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# RESULTS WITH ALUMINA LIMITER AND LINER ON THE TOKAMAK PETULA

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## ABSTRACT.

For the purpose of T.T.M.P. heating experiment, a new vacuum vessel has been built which is mostly alumina. The energy confinement time and $Z_{eff}$ are compared to those obtained with the previous stainless steel liner. Using gas injection during the discharge, high density ($n \simeq 4.10^{13}$ e/cm$^3$) and low Z (< 2) are obtained. The reproducibility of the discharges, impeded by oxygen release, may be improved by various wall treatment procedures.

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## I - INTRODUCTION.

To allow the penetration of the electromagnetic field ($f \simeq 150$ kHz) required for T.T.M.P. (transit time magnetic pumping) heating, the Tokamak PETULA was designed with a special vacuum chamber made of alumina and stainless-steel. It has been previously described /1/. The metallic bellows are protected by alumina shields, in such a way that 80 % of the wall facing the plasma is alumina. The static vacuum properties appear to be comparable to those with the stainless steel chamber. A base pressure of $10^{-8}$ Torr is obtained in PETULA.

In addition, to avoid metallic deposition on the wall, an alumina limiter, previously tested in the stainless-steel chamber /2/, is used.

Since the T.T.M.P. efficiency is directly proportionnal to $n_i . T_i^{3/2}$, we have to resolve the same problems as the others Tokamaks so :

- Increase $n_i$ and $T_i$
- Decrease $Z_{eff}$

## II - GENERAL RESULTS : IMPROVEMENT OF THE $Z_{eff}$ and $\tau_E$ BY ALUMINA.

Table I and II show the values of $Z_{eff}$ and $\tau_E$ for various experimental conditions, since the beginning of PETULA operations : B = 16 kGauss, I = 50-70 kAmp., R = 72 cm, r = 14.5 cm.

TABLE I

| GAS | HYDROGEN | | | | | | |
|---|---|---|---|---|---|---|---|
| Wall | S.S. | S.S. | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ |
| Limiter | W | W | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ |
| $Z_{eff}$ | 4.2 | 6.3 | 1.6 | 1.5 | 1.9 | 1.55 | 2.1 |
| $\tau_{E (ms)}$ | 1.2 | 1.4 | 4.5 | 4.3 | 4.1 | 4.0 | 3.9 |

TABLE II

| GAS | DEUTERIUM | | | | | | |
|---|---|---|---|---|---|---|---|
| Liner | S.S. | S.S. | S.S. | S.S. | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ |
| Limiter | W | W | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ | $Al_2O_3$ |
| $Z_{eff}$ | 6.3 | 4.8 | 3.0 | 2.7 | 3.5 | 4.3 | 3.7 |
| $\tau_E$(ms) | 2.0 | 1.7 | 2.8 | 2.6 | 2.8 | 3.7 | 3.3 |

The main conclusion is that, with an alumina limiter, or with an alumina limiter and liner, the energy confinement time and $Z_{eff}$ are both improved relative to the metallic liner and limiter case. We may remark that this good result is particulary evident for hydrogen operation and less pronounced for deuterium. It seems, at this time, that the major improvement in deuterium was obtained by changing only the limiter. In order to understand these results we have tried to look in more detail at the recycling properties of alumina during plasma operating conditions.

## III - RECYCLING PROPERTIES OF ALUMINA.

As we have previously reported /3/, alumina appears to be a good getter for hydrogen or deuterium. The electron density during the discharge for the two wall materials is shown in Fig. 1. This result is similar to the effect of gettering with titanium in A.T.C. or DITE for example /4/. This is consistent with the fact that when we change the filling gas, we observe that the release of the preceding gas is rapidly decreased, which is not the case with a stainless steel wall /5/. Fig. 2 shows deuterium desorption after six months of deuterium operation. After two-hundred cleaning discharges with hydrogen, the release of deuterium become negligible, and discharge cleaning on subsequent days shows only a small deuterium release. Similarly, at the beginning of deuterium operations, the Lyman $\alpha$ lines for H and D show very low recycling of hydrogen (less than 10 %).

## IV - INCREASE OF THE PLASMA DENSITY.

Very recently, we have tried to improve density in order to obtain the best conditions for T.T.M.P. heating. Fig. 3a shows for hydrogen operations, 3 different types of discharges. Curve 1 corresponds to an operation without pulsed gas injection during the shot ; in case 2 we inject a small amount of $H_2$ during a short time ; in case 3, we inject much more gas. Gas injection procedure is presented on the Fig. 3b.

These curves show that without any special preparation of the wall, we can obtain high density $\bar{n} = 4.10^{13} e/cm^3$ and low $Z_{eff}$ ($\leq 2$) in PETULA. In this way, we can vary the density by about one order of magnitude. Fig. 4 shows the corresponding variation of $T_i$ which follows the $n^{1/3}$ Artsimovitch law quite well (dotted line).

## V - REPRODUCIBILITY OF SHOTS.

If we try to make a series of dense shots such as curve 3 of Fig. 3, then we obtain the evolution of the density curves shown in Fig. 5. In this figure, the curve labelled I is the first in the series in which hydrogen injection is used to increase the density, VI is the 6th, and XIV is the 14th. The hydrogen injection is stopped after the 14th, so the curves XV et XVI show the recovery to the original type of discharge.

Figures 6a, 6b show the shot-by-shot evolution of several parameters for the same sequence. These parameters are evaluated at t = 50 ms., which is the time when the discharge current reaches its maximum. In this figure, the density of $O^{VI}$ is determined from the intensity of the 1032 Å line, the hydrogen density from Hβ, the $Z_{eff}$ from the resistivity, and the oxygen density from $Z_{eff}$ assuming that oxygen is the dominant impurity.

These two figures, together, show that, by maintaining the gas injection constant, the maximum density increases from one shot to the next. The evolution of the impurity parameters shows, however, that this density increase is largely due to the increase in oxygen influx. In the same time, we observe a weak decrease of $H_o$ at the plasma edge. The recovery to the original conditions can be effected within 2 shots by terminating the gas injection.

Similar results have been previously obtained in PULSATOR experiment with a stainless-steel vessel /6/.

The oxygen release is more efficient and the sequency is consequently shorter with deuterium discharges than with hydrogen, probably because sputtering by D is more efficient than by H. Figure 7 shows, for a typical sequency for $D_2$ discharges, $Z_{eff}$, $\overline{n}_e$, $T_e$ (0) at the same time during the discharge (t = 50 ms). One can remark that $Z_{eff}$ is significantly higher in $D_2$ than $H_2$. This result is consistent with the general observations made previously on the energy balance results (Tables I and II).

REMARKS ON ALUMINIUM.

The $Al_2$ line (1670 Å) has been measured during the discharges. Fig. 8 shows a very good correlation between the emissivity of this line and the radial displacement of the plasma. In this figure, the three curves, which are typical, correspond to the same conditions as the curves in Fig. 3.

Aluminium release appears to be closely related to inward displacement. However, we have never observed significant variation of $Z_{eff}$ related to this effect. Since the intense line of $Al^{XI}$ ($\lambda$ = 550 Å) has never been observed, we assume the density of Al is less than $10^{10}/cm^3$

## VI - CONCLUSIONS.

Alumina acts as a good getter for hydrogen and deuterium ; thus allowing good control of the plasma density.

The use of an alumina limiter and wall, without any special preparation, leads to a value of $Z_{eff}$ lower than 2, which is comparable that obtained in other Tokamaks with a cleaning procedure. Oxygen appears to be the dominant impurity. Use of gas injection allows high density operation ($n \simeq 4.10^{13} e/cm^3$) but with lack of reproducibility. The non-reproducibility is correlated with the increase of oxygen density.

In turn this suggests that wall preparation between high density shots would be beneficial.

For example, the procedure recently used which consists of a high density shot followed by a low density shot gives up to now good results.

## REFERENCES.

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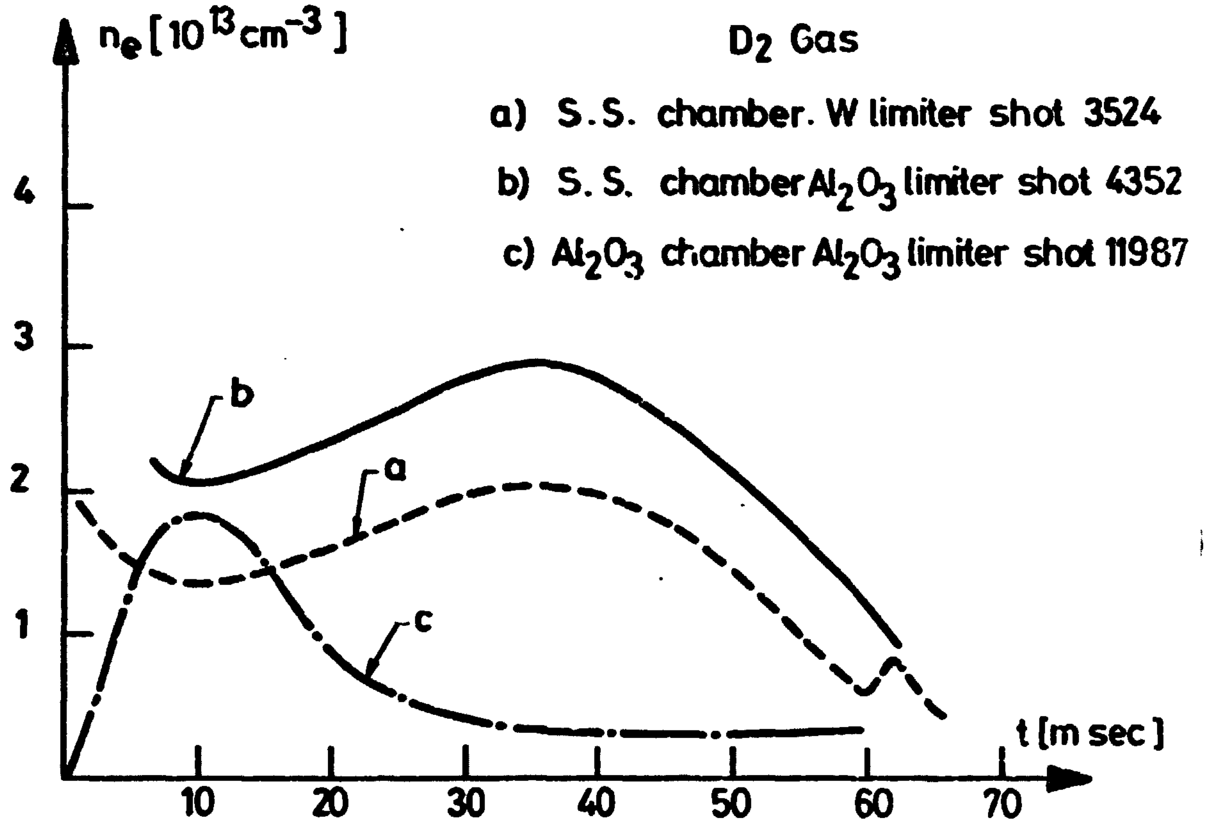
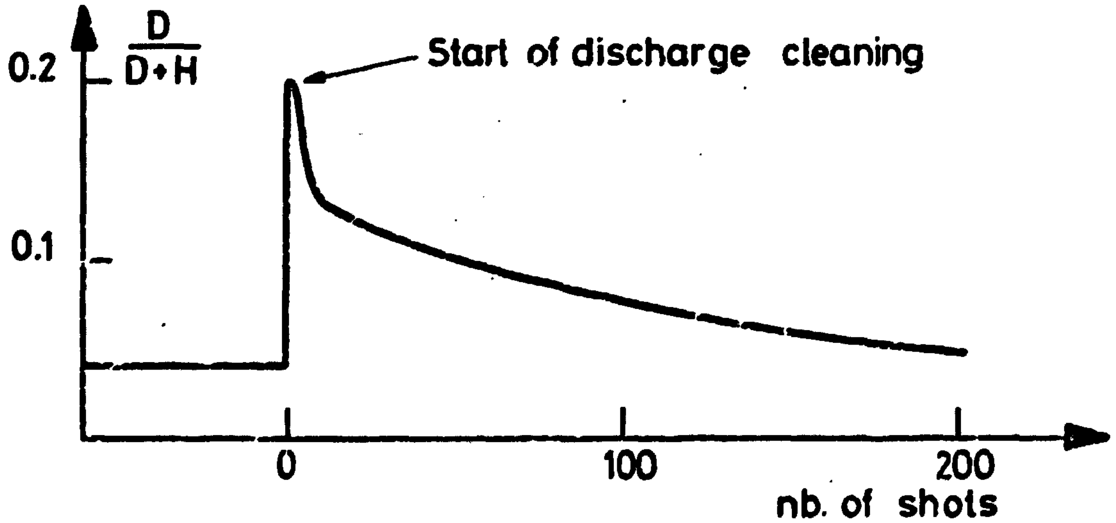


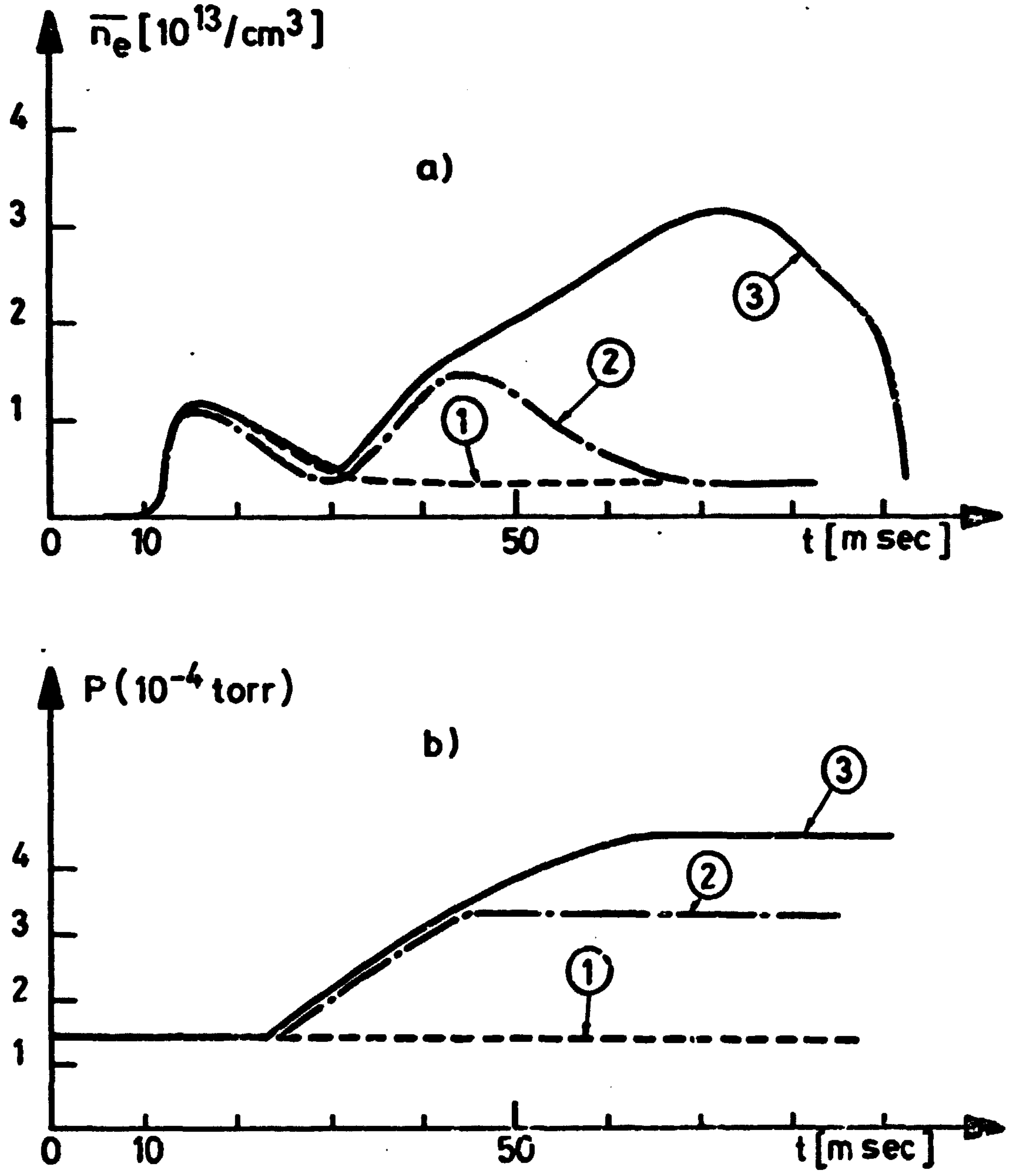
Electron density for different wall and limiter materials

Fig. 1



Desorption of deuterium

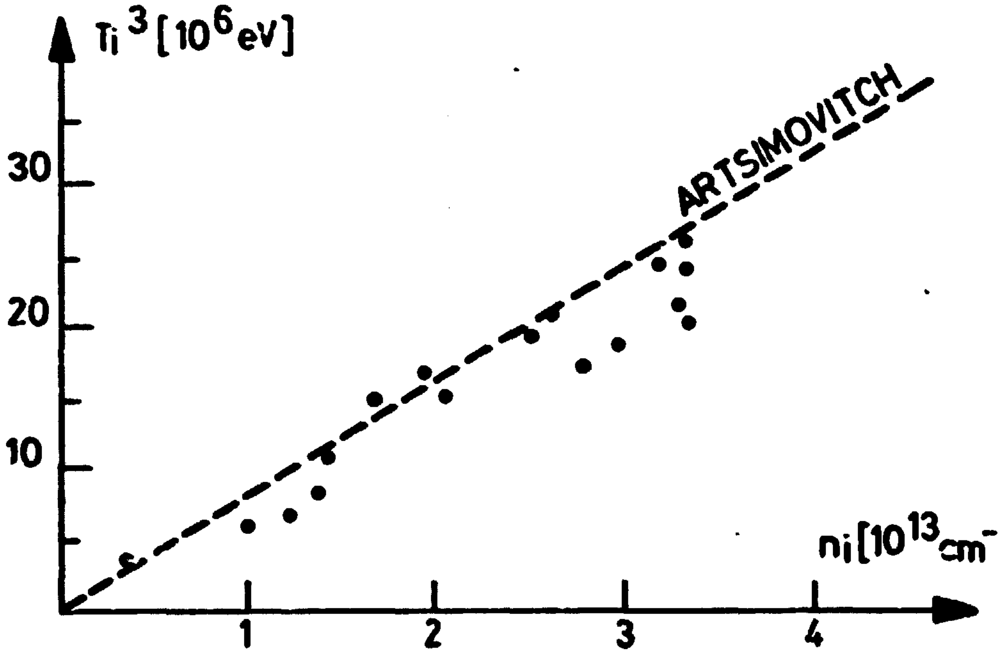
Fig. 2



3 a) Density evolution

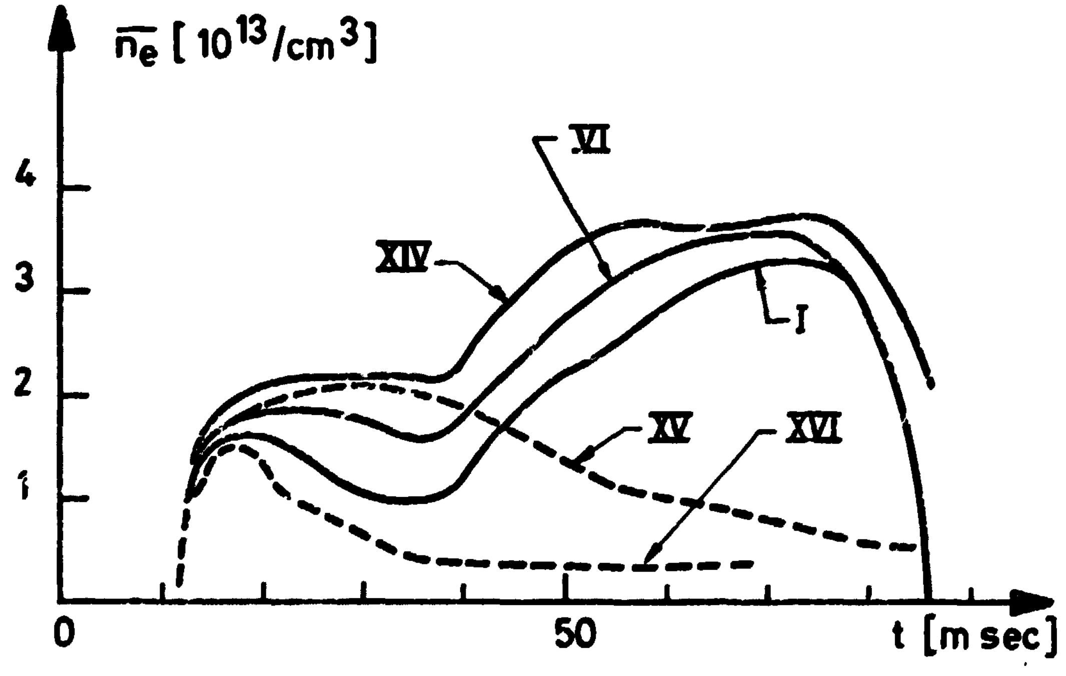
3 b) Injected neutral pressure

Fig. 3



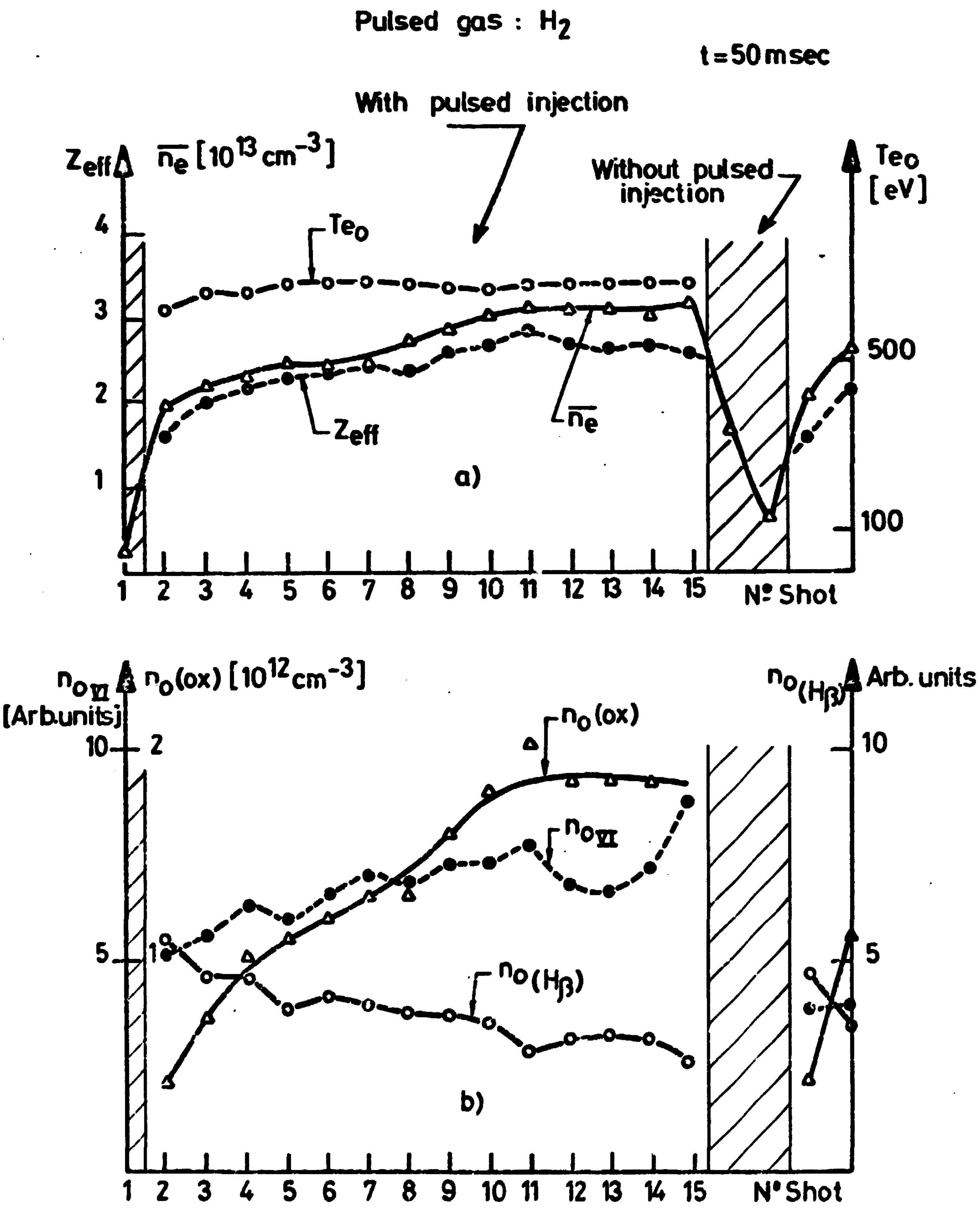
Ion temperature results compared to the Artsimovitch law

Fig. 4



Evolution of the electron density

Fig. 5

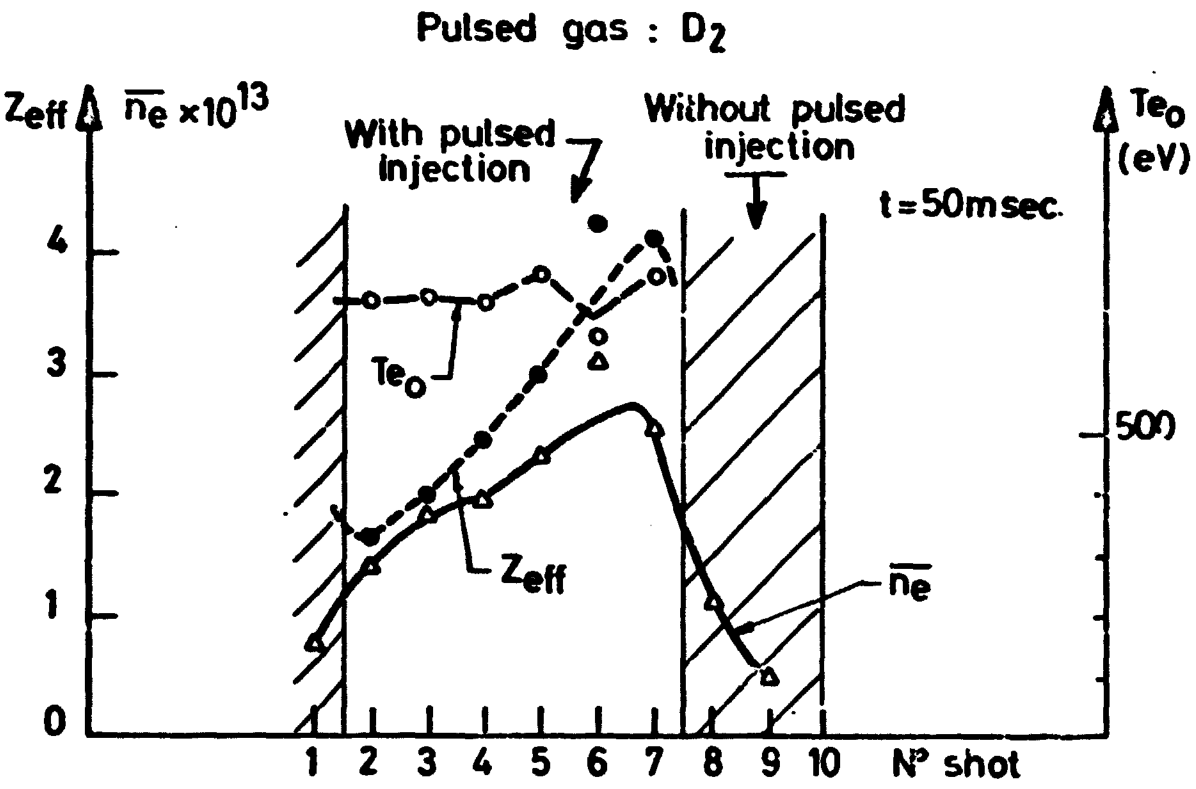


Pulsed gas : $H_2$

t=50msec

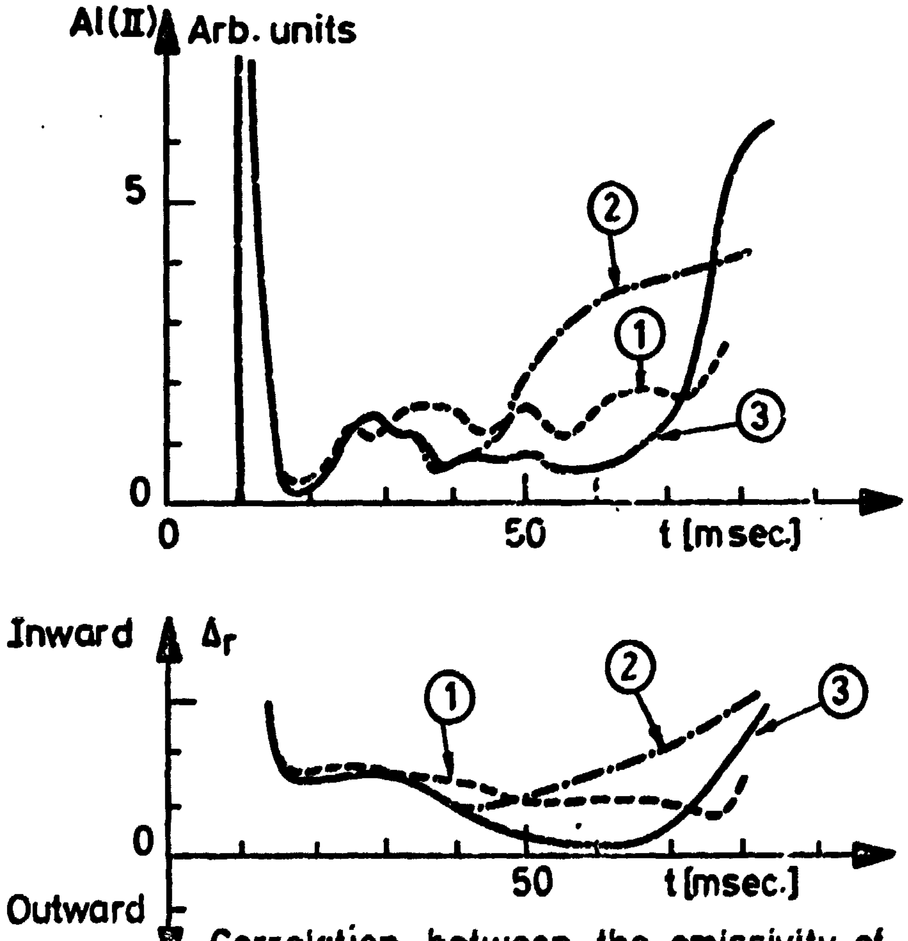
Sequency with hydrogen injection

Fig. 6



Sequancy with deuterium pulsed injection

Fig. 7



Correlation between the emissivity of Al and the radial displacement

Fig. 8