Tungsten as first wall material in the main chamber of ASDEX Upgrade

V. Rohde, R. Neu, A. Geier, R. Dux, O. Gruber, A. Kallenbach, K.Krieger, H. Maier, R. Pugno and ASDEX Upgrade-Team

Max-Planck-Institut für Plasmaphysik, EURATOM Association, Garching , Germany

Introduction

Today most fusion experiments are using carbon as plasma facing material. Due to the codeposition of tritium with carbon a future fusion reactor has to minimise the graphite plasma facing components [1]. A promising alternative material is tungsten, which has a high melting point, low erosion rate in cold scrape off layer plasma and a small tritium retention. However the maximum allowed tungsten concentration in the core plasma is strongly restricted due to radiation losses.

Based on the experience with the tungsten divertor [2] a step by step strategy to insert tungsten in the main chamber of ASDEX Upgrade was followed. First tests were performed using markers and mid-Z coating [3]. The erosion found at the inner heat shield could not be explained by CX neutral only, but by ion impact [4]. During the experimental campaign 2000 1.2 m^2 of the lower part of the central column was coated by tungsten. This region corresponds to the divertor baffles, where the present ITER-FEAT design uses tungsten. No negative influence on the plasma performance, even in high power H-mode or advanced discharge scenarios, was observed [5]. Mostly it was not even possible to detect tungsten at the core by spectroscopic methods within a detection limit more than hundred times less than the maximum tolerable concentrations in ASDEX Upgrade. Post mortem analysis of the inserted tungsten tiles indicate that the erosion found is mostly due to ions. Typical erosion rates of about 50 nm during one experimental campaign were found on not shaded surfaces [6]. These erosion rates show that for today pulsed experiments layers of 1μm are sufficient for applying materials as surface coatings.

Experimental setup

The present campaign started in April 2001 with a total coverage of the central column, except for regions, which may be hit directly by neutral beam injection or are used as a limiter. The carbon tiles were shaped to reduce edge erosion and coated with $0.6-1.5$ μm tungsten by Plasma Arc Deposition. Altogether 6.5 m^2 of coated tiles were inserted at the central column of ASDEX Upgrade (Fig. 1). Additional two complete columns of thinner coated tiles were mounted to analyse the complete poloidal tungsten erosion also at the limiter region. The experimental campaign was started without additional wall conditioning by boronisation or siliconisation to measure the pure tungsten surface. During the first two weeks of operation a dedicated program to investigate the performance of tungsten as plasma facing material was executed. During this time all relevant scenarios were tested. Additionally special discharges were performed, to investigate the physics of the tungsten erosion and trans-

port. Thereafter a boronisation was applied to reduce the oxygen content of the discharges. No failure of the tungsten coating during plasma operation was observed until now.
The core tungsten concentration, which is relevant for the fusion performance, was measured using a W-quasi-continuum at about 5 nm and from single W-lines in the soft X-ray spectral region. The tungsten influx was determined using the intensity of a WI line at 400.8 nm. All spectrometer are cross calibrated using tungsten laser blow off [5]. Additionally probes were exposed using the midplane manipulator and analysed using ion beam techniques. The plasma parameters at the heat shield were measured by Langmuir probes. Due to this complete set of measurements we will be able to get information of the history of tungsten. This will also produce detailed input data for numerical simulations.

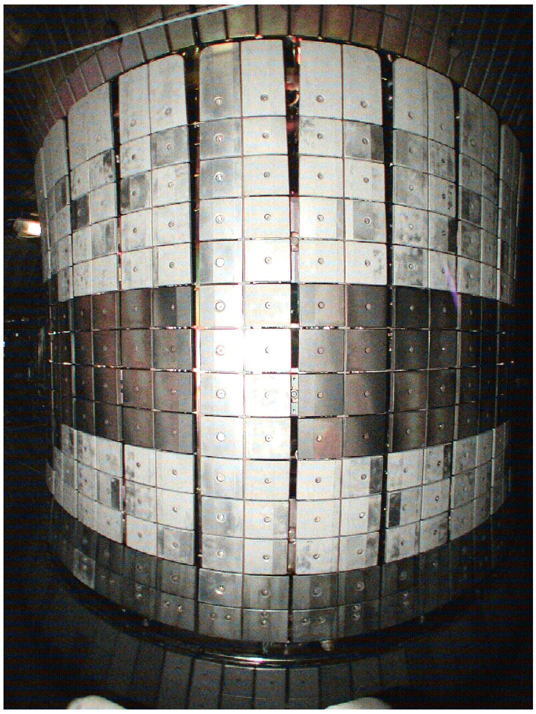

Fig.1: *View of the central column of ASDEX Upgrade showing the tungsten coated tiles. The middle four rows are made of graphite and CFC and are temporally used as limiter.*

H-mode discharges

First ordinary H-mode discharges were investigated. No problems due to tungsten occur. Indeed the total radiation and Z_{eff} were higher than for a good conditioned machine, but this is mostly attributed to the high oxygen content (few percent) because of the lack of boronisation. Fig. 2 shows two H-mode discharges with different densities. For low density the central tungsten concentration is always $\approx 1 * 10^{-6}$, about ten times smaller than required for ITER. The situation is even better for high density discharges (0.8 of Greenwald density), as the central tungsten concentration is often below the detection limit. A significant amount of tungsten influx was measured during plasma start-up, when the tungsten tiles are used as a limiter, and in special designed discharges, which has low clearance with respect to the tungsten tiles.

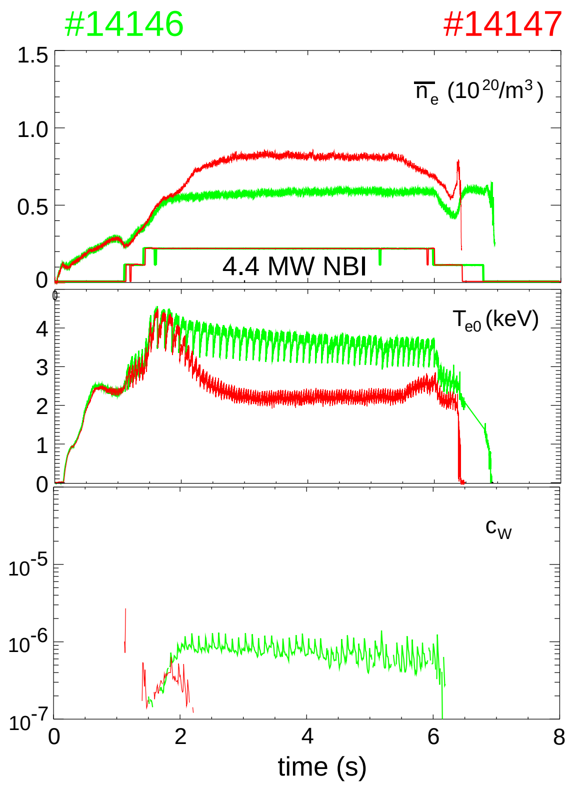

Fig.2: *Typical H-mode discharges for different plasma densities.*

A comparison of these data with deposition probe measurements is still under investigation. The central tungsten concentration shows strong correlation with the saw tooth activity. As demonstrated in Fig.2, it is always reduced during saw tooth activity. This gives a hint that the central tungsten content depends mostly on the internal transport, but not on the source at the edge. Earlier measurements during the divertor tungsten experiment [7], where a strong correlation of the tungsten source with the SOL tungsten density but not with the central density was found, fit into this picture.
To study the behaviour of tungsten, special designed discharges were performed. From former experiments accumulation of tungsten is known for limiter discharges and low voltage NB heated discharges.

Limiter discharges

A common scenario with internal transport barrier on ASDEX Upgrade uses the heat shield as limiter to maintain a L-mode edge. During these discharges high energy ions hit the tungsten surfaces, which results in the erosion of tungsten. As indicated in Fig. 3 the central tungsten concentration rises as soon as the LCFS contacts the tungsten heat shield (0.7 s). The discharges exhibits a short weak transport barrier (0.8 - 0.9 s), which results in high tungsten accumulation. Because of the transport time the highest tungsten peak values were reached soon after. This scenario results in the highest tungsten concentrations measured during this campaign. The absolute concentration could not be derived, because the detector is saturated. However the discharge still survived. After this phase the profile changes and the central tungsten concentration drops. The onset of sawteeth results in a stronger reduction of the tungsten. Although this is a limiter discharge the plasma completely recovers from the former high tungsten concentrations and reaches still tolerable tungsten concentrations. As the core temperature drops below 2 keV the temperature is to low to measure ^{46}W with the spectrometer and no central concentrations are available. For stronger transport barrier discharges even higher concentrations were found. changed. The strong variation of the central tungsten concentration can only be explained by a strong variation of the transport into the core plasma.

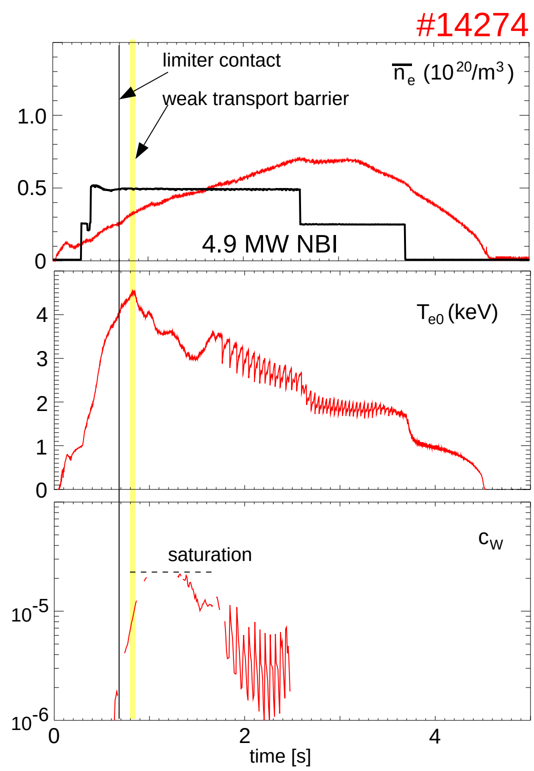

Fig.3: *Limiter discharge with internal transport barrier showing tungsten accumulation. After vanishing of the barrier the central tungsten concentration drops.*

Variation of the heating profile

From divertor tungsten experiments the tendency of tungsten accumulation for low energy, i.e. off axis, NBI heated discharges is known [2]. To investigate this effect the NB energy was reduced from 60 keV to $35-40$ keV. Due to this the heating profile is shifted from central to off-axis heating. Again we find higher tungsten core concentrations for off-axis heated discharges than for central heating. As shown in Fig. 4 the discharge 14225 shows a clear tendency to accumulate tungsten at 3 s. This results in an enhanced radiation. The same scenario was used in shot 14222, but 1.2 MW of central deposited ECRH was added. Due to this central plasma heating, the core tungsten concentration dropped dramatically. This effect is even verified after switching off the ECRH heating, when the tungsten concentration rises again. This demonstrates again that the central tungsten concentration depends mostly not on the source but on the transport in the core plasma. The mechanism of this accumulation may depend on neoclassical transport, but is not analysed in detail until now. Experimentally it was shown that the central tungsten concentration can be controlled by the heat deposition. This effect may enable to operate future fusion devices with higher tungsten edge concentrations.

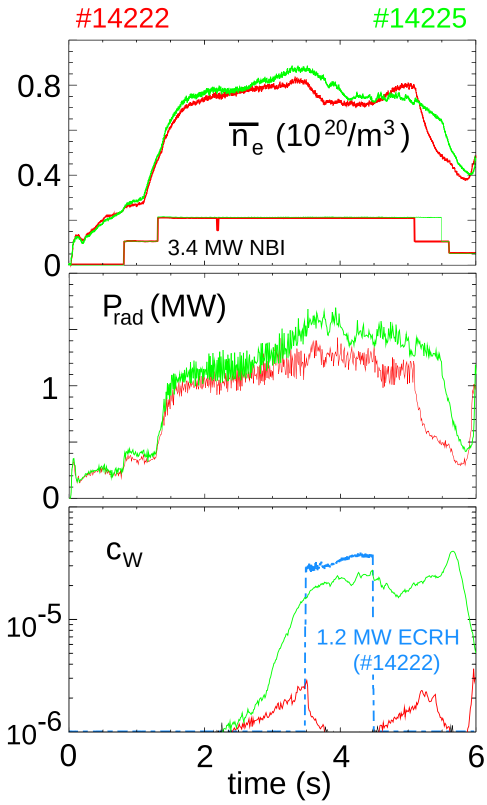

Fig.4: *Discharge with low energy NB heating showing tungsten accumulation (grey), which can be avoided by ECRH central heating (red).*

Summary and conclusions

Due to the large surface covered with tungsten a sensitive check of the influence of tungsten as a plasma facing material in the main chamber on the plasma performance under fusion reactor relevant conditions, was done. No negative influence on the plasma performance was found, except for special designed test discharges. The core tungsten density was always below the limit for ITER. The core plasma transport could be identified as most relevant for the core impurity concentration. Central heating by NI or ECRH reduced the tungsten core concentration significantly. This gives a knob to control the central impurities, but detailed calculations are still required. Our results underline that tungsten is a suitable first wall material for future fusion devices.

[1] G. Federici, et al., J. Nucl. Mat., 290-293 (2001) 260
[2] R. Neu, et al., PPCF 38 (1997) A165
[3] V. Rohde, et al., Proc. ,IAEA 2000, Sorrento
[4] A. Tabasso et al., Nucl. Fusion, 40 (2000) 1441
[5] R. Neu, et al., J. Nucl. Mat., 290-293 (2001) 206
[6] W. Schneider, this conference
[7] K. Krieger, et al., ECA, 21A, (1997), p1421
[8] V. Rohde et al.,ECA, 24B, (2000), P3.097