MODELING OF IMPURITIES IN THE ASDEX UPGRADE DIVERTOR II WITH DIVIMP AND B2-EIRENE

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Introduction In this study the spectroscopic measurements of C^{2+} emission in the Divertor II configuration of ASDEX Upgrade are compared with modeling results of carbon erosion and transport. The plasma is simulated using the multifluid-Monte Carlo 'B2-EIRENE' code package [1]. The computed hydrogenic plasma is also used as input for the two dimensional Monte Carlo impurity transport code 'DIVIMP' [2]. Line of sight integrated C^{2+} emissivities obtained from both codes are compared with measurements.

Experiment In the ASDEX Upgrade divertor arrays of lines of sight viewing radially across the strike points are available for spectroscopic measurements in the visible spectral range (Fig.1). The lines of sight are coupled via optical fibers to two photomultiplier systems equipped with interference filters. The C^{2+} line at 465 nm was measured with a time resolution of 150 μs. The discussed results refer to the stationary phase of a hydrogen fuelled L-mode discharge (#11275). The main plasma parameters are as follows: plasma current $I_p = 1$ MA, average electron density $n_e = 4{\cdot}10^{19}\,m^{-3}$, toroidal magnetic field B_t = -2.5 T, neutral beam power P_{NBI} = 3.4 MW. The plasma was radially shifted during the discharge to provide improved spatial resolution of edge temperature and density measurements. The presented measured data are the time average between 2.1 and 2.7 s.

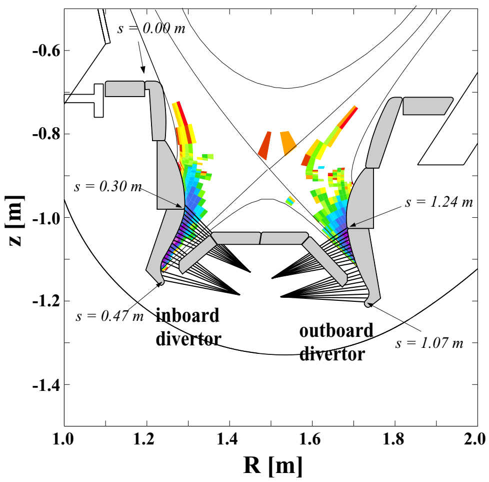

Figure 1: Simulated 465 nm C^{2+} emissivity $[ph\,m^{-3}s^{-1}sr^{-1}]$ obtained from 'DIVIMP' and geometry of the measuring lines of sight in the divertor .

Plasma modeling The plasma is modeled by using the 'B2-EIRENE' code package. Bulk species H^+ and C^{1+}-C^{6+} are considered and described in the fluid approximation by the 'B2' multi-fluid code. This description is self-consistently coupled to the 'EIRENE' Monte Carlo code, which calculates the spatial distribution of neutral hydrogen and the source term for the impurities. The numerical grid for the simulation is obtained from magnetic equilibrium data of the analyzed shot.

For parallel transport, classical coefficients are used. With respect to the cross-field diffusion, anomalous heat and particle diffusion are assumed. The heat diffusivity and the particle diffusion coefficients are assumed constant with values obtained from the interpretive version of the two dimensional edge plasma fluid code 'B2.5-SOLPS5.0' [3]. The diffusion coefficients for the discharge ($\chi = \chi_e = \chi_i \simeq 1\,m^2/s$, $D_\perp \simeq 1\,m^2/s$) are obtained by minimizing the difference between code prediction and measurements. This interpretive vesion of the code is faster and well suited to model the main plasma, but not very accurate in divertor plasma modelling. No pinch velocity is considered.

The diffusion coefficients, the temperature and density profiles and other main chamber measurements are used as input parameters for the full version of the code. Since divertor measurements are not used as code input, it is important to validate the computed plasma in the divertor.

The integrated flux and power in both divertor legs and the total radiated power are reasonably well reproduced by the code (Tab.1). The inboard divertor is however partially detached. In this conditions the measurements are more difficult to interpret and the code has difficulties to model the observed asymmetries between the two divertor legs. In the following the discussion is therefore restricted to the results for the outboard divertor.

In Fig.2 are plotted a) power density measured from thermography and radiation power density onto the target plate from bolometry deconvolution, b) flux density and c) electron temperatures measured from Langmuir probes and the corresponding values predicted from the code as function of the distance S along the target in the outboard divertor. The computed plasma in the outboard divertor reproduces nicely the measurements and therefore will be used to study impurity production from the target plate.

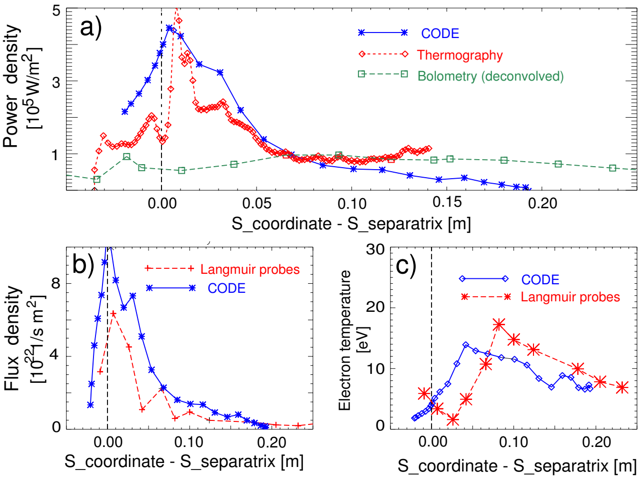

Figure 2: a) Power density and radiation power density, b) ion flux density c) electron temperature and the corresponding calculated quantities as function of the coordinate S-S$_{sep}$ along the target.

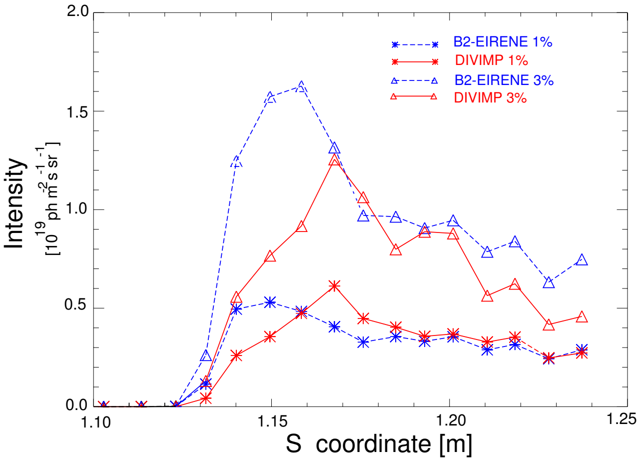

Figure 3: Line of sight integrated C^{2+} intensity (465 nm) for 1% and 3% chemical erosion yield for DIVIMP and B2-EIRENE.

Impurity modeling Both 'DIVIMP' and 'B2-EIRENE' codes can treat impurities, however with different underlying physical models. 'DIVIMP' follows trajectories of impurity neutrals and ions in a given background plasma. 'EIRENE' calculates the particle sources with the resulting ion source rate transferred to B2, which treats the ion species as a fluid. In 'DIVIMP' the impurity source is calculated similarly to 'EIRENE', however without taking into account neutral hydrogen impact.

Integral values	DIVIMP	B2-EIRENE	Measurements
Particle Flux In [s^{-1}]	6.6e22	5.3e22	1e22
Particle Flux Out [s^{-1}]	6.4e22	6.2e22	3e22
Power In [W]	5.1e5	3.1e5	2e5(Probes)/2.5e5(Therm.)
Power Out [W]	7.2e5	8.6e5	6e5(Probes)/2.8e5(Therm.)
Total radiation [W]	1.1e5 (Only C)	6.3e5	7.5e5

Table 1: Comparison of global plasma measurements and code predictions

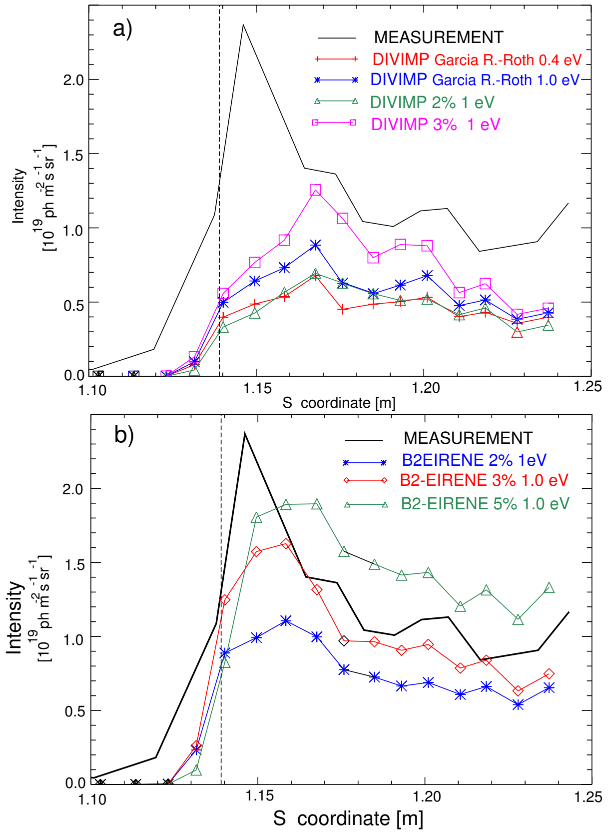

Figure 4: Measured and calculated line of sight integrated C^{2+} intensity (line at 465 nm) for different chemical erosion models with a) 'DIVIMP'and b) 'B2-EIRENE'.

'DIVIMP' needs as input the plasma geometry mesh, as also used by 'B2-EIRENE', the plasma background parameters and the cross field diffusion coefficient $D_\perp$ (here assumed radially constant). The background plasma is obtained from 'B2-EIRENE' and the diffusion coefficient set to $D_\perp = 1\ m^2/s$ according to the 'B2-EIRENE' value. For the calculation of the carbon source term, both physical sputtering and chemical erosion are taken into account. The self-sputtering contribution are negligible. Atomic data used for calculation of line emissivities are taken from the ADAS database [4] for both codes.

Fig.3 shows the line integrated intensities along the line of sight in the outboard divertor as function of the cross-section coordinate S (see Fig.1) of the line of sight with the target plate, assuming physical sputtering and 1% and 3% constant chemical erosion yield for both 'B2-EIRENE' and 'DIVIMP', using the corresponding 'B2-EIRENE' background plasma. The two models agree for S $\geq$ 1.17 m, but differ towards the separatrix. Here and in the following physical sputtering is always considered, in addition to chemical erosion, with yields obtained from Eckstein/93[5].

Results and discussion Fig.4(a) shows line integrated C^{2+} intensities from 'DIVIMP' assuming chemical erosion yields according to Roth-GarciaRosales/96 [6], with 0.4 eV and 1 eV input (Franck-Condon) energy, and for constant chemical erosion yield (2% and 3%, 1 eV Franck-Condon energy). The best agreement with the experiment is obtained with 3% constant chemical yield. Still this sputtering option fails to reproduce the emission maximum near the separatrix at the strike point.

Fig.4(b) shows the line integrated emission obtained from ‘B2-EIRENE’ for 2%, 3% and 5% constant chemical erosion yields, with 1 eV input energy. The best matching is obtained for a erosion yield between 3% and 5%.

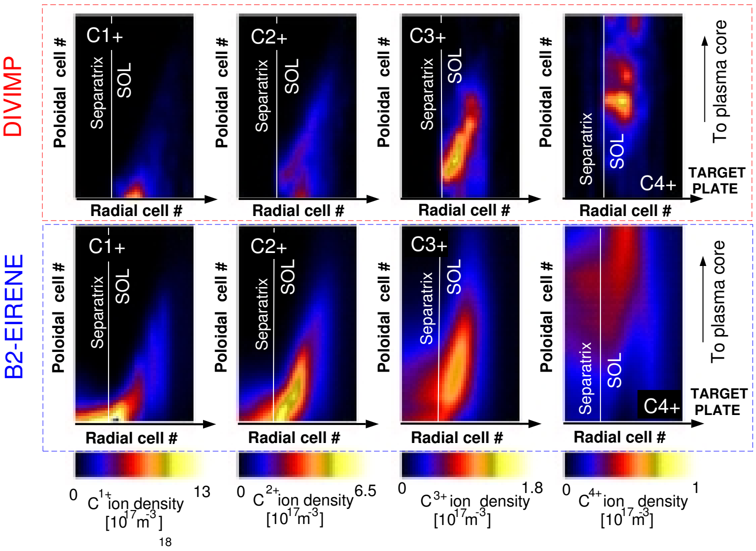

Figure 5: Carbon densities for different ionization states calculated from ‘DIVIMP’and ‘B2-EIRENE’.

To illustrate the influence of the transport models on the calculated spatial distribution of carbon, Fig.5 shows the two dimensional density distribution for different carbon ionization states for both codes. In each image in the Figure the vertical coordinate represents the magnetic field line direction from the target (bottom) towards the plasma core (top) and the horizontal coordinate represents the perpendicular direction to the field, from private flux region (PFR,left) into the scrape off layer (SOL, right). The C^{1+} density in the SOL is similar in both the codes, but differs in the PFR. Moreover the different evolution in the ion density distribution among the different ionization states for the two codes, indicates an effect of the different transport models.

Conclusion Similar results are obtained with ‘B2-EIRENE’ and ‘DIVIMP’ using the same background plasma and analog sputtering models, but significant discrepancies arise approaching the separatrix position. A fairly good agreement is shown between divertor measurements and model predictions, both for the profile shape and the absolute value in the outboard divertor. ‘B2-EIRENE’ is able to reproduce the emission maximum near the separatrix better than ‘DIVIMP’. This is explained with an important contibution to the carbon influx from neutral particles sputtering, accounted for in ‘B2-EIRENE’ but not in ‘DIVIMP’. Another difference, but apparently less important in this first analysis, is the different underlying transport approach: fluid in the first case, kinetic in the second. More measurements and analysis are underway for comparing other emission lines (CII, H_α) in both L-mode and H-mode discharges.

References

[1] D.P. Coster et al., J.Nucl.Mater. **241-243** (1997) 690.

[2] P.C. Stangeby and J.D. Elder., J.Nucl.Mater. **196-198** (1992) 258.

[3] J.W. Kim et al., J.Nucl.Mater. **290-293** (2001) 644.

[4] H.P. Summers, in: Atomic Data and Analysis Structure User Manuals Users Manual, Rep. JET IR(94) 06, JET Joint Undertaking, Abingdon (1994)

[5] W. Eckstein et al., Sputtering Data Rep. IPP 9/82, Max-Planck-Institut fur Plasmaphysik, Garching (1993).

[6] J. Roth, C.Garcia-Rosales, Nucl.Fus. **36** (1996) 1647.