*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-2.111 (2005)*

Guiding-centre simulations of ion orbit loss heat loads on JET divertor targets

S.K. Sipilä [1], W. Fundamenski [2] and JET EFDA contributors[*]

[1] *Assoc. Euratom-Tekes, Helsinki U. of Technology, P.O.B. 2200, FIN-02015 HUT, Finland*
[2] *Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxon, UK*

Introduction. The particle and heat loads on the divertor targets play a significant role in determining the economical feasibility of a tokamak fusion reactor. They are determined by a combination of mechanisms, one of which is ion orbit loss from the edge plasma (pedestal) region [1]. The Monte Carlo guiding-centre code ASCOT [2] has been previously applied to study ion orbit loss using real magnetic geometry and background plasma data. Sensitivity to a number of parameters has been investigated, including SOL radial electric field, edge plasma density and temperature, magnetic field strength and direction and the effect of toroidal field ripple [3]. In these simulations, a strong dependence of *direct* ion orbit loss (no collisions in the SOL) load profiles on the magnetic field direction was observed. Since the experimentally observed dependence is much weaker, this indicates that direct ion orbit loss is not the dominant energy transport mechanism in the pedestal and near-SOL region. It further suggests that ion-ion collisional diffusion must be taken into account to explain the observed load profiles. The importance of collisions is reinforced by indications that (neo)classical ion conduction plays a leading role in the SOL radial energy transport [4].

Simulations. The purpose of the present work is thus to study the effect of SOL/divertor collisionality on the divertor target load profiles for typical JET parameters. The magnetic background and SOL temperature and density data for ions and neutrals for JET discharge 50401 at t = 54 s were used in ASCOT. The pedestal temperature was assumed as 1 keV with a 15 mm temperature pedestal width; the pedestal density was taken as 1.5×10^{19} m^{-3}. 420.000 test deuterons were initialized inside the separatrix according to the local background temperature and density profiles. The guiding-centre orbits of the test deuterons were tracked for 1 ms in the presence of Coulomb collisions in a static Maxwellian background both in the core and in the SOL/divertor. Charge-exchange (CX) collisions in

[*] See the Appendix of J. Paméla *et al*., Fusion Energy 2004 (Proc. 20th Int. Conf. Vilamoura, 2004) IAEA, Vienna.

the SOL were also taken into account, following neutralized test particles along straight lines until re-ionization, re-entry into the core plasma, or wall/divertor collision. To ensure a realistic orbit-loss source, a stationary density profile was maintained inside the separatrix by evaluating the neoclassical ambipolar radial electric field self-consistently from the radial current balance. After a steady-state radial electric field profile was reached, the energy and location of test particles hitting the divertor targets were recorded. Such particles were then re-introduced in such a way that the density profile was kept constant. The hits on the divertor targets from ions and from neutrals were recorded to yield the target load profiles.

Results. The default case corresponds to the reference simulation of shot 50401 described in [5]; the SOL/divertor plasma background was reconstructed based on divertor Langmuir probes using the OSM2/EIRENE code [5]. The radial electric field in the SOL was set to zero in all simulations presented below; in the past, the values of $E_r^{SOL} \sim 30 - 50$ kV/m were found to be necessary to reproduce the observed in-out asymmetries and absolute levels in forward field experiments. However, this strong electric field then led to a large change in asymmetry in reversed field profiles, contrary to experiment. For this reason, the following simulations assume zero electric field from the outset.

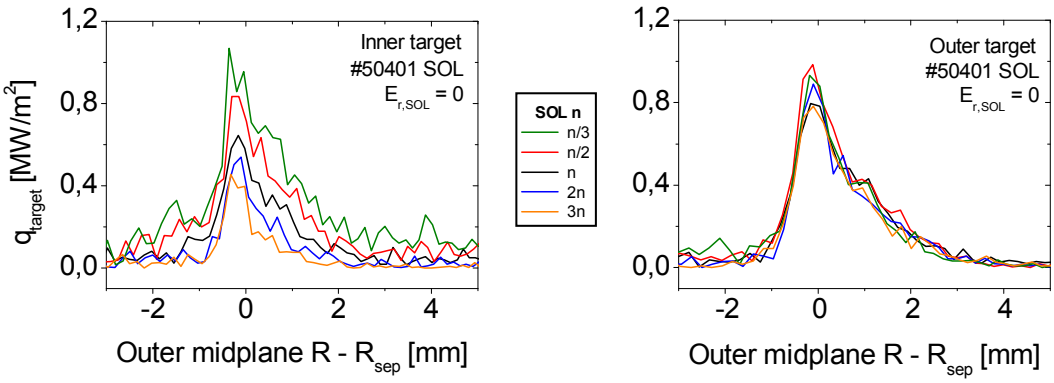

Figure 1. The effect of SOL/divertor density on divertor target loads.

In the first instance, we consider the effect of changing the SOL/divertor plasma and neutral densities while keeping the temperature constant. The resulting heat load profiles on the inner and outer targets are shown in Figure 1, where the radial coordinate has been mapped to the outer mid-plane. Whereas the outer target profiles show little variation with SOL/divertor density (20% per decade), the inner profiles vary by more than a factor of 2 per

decade of density. This effect is caused mainly by a reduction of the ion flux onto the inner target, which drops by a factor of 3 per decade density variation (the outer target ion flux is reduced only by 40% in the same range). The stronger variation of inner target fluxes can be explained by the longer path which the lost ion must travel in the SOL before reaching the inner target (in the forward field direction, ion grad *B* drift pointing down). Nonetheless, the peak heat load of ~ 1 MW/m^2 represents only ~ 15% of the value found in the experiment, suggesting that ion orbit loss accounts for only a minor fraction of the ELM-averaged peak heat load (~ 7 MW/m^2 under these conditions [4,5]). The in-out peak heat load asymmetry $q_{t,outer}/q_{t,inner}$ changes from 1.3 for the default case to 1.8 for double the density and 1.2 for half the density, *cf.* $q_{t,outer}/q_{t,inner}$ ~ 3 measured in the experiment.

As a next step, the SOL/divertor plasma temperature was varied while keeping the density constant, with the results shown in Figure 2. Once again, the outer target profiles are insensitive to background plasma variation, while the inner target peak heat loads change by a factor of 2.5 for decade temperature variation, with largest heat loads for highest temperatures. The peak ion flux on both targets is insensitive to the background temperature variation. The results of both the density and temperature scans are consistent with the expected variation with ion-ion collisionality, $\nu^* \sim n'/T'^2$, where n' and T' are the density and relative temperature of the colliding ions, *i.e.* highest ion orbit loss heat loads with fewest ion-ion collisions.

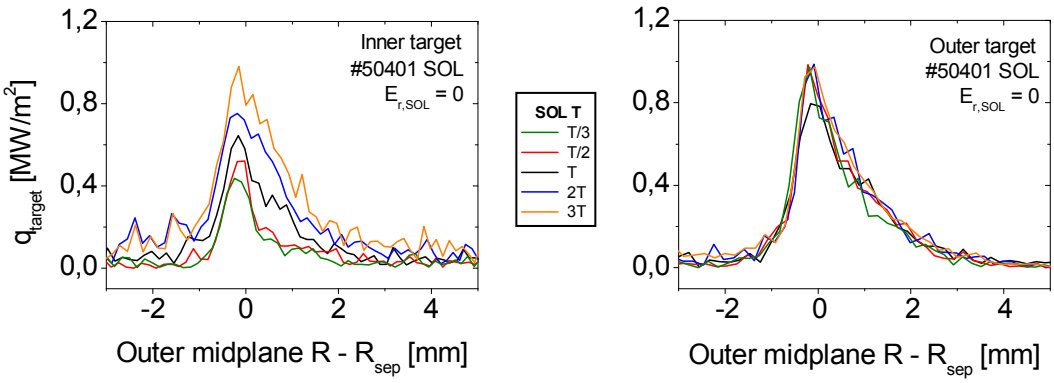

Figure 2. The effect of SOL/divertor temperature on divertor target loads.

Finally, the background density and temperature were varied such as to keep the pressure, $n \cdot T$, constant. The results, shown in Figure 3, are in line with the individual n and T scans. The outer heat load is reduced by ~ 50 % for a decade variation in pressure, while the inner

heat load scales roughly linearly with pressure (factor of ten variation per decade in pressure). The corresponding $q_{t,outer}/q_{t,inner}$ increases to 4 for highest pressure and drops to unity for lowest pressure. The above results are consistent with the collisional origin of the observed effect. This conclusion is further reinforced by simulation in which the ion-neutral charge exchange collisions were disabled with little effect on the resulting load profiles.

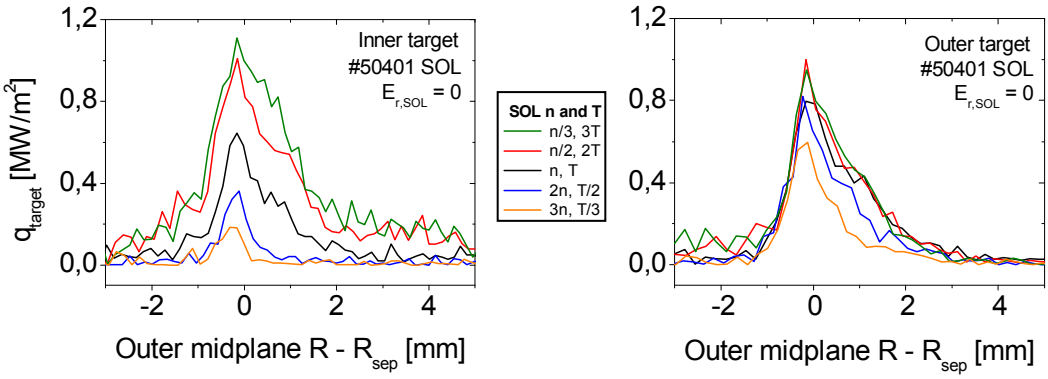

Figure 3. The effect of SOL/divertor collisionality on divertor target loads.

Summary. The impact of collisions with SOL/divertor ions and neutrals on ion orbit loss heat loads was investigated for realistic JET geometry (forward field direction) and plasma profiles. The effect is seen to be much more pronounced on the inner target, consistent with the longer path of the loss ions to that target (with **B**×∇B towards the X-point). Based on independent density and temperature scans, the ion-ion collisionality was shown to be the governing parameter for the peak heat load profiles, *e.g.* peak in-out asymmetry. The effect of charge exchange collisions was found to be relatively minor in comparison. Although the inclusion of ion-ion collisions offers improved agreement with experiment (*e.g.* the large radial electric field in the SOL is no longer required), it can only account for at most 20% of the observed ELM-averaged peak outer target heat loads. Enhanced radial transport, either collisional or anomalous, is clearly necessary to explain the observed load magnitudes.

This work has been conducted under the European Fusion Development Agreement. The computing resources of CSC –Scientific Computing Ltd were used.

[1] G.F. Matthews *et al.*, Journal of Nuclear Materials **290-293** (2001) 668.
[2] J.A. Heikkinen *et al.*, Journal of Computational Physics **173** (2001) 527.
[3] W. Fundamenski *et al.*, Nuclear Fusion (2005), in press.
[4] W. Fundamenski, S. Sipilä *et al.,* Journal of Nuclear Materials **313-316** (2003) 787.
[5] W. Fundamenski, S. Sipilä *et al.*, Plasma Physics and Controlled Fusion, **44** (2002) 761.