Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Nuclear Materials 337–339 (2005) 55–59

journal of nuclear materials

www.elsevier.com/locate/jnucmat

Studies on ^{13}C deposition in ASDEX Upgrade

E. Vainonen-Ahlgren [a,*], J. Likonen [a], T. Renvall [a], V. Rohde [b], R. Neu [b], M. Mayer [b], R. Pugno [b], K. Krieger [b], ASDEX Upgrade Team

[a] *VTT Processes, Association EURATOM-Tekes, P.O. Box 1608, 02044 VTT, Espoo, Finland*

[b] *Max-Planck-Institut für Plasmaphysik, EURATOM-Association, Boltzmannstrasse 2, D-85748 Garching, Germany*

Abstract

To investigate material transport in scrape-off layer plasma and in/out asymmetries in divertor, $^{13}CH_4$ was puffed at the end of 2002/2003 experimental campaign into ASDEX Upgrade from the outer mid-plane. Ex-situ analyses of the tiles were performed by secondary ion mass spectrometry and Rutherford backscattering spectrometry. The highest amount of ^{13}C was detected at the top of inner divertor, and below the inner and outer strike points towards the roof baffle. The ^{13}C peaks below the strike points correlate with thick long term deposition layers detected in ion beam analysis experiments.

PACS: 52.40.Hf; 52.55.Fa; 52.55.Rk; 82.80.Ms

Keywords: ASDEX Upgrade; Divertor; Carbon based materials; Erosion & Deposition

1. Introduction

Erosion and redeposition are issues of major importance for ITER in that the rate of erosion of the divertor targets and building up of deposited films (and the T retained therein) may ultimately limit the choice of divertor materials and the operational space for ITER. Most existing fusion devices use carbon, which has excellent thermal and mechanical properties. Carbon is also considered as divertor target material for ITER [1]. However, the major disadvantage of carbon as a first wall material in a fusion device is the trapping of hydrogen isotopes by co-deposition with eroded carbon atoms [2]. Tritium trapped in these co-deposited layers will contain a significant amount of the total tritium inventory of a nuclear fusion reactor [3]. At the present the mechanisms which form the layers are not completely understood. Moreover, carbon deposition at ASDEX Upgrade and JET has been generally observed to be much higher at the inner than the outer divertor [4,5]. The reason for this asymmetry is still under discussion. Various explanations have been proposed [5,6]. Also the difference in divertor temperature could be considered. The inner divertor is cooler and the plasma mostly detached. This causes a lower potential at the inner divertor than at the outer one. This leads to a drift in the scrape-off layer (SOL) from the outboard to the inboard side so the most of erosion takes place at the outer divertor. The aim of this work was the experimental investigation of material transport in SOL and the study of in/out asymmetries in divertor deposition by measuring the deposition pattern of carbon on plasma facing components under controlled source conditions.

* Corresponding author. Tel.: +358 9 4566320; fax: +358 9 4566390.

E-mail address: elizaveta.vainonen-ahlgren@vtt.fi (E. Vainonen-Ahlgren).

0022-3115/$ - see front matter
doi:10.1016/j.jnucmat.2004.08.028

2. Experimental setup

For post mortem erosion/deposition analyses a full poloidal set of marker tiles (stripes of 3–7 μm thick carbon layer on a 100 nm Re layer, prepared by arc discharge method) was installed in the lower divertor (see Fig. 1) during the shutdown in 2002 [7].

At the end of the 2002/2003 experimental campaign $^{13}CH_4$ was puffed into the torus from the outer midplane at one toroidal location during 13 identical bottom single null H-mode (ELM type I) discharges (# 18190–18202) in hydrogen with an integrated puff time of 37 s. The puff was localised only in the sense that one gas valve was used. However, the valve is quite remote in the port and therefore effectively the whole port acts as a source. This means it has the size of about $0.5\ m^2$. The molecules will penetrate the SOL to quite different depths which, combined with the large shear in the SOL, will lead to a very rapid distribution of the particles and therefore to a quite symmetric toroidal distribution [8]. The main plasma parameters were $I_p = 1.0$ MA, $B_t = -2.0$ T, $n_e = 8.5 \times 10^{19}\ m^{-3}$ and $P_{aux} = 6.5$ MW. The total amount of ^{13}C injected during the experiment was 9×10^{21} atoms. ^{13}C serves as a marker because it can be distinguished from ^{12}C isotope with surface analytical methods.

For ^{13}C profiling secondary ion mass spectrometry (SIMS) was utilised. A set of samples of 17 mm in diameter was cut from the divertor tiles using a coring technique [9,10]. The number of the samples (1–5 samples from each tile depending on the tile size) was chosen to provide as many measurement points as possible along the marker stripes. SIMS analysis was made with a double focusing magnetic sector instrument (VG Ionex IX-70S) at VTT. The current of the 5 keV O_2^+ primary ions was typically 500 nA during depth profiling and the ion beam was raster-scanned over an area of $300 \times 430\ \mu m^2$. Crater wall effects were avoided by using a 10% electronic gate and 1 mm optical gate. ^{13}C was profiled using a high mass resolution of 2000 (m/Δm at *m/z* 28) to separate the element peak from the interfering isobar $^{12}CH^+$. The pressure inside the analysis chamber was 5×10^{-8} Pa during the analysis. The depth of the craters was measured by a profilometer (Dektak 3030ST) after SIMS analysis. The uncertainty of the crater depth was estimated to be 5%.

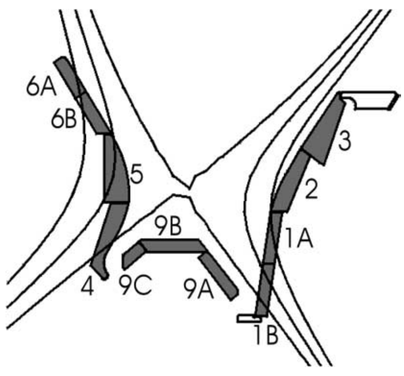

Fig. 1. Sketch of divertor IIb together with the magnetic surfaces. Numbers correspond to the divertor tile numbers.

3. Results and discussion

Fig. 2 shows ^{13}C depth profiles for outer divertor (1B) and roof baffle (9A) tiles corresponding to s-coordinate of 1.15 and 0.87 m, respectively. S-coordinate represents the distance from the top of the inner divertor along the surface of the tiles and describes poloidal positions ($s = 0$ corresponds to the top edge of tile 6A). ^{13}C signal was normalised with ^{12}C level and natural ^{13}C background was subtracted. Data indicate the presence of ^{13}C at the surface region with following decrease within the bulk. Larger content of ^{13}C accumulated in the outer tile compared to the baffle one can be observed. Because of small problems with calibration samples, quantitative ^{13}C amount in the analysed samples will be determined afterwards and results will be presented in forthcoming paper. The qualitative trend, however, will stay the same.

The strike point position from magnetic reconstruction together with Langmuir probe data during last 13 shots of the campaign as a function of s-coordinate is presented in Fig. 3. The ion fluxes measured with Langmuir probes were integrated over each discharge, and total fluence during all shots was calculated. Because ELMs affect the measured Langmuir probe signal, the

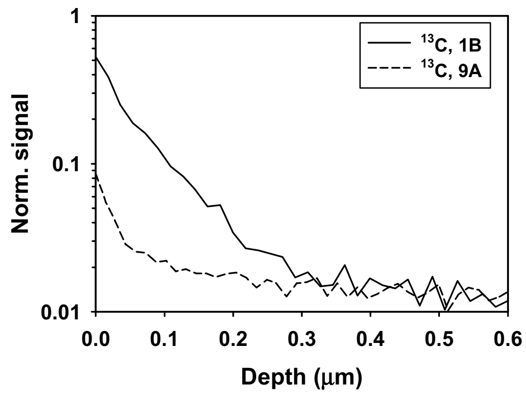

Fig. 2. SIMS depth profiles of ^{13}C normalised to ^{12}C signal and natural ^{13}C background subtracted. Presented are profiles for tiles 1B ($s = 1.15$ m, above the strike point close to the boundary with tile 1A) and 9A ($s = 0.87$ m, close to the central part of the tile).

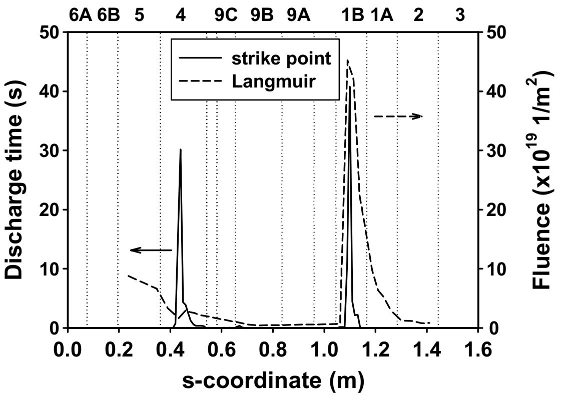

Fig. 3. Strike point position from magnetic reconstruction (solid line) together with fluence from Langmuir probes data (dashed line) during last 13 shots of the campaign.

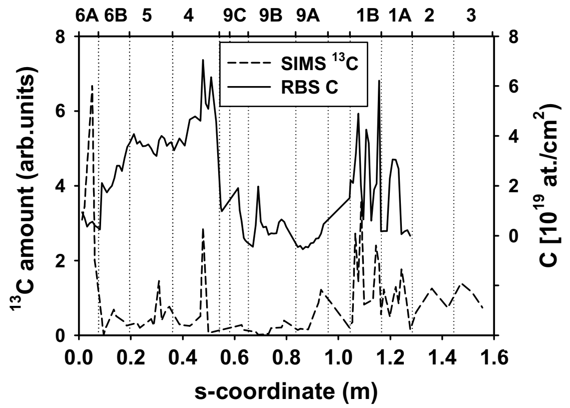

Fig. 5. ^{13}C distribution (dashed line) together with long term carbon deposition data (solid line).

corresponding time slices were not taken into account. During the ^{13}C puffing experiments the strike points were at the centre of the inner divertor tile 4 and the outer divertor tile 1B. The strike point position in the outer divertor corresponds to the peak of fluence on tile 1B. But unlike to this, there is no drastic increase of fluence in the inner strike point. Detailed distribution of ^{13}C together with strike point position from magnetic reconstruction during last 13 shots of the campaign as a function of s-coordinate is presented in Fig. 4. ^{13}C peaks are observed on tiles 6A ($s = 0.05$ m), 4 ($s = 0.48$ m) and 1B ($s = 1.07$, 1.09 and 1.15 m). The peaks on the tiles 4 and 1B are shifted toward the roof baffle with respect to the inner and outer strike points, respectively. At the inner divertor, the shift is ~4 cm whereas at the outer divertor it is somewhat smaller ~1–2 cm (the accuracy of the outer strike point position from magnetic reconstruction is ±1 cm). Roof baffle tiles contain almost no

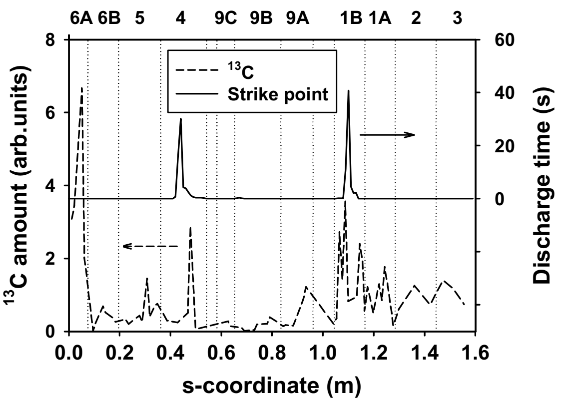

Fig. 4. ^{13}C distribution at the divertor (dashed line) together with strike point position from magnetic reconstruction during last 13 shots (solid line).

^{13}C except a small bump detected at $s = 0.93$ m (tile 9A) which could be caused by ^{13}C particles escaped from tile 1B after being deposited there.

Unexpected consistence of ^{13}C results with long term carbon deposition data (Fig. 5) measured with Rutherford backscattering spectrometry can be noticed. The ^{13}C peaks on tiles 4 and 1B are observed at the same position that long term deposition occurs. The long term deposition peaks are also located closer to each other (and to the bottom of the divertor) with respect to the long term strike points (for details see [7]). Probably the positions of ^{13}C accumulation and the long term deposition can be explained as follows. At the position of the strike point some surface material is eroded during the shot. On the other hand being transported by the SOL plasma to the divertor, carbon is locally redeposited and re-eroded a few times and finally ends up at the lower part of the divertor together with material eroded at the strike points. This effect of local redeposition was suggested earlier for migration of eroded tungsten in ASDEX Upgrade [11] and observed for carbon migration in JET [12].

The following effect is surprising. Long term carbon distribution at tile 1B consists of three peaks what might be associated with different outer strike point position through the whole campaign. However, ^{13}C distribution also consists of three peaks while the strike point position stayed constant. It is hard to say what causes this fine structure of the peaks. A peak at $s = 1.15$ m might be associated with area shadowed by the neighboring tile 1A.

A very high peak of ^{13}C was observed at the top of the tile 6A (Fig. 5). The amount of ^{13}C transported to this place corresponds to 59% of total ^{13}C detected on the inner divertor. However, no similar accumulation of ^{13}C at the top part of the outer divertor was detected. It might be explained by the higher drift of the SOL particles from the outer mid-plane to inboard than to outboard.

The amount of carbon deposited at the inner divertor has been reported to be about 2.5 times larger than at the outer divertor [13]. Our data demonstrate the total amount of ^{13}C transported to inner divertor is a factor of 1.5 smaller than the one found at the outer divertor. Of course, it should be kept in mind that erosion/deposition data [13] describe the situation after the whole campaign with different conditions while the ^{13}C results were collected after identical shots. It is also worth noticing that long term deposition can be considered as a superposition of the carbon coming from the main chamber and divertor. According to spectroscopic data [14] and as mentioned above, due to multiple re-erosion and redeposition long term carbon migrates to the places where it is not eroded anymore. While ^{13}C is primarily transported by the plasma along field lines (see above). However, subsequently it migrates (erodes and redeposits) in small steps to positions where there is no further erosion. The time scale of the experiment was very short that ^{13}C (attributed with the main chamber) would be re-eroded and redeposited many times. So the re-eroded/redeposited ^{13}C does not travel around the torus.

A similar experiment on impurity transport was performed at JET [10], where during the last day of the campaign, $^{13}CH_4$ was injected through the module on the top of the vessel. During gas puffing (ohmic plasma pulses), the reciprocating probe with retarding field analyser was fitted and inserted twice for each pulse into the plasma boundary. The drift velocity was in the direction required to sweep impurities into the inner divertor. Ex-situ measurements showed the presence of some ^{13}C and deposition occurring in the inner divertor, heavy deposition and very small amount of ^{13}C at floor tiles, and erosion and ^{13}C at the level of natural abundance in the outer divertor (long term processes are denoted as deposition and erosion). A peak of the ^{13}C content was observed at the top part of inner divertor tile [15] which agrees with our results on tile 6A.

Based on the results from JET and the data reported in this study it can be concluded that the deposition pattern of carbon injected from the outer mid-plane of typical discharges shows a remarkable difference with the long term carbon deposition pattern. Carbon originating from the outer mid-plane is transported in almost similar amounts to the inner and outer divertors, and the maximum deposition is found at the top of the inner baffle. This might indicate either that the long term carbon deposition is determined by singular discharges or events, or that the outer mid-plane is not the major carbon source. This would be in qualitative agreement with the recent observation of net erosion at the outer strike point tiles [7].

4. Conclusions

Experimental investigation of material transport in the SOL plasma and the study of in/out asymmetries in divertor deposition was performed by measuring the deposition pattern of carbon on plasma facing components under controlled source conditions. For this purpose $^{13}CH_4$ was puffed at the end of the 2002/2003 experimental campaign into the torus from the outer mid-plane. Peaks of ^{13}C were detected below strike points towards the roof baffle at the inner and the outer divertor, and at the top part of the inner divertor. This contribution of the main chamber processes to the deposition can be associated with transport by the SOL plasma.

Acknowledgements

This work has been partly funded by EURATOM, National Technology Agency of Finland.

References

[1] G. Federici, C.H. Skinner, J.N. Brooks, J.P. Coad, C. Grisolia, A.A. Haasz, A. Hassanein, V. Philipps, C.S. Pitcher, J. Roth, W.R. Wampler, D.G. Whyte, Nucl. Fus. 41 (2001) 1967;
R. Aymar, P. Batabaschi, Y. Shimomura, PPCF 44 (2002) 519.

[2] M. Mayer, V. Philipps, P. Wienhold, H.G. Esser, J. von Seggern, M. Rubel, J. Nucl. Mater. 290–293 (2001) 381.

[3] G. Federici, J.N. Brooks, D.P. Coster, G. Janeschitz, A. Kukushkin, A. Loarte, H.D. Pacher, J. Stober, C.H. Wu, J. Nucl. Mater. 290–293 (2001) 260.

[4] V. Rohde, M. Mayer, J. Nucl. Mater. 313–316 (2003) 337.

[5] J.P. Coad, N. Bekris, J.D. Elder, S.K. Erents, D.E. Hole, K.D. Lawson, G.F. Matthews, R.-D. Penzhorn, P.C. Stangeby, J. Nucl. Mater. 290–293 (2001) 224.

[6] A.V. Chankin, G. Corrigan, S.K. Erents, G.F. Matthews, J. Spence, P.C. Stangeby, J. Nucl. Mater. 290–293 (2001) 518;
N. Asakura, S. Sakurai, K. Itami, O. Naito, H. Takenaga, S. Higashijima, Y. Koide, Y. Sakamoto, H. Kubo, G.D. Porter, J. Nucl. Mater. 313–316 (2003) 820;
G.F. Matthews, G. Corrigan, S.K. Erents, W. Fundamenski, A. Kallenbach, T. Kurki-Suonio, S. Sipilä, J. Spence, Contributors to the EFDA-JET workprogramme, J. Nucl. Mater. 313–316 (2003) 986.

[7] M. Mayer, V. Rohde, J. Likonen, E. Vainonen-Ahlgren, K. Krieger, X. Gong, J. Chen, ASDEX Upgrade Team, these Proceedings. doi:10.1016/j.jnucmat.2004.10.046.

[8] A. Geier, PPCF 44 (2002) 2091.

[9] R.-D. Penzhorn, N. Bekris, P. Coad, L. Dörr, M. Friedrich, M. Glugla, A. Haigh, R. Lässer, A. Peacock, Fus. Eng. Des. 49&50 (2000) 753.

[10] J. Likonen, S. Lehto, J.P. Coad, T. Renvall, T. Sajavaara, T. Ahlgren, D.E. Hole, G.F. Matthews, J. Keinonen, Fus. Eng. Des. 66–68 (2003) 219.
[11] K. Krieger, V. Rohde, R. Schwörer, K. Asmussen, C. Garcia-Rosales, A. Hermann, R. Neu, J. Roth, A. Thoma, M. Weinlich, ASDEX Upgrade, J. Nucl. Mater. 241–243 (1997) 734.
[12] G.F. Matthews, M. Stamp, P. Coad, J. Likonen, V. Philipps, M. Rubel, J.D. Strachan, JET EFDA Contributors, 30th EPS Conference on Control. Fus. Plasma Phys., St. Petersburg, Russia 7–11 July 2003 ECA Vol. 27A, P-3.198.
[13] M. Mayer, V. Rohde, A. von Kuedell, ASDEX upgrade team, J. Nucl. Mater. 313–316 (2003) 429.
[14] T. Puetterich et al., PPCF 45 (2003) 1873.
[15] J. Likonen, S. Lehto, J. Keinonen, T. Ahlgren, T. Sajavaara, P. Coad, J. Kolehmainen, S. Tervakangas, T. Renvall, EFDA JET Task No. JW2-FT-1.8 (final report).