

A. Kirschner, V. Philipps, P. Wienhold, W. Fundamenski, G. Matthews, P. Coad,  
M. Stamp, D. Coster, D. Elder, P. Stangeby and JET EFDA Contributors

# Modelling of Carbon Erosion and Deposition in the Divertor of JET

---



# Modelling of Carbon Erosion and Deposition in the Divertor of JET

A.Kirschner<sup>1</sup>, V.Philipps<sup>1</sup>, P.Wienhold<sup>1</sup>, W.Fundamenski<sup>2</sup>, G.Matthews<sup>2</sup>, P.Coad<sup>2</sup>,  
M.Stamp<sup>2</sup>, D.Coster<sup>3</sup>, D.Elder<sup>4</sup>, P.Stangeby<sup>4</sup> and JET EFDA Contributors\*

<sup>1</sup>*Institut für Plasmaphysik, Forschungszentrum Jülich GmbH, EURATOM Association, Trilateral Euregio Cluster, D-52425 Jülich,*

<sup>2</sup>*EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxon OX14 3DB, UK,*

<sup>3</sup>*Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany,*

<sup>4</sup>*University of Toronto, Institute for Aerospace Studies, Fusion Research Group, 4925 Dufferin Str., Downsview, ON, M3H 5T6, Canada.*

*\*See appendix of the paper by J.Pamela "Overview of recent JET results",  
Proceedings of the IAEA conference on Fusion Energy, Sorrento 2000*

Preprint of Paper to be submitted for publication in Proceedings of the  
EPS Conference,  
(Madeira, Portugal 18-22 June 2001)

“This document is intended for publication in the open literature. It is made available on the understanding that it may not be further circulated and extracts or references may not be published prior to publication of the original when applicable, or without the consent of the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK.”

“Enquiries about Copyright and reproduction should be addressed to the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK.”

## 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].

### 1. INPUT PARAMETERS FOR THE SIMULATIONS

For the simulations the edge plasma parameters of a representative standard gas fuelled ELMy H-mode discharge (12MW) of MKIIA are used. The density and temperature distribution are calculated from the Onion Skin model using target Langmuir data and are shown in Fig. 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 6eV at the inner strike point and 10eV at the outer strike point and densities  $n_e$  of about  $6 \cdot 10^{13} \text{ cm}^{-3}$  and  $6.5 \cdot 10^{13} \text{ cm}^{-3}$  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  $\text{CD}_4$  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 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.

### 2. LOCAL TRANSPORT OF CHEMICALLY ERODED METHANE MOLECULES

To visualise the local transport of eroded methane molecules Fig. 2 shows the two dimensional distribution of the  $\text{CD}_4$  and  $\text{C}^+$  density for the sticking assumption  $S = 1$  of hydrocarbons. Due to the high electron density near to the strike points the penetration depth of  $\text{CD}_4$  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  $\text{C}^+$  ions, which are a reaction product at the end of the dissociation chain of  $\text{CD}_4$  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 (Fig. 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 Fig. 3, upper part.

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 Fig. 3 is the position along the plates whereby the starting point  $x = 0$  corresponds to  $ZC = -148\text{cm}$  at the vertical plate and the end point  $x = 430\text{mm}$  to  $RC = 255\text{cm}$  at the horizontal (base) plate. For the case of fully sticking ( $S = 1$ ) almost all particles eroded near to the strike point ( $x = 400\text{ mm}$ ) are redeposited locally. This is a consequence of the above mentioned short penetration of  $\text{CD}_4$  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  $x$ -values) 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 re-ejected 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 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 upper part of Fig. 3 the resulting net-deposition and net-erosion zones along the plates for the two sticking assumptions are shown.

	Inner Divertor		Outer Divertor	
	Redeposition	Particles to Louvre	Redeposition	Particles to Louvre
$s = 1$	97%	1.5%	98%	1%
$s = 0$	86%	10%	85%	12%

The table summarises the integrated amount of redeposition at the inner and outer divertor for the different sticking assumptions. The amounts of 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  $Y_{D+ \rightarrow CD_4} = 5\%$ . 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.

### 3. 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  $D^0$ .

### REFERENCES

- [1]. P.Coad et al., J.Nucl. Mat., 290-293 (2001), 224
- [2]. A.Kirschner, V.Philipps, J.Winter, U.Kögler, Nucl. Fus., Vol. 40, No. 5 (2000), 989

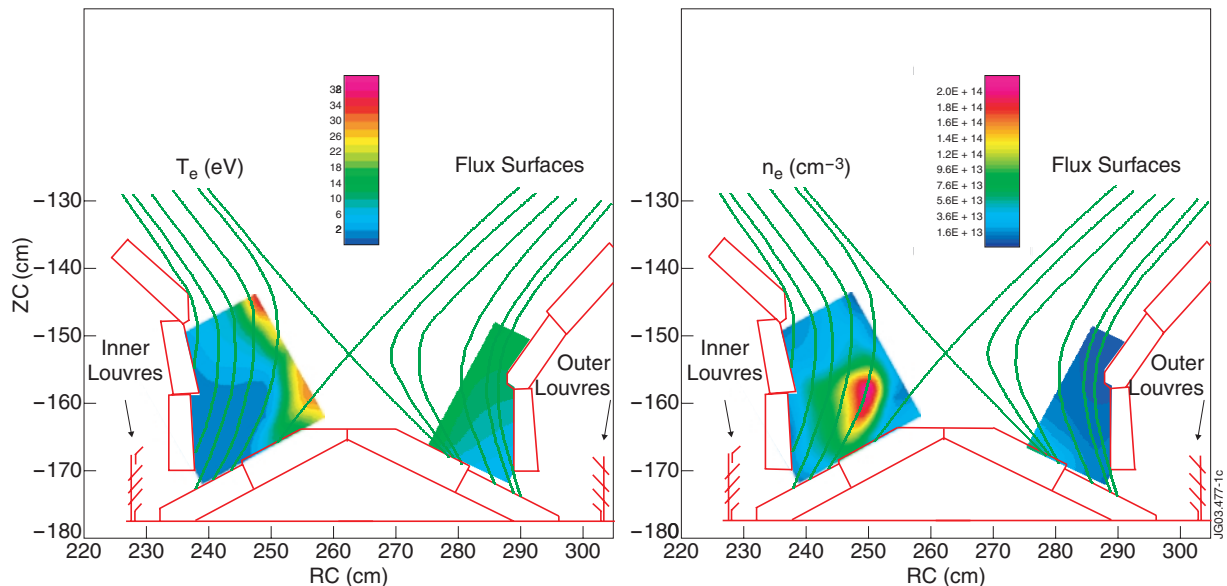


Figure 1: Plasma parameters for the simulations: Electron temperature (to the left) and density (to the right) of an ELMy H-mode discharge in JET MKIIa calculated with the Onion Skin Model.

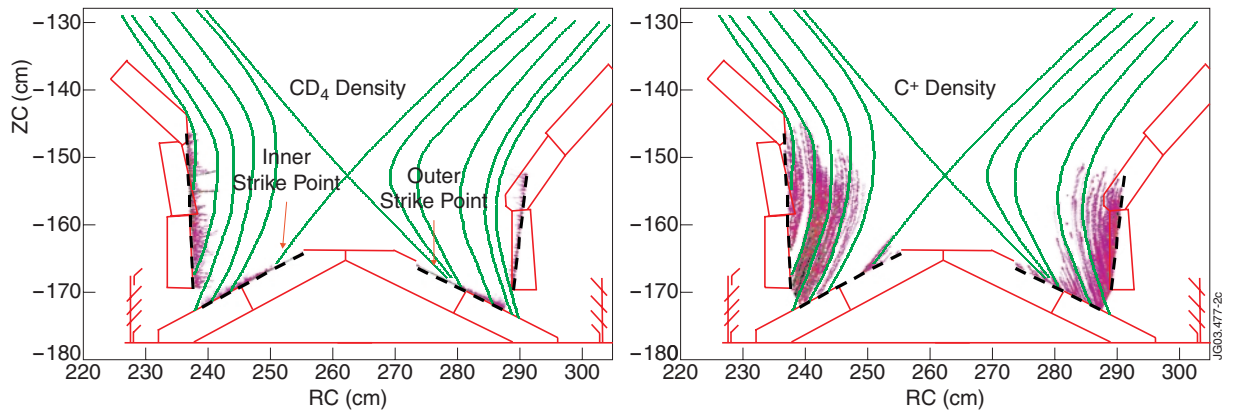


Figure 2: Simulated density distribution of chemically eroded  $CD_4$  molecules (to the left) and  $C^+$  ions (to the right) in the divertor of JET MKIIa.

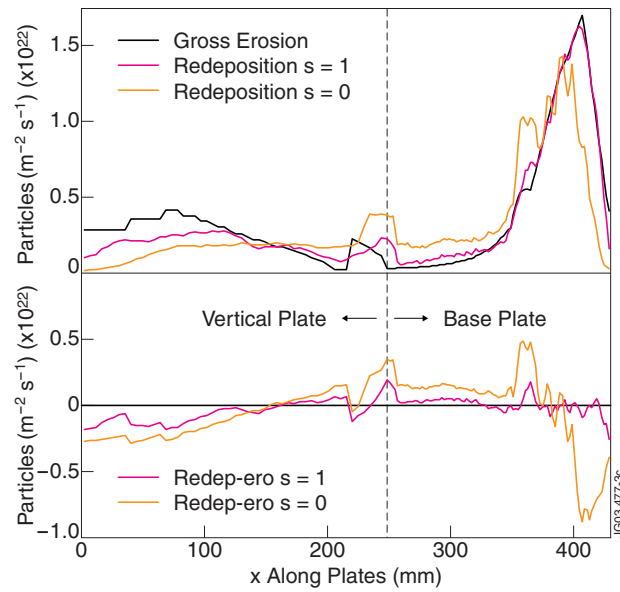


Figure 3: Profiles of erosion and redeposition along the inner plates for fully ( $S = 1$ ) and zero ( $S = 0$ ) sticking of hydrocarbons (upper part). Resulting profiles of redeposition minus erosion (lower part).