*36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-1.162 (2009)*

ELM characteristics in ASDEX Upgrade helium discharges

A. Scarabosio, M. Gemisic Adamov, A. Herrmann, N. Hicks,
H. W. Müller, T. Pütterich, F. Ryter, E. Wolfrum and the ASDEX Upgrade Team
Max-Planck-Institut für Plasmaphysik, EURATOM-Association, Boltzmannstr. 2, D-85748, Garching, Germany

At present the predictions for Edge Localised Modes (ELM) related phenomena in ITER, such as the maximum power loads to the targets due to ELM losses, spatial distribution of losses, etc..., are still highly uncertain [1]. However, this knowledge is of particular concern for ITER (especially for large ELMs of type I) in order to address a number of edge plasma/divertor physics and technical issues as ELM pacing and mitigation techniques. Given the rather different edge/divertor plasma conditions expected for ITER it is also not clear whether precise enough predictions can be obtained from experiments on present day machines. Therefore achieving the high confinement regime (H-mode) during the non-nuclear phase of ITER in hydrogen or helium plasmas is highly desirable. The power threshold (P_{thr}) for reaching the H-mode in hydrogen is typically about 2 times larger than in deuterium [2] making this scenario very unfavourable due to the limited external heating power available. In contrast, it has been shown in JET [3] that P_{thr} in helium is only 40% higher than in D and very recent experiments in ASDEX Upgrade (AUG) in 2008 [4, 5] have found no difference in P_{thr} between He and D plasmas. This, of course, makes the use of helium very attractive for ITER. It is not yet clear,

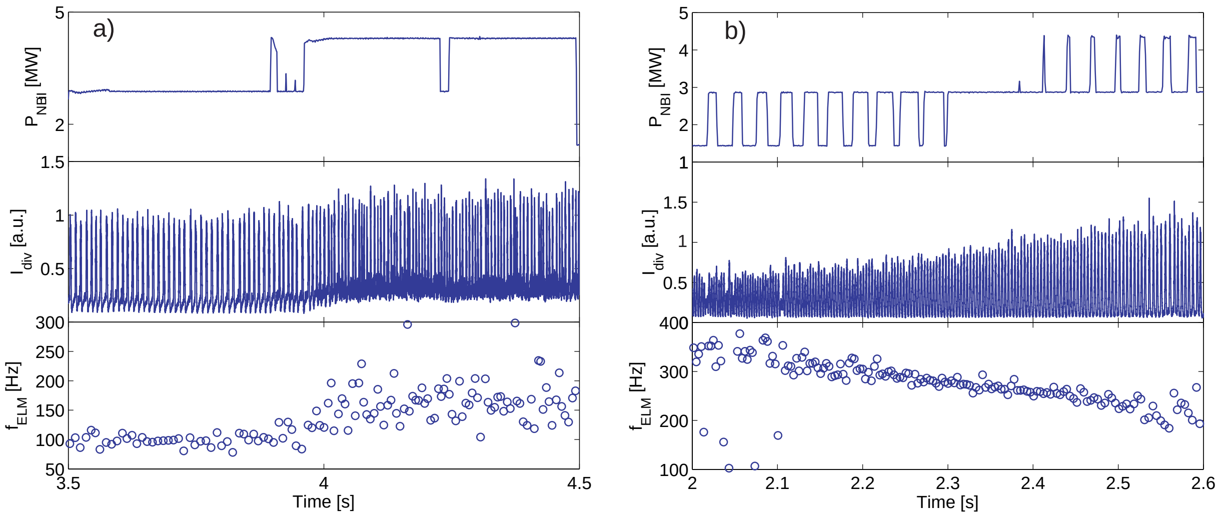

Figure 1: *From top to bottom the signals shown are time traces of total heating power, divertor currents and derived ELM frequency. a) 0.6MA/-1.5T He discharge (#23602) showing type-I ELM behaviour. b)1MA/-2T He discharge (#23609) showing type-III ELM behaviour.*

however, what can be learned about power loads and energy losses from ELMs in the D-D or the D-T phase from experiments in He. In fact, the physic of ELMs and the energy loss mechanisms may be different and also the plasma conditions may be too different since the expected total heating power is close to the L-H threshold. In this work we investigate the ELM characteristics in He discharges on AUG and compare them with similar discharges in D in order to clarify the possibility of extrapolating from He to D plasmas in ITER. The 2008 AUG He discharges [4, 5] together with older experimental data are used as database. This consists of a set of He plasmas heated with hydrogen or deuterium neutral beam injection (NBI) and/or electron cyclotron resonant heating (ECRH). The main plasma parameters, namely plasma current, magnetic field, volume averaged density, total heating power, safety factor and plasma triangularity range respectively between I_p=0.6-1MA, B_T=1.5-3T, $< n_e >$=3.6-9.1e19m^{-3}, P_{tot}=1.7-6.5MW, q_{95}=3.1-5.1 and δ=0.14-0.28. The He content, $n_{He}/(n_{He}+n_H)$, is up to about 75% in pure ECRH heated discharges and lower with NBI. The target plates are CFC or W-coated graphite and the first wall is all W-coated. The database and the experiments are described in more details in [4, 5]. Particular emphasis is given here to plasmas with input power marginally above the P_{thr}, a condition to be expected in ITER He-plasmas.

ELM characteristics in He

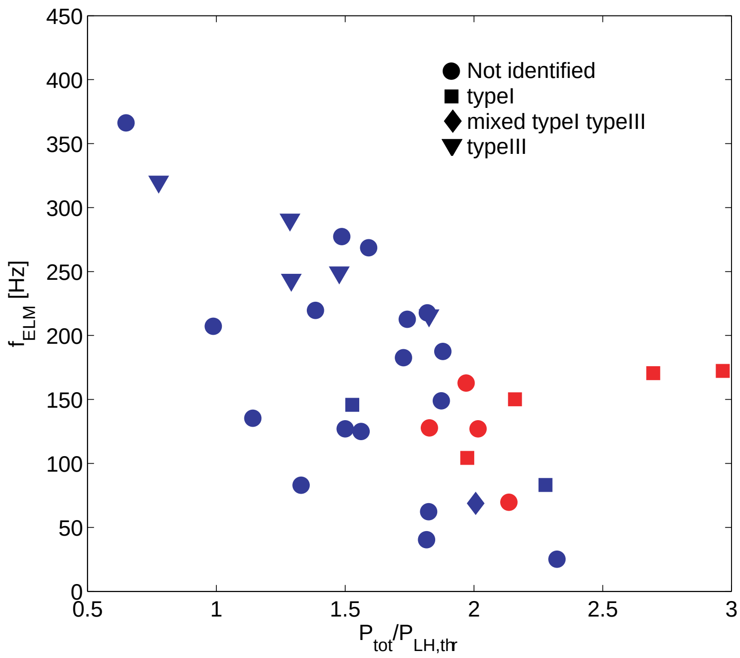

Figure 2: *ELM frequency versus total heating power, scaled to the Deuterium L-H transition power for the full database of He ELMy discharges. The data points are classified according to their power dependence and plasma current. Circles are for the 'not identified' type, square symbols are type-I, diamonds mixed type, triangles type-III. Blues symbols are 1MA discharges and red symbols 0.6MA.*

In these He discharges we find two different types of ELMs. The first has frequency between f_{ELM}=25-200Hz and relatively large crashes in the plasma energy. Clearly defined peaks appear on many quantities such as divertor currents, W influx and thermal target loads which are used as 'ELM monitors'. An example of the first type of ELM is shown in figure 1a). f_{ELM} increases from 100Hz to 150-180Hz at the last power step showing type-I behaviour (following the standard classification of ELMs according to the power dependence of f_{ELM} [6]). The second type of ELM encountered has generally higher f_{ELM}=200-500Hz which decreases with heating power and often smaller peaks in the ELM's monitors. The NBI power ramp up in figure 1b) causes an increase of the divertor currents and a monotonic decrease of f_{ELM}. This ELM type is thus identified as type-III. We note that the power dependence of this type-III ELM is the same as for D plasmas but opposite to what it is found in JET He plasmas for small and frequent ELMs (and thus called type-III) [3]. In many discharges of the database, the direct identification of the ELM's type (through power dependence) is complicated by the simultaneous variation of the plasma density (and thus the associated fueling and recycling level), which was not controlled during the H-mode phase. Thus the ELM could be clearly identified only in a limited number of discharges as shown figure 2. The ELM frequencies and powers are averaged over the stationary phase of the discharges. We note, however, that there is a tendency for the type-I and in general for low frequency ELMs to appear at higher P_{tot} (normalised to the expected L-H power threshold $P_{thr} = 0.049 B_T^{0.8} n_{20}^{0.72} S^{0.94}$ [7, 5]) whereas the type-III are more common at low P_{tot}/P_{thr}. Also, at lower I_p, only type-I are observed with f_{ELM} clearly increasing with P_{tot}/P_{thr}. At intermediate P_{tot}/P_{thr} there are discharges in which low and high frequency ELMs coexist and cases where sharp transitions between the two frequency ranges are observed. The pure ECRH heated plasmas tends to have type-III ELM of even smaller, below detection limit. This may be due to the limited power available $P_{ECH} \leq 2.1$MW. Finally we note that deuterium plasmas, at the same P_{tot}/P_{thr}, have f_{ELM} in the lower boundary of the He plasmas, thus appearing to enter the type-I regime somewhat more easily.

Energy losses during ELMs in He

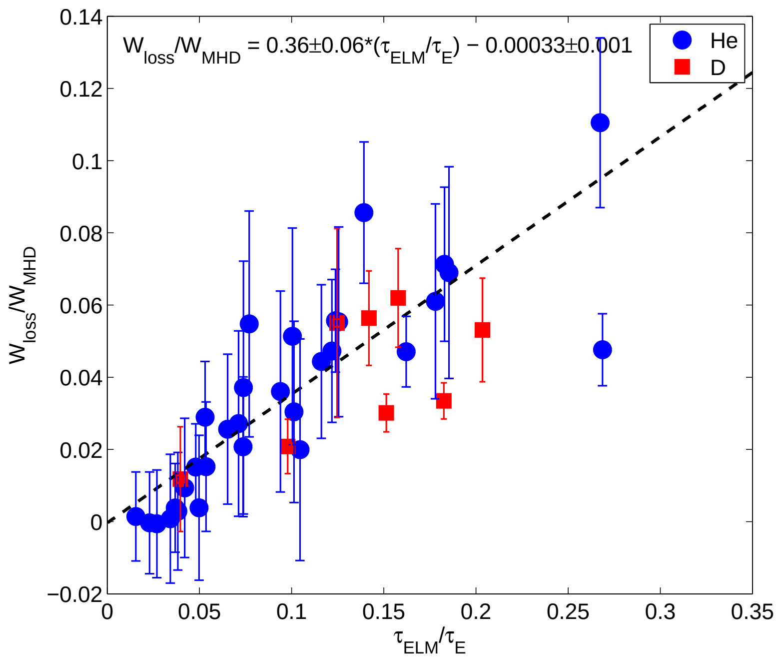

Figure 3: *Energy loss fraction as a function of the ELM period normalised to the energy confinement time for discharges with δ>0.2 The linear fit is shown with a dashed black line.*

The ELM energy losses ΔW_{loss} from the equilibrium reconstruction are calculated for each ELM during the stationary phase of the discharge for the available database. We then take the mean value and standard deviation as estimators for ΔW_{loss}. The standard deviation (which includes the statistical errors plus the intrinsic variation of ΔW_{loss} mainly due to variation of the ELM cycle ie. of f_{ELM}) ranges from 100-200% for $\Delta W_{loss} \leq 5$kJ to down to 15-30% for $\Delta W_{loss} \geq 20$kJ. The largest ELM loss in the database is of about 34kJ.

It has been shown for ASDEX

Upgrade and JET Deuterium plasmas a link between the fraction of ELM energy loss and the ELM period $\tau_{ELM} \equiv 1/f_{ELM} (\equiv 1/f_{ELM})$ normalised to the energy confinement time τ_E, ie. $\Delta W_{loss}/W_{MHD} \propto \tau_{ELM}/\tau_E$ [8, 9]. Figure 3 shows quite good correlation (r=0.85) of $\Delta W_{loss}/W_{MHD}$ with τ_{ELM}/τ_E. Both type-I and type-III ELMs are plotted. At low I_p, up to 11% of the plasma energy can be lost during a single ELM. Interestingly, the fraction of ELM energy losses in Deuterium lies in the same range and seems to scale similarly with τ_{ELM}/τ_E, despite the difference in confinement time and energy content between D and He plasmas (mainly due to ion dilution $W_i(He) =\simeq 0.5W_i(D)$ [5]). If fact, the longer confinement time in D (for the same P_{tot}) is compensated by the larger W_{MHD}. This may indicate that the ELM affected area and loss dynamic are similar for D and He for the same plasma conditions. The fraction of ELM power loss $P_{ELM}(\equiv f_{ELM} \cdot \Delta W_{loss})/P_{tot}$ ranges between 10-60% in He and 10-40% for D for similar heating scheme, where the highest P_{ELM}/P_{tot} values are reached for type-III ELMy discharges. The power loss fraction does not appear to depend on P_{tot}, I_p or Greenwald fraction. The energy reaching the inner and outer target, ΔW_{target}, can be derived from infra red thermography. Similarly to what found in [9] for deuterium we obtain in helium $\Delta W_{target} \approx 0.5 \Delta W_{loss}$, independently from the amount of the losses and plasma parameters.

In summary, in helium H-mode discharges on AUG we observe similar ELM phenomenology as in deuterium showing both type-I and type-III like behaviour. A somewhat larger heating power in He than in D seems to be needed to enter reliably the type-I regime. The fraction of ELM energy losses lies in the same range and scale similarly with confinement and ELM frequency. About 50% of the energy loss reaches the targets. These first results on AUG indicate that type-I ELM regime in helium is reached with $P_{tot}/P(He)_{thr} \geq 1.5$. Assuming for ITER about 70-80MW available for heating and the predicted $P(D)_{thr} = 53MW$ [7], type-I ELM may be reached only if $P(He)_{thr} \approx P(D)_{thr}$ as seen for AUG [5]. In this case a number of technical and physics issues related with ELMs may be addressed on ITER during the helium non-nuclear phase. If the L-H power threshold is considerably higher as in JET, [3] type-I ELM in helium may be still obtained at reduced plasma current.

References

[1] A. Loarte et al., Physics of Plasmas, 11 (2004), 2668

[2] E. Righi et al., Nucl. Fusion, 39 (1999) 309-319

[3] D. C. McDonald et al.,Plasma Phys. and Controlled Fusion 46 (2004) 519-534

[4] F. Ryter et al. Paper PD-1, 22^{nd} Fusion Energy Conference, Geneve, Switzerland (2008)

[5] F. Ryter et al., Nucl. Fusion, 49 (2009) 062003

[6] H. Zohm et al., Nucl. Fusion, 38 (1996) 105-128

[7] Y.R. Martin et al., J. Phys.:Conf. Ser. (2008) 123 012033

[8] H. Urano et al., Plasma Phys. and Control. Fusion, 45 (2003) 1571-1596

[9] A. Hermann et al., J. Nuclear Mater., (2003) 313-316, 759