Bolometric measurements in the ASDEX Upgrade divertor

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1 Introduction

The radiation distribution in the ASDEX Upgrade divertor has been investigated by bolometric measurements. Eight lines of sight of a horizontal pinhole camera through the X-point and four lines of sight of collimators over each target plate are used to measure the radiation from the divertor and X-point region with a time resolution of up to 1 ms. These new divertor bolometers allow to determine the radiation distribution from the divertor region with a high spatial resolution and thus together with the other 72 bolometer lines of sight of ASDEX Upgrade they provide the possibility to perform a much improved tomographic reconstruction of the radiation distribution in a poloidal cross section of the plasma of both the bulk plasma and the divertor region.

Since bolometric measurements may be affected by the cooling effect of the neutral gas pressure, the influence of this neutral gas pressure on the measured line integrals has been studied in laboratory experiments.

2 Bolometric diagnostic at ASDEX Upgrade

In the ASDEX Upgrade tokamak radiation losses are recorded by 88 bolometers placed in six pinhole cameras and two collimators which are mounted around one poloidal cross section of the plasma inside the vacuum vessel (Fig. 1). The bolometers are miniaturized, low noise metal resistor bolometers [1] which are excited by a 50kHz sine wave and effectively suppress thermal drift and electromagnetic interferences. Radiation from the X-point and divertor region is observed with an 'horizontal' camera with 8 channels and a spatial resolution of about 6cm and two collimators with 4 channels over each target plate. Radiation from the main plasma is measured by four 'horizontal' cameras with together 48 channels and spatial resolutions between 3cm and 10cm and a vertical camera with 24 channels.

In order to obtain the distribution of the local radiation emissivity in a poloidal cross section of the plasma, the measured line integrals must be unfolded. This is done with the 'Anisotropic Diffusion Model Tomography' algorithm, which is based on the fact that the variation of the radiation emissivity along magnetic field lines is much smaller than perpendicular to them. This behaviour is described by an anisotropic diffusion model with different values of the diffusion coefficients $D_{\|}$, $D_{\perp}$ along and perpendicular to the magnetic field lines. [2]

3 Radiation distribution in the ASDEX Upgrade divertor

The measurements of the new X-point and divertor bolometers have been used to reconstruct the radiation distribution from both the divertor region and the main plasma for different types of plasma discharges.

3.1 CDH mode discharges

Fig. 1 shows the radiation distribution in a poloidal cross section for the transition from the H to the CDH mode [3]. During a shot with 1MA plasma current and 7.5MW neutral injection neon has been puffed in order to achieve a detached divertor and a radiative boundary. The amount of the puffed neon was controlled such that the total radiated power was 80% of the input power. Fig. 1a shows the radiation distribution during the H mode before neon injection. The main radiation is located directly in front of the both divertor target plates. About 30% of the input power is radiated in the divertor, ca. 20% over the outer plate and 10% over the inner plate (the radiation over the inner plates is mainly due to ELMs, over which the bolometers generally integrate in time). Fig. 1b shows the radiation distribution during the neon puffing (CDH mode). A clear radiation boundary has been developed and the maximum of the radiation now is located above the X-point inside the closed flux surfaces. The radiation over each target plate has decreased to less than 5% of the input power.

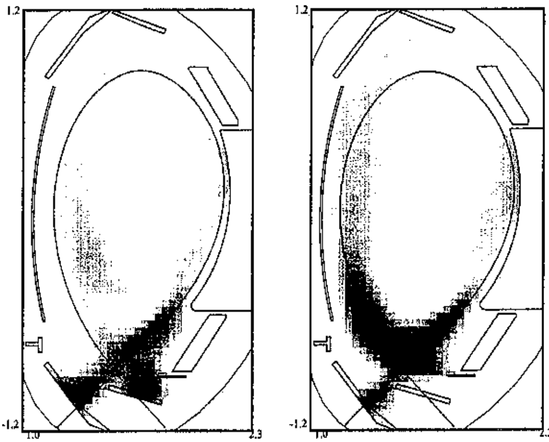

Figure 1: *Development of the radiation distribution during the transition from H mode (left) to CDH mode (right)*

3.2 Density limit shots

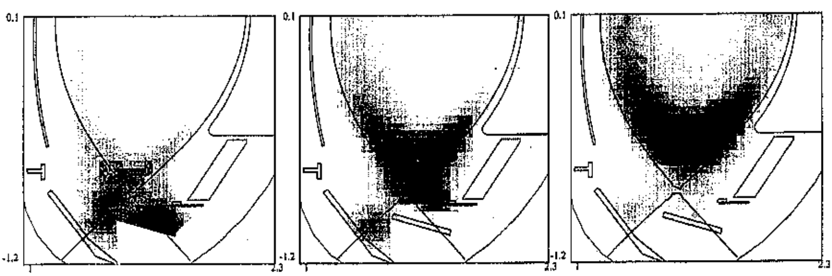

Figure 2: *Evolution of a marfe during an ohmically heated density limit shot: a) medium density, no marfe; b) increasing density, marfe starts to develop onto closed flux surfaces; c) density limit almost reached, marfe fully developed*

Fig. 2 shows the development of a marfe during an ohmically heated density limit shot. At a medium density (Fig. 2a) the maximum of the radiation is located over the outer target plate, ca. 30% of the total radiated power is radiated in the divertor region. With increasing density the radiation over the plate decreases and the maximum of the radiation shifts upwards onto closed flux surfaces (Fig. 2b). Finally, the marfe on closed flux surfaces is fully developed and moves further upward (Fig. 2c). Now only less than 10% of the total radiated power comes from the divertor.

In density limit and density ramp shots with additional heating by neutral injection, the development of the radiation profiles is slightly different to the ohmically heated plasmas: Fig. 3 shows two radiation profiles from a density ramp shot with 800kA plasma current and 2.5MW neutral injection. The line averaged electron density has been varied up to $6.5 \cdot 10^{19}\mathrm{m}^{-3}$ and down again [4]. Fig. 3a shows the radiation profile in an early state at a medium density, where the maximum of the radiation is again located in front of the outer target plate. At the maximum density however (Fig. 3b) the maximum of the radiation has shifted upward, but no marfe on closed flux surfaces has been developed yet. With decreasing density, this behaviour is reversible and the maximum of radiation shifts down again over the outer target plate.

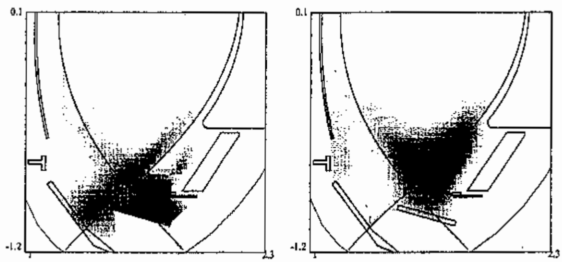

Figure 3: *Radiation profiles during a density ramp with neutral beam injection: a) medium density, radiation located at outer target; b) maximum density, radiation maximum shifted upward, but not onto closed flux surfaces*

In additionally heated density limit shots one finds that the marfe on closed flux surfaces develops only very late before the density limit is reached and does not stay on closed flux surfaces as long as in ohmically heated density limit discharges.

At low and medium densities, up to 80% of the total radiated power may be radiated from the divertor, with a clear maximum over the outer target plate (for L mode discharges). With increasing density, the radiation from the divertor region decreases to about 10% of the total radiated power (Fig. 4).

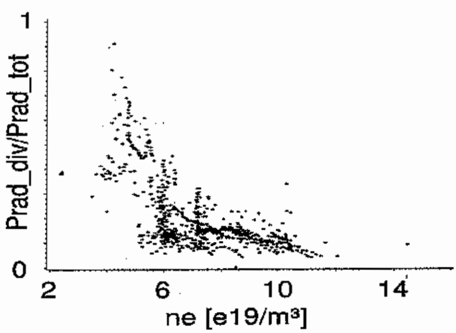

Figure 4: *Fraction of the power radiated from the divertor to the total radiated power as a function of the line averaged electron density n_e during L mode for several discharges with neutral beam injection*

4 Influence of the neutral gas pressure

Divertor radiation losses are favourably measured with bolometer cameras which are mounted inside the divertor chamber, close to the plasma. Such a positioning allows the observation of the total divertor plasma volume and minimizes the plasma screening of charge exchange neutrals. But bolometric radiation measurements in the divertor may considerably be falsified at high neutral gas pressure which usually arises during high density, high power plasma discharges. Two effects of the neutral gas on the bolometer can be distinguished. Either the bolometer sensitivity and the bolometer bridge offset voltage varies with the gas pressure. In Fig. 5a the pressure dependence of the sensitivity

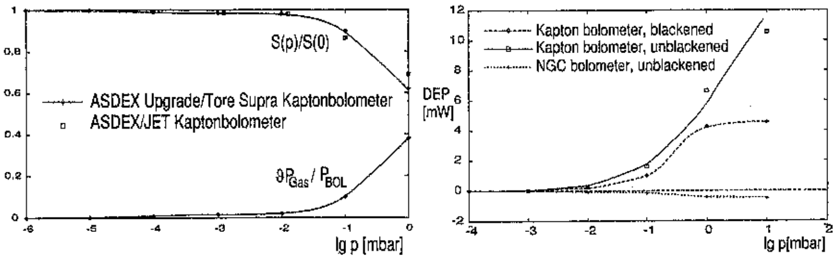

Figure 5: *Pressure dependence a) of the normalized bolometer sensitivity $S(p)/S(0)$ and the fraction of the gas cooling power $\vartheta P_{gas}(P)$ to the absorbed radiation power P_{BOL} in air; b) of the drift equivalence power DEP=offset voltage/S for various bolometer types in air*

of two types of Kapton bolometers in air as working gas is represented. This decrease of the sensitivity is common to most types of bolometers and is caused by heat conduction via the surrounding gas from the absorber to the housing of the bolometer corresponding to a reduction of the bolometer cooling time constant τ. More critically the offset voltage of the bolometer bridge varies with the gas pressure like a Pirani pressure gauge. Small differences in the parameters of related measuring and reference bolometers, mainly of the cooling time constants, result in substantial offset voltages at higher gas pressures (Fig. 5b). The offset can be positive or negative and depends in a complicated manner from the asymmetries of the bolometer detector and from the gas species. Kapton bolometers additionally show a sharp positive rise of their offset with higher gas pressures ($> 10^{-2}$mbar) which could be attributed to a strain gauge effect.

A much improved behaviour (Fig. 5b) was found for a newly developed high impedance MICA bolometer array with optimized ventilation (Neutral Gas Compensated Bolometer) which is mounted in the new Divertor II of ASDEX Upgrade.

Neutral gas pressures up to $5 \cdot 10^{-2}$mbar were measured in the divertor I of ASDEX Upgrade. The relevant offset voltages of the divertor I bolometers were compensated numerically in the tomographic reconstructions shown above, using measurements of an ionization pressure gauge [5] which was installed nearby.

References

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