Comparisons between EDGE2D/EIRENE simulations and D and low Z impurity spectral emission from JET ITER-like wall L-mode plasmas

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1. Introduction

An understanding of the behaviour of the plasma edge and divertor physics is essential for the design of next-step machines such as ITER, for which JET with its ITER-Like Wall (ILW) of Be in the main chamber and W in the divertor is ideally suited. The fuel and edge impurities affect the power balance, this determining the power reaching the divertor target plates, which are limited by the mechanical and thermal properties of the plates. A recent comparison (Groth *et al.*, 2013) of L-mode discharges run during the present JET-ILW campaign and previous JET-C campaigns, in which the plasma-facing surfaces were predominately C, have consistently shown a shortfall in the radiated power calculated from EDGE2D/EIRENE simulations below that measured by bolometry. In order to understand this discrepancy, the contributions to the divertor radiated power as predicted by the simulations have been quantified and the results compared with measurements from a recently upgraded poloidally scanning VUV/visible spectrometer (Lawson *et al.*, 2012).

2. The poloidally scanning VUV / visible spectrometer

The spectrometer has two systems, one with a vertical view of the divertor, the other looking from a horizontal port towards the top of the inner wall (figure 1). Each system includes a VUV spectrometer, which measures 2 spectral lines within the wavelength range ~200 to 1500 Å and a tritium-compatible visible telescope that collects light for transmission via optical fibres to a room remote from the torus hall. The light is analyzed by 8 PMT/filter combinations and a Czerny-Turner spectrometer. The poloidal scan of ~125 (vertical) and ~105 ms (horizontal) is achieved by compact oscillating mirrors outside the torus vacuum. Results from the divertor view are presented here.

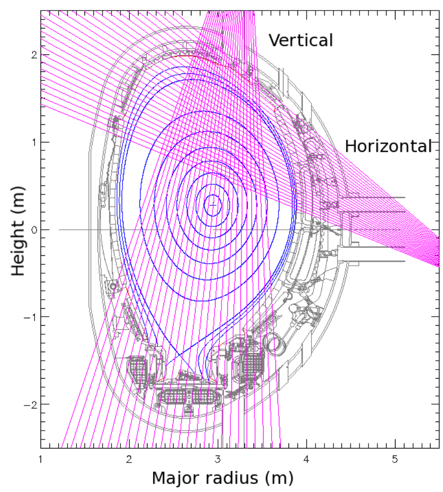

Figure 1. The spectrometer lines-of-sight.

3. Contributions to the modelled power radiated from the divertor

The simulations of the JET-ILW, L-mode, NBI heated discharges of Groth *et al*. have been used to determine the radiated power contributions. They apply to a density scan series of 2.5MA / 2.5T, L-mode pulses (81472-81492) heated with 1.1, 1.2 or 1.6MW of NBI. The simulations are listed under pulse 81472 and have D fuel with Be and W impurities. They have been carried out for a range of outer midplane separatrix densities, $n_{e,sep}$, (7×10^{18} m^{-3} up to the maximum at which the simulations converge of $2\text{-}2.2\times10^{19}$ m^{-3}). A range of powers transported across the separatrix into the Scrape-Off Layer (SOL) was considered, although results are only presented for the extreme cases of 2.2 and 2.8 MW. The version of the EDGE2D/EIRENE code adapted to include D_2 and D_2^+ molecules was used (Kotov *et al*., 2008). To allow comparisons with the spectrometer measurements, the contributions are integrated along the diagnostic lines-of-sight, although the D emission predominately comes from the divertor region. Table 1 presents the results, the estimate of the Be impurity radiation being given by the simulations described in section 5.

Table 1. Contributions to the divertor radiated power.

Contributions from D+Be+W simulations	
Line radiation from D.	Ly_α ~85-90%, Ly_β ~10% and other lines ~3%.
D line radiation due to recombination directly populating excited D atomic levels.	$<10^{-5}$ of D line radiation.
Line radiation from D_2 molecules.	~10% of D line radiation.
Line radiation from D_2^+ molecules.	~3% of D line radiation.
Radiative recombination to D followed by cascading + Bremsstrahlung.	$<10^{-2}$ at low $n_{e,sep}$, rising to ~30% at high $n_{e,sep}$.
Contributions from D+Be simulations (section 5)	
Be impurity radiation.	Variable - few % in cases considered.
Estimated contributions	
C and O impurity radiation.	Variable - generally less than Be.
High Z impurity (Ni, Cu and W) line radiation.	Generally smaller than low Z elements at the low T_e of the divertor.

It can be seen that the largest component is due to D line radiation, in particular from the Ly_α line. An estimate of the electronic line radiation from molecules (the dominant component) is obtained by assuming the same electron collisional excitation and radiative decay rates as for D atoms. Free electron recombination, which for D is radiative recombination, is comparatively small for many of the simulations, the power radiated, including from the subsequent cascading and from Bremsstrahlung being <1%. The power radiated by Be is obtained from the simulations described in section 5. The line-integrated radiated powers along the diagnostic line-of-sight can be further integrated across the divertor from a major radius R = 2.31 to 2.94 m (figure 2).

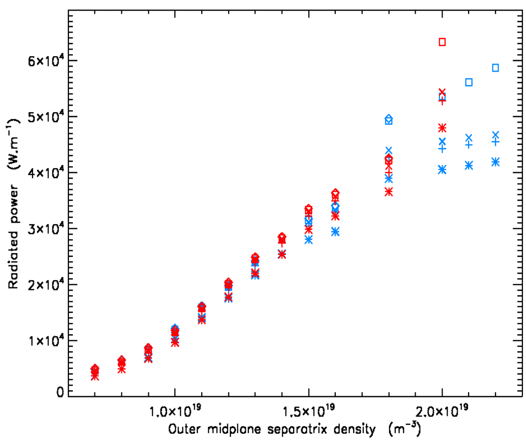

Figure 2. Cumulative component powers radiated from divertor. * D, + D_2, × D_2^+ lines, □ recombination and ◊ Be impurity. Power to SOL 2.2 MW blue symbols and 2.8 MW red symbols.

4. Comparison with measured D emission profiles

Figure 3 compares measured and simulated D_α line-of-sight integrated emission profiles plotted against R at a height of z = -1.6 m for a low and high $n_{e,sep}$ case. It is noted that there is up to a ~6 cm uncertainty in the radial position of the measured features. Further, Ly_α intensities can be obtained from those of Ly_β using ratios from the simulations and the power radiated by D lines determined. The D line powers found in this way and integrated across the inner (R = 2.31-2.53 m) and outer (R = 2.53-2.94 m) divertor regions and the total divertor signal are compared with the corresponding parameters from the simulations in figures 4-6 for the pulses 81472-81492. $n_{e,sep}$ of the measurements is determined from an edge line-averaged density measured by interferometry, normalised to the lowest density point, pulse 81472 at 50 s. Good agreement is found for both Ly_β / D_α and the total powers at low $n_{e,sep}$, although an imbalance is seen between the inner and outer divertor emissions. The simulations underestimate the inner intensities and power and overestimate those from the outer divertor. Drifts are not included in the present simulations; their inclusion would be expected to ameliorate this discrepancy, as well as cooling the inner divertor plasma, bringing the peaks in the simulated and measured inner divertor emission profiles closer together. At high $n_{e,sep}$ all measurements exceed the simulation results, in the case of the total divertor power by ~×2. It is noted that the analysis does not take opacity into account, this effect increasing the discrepancy.

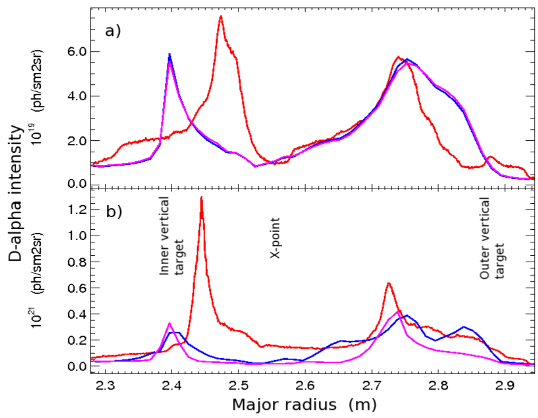

Figure 3. Measured (red) and simulated (blue 2.2 MW power to SOL, purple 2.8 MW) D_α intensities. Pulse 81472 a) 50 s, $n_{e,sep}$ = 8.0×10^{18} m^{-3}, b) 57 s, $n_{e,sep}$ = 1.8×10^{19} m^{-3}.

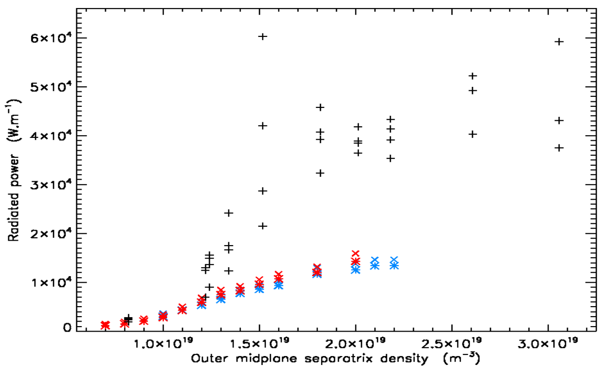

Figure 4. Measured and simulated powers radiated from inner divertor. + measured, * D and × $D+D_2+D_2^+$ lines. Power to SOL 2.2 MW blue symbols and 2.8 MW red.

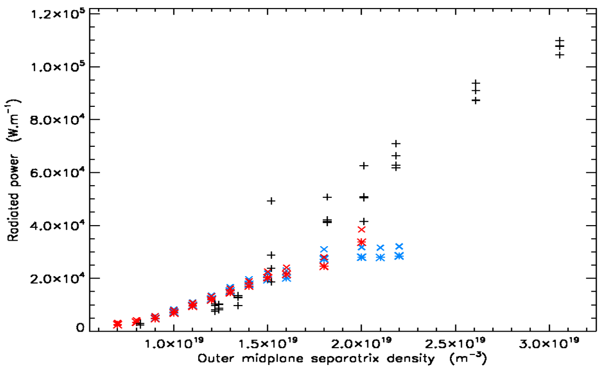

Figure 5. Measured and simulated powers radiated from outer divertor. + measured, * D and × $D+D_2+D_2^+$ lines. Power to SOL 2.2 MW blue symbols and 2.8 MW red.

5. Comparison with measured Be emission profiles

The EDGE2D/EIRENE simulations with a W divertor underestimate the Be emission in the region of the divertor. In the code, no allowance is made for the previous deposition of Be onto the W divertor plates during plasma operations (Krieger *et al.*, 2013) and its release from the plates during a pulse. This process adds to the Be ion density in the divertor region, beyond that transported from the torus walls. To simulate this, runs were carried out with pure Be divertor plates (i.e. all plasma facing surfaces are Be), but with a reduced sputtering yield. Figure 7 shows that the yield must be reduced by a factor ~20 to match the measured 527nm, Be II profiles in the divertor, although a serious shortfall in the outer divertor simulated emission is still observed at high $n_{e,sep}$. It should be emphasized that these simulations are only illustrative in that the yield is reduced for all Be surfaces, including, inappropriately, the Be walls.

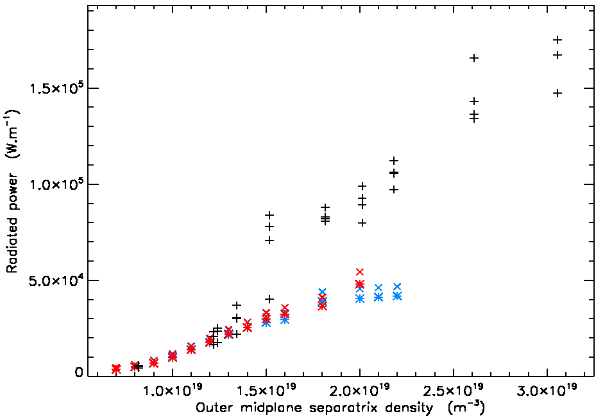

Figure 6. Measured and cumulative simulated powers radiated from the divertor. + measured, * D and × $D+D_2+D_2^+$ lines. Power to SOL 2.2 MW blue symbols and 2.8 MW red.

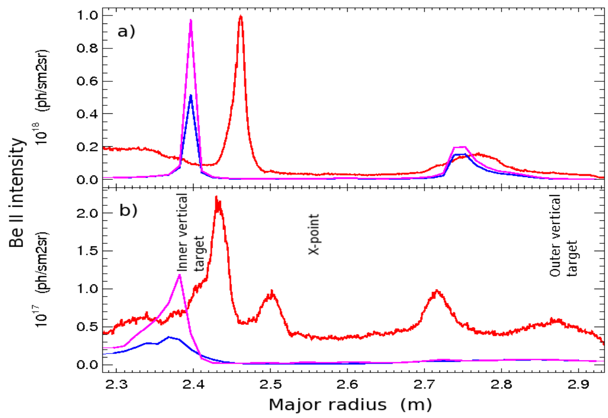

Figure 7. Measured (red) and simulated (blue 2.2 MW power to SOL, purple 2.8 MW) 527nm, Be II intensities. Pulse 81472 a) 50 s, $n_{e,sep}=8.0\times10^{18}$ m^{-3}, b) 57 s, $n_{e,sep}=1.8\times10^{19}$ m^{-3}. Reduction in sputtering yield ×20.

6. Conclusions

The components of power radiated from the JET divertor in a density scan series of L-mode, NBI heated discharges have been assessed through an analysis of EDGE2D/EIRENE simulations. It is shown that D, D_2 and D_2^+ line radiation accounts for >90% of the radiation at low $n_{e,sep}$, with radiative recombination becoming important (~30%) at high $n_{e,sep}$. The D_2 and D_2^+ molecules add ~13% of the D line contribution to the power, while contributions from impurities in the cases considered is small (a few %). The spectroscopic measurements of the D_α / Ly_β line intensities agree with EDGE2D/EIRENE simulations at low $n_{e,sep}$, but exceed the simulations at high $n_{e,sep}$. These data permit the power radiated by D lines to be determined, for which there is a corresponding agreement at low $n_{e,sep}$ and excess at high $n_{e,sep}$ of ~×2. Be is deposited on the W divertor plates during plasma operations and its subsequent release requires a sputtering yield a factor ~20 lower than from pure Be divertor plates to match the Be spectroscopic measurements.

References

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Acknowledgments

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* *See the Appendix of F. Romanelli et al., Proc. of the 24th IAEA Fusion Energy Conference 2012, San Diego, USA*