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MASTER

NOTICE

Residual Gas Analysis in ISX-A*

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Abstract

A computer-controlled mass analyzer was utilized to observe the residual gases in the ISX-A tokamak. This residual gas analysis (RGA) system enabled time resolved measurements of preselected m/e peak heights to be made during and after tokamak discharges. Routine mass scans were also made and displayed in the form of semilogarithmic plots of partial pressure (torr) versus m/e. Wall conditioning of the stainless steel torus consisted of hydrogen discharge cleaning and titanium gettering, which ultimately produced gage pressures on the order of 10^{-8} and 10^{-9} torr, respectively. The dominant plasma impurities, carbon and oxygen, were observed by the RGA as light hydrocarbons and water vapor. Entrapment of deuterium by the walls was investigated by monitoring the residual D_2 content after the working gas was changed to H_2. The effective nuclear charge (Z_{eff}) was found to be proportional to the residual contaminants measured by the RGA immediately following a discharge.

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INTRODUCTION

The Impurities Study Experiment (ISX-A),[1] a tokamak plasma generator, was dedicated to the study of plasma impurities and plasma-wall interactions. Typical plasma parameters are shown in Table I. Outstanding features of the plasma include high density (n_e), high central ion temperature (T_i), low effective nuclear charge (Z_{eff}), and long confinement time (τ_E) at low magnetic field (B_T).[2]

The toroidal vacuum chamber, with a major radius of 92 cm and a minor radius of 26 cm, was constructed of 304 stainless steel. Metal seals were utilized throughout with the exception of Viton gate valve seals which were preconditioned by a vacuum bake. A 500 liters/sec turbomolecular pump provided a conductance-limited pumping speed of 200 liters/sec.

A quadrupole mass analyzer was connected to the torus as shown in Fig. 1. When operated at an elevated temperature to reduce adsorption, the gage pressure was 5×10^{-9} torr. A computer was interfaced to the system for data acquisition and remote control. After the RGA was initially calibrated with various gases, the output was scaled, converted to partial pressures (torr), and plotted on a semilogarithmic scale.

RESULTS AND DISCUSSION

A history of the vacuum conditions from initial pump-down through preliminary tokamak discharges is shown in Fig. 2. These data were normalized to a base pressure with a high hydrogen-to-contaminant ratio, since the containment levels were observed to increase in proportion to an increase in the hydrogen. Hydrogen discharge cleaning, which consisted of 0.5-msec

pulses occurring at a rate of 120/sec in a toroidal field of 200 G, was utilized extensively during this period. Prior to the first tokamak discharges, the levels of the major gaseous impurities decreased by a factor of approximately three, but following these initial discharges the partial pressure of mass 18 (the dominant impurity during this period) decreased by an order of magnitude. Overnight discharge cleaning was continued for 4-1/2 months and produced base pressures as low as 8×10^{-8} torr. Titanium gettering was then employed and discharge cleaning was discontinued. The titanium was sublimed onto the upper half of the torus during hour-long depositions and short (10-min.) depositions, as necessary, between tokamak discharges. This technique reduced the total pressure by an order of magnitude, due mostly to the much higher pumping speed of the titanium surface for hydrogen.

A relatively large partial pressure of hydrogen was always observed, particularly after discharge cleaning. This was due to the decreased pumping speed of the turbomolecular pump for hydrogen and to significant hydrogen entrapment by the wall. After a changeover from deuterium to hydrogen, some 400 tokamak discharges occurred before the partial pressure of deuterium decreased to near zero.

The principal contaminants in the plasma, carbon and oxygen,[3] appeared primarily as CH_4(16), CO(28), and H_2O(18) residual gases. Figure 3 illustrates typical behavior of these gases during a series of tokamak discharges without titanium gettering. The torus was prefilled with hydrogen to a pressure of 1×10^{-4} torr and held at that pressure throughout the series. Before the first tokamak discharge, these contaminants increased by a factor of $\sim$ 50 since, as previously noted, contaminant partial pressures were proportional to the hydrogen pressure. Equilibrium was achieved after three

discharges, and the residual gases remained essentially constant during the remainder of the series.

A similar series with titanium gettering is shown in Fig. 4. After overnight gettering the impurity levels were similar to those shown in Fig. 3 after discharge cleaning. In this case, however, the torus was not prefilled with hydrogen so that saturation of the titanium surface could be avoided. Instead, hydrogen was admitted by puffing immediately before and during discharges. Partial pressures of the impurity gases began to rise significantly after about 15 discharges but remained at least an order of magnitude below those in Fig. 3 after an equal number of discharges.

Time-resolved measurements describing impurity behavior immediately following a tokamak discharge are shown in Fig. 5. The partial pressure of each containment gas increased after the discharge, reaching a maximum two to three seconds later, and then decreased in relation to the pumping speed of the system for that species.

Z_{eff} is a measure of the total plasma impurity content. For a relatively "clean" hydrogen plasma with a single impurity species, Z_{eff} may be written as:

$$Z_{eff} \approx 1 + \frac{N_{IP}}{N_{HP}} \quad Z_I^2 \qquad (1)$$

where N_{IP} is the number of plasma impurity ions with charge Z_I and N_{HP} is the number of plasma hydrogen ions. Since the major plasma contaminants were carbon and oxygen with $\bar{Z} \approx 7.5$, we have explored the possibility that a relationship exists between Z_{eff} and $\frac{N_I}{N_H} \bar{Z}^2$ (where N_I and N_H are impurity and hydrogen residual gas atoms) computed from RGA scans.[4] Figure 6 shows four such scans taken 15 sec after each of several discharges. The values

of Z_{eff} shown were taken from conductivity measurements coupled with $T_e(r)$ profiles, and Fig. 7 compares these values of Z_{eff} with $\frac{N_I}{N_H}$ from the m/e scans (Fig. 6).

CONCLUSIONS

The major impurities in ISX-A, carbon and oxygen, appeared as light hydrocarbons and water vapor in the residual gas. Hydrogen discharge cleaning and titanium gettering were both beneficial in reducing these impurities in the background gas, although gettering produced lower total pressures because of the higher pumping speed for hydrogen. With the combination of titanium gettering and hydrogen gas puffing, the impurity gases remained more than an order of magnitude below the levels achieved without gettering, and Z_{eff} approached one. However, when operating with a hydrogen prefill, most of the increase in impurities occurred before the first discharge. A "wall effect" which produced increases in the impurity levels with increases in hydrogen partial pressures is indicated. This effect was also observed from routine m/e scans taken after hydrogen discharge cleaning. Because most of the impurities in ISX-A were derived from oxygen and carbon, a relationship between the residual gas and Z_{eff} could be found.

ACKNOWLEDGMENTS

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TABLE I ISX-A PLASMA PARAMETERS

Parameter	Stainless Steel Limiter	Carbon Limiter	Optimum
B (kG)	13.2	13.2	14.8
I_p (kA)	120	116	175
q (a_ℓ)	4	4	2.5
n_e (0) ($10^{13}cm^{-3}$)	5.2	4.8	9
V (V)	1.5	1.5	0.9
T_e (0) (keV)	0.69	0.82	1.5
T_i (0) (keV)	0.42	0.39	0.55
τ_E (msec)	22	20	30
Z_{eff}	1.8	3	1

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[1] R. J. Colchin and T. C. Jernigan, J. Nucl. Mater. 63, 83 (1976).

[2] M. Murakami, et. al., "Plasma Confinement and Impurity Flow Reversal Experiments in the ISX-A Tokamak," to be published in Proc. 7th Int Conf on Plasma Physics and Controlled Nuclear Fusion Research, Innsbruck, Austria, 1978. Paper IAEA-CN-37-N-4.

[3] R. C. Isler, Oak Ridge National Laboratory, Oak Ridge, Tennessee, private communication.

[4] R. J. Colchin, et. al., "Plasma Wall Impurity Experiments in ISX-A," 3rd Int Conf on Plasma Surface Interactions in Controlled Fusion," Culham, England, April 3-7, 1978 (to be published in J. Nucl. Mater.).

FIGURE CAPTIONS

Fig. 1. RGA system. The mass analyzer was opened to the torus through Value A (straight through) or through orifice and Value B, depending on the operating H_2 gas pressure in the torus.

Fig. 2. A history of the vacuum conditions in ISX-A from initial pump-down through the startup phase.

Fig. 3. The behavior of the major gaseous impurities during a series of tokamak discharges with hydrogen prefill and no titanium gettering. The data were taken from mass scans made 15 sec after each discharge indicated.

Fig. 4. The behavior of the major gaseous impurities during a series of tokamak discharges with titanium gettering and hydrogen puffing. The data were taken from mass scans made 15 sec after each discharge indicated.

Fig. 5. Time-resolved behavior of the major gaseous impurities following a tokamak discharge.

Fig. 6. m/e scans taken 15 sec after tokamak discharges. The values of Z_{eff} shown were taken from $T_e(r)$ profiles.

Fig. 7. Z_{eff} (computed from conductivity measurements coupled with $T_e(0)$ scans) vs. $\frac{N_I}{N_H}$ (computed from RGA scans).

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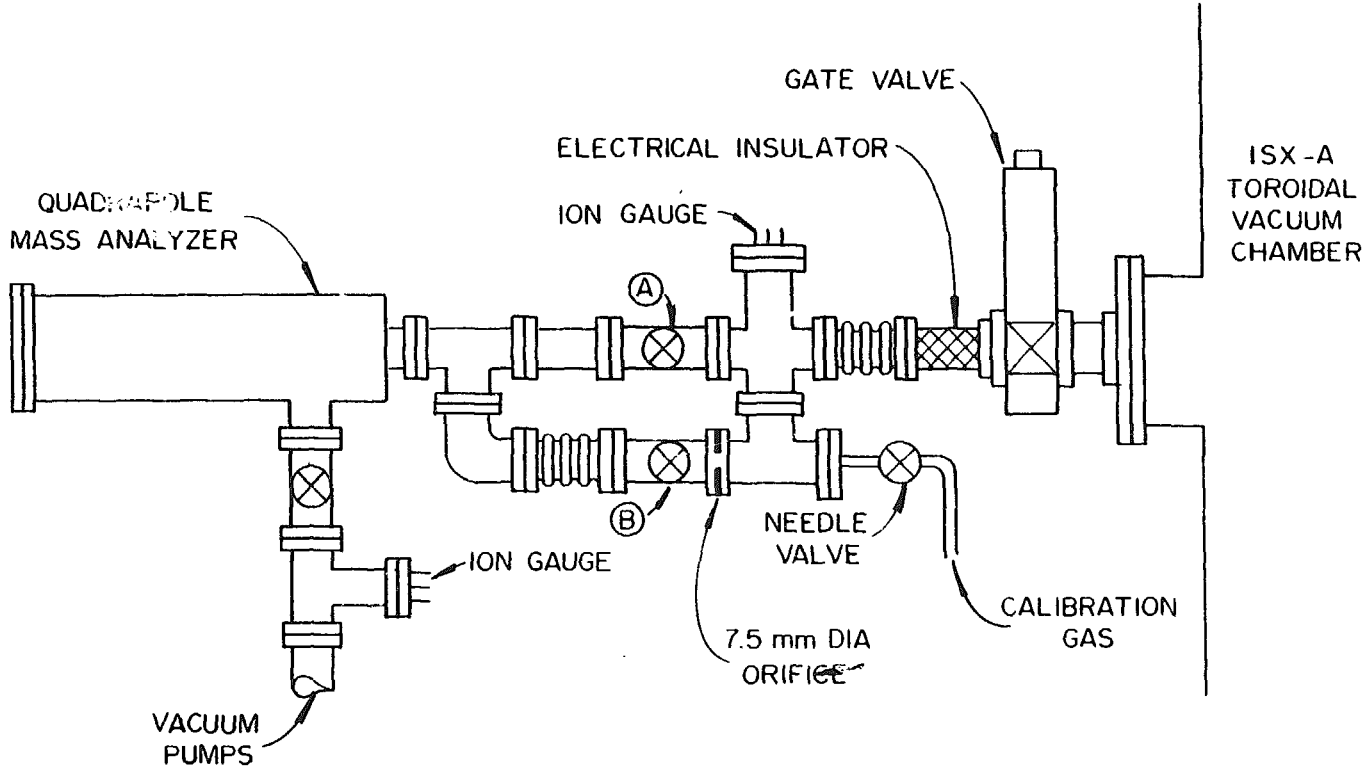
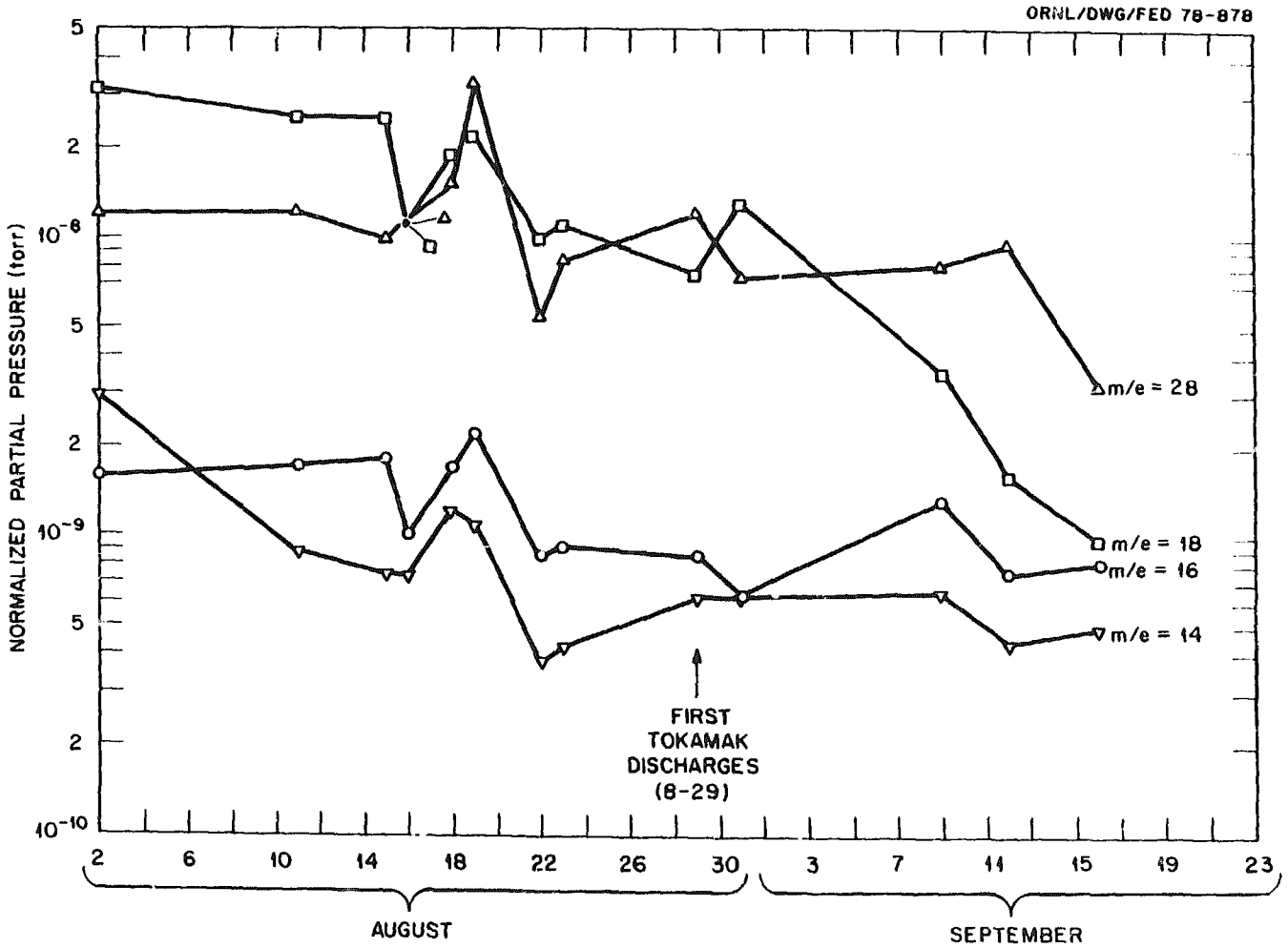
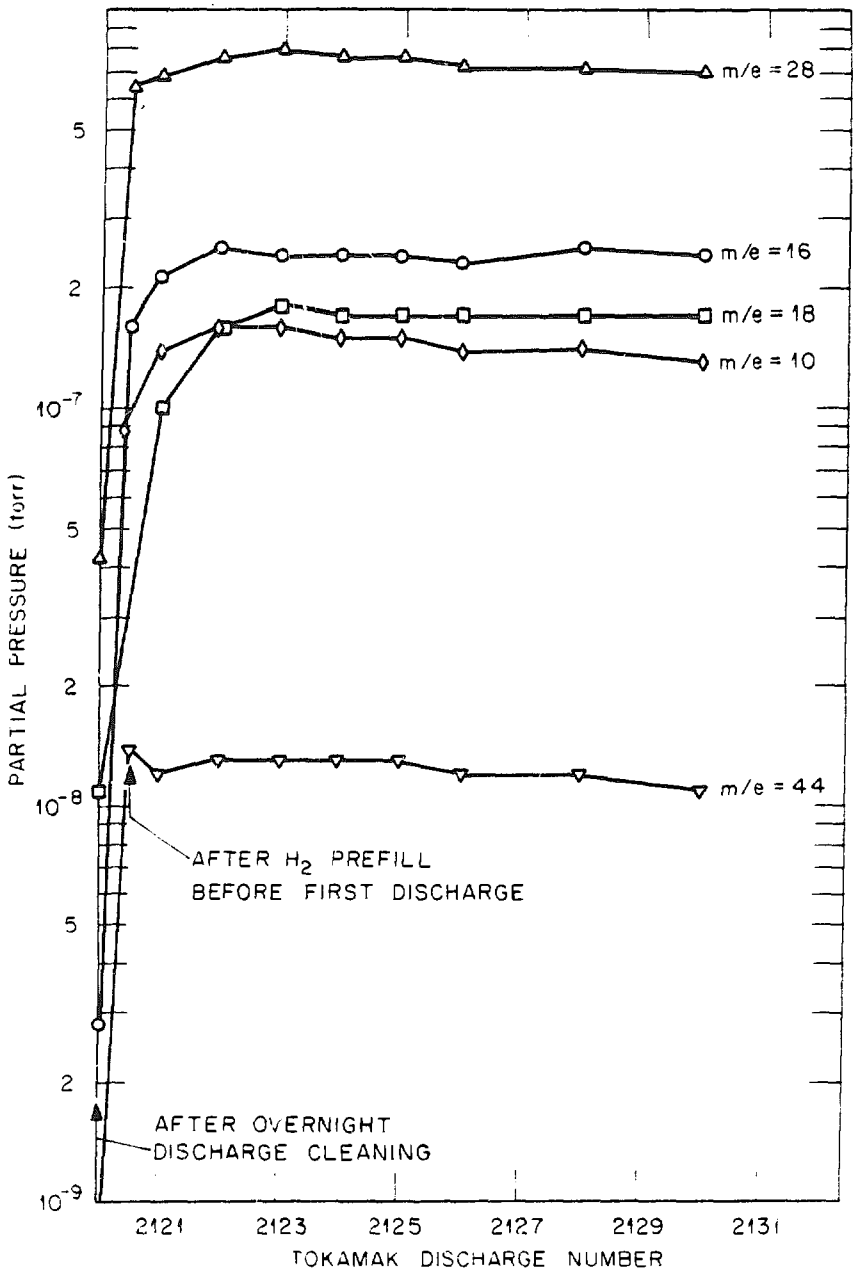
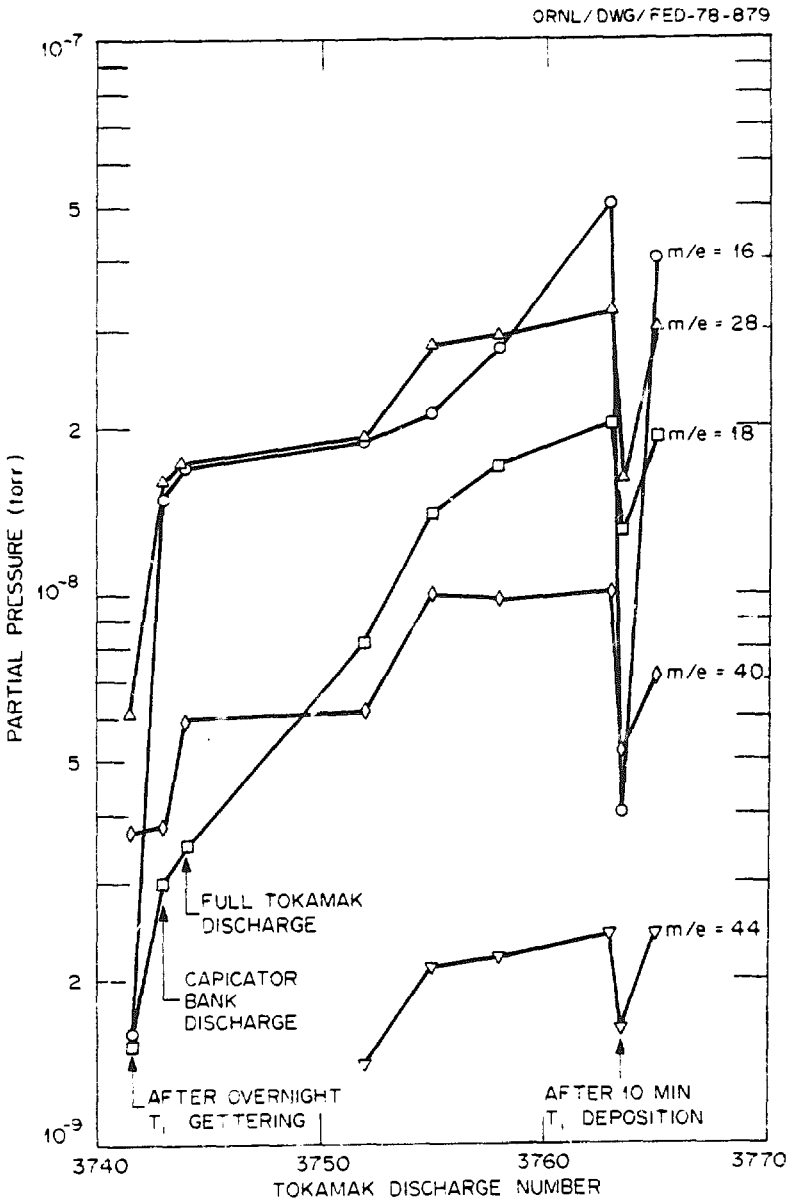


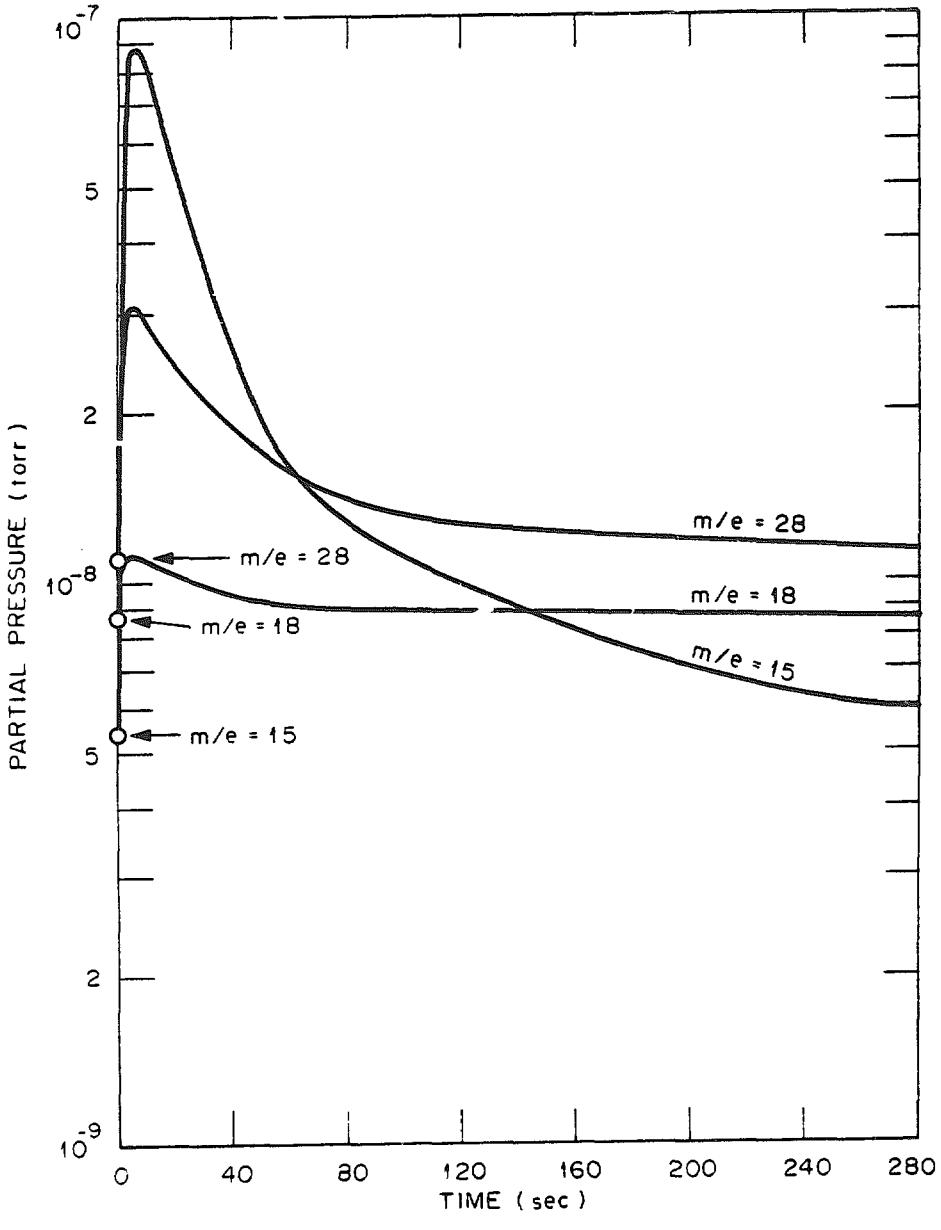

ORNL/DWG/FED 78-878
NORMALIZED PARTIAL PRESSURE (torr)
5
2
10^{-8}
5
2
10^{-9}
5
2
10^{-10}
m/e = 28
m/e = 18
m/e = 16
m/e = 14
FIRST
TOKAMAK
DISCHARGES
(8-29)
2
6
10
14
18
22
26
30
3
7
11
15
19
23
AUGUST
SEPTEMBER

ORNL/DWG/FED 78-877




ORNL/DWG/FED-78-879
PARTIAL PRESSURE (torr)
TOKAMAK DISCHARGE NUMBER
m/e = 16
m/e = 28
m/e = 18
m/e = 40
m/e = 44
FULL TOKAMAK DISCHARGE
CAPICATOR BANK DISCHARGE
AFTER OVERNIGHT T, GETTERING
AFTER 10 MIN T, DEPOSITION

ORNL/DWG/FED-78-924



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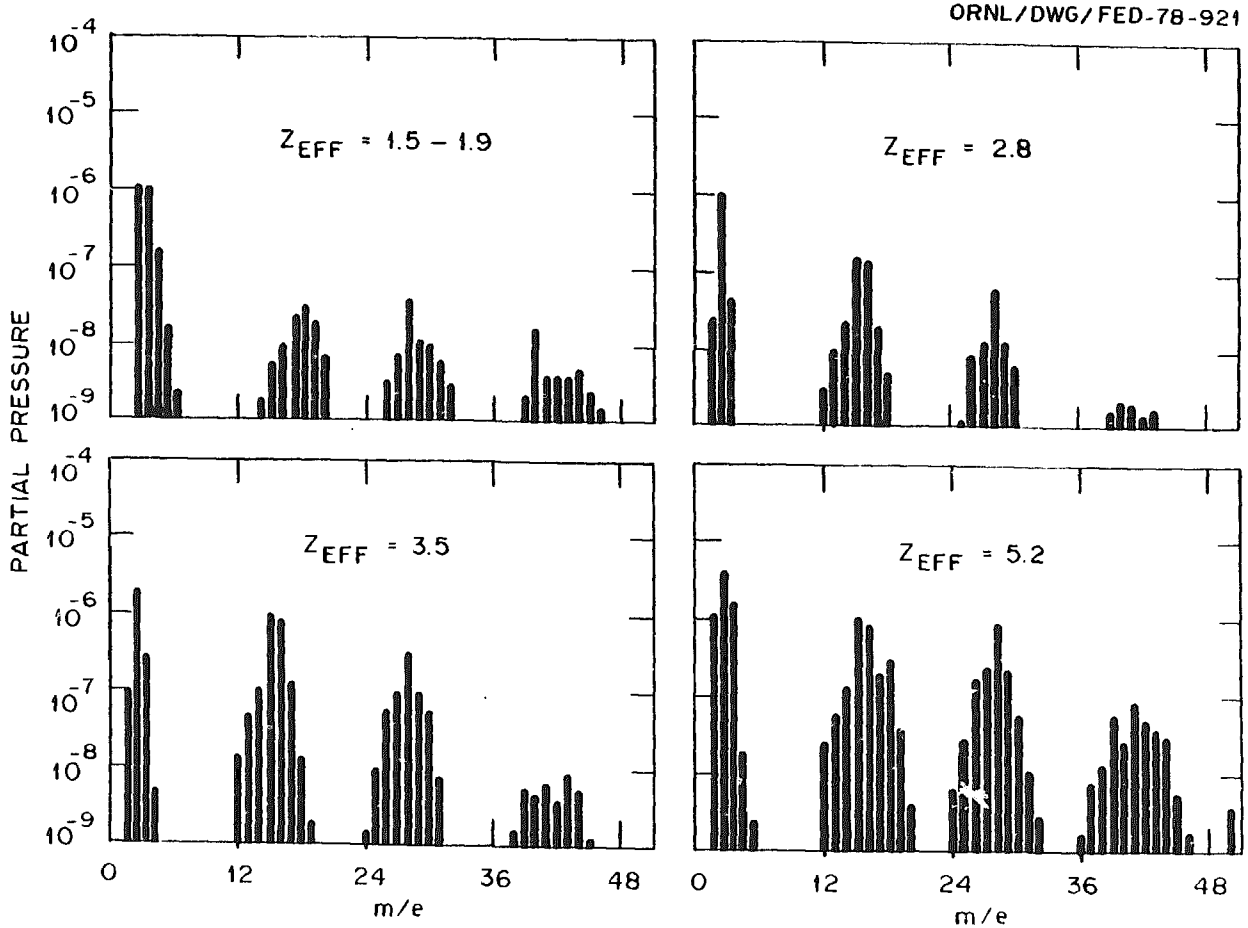

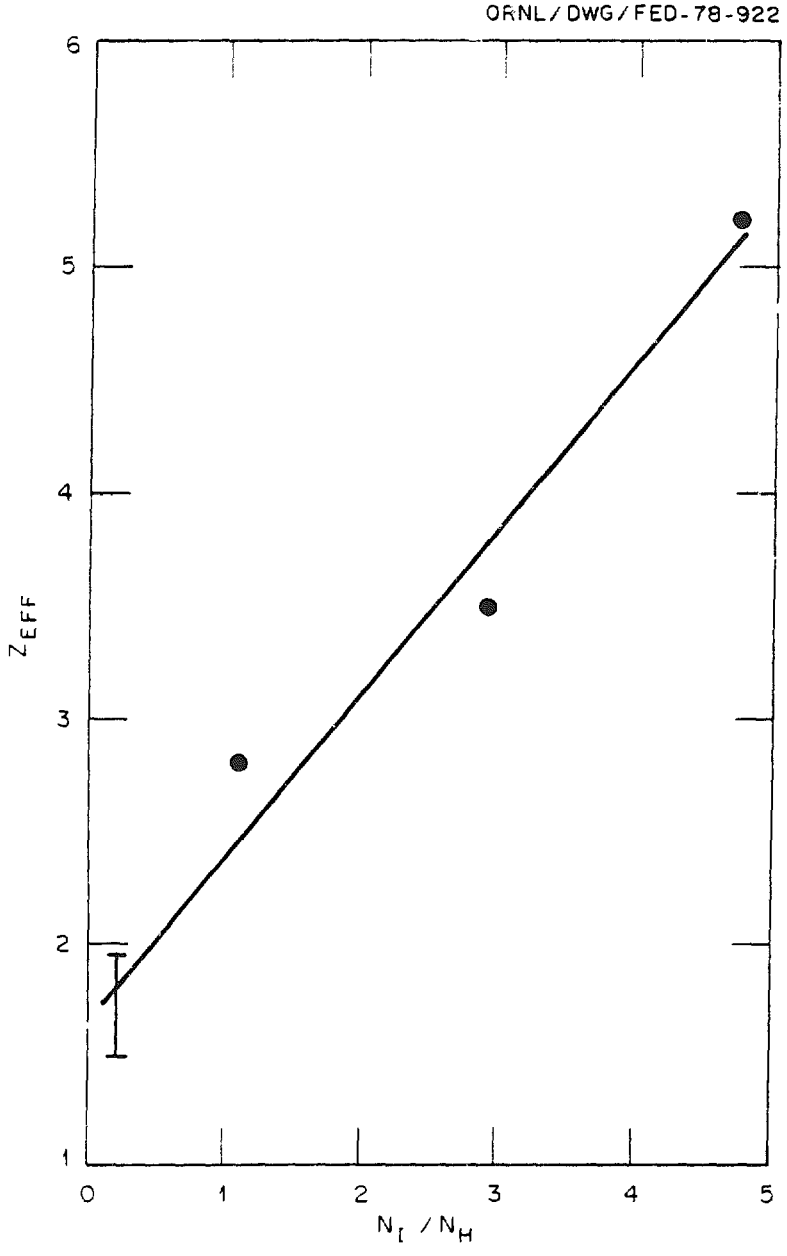
ORNL/DWG/FED-78-922
6
5
4
3
2
1
Z_{EFF}
0
1
2
3
4
5
N_I / N_H