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VACUUM CONDITIONS IN JFT－2

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Vacuum Conditions in JFT-2

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The efficiency of discharge cleaning in the tokamak-type apparatus has been studied. The duration of repeated discharges is longer than the pumping-out time; the discharges of large current are more effective in removing impurities from the surfaces. The discharges in hydrogen gas produce hydrocarbons. Evacuation characteristics of a turbomolecular pump, a bulk getter pump and a sputter ion pump are comparatively investigated.

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JFT－2の真空状態

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トカマク型装置での放電洗浄の効果について報告する。放電の繰り返し時間は排気時間より長いが，不純物を表面から取り去るには大電流放電がより効果的である。水素ガスでの放電では炭化水素が生成されることがわかった。ターボモレキュラーポンプ，バルクゲッターポンプ，スパッターイオンポンプの排気特性の比較を行なった。

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* 東芝

目次なし

1. Introduction

Impurities are serious disadvantage in obtaining high temperature plasma. Especially gases desorbed from surface of a vacuum vessel by bombardment of plasma particles are one of the causes to limit the plasma temperature. This problem can frequently be overcome by conditioning.

The tokamak-type apparatus, JFT-2, has been constructed at the beginning of April in 1972.(1) After adjustments of the apparatus and measurements of magnetic fields, the improvement and conditioning of the vacuum vessel has been performed.(2) In consequence the plasma temperature has reached to 300 eV at the end of 1972.

The conditioning is carried out by running discharges. In the present paper we discuss the efficiency of the discharge cleaning in JFT-2. An analogous experiment has been made in ref.(3), where the repetition time of discharges is shorter than the pumping out time. On the contrary, discharges in JFT-2 are carried out after impurities produced by the previous discharge sufficiently decrease.

2. Vacuum System

The vacuum system is shown in Fig.1. The vacuum vessel consists of 4 liners connected by 3 diagnostic boxes and a evacuating box. The liners are made of stainless steel bellows of 0.6 mm thickness, whose major and minor radii are 900 mm and 300 mm, respectively. The evacuating box has a window of 66×600 mm^2 and is connected to a manifold, through which the vessel is evacuated.

The liners are baked up to 200 °C by the induction heating, and the boxes and the high-vacuum conduit pipes are baked up to 100 °C by oil.

The pumping system consists of turbomolecular pumps (TMP), sputter ion pumps (SIP), bulk getter pumps (BGP), oil rotary pumps, sorption pumps and liquid nitrogen traps, as shown in Fig.1. The SIP is used for the conservation of the apparatus.

The working hydrogen gas purified through the palladium film is continuously introduced into the vessel, whose pressure is adjusted to $10^{-3} \sim 10^{-4}$ Torr by evacuating only with the TMP.

3. Conditioning by Discharge Cleaning

All the elements are cleaned with acetone and the surfaces of the boxes are scraped off with the glass beads spray. The vacuum vessel is evacuated with 3 TMPs. The ultimate pressure of 3.0×10^{-7} Torr and the total outgassing rate of 1.1×10^{-4} Torr·l/sec are obtained after 20 hours baking. About 2000 shots of discharges from the 1900th shot to the 4200th are carried out for the conditioning.

The conditioning discharges are produced under the following condition, the filling pressure of the hydrogen gas P_f is 1.0×10^{-4} Torr, the toroidal magnetic field B_t is 7 kG, the plasma current I_p is $40 \sim 120$ kA and the repetition time of discharges t_r is 1.5 min. In the case of the measurement of impurities, the discharge condition is following, $P_f=1.0 \times 10^{-4}$ Torr, $B_t=10$ kG, $I_p=50 \sim 180$ kA and $t_r=2$ min.

A number of impurities are desorbed and created by particle bombardment during discharges. The ratio of the mass to the charge of impurities(M/e) is measured by the quadrupole-type mass analyzer installed in the manifold. Figure 2 shows all the impurities for M/e from 1 to 50 at the 1920th and the 4174th shots. It is remarkable that hydrocarbons C_mH_n (M/e=12m+n) except for carbon (M/e=12), water (M/e=18) and nitrogen and/or carbon monoxide (M/e=28) appear at the early stage of the conditioning. These hydrocarbons are seemed to be produced from the working gas and the carbon generated from the oils which contaminate the surfaces. Disappearance of the oxgen (M/e=32) at the 4174th shot suggests that most molecles of M/e=28 are carbon monoxides, which is supported by the spectroscopic measurement.

Figure 3 illustrates the time evolution of impurities. The characteristic decreasing rate indicates the pumping speed of 250 l/sec. This contains the evacuation of the TMP and the sorption of the surfaces. Very small difference between M/e=28 peaks before and after discharges at the 4174th shot suggests that the working gas contains the carbon monoxide.

The changes of some impurities before and after discharges are shown in Fig.4. It is noticeable that the methane and its cracking (M/e=16,15) slowly decrease compared with the water and the M/e=28 molecles. The M/e=28 molecles seem to have two components. One is the carbon monoxide which is remained at the end of the conditioning. Another is the nitrogen gas which is absorbed in the surfaces at the beginning of the conditioning and is removed by the conditioning.

The electron temperature of the plasma increases rapidly with the decrease of impurities. At the beginning of the conditioning the temperature is only 6 eV, but at the 4200th shot it reaches to 300 eV, as shown in Fig.5.

4. Evacuation Characteristics

JFT-2 has three types of pumps (TMP, BGP and SIP) as previously mentioned. The evacuation characteristics of these pumps and their combinations are compared. This experiment has been carried out under the following conditions. After 100 hours baking and 2000 shots of discharges the ultimate pressure and the total outgassing rate are 8.5×10^{-6} Torr and 1.2×10^{-3} Torr·l/sec, respectively. Moreover the surfaces of the vessel have been contaminated by oils. The speeds of TMP,SIP and BGP are 260, 500 and 500 l/sec, respectively.

Figure 6 shows representative impurities with and without discharges after isolating the pumps. The rise of M/e=28,14 peaks suggests the air leak. Impurities desorbed from the surfaces by the bombardment of plasma particles don't decrease, which seems to indicate the contamination of the surfaces.

The dynamic evacuation characteristics of pumps after discharges are shown in Fig.7. The BGP has a larger speed for M/e=28 than the TMP or the SIP. While, the speed for M/e=16,15 of BGP is very small, and the BGP seems to desorb the methane and its cracking. This suggests that the methane is weakly adsorbed on the getter and are easily exchanged by the carbon monoxide and/or nitrogen.

The static evacuation characteristics of TMPand SIP are shown in Fig.8. The curves of M/e=28,32 show that SIP has the same evacuation speed for N_2 and/or CO as TMP, and that the speed for O_2 of SIP is larger than TMP. The curves of M/e=15,16 suggest that SIP is contaminated with the methane.

5. Discussion

5.1. Efficiency of Discharge Cleaning

Usually the conditioning is performed with discharges of 50 60 Hz or glow discharges, discharge current of which is considerably small. In JFT-2, on the other hand, the repetition time of our discharges is 1.5 min as previously mentioned, but discharge current is very large and temperature of discharges is high. In our case, therefore, the energy of bombardment particles is large, and the efficiency per shot of discharges in removing impurities is better.

5.2. Introduction of Air to Cleaned Surfaces

After the conditioning mentioned in chapter 3, air is introduced in the vessel up to 1 Torr. The changes of some impurities before and after the introduction of air are compared in Fig.9. The decreasing rate of impurities after the air introduction is very slow. This means that the introduction of impurities to the cleaned surface strengthens their adsorption.

5.3. Threshold Value of Impurities

Figures 10 and 11 show the conditioning with the 500^{ϕ} and 327^{ϕ} limiters, which limit the plasma diameter in JFT-2. The temperature of discharges with the 500^{ϕ} limiter does not increase in spite of the decrease of impurities. While, the temperature of the 327^{ϕ} discharge rises gradually, but the rate of the decrease of impurities is not more than the 500^{ϕ} discharge. It seems that there is a threshold value of impurities in rasing the plasma temperature.

6. Summary

1) Impurities are decreased to the considerably low level by the discharge cleaning.

2) A number of hydrocarbons are produced in the hydrogen gas discharges.

3) Persistently left impurities are the methane and its cracking.

4) Discharges of large current are effective in removing impurities, although the repetition time of discharges is longer than the pumping out time.

5) A large amount of methane are contained in the vessel evacuated with the getter pump, comparing with the mechanical pump.

6) The introduction of impurities to the cleaned surface strengthens their adsorption.

7) The SIP has a large evacuation speed for oxygen gas compared with the TMP.

8) There is a threshold value of impurities in raising the plasma temperature.

Acknowledgement

We should like to thank Dr. S. Komiya in ULVAC for his many fruitful discussion of the results. We are grateful to Dr. S. Mori, Chief of Nuclear Fusion Lab., for his support and encouragement. Many thanks are also due to Mr. S. Kunieda and JFT-2 member for operating the machine.

Reference

1) S.Itoh et. al.: the Fifth European Conference on Controlled Fusion and Plasma Physics, 1972, vol.1, p.3 and vol.2, p.231

2) N.Fujisawa et. al.: JAERI-memo 5226.

3) V.A.Simonov et. al.: Nuclear Fusion Supplement (1962), p.325

Figure Caption

Fig. 1 JFT-2 vacuum system

Fig. 2 Impurities for M/e from 1 to 50 at the 1920th and the 4174th shots.

Fig. 3 Time evolutions of impurities at the 1920th and the 4174th shots.

Fig. 4 Decreases of representative impurities before and after discharges versus shot numbers.

Fig. 5 Relation between the electron temperature and the shot number.

Fig. 6 Representative impurities with and without discharges after isolating pumps.

Fig. 7 Dynamic evacuation characteristics of TMP, SIP and BGP, and their cmbinations after discharges.

Fig. 8 Static evacuation characteristics of TMP,SIP and their combination.

Fig. 9 Changes of impurities after the introduction of air.

Fig.10 Time evolutions of impurities with 500^{ϕ} and 327^{ϕ} limiters.

Fig.11 Relation between the electron temperature and the shot number in the case of Fig.10.

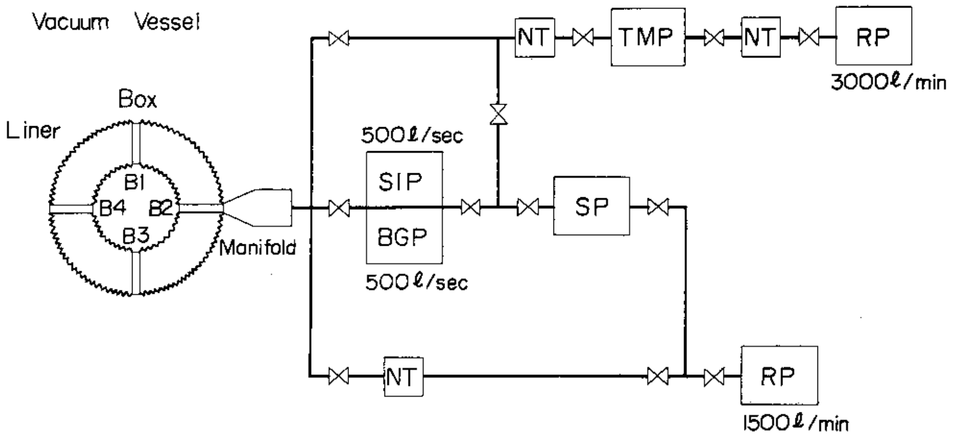
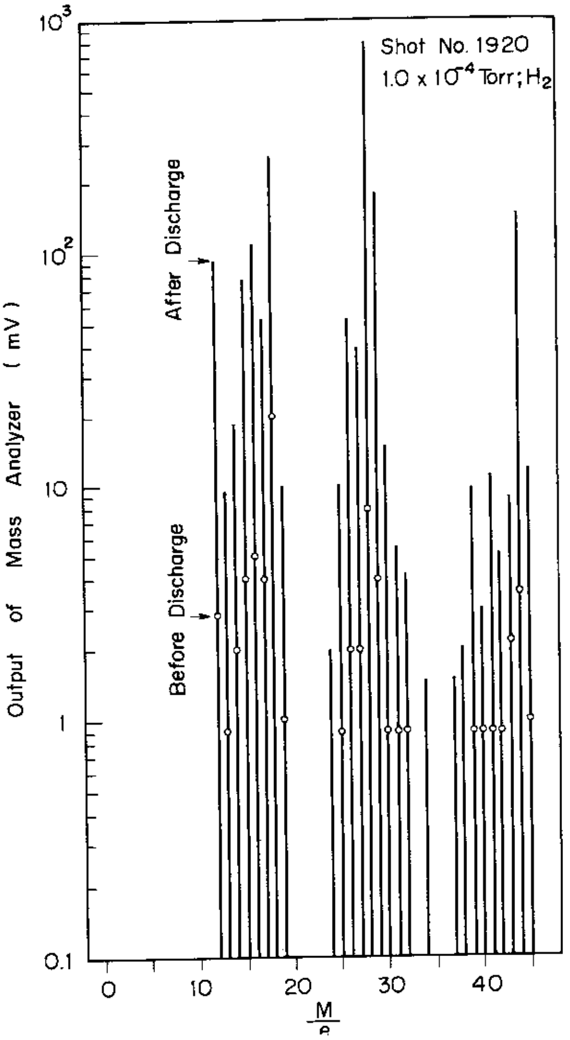


Fig.1



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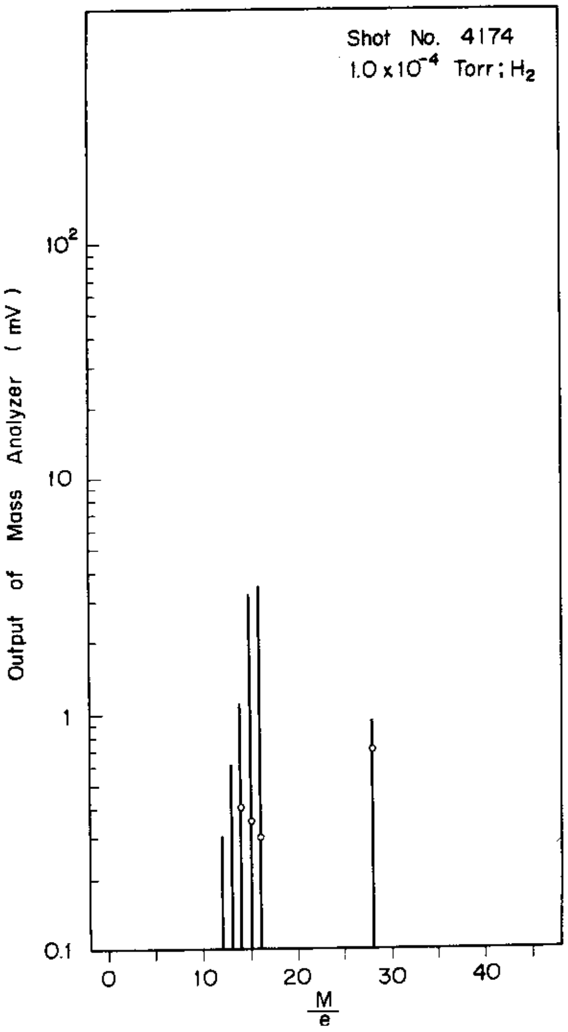

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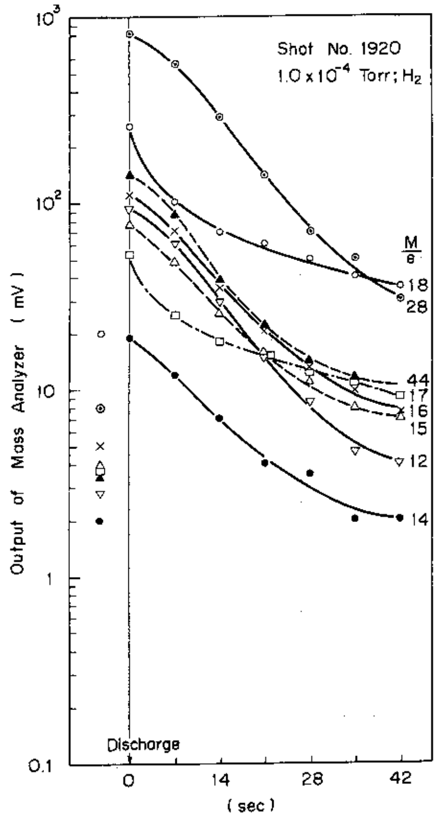

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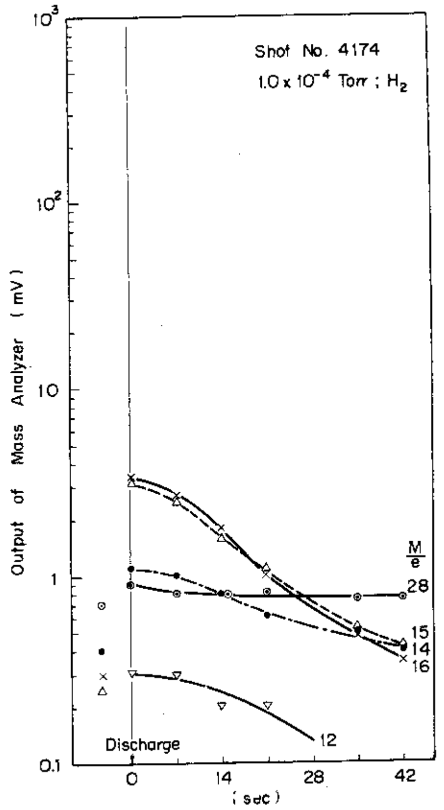

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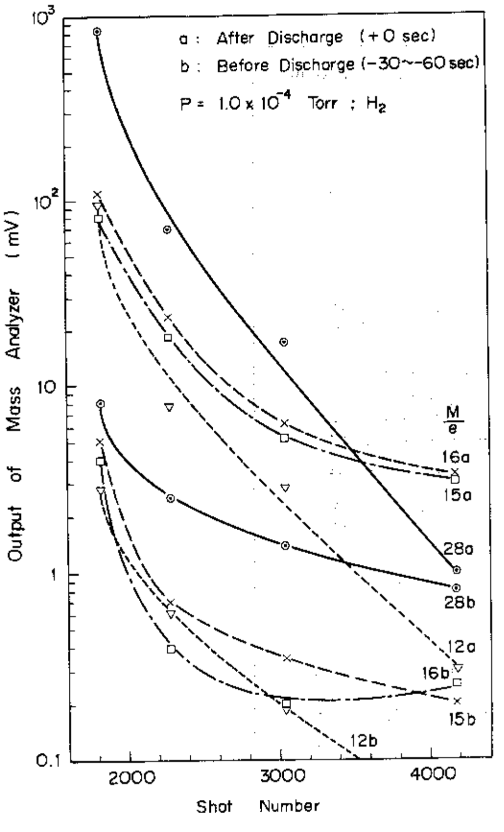

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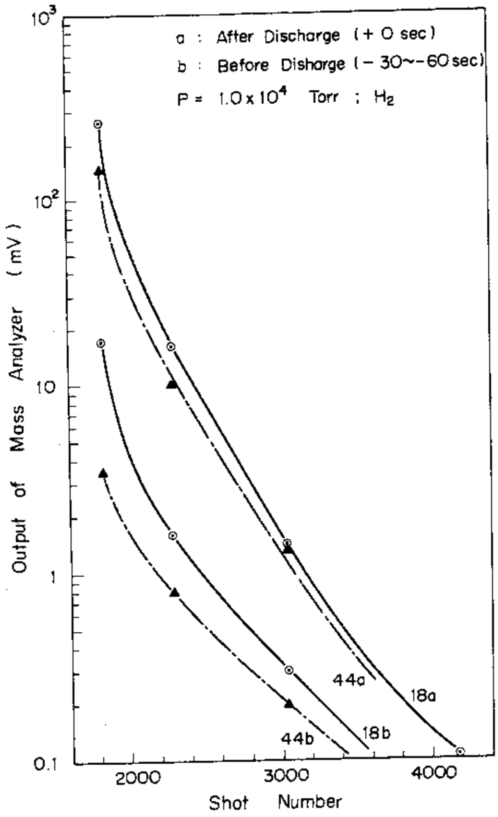

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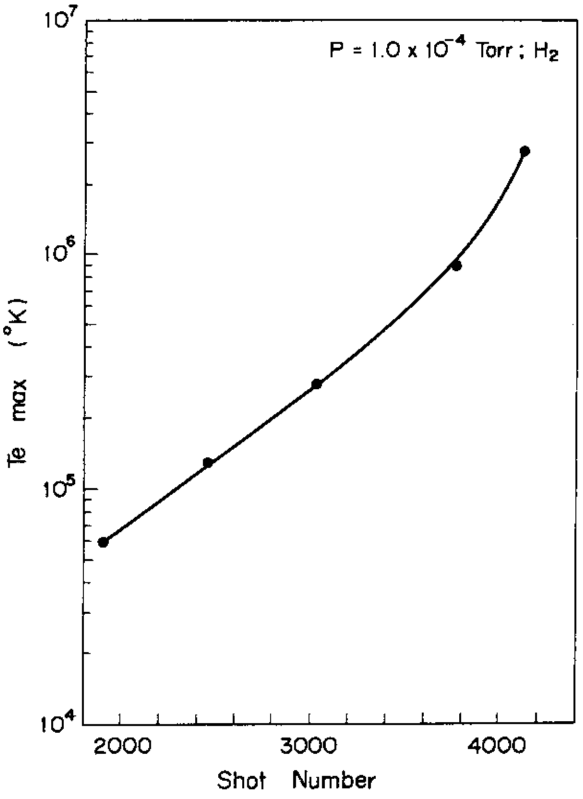
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10^7
10^6
10^5
10^4
Te max (°K)
2000
3000
4000
Shot Number

Fig.5

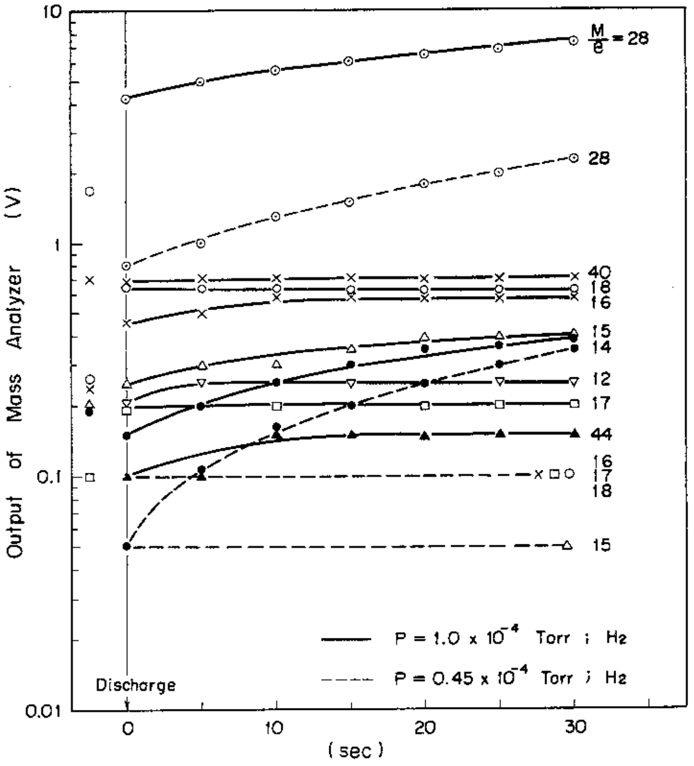
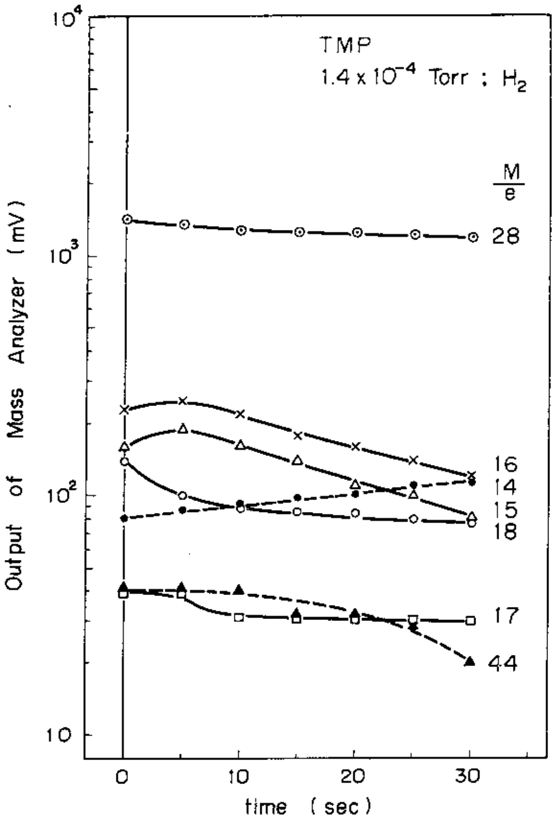

10
1
0.1
0.01
Output of Mass Analyzer (V)
$\frac{M}{e}$ = 28
28
40
18
16
15
14
12
17
44
16
17
18
15
$P = 1.0 \times 10^{-4}$ Torr ; H_2
$P = 0.45 \times 10^{-4}$ Torr ; H_2
Discharge
0
10
20
30
(sec)

Fig.6



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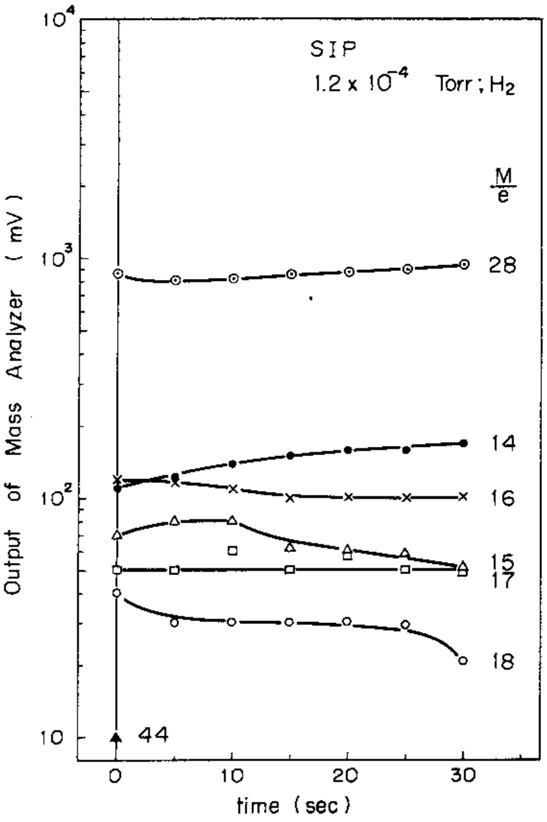

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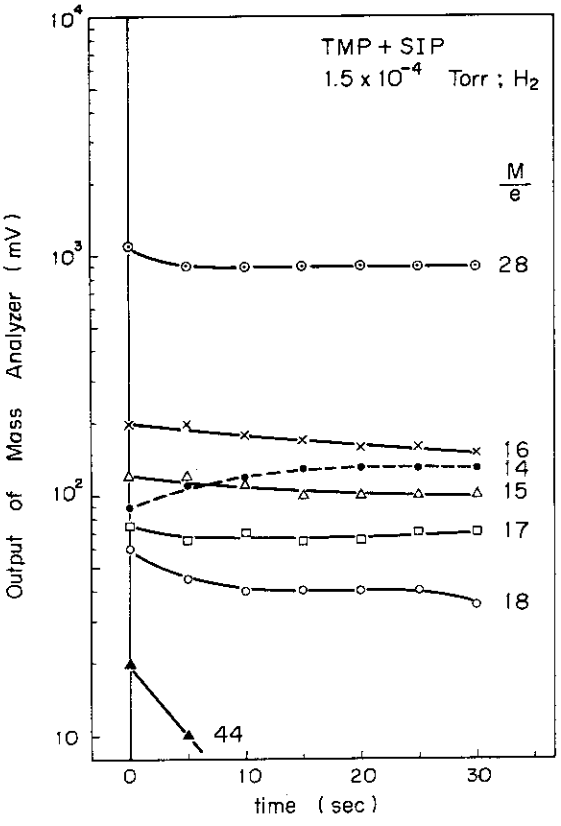

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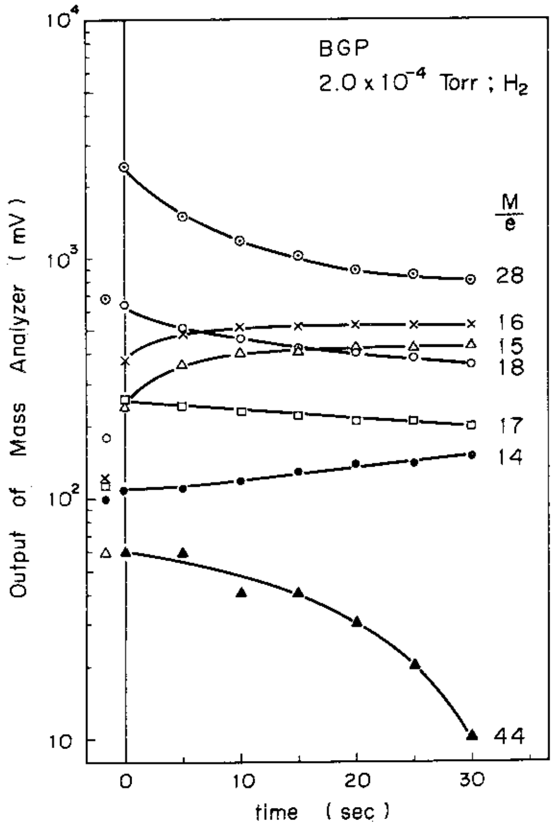

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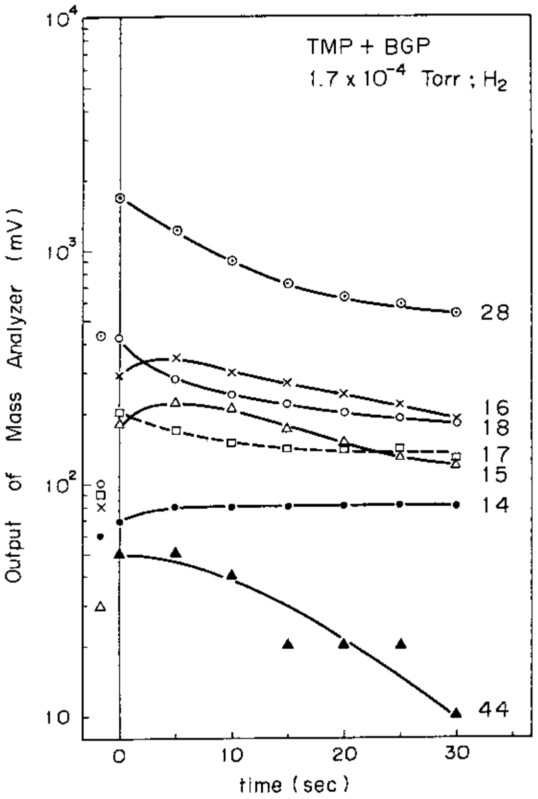

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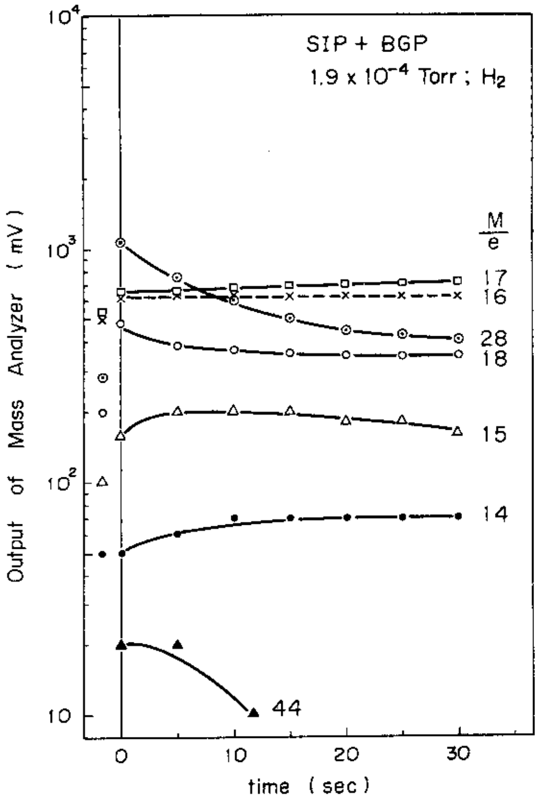

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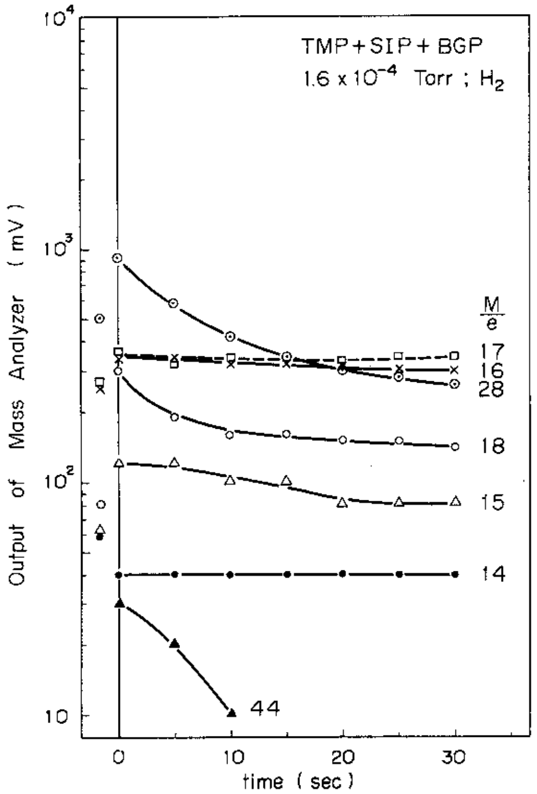

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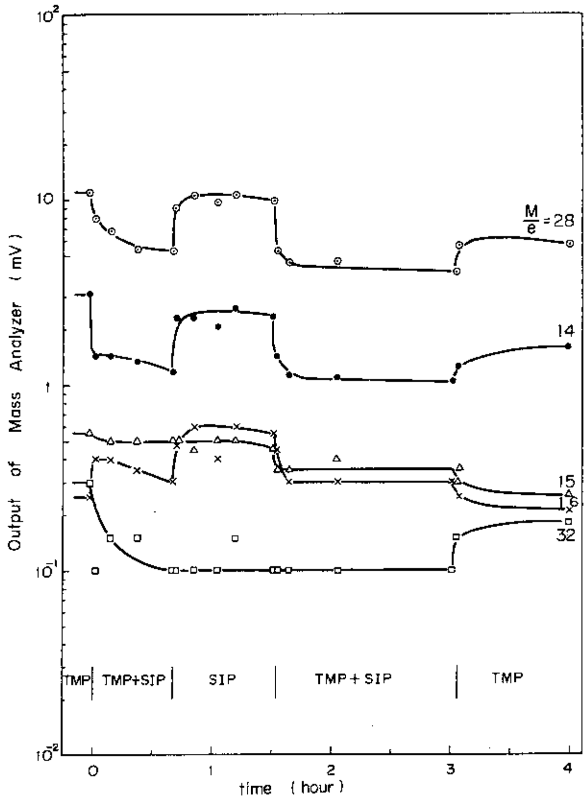
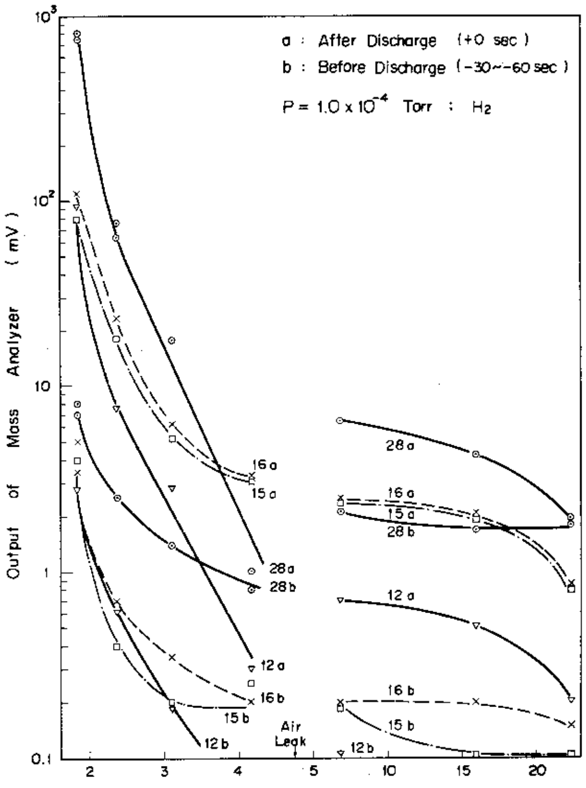


Fig.8



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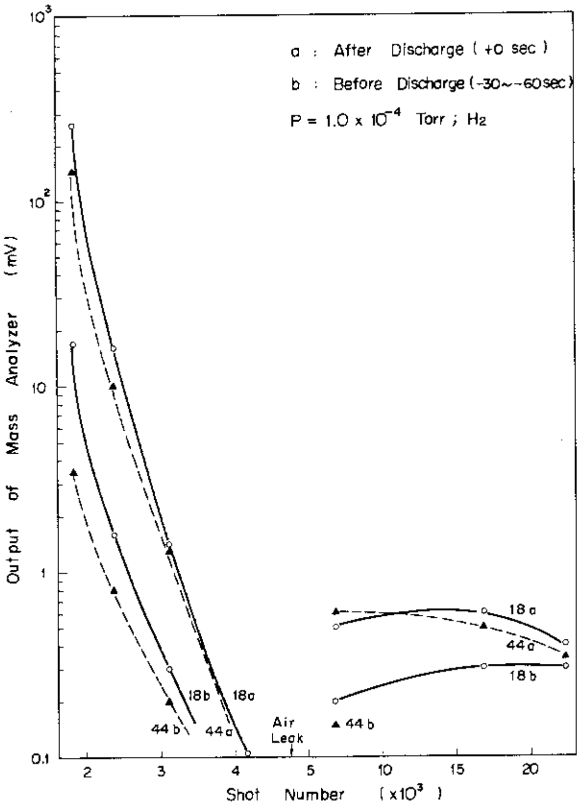

Fig.9(b)

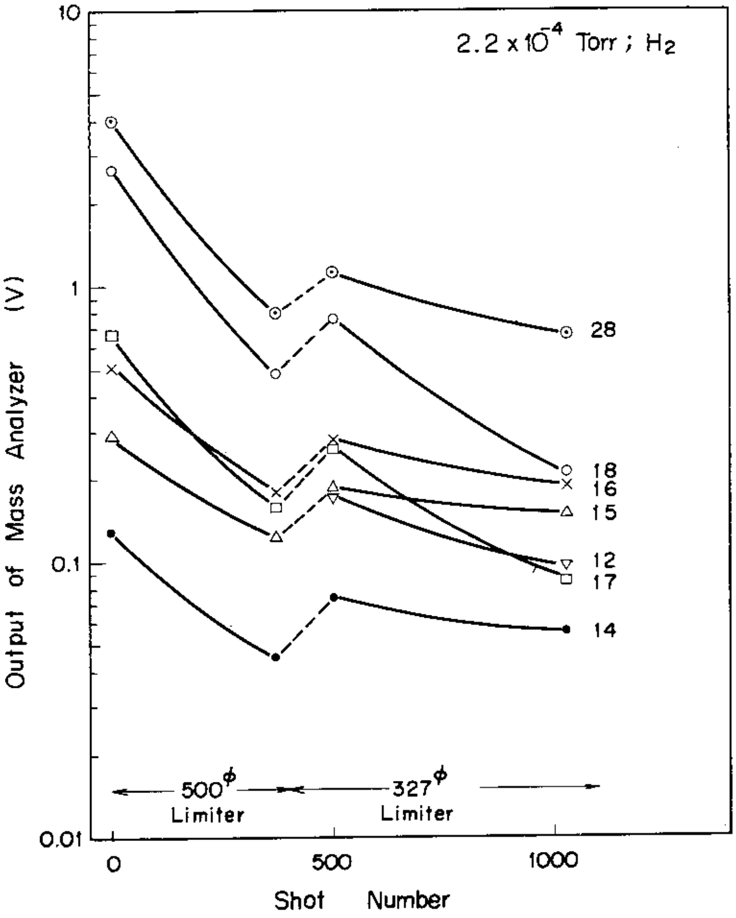
2.2 x 10^{-4} Torr ; H$_2$
Output of Mass Analyzer (V)
10
1
0.1
0.01
28
18
16
15
12
17
14
500$^{\phi}$ Limiter
327$^{\phi}$ Limiter
0
500
1000
Shot Number

Fig.10

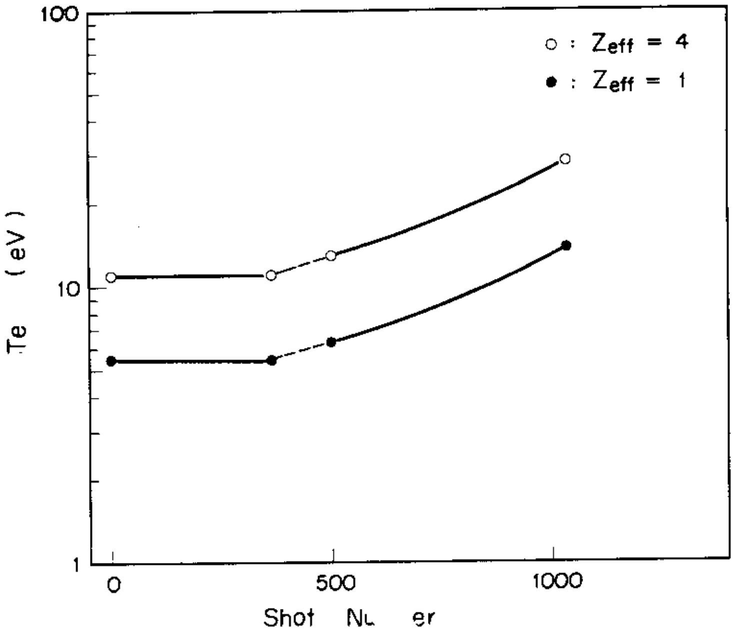
○ : Z$_{eff}$ = 4
● : Z$_{eff}$ = 1
Te (eV)
100
10
1
0
500
1000
Shot Nu er

Fig.11