Assessment of Intrinsic Impurity Behaviour in ASDEX Upgrade

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Introduction

Since 1999 ASDEX Upgrade pursues the progressive increase of tungsten plasma facing components [1]. Whether, or to what degree tungsten can be used as plasma facing material is a key question for all future fusion devices, having in mind the complex chemistry carbon exhibits in the presence of hydrogen isotopes. The incremental approach in the transition to a W dominated device, which is mostly due to technical reasons, may jeopardise the results and conclusions on the influence of W. At the same time it provides the opportunity to identify the influence of different W- and C-components and to explore mixed material effects.

Experimental Setup

During the present campaign the complete central column (heat shield, HS), the inner divertor baffle (DB) and the upper passive stabiliser loop (PSL) have been covered with new tiles coated by 1 μm of tungsten. This surface has the size of 14.6 m^2 and represents about 40% of the whole plasma facing components (PFCs) in ASDEX Upgrade (see Fig. 1). Spectroscopy is the key diagnostics when dealing with impurities. As usual C influxes were monitored by C II and C III spectral lines as well as by using the CD/CH band head. The densities of light impurities as C, F, O are deduced from soft X-ray spectroscopy, detecting the Lyman-α spectral lines of the H-like species and by charge exchange spectroscopy in the visible spectral range [2]. With the latter method the extraction of central He- and B-densities was also possible. Additionally, the long term evolution of the H/D-ratio was monitored by two neutral particle analysers (NPAs). In order to get information on the ion fluxes impinging on the HS, five Langmuir probes (single pin) were mounted equidistantly along the poloidal cross section of the HS. Special care was taken for the W measurements. The influx of tungsten was monitored by the prominent W I line at 400.8 nm and with a poloidal array of viewing chords across the HS and the DB. The W concentration in the core plasma was routinely determined from a strong line at 0.793 nm of W^{46+} and from a quasi-continuum structure emitted by charge stages around W^{29+} at about 5 nm. Since these charge states exist at different temperatures, the measurements also give some profile information.

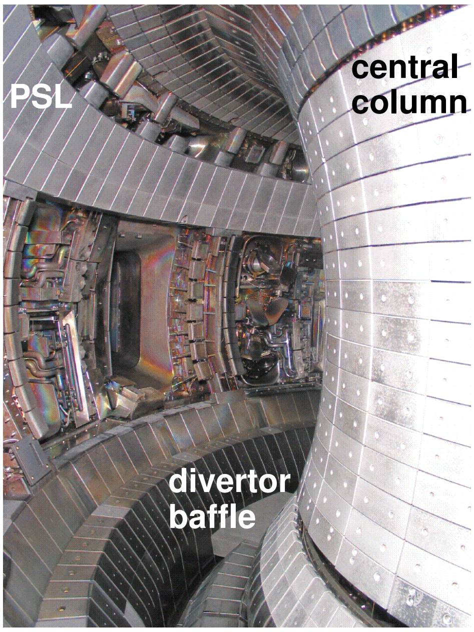

Fig. 1: *View into ASDEX Upgrade. During the campaign 2002/2003 the complete heat shield (HS), the upper passive stabiliser loop (PSL) and the inner divertor baffle (DB) have been covered with new tiles coated by W.*

Long term evolution of intrinsic impurities

Fig. 2 shows the evolution of the H content as a function of the discharge number after a major vent. Three different campaigns are compared. In 1999 only 1.2 m^2 (black) of W were newly installed, in 2001 (red) about 1.6 m^2 were added to the existing 5.5 m^2 (in 2000 only a short campaign was run due to the installation of the new diveror IIb) and before the present campaign (2002, blue) 14.6 m^2 of fresh W-surfaces were installed. Different symbols within one colour denote phases after intermediate vents. Despite this large new PFCs the hydrogen content is already at the lower end of the three campaigns compared. This more effi cient isotope exchange hints to weaker chemical bonds as in the case of carbon PFCs. However, the expected strong reduction of C in the plasma discharges is not observed. This may be partly due to an accidentially misaligned graphite tile in the lower divertor which led to strong overheating and sublimation. On the other hand, the CFC guard limiters in the main chamber are still a strong primary source and, according to influx measurements, a dynamical C-source quickly builds up on the central column, giving cause of C-recycling [3].

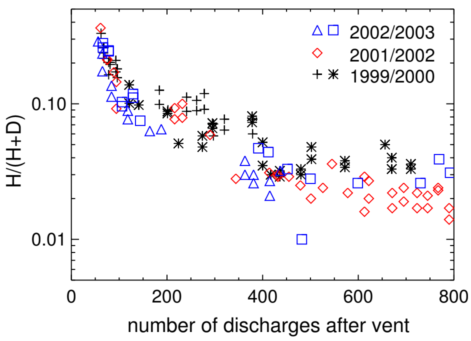

Fig. 2*: Behaviour of the H/(H+D) ratio after major vents in ASDEX Upgrade (description see text).*

As already stated in [1], the central W concentrations are mainly governed by the central impurity transport, which strongly depends on the local heat fluxes as could be shown recently with Si trace-injections [4]. Another critical parameter for the W inventory is the transport near the edge as has been known for long from ELM-free H-Modes. A new observation here is the indication for a feed back loop which leads to an instable situation in the case of the operation near the L-H threshold at natural density. There, the ELM-frequency is low and during the time in-between ELMs, impurities penetrate much easier the plasma [5], leading to increased impurity concentration and radiation. In contrast to C, which under normal plasma conditions mostly radiates in the SOL, a substantial amount is radiated within the separatrix when heavier species (mid-Z as well as W, both observed in ASDEX Upgrade) are involved. This leads to a reduced power flux crossing the pedestal region and consequently results in a lower ELM frequency, closing the feedback loop. Fig. 3 shows the long term evolution of signifi cant plasma pa-

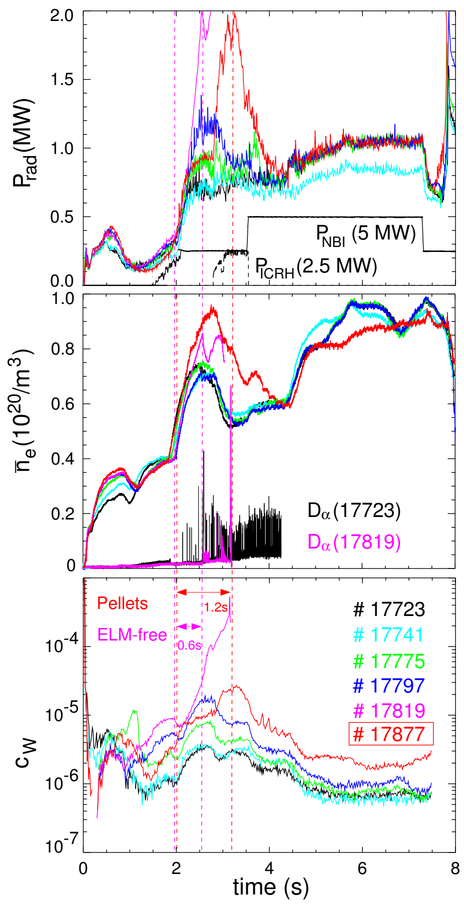

Fig. 3*: Temporal behaviour of plasma parameters in standard-H-mode discharges for different states of machine conditioning. In #17877 80Hz pellets were injected from 2.0-3.2 s*

rameters in 'Standard H-Mode' discharges ($I_p = 1$ MA, $B_t = -2$ T, $q_{95} = 3.2$, $\delta = 0.15$), run once every day of operation. Boronisation was performed before #17680. The evolution of c_W is very gradually until discharge #17819, and the difference in c_W between the first and the second last discharge of the period, during the phase at 4 s with low density and 5 MW auxiliary heating, is only a factor of 2. During this phase the discharges have very similar density and confinement and therefore this increase in the W-concentration is a good measure for the growth of the W source with degrading boronisation. During the low power phase, at the front end of the discharge, the ELM-free period is prolonged from initially 250 ms to above 600 ms in the discharge with the radiation collapse. This is leading to increased W-concentrations and to the feedback-loop described above. A remedy is to increase the heating power. This was done directly after the discharge with the high radiation, by switching on the second beam source at 2.2 s. As expected the radiation remained much lower and at 4 s, $c_W \approx 3 \cdot 10^{-6}$ was similar to the level in #17797.

Another possibility to break the self-amplifying cycle is to enforce ELM activity by pellet injection (see also [6]). In discharge #17877 a train of small pellets was injected at 80Hz from 2.0 s - 3.2 s. The confinement was degraded only by about 10% compared to best values obtained during this phase. c_W remained low and the discharge could be performed similar to #17797, demonstrating the subordinated role of the W source. The reason for the radiation increase during ICRH ($t = 2.8$ s) is not yet clear, but it is a general observation in discharges at the L-H threshold in a poorly conditioned machine.

Comparison of limiter and divertor operation

In contrast to operation in an 'all-carbon' device, there is a strong difference between W-limiter and divertor operation. This was documented in a discharge with divertor-limiter-divertor transitions under otherwise similar discharge conditions. Unlike previous experiments, this allows a direct comparison of both modes of operation and demonstrates that the strong bulk W-contamination is suppressed after the re-transition to divertor operation. This is shown in the discharge of Fig. 4 where at $I_p = 1$ MA, $B_t = -2.4$ T a scan of the inner gap was performed.

Additionally, this discharge clearly proves, that the W-surfaces are visible to the plasma still after half a year of operation. From the almost identical W-level before and after the shift, a strong coverage by low-Z elements can also be excluded. This is in line with the post mortem analysis of W-tiles described below.

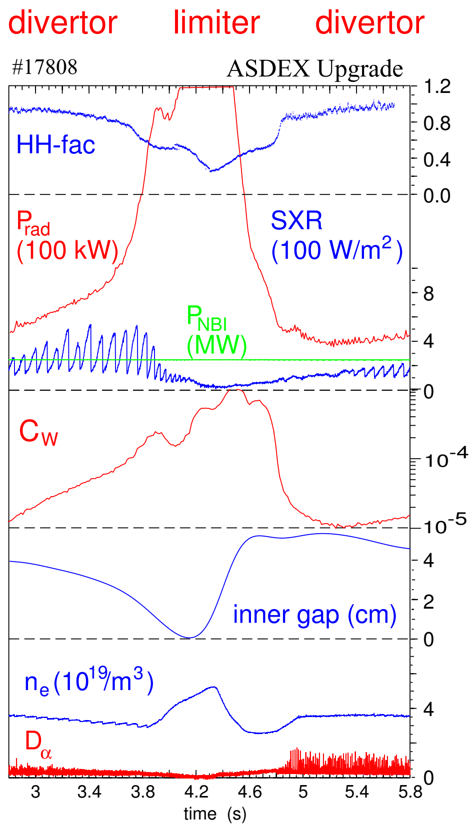

Fig. 4: *Plasma parameters during a transition from divertor to limiter and back to divertor operation induced by a scan of the inner gap for a $I_p = 1$ MA, $B_t = -2.4$ T discharge.*

The W-influx from the HS was estimated from Langmuir probe data using the yields measured during the W-divertor experiment [7]. During the divertor phase temperatures of

$T_e \approx 6$ eV connected to electron densities below 10^{18} m^{-3} are observed, yielding W-influxes $\Gamma_W \leq 4 \cdot 10^{17}$ s^{-1}m^{-2}. As soon as the the separatrix is lost and the plasma is limited at the HS the temperature and density rise, leading to $\Gamma_W \approx 3 \cdot 10^{19}$ s^{-1}m^{-2}. The increase of the W influx by almost a factor of 100 is reflected in the increase of c_W as can be judged from Fig. 4.

Surface Analyses of W-tiles

The W-coating of test tiles ($d = 60$ nm), which were installed during 2001 were reanalysed using the SIMS and AES techniques. Similar to the results reported earlier [8], strong erosion was found above the midplane (almost the whole layer). At the same time, the measurements allowed the extraction of depth profiles. They prove that a considerable amount of W exists at the surface (5%-40%). They could also identify regions of strong re-deposition of W, as is predicted by DIVIMP calculations performed for a limiter-plasma configuration [9].

Conclusions and 0utlook

The behaviour of intrinsic impurities in ASDEX Upgrade has not yet changed significantly despite the exchange of 40% of the plasma facing components from graphite to tungsten. However, hints are found that the isotope exchange in the device after venting can be achieved more easily as previously, but at the same time a more pronounced dependence of the operation at low heating power on the conditioning is observed. This is expressed by a prolongation of ELM-free periods leading to increased central radiation and thereby to a feedback loop delaying the first ELM even further. Remedies to overcome easily this situation is to increase the heating power, or enforce ELM activity by pellet injection. Unlike in 'all-carbon' machines there is a huge difference in plasma radiation comparing limiter and divertor mode of operation, emphasising the crucial role of the divertor when operating with high-Z PFCs. Although C influxes are found all over the central column, the limiter experiments as well as post mortem analyses of the tiles prove that the W surface is not significantly covered. Against this background, the C-influxes seem to be in a highly dynamical equilibrium quickly building up during discharges.

Although the operation of ASDEX Upgrade has to be performed more carefully, the tools developed (central heating and ELM triggering) allowed to achieve all the experimental goals set so far. Therefore, the W-programme will be pursued by additionally converting the full upper divertor to W as well as the outer baffle regions of the lower divertor. Together with the already existing W-tiles, this will add up to 70% of the total PFCs in ASDEX Upgrade. The further conversion to an all W-device will deliver additional benchmarks for the use of W on a larger scale than it is currently envisaged for ITER.

References

[1] R. Neu et al., Journ. Nucl. Mater. 313 - 316 (2003) 116
[2] C. Maggi et al., this conference, P 1.63
[3] T. Pütterich et al., submitted to PPCF
[4] R. Dux et al., this conference, P 1.132
[5] R. Dux, Fusion Technology (2003) in press
[6] P.T. Lang et al., this conference, P 1.129
[7] A. Thoma et al., PPCF 39 (1997) 1487
[8] K. Krieger et al., J. Nucl. Mater. 313 - 316 (2003) 327
[9] A. Geier et al., this conference, P 1.156