26th EPS Conf. on Contr. Fusion and Plasma Physics, Maastricht, 14 - 18 June 1999 ECA Vol.23J (1999) 1385 - 1388

Variation of radiation profiles with plasma parameters in ASDEX Upgrade

J.C. Fuchs, K.F. Mast, D. Coster, A. Herrmann, R. Schneider,
and the ASDEX Upgrade Team

MPI für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany

1. Introduction

Radiation losses in the new Lyra divertor (DIV II) of ASDEX Upgrade are investigated. A detailed knowledge of the radiation distribution in the divertor is necessary in order to increase and control the divertor radiation with the aim of reducing the power load on the divertor plates under ITER relevant conditions.

In ASDEX Upgrade radiation losses are measured with 100 bolometers placed in 7 pinhole cameras which are mounted in one poloidal cross section of the torus inside the vacuum vessel. Two bolometer pinhole cameras with 7 lines of sight each measure radiation from the inner and outer divertor leg and allow for a correction of the neutral gas pressure dependent bolometer sensitivity and of the residual bolometer offset drift. The region around the X-point is observed with an 8 channel pinhole camera, the main plasma with 72 bolometers placed in five cameras. 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.

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]

Radiation distributions and power balance have been investigated for a wide variety of plasma regimes. Some different examples will be presented and the dependence of the radiation profile and the radiated power on different parameters will be investigated.

2. Radiation pattern

The measured line integrals of the 22 divertor bolometers together with the other 72 bolometers of ASDEX Upgrade have been unfolded in order to reconstruct the radiation distribution in the divertor region as well as in the main chamber.

Fig. 1 shows a typical, ELM-averaged radiation profile for a discharge with I_P=1MA, $n_e=7\cdot10^{19}m^{-3}$, q_{95}=4 and 5MW neutral beam injection power. The highest radiation is found in the divertor fans near the strike points with local radiation emissivities of up to 10MW/m³ at the inner and 7MW/m³ at the outer strikepoint. The radiation in the inner divertor is higher than in the outer divertor due to ELMs. The shape of the radiation profile does not change considerably if the neutral beam injection power is increased, but scales almost linearly with the heating power.

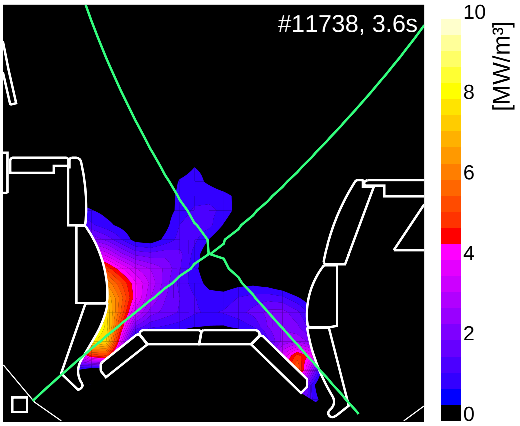

Fig 1: Reconstructed radiation pattern in the ASDEX Upgrade LYRA divertor with pronounced radiation peaks in the inner and outer divertor fan at the strikepoints. The input power is 5MW

Integrating over the plasma one finds a total radiated power of about 80% of the input power, and a radiated power in the divertor (defined by a horizontal line through the X-point) of about 40% of the input power (Fig 2). These values are also almost independent of the heating power (Fig. 4). Subtracting from the input power the total radiated power measured by bolometers, the power load on the divertor plates measured by thermographic cameras, the change of the internal plasma energy, and taking into account that parts of the divertor radiation is measured by both bolometer and thermographic cameras, one arrives at a reasonably good power balance (Fig. 2).

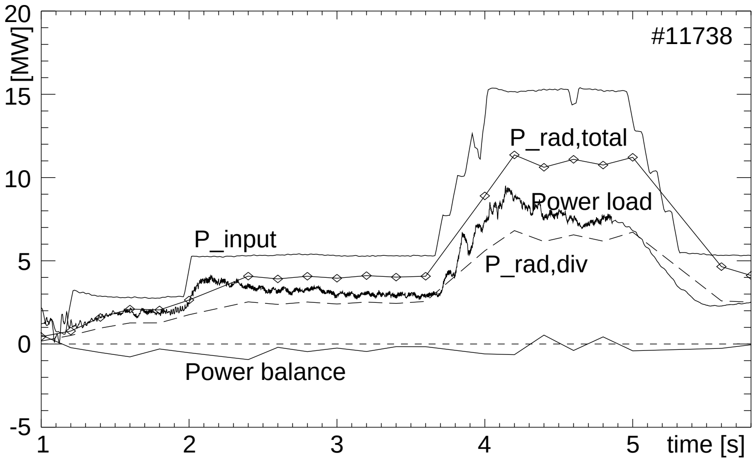

Fig. 2: Power balance for the discharge from Fig. 1, showing time traces of the input power, the total radiated power, radiated power in the divertor, power load on the divertor plates measured by thermographic cameras and the radiation corrected power balance.

For discharges with increased triangularity in the present divertor configuration the outer strikepoint must be moved on the roof baffle, which means a horizontal target plate in contrast to the normal vertical one. Fig. 3 shows the radiation profile for such a discharge with a horizontal target plate and I_p=1MA, $n_e=7\cdot10^{19}m^{-3}$, q_{95}=4 and 5MW neutral beam injection power. Again we find the highest radiation near the strikepoints, however at the outer strikepoint the radiation density now is only about $3MW/m^3$. Whereas the total radiated power (75% of the input power) remains nearly unchanged compared to discharges with both strike points on the vertical plates, the divertor radiation is lower (only 25% of the input

Fig. 3: Radiation profile for a shot with the outer stikepoint on roof baffle (horizontal target). The input power is 5MW.

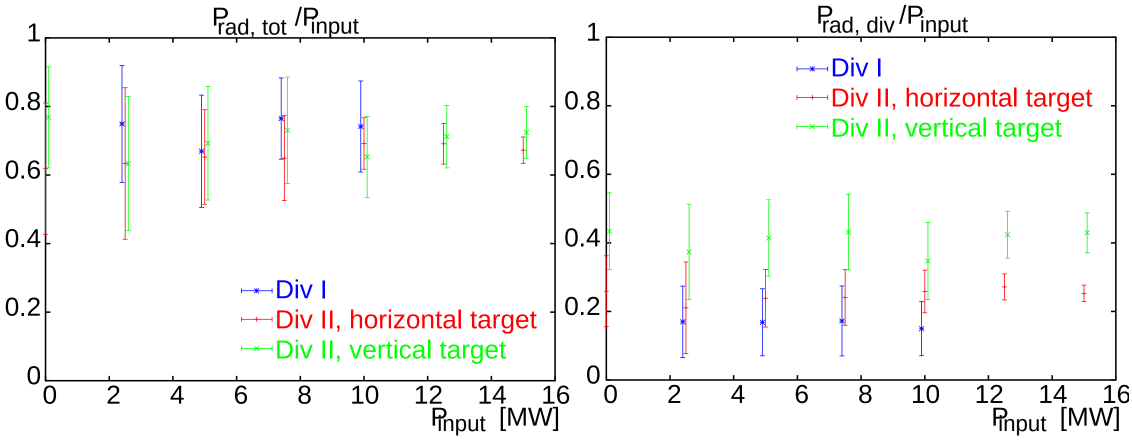

Fig. 4: Fraction of the total radiated power to the input power (left) and the radiated power in the divertor to the input power (right) as a function of the input power. Green: Outer strikepoint on the strikepoint-module (vertical target), red: outer strikepoint on the roof baffle (horizontal target), blue: divertor I (two horizontal targets). The crosses indicate average values, the lines the standard deviation for a large number of individual time points.

power), and the radiation in the main chamber has increased. Also these values are nearly independent of the heating power (Fig. 4), and they are comparable to the values from the former divertor I of ASDEX Upgrade, where both strikepoints were on almost horizontal target plates [3].

3. Effect of high energetic neutrals

High energetic neutrals from charge exchange processes which reach the bolometer detectors affect the bolometric measurements. For non-blackened gold-foil detectors which are used in all bolometers of ASDEX Upgrade, about 60% of the energy of the neutrals is absorbed by the bolometer. Since the plasma is normally not opaque for these neutrals, only bolometers which are mounted near the plasma can measure the energy of the neutrals. This may lead to inconsistent measurements of different bolometers in different positions, which may cause difficulties in the tomographic reconstruction of the radiation profile.

Therefore, in order to estimate the influence of the high energetic neutrals on the bolometric measurements, the energy flux of neutrals (both atoms and molecules) leaving the plasma and reaching the bolometers has been calculated from B2-Eirene modelings. It was found that the only bolometers for which this energy may be larger than the noise in the measurements are those of the two divertor cameras mounted below the roof baffle and viewing through the inner and outer divertor fans. However, for normal discharges with a medium density ($n_e=0.6n_{GW}$) a significant influence was found only for the lowest lines of sight through the outer divertor fans (Fig. 5), where the energy of the neutrals may reach up to 50% of the measured bolometer line integrals (Taking into account that only 60% of the energy of the neutrals is absorbed, the contribution of the neutrals to the line integrals reduces to 30%). Calculating the tomographic reconstruction of the radiation profiles once from the measured line integrals and once from the line integrals reduced by the energy of the neutrals, we find a slightly reduced radiation emissivity in the outer divertor fan. However, integrating over the whole plasma we find a reduction of the total power loss from 70% of the input power for radiation and neutrals to 68% for radiation only, which is negligible and well within the noise of the measurements.

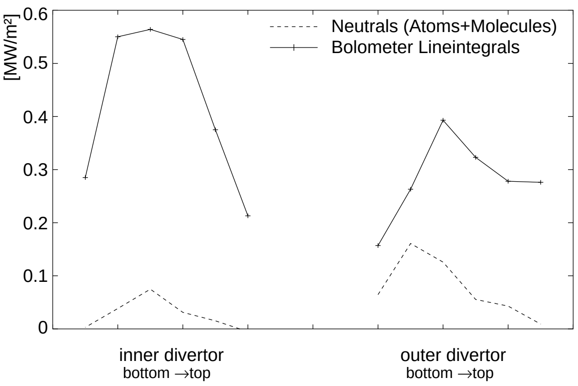

Fig. 5: Comparison of the measured line integrals of the divertor bolometers and the power of the high energetic neutrals reaching these bolometers for a shot with 8MW input power and a medium density.

Although for higher densities where the plasma is detached the influence of the energy of the neutrals on the measured line integrals is noticeable for more of the divertor bolometers, the difference in the total power loss (83% for both radiation and neutrals, 79% for radiation alone) is still small.

It should be noted that not only the high energetic neutrals affect the bolometric measurements, but also the neutral gas pressure which changes the bolometer sensitivity and the residual bolometer offset drift. Therefore, both of the divertor bolometer cameras have one detector which is not exposed to the radiation, so it is used to measure the gas pressure in the camera itself and to correct the measured line integrals of the other bolometers [4].

4. Global scalings of the radiated power

Typically the total radiated power in discharges in ASDEX Upgrade is about 60%-80% of the input power, and the radiated power from the divertor is about 40%-50% of the input power.

However, looking at discharges with a wide variety of plasma parameters, one finds a considerable variation in the values for the radiated power (Fig. 4: The lengths of the individual lines indicate the standard deviation of the values for many different time points. The smaller standard deviation for higher input power does not necessarily mean that there is a lower scatter, but only that there are less points available). In order to explain this variation, the dependence of the radiated power on various global plasma parameters has been investigated by statistical methods. The database consists of a large number of time points for ohmic, L- and mostly H-mode plasmas with heating powers up to 15MW.

It was found that the divertor radiation depends mainly linearly on the input power, less on the plasma current, the line averaged density of the main plasma, and slightly on the magnetic field:

$$P_{rad,divertor} \sim P_{input}^{0.98}\overline{n}_e^{0.24}I_P^{0.59}B_T^{-0.11} \approx P_{input}\overline{n}_e^{0.25}I_P^{0.5}q^{-0.1} \qquad (R^2 = 0.75)$$

The dependence of the total radiated power on the input power is slightly less than linear. It depends also on the line averaged density, but only very weakly on the plasma current and the magnetic field:

$$P_{rad,total} \sim P_{input}^{0.86}\overline{n}_e^{0.49}I_P^{-0.04}B_T^{0.046} \approx P_{input}^{0.86}\overline{n}_e^{0.5}q^{0.04} \qquad (R^2 = 0.88)$$

For the radiated power in the main plasma a reasonable good agreement with the Matthews-scaling $P_{rad} \sim n_e^2(Z_{eff}-1)$ was found.

However it was also found that for times very early in the discharge these scalings do not describe the radiation very well, because in the first 200-500ms after the X-point and strikepoints have developed, the total radiation rises slowly from ca. 30% to 80% of the input power. Both the radiation from the main plasma (7%→15% inside the separatrix) and from the divertor region (20%→50%) slowly rise with time. Although in many cases there is simultaneously an increase in the electron density during this time, the increase in the radiation is larger than predicted by the global scalings mentioned above, and it also occurs for discharges with constant line averaged density (Fig. 6).

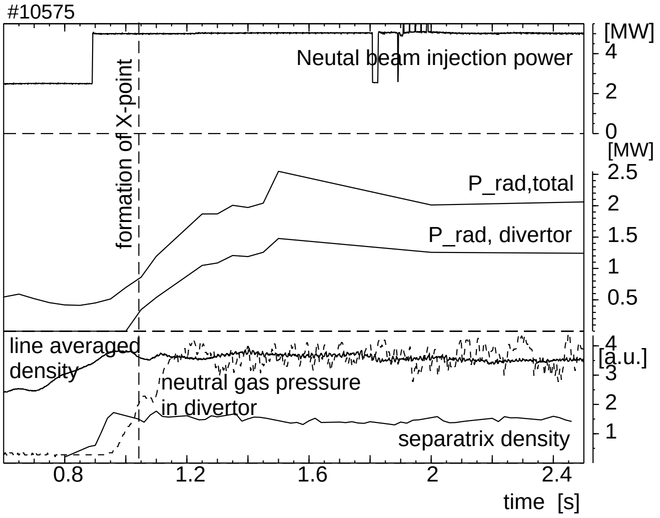

Fig. 6: Slow increase of radiation in the beginning of a shot in spite of constant global plasma parameters.

The heat flux to the divertor plates rises also during this phase, but not as drastically as the radiation. However it is found that the local heat deposition on the plates becomes more concentrated near the strikepoints, and especially at the outer strikepoint it increases by a factor of 4 or more in the first 500 ms after formation of the X-point.

A possible explanation for this behaviour might be the non-equilibrium between fluxes and densities during the non-stationary early phases of plasma discharges. Furthermore, in the beginning of a discharge the plasma is still very clean and Z_{eff} is low due to the large gas puffing in this phase.

References

[1] K.F. Mast, J.C. Vallet, C. Andelfinger et al., Rev. Sci. Instrum. **63**(3) (1991), 744ff
[2] J.C. Fuchs, K.F. Mast, A. Herrmann, K. Lackner et al., Contrib 21st EPS (1994), 1308ff
[3] A. Kallenbach, M. Kaufmann, D. Coster, J.C. Fuchs et al, Nucl. Fusion, in press
[4] J.C. Fuchs, K.F. Mast et al, Contrib 25th EPS (1998), 1510ff