# Modelling of carbon erosion and deposition in the divertor of JET

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#### 1. Introduction

In the JET MKIIA divertor a strong asymmetry of carbon deposition between inner and outer divertor leg is observed with deposition at the inner leg - particular on the inner louvres - and essential no or very little deposition in the outer divertor including the louvre region [1]. Thick carbon deposits on the inner louvres contain the majority of the hydrogenic species retained on a long term basis. Understanding and modelling the carbon deposition is of particular importance to estimate the long term tritium inventory and the lifetime of target plates in future fusion devices. This contribution presents Monte-Carlo simulations of the local transport of chemically eroded methane molecules in the divertor of MKIIa using an adapted version of the ERO-TEXTOR code [2].

#### 2. Input parameters for the simulations

For the simulations the edge plasma parameters of a representative standard gas fuelled ELMy H-mode discharge (12 MW) of MKIIA are used. The density and temperature distribution are calculated from the Onion Skin model using target Langmuir data and are shown in figure 1. The areas where the temperature and density is plotted correspond to the calculation volumes used for the simulations. The plasma represents a condition where the inner divertor plasma is partially detached whereas at the outer plate an attached plasma is formed with electron temperatures  $T_e$  of about 6 eV at the inner strike point and 10 eV at the outer strike point and densities  $n_e$  of about  $6 \cdot 10^{13}$  cm<sup>-3</sup> and  $6.5 \cdot 10^{13}$  cm<sup>-3</sup> respectively. From  $T_e$  and  $n_e$  along the plates the incoming deuterium ion flux is calculated according to  $\Gamma^{D+} = n_e \cdot c_s$  with  $c_s = c_s(T_e)$  the ion flow velocity.

The incoming deuterium ion flux is assumed to erode methane  $CD_4$  with a fixed erosion yield of 5%. To investigate the influence of the sticking probability of hydrocarbon fragments hitting the divertor plates the two extreme cases of fully (S = 1) and zero sticking (S = 0) have



*Figure 1* Plasma parameters for the simulations: Electron temperature (to the left) and density (to the right) of an ELMy H-mode discharge in JET MKIIa calculated with the Onion Skin Model.

been analysed. In the latter case the hydrocarbons are re-ejected as saturated methane molecules into the edge plasma. A negligible sticking of hydrocarbons cannot be explained with a simple energetic reflection but with a high re-erosion of a soft a-C:D layer built up by the hydrocarbons. The sticking of carbon atoms and ions is determined according to reflection coefficients calculated with TRIM.

## 3. Local transport of chemically eroded methane molecules

To visualise the local transport of eroded methane molecules figure 2 shows the two dimensional distribution of the CD<sub>4</sub> and C<sup>+</sup> density for the sticking assumption S = 1 of hydrocarbons. Due to the high electron density near to the strike points the penetration depth of CD<sub>4</sub> is extremely small in these regions. At locations away from the strike points the penetration depth is in the order of a cm or slightly smaller especially for the outer divertor. The  $C^+$  ions, which are a reaction product at the end of the dissociation chain of  $CD_4$ molecules, penetrate deeper into the plasma. Due to the Coulomb interaction with the plasma ions (friction force) they are driven back to the divertor plates or into the louvre regions by gyrating along the magnetic field lines (figure 2, right hand side). The density distributions in the case of zero sticking S = 0 for hydrocarbons do not differ significantly from the S = 1 case so that they are not shown here. Nevertheless, the different sticking assumptions lead to differences in the redeposition properties. The integrated amount of redeposition relative to the amount of eroded molecules decreases in the case of zero sticking. At the inner divertor 97% are redeposited with S = 1 and only 87% with S = 0. A similar behaviour is found at the outer divertor: the redeposition decreases from 98% to 85%. The profiles of erosion and redeposition along the plates for the inner divertor are shown in figure 3, upper part.



*Figure 2* Simulated density distribution of chemically eroded  $CD_4$  molecules (to the left) and  $C^+$  ions (to the right) in the divertor of JET MKIIa.

Only the inner divertor is shown since the simulations do not reveal significant differences between the inner and outer divertor. The coordinate x used in figure 3 is the position along the plates whereby the starting point x = 0 corresponds to ZC = -148 cm at the vertical plate and the end point x = 430 mm to RC = 255 cm at the horizontal (base) plate. For the case of fully sticking (S = 1) almost all particles eroded near to the strike point ( $x \approx 400$  mm) are redeposited locally. This is a consequence of the above mentioned short penetration of CD<sub>4</sub> molecules in this region. Eroded particles at the vertical plates have larger penetration depths and have therefore a certain probability to be transported away from their origin. Thus at low x-values on the vertical plates the redeposition is significantly smaller than the erosion and part of the eroded particles is transported downwards along the vertical plates (higher xvalues) to be redeposited or to enter the louvre region. In the zero sticking case the redeposition profile near to the strike point is shifted along the horizontal plates towards the

louvre region to smaller x-values. Most of the eroded molecules return to the plate near to their erosion site as hydrocarbon fragments. Due to the assumption S = 0 they are reejected into the plasma. In the calculation this process is repeated until the particle returns as carbon atom or ion to the surface for which the reflection coefficient is significantly small under the given



**Figure 3** Profiles of erosion and redeposition along the inner plates for fully (S = 1) and zero (S = 0)sticking of hydrocarbons (upper part). Resulting profiles of redeposition minus erosion (lower part).

plasma conditions. The repetition of these processes together with the movement of charged species along the magnetic field lines leads to a redeposition left from the erosion site at smaller x-values. In the lower part of figure 3 the resulting net-deposition and net-erosion zones along the plates for the two sticking assumptions are shown.

The table summarises the integrated amount of redeposition at the inner and outer divertor for the different sticking assumptions. The amounts of

	Inner divertor		Outer divertor	
	redeposition	particles to louvre	redeposition	particles to louvre
<b>S</b> = <b>1</b>	97%	1.5%	98%	1%
<b>S</b> = <b>0</b>	86%	10%	85%	12%

particles which enter the louvres show no difference between inner and outer divertor. This is in strong contradiction to measurements where significant carbon deposition was found at the inner louvres and almost no at the outer. This evidently shows that additional physical processes determine the long range transport of eroded carbon. The most likely are asymmetric flows driving particles from outer to inner divertor (which is not included in the simulations). In fact, measurements of the Mach number at JET seem to confirm such flows even though there is no final explanation of their origin. The recent calculations do not simulate either the amount of carbon that is deposited in the louvre region. From the measured deposition the amount of particles entering the inner louvre region can be estimated to  $\approx 4\% \cdot \Phi_{D^+}$  whereas the simulations result in  $\approx 0.08\% \cdot \Phi_{D^+}$  for S = 1 and  $\approx 0.5\% \cdot \Phi_{D^+}$  for S = 0 assuming a chemical erosion yield of  $Y_{D+\rightarrow CD4} = 5\%$ . Even for S = 0 the simulated value is about one order of magnitude too small. The most probably reason for this discrepancy is that the present calculation does not include the erosion by atomic deuterium. In the inner divertor we have to assume large neutral fluxes on the target plates which in combination with a large chemical erosion yield re-erode the deposited carbon layer effectively such that the carbon finally is transported to the louvre region.

## 4. Summary

The simulations of the transport of chemically eroded hydrocarbons in the divertor of JET MKIIa show in opposite to experimental observations no asymmetry between inner and outer divertor. Therefore additional effects like asymmetric flows, which are not yet included in the modelling, seem to be important. Also the simulated amount of particles entering the inner louvre is too small. This can be explained by a higher chemical erosion, e.g. due to  $D^0$ .

[2] A. Kirschner, V. Philipps, J. Winter, U. Kögler, Nucl. Fus., Vol. 40, No. 5 (2000), 989

<sup>[1]</sup> P. Coad et al., J. Nucl. Mat., 290-293 (2001), 224