31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-4.132 (2004)

Details of power deposition in the thermal quench of ASDEX Upgrade disruptions.

G. Pautasso, T. Eich, A. Herrmann, D. Coster, C. Konz, O. Gruber, K. Lackner, W. Schneider and the ASDEX Upgrade Team, Max-Planck-Institut für Plasmaphysik, EURATOM Association, 85748 Garching, Germany

Introduction.

The issues of (1) duration of the thermal quench, (2) broadening of the SOL during thermal quench and (3) poloidal asymmetries of the conducted/convected heat fluxes in the SOL are presently subject of experimental investigation and analysis in ASDEX Upgrade. These parameters strongly influence the extrapolated thermal loads to the ITER first wall and the choice of the appropriate material. This work is part of the broader international effort aimed to review the Physics Basis for ITER on the basis of more recent experimental results.

The main diagnostics used for this work are the IR camera looking at the strike point modules of the lower divertor and the 2D IR camera monitoring the upper divertor or the inner and outer wall [1,2].

Duration of the thermal quench.

The duration of the thermal quench is predicted to be of the order of 1ms in ITER and assumed to scale proportionally to the minor radius of the device. The measurements of power deposition in divertor during thermal quench on ASDEX Upgrade show heat pulses longer than 1 ms and therefore do not support this assumption.

The duration of the thermal quench needs first of all to be defined empirically. It can be defined in several ways:

(1) as the decay time of the plasma thermal energy. This measurement is available from the equilibrium reconstruction with a time resolution as fine as 0.1 ms. Nevertheless the redistribution of the toroidal plasma current cause a large loop voltage that disturbs the magnetic measurements on which the FP reconstruction is based. Therefore the evaluation of the plasma thermal energy may not be valid during the thermal quench;

(2) as the decay time of the electron temperature. The ECE measurements are available with a fast time resolution (ms) but they are mostly in cut-off at the time of the disruption or may become affected by cut-off during the thermal quench. The extrapolation to ITER was based on ECE data [3];

(3) as the decay time of the SXR. The SXR emission is not measurable anymore during the last phase of the disruption or before the disruption itself because of the low plasma temperature;

(4) as the duration of the heat pulse on the divertor/wall.

In this work we base the definition of the thermal quench duration on the measurement of the heat pulse onto the divertor and in particular onto the strike point modules of the divertor. This restriction is necessary because the time history of the power varies from tile to tile in the poloidal direction.

Figure 1 shows a typical heat pulse integrated on the strike point modules of the lower divertor and the duration of the rising phase (τ_r, from $P = 0.15 * P_{max}$ to P_{max}; P is the deposited power) and the decay phase of the heat pulse (τ_d, from P_{max} to $0.5 * P_{max}$).

Only IR camera data sets with a time resolution (Δt_{therm}) of 0.12 and 0.24 ms have been used. The database for this work contains 50 shots, density and radiation limit disruptions, pertaining to the shot range 13000-15000. 35 % of data analyzed do not show an isolated peak, which falls in the definition of Fig. 1. For half of the remaining 33 cases, the heat pulse has a more complicated structure and results from the superimposition of several pulses. The remaining cases show a rising and a decaying phase, lasting a time τ_r and τ_d respectively, plotted in the histograms of Fig. 2. τ_r may be shorter than or as short as the time resolution of the thermography and up to 1-2 ms long. τ_d is longer than Δt_{therm}, in average 1 ms long, and therefore well resolved.

The attempt to characterize the time scale of the power deposition during thermal quench as function of plasma parameters is not very promising. τ_r and τ_d are not functions of the plasma thermal energy (in the 40-200 kJ range) and may vary within one order of magnitude. The dependence of τ_r and τ_d on the electron temperature (expected from theoretical considerations) cannot be assessed since measurements of electron temperature (from ECE) and density (from the DCN) are mostly not available before disruption.

Energy balance and reproducibility of the power deposition.

Recent dedicated experiments (shot range 18000-19000) aimed to measure the power deposition on the upper divertor in disruptions were carried out in Spring 2004 on ASDEX Upgrade. Density limit disruptions were caused by rising the density in a preprogrammed way with gas puffing. The plasma parameters were: upper single null, $I_p = 0.8$ MA, q_{95} = 3, 4.5 and $P_{NI} = 2.5$, 5 MW. The discharges with the lowest values of q_{95} and P_{NI} disrupted at $E_{th} = 150$ kJ. The other discharges underwent a series of minor disruptions, which degrades the energy from 150 to 40-50 kJ. The power deposition pattern is similar in these discharges. Nevertheless the fraction of thermal energy deposited on the primary divertor was striking different , ranging from 30 to 100 %. We do not have measurements of radiated power for this experiment. The causes of the energy *in-balance* may be different and cannot be quantitatively specified at the moment because of lack of diagnostic coverage:

(1) the power flux to the divertor is likely to be toroidally asymmetric (the IR measurements cover a thin poloidal profile of the divertor);

(2) the repartition between conducted/convected and radiated energy may differ from case to case;

(3) a fraction of the thermal energy may remain in the plasma.

Spatial distribution of the thermal energy deposited on the PFC during the thermal quench.

The ITER Physics Basis reports that the SOL width during the thermal quench broadens typically by a factor of 3 relative to the predisruption width. This prescription is not supported by recent and older measurements of ASDEX Upgrade which indicate that the SOL expands more than that during the thermal quench. Profiles of power deposition extend to the whole divertor and outside of it, as shown in Figure 3. Mapping of these profiles on the outer midplane show that the heat flux channel (expanded SOL) is larger than the sight of view of the IR camera (5 cm if mapped on the midplane). The typical

SOL width in ASDEX Upgrade is of the order of 1 cm .

For technical reasons the sight of view of a IR camera is limited to a fraction of the PFCs. Therefore a series of dedicated experiments is being carried out on ASDEX Upgrade using the 2D IR movable camera: the aim of the experiment is to measure the time history of the whole profile of deposited power by repeating the same disruption and taking snapshots of the wall with different IR views. The measurements show a rather homogeneous distribution of power on the inner wall and on the graphite coverage of the ICRH antenna on the outer wall. Already during preceding minor disruptions a few MW/m^2 are deposited on the inner and outer wall. During the thermal quench the power flux to the wall increases up to 5-10 MW/m^2 on most of the surface.

In-out asymmetry .

A common feature of power deposition in the analyzed thermal quenches is the time delay of 100 μs between the arrival of the heat pulse on the outer and the inner divertor plates. For the standard toroidal field (< 0) and plasma current (> 0) configuration the heat flux is firstly seen on the outer divertor plate in both of upper and lower X point configurations. The physical mechanism behind this observation is being investigated with the fluid neutral version of the SOLPS code [4].

The energy deposited in the thermal quench is predominantly deposited on the outer upper divertor. There is no evidence of significant poloidal asymmetry of the energy deposition on the lower divertor [5].

Comments and conclusions.

The heat flux onto PFCs during thermal quench mostly consists of overlapping pulses which prolong the duration of the thermal quench. The rising phase of the pulse may be shorter or as short as 100 μs; the pulse itself lasts longer than 1 ms.

The SOL width at the midplane during thermal quench is typically larger than 5 cm.

Significant distributed deposition of the energy on the inner and outer wall of the plasma chamber is observed during minor and major disruptions.

There are clear poloidal asymmetries in the energy deposition on the divertor with the upper outer plates being more loaded than the inner plate for plasmas with an upper single null configuration. We also observe a time delay between the arrival of the heat flux onto the outer and the inner divertor plates. The toroidal asymmetry of the heat deposition cannot be investigated at the moment because of lack of diagnostic coverage but it could be responsible for occasional energy in-balance during the thermal quench.

References.

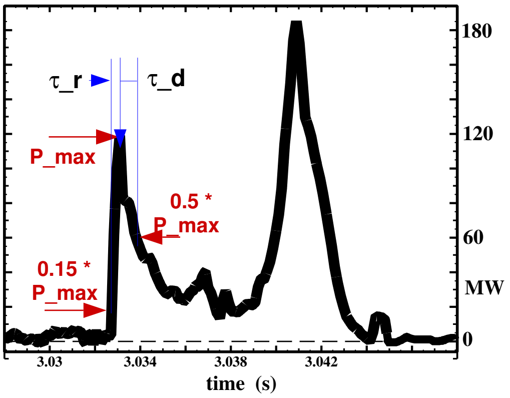
[1] A. Herrmann et al., 16th International Conference on Plasma Surface Interactions, 5.2005, Portland, Main, USA

[2] T. Eich et al., 16th International Conference on Plasma Surface Interactions, 5.2005, Portland, Main, USA

[3] ITER Physics Basis Nuclear Fusion **39** (1999) 2137

[4] D. Coster et al., 19th IAEA Fusion Energy Conference, 10.1002, Lyon, France.

[5] G. Pautasso et al., 30th EPS Conference on Controlled Fusion and Plasma Physics, 7.2003, St. Petersburg, Russia



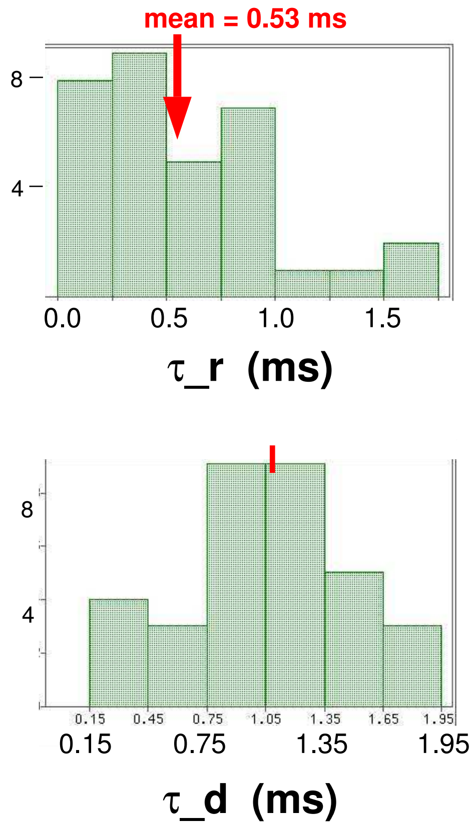


Figure 1. (top) Definition of the rising (τ_r) and decaying (τ_d) time of the power load on the divertor during thermal quench.

Figure 2 (right). Statistical distribution of τ_r and τ_d.

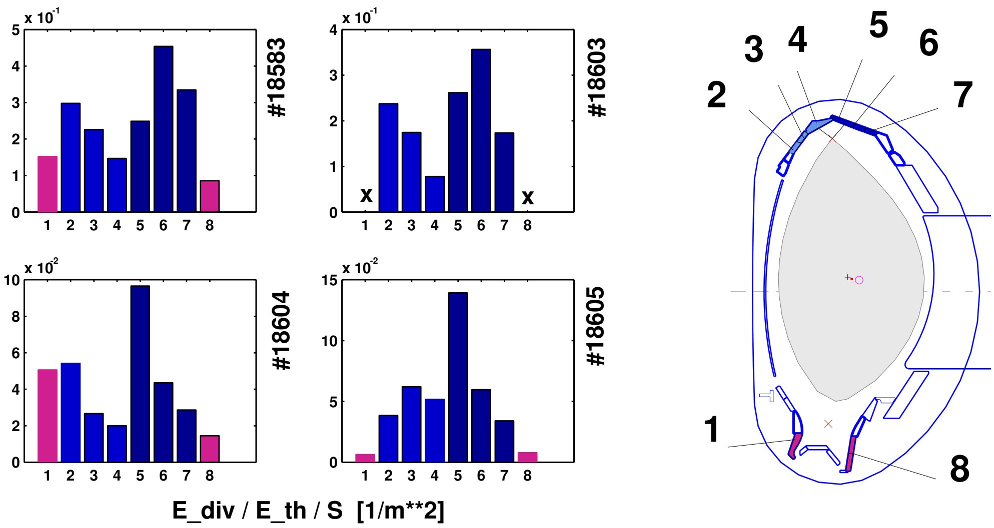


Figure 3. Distribution of the energy on different tiles of the divertor plates during the thermal quench for 4 density limit disruptions.