Effects of Density and Plasma Configuration on the Divertor Asymmetries

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1. INTRODUCTION.

Asymmetric power deposition with more power going to the outer divertor target is usually observed in single null divertor configurations and is expected from geometrical toroidal effects (higher area of outer magnetic surfaces) and higher anomalous transport towards the outer midplane. The additional effect of drift forces has been discussed in [1]. This paper presents the first results of an analysis of the asymmetries obtained in H-mode regimes. It is found that the magnetic configuration has a strong influence on the imbalance of power and particle fluxes in the divertor. The effects of gas fuelling are also discussed. Two regimes are distinguished: 1)hot ion mode regimes: these have high power (18 MW), central fuelling with the neutral beams (no gas fuelling) and result in a high temperature, poloidally isothermal scrape-off layer (SOL); one expects poloidal drifts to increase the asymmetries; 2) radiative divertor regimes: medium to high power (12MW), edge gas fuelling: these result in a high radiation fraction in the divertor region, and non-isothermal SOL, with possible extra radial drifts[1] which in turn may modify the particle and power exhaust ratios. Langmuir probe data implies high edge ion temperatures in low density hot ion modes. There is empirical evidence from other machines that high edge temperatures are associated with toroidal momentum [2] in the edge plasma. This effect has the correct sign to increase the density at inner divertor.

2. HOT ION MODE: EFFECTS OF THE PLASMA CONFIGURATION.

In general, the power flow towards the outer strike zone should be larger due to geometrical toroidal effects [3] (higher area of the outer magnetic surfaces: calculations yield a 23% higher outer pressure for JET toroidicity), higher $D_\perp$ towards outer mid-plane, and the Shafranov shift ([1] and references therein). Furthermore, in the low density/low recycling hot ion mode regime, one expects high and poloidally uniform edge temperatures to cause strong radial electric field and poloidal $E_r \times B$ drifts that should increase the asymmetry.

Higher power to the outer strike zone has been observed in most JET magnetic configurations (see[1] for ohmic and L-mode discharges). This was also evidenced by the fact hat most of the damage occurred on outer divertor tiles.

However, we have found that **high magnetic shear** configurations show a more even power distribution than the low shear equivalent discharges, and the power imbalance can even be reversed in favour of the inner strike zone. High confinement regimes have been found to depend on the magnetic configuration in DIII-D [4] and JET [5].

Fig 1 shows time traces for two discharges with I_p=3.8MA, B_t=3.4T . Discharge #32969 has a shear at q=95% SH_{95} =3.6, discharge 36677 has SH_{95} =5.0, at the time of the peak neutron rate . It can be seen that the inner and outer strike zone peak temperatures are very similar in the higher shear case. The effect of shear (or more generally, of the shape of the plasma) has been studied for two series of discharges of hot ion modes: 1) the 20 best discharges of the campaign in terms of peak neutron production (plasma current 3MA $\leq I_p \leq$ 4MA, toroidal field B_t= 3.4T, input power P_{in}= 18MW NBI, shear values 3.1 $\leq SH_{95} \leq$ 5, no gas fuelling); 2) a series of 12 discharges of a configuration scan (I_p = 2.5MA, B_t = 2.5T, P_{in} = 10MW NBI, shear values 2.8 $\leq SH_{95} \leq$ 4.2, no gas fuelling, no tile temperature data available). All the discharges in the high performance dataset have moderate to high shear. The dataset includes two main types of configurations: the high flux expansion single null (moderate shear) and the double null type of discharge (high triangularity, high shear).

All these discharges have low divertor densities and electron temperatures above 50eV, as measured by Langmuir probes. For the probe measurements the power accountancy is poor, indicating that the ions carry a higher fraction of power to the divertor than electrons. Good global power balance is found with the IR camera measurements. These discharges radiate below 10% of total input power, and show a constant and very weak D_α emission in the divertor during the ELM free period. It is observed that: 1) the ratio of outer to inner peak surface temperatures decreases with magnetic shear during the ELM- free H-modes (fig. 2); 2) the same trend is observed in the D_α ratio (fig3), as one would expect in a high temperature SOL, with no temperature gradients along the field lines; 3) the same effect on the temperature ratio is observed in the low confinement phase that follows the hot ion mode, although the temperature values are more scattered (movement of the strike points due to β changes).

Drifts alone cannot explain the higher power going to the inner strike zones at high shear for poloidally isothermal plasmas. Other possible explanations could be related to: 1) toroidal momentum: its effect is expected to be important at high edge temperatures; however high electron temperatures are measured in all the high performance dataset; unfortunately ion temperature data are not available to show if there is any effect of the plasma configuration. 2) fluctuations, observed to be different in the high and low field side; however, the position of the heat source does not seem to matter too much in isothermal SOLs; 3) thermoelectric currents in the SOL.

It has to be noted that the same trends are obtained by plotting the data against the triangularity of the plasma. The values of the triangularity are calculated with a greater accuracy than those of shear, because it is an edge parameter. However, there is a strong correlation between shear and triangularity in the dataset used. Finally, no correlation with the plasma current or with q was found.

3. RADIATIVE DIVERTOR REGIMES: EFFECT OF DENSITY (GAS FUELLING).

When gas is injected in the divertor or the SOL, the resulting increase of the edge density will change the pattern of radiation in the divertor region. This is particularly important for radiative divertor regimes. In L-mode confinement regimes [1], the ratio of the power in the outer and inner strike regions ranged from a factor ≈ 1.5 to values ≈ 3. In general, the asymmetries in the electron density, temperature and D_α fluxes appeared to be consistent with radial $E_\theta \times B$ drifts playing an increasingly important role as the density and hence the parallel temperature gradient was increased. However, the effect of increasing the divertor density on the power distribution was obscured by the onset of detachment occurring at the inner strike zone.

Two discharges at high power and far from detachment have been chosen to compare the effects of the density. The configuration is one of moderate shear ($SH_{95}=3.3$), and the power going to the target plates is very similar in the two cases. It can be seen (fig.4) that gas fuelling increases the density by a factor of two and brings the asymmetry factor in the divertor temperatures from 1.1 to 1.6 . The relative change in the radiated power in the divertor $\mathrm{Prad}_{\mathrm{outer}}/\mathrm{Prad}_{\mathrm{inner}}$ changes only from a value of 1 at low density to 0.85 at high density. This result is consistent with the development of a poloidal temperature gradient in the SOL as the density increases, giving rise to high radial $E_\theta \times B$ drifts.

4. CONCLUSIONS.

In the majority of the configurations used at JET more power flows to the outer than to the inner strike point, as expected from theoretical predictions; however in hot ion mode regimes (poloidally isothermal SOL) we observe a more even power distribution as the magnetic shear (or the triangularity) is increased. This effect is also observed in the particle flux to the divertor region. These observations are not accounted for by any classical drift. Toroidal momentum could play a role in the development of these asymmetries. However edge ion temperature data are needed to determine its importance.

The effect of gas fuelling on the power ratio is consistent with the development of a poloidal temperature gradient in the SOL as the density increases, giving rise to radial $E_\theta \times B$ drifts. The effect of the magnetic configuration on the power and particle distribution poses a problem for the design of a divertor for ITER. Codes based on edge and divertor parameters may need to have a model of the central plasma coupled to make reliable predictions.

The work of P J Lomas and Task Force H is gratefully acknowledged.

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4. J Stambaugh and the DIII-D Team, Proc. of the 15th IAEA Conference on Plasma Physics and Controlled Nuclear Fusion (1994) 83.
5. PJ Lomas and the JET Team, as above, p.211.

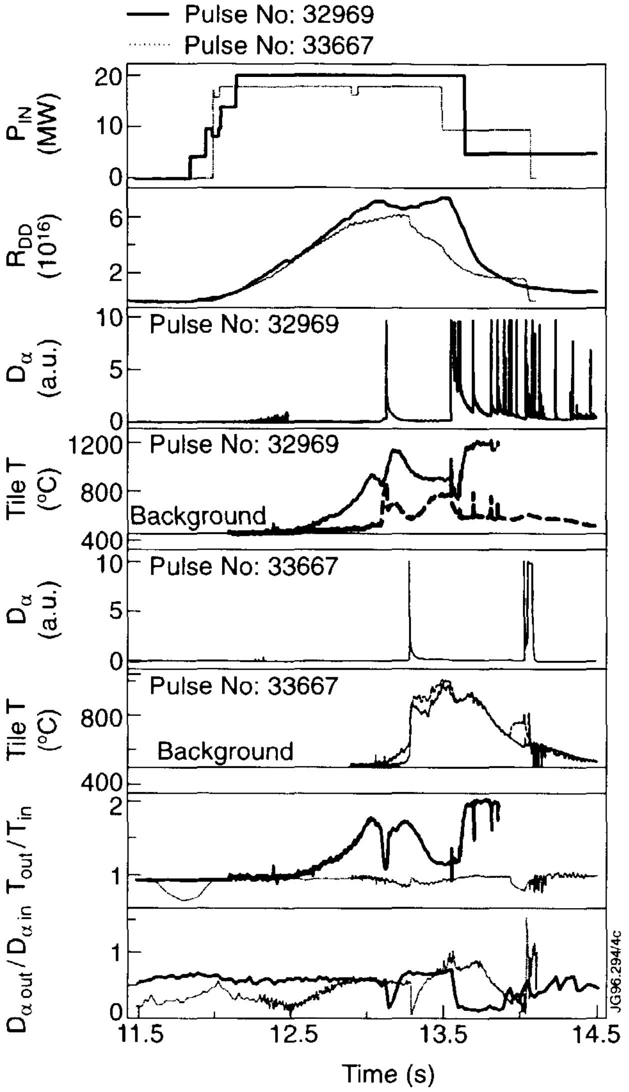

Figure 1 Time traces of the input power, radiated power, power going to the divertor target, central line density and the temperatures of the inner and outer strike zones for shots #35752(no gas fuelling) and #35752 (high gas fuelling).

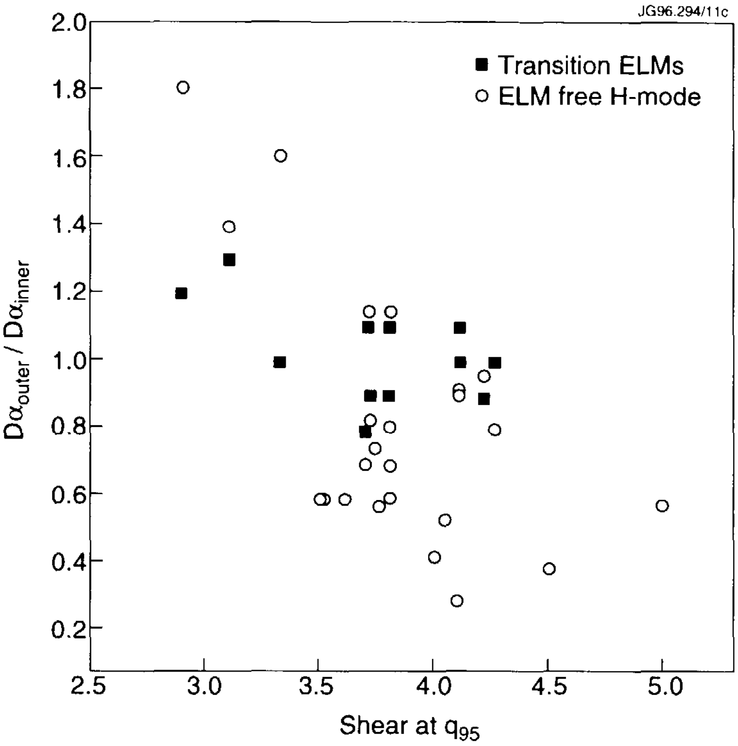

Figure 2 Ratio of the outer to inner strike zone total integrated particle fluxes versus shear at q_{95}.in ELM-free H-modes, and during the transition ELMs.

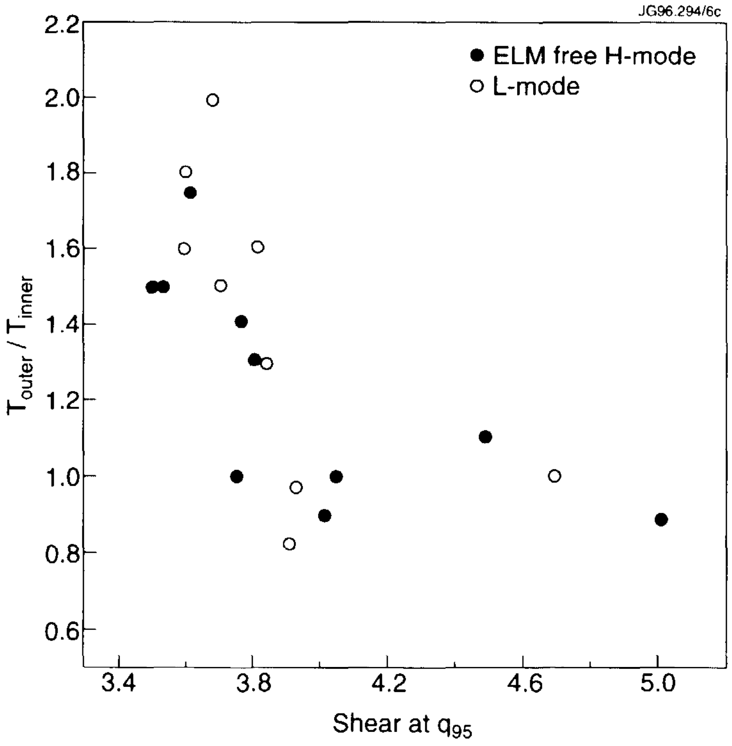

Figure 3 Ratio of the peak values of the outer to inner strike zone tile temperatures versus shear at q_{95} in .H-mode, ELM-free and L-mode.

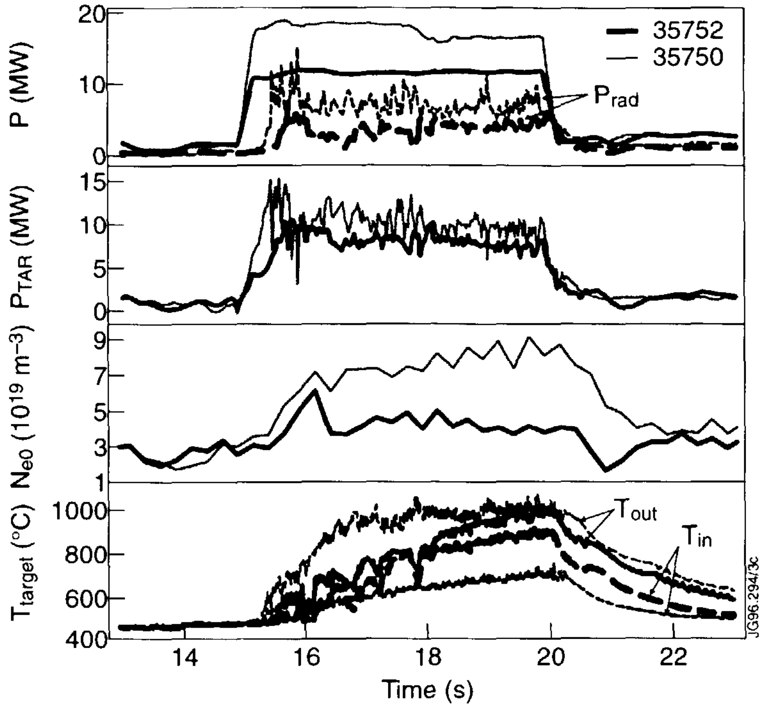

Figure 4 Time traces for shots #32969 and #33667: total input power, neutron reaction rate, D_α, *peak tile temperatures in the inner and outer divertors, and the ratios of outer to inner values in temperature and* D_α *integrated photon fluxes.*