HYDROGEN ISOTOPE INVENTORIES IN PLASMA FACING COMPONENTS OF ASDEX UPGRADE

K. KRIEGER, H. Maier, D. Grambole[+], D. Schleussner[‡], P. Franzen
and the ASDEX UPGRADE TEAM

Max-Planck-Institut für Plasmaphysik, EURATOM Association,
D-85748 Garching
[+]Forschungszentrum Rossendorf e.V., D-01314 Dresden
[‡]Otto-von-Guericke-Universität, D-39016 Magdeburg

Abstract

Deuterium inventories have been measured in plasma facing components of ASDEX Upgrade. Nearly 60% of the total D-inventory was observed in the lower inner divertor target plate in redeposited layers of low-Z material. The outer divertor, however, was found to be dominated by erosion processes and correspondingly retained a much lower amount of deuterium. The D-inventory at the main chamber plasma facing components can be explained by a model employing implantation of charge-exchange neutrals, which yields very good agreement with the experimental findings for all surfaces not exposed to direct ion fluxes.

1. INTRODUCTION

Hydrogen isotope inventories in fusion devices are built up by various processes, in particular implantation due to bombardment of plasma facing surfaces by energetic charge-exchange (CX) neutrals and by codeposition with eroded and subsequently redeposited carbon ions. They may be released by transient high power loads to the respective plasma facing components thus providing an additional unwanted particle source, which might hamper density control. Furthermore, the formation of significant tritium inventories will lead to severe radiological problems.

Therefore, the formation of hydrogen isotope inventories in plasma facing components and the underlying mechanisms of hydrogen retention in the respective materials have been extensively studied in ASDEX Upgrade. In this paper, results are presented for deuterium inventories in the graphite components of the main chamber and in graphite and tungsten divertor target plates, respectively.

2. EXPERIMENTAL

Total deuterium inventories were determined by means of thermo-controlled desorption spectroscopy (TDS) [1]. Samples are heated up to 2100 K and the released deuterium molecules, hydrocarbon molecules and radicals are detected by mass spectroscopy. Deuterium inventories in near surface layers (thickness $1-2\,\mu$m) were determined by nuclear reaction analysis (NRA) using the reaction 790 keV $^3\mathrm{He} + \mathrm{D} \rightarrow {}^4\mathrm{He} + \mathrm{p}$. Depth profiles of deuterium and hydrogen concentration, respectively, were measured by elastic recoil detection analysis (ERDA) using a micro beam (diameter $\approx 3\,\mu$m) along an ion beam slope cut (IBSC) sample [2]. Tungsten depth profiles were determined by Rutherford backscattering (RBS) using 2 MeV protons and also by particle induced X-ray emission (PIXE) on the IBSC-samples.

3. RESULTS AND DISCUSSION

After the tungsten divertor campaign, the deuterium inventory of a complete poloidal set of wall components was measured using the NRA technique. The results are plotted in Fig. 1 along the poloidal circumference. In the main chamber, the deuterium inventory shows only weak variations. In contrast, the inventory at the divertor plates varies significantly with much higher values at the inner divertor. This corresponds to the different plasma conditions in inner and outer divertor, respectively. While the outer divertor is dominated by erosion of target plate material, in the inner divertor deposition prevails due to the lower plasma temperature. This was verified by the results of the RBS analysis [3]. In the inner

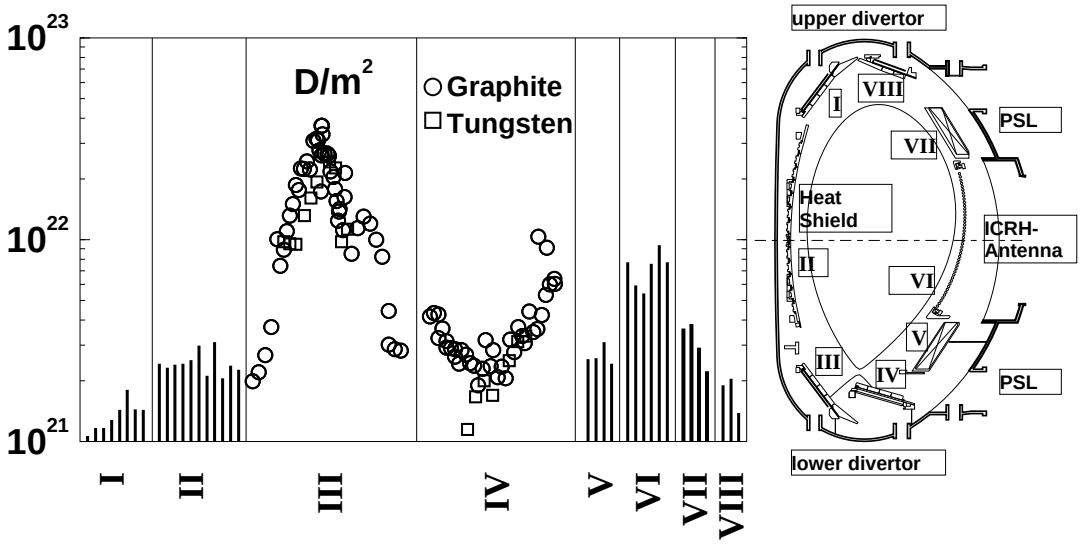

Figure 1: *Poloidal distribution of the near surface deuterium inventory in the plasma facing components of ASDEX Upgrade.*

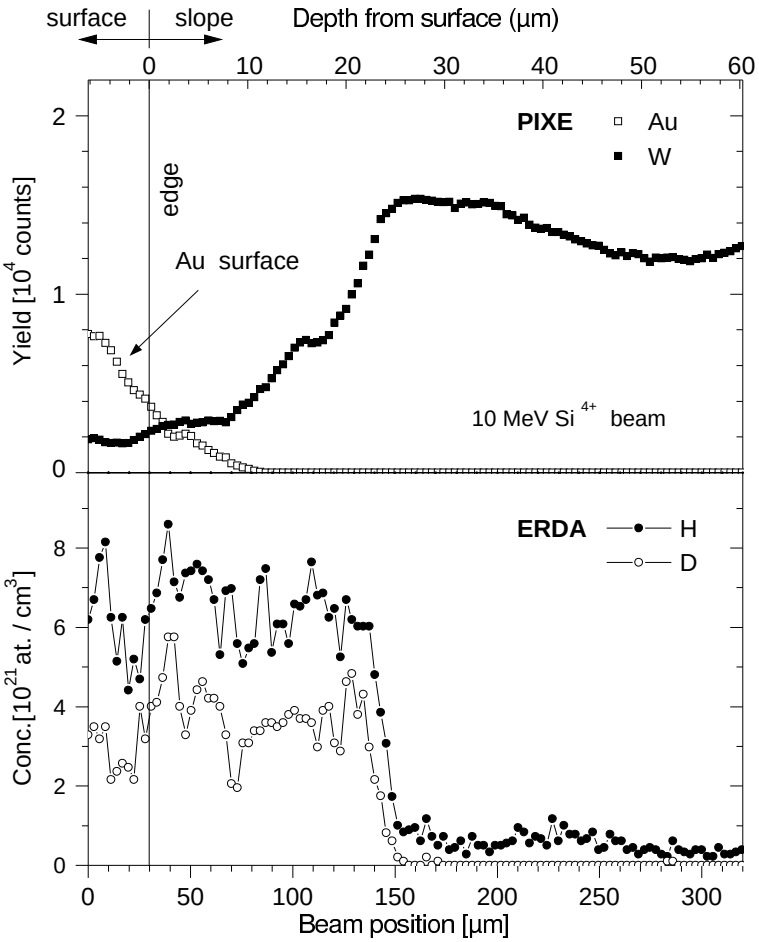

Figure 2: *Depth profiles of W measured by PIXE (a) and H and D measured by ERDA (b) as a function of depth. Depth information was obtained by scanning along an ion beam slope cut of the sample [2]. Significant hydrogen isotope concentrations are only found in the deposited low-Z layer near the surface (region of low W-concentration).*

divertor the tungsten surface was found to be completely covered by low-Z material eroded at graphite first wall components, while in the outer divertor the tungsten tile surface composition was almost unaltered compared to the virgin tiles. The total deuterium inventory in these samples (TDS-results) agrees with the NRA-results, which represent the near surface amount. The observation of deposition of low-Z material in the inner divertor as well as the agreement of NRA and TDS results suggest co-deposition [4] as the dominant retention mechanism. This was directly confirmed by the IBSC results shown in Fig. 2. There is a clear anti-correlation between the tungsten and deuterium concentrations, showing that deuterium is trapped in the deposited layer on top of the tungsten bulk. In the erosion dominated outer divertor, low-Z material is only implanted in small amounts and consequently deuterium inventories are smaller by a factor of 10 compared with the inner divertor.

Divertor D-inventories were also determined for graphite target tiles which had been installed in previous experimental campaigns. No substantial difference was observed between the two materials concerning the near surface deuterium content. The total deuterium inventory of the graphite target tiles, however, as measured by TDS, turned out to be one to two orders of magnitude larger than the near surface inventories [5]. For the significantly higher bulk inventory, two different mechanisms might contribute. On the one hand deuterium can diffuse into the bulk material along the grain boundaries of the graphite [6]. On the other hand, increased inventories can also be formed by co-deposition into the porous graphite surface [7].

In the main chamber, implantation by charge exchange (CX) neutrals was examined as the basic mechanism for the inventory formation. The total amount of implanted deuterium depends on the saturation level and the deposition depth of the incident particles, which is a function of the particle energy. Energy spectra of the CX neutrals were calculated by the B2/EIRENE code and validated by experimental data [8]. From the simulated spectra, the implanted amount of deuterium integrated over the experimental period was calculated as a function of the poloidal circumference. As shown in Fig. 3, the simulated results agree well with measured inventories at the inner heat shield, the upper divertor plates and on long term deposition samples exposed at the outer main chamber wall, confirming implantation of CX-neutrals as the main mechanism for the formation of hydrogen inventories in main chamber plasma facing surfaces. The large deviation between model and experimental results at the ICRH antenna limiters results from the direct exposure of the limiter surfaces to the ion flux in the plasma scrape-off layer.

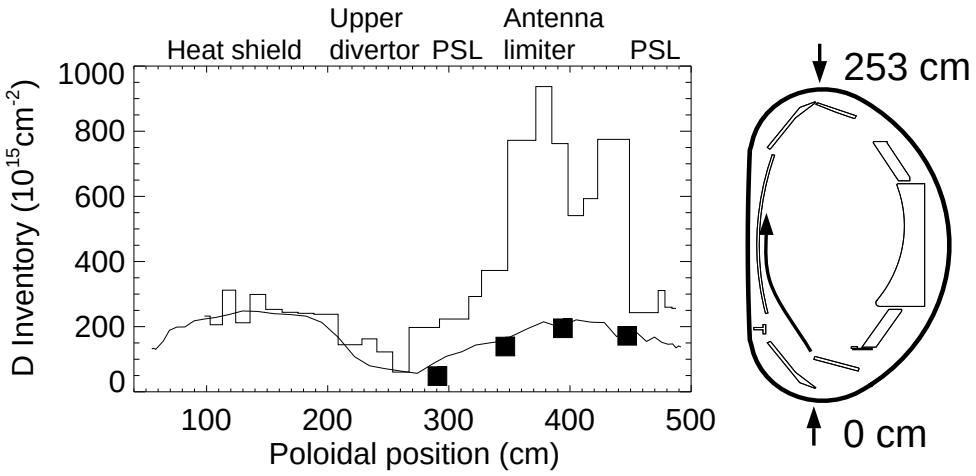

Figure 3: *D-inventories in the main chamber graphite plasma facing surfaces of ASDEX Upgrade.The histogram denotes the experimental data obtained from first wall components, while the squares denote results from long term graphite samples mounted at the outer vessel wall. Except for the ICRH antenna limiters, which were primarily subject to impact of direct ion fluxes, the theoretical model (solid line) of implanted CX-neutrals agrees very well with the measurements.*

With the results presented in this section the total D-inventories for each of the plasma facing components of ASDEX Upgrade as designated in Fig. 1 can be obtained. Assuming toroidal symmetry the respective inventories were weighted with the total surface area of the corresponding first wall components. It turned out that almost 60 % of the total D-inventory present in ASDEX Upgrade after the tungsten divertor campaign was retained in the co-deposited layers in the lower inner divertor, which accounts for $\simeq 5$% of the total plasma facing surface, while the whole main chamber graphite components (including the upper divertor) contained only about 35 % of the total inventory.

Finally, the estimate of the total D-inventory present in ASDEX Upgrade after the tungsten divertor campaign can be compared with the integrated D-input by gas valves and neutral beam injection. It turns out that only 2 % of the deuterium supplied into the vessel during the campaign was retained in the vessel's graphite components.

4. SUMMARY

Deuterium inventories in ASDEX Upgrade are dominated by co-deposition with low-Z material in the inner divertor. Implantation of CX-neutrals in the main-chamber plasma facing surfaces account only for one third of the total inventory despite the much larger total area.

It should be noted that retention of hydrogen isotopes in tungsten bulk material was found to be negligible compared to the results for graphite. Therefore, hydrogen inventories might be greatly reduced by using tungsten as plasma facing material. This benefit, however, will be partially lost by simultaneous use of low-Z material for other plasma facing components because of co-deposition. If co-deposition cannot be avoided, appropriate techniques need to be developed for efficient removal of such layers from deposition dominated surfaces.

The authors would like to thank R. Behrisch, M. Mayer and J. Roth for valuable support an helpful discussions.

REFERENCES

[1] SCHLEUSSNER, D. et al., Hydrogen isotope inventories in the ASDEX Upgrade tungsten divertor tiles, J. Nucl. Mat. in press, 1998.

[2] GRAMBOLE, D. et al., Hydrogen and deuterium depth profiling in divertor tiles of a fusion experiment by micro-ERDA, submitted to Nucl. Instr. and Methods, B.

[3] MAIER, H. et al., Erosion and deposition in the ASDEX Upgrade tungsten divertor experiment, J. Nucl. Mat. in press.

[4] MAYER, M. et al., J. Nucl. Mater. **230** (1996) 67.

[5] KRIEGER, K. et al., Conclusions about the use of tungsten in the divertor of ASDEX Upgrade, J. Nucl. Mat. in press.

[6] FRANZEN, P. et al., Nucl. Fusion **37** (1997) 1375.

[7] HILDEBRANDT, D. et al., Observation of nonuniform erosion and deposition phenomena on graphite after plasma exposure, 8th Int. Workshop on Carbon Mat., Jülich, Germany, 1998 (submitted to Phys. Scripta), 1998.

[8] VERBEEK, H. et al., Nucl. Fusion in press.