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Possible influence of near SOL plasma on the H-mode power threshold[☆]

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ABSTRACT

A strong effect of divertor configuration on the threshold power for the L-H transition (P_{LH}) was observed in recent JET experiments in the new ITER-like Wall (ILW) [1–3]. Following a series of EDGE2D-EIRENE code simulations with Be impurity and drifts a possible mechanism for the P_{LH} variation with the divertor geometry is proposed. Both experiment and code simulations show that in the configuration with lower neutral recycling near the outer strike point (OSP), electron temperature (T_e) peaks near the OSP prior to the L-H transition, while in the configuration with higher OSP recycling T_e peaks further out in the scrape-off layer (SOL) and the plasma stays in the L-mode at the same input power. Code results show large positive radial electric field (E_r) in the near SOL under lower recycling conditions leading to a large $E \times B$ shear across the separatrix which may trigger earlier (at lower input power) edge turbulence suppression and lower P_{LH}. Suppressed T_e's at OSP in configurations with strike points on vertical targets (VT) were observed earlier and explained by a geometrical effect of neutral recycling near this particular position, whereas in configurations with strike points on horizontal targets (HT) the OSP appears to be more open for neutrals (see e.g. review paper [4]).

1. Introduction

There is growing experimental evidence for a strong effect of divertor configuration on the threshold power for the L-H transition (P_{LH}) (see e.g. [1–3] and refs. therein). Recent experiments in JET in the ITER-like (Be/W) wall showed a factor of two reduction of P_{LH} in a configuration with the outer strike point (OSP) on the horizontal tile 5 (hence, 'HT' configuration of pulse #81883) compared to that with the OSP on the vertical target (hence, 'VT' configuration of pulse #84727), see Fig. 1, observed in the high density branch where P_{LH} increases with plasma density. The two magnetic configurations with the plasma current 2.0 MA and toroidal field 2.4 T, as well as plasma parameter profiles, were similar in the core, inside of the magnetic separatrix. Sometimes traces for a pulse similar to the #81883 pulse in the VT configuration can be found in [5].

With no significant difference between global parameters in these two pulses, it was concluded that the explanation for the difference in P_{LH} may be related to a difference of plasma parameters in the extreme edge: in the scrape-off layer (SOL) and divertor. EDGE2D-EIRENE [6–8] simulations reproduced a large difference in experimental target profiles which are described below, leading to a large difference is radial electric field (E_r) which, in turn, may influence plasma turbulence around the separatrix location via $E \times B$ shear [3].

It has to be noted that large differences between target profiles in divertor configurations with strike points on horizontal and vertical tiles were observed earlier in different machines and attributed to different neutral recycling patterns: in VT configurations, neutrals recycling from the target had larger probability to be ionised on flux surfaces hitting the target near the strike point, compared with HT configurations, which appeared to be more open to neutrals (see e.g. review paper [4]). Consequently, measured electron temperature (T_e) had a tendency to peak near the strike point in HT configurations, while being lower at the strike point in VT configurations. One expects similar behaviour in configurations shown in Fig. 1, just that this difference should apply

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[1] See the Appendix of F.Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia.

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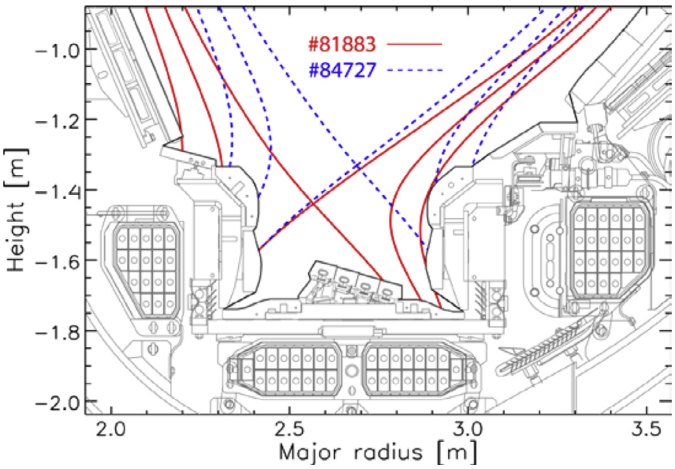

Fig. 1. Magnetic configurations of the HT (#81883) and VT (#84727) discharges in the divertor.

only to OSP, since inner strike points (ISP) are on vertical tiles in both configurations.

2. Setup of EDGE2D-EIRENE cases

EDGE2D-EIRENE grids were built using magnetic equilibria of JET pulses shown in Fig. 1. The grids were optimised for numerical stability of the code runs in the presence of parallel currents and drifts. The optimisation was mainly aimed at avoiding very narrow separation between radial 'rows' in some parts of the grid, e.g. along the row connecting the X-point with the inner target along the separatrix, which resulted in very small cell sizes. Since sharp switching of drifts often leads to numerical instabilities, they were switched on gradually across the entire computational domain. All drifts velocities were multiplied by the coefficient α, which was raised linearly from 0 to 1 over 1 ms time period, which is a standard drift-related option in EDGE2D-EIRENE. Material surfaces in the code runs were assumed as in the ITER-like wall (ILW), and ion species included deuterium (D) and beryllium (Be) with the latter being physically sputtered from the wall. Tungsten (W) was not included in the ion mixture, as W concentrations inside of the plasma covered by the EDGE2D-EIRENE grid were found to be negligible. A neoclassical self-consistent model for E_r was implemented in the core which impeded surface averaged radial currents.

The EIRENE version with Kotov-2008 model [9] was used to describe neutral behaviour. The plasma density was controlled by a combination of gas puff from the PFR and wall recycling ('puff+recycling' option in EDGE2D-EIRENE), aiming at maintaining a specified electron density at the outer midplane (OMP) position of the separatrix, $n_{e,sep}$. Due to some difference in line average electron density (larger by ~8.5% in the HT pulse), a somewhat higher electron separatrix density at OMP in the HT case, $n_{e,sep} = 1.2e19\,m^{-3}$, compared to $1.0e19\,m^{-3}$ in VT, was specified. These choices were partly motivated by the known effect of a non-linear dependence of $n_{e,sep}$ on line-average density at low to medium densities, and partly by the desire to match target profiles measured by Langmuir probes.

The input power into the grid was set at 2.7 MW in both cases, to match experimental power balance. In the code, the input power was equally split between ion and electron channels.

Divertor and target plate parameters in EDGE2D-EIRENE cases are strongly influenced by arbitrarily specified anomalous transport coefficients. Between ion and electron heat conductivities, and particle diffusion coefficient, often the relation $\chi_{e,i} = 2/3D_\perp$ is assumed. At the same time, in recent EDGE2D-EIRENE simulations of JET -L-mode plasmas it was found that better match with target Langmuir probe measurements can be achieved if $\chi_e \approx D_\perp$ across most of the SOL and PFR is assumed, with $D_\perp$ being reduced in the outer core and SOL regions around the separatrix position [10]. In the simulations described here, the following transport coefficients were assumed: $D_\perp = 1\,m^2\,s^{-1}$ and $\chi_i = 2\,m^2\,s^{-1}$ across the whole grid, $\chi_e = 1\,m^2\,s^{-1}$ everywhere except for the main SOL (not including the divertor) where it was reduced to $0.5\,m^2\,s^{-1}$.

Physical sputtering model for Be impurity was assumed. In all EDGE2D-EIRENE cases, however, Be radiation represented only a few percent of the total radiated power which was dominated by the deuterium Lyman alpha radiation. The same result comes from the experiment [11]. Also, target $T_{e,i}$ and n_e profiles in cases with Be were quite close to those with pure deuterium.

Catalogued EDGE2D-EIRENE cases can be found in: alexc/edge2d/jet/81883/nov1015/seq#1 for HT and alexc/edge2d/jet/84727/nov1015/seq#1 for VT configurations.

3. Comparison between EDGE2D-EIRENE output and experimental results

Fig. 2 shows experimental Langmuir probe and EDGE2D-EIRENE simulated target profiles of T_e, n_e and ion saturation current j_{sat} along inner and outer targets in both configurations, mapped to radial positions at OMP. The profiles are plotted vs. distance from the separatrix (strike points on both targets) which are indicated by horizontal dash-dotted lines mapped to positions at the OMP. Due to uncertainties in the equilibrium reconstruction experimental profiles were arbitrarily shifted (IT profiles by 0.5 cm in both HT and VT cases, and OT profiles by 1.2 cm in the HT and 1.7 cm in the VT case, all shifts towards the high field side) and their positions on the targets were converted into distances from the separatrix using linear interpolation based on EDGE2D-EIRENE positions.

The most important feature of the code results is a much more peaked T_e at OT in the HT configuration, obtained for the same input parameters as in VT (even, in the more challenging setup, with a 20% higher $n_{e,sep}$). This is related to the recycled neutrals being ionised more strongly along the separatrix in the VT, compared to HT configurations, which is a purely ballistic effect of recycling neutrals [4]. This results in lower target T_e and higher target n_e near strike points at outer target (OT) in the VT compared to the HT configuration. At the inner target (IT), the situation regarding code to the experiment comparison is similar for the two configurations, since the configurations are almost the same on the inner (high field) side. It has to be noted that results analyzed in [4] were obtained in machines with carbon walls, while experimental and code results presented here are obtained in the ILW environment on JET. One of the consequences of this change is the loss of the intrinsic radiator (C) in ILW: W concentrations in the SOL and divertor are negligible, while some Be sputtering from the main chamber (Be) wall doesn't lead to high enough radiation losses which would strongly influence the radiation pattern established by the main working gas (usually D) radiation. As a result, an introduction of non-intrinsic impurities (N, Ne etc. gases) is required to increase radiation in the SOL and divertor. All these aspects, focusing on the difference between the C and ILW environments are discussed in the review paper [12].

In the HT configuration, all code OT parameters are more peaked near the strike point and larger than experimental ones in the common flux region (CFR), on the main SOL rings. According to the probes, there exists the plasma in the private flux region (PFR), especially at the outer target, which is not seen in the code output. The reason for this strong discrepancy may be related to deficiencies of the transport model used in the code or the neglect of neutral leakages from divertor structures (see [12] and refs.