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Numerical simulation of the opacity effects in divertor plasma of large scale tokamak devices

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Currently the steady-state modelling of the ITER divertor plasma is performed with SOLPS4.2 (B2-EIRENE) code package [1]. It comprises 2D multi-species plasma fluid code B2.4 [2] (without classical drifts [3]) and the Monte-Carlo neutral transport code EIRENE [4]. The SOLPS4.2 supports a number of advanced features of EIRENE code (which are absent and SOLPS4.0,5.0 [3]) such as neutral-neutral collisions (NNC) in BGK approximation [5], refined model for molecular kinetics [6] including elastic collisions $D_2 + D^+$ and Molecular Assisted Recombination due to ion conversion $D_2(\nu) + D^+ \rightarrow D_2^+ + D$ (MAR) [7]. The EIRENE model was recently extended by radiation transport of Lyman (Ly) series photons [8] and subsequent adaptation of the effective ionization rate for the hydrogen atom [9] due to ionization from the photo-excited states (this effect is referred below as "photon opacity").

An analysis of the impact of different model features was carried out for a series of ITER cases with full carbon walls and 100 MW input power [1, 10]. It was found that for the operational scalings of the main engineering parameters, e.g. maximal target heat flux, the main new effect comes from NNC and from $D_2 + D^+$ collisions, Fig. 1a. The photon opacity is found to be significant for ionization-recombination balance. In the high density case (average divertor neu-

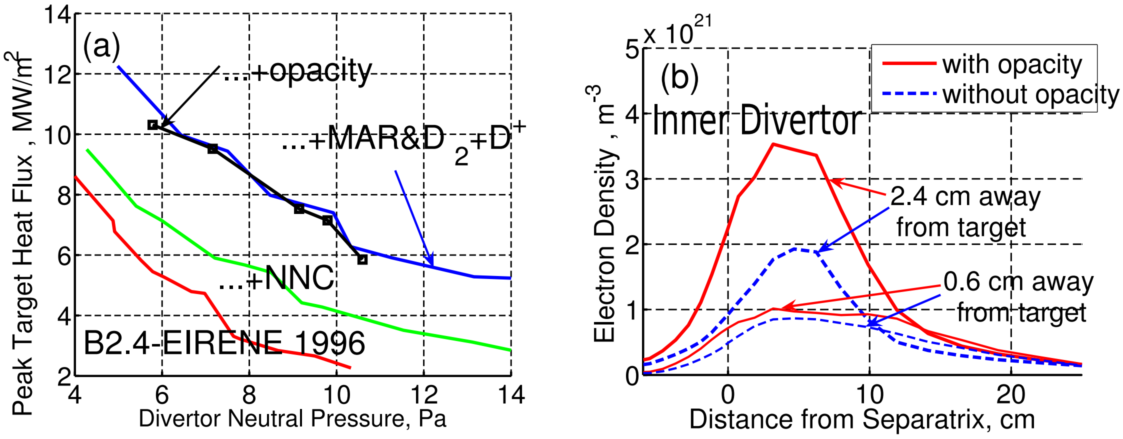

Figure 1: Effect of the new EIRENE for the ITER modelling

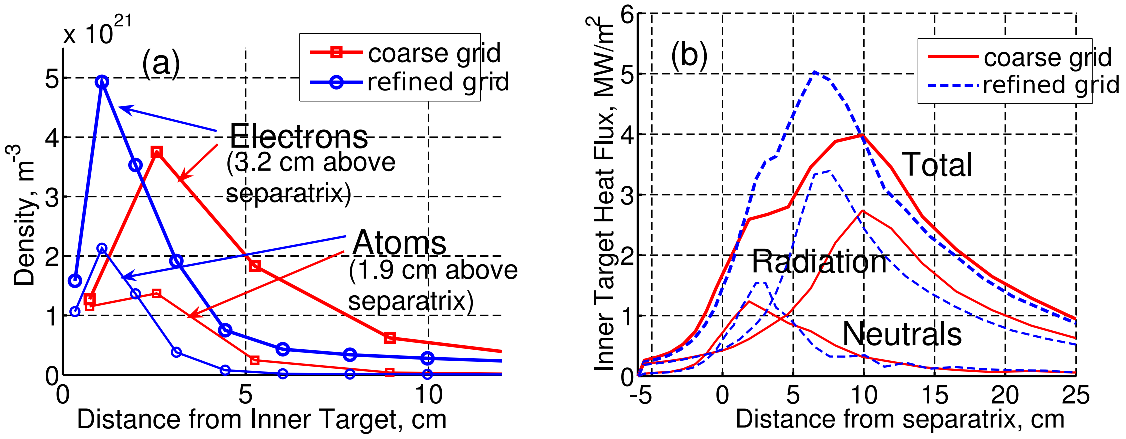

Figure 2: Influence of the grid resolution on the results of the calculations

tral pressure P_{neut} =10.5 Pa) this additional channel is responsible for 80 % of ionization source for inner and for 50 % for outer divertor. This leads to significant (factor 2) rise of predicted electron density in front of the targets, Fig. 1b, accompanied by somewhat lower temperatures. The total ionization source increases 2-3 times compared to the optically thin case. This rise is followed by the rise of the volume (3-body) recombination which then becomes larger than the target recycling sources [10].

The calculations for ITER are typically made on a relatively coarse grid (for reasons of numerical performance). A test calculation was made doubling the poloidal resolution of the grid in the divertor. This simulation shows the maximum plasma density closer to the target and higher densityes near the targets, Fig 2a. The distribution of the plasma parameters in front of the targets and the target heat flux, Fig 2b, are nearly the same. The difference is smaller for the outer divertor. The ionization-recombination balance and the emission-absorption balance for Ly radiation are the same for both grids. However, the presence of strong gradients near the targets make it desirable to use finer grids in future.

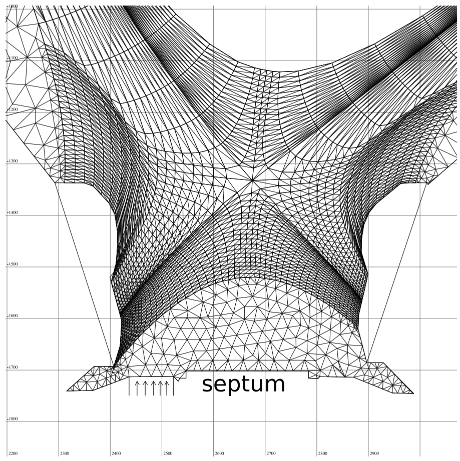

Figure 3: Computational grid and structure for the JET model

Recently a first calculations with SOLPS4.2 were done for a JET model with Diagnostic Optimised Low (DOC-L) magnetic configuration [11] and Mk2GB-SR divertor structure, Fig 3. The "reference case" has the power flux from the core $P_{in} = 14\ MW$ and radiated power $P_{rad} = 5\ MW$ (carbon sputtering yield $Y_{chem} = 0.45$ %). The wall and pumping albedo A_w and A_p were

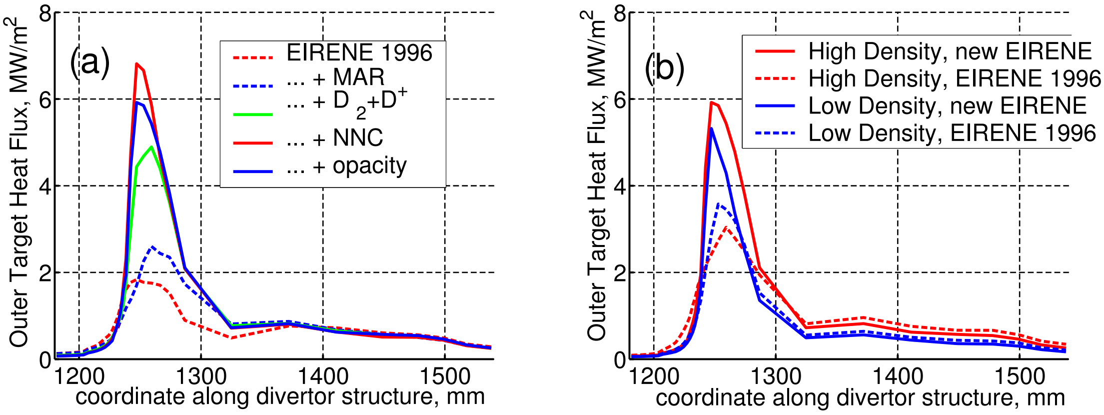

Figure 4: Contributions of the individual effects of the neutral model to the solution

specified to get a certain neutral flux ($F_{neut} = 5.6 \cdot 10^{22}\ m^{-2}/s$, flux of molecules) to the septum plate, Fig 3. The corresponding density at the core-edge interface was $n_{up} = 2.9 \cdot 10^{19}\ m^{-3}$. The calculated maximum electron density in the divertor reaches $1.2 \cdot 10^{21}\ m^{-3}$.

To study the contribution of each of the new features in SOLPS4.2 individually a series of calculations was performed with: 1) model of EIRENE 1996 (which is used in SOLPS4.0, 5.0 [3]); 2) "model 1" plus MAR and improved reaction rates [**?**, 9]; 3) "model 2" plus elastic collisions $D_2 + D^+$; 4) "model 3" plus NNC; 5) "model 4" plus photon opacity. An example of the results is shown in Fig 4a. The largest effect is due to elastic collisions $D_2 + D^+$. In those calculations Y_{chem}, A_w and A_p were the same for all models. Therefore the observed large difference between the EIRENE 1996 and the most recent model ("model 5") could be because of the different resulting P_{rad} and F_{neut}. To perform physically correct comparison the same P_{rad} and F_{neut} as in the reference case (previous paragraph) were restored for EIRENE 1996. The difference becomes smaller but remains significant, Fig 4b. "High Density" in Fig. 4b is the reference case and "Low Density" is the case with $P_{in} = 10\ MW$, $F_{neut} = 2.8 \cdot 10^{22}\ m^{-2}/s$ ($n_{up} = 2.1 \cdot 10^{19}\ m^{-3}$), $P_{rad} = 4\ MW$ ($Y_{chem} = 0.7\ \%$). The old model predicts lower maximal heat flux, Fig 4b, and broader radial density profile. The difference becomes smaller for lower densities. For the old model the same total radiation was achieved with only Y_{chem}=0.15-0.25%.

It is found that for the reference case 70 % of the total Ly_α radiation and 30 % of Ly_β radiation is trapped. Ionization from the photo-excited states constitutes 15 % of the total ionization sources (22 % for the inner divertor alone). Most of the radiation is trapped in the region of high atom density ($n_a > 10^{19}\ m^{-3}$) near the strike points and below the separatrix (in the Private Flux Region where $n_a \sim 10^{18}\ m^{-3}$). In this region the photo-excitation provides the main channel of ionization, Fig 5. However, the overall effect on the plasma parameters is small. It is even weaker than the effect of NNC, Fig 4a.

The presented study shows that self consistent simulations of the divertor plasma of the large machines (JET, ITER) are sensitive to the details of the description of the neutral gas and especially the molecular dynamics. Since only effects known to be operatative are added, such refinements may lead to modified conclusions about the remaining free model parameters, e.g. cross field transport and chemical sputtering yield. Photon opacity may be important for understanding the processes in the Private Flux Region. For studied JET cases the photo-induced ionization is found to have small influence on the major plasma parameters despite high opacity for Ly radiation. But for the ITER conditions it can significantly alter the plasma density and temperature in front of the targets. Further development of the model for neutrals will include more comprehensive description of the molecular vibrational kinetics (including heat transfer in vibrational and rotational states) and carbon chemistry. The comparison with JET experimental data is in progress.

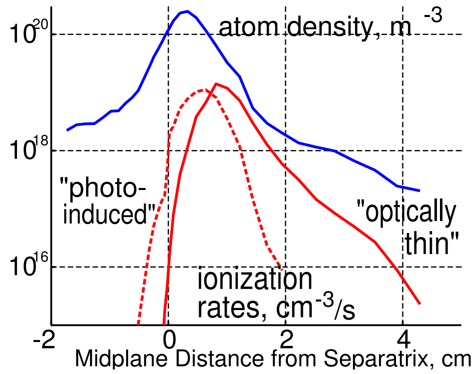

Figure 5: "Optically thin" and "photo-induced" ionization rates in front of the inner target

References

[1] Kukushkin A. S., Pacher H. D., Kotov V., Reiter D., et al., Nucl. Fusion, **45**, 608 (2005)

[2] Braams B. J., Ph.D Thesis, Rijksuniversitet Utrecht (1986)

[3] Schneider R., Bonin X., Borrass K., Coster D., et al., Contrib. Plasma Phys, **46**, 3 (2006)

[4] Reiter D., Baelmans M., Börner P., Fus. Sc. Tech, **47**, 172 (2005) and www.eirene.de

[5] Reiter D., May C., Baelmans M., Börner P., J. Nuclear Mater., **241-243**, 342 (1997)

[6] Fantz U., Reiter D., et al., J. Nuclear Mater., **290-293**, 367 (2001)

[7] Krasheninnikov S. I, Pigarov A. Yu., Sigmar D. J., Physics Letters A, **214**, 285 (1996)

[8] Reiter D., Wiesen S., Born M., J. Nuclear Materials, **313-316**, 845 (2003)

[9] Sawada K., Fujimoto T., J. Appl. Pwhich arehys., **78**, 2913 (1995)

[10] Kotov V., Reiter D., et al., 10th PET, Jülich, Germany, Oktober, 2005 / Paper O10 (in printing in Contrib. Plasma Phys)

[11] Kallenbach A., et al., Plasma Phys. Control. Fusion **46**, 431 (2004)