Re-deposition of impurities on the ITER diagnostic first wall

Vladislav Kotov

Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung - Plasmaphysik, EURATOM Association, 52425 Jülich, Germany

Deposition of impurities can lead to strong degradation of reflectivity of the diagnostic mirrors in ITER [1]. Estimates of impurity fluxes are, thus, crucial for the life-time evaluation and planning of protecting measures. In the present paper modelling of neutral particles incident to the front faces of the ITER port-plugs (PP) is discussed. Fluxes and distribution functions obtained in this model are to serve as boundary conditions for simulations of the particle transport in the diagnostic ducts inside PP and to the mirrors themselves.

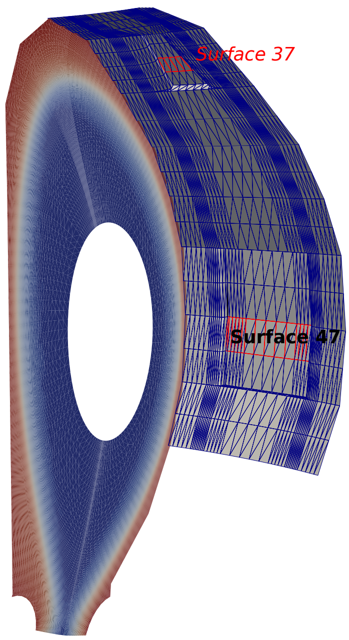

Figure 1: Plasma domain and 3D structure of the first wall and ports

Since full 3D plasma transport modelling would be too resource consuming and is currently not feasible, a simplified approach - "2.5D model" - is applied. In this approximation toroidally uniform plasma is defined on a 2D grid, and 3D structure of the first wall and ports is attached behind this grid, Figure 1. One 20^o sector is modelled. It is assumed that the PP face can only be reached by the neutral particles. Both hydrogenic (D/T) atoms and molecules and impurities (Be) are modelled with the Monte-Carlo code EIRENE [2] on a fixed plasma background, see Figure 2. The simulations are made for the discharge phase between ELMs (or with mitigated ELMs).

Magnetic configuration F57 [3] is the nominal current and power configuration. Plasma parameters in the core and pedestal zones inside the 1st separatrix are taken from the ITER specifications [4, 5, 6]. Exponential radial profile is assumed in the scrape-off-layer (SOL):

$$X(r) = [X_{sep} - X^*] \cdot \exp\left(-\frac{r}{\lambda_x}\right) + X^*, \quad X^* = \frac{X_w - X_{sep}\exp\left(-\frac{r_w}{\lambda_x}\right)}{1 - \exp\left(-\frac{r_w}{\lambda_x}\right)} \tag{1}$$

Here r is the distance from separatrix on the outer mid-plane (OMP), X is the parameter: density n^i of the ion species i, electron T^e or ion T^i temperature; r_w is the magnetic surface which first touches the inner wall (this surface is close to 2nd separatrix). Plasma parameters stay constant on the magnetic surfaces. Radial decay lengths and separatrix density n_{sep} are defined

Table 1: Parameters of the studied plasma scenarios

Scenario	n_w, m^{-3}	T_w^e, eV	T_w^i, eV	Γ_{DT}^+, m$^{-2}/s$	Γ_b^0, s^{-1}
LD (Low Density)	1e18	20	40	2.4e21	1.0e23
MD (Medium Density)	2e18	10	20	3.5e21	1.3e23
HD (High Density)	5e18	5	10	6.1e21	2.1e23
xHD (eXtreme HD)	1e19	2	2	6.3e21	0

in accordance with the multi-machine scalings [7]. The separatrix temperatures $T_{sep}^{e,i}$ are taken from the B2-EIRENE (SOLPS) modelling of ITER SOL [3]. Definition of plasma parameters in front of the first wall: after surface $r = r_w$, is the most uncertain. Here conservative assumption of a flat radial profile in this far-SOL region is used, parameters n_w, $T_w^{e,i}$ are based on the B2-EIRENE modelling experience [3] and experimental observations [8, 9]. Several scenarios have been investigated, see Table 1. The model plasma consists of 50 % D^+ and 50 % T^+, the density of all other ions is set to zero, the average ion velocity in the plasma volume is zero.

In the 2.5D model ions incident to the wall are sampled on the toroidally uniform boundary of the plasma grid, and then projected ("teleported") along the normal to this surface to the toroidally shaped wall element, Figure 2. This is done in order to take into account the line-of-sight transport of sputtered material from inclined wall to the PP face.

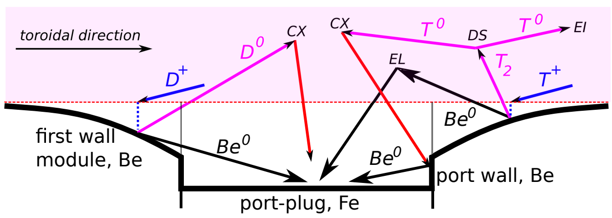

Figure 2: Sketch of the neutral transport model

The ion flux density Γ_i^+ depends in general from the angle ψ between the magnetic field **B** and the wall. There is an experimental evidence that this dependence saturates for small ψ at a certain fraction of the parallel flux density [11], see also discussion in [10], Chapter 25.2. For this reason Γ_i^+ is calculated as follows:

$$\Gamma_i^+ = \frac{1}{2} n_w^i \left(0.1 \sqrt{\frac{T_w^i + Z_i T_w^e}{m_i}} + v_i \cos\alpha \right), \quad 0.1 = \sin 5.7^o \tag{2}$$

Here m_i is the ion mass, Z_i is the charge number, α is the angle between the magnetic and solid surfaces, v_i is the velocity perpendicular to magnetic surfaces (not zero only for blob species, see below). Γ_i^+ for scenarios studied is given in Table 1 (55 % of Γ_{DT}^+ is D^+, 45% is T^+).

Blobs which carry hot plasma from the near separatrix region, see [12], can significantly enhance physical sputtering due to both ions and fast atoms. To approximately take their effect

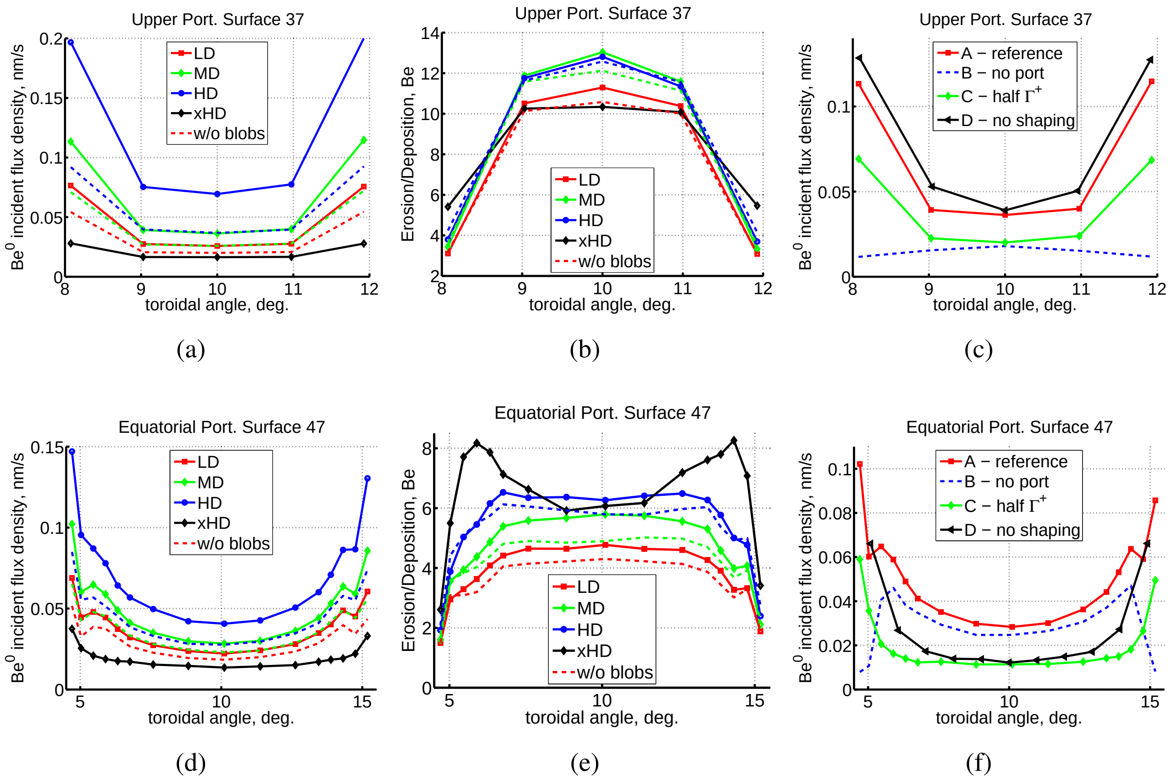

Figure 3: Results of calculations for diagnostic surfaces shown in Figure 1

into account the blobs are introduced in the model as extra hot ion species on the outboard side between the separatrix and wall. In this model without explicit time-dependency the correlation of the plasma fluctuations and fast recycling of atoms, see [13], is neglected.

The density and ion temperature in the blobs are set to separatrix parameters $n_b = n_{sep}$=4e19 m^{-3}, $T_b = T^i_{sep}$=400 eV. An opposite assumption is used for electrons - that due to fast equilibration T^e in the blob is the same as the "unperturbed" temperature (equation (1)). The (constant) blob radial velocity is set to v_b^{omp}=1000 m/s on OMP. Their velocity (normal to magnetic surfaces) at other poloidal locations is calculated on assumption that blobs do not bend: $v_b = v_b^{omp} \frac{B_p^{omp} R_{omp}}{B_p R}$. Here B_p is the poloidal field strength and R is the major radius: local and on OMP.

The time-averaged density of blobs is calculated with the following equation:

$$\langle n_b \rangle = n_b \frac{B}{2\pi R_{omp} B_p^{omp}} \frac{\Gamma_b^0}{n_b^0 L_b^0 v_b^{omp}} \approx \frac{n_b}{n_b^0 v_b} \frac{\Gamma_b^0}{2\pi R \frac{B_p}{B} L_b} \qquad (3)$$

Here n_b^0 is the initial ion density in the blob, L_b^0 is the initial parallel length of the blob, Γ_b^0 is the total initial ion flux carried out by blobs. This equation is derived on extra assumption that the blob area perpendicular to **B**-field is constant along the blob, and stays constant as the blob propagates radially. The approximate formula is valid for the uniform **B**-field. The flux Γ_b^0 is calculated as a certain fraction (2/3 here) of the total particle source inside the separatrix. This latter is estimated as a sum of the pellet fueling, leak of neutrals from divertor and from the main chamber wall (flux required to restore the particle content after an ELM is set to zero). The resulting Γ_b^0 for scenarios in question is shown in Table 1 (case xHD has no blobs). For assumptions taken here $\langle n_b \rangle \sim \left(10^{-3}..10^{-2}\right) n_{sep}$.

The results of calculations are presented in Figure 3. In the middle of PP the incident flux of Be ($\approx$ gross deposition rate) lies in the range 0.02...0.08 nm/s, Figures 3a, 3d. Sputtering of Be from the port walls leads to peaks of deposition in their vicinity. The probability of net erosion of deposits can be characterized by the ratio E/D: Be erosion rate divided by the incident flux of Be atoms. This ratio is always > 1, and in the middle of PP faces $E/D > 4$, Figures 3b, 3e. That is, net erosion conditions are highly probable. Dashed lines in Figure 3 are results of calculations made without extra blob fluids. Under present assumptions the effect of blobs is moderate.

In Figures 3c, 3f (made for case MD) sensitivity with respect to the primary impurity sources is investigated. Plot "A" is the reference calculation. "B" is the calculation made with no Be sputtering from the port walls. A very large effect on the Upper Port is clearly seen. This example indicates that even surfaces which are not in direct contact with plasma can represent significant local sources of impurities due to sputtering by fast atoms. Plot "C" demonstrates reduction of the incident fluxes to the PP with halved toroidal extent of the plasma exposed area. The incident fluxes of both D/T and Be atoms are reduced such that the E/D ratio is not decreased in this case. Plot "D" is the calculation made without toroidal shaping of the first wall panels. One can see a moderate effect on the Upper Port, but a factor of two effect on the Equatorial Port - because of steeper toroidal slope of the panels.

References

[1] Litnovsky A., Voitsenya V. *et al.* 2009 *Nuclear Fusion* **49** 075015

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

[3] Kukushkin A. S. *et al.* 2009 *Nuclear Fusion* **49** 075008

[4] Doyle E. J. *et al.* 2007 *Nucl. Fusion* **47** S18

[5] How J. and Reichle R. 2009 *Plant description* IDM 2X6K67

[6] Lisgo S .W. *et al.* 2011 *J. Nuclear Mater.* **415** S965

[7] Kallenbach A. *et al.* 2005 *J. Nuclear Mater* **337-339** 381

[8] Neuhauser J.*et al.* 2002 *Plasma Phys. Control. Fusion* **44** 855

[9] Rudakov D. L. *et al.* 2005 *J. Nuclear Mater.* **337-339** 717

[10] Stangeby P. C. 2000 *The plasma boundary of magnetic fusion devices* (Bristol: IoP Publishing)

[11] Matthews G. F. *et al.* 1990 *Plasma Phys. Control. Fusion* **32** 1301

[12] D'Ippolito D.A., Myra J.R. and Zweben S.J. 2011 *Phys. Plasm.* **18** 060501

[13] Marandet Y., Mekkaoui A. *et al.* 2011 *Nuclear Fusion* **51** 083035