IMPURITY PRODUCTION DURING ICRF HEATING

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Abstract:
ICRF heating at $2\Omega_{CH}$ was investigated for a variety of different target plasmas and heating regimes. In all cases a significant increase of the radiated power, caused mainly by a higher iron concentration in the plasma, is observed. Neither the moderately improved particle confinement nor a reduction of impurity screening on account of changed plasma edge parameters is responsible for the high radiation losses, but enhanced wall erosion is required to explain the experimental data. The impurity production mechanisms are not yet fully understood. Impurity sputtering by oxygen and carbon, however, could be experimentally excluded as possible production processes. In all experiments a clear anticorrelation between wave absorption and impurity production was observed. Moreover, we find that suprathermal ions are produced in the plasma edge region by the non-absorbed ICRF power. It is assumed that these particles are responsible for the excessive impurity production.

General statements and features

ICRF heating at the second harmonic of hydrogen has been launched into different target plasmas (pure H, mixed H/D, and He; OH and NI preheated). The influence of wall carbonization has also been investigated /1/. As already outlined in /2/, in any case a significant increase of the impurity concentration (Fe, Ti - non-carbonized; C, Ti - carbonized) in the plasma and a concomitant enhancement of the radiation losses are found. In the non carbonized case the radiation profiles measured by a bolometer array are peaked in the plasma centre, whereas with carbonized walls the plasma radiates mainly in the edge region. Though the volume-integrated radiation losses are comparable in both cases (~45 % of input power), high-power ICRH (up to the maximum available level of 2.5 MW) can be launched into ohmic discharges only under carbonized conditions. Without carbonization the maximum ICRF power is limited to 1.5 MW owing to disruptions. In NI preheated discharges no power limit is oberved and the radiation losses are significantly reduced under both circumstances.

These observations underline the importance of impurity radiation in the case of high-power ICRF heating. An enhancement of the central impurity density can have various causes. We first checked the following possibilities:

- The impurity confinement in the core plasma is assessed from the decay of the TiXX line radiation after Ti injection by means of laser blow-off techniques into OH, ICRF, NI and combined NI/ICRF-heated plasmas. It is

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found that the corresponding impurity confinement times (τ_I in the case of OH: 49 ms, NI: 19 ms, ICRH: 32 ms, NI + ICRH: 33 ms) are increased by a factor of ~1.5 when ICRH is added ($P_{NI} = P_{ICRH} = 0.8$ MW). This marginal improvement of central confinement cannot explain on its own the enhancement of the radiation losses.

- Larger changes of the plasma edge parameters, which could result in a deterioration of the screening efficiency could not be substantiated by edge diagnostics.

Consequently, enhanced wall erosion is required to explain our findings. The first hypothesis on impurity production mentioned in /3/ assumed that vertically drifting ions are accelerated in the resonance layer and release impurities at structural elements in the vicinity of the upper stagnation point. This hypothesis, however, had to be discarded on the basis of more extended investigations including spectroscopic Fe-flux measurements described below. In the following we present new experimental results with respect to the impurity production mechanisms.

Fe flux measurements

A double mirror system, specially developed for poloidal scanning, was used to measure spectroscopically the Fe fluxes originating in the vicinity of the upper and lower stagnation points, as well as from the inner wall (Fig. 1). The spectrometer used was a 1.5 m Cerny-Turner visible monochromator equipped with an OMA diode-array camera providing a high resolution (1000 channels, $\lambda/\Delta\lambda = 6000$). The evaluation of the spectra is rendered difficult by blending of the weak FeI lines with strong light impurity lines. For evaluation we used the 3719.9 Å and the 3734.9 Å FeI resonance lines. The system allows measurements during NI and combined NI + ICRF heating phases, but fails because of intensity problems during the OH phase. As seen from Fig. 1, no drastic increase of the FeI fluxes with the onset of ICRH occurs in contrast to the strong enhancement of the Fe concentration in the core plasma. Furthermore, in striking contradiction to the hypothesis mentioned in /3/ no up-down asymmetry in the fluxes is found (Fig. 1).

Sputtering by impurities

The possibility of sputtering by highly ionized light impurity ions, such as O^{+8} and C^{+6}, which compared with H^+ and D^+ have a much higher sputtering yield (~20 % instead of ~1 % for H^+), was checked by puffing oxygen and methane during the ICRH pulse. According to CX recombination/line intensity measurements of CVI and OVIII the concentrations of these light impurities were increased by a factor of 1.5. No change, however, of the Fe density (deduced from the FeXVI intensity) in the plasma could be seen. Self-sputtering of iron as a dominating mechanism can also be excluded, since under these circumstances the Fe signals should increase exponentially during the ICRF pulse, whereas generally a stationary behaviour is seen.

$2\Omega_{CH}$-heating in pure He plasmas

ICRH at $2\Omega_{CH}$ was applied to a pure helium plasma ($n_{H^+}/n_{He^{++}} \lesssim 3$ %). In this case no heating could be established and a low power limit at 200 kW exists. The FeXVI line intensity, the total radiation losses and the eletron density rise steadily during the whole ICRF pulse. In accordance with this behaviour we observe a reduction of the H_α divertor radiation, which is representative of the power flow into the divertor. Puffing hydrogen during the ICRF pulse, in order to increase the H^+ concentration to $n_{H^+}/n_{He^{++}} \sim 10$ %, results in a moderate heating of the plasma and the power limit is shifted up to 500 kW. The radiation losses and the FeXVI line intensity become stationary and are

reduced by factors of 2 and 4, respectively, at the end of the ICRH period. In this case the H_α divertor intensity does not change when ICRH (200 kW) is applied, indicating a power flow into the divertor during ICRH comparable to the OH phase. A similar type of discharge heated by 500 kW ICRF is presented in Fig. 2. In this case we stop hydrogen blowing 200 ms prior to the end of the ICRF pulse. As is clearly demonstrated in Fig. 2, all radiation signals (FeXVI, bolometer, soft X-ray) start to rise immediately after the end of H_2 puffing. A similar increase is found in the H^o CX-particle flux at 10 keV originating from the plasma edge (Fig. 2). These particles are produced by the wave and can be assumed to be representative of the behaviour of the non-confined high energy ions.
It is important to note that in contrast to the above-described relations no changes were observed when puffing deuterium instead of hydrogen into pure He discharges.

B_T-scans

In order to change the position of the resonance layer of the $2\Omega_{CH}$ ICRF in the plasma, the toroidal field B_T was varied in a sequence of discharges. In all these experiments a minimum of the radiation losses is found when the resonance layer is located in the vicinity of the plasma centre (Fig. 3). Furthermore, the H^o CX particle flux at 17 keV shows the same tendency. On the other hand, the heating efficiency (lower insert Fig. 3) is maximum for the optimum position of the resonance layer. These results also support the interpretation deduced from the He experiments that the variation of impurity density with the position of the resonance layer /3/ is caused by changes of the wave absorption.

Conclusions

ICRF heating in He discharges revealed a clear anticorrelation between wave absorption and impurity production. Consistently with these observations, we find strong indications that changes of the impurity density as a function of the resonance layer position can also be explained by a variation of the absorption conditions. Impurity sputtering as a possible process for enhanced wall erosion could be excluded by appropriate puffing experiments. Spectroscopic Fe-flux measurements did not yield strong poloidal asymmetries in the accessible range at the top and bottom divertor entrances and inner wall region. The observed Fe fluxes roughly correlate with the additional power input but no excessive increase is found in the case of ICRH. Therefore, it must be assumed that the excessive wall erosion takes place either at a closer distance to the antennae or at the outer wall regions which could not be observed. From CX-flux measurements we learned that - particularly in the case of bad ICRH absorption - high-energy ions ($\gtrsim$5 keV) are produced in the plasma boundary region. These particles are likely to move on purely confined banana orbits and may hit the outer torus wall at grazing incidence. Under these conditions enhanced sputtering is to be expected. This effect could possibly explain the discrepancy mentioned in /2/, where it was pointed out that with a maximum sputtering yield of 1 % (H^o - Fe) for normal incidence the necessary H^o/H^+ fluxes cannot be achieved under reasonable assumptions.

References:

/1/ K. Steinmetz, et al., this conference.
/2/ G. Fussmann, et al., Proc. 12th Int. Conf. on Controlled Fusion and Plasma Physics, Budapest (1985), Part I, A P Th 002.
/3/ K. Steinmetz, et al., Plasma Physics and Controlled Fusion, Vol. 28, No. 1A, pp. 235-238, 1986.

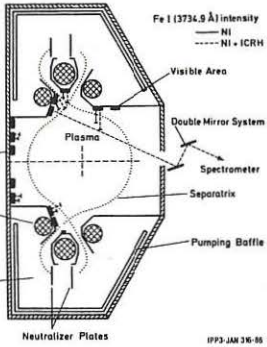

Fig. 1: Spectroscopic arrangement for Fe-flux measurements. The Fe I fluxes measured are proportional to the lengths of the bars perpendicular to the indicated areas.

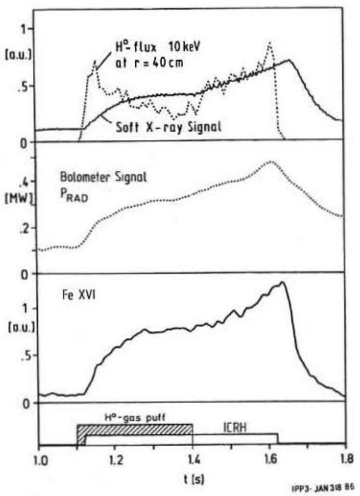

Fig. 2: Fe XVI line intensity, bolometer signal, soft X-ray signal, and the 10 keV H^0-CX flux, demonstrating the anticorrelation of impurity production and hydrogen concentration in a He discharge during ICRF heating (2 Ω_{CH}).

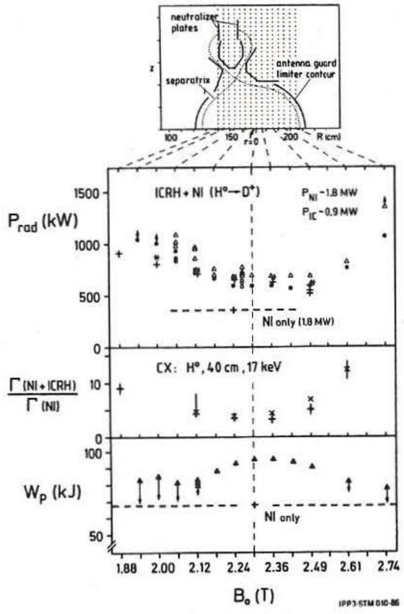

Fig. 3: Various plasma parameters during ICRH: total radiation losses (bolometer), relative fluxes of fast protons at the plasma edge and plasma energy content as a function of the position of the resonance layer (B_T-scan). Arrows in the W_p-plot indicate the increment of W_p due to increased ohmic input.