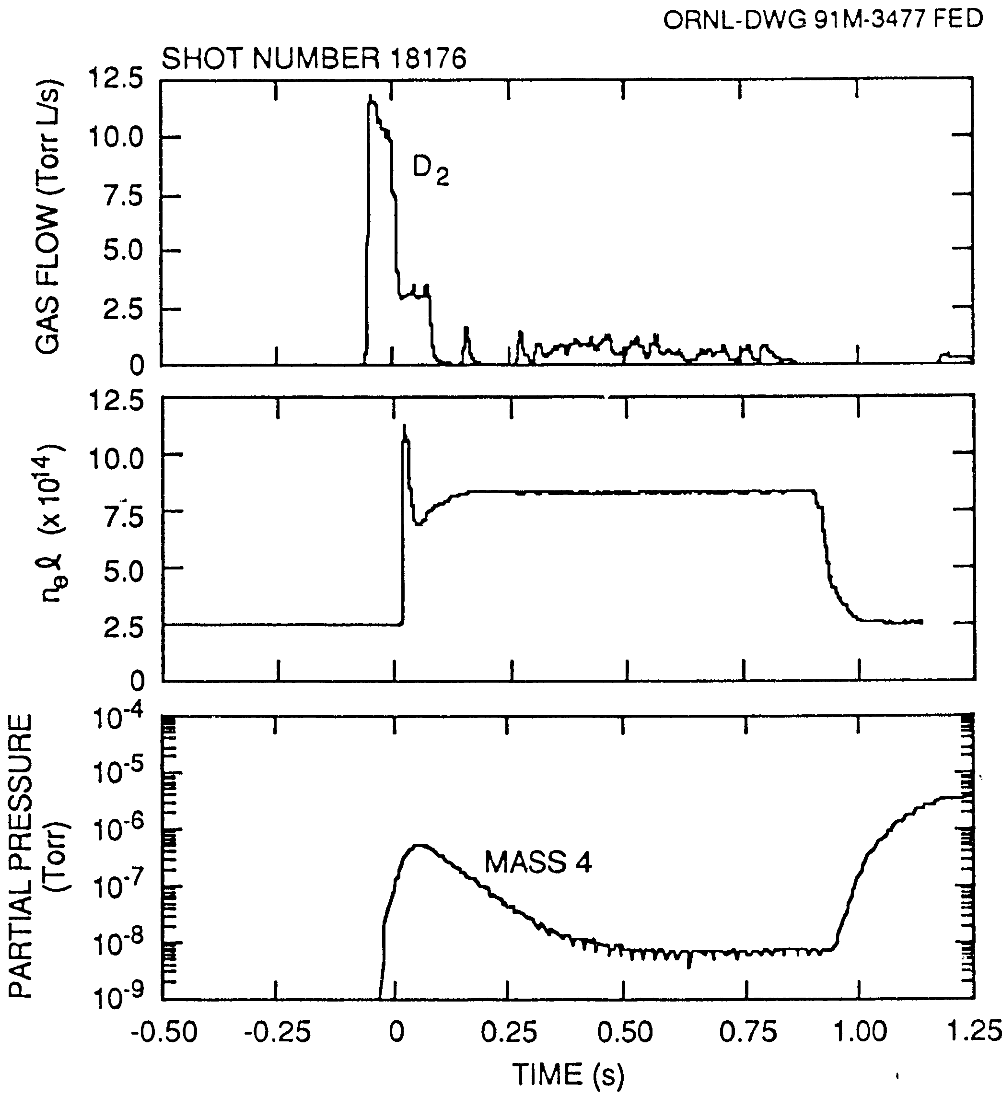

ORNL-DWG 91M-3477 FED
SHOT NUMBER 18176
GAS FLOW (Torr L/s)
12.5
10.0
7.5
5.0
2.5
0
D2
ne l (x 10^14)
PARTIAL PRESSURE (Torr)
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
MASS 4
-0.50
-0.25
0
0.25
0.50
0.75
1.00
1.25
TIME (s)

Fig 7

END

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