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ALT-I Pump Limiter Experiments With ICRF Heating On TEXTOR

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Abstract

The ALT-I (Advanced Limiter Test - I) was installed on TEXTOR to benchmark the ability of a pump limiter as an efficient particle collector and to determine the physics of pump limiter operation. Experiments continue to show its capability of removing particles from the plasma edge under different operating conditions.

In this paper we report first experimental results using ALT-I in conjunction with high power ICRF heating. The particle removal rate increases as the edge flux and density increase during the ICRF pulse. For a head geometry that collects flux from both electron and ion drift sides, the plasma temperature rise is asymmetric with electron temperature on the electron side increasing more than on the ion side during the ICRF pulse. When ALT-I is the major limiter, the particle fluxes on both sides increase by about the same factor and the particle flux on the ion side is always larger, by a factor of 1.5 to 2 than on the electron side during both ohmic and ICRF periods. The degradation of particle confinement inferred from Langmuir probe measurement is more than a factor of two at a maximum achieved power of 2 MW.

1. Introduction

The Advanced Limiter Test [1] is a pump limiter experiment in the TEXTOR tokamak. It defines the plasma boundary and simultaneously removes particles through the opening on the limiter sides. The ALT-I performance under ohmic discharge has been discussed in previous papers [2,3,4,5], indicating efficient particle removal ability with large density control (up to 60%). Study of particle removal under actively pumped and unpumped conditions, different limiter head configurations and discharge conditions has improved our understanding of the pump limiter physics and our understanding of plasma-neutral interaction in the operation of a pump limiter [6].

The module used in this experiment is referred to as the 'fix geometry 2' module (FG2), made of uncoated EK-98 graphite, and collects particles both on the ion and electron diamagnetic drift sides (fig.1). There are two Langmuir probes on this module, one on each side of the entrance slots. A detailed description of the probes can be found in reference 5. The slots are 26cm long and 2cm wide. The front surface is poloidally curved with a radius of curvature of 44cm. The toroidal curvature is such that there is a uniform particle flux on the front surface with scale length of 1 cm.. The leading edges are 1cm from the tangency point on both sides. An IR camera is used to monitor the head surface which is in contact with the plasma during a discharge. D_{α} emission from the front surface is monitored. Particles entering the 700 liter pump limiter chamber are pumped by a 7000l/s cryopump. There is a fast ion gauge at the back of the chamber monitoring the pressure during a shot.

TEXTOR [7] is a long pusle (about 3 seconds) and high recycling tokamak. In our experiment, the magnetic field is set at 2T and the central line-averaged density varies from $3\times10^{13}\text{cm}^{-3}$ to $4.6\times10^{13}\text{cm}^{-3}$. The plasma current is 480 KA and the loop voltage is about 1V.

The minor radius position of ALT-I can be varied from 40cm to 50cm. The position of the main limiter can be set from 44cm to 50cm and is 270 degrees toroidally from ALT-I on the electron drift side. The ICRF antennae are located at 48.8cm and 40 degrees toroidally away on the electron drift side. The inner-bumper limiter is at 48.5cm.

During ICRF heating [8,9] in TEXTOR, the plasma density is increased and the plasma density profile broadens. At low current (340 KA) operation, the increase in density may become so large that the density limit is exceeded leading to disruption even at low ICRF power (350 KW) . ALT-I has been used previously to suppress the density increase to prevent disruptions [10]. It was shown indeed that the removal rate of ALT-I increased significantly in the ICRF environment.

In this paper, we report first results of ALT-I operation in conjunction with high power (up to 2MW) auxiliary ICRF heating and high plasma current (480 KA) in TEXTOR tokamak. We have carried out two set of runs, one with ALT-I at 44cm and the main limiter at 46cm. The other set is with both ALT-I and the main limiter at 46cm.

The following is an outline of this paper. The next section describes the experimental set up and plasma discharge conditions for the runs. Section three presents the results of ALT-I performance and inferred particle confinement scaling with ICRF. Section four icontains a disscusion and summary of the experiments.

2. Experimental set up

The discharge conditions for these experiments are B_T = 2 T, Ip = 480KA and n_e = 3-4.6x10^{13}cm^{-3}. The plasma current ramps up from zero to 480KA in the first 500ms, maintains a flat top for about 1 second, and then decays from 1500ms to the end of discharge. ALT-I can be moved horizontally between shots and since ALT-I can change the core density strongly, the discharge condition will be different with different ALT-I positions. A set of discharges were carried out for ALT at different radial position and, at each position for different level of ICRF power.

The line-averaged density is found to reach a maximum at 500ms and remain constant, and then ramps down after about 1500ms for ALT-I at 46cm without ICRF. When ALT-I is at 44cm the electron density does not maintance a plateau because of the strong pumping effect of the limiter. The ICRF pulse is turned on at 800ms, after the plasma has reached its flat top, and remains on for 300 to 800ms. The power leaving the antennae varies from 0 to about 2 MW.

For the run with ALT-I at 44cm and main limiter at 46cm, the chamber was carbonized [11] prior to experiment. This usually means that recycling is very high. For the run with ALT-I at 46cm and the main limiter at 46cm, no carbonization was done. The D_α monitor is looking at a spot of about 1cm in diameter on the equatorial plane of the limiter head. In order to avoid metal parts close to the plasma, the limiter segments, inner-bumper limiter and the ICRF antenna limiter are all graphite.

3. Results

In figure 2, we show the response of various diagnostics for a plasma discharge with ICRF, with ALT-I at 44cm and with the main limiter at 46cm. The central line-averaged density typically increases from 5 to 15 percent depending on the power of ICRF and the ALT-I position. For the same density, the increase of density is larger for higher ICRF power. The electron temperature and particle flux measured with the probes on the module are also shown. The particle fluxes increase at the entrances during the ICRF pulse. The increase is comparable on both the electron and ion sides. Usually the increase goes up with power. Along with this increase in particle flux at the entrances, the pressure measured by the fast ion gauge also registers an increase. This indicates an increase of particle removal by ALT-I. In figure 3, a discharge with ALT-I at 46cm and main limiter at 46cm is shown. Note the difference in electron temperature measured by the probe.

3.a. Ion drift side and electron drift side asymmetry

It was found in the past that an asymmetry of particle flux existed on the two opposite entrances of the ALT-I module during ohmic discharge [2,5]. During ICRF heating, the same asymmetry is roughly maintained. The ion side flux is larger than the electron side particle flux and the ratio is about the same. In Figure 4, the average particle fluxes are shown for the two sets of runs. For the run in case one, the ICRF power reaches 600KW. For the run in case two, ICRF power of over 2MW is successfully launched. We do not speculate on the nature of the asymmetry.

There is also an asymmetry in the electron temperature during ICRF heating, which is not seen in ohmic heating. The effect is not as obvious in case one. But in case two, the electron side electron temperature can increase from 8eV to about 30eV during ICRF heating while T_e on the ion side registers only a few eV increase. The difference in case one and case two may be due to the fact that when ALT-I is at 46cm, it is closer radially to the antennae. Also, much higher heating power is achieved in case two.

3.b. Removal rate scaling

The removal rate of ALT-I can be represented by

$$Q = P S + V dP/dt \qquad (1)$$

where P is the pressure of the ALT-I chamber
S is the pumping speed
V is the volume of ALT-I chamber

Because the pumping speed is very large (7000 l/s) the second term on the right hand side of equation (1) is only a small contribution to the removal rate. Both the removal rate and particle particle flux increase with ICRF power (figure 5). Even at the 2MW ICRF power level, the removal rate seems still to be increasing, although there is a slight sign of saturation. Higher power will be needed to determine this.

Because the particle flux increase faster then the removal rate, the removal efficiency decreases with ICRF power. The removal efficiency degradation is proportional to the power.This is understandable because the electron temperature at the entrance goes up with ICRF power. The effect of plasma-neutral interaction [6] may play an important role in this phenomenon.

3.c Particle confinment scaling.

Since ALT-I is not the only component in contact with the plasma, an estimation of the absolute particle confinement time entail knowling the values of the particle fluxes to the main limiter, ICRF anntenae and the liner. Because there is no SOL profile information available for these runs , a relative comparison is attempted here to scale τ_p with ICRF power. We assume that (1) the sharing of particle flux among ALT-I, the main limiter, ICRF antennae and the liner does not change with ICRF and (2) the scrape off length do not change during ICRF heating. We start with

$$Q_{total} = N_e/\tau_p \qquad (2)$$

where Q_{total} is the total particle outflow at the edge
N_e is the total electron number in the plasma
τ_p is the particle confinement time

We can approximate N_e with

$$N_e = n_e V \qquad (3)$$

where n_e is the line-averaged density
V is the plasma volume

Also, with our assumptions (1) and (2),

$$Q_{total} \propto \Gamma_{probe} \qquad (4)$$

leading to the proportionality

$$\tau_p \propto n_e/\Gamma_{probe} \qquad (5)$$

The density range for case one is from 3 - 3.4 10^{13} cm^{-3}. For case two, the range is 3.5 - 4.6 10^{13} cm^{-3}. There is an indication that τ_p changes with density [5]. In order to differentiate the effect of density change and the effect of ICRF heating on the τ_p, we normalized τ_p with n_e. In figure (6), $\tau_p/n_e \propto 1/\Gamma_{probe}$ vs ICRF power is plotted for the two cases. Since electron side and ion side fluxes are in proportion, ion side probe flux is used in the scaling. In both cases, the normalized τ_p decreases with ICRF power. The relative change follows roughly the results of the corresponding τ_E scaling [9].

4. Discussion and summary

The performance of ALT-I FG2 module in the ICRF enviroment is discussed. It is found that the particle flux asymmetry is roughly maintained during ICRF heating. The increase of ICRF power makes no noticeable change in this respect. We see an increase of electron temperature at the entrance of ALT-I with ICRF power. There is an asymmetry in the measured electron temperature at the two sides of the entrance during auxiliary heating. The electron drift side seems to become hotter than the ion drift side and the difference increases with ICRF power. Also, this effect is more pronounced when ALT-I is closer to the antennae radially. The flux on both sides always increases with ICRF power.

In our experiments, the main limiter is set at a minor radius of 46cm and ALT-I is varied from 44cm to 46cm. In the first case, the ion side partcle flux is about a factor of two higher than the electron side particle flux with and without ICRF heating. In the latter case, the ion side particle flux is about four times the electron side particle flux in ohmic heating but the ratio decreases to about two times during ICRF heating. The electron temperature on the electron drift side can increase from about 8 eV to over 30 eV while that on the ion side only increases by a few eV. The change in line-averaged plasma density can be as much as 15 percent at high (2MW) ICRF power. It is found that the particle removal rate is proportional to the ICRF power and the correspondence removal efficiency decreases with ICRF power. The inferred scaling of τ_p with power follows that of the globel energy confinement time during ICRF heating [9]. The degradation of particle confinement time is more than a factor of two when ICRF power is above 2 MW.

The nature of the ion side and electron side asymmetry is not known. More detailed experiments are underway.

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References

1. R. W. Conn, et al., "Advanced limiter Test (ALT-I) in the TEXTOR Tokamak" in Fusion Technology, 1982 (Proc. 12th S.O.F.T. Pergamon Press) 1, 497(1982).
2. A. E. Pontau, et al., J. Nucl. Mat., 128&129, 434 (1984) .
3. K. H. Dippel, et al., Plasma Physics and controlled Nucl. Fusion Research (Proc. 10th Intl. IAEA Conf., London (1984), Vol. 1, IAEA Vienna), 249(1985).
4. G. J. Thomas, et al., J. Vac. Sci. Tech, Proc. Am. Vac. Soc., Fusion Tech. Div. Meeting, Houston, Texas (1985).
5. D. M. Goebel, et al., "Langmuir Probe Measurements in the TEXTOR Tokamak during ALT-I Pump Limiter Experiment", UCLA report PPG-945.
6. G. A. Campbell, et al., "The influence of Plasma-Neutral interaction on the behaviour of pump limiter", UCLA report PPG-958.
7. G. Waidmann, et al., Plasma Physics and controlled Nucl. Fusion Research (Proc. 10th Intl. IAEA Conf., London (1984)), Vol. 1, IAEA Vienna, 193(1985).
8. R. R. Weynant, et al., Proc. 6th Topical Conf. on Radio Frequency Plasma Heating, Atlanta, USA (1985).
9. A. M. Messiaen, et al., Plasma Phys. and cont. Fusion 28, 71(1986).
10. W. K. Leung, et al., Bull. Am. Phys. Soc., 30, 1442 (1985).
11. J. Winter, et al., J. Nucl. Mat., 128&129, 841(1984).

Figures

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    ALT-I=44cm, main limiter=46cm

Table 1. Experiment conditions for two sets of run

Case	ALT-I position	Main limiter position	Carbonisation	Highest ICRF power
1	44cm	46cm	yes	600KW
2	46cm	46cm	no	2MW

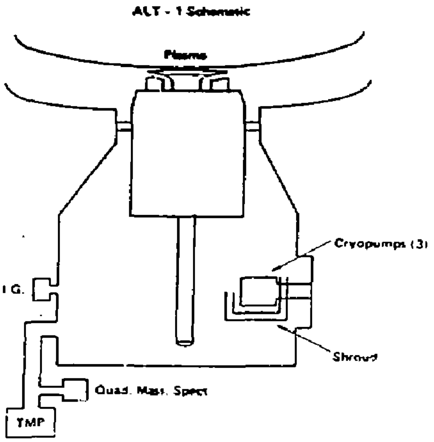


Fig 1 (a) Schematic of ALT - 1

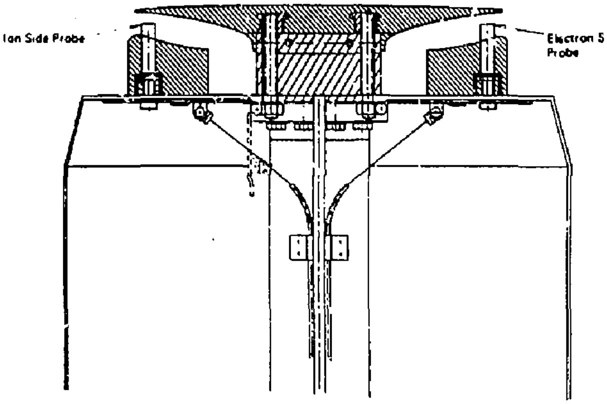


Fig 1 (b) FG2 module

Figure 1. ALT-I with FG2 module

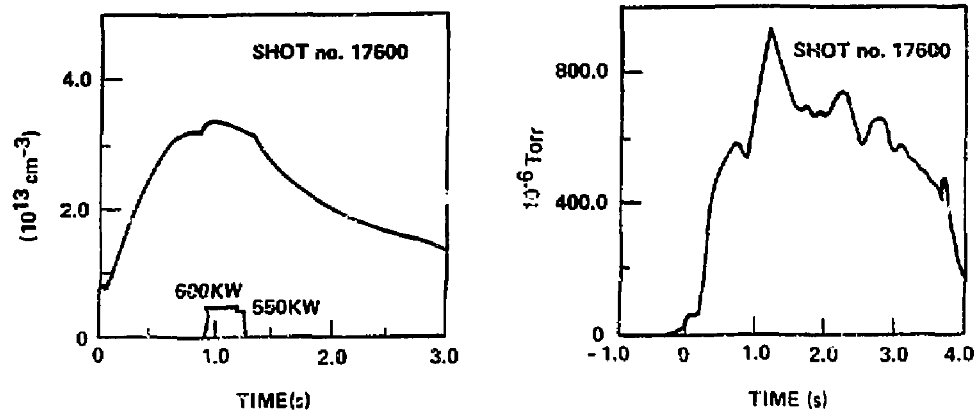


Fig 2 (a) Central line-averaged density

Fig 2 (d) Pressure in ALT-1 Chamber

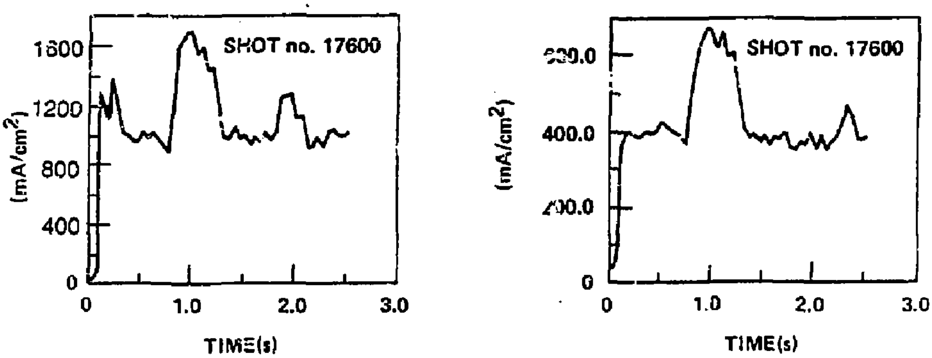


Fig 2 (b) Ion side probe flux

Fig 2 (e) Electron side probe flux

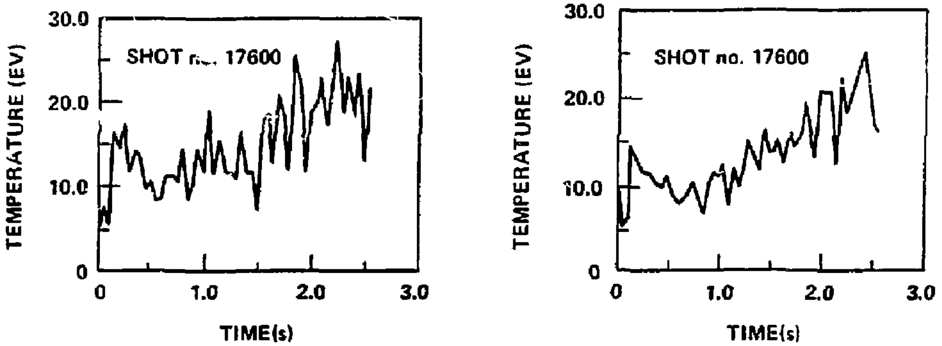


Fig 2 (c) Ion side electron temperature

Fig 2 (f) Electron side electron temperature

Fig 2 ALT - 1 = 44cm, main limiter = 46cm, ICRH power = 600KW

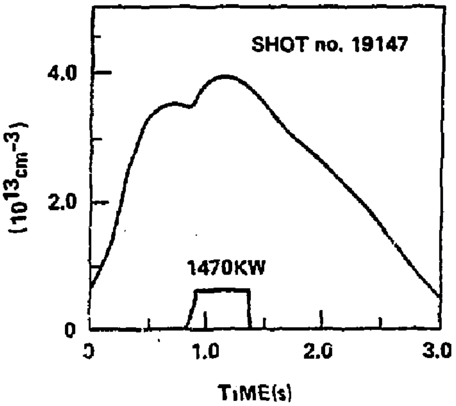


Fig 3(a) Central line-average density

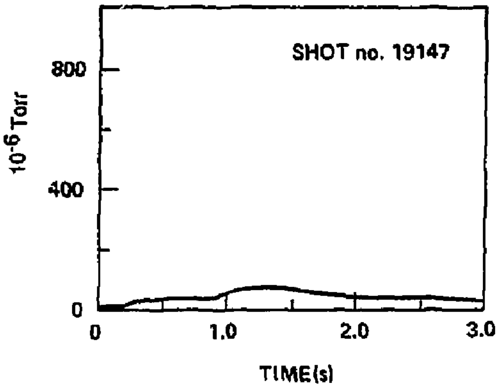


Fig 3(d) ALT-1 Chamber pressure

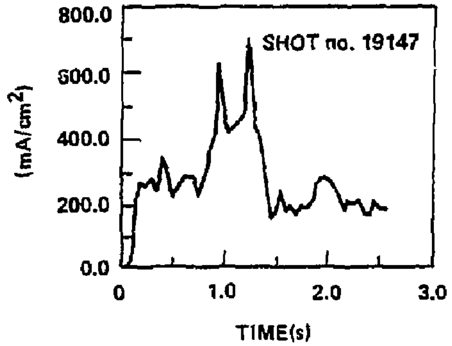


Fig 3(b) Ion side probe flux

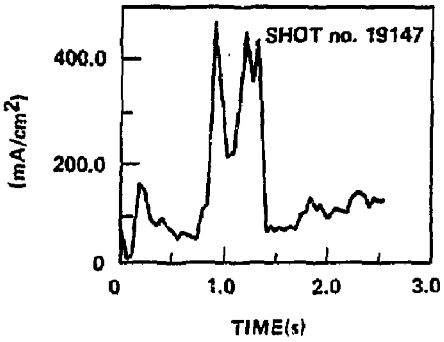


Fig 3 (e) Electron side probe flux

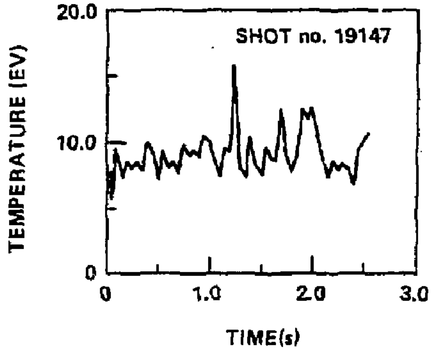


Fig 3 (c) Ion side electron temperature

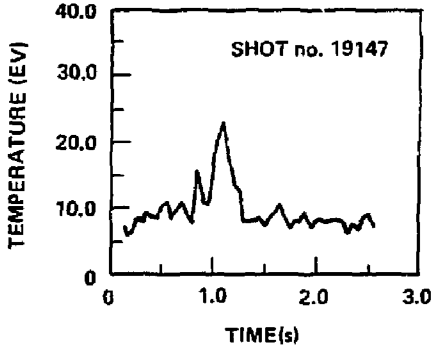


Fig 3 (f) Electron side electron temperature

Fig 3 ALT = 46cm, main limiter = 46 cm, ICRF = 1470 KW

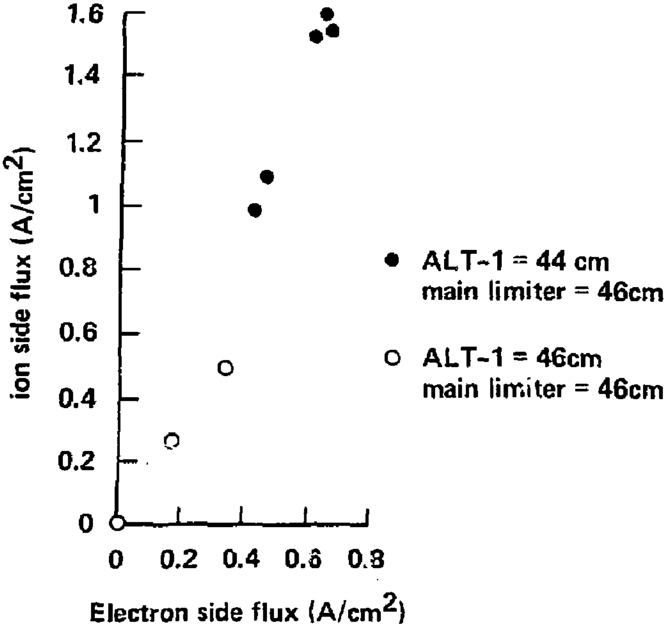

1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
ion side flux (A/cm^2)
0
0.2
0.4
0.6
0.8
Electron side flux (A/cm^2)
● ALT-1 = 44 cm
main limiter = 46cm
○ ALT-1 = 46cm
main limiter = 46cm

Figure 4

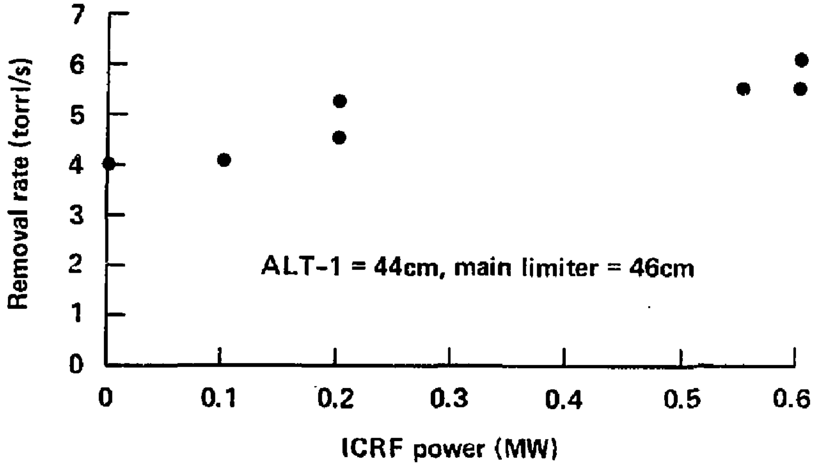

Removal rate (torrl/s)
7
6
5
4
3
2
1
0
ALT-1 = 44cm, main limiter = 46cm
0
0.1
0.2
0.3
0.4
0.5
0.6
ICRF power (MW)

Figure 5a

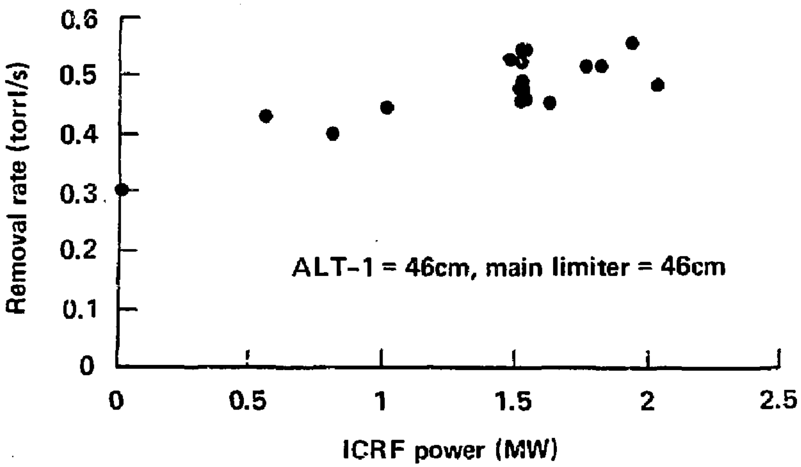
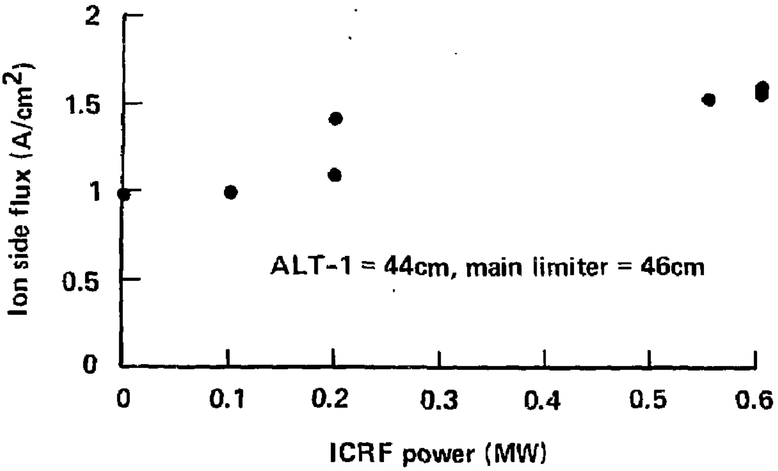

Removal rate (torrl/s)
0.6
0.5
0.4
0.3
0.2
0.1
0
ALT-1 = 46cm, main limiter = 46cm
0
0.5
1
1.5
2
2.5
ICRF power (MW)

Figure 5b



Ion side flux (A/cm^2)
2
1.5
1
0.5
0
ALT-1 = 44cm, main limiter = 46cm
0
0.1
0.2
0.3
0.4
0.5
0.6
ICRF power (MW)

Figure 5c

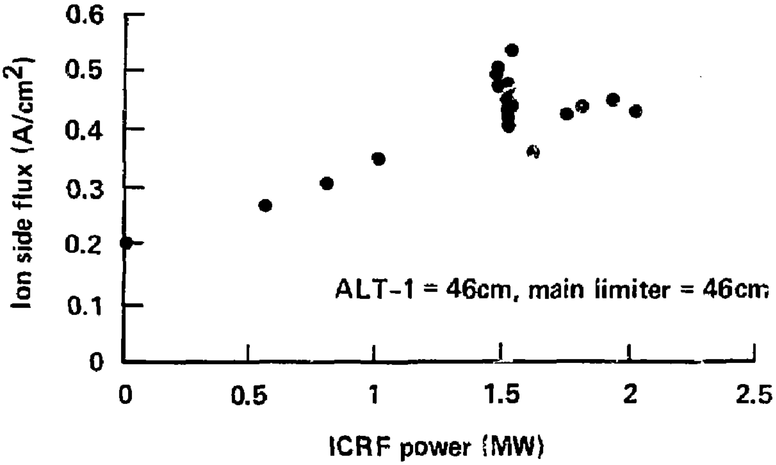

0.6
0.5
0.4
0.3
0.2
0.1
0
Ion side flux (A/cm2)
ALT-1 = 46cm, main limiter = 46cm
0
0.5
1
1.5
2
2.5
ICRF power (MW)

Figure 5d

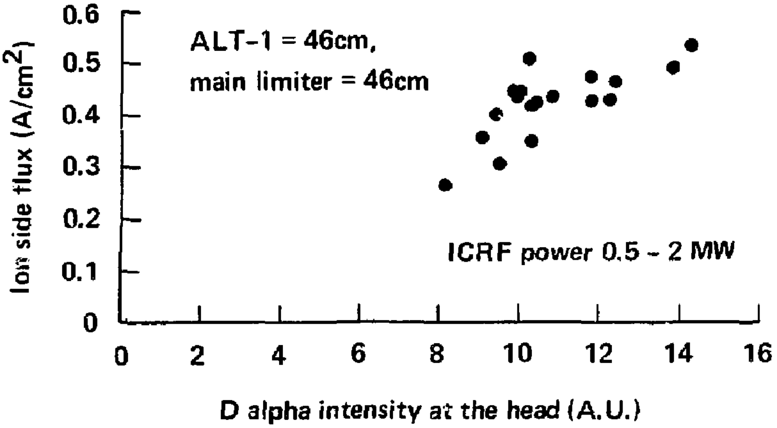

0.6
0.5
0.4
0.3
0.2
0.1
0
Ion side flux (A/cm^2)
ALT-1 = 46cm,
main limiter = 46cm
ICRF power 0.5 - 2 MW
0
2
4
6
8
10
12
14
16
D alpha intensity at the head (A.U.)

Figure 6a

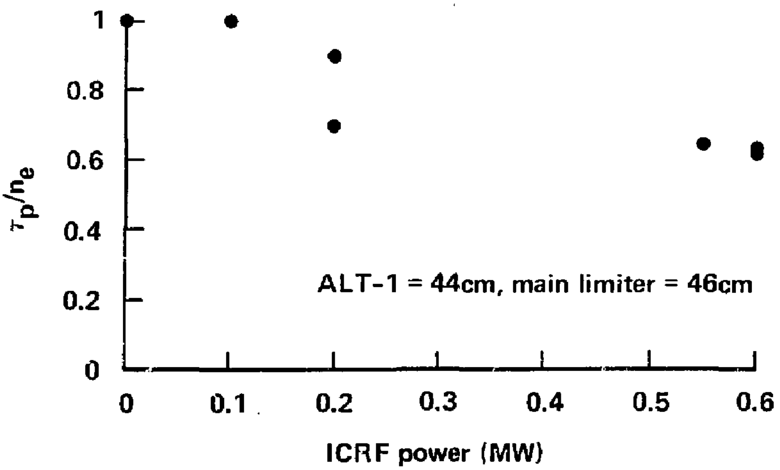

1
0.8
0.6
0.4
0.2
0
τ_p/n_e
ALT-1 = 44cm, main limiter = 46cm
0
0.1
0.2
0.3
0.4
0.5
0.6
ICRF power (MW)

Figure 6b

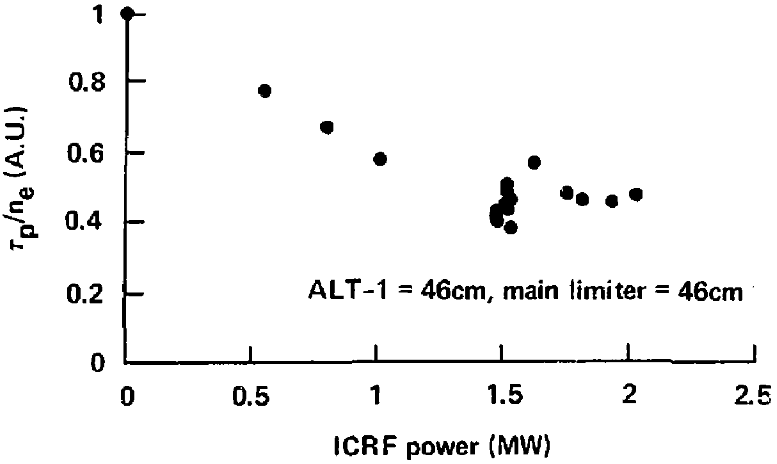

1
0.8
0.6
0.4
0.2
0
τ_p/n_e (A.U.)
ALT-1 = 46cm, main limiter = 46cm
0
0.5
1
1.5
2
2.5
ICRF power (MW)

Figure 6c