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FIRST-WALL AND LIMITER CONDITIONING IN TFTR

By

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MASTER

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FIRST-WALL AND LIMITER CONDITIONING IN TFTR*

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ABSTRACT

A progress report on the experimental studies of vacuum vessel conditioning during the first year of TFTR operation is presented. A previous paper[1] described the efforts expended to condition the TFTR vessel prior to and during the initial plasma start-up experiments. During the start-up phase, discharge cleaning was performed with the vessel at room temperature. For the second phase of TFTR operations, which was directed towards the optimization of ohmically heated plasmas, the vacuum vessel could be heated to 150°C. The internal configuration of the TFTR vessel was more complex during the second phase with the addition of a TiC/C moveable limiter array, Inconel bellows cover plates, and ZrAl getter pumps. A quantitative comparison is given on the effectiveness of vessel bakeout, glow discharge cleaning, and pulse discharge cleaning in terms of the total quantity of removed carbon and oxygen, residual gas base pressures and the resulting plasma impurity levels as measured by visible, UV, and soft X-ray spectroscopy. The initial experience with hydrogen isotope changeover in TFTR is presented including the results of the attempt to hasten the changeover time by using a glow discharge to precondition the vessel with the new isotope.

*Presented at the 6th International Conference on Plasma Surface Interactions, Nagoya, May 1984.

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1. INTRODUCTION

This paper describes the conditioning of the TFTR vacuum vessel and first-wall structures during the OH - optimization phase of TFTR operations from October 1983 to January 1984.

The initial conditioning of the TFTR vessel, which preceded first plasma operation in the device, has been described previously [1]. At the time of the initial conditioning, the first wall of the TFTR vessel consisted of the 304LN stainless steel of the primary structure of the vessel, Inconel 625 bellows which separated the solid stainless steel sections of the vessel [2], and a poloidal limiter constructed of graphite. Additional first-wall hardware was installed within the TFTR vessel during the summer of 1983 which added additional surface area exposed to vacuum and considerable heterogeneity to plasma-exposed surfaces. This new first-wall hardware included an array of slatted bellows cover plates (constructed of Inconel x750), a moveable limiter mechanism with water-cooled graphite tiles coated with TiC, and eight, nominal 20,000 ℓ/s ZrAl surface pumping panels. The design of the hardware has been described previously [3], and a detailed discussion of the effect of the hardware on plasma operations is described in a companion paper [4]. A preliminary analysis of the plasma physics results from the OH-optimization operations period has been given by R. J. Hawryluk et al. [5].

The task of conditioning the first-wall hardware for plasma operations, although complicated by the additional hardware noted above, was aided by two developments unavailable during the initial conditioning period. First, the vacuum vessel bakeout system was commissioned at the end of the previous run, thus allowing discharge cleaning of the vacuum vessel to be performed at more efficient elevated temperatures (120°C). Second, the plasma-contacting limiter components (TiC-coated graphite tiles) were preconditioned [4] by vacuum baking at high temperature (800°C). This paper describes the *conditioning procedures* that were employed during the OH-optimization period, including: (1) the outgassing of the vessel as it was raised to 120°C; (2) a short (15 hr.) glow discharge cleaning period preceding the operations period, and (3) two periods of pulse discharge cleaning, one preceding and one midway through the operations period. The efficiency of the vessel conditioning was assessed primarily from spectroscopic measurements of plasma impurity levels. Residual gas measurements were used to monitor and optimize the progress of the discharge cleaning. To simplify the residual gas analysis, the discharge cleaning was performed in H_2 except for a final brief glow discharge in D_2 to facilitate the changeover to D_2 fueled high power discharges. Measurements of the time dependence of hydrogen isotopic exchange, and preliminary measurements of the retained deuterium in the limiter tiles are discussed.

2. EXPERIMENTAL

The experimental details of the glow discharge cleaning (GDC) and pulse discharge cleaning (PDC) schemes used in TFTR have been described previously [1]. Table 1 gives a brief summary of the important GDC and PDC parameters. A variety of measurement techniques was employed to monitor and assess the effectiveness of the vessel conditioning. Residual gas analysis, using one of two differentially pumped quadrupole mass spectrometer systems, was the primary diagnostic measurement. A description of the TFTR Residual Gas Analyzers (RGA) and the calibration procedures have been published previously [6].

For plasma impurity measurement several standard diagnostic techniques were used. Impurity line emission was monitored at visible, VUV, and soft X-ray wavelengths. The effective charge (Z_{eff}) of the plasma could be calculated from three different measurements: (1) enhancement of the visible bremsstrahlung; (2) enhancement of the continuum and the intensities of K_α lines in the X-ray region; and (3) from the plasma resistivity. For the hydrogen isotope exchange measurements both RGA and H_α/D_α emission intensity ratio measurements were made.

3. RESULTS

3.1 Vessel Bakeout and Discharge Cleaning

Following the summer 1983 installation period, the TFTR vacuum vessel was pumped down with the turbo-pump based torus vacuum pumping system (TVPS) [7] and leak-checked. Rate-of-rise measurements showed that the initial vessel outgassing was dominated by H_2O ($Q_{H_2O} \approx 10^{-2}$ torr-ℓ/s) and the total air in-leakage rate was $Q_{N_2} \approx 10^{-5}$ torr-ℓ/s. In October 1983 the torus bakeout system was activated to heat the torus to 120°C for a three-week period of vessel conditioning. Figure 1 shows the time dependence of the partial pressure of H_2O in the torus as a function of the average torus temperature during the conditioning period. While the vessel was hot, 15 hours of GDC and 53 hours of PDC (~ 25,000 pulses) were applied to the vessel in discontinuous periods as indicated by the cross-hatched areas in Fig. 1.

Figure 2 shows the time-dependence of the predominant residual gases (H_2O, CH_4, and CO/C_2H_4) produced during the GDC. The mass 16 (CH_4) and mass 28 (CO/C_2H_4) peaks show an approximate 1/t decrease with discharge time, similar to the dependence observed during the previous GDC runs performed with the vessel at room temperature [1]. In contrast, the partial pressure of H_2O shows a decrease with time that is much faster than 1/t, whereas in the previous GDC runs at ambient temperatures the H_2O dependence roughly followed the other residual gases. The observed increased efficiency for H_2O removed at moderate wall temperatures is consistent with laboratory measurements of hydrogen glow discharge cleaning [8].

It should be noted that the measurements of Fig. 2 probably underestimate the H_2O production within the torus because the RGA samples the residual gases through the large TVPS pumping ducts which were not heated during this conditioning period. Some of the problems of sampling H_2O with temperature gradients occurring across the intervening piping have been discussed by Waelbroeck et al. [8]. (The TFTR Bakeout System is expected to be fully commissioned in May, 1984, affording the capability of bakeout of the entire vacuum vessel including the TVPS ducts, and many of the diagnostic appendages.)

After the relatively brief exposure of the torus to GDC, PDC was applied in discontinuous periods of 4-8 hours. Figure 3 shows the time dependence of the residual gas production during the entire 53-hour PDC exposure in October 1983. During the first 50 hours of PDC the partial pressure of H_2O had dropped from 9×10^{-6} to 6×10^{-7} Torr; CO dropped from 2×10^{-6} to 4×10^{-7} Torr; and CH_4 dropped slightly from 9×10^{-7} to 6×10^{-7} Torr. After 50 hours of PDC, the vessel heating system was turned off and by the time the vessel had cooled from 120 to 56°C, the partial pressures of CO and H_2O during PDC had fallen an additional factor of 4-6 to $\sim 9 \times 10^{-8}$, and CH_4 had fallen a factor of 2 to 3×10^{-7}.

No additional discharge cleaning was performed during October 1983 after the vessel heating system was turned off except for a brief GDC period to prepare the vessel for operating high power discharges in D_2 (see Sec. 3.3). High power plasma operation resumed in November 1983 and continued to the end of the operations period in January 1984. Early in January 1984, an additional 7 hours of PDC (in D_2) was performed with the vessel at 80°C to see if there had been any significant redeposition of discharge-accessible carbon or oxygen during the intervening interval. The residual gas production for this PDC period (Run 3), which was predominantly the deuterated hydrocarbons CD_4 and C_2D_4, is also plotted in Fig. 3. (The C_2D_2 derivative peak of C_2D_4 is plotted to separate this gas from CO.) Because of the added complication of deciphering cracking patterns with deuterated gases, only an upper limit for the oxygen containing residual gases (CO and H_2O) could be determined. However, this upper limit ($< 5 \times 10^{-8}$ Torr) is a relatively insignificant level of PDC production.

The effect of the vessel bakeout and discharge cleaning on the background residual gas spectra are shown in Fig. 4. As noted above, the dominant residual gas before any vessel conditioning was H_2O, and the partial pressure was $\sim 10^{-6}$ Torr with just the TVPS pumping the torus. After the bakeout and discharge cleaning Fig. 4 shows that the partial pressures of all impurity gases at masses 16, 18, 27, and 44 have been reduced to the 10^{-9}–10^{-8} Torr range. Mass 28 appears less affected by the conditioning but instead reflects the appearance of a significant leak, $\sim 10^{-4}$ Torr ℓ/s, in one of the turbo-pump isolation valves. Figure 4 also shows the subsequent reduction in residual gas levels obtained after activation of six ZrAl surface pumping panels with a net speed of ~ 120 kℓ/s for D_2. The activated pumping panels increased the torus pumping speed by more than an order of magnitude and lowered the active residual gas partial pressures to the 10^{-10}–10^{-9} Torr range. More details of the initial operation of the surface pumping panels are given in Ref. (4).

3.2 Plasma Impurity Measurements

Figure 5 summarizes Z_{eff} measurements that were obtained from a series of high power (I_p = 0.6-1.4 MA) deuterium plasma discharges in primary contact with the moveable limiter [5]. The Z_{eff} values that are shown in Fig. 5 are derived from three separate measurements: (1) the enhancement of the continuum and the intensities of K_α lines in the X-ray region; (2) the enhancement of the visible bremsstrahlung; and (3) the plasma resistivity assuming a neoclassical or Spitzer model and using measured values of the electron temperature and surface voltage as inputs. The estimated uncertainty for the Z_{eff} determination from X-rays is ± 30% and from the visible measurement, ± 20%.

The trend of the data in Fig. 5 shows the value of Z_{eff} decreasing with density and increasing with plasma current. At the high density limit for each value of current, there appear to be no severe impurity problems with Z_{eff} values in the range of 2-3. From the soft X-ray measurements the contribution to Z_{eff} of the primary metallic impurity observed in the discharge, Ti, is $\lesssim$ 0.1 at high densities ($n_e \simeq 3 \times 10^{13}$ cm^{-3}), with concentrations (n_{Ti}/n_e) determined to be $< 10^{-4}$. Other vacuum vessel metals (Cr, Fe, and Ni) are observed but at concentrations considerably smaller than Ti (except for the special case of plasma operation with contact on the Inconel bellows cover plates, where Ni replaces Ti as the primary metallic impurity [4]). The remaining contribution to the value of ($Z_{eff} - n_p/n_e$) is a combination of oxygen and carbon based on a qualitative evaluation of the VUV spectra.

The primary contribution to the increasing value of Z_{eff} with decreasing density is due to Ti which increases to concentrations of nearly $n_i/n_e \sim 1\%$ at densities of $n_e \simeq 1 \times 10^{13}$ cm^{-3}. The observed density dependence of the titanium concentration is qualitatively consistent with ion sputtering of the limiter coating being the source of impurity input to the plasma [9]. This problem is discussed in more detail in the companion paper by Cecchi et al. [4].

3.3 Hydrogen Isotope Exchange

Careful control of the hydrogen isotope retention and exchange in first-wall components is important for the planned D-T experiments in TFTR [10] because of the limited on-site tritium inventory (50 kCi). During the pretritium phase of operations, we are taking advantage of the opportunity afforded by H to D (or vice versa) changeover experiments to study the exchange process. We report on our initial attempts to accelerate the changeover process by exposing the torus to a short glow discharge in the new isotope previous to plasma operation, and our observations of the isotopic ratios during the OH optimization operations period.

At the end of the plasma start-up phase of TFTR operations in June 1983, several days of deuterium operation were performed. Preceding the high power plasma experiments, the vessel was subjected to a 115-minute glow discharge in D_2 (with the vessel at 25°C) to accelerate the isotopic exchange in first-wall components. Because of the short run period, only a few isotopic ratio measurements were made which showed the remaining H concentration (H/H + D) to be in the range of 20-30%.

Following shutdown of the device in July 1983, the vessel was exposed to 90 minutes of glow discharge in H_2 (with the vessel temperature at 100°C) to exchange the implanted D_2 to facilitate subsequent leak checking with He. This treatment was found to lower the D_2 outgassing rate by a factor of five.

A similar glow discharge treatment was used in November 1983, following

PDC, to prepare the vessel for high power plasma operation with D_2. In all three glow discharge exchange experiments, the exchange rate was rapid, as measured by the disappearance of concentration of HD in the discharge. The ratio of HD to D_2 (or H_2) decreased to less than 1% in less than 10 minutes of discharge time at ambient temperatures, and the same decrement occurred in less than two minutes with the vessel elevated to 100°C.

During the December 1983 to January 1984 high power plasma operations, the evolution of the H/D isotopic ratio could be monitored by residual gas analysis and H_α/D_α light emission. Figure 6 shows the evolution of the ratio H/H + D as measured by both techniques during the run. Given the relatively long time (~ 500 discharges) necessary for the H-concentration to decay to less than 10%, it is evident that the glow discharge treatment is ineffective in removing the minority species from near-surface areas on first-wall components which are accessible to exchange during high power discharges. The obvious source for this lag in exchange time is the moveable limiter, since both the TiC coating and graphite substrate have high H-retention levels and small diffusivities compared to stainless steel [11,12]. A preliminary analysis of retained D_2 in limiter tiles that were removed from the vessel after this operations period shows retention levels of $1-2 \times 10^{17}$ D atoms cm^{-2} [13]. A qualitatively similar, although less pronounced, increase in isotopic exchange time has been observed in the comparison of Inconel and graphite limiters on the TFR device [14].

4. CONCLUSIONS

The combination of preconditioning of the graphite limiters, and insitu conditioning of all first-wall components with H_2 glow discharge cleaning and pulse discharge cleaning at moderate vessel temperatures (~ 120°C), has enabled extended performance of TFTR ohmically heated plasmas. Values of Z_{eff} (2-3) have been obtained at the observed density limits ($n_e < 3.2 \times 10^{13}$ cm^{-3}) for the achieved plasma currents (1.4 MA) and toroidal fields (2.7 T) for discharges run on the moveable limiter. No significant metallic impurity problems are observed at the higher densities studied: the dominant metallic impurity, Ti, contributes less than 0.1 to Z_{eff} at high densities.

Hydrogen isotope exchange during high power plasmas appears to be dominated by H-retention and exchange processes in the graphite limiter tiles. The concentration of the minority species (H) in the plasma did not decay to levels of 10% or less until 500 discharges in the new isotope (D) had occurred. Preconditioning the vessel with a glow discharge in the new isotope was evidently not effective in accelerating the exchange process in the present experiments. Possible extensions of these glow discharge exchange experiments in order to increase the exchange ratios are: (1) biasing of the limiter components during GDC to accelerate glow discharge ions to deeper regions of the graphite; and (2) specific bakeout of the limiter during the glow discharge process to enhance the bulk diffusivities.

ACKNOWLEDGMENTS

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DISCLAIMER

TABLE 1: DISCHARGE CLEANING PARAMETERS

1A. Glow Discharge Cleaning (GDC)

H_2 pressure	5-6 mTorr
Discharge current	15 A
Discharge voltage	390 V (dc)

1B. Pulse Discharge Cleaning (PDC)

	High Current Mode	Low Current Mode
H_2 pressure	(1-2) x 10^{-5} Torr	(1-2) x 10^{-4} Torr
Discharge current	100-200 kA	20-40 kA
Discharge duration	40-100 ms	$\leqslant$ 50 ms
Repetition rate	1/6-1/8 s^{-1}	1/6-1/8 s^{-1}
Toroidal field	4 kG	4 kG

FIGURE CAPTIONS

Fig. 1 Plot of the partial pressure of H_2O and the average vessel temperature during the conditioning period (Oct. 1983) described in this paper. The cross-hatched areas indicate periods of glow-discharge cleaning (GDC) and pulse discharge cleaning (PDC).

Fig. 2 Time dependence of the partial pressures of the predominant residual gases produced during the glow discharge cleaning run in Oct. 1983. At point A the GDC run was interrupted for a brief (less than one day) period for a repair inside the vacuum vessel.

Fig. 3 Time dependence of the average partial pressures of the predominant residual gases produced by pulse discharge cleaning (low current mode). Two cleaning periods are shown. Run 2 occurred during the initial conditioning period of the vessel during Oct. 1983, and Run 3 was a brief period of conditioning in Jan. 1984 to check the cleanliness of the vessel. Run 2 was performed in H_2 with the vessel at 120°C except for the last five hours where the vessel temperature had cooled to 56°C. Run 3 was performed in D_2 with the vessel at 80°C. Only hydrocarbon production was observed in this latter run; an upper limit for production of oxygen containing residual gases (H_2O, CO) is noted.

Fig. 4 TFTR base residual gas spectra before vessel conditioning, after bakeout and discharge cleaning, and after activation of the ZrAl surface pumping panels.

Fig. 5 Measurements of the effective charge (Z_{eff}) of high power plasma discharges by various methods, as a function of the line-averaged plasma density ($\bar{n}_e$).

Fig. 6 Spectroscopic and residual gas measurements of the hydrogen concentration (H/H + D) in high power discharges over the period Dec. 1983–Jan. 1984.

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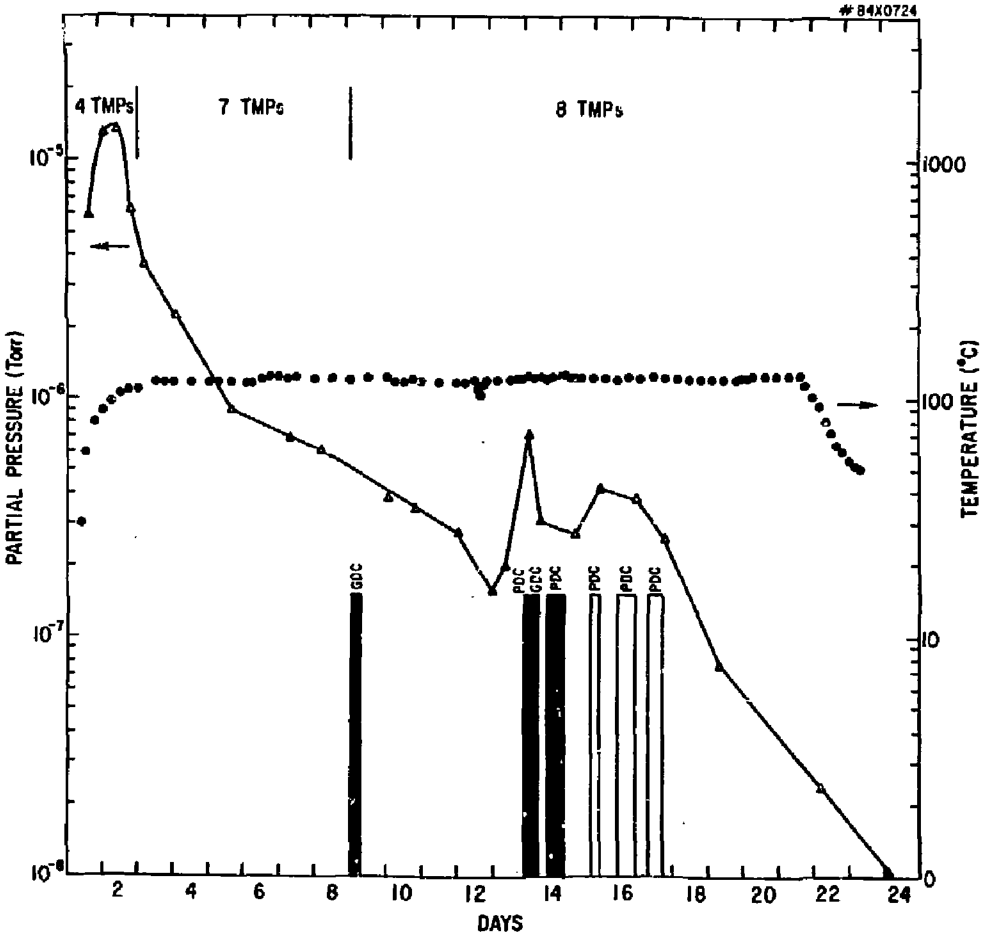


84X0724
4 TMPs
7 TMPs
8 TMPs
PARTIAL PRESSURE (Torr)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
TEMPERATURE (°C)
1000
100
10
0
GDC
PDC
GDC
PDC
PDC
PDC
PDC
2
4
6
8
10
12
14
16
18
20
22
24
DAYS

FIGURE 1

#84X0514

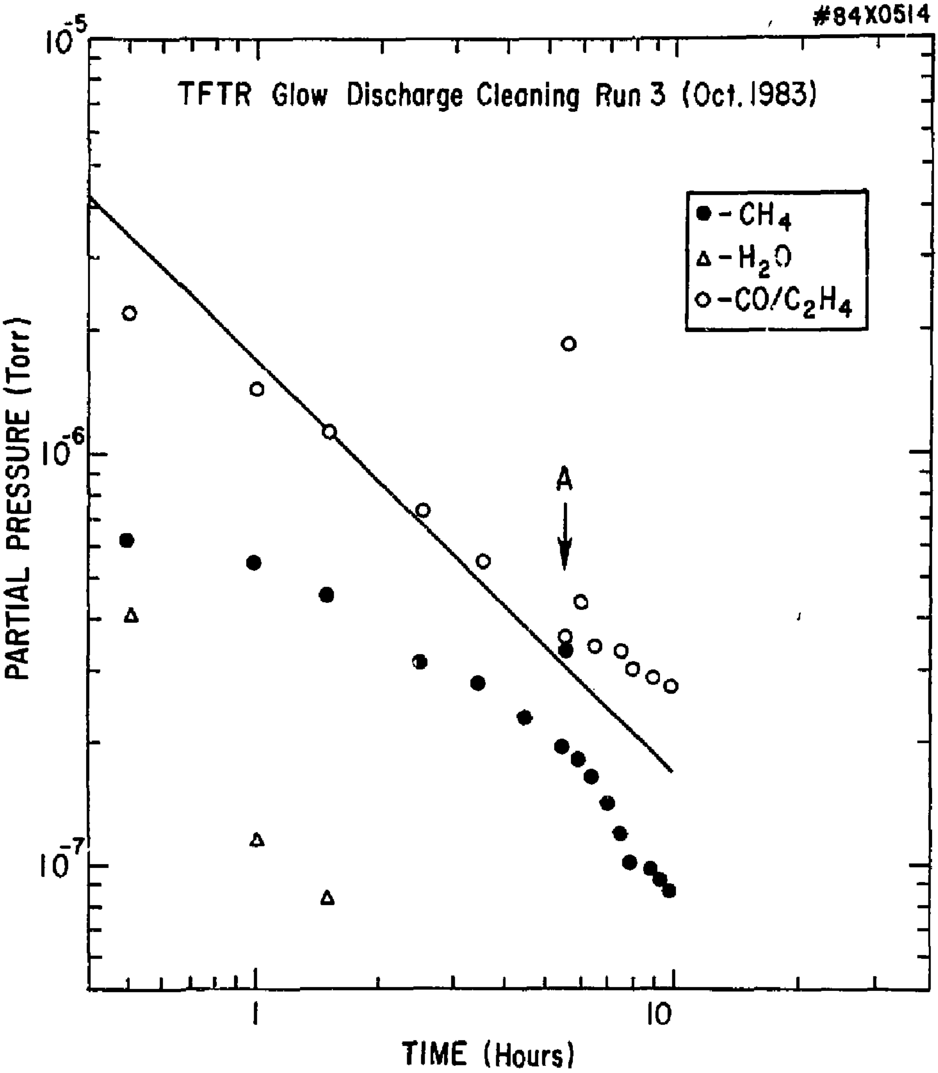


FIGURE 2

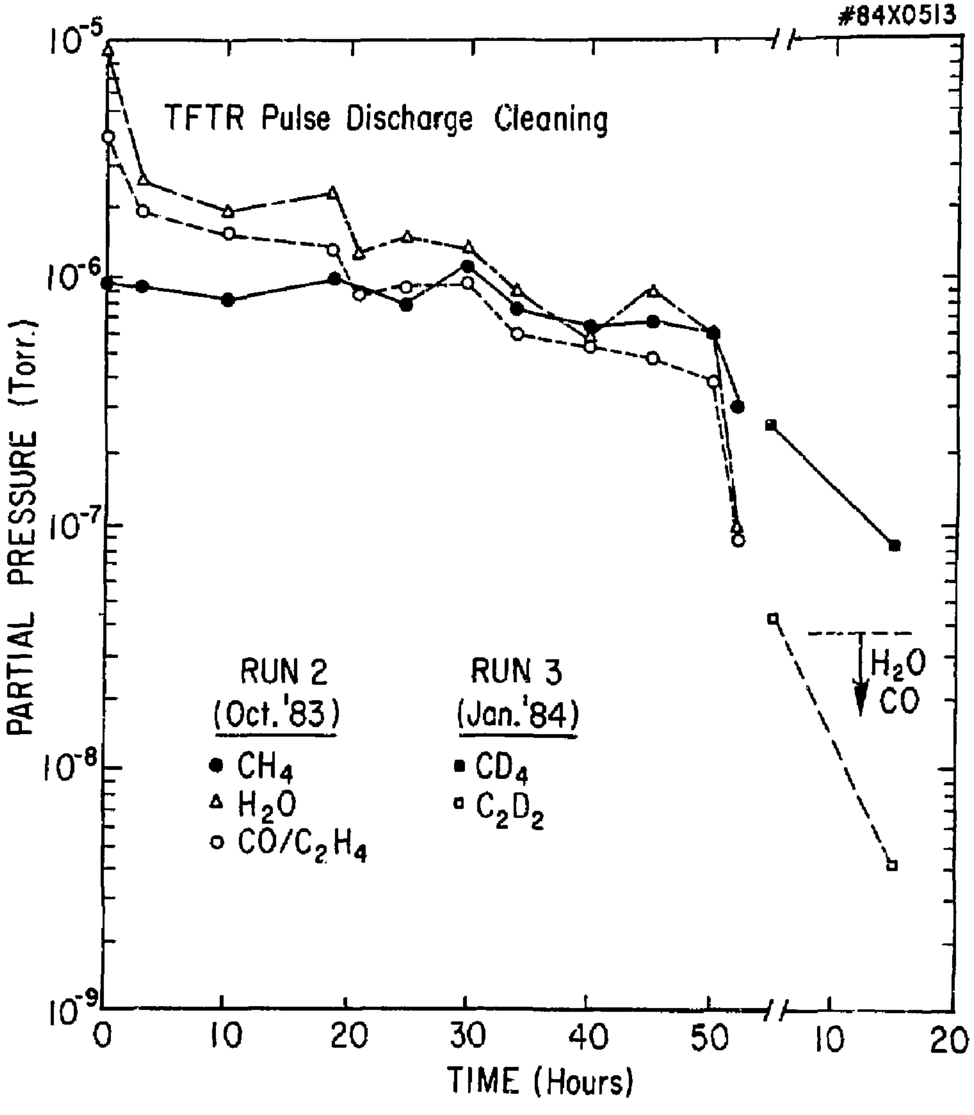

#84X0513
TFTR Pulse Discharge Cleaning
PARTIAL PRESSURE (Torr.)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
RUN 2
(Oct.'83)
● CH_4
△ H_2O
○ CO/C_2H_4
RUN 3
(Jan.'84)
■ CD_4
□ C_2D_2
H_2O
CO
0
10
20
30
40
50
10
20
TIME (Hours)

FIGURE 3

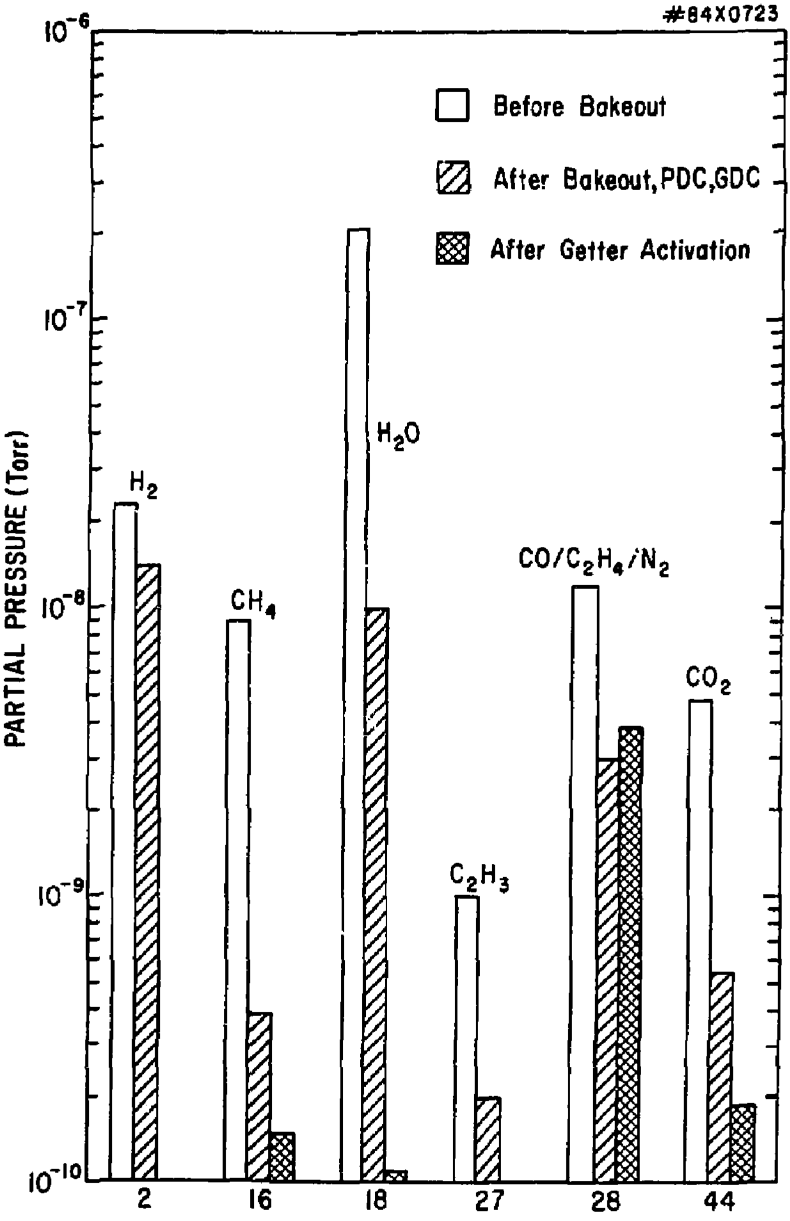

#84X0723
Before Bakeout
After Bakeout, PDC, GDC
After Getter Activation
PARTIAL PRESSURE (Torr)
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
H_2
CH_4
H_2O
C_2H_3
$CO/C_2H_4/N_2$
CO_2
2
16
18
27
28
44
ATOMIC MASS UNITS

FIGURE 4

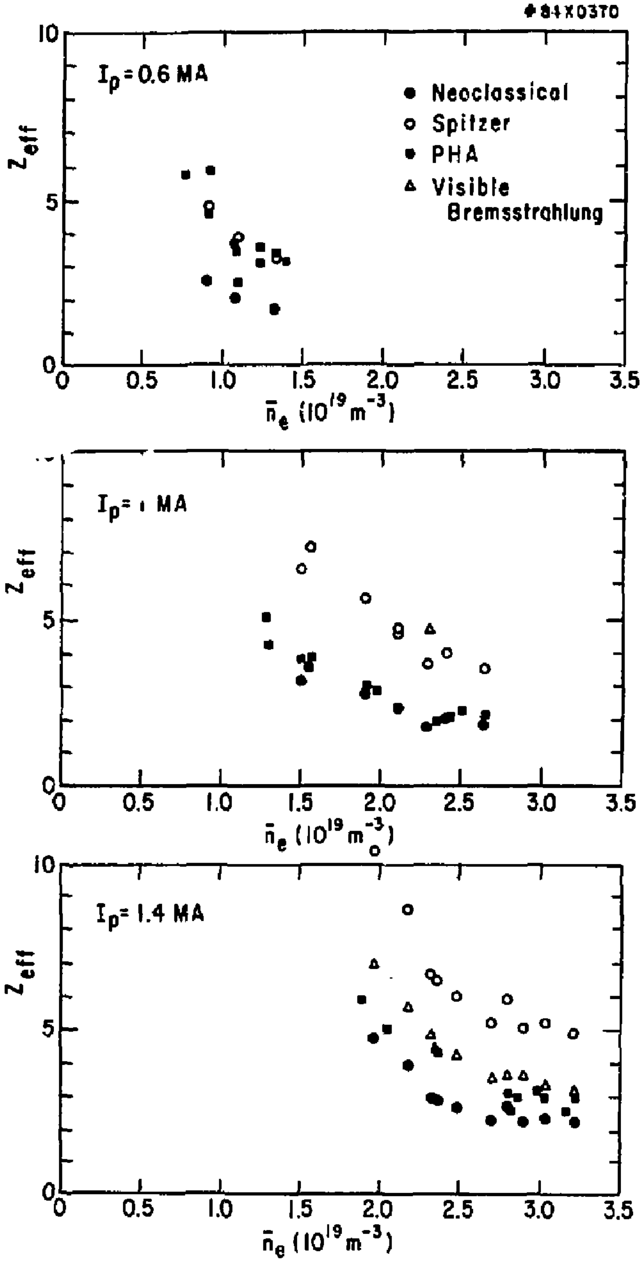
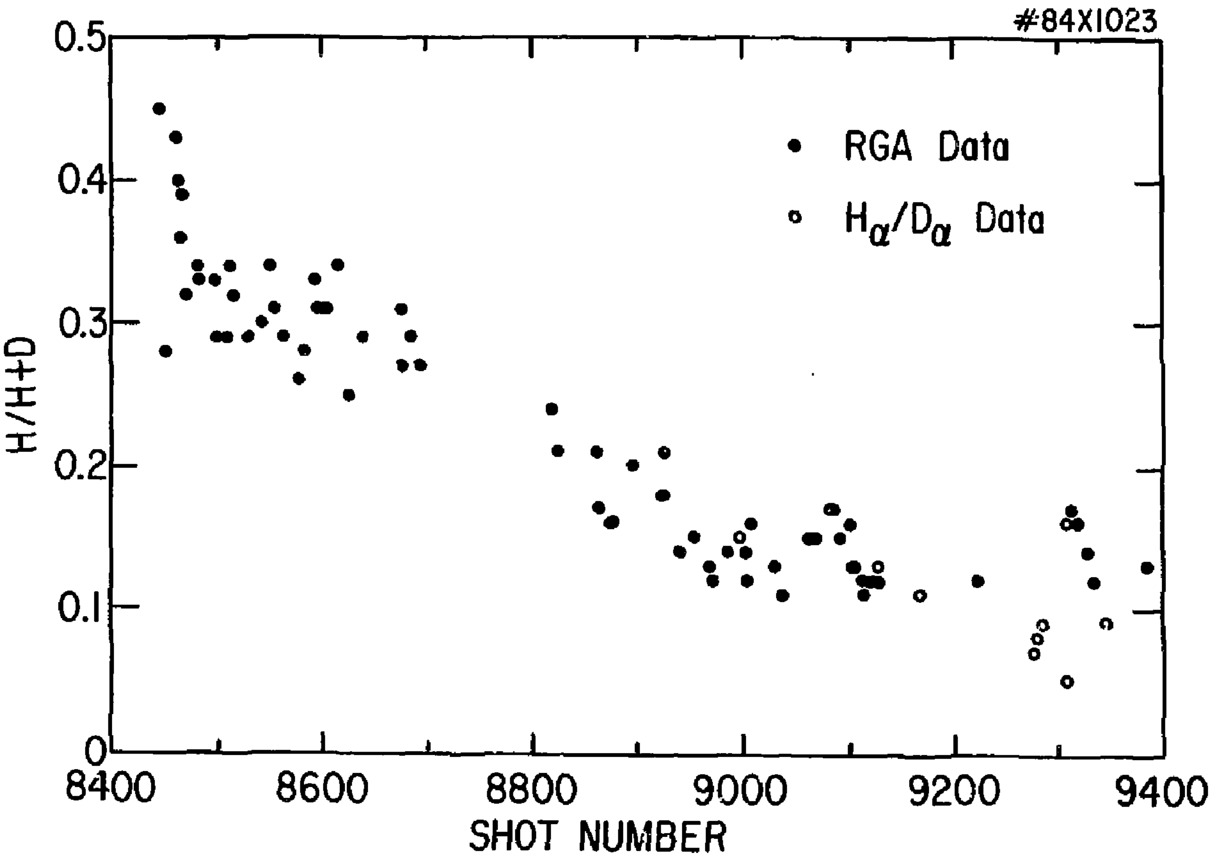

#84X0370
I_p = 0.6 MA
● Neoclassical
○ Spitzer
■ PHA
△ Visible Bremsstrahlung
Z_{eff}
10
5
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
$\bar{n}_e$ (10^{19} m^{-3})
I_p = 1 MA
Z_{eff}
5
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
$\bar{n}_e$ (10^{19} m^{-3})
I_p = 1.4 MA
Z_{eff}
10
5
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
$\bar{n}_e$ (10^{19} m^{-3})

FIGURE 5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H_α/D_α Data
H/H+D
0.5
0.4
0.3
0.2
0.1
0
8400
8600
8800
9000
9200
9400
SHOT NUMBER

FIGURE 6

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