EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT JET

EFDA–JET–CP(01)02-42

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**See appendix of the paper by J.Pamela "Overview of recent JET results",*
Proceedings of the IAEA conference on Fusion Energy, Sorrento 2000

Preprint of Paper to be submitted for publication in Proceedings of the
EPS Conference,
(Madeira, Portugal 18-22 June 2001)

ABSTRACT

H-mode divertor load distributions in JET are simulated with the orbitfollowing Monte Carlo code ASCOT. Several background parameters are varied in order to assess their relative importance. The SOL radial electric field emerges as the most important factor in determining the JET divertor loads in H-mode conditions.

1. INTRODUCTION

Extending the lifetime of the divertor targets is a key question in the design and operation of ITER, and will also be of great concern in JET under the Enhanced Performance operation. In JET, measurements of the heat loads to the divertor targets have produced some alarming results: the heat load is not evenly distributed on the targets but displays a narrow (few mm) peak close to the separatrix. Such a ‘hot spot’ structure can lead to the need of a premature disposal of the divertor targets. Furthermore there is a strong asymmetry between the inner and outer targets, and the ions seem to dominate the load at least in H-mode conditions [1]. Because sharp structures in the deposition profile are hard to conceive within the fluid approach, these observations call for a detailed study of the kinetic behaviour of the ion component in the vicinity of the separatrix. In this work, the H-mode divertor load distributions in JET are simulated with the orbit-following Monte Carlo code ASCOT [2] using experimental magnetic background, density and temperature profiles as well as wall and divertor location data together with OSM2/EIRENE SOL density and temperature data obtained from JET. A scan of the various background parametres is made in order to assess their relative importance and to find the key mechanism behind the observed features in the measured deposition profiles. The SOL radial electric emerges as the most important factor in determining the heat load asymmetry between the inner and outer divertor targets as well as the observed peaking of the load profile near the separatrix.

2. MONTE CARLO SIMULATIONS

The guiding center orbit-following Monte Carlo code ASCOT was utilized in a scan of various parameters that may have a role in causing the observed features in JET divertor loads. First, in simple simulations searching for divertor target asymmetry trends caused by varying one parameter, ion ensembles of 1000 deuterons representing edge plasma ions in JET configuration (H-mode Pulse No: 49511) were launched from $\rho = 0.95$. Each particle was followed for 0.1s or until it hit a divertor target. The particles suffered Coulomb collisions from a fixed background plasma. The edge density in this simulation was $2.4 \cdot 10^{19}\ \mathrm{m}^{-3}$ for electrons and ions, and the temperature was 830eV for electrons and about 580eV for ions. The results of a basic case in the normal and reversed magnetic field configuration shown in Fig. 1a indicate an asymmetry in the load distribution. Under normal configuration the particle load to the inner target is much higher than to the outer target. In the reversed magnetic configuration, the asymmetry is reversed.

These asymmetries are, unfortunately, in striking disagreement with the experimental observations

(Fig. 2). It is therefore necessary to find the physical mechanism that is missing from the simulations and responsible for reversing the asymmetries.

The initial ASCOT simulations did not model neutral collisions in the SOL. Experimentally, the neutral gas density is found to be higher in front of the inner target, thus possibly reducing the flux incident on the target. Therefore a numerical model for neutral collisions was added to ASCOT. While the density and temperature profiles inside the separatrix are assumed poloidally symmetric, the neutral collision model built for the SOL has 2D background profiles obtained from the OSM2/EIRENE code. Figure 3 shows the SOL atomic collisionality used in the ASCOT simulations. Atomic collisions were found to be the dominant effect in the SOL, but ion collisions were also modelled. Repeating the simulations with SOL collision modelling lowered the overall target loads by about 60%, but did not change the load asymmetry towards the experimentally observed value (see Fig. 1b). It was concluded that neutral collisions play a minor role in this process.

Another possible factor affecting the divertor load asymmetry is the radial electric field—E_r close to the separatrix inside the plasma. Simulations with different values of edge E_r (ranging from -75kV/m to +75kV/m) were made using ASCOT. By squeezing the orbits thinner, a negative edge E_r substantially reduced the number of particles hitting the targets. The opposite phenomenon was seen for positive edge E_r. However, the results (shown in Fig. 1c) did not indicate any significant change in the load asymmetry.

An obvious mechanism that could not only reverse the in-out asymmetry but also even strengthen the kinetic nature of the deposition profile is the radial electric field in the SOL. A positive E_r (pointing radially outwards) provides the ions with a poloidal drift velocity that would favor the outer divertor target. Indeed, as shown in Fig. 1d, the load asymmetry can be reversed by the SOL E_r.

To study the divertor loads quantitatively, it is necessary to simulate the neoclassical steady state situation in which any radial currents are balanced by an ambipolar radial electric field [2]. This method provides a steady-state density profile. Detailed self-consistent simulations with 420 000 particles were made to obtain particle and energy deposition profiles on the targets. The SOL—E_r was assumed constant in the narrow region outside the separatrix which is relevant to ions escaping from the plasma. The results, shown in Fig. 4 as a function of $R - R_{sep}$ (the distance [mm] of the strike point magnetic surface from the separatrix along the outer midplane) display a very narrow peak in the particle deposition profile to the outer target. With increasing E_r, the peak power at the outer target grows while the peak power to the inner target diminishes and the power is spread more evenly towards higher $R_{equator}$ (upwards on the target). This is because the $E_r \times B$ drift points poloidally towards the outer target, so that ions that are moving towards the inner target have a smaller poloidal velocity, and thus the $B \times \nabla B$ drift has more time to displace them towards outer magnetic surfaces in the lower hemisphere. On the outer target, the opposite effect takes place. At large positive SOL E_r values, the profiles as well as the target load asymmetry are in satisfactory agreement with measurements.

CONCLUSIONS.

We have investigated a host of processes possibly affecting the heat and particle loads on divertor targets in a tokamak. Because measurements on JET divertor targets have indicated that, in H-mode conditions, the ion contribution dominates the target loads, we have used the orbit-following Monte Carlo code ASCOT to evaluate the ionic flow from plasma bulk to the divertor targets in JET. Under normal conditions (∇B-drift towards the targets) the in-out asymmetry was found to favor the inner target. Because the experimentally observed asymmetry is opposite to this, new physics was added to the simulations to find out if the asymmetry could be reversed to match the measured one. The collisions (both in the plasma bulk and in SOL, where also atomic collisions were included and the collisionality was allowed to vary poloidally from one target to another) could but reduce the loads but not reverse the asymmetry. The same was the case for varying the radial electric field inside the separatrix. However, imposing a large outward E_r in SOL appears to reproduce all the experimental features: the correct asymmetry as well as a sharp peak in the deposition profile next to the separatrix.

ACKNOWLEDGEMENT

This work has been carried out under the European Fusion Development Agreement.

REFERENCES

[1]. G.F. Matthews et al., Journal of Nuclear Materials 290-293 (2001) 668; W. Fundamenski et al., this conference.

[2]. J.A. Heikkinen et al., Physics of Plasmas 8 (2001) 2824; J.A. Heikkinen et al., to appear in Journal of Computational Physics.

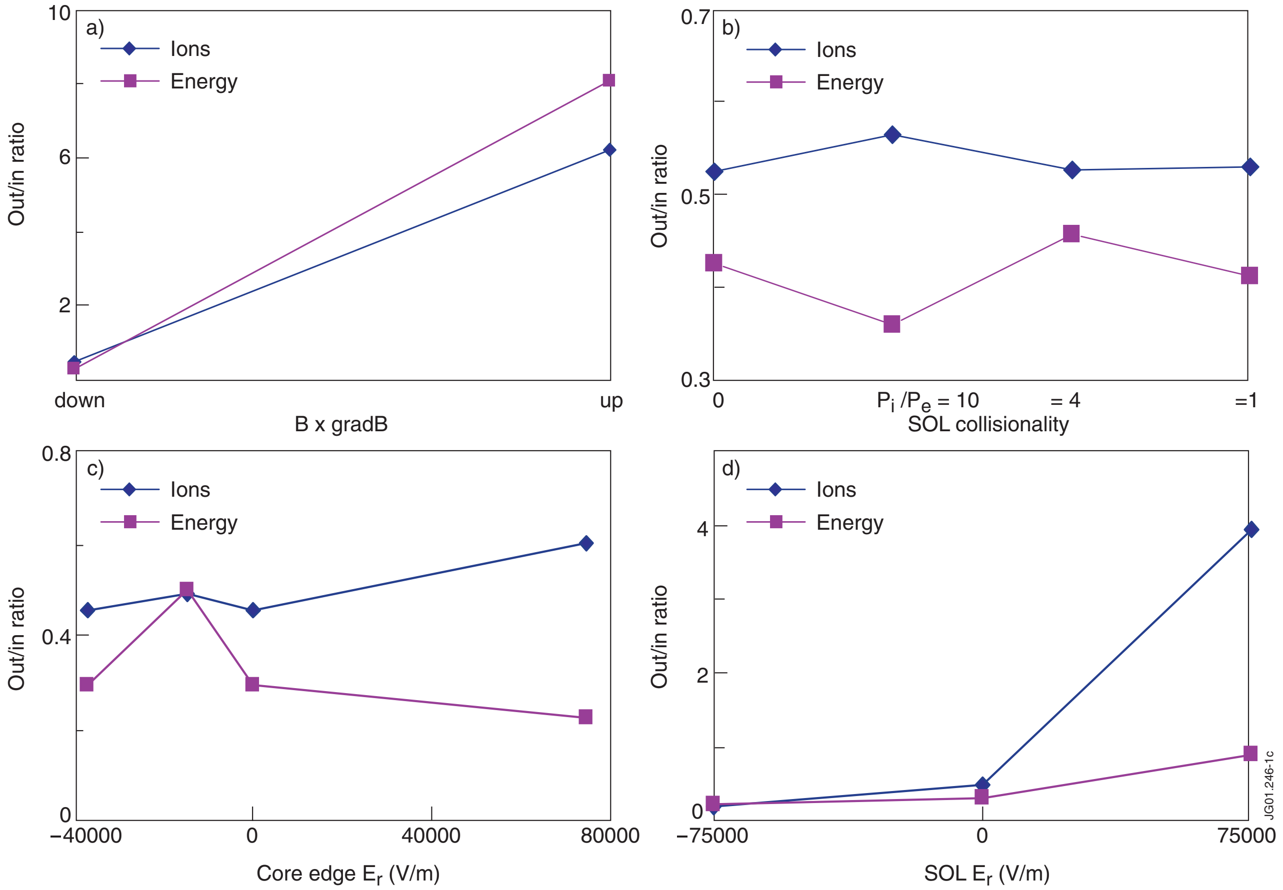

Figure 1: Outer/inner target flux ratios for total ion flux (diamonds) and total heat flux (squares). (a) Normal and reversed magnetic field configuration. (b) The effect of SOL collisionality. P_i=P_e refers to the ion and electron power ratio, and the collisionality thus grows from left to right. (c) As a function of edge E_r inside the plasma. (d) As a function of SOL E_r.

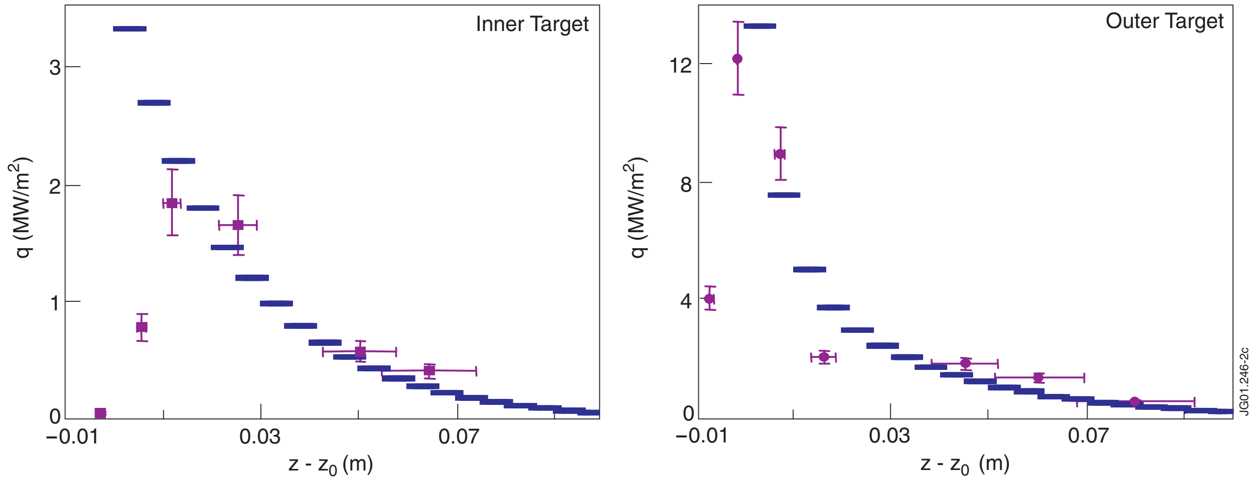

Figure 2: Shot-by-shot (with error bars) and swept measurements of the divertor heat deposition profiles in JET. On the horizontal axis is the vertical distance from the separatrix.

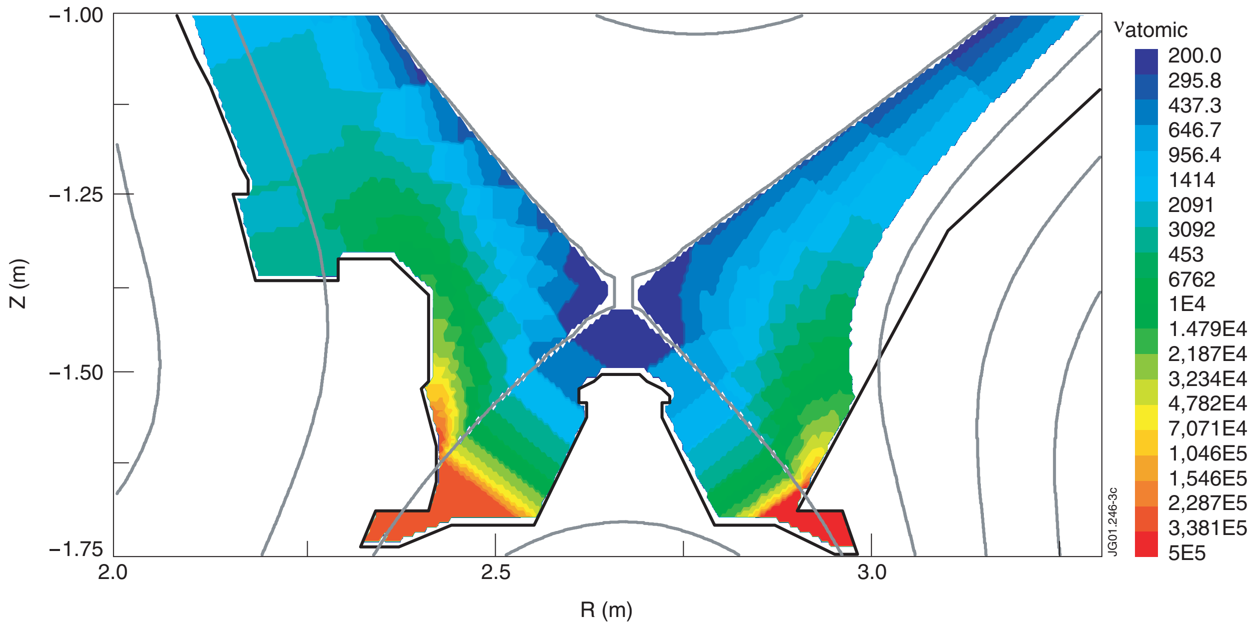

Figure 3: Atomic collisionality in the SOL as seen by ASCOT (only divertor region shown) based on JET Pulse No: 49511. The data was obtained from the OSM2 EIRENE code.

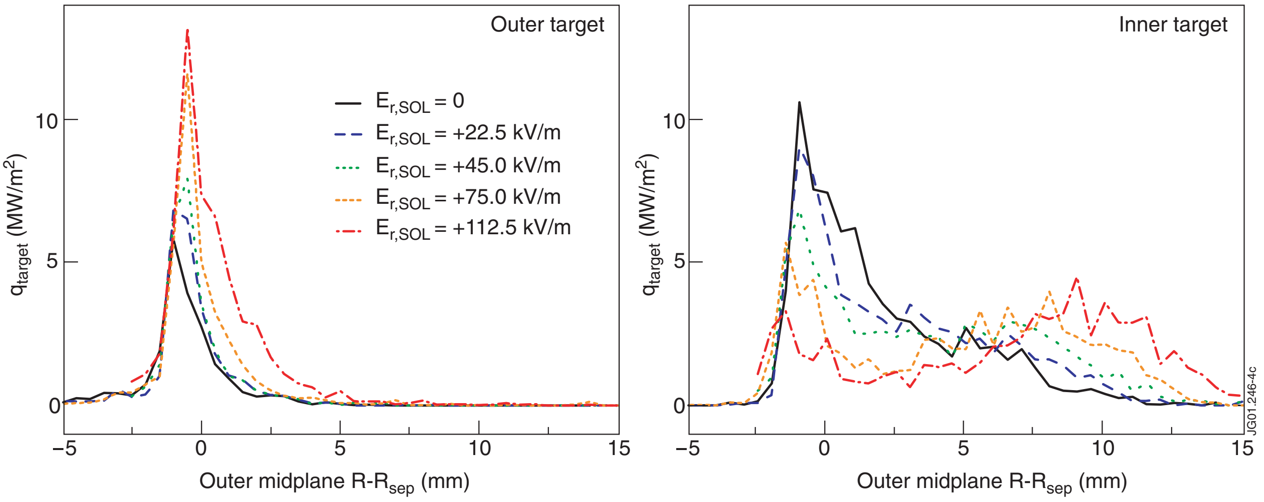

Figure 4: ASCOT simulation of the effect of SOL E_r on power load profiles of outer (left) and inner (right) targets vs. the strike point magnetic surface distance from the separatrix along the outer midplane.