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**See Annex of J. Pamela et al., "Overview of Recent JET Results and Future Perspectives",*
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ABSTRACT

Modelling of the transport of externally injected methane through a testlimiter exposed to the edge plasma of TEXTOR shows that the observed pattern and low amount of carbon deposition at the limiter can only be simulated when a yield for erosion of re-deposited carbon significantly higher than for graphite together with a low effective sticking probability of hydrocarbons (neutral and ionised CHx) is assumed. Similar assumptions have to be made to reproduce the high amount of carbon deposition observed at the inner louvers in the divertor MkIIa of JET. In contrast to carbon the beryllium transport modelled for JET MkIIa shows no significant deposition at the louvers which is in agreement with the experiment and can be explained by the absence of chemical erosion. Predictive simulations of erosion and re-deposition for ITER have been performed. They show that the maximum net erosion rate at the strike point is less critical than the long-term tritium retention rate, which is estimated to about 6mg/s.

1. INTRODUCTION

The crucial processes for erosion, deposition and tritium retention within the ITER divertor structure are the production and migration of hydrocarbons and its radicals. In this paper we present latest results from the Monte-Carlo code ERO-TEXTOR [1] and its variants (ERO-JET, ERO-ITER). These codes are used to simulate experimental findings from spectroscopy, surface analysis and other related data from present experiments. To validate atomic data, assumptions on surface physics and local transport mechanisms two different experiments have been modelled: external injection of methane in TEXTOR and the chemical release and transport of methane in the JET divertor. In addition predictive calculations for ITER are presented.

2. SIMULATION OF HYDROCARBON TRANSPORT IN PRESENT DEVICES

Experiments with external injection of methane molecules $^{13}CH_4$ through the surface of a testlimiter exposed to the Scrape-Off Layer (SOL) of TEXTOR show a very low local deposition efficiency of ^{13}C at the testlimiter surface of about 0.5% [2]. In contrast to this, simulations with the ERO-TEXTOR code (using the Ehrhardt-Langer database [3] for the dissociation of hydrocarbons, 1.5% chemical erosion, reflection of carbon atoms and ions according to TRIM) reveal a local deposition efficiency of about 3% even with the extreme assumption of a zero sticking probability (S = 0) for charged and ionised hydrocarbons CHx returning to the limiter [2]. New simulations have been carried out considering revised data for the rate coefficients of the CH4 reaction chain from Janev et al. [4]. These calculations result in an even higher local deposition efficiency (14% versus 3%) again assuming S = 0 for all hydrocarbons. However, a comparison of the simulated and measured light emission of CH radicals and C^+ ions shows a good agreement. Therefore we conclude that the observed low local deposition probability might be dominated by the *erosion and deposition processes* rather than by the *transport* of hydrocarbons through the plasma. We assume that the re-erosion yields of deposited hydrogen-rich carbon layers are underestimated [5]. Therefore in addition to zero effective sticking (S = 0) of all hydrocarbons returning to the surface an enhanced chemical erosion yield for re-deposited carbon atoms and ions of 8% compared to 1.5% for pure graphite is assumed. This reduces the simulated local ^{13}C deposition from 14% to 0.5% and hence results in a very good agreement with the measured value.

Figure 1 shows a comparison of the measured and simulated ^{13}C deposition pattern at the testlimiter surface using the above-described assumptions. With the revised data from Janev the agreement between these distributions is further improved compared to former simulations with the Ehrhardt-Langer data [2]. Only with a negligible *effective sticking* of hydrocarbons the simulated maximum of carbon deposition is located several centimetres away from the injection hole which is in agreement with the experiment. The negligible "effective" sticking of hydrocarbons is understood not as a high reflection probability in the first collision of the hydrocarbon with the surface but as a very effective re-erosion of the deposited carbon by the hydrogen atoms incorporated in the arriving hydrocarbon species. This finally results in a negligible effective sticking of hydrocarbons which in the ERO-TEXTOR modelling is simulated with the assumption S = 0. Therefore within this model only carbon ions (and atoms) hitting the surface can contribute to the build-up of a layer. But again they are forming hydrogen-rich layers which suffer from an enhanced chemical erosion (8% compared to 1.5% for graphite) caused by the background hydrogen.

Also the modelling of the transport of chemically eroded methane in the inner divertor MkIIa of JET with standard assumptions (S = 1) and a chemical erosion yield of about 2% cannot reproduce the high amount of carbon deposition observed at the remote areas of the louvers [6, 7]. We have to assume, as for the TEXTOR simulations, an increased erosion of re-deposited carbon in combination with negligible sticking of hydrocarbons (S = 0). The transport of carbon into the louver region can then be understood as the result of many steps of re-deposition and re-erosion. While in the vicinity of the strike point the erosion of carbon is dominated by deuterium ions, at locations far away also deuterium atoms may play a role. ERO simulations of the CIII light emission observed in the divertor of JET MkIIGB during an H-Mode discharge (Pulse No: 53070) show a good agreement with the experiment (fig.2). In particular the difference of the CIII pattern in the inner divertor (which is clearly detached from the target plates) to the outer divertor (attached) can be reproduced.

This asymmetry can be ascribed to a higher electron temperature in the outer divertor. Transport of physically sputtered beryllium in MkIIA can be described qualitatively by the simulations. In contrast to carbon there is no chemical erosion and also no enhanced erosion of soft re-deposited layers. Therefore the long range transport as for carbon does not exist which leads to a net beryllium deposition especially near the strike point and almost no transport into the louver region.

3. PREDICTIVE CALCULATIONS FOR ITER

For the ERO-ITER calculations the two-dimensional plasma parameters are taken from B2- Eirene for the reference case 345 (410MW fusion power at Q = 10, 30% power radiated from the core). For comparison the sticking of hydrocarbons S is assumed to be either zero or one. Chemical erosion is assumed to be 2% whereas at the moment different erosion yields for substrate and re-deposited material are not yet considered. Since there is no significant difference in the simulation between inner and outer divertor the following is restricted to the outer divertor only. Figure 3 shows the profiles of erosion and re-deposition along the outer divertor plate together with the net deposition profiles resulting from the difference of both. Zero sticking S = 0 leads to a re-deposition probability on the target plates of about 86% and a net erosion peak of 15nm/s near the strike point. The assumption of S = 1 leads to an increased re-deposition of about 95% and a decreased erosion peak of 8nm/s. Particles not re-deposited at the divertor plate are lost into the private flux region – mainly as neutrals. To estimate the long-term tritium retention in deposited layers it is assumed that only these "lost" particles lead to a build- up of C-layers at those areas. With a T/T+C ratio of 0.5, a chemical erosion of 2% for the inner and outer divertor and S = 0 we obtain a total co-deposition rate of tritium of 6mg per second trapped in remote areas. The safety limit (licensing) of 350g tritium would then be reached after about 150 discharges of 400s duration. With S = 1 the tritium retention decreases by a factor of about 3. In the current calculations no material flux from the main chamber is considered and under those conditions the lifetime of the inner target plate (peak erosion at the outer is slightly lower) can be estimated to ~625 ITER discharges assuming a maximum tolerable erosion of 0.5cm. This is less critical than the tritium retention and will be even much more relaxed if we take Be deposition from main chamber into account.

CONCLUSIONS AND OUTLOOK

Simulations of the hydrocarbon transport in TEXTOR and JET reveal that a reasonable agreement with observations can only be achieved if a negligible effective sticking of hydrocarbons together with an enhanced erosion of re-deposited carbon compared to pure graphite is assumed. This leads to a long range transport of carbon to remote areas shadowed from the plasma. Due to the lack of chemical erosion beryllium is not transported along large distances but re-deposited near the erosion site. The calculations for ITER show that the issue of tritium retention is much more crucial than the lifetime of the target plates. However, these calculations have to be improved by taking into account different erosion yields for graphite and re-deposited carbon (as suggested by the above-described simulations for TEXTOR and JET) which in particular will lead to a further increase of T-retention. However, a beryllium background flux from the main chamber leading to Be coverage at the graphite target has to be taken into account which will reduce the chemical erosion. For this, results obtained in PISCES in which the effect of Be coverage on the erosion of the graphite target is studied will be modelled with the ERO code and applied to ITER. However, we can conclude that for a higher availability of ITER under these conditions in-situ means for tritium release from these layers have to be developed.

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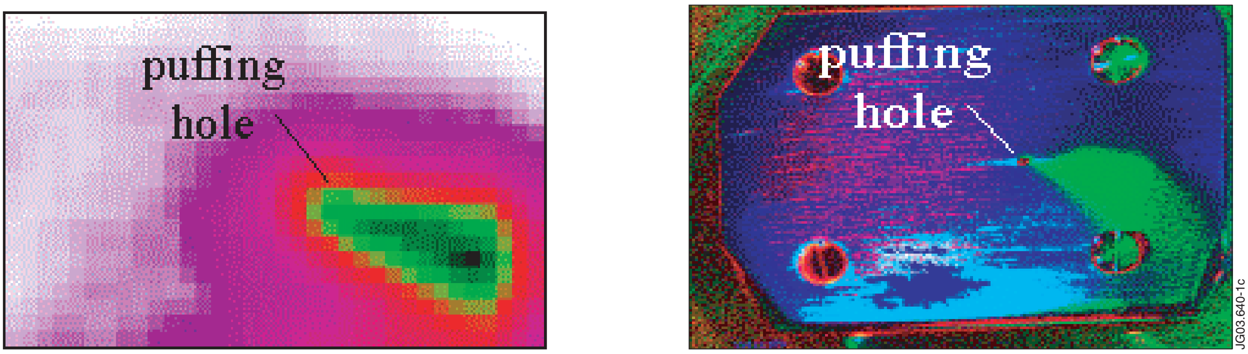

Figure 1: Simulated (left) and observed (right) ^{13}C deposition pattern after $^{13}CH_4$ injection through a hole at a testlimiter exposed to the SOL of TEXTOR (top view onto the testlimiter).

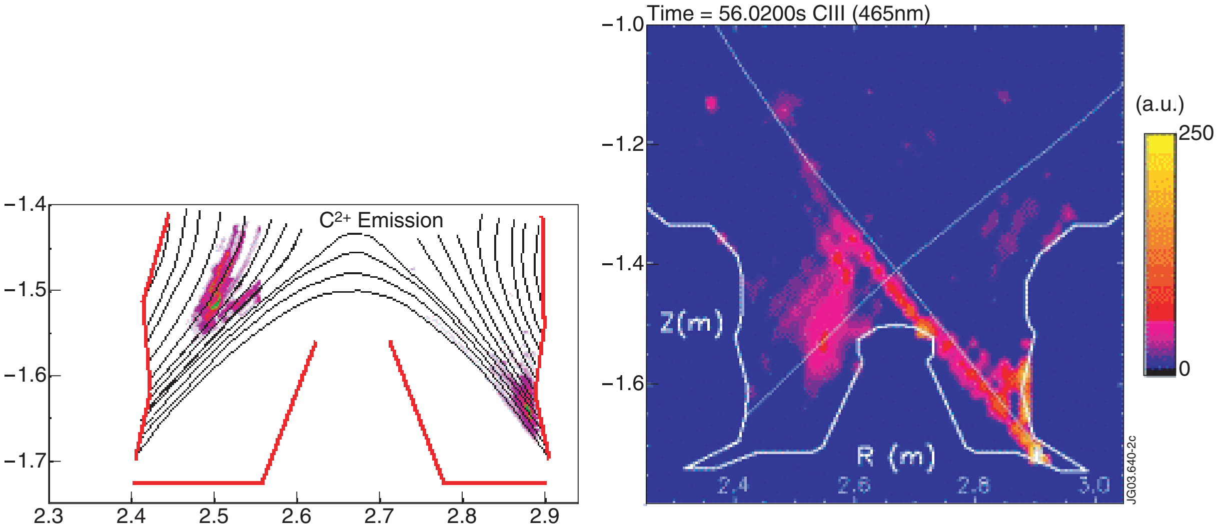

Figure 2: Simulated (left) and observed (right) CIII emission pattern in the divertor MkIIGB of JET during an H-mode discharge.

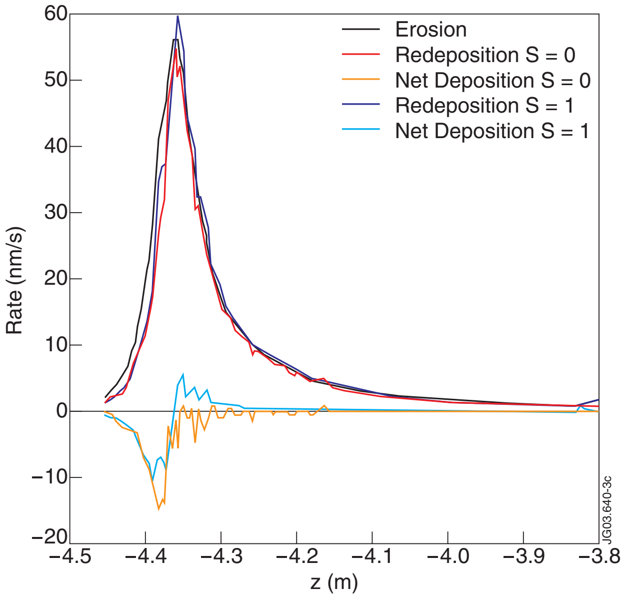

Figure 3: Simulated erosion and re-deposition profiles along the outer divertor plate in ITER.