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**See Annex of J. Pamela et al., "Overview of Recent JET Results and Future Perspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

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ABSTRACT.
In high triangularity ($\delta \equiv 0.5$) JET ELMy H-modes,with safety factor $q_{95} \cong 3$ and plasma current I_p = 2.5MA, high confinement (H98y $\cong$ 1) is achieved with line averaged density of $\cong$ 0.95 of the Greenwald density n_{GR}. In those high density plasmas the Type I ELM frequency f_{ELM} decreases and Type II ELMs are observed in the inter-ELM period: this regime is called the mixed Type I/II ELMy regime. New experiments have started in JET to study the scaling with plasma current (up to I_p = 3.5MA) of the energy confinement of high δ ELMy H-modes and the edge operational space of the mixed Type I/II regime. Since $\delta \cong 0.5$ is not technically possible in JET at 3.5MA,a plasma configuration with reduced triangularity was selected for those experiments. The extension of high density ELMy H-modes to lower ν^* also requires the higher input power P_{IN}, that will be soon available with the NBI upgrade,as well as the use of ICRH heating ($P_{IN} = P_{NBI} + P_{ICRH} \geq$ 25MW). This paper presents the results of experiments carried out to prepare for the extension to high I_p of the high density ELMy H-mode regime:it reports the study of the performance of the new plasma configuration at reduced I_p (2.5MA),and the results of the first experiment at 3MA.

1. DESCRIPTION OF THE EXPERIMENT

The good confinement at high density reported in [1]was obtained with a $\delta \cong 0.47$ "ITER like" configuration at I_p = 2.5MA and toroidal field B_t = 2.7T,with $q_{95} \cong 3$. The new configuration (called HT3) designed for the experiment described here,has the maximum triangularity that is technically possible at 3.5MA: $\delta \cong 0.42$,and it is optimized to reduce the VDE forces.Compared with the ITER like configuration HT3 has larger minor radius ($a \cong$ 0.93-HT3, $a \cong$ 0.89-ITER like),similar elongation (HT3, $\kappa \cong 1.72$)and lower X-point position. Three separate experiments in the HT3 configuration are reported in this paper:the main parameters for each are summarized below.

Configuration	B_T *(T)*	I_P *(MA)*	q_{95}	*Injected power:* P_{IN} *(MW)*	*Density*
HT3	*2.7*	*2.5*	*3.6*	*12.5 - 16.5*	*density scan*
HT3	*2.25*	*2.5*	*3*	*14*	*only high density*
HT3	*2.7*	*3*	*3*	*16.5-17-19*	*mainly high density*

In all cases additional heating is a combination of NBI and 2-3.5MW of ICRH power (H minority central resonance with dipole phasing).The aim of first experiment was to assess if the regime of good confinement found in the ITER like configuration,with mixed Type I/II ELMs,is still achievable with the new HT3 configuration at the same I_p and B_t, despite the lower δ. In the second experiment, q_{95} was reduced from 3.6 to 3 at 2.5MA (B_t =2.25T),to study the performance at high density with the same q_{95} of the 3MA/2.7T and 3.5MA/3.2T plasma. Finally, results will be presented from a first assessment of the confinement at high density at 3MA/2.7T,with q_{95} = 3. A significant density scan, achieved by increasing the gas fuelling pulse by pulse,was only carried out in the first experiment.In the $q_{95} = 3$ cases mainly data at high density exist.In order to maintain a similar ratio between P_{IN} and the L-H threshold power, P_{L-H},when both I_p and B_t are increased at high density ($n_e \propto n_{GR}$), P_{IN} has to be increased approximately as the product $I_p * B_t$, since $P_{L-H} \propto n_eB_t$ and $n_{GR} \propto I_p$. As a consequence,the maximum input power available in JET limits the maximum I_p (B_t) at which high density ELMy H- modes are achievable. Therefore, in order to minimise the power requirements at high I_p, P_{IN} was reduced at high density as part of the experiments at 2.5MA,to evaluate the minimum power at which the good confinement at high density can be obtained. It was found that this minimum P_{IN} was not limited by the transition to Type III ELMs but by continuous peaking of the density profile, with similar phenomenology as described in [2]. All the discharges analysed in this paper,for global and pedestal data,have no continuous density peaking: core and edge density are steady. A (3,2)NTM mode was often triggered,during the density built up, by the first sawtooth crash. Methods to reduce the extent of the sawtooth crash and avoid the NTM onset were employed. The data presented here are from plasma with no (3,2) NTM. Some of the 3MA/ 2.7T have a (4,3) MHD mode (see par.2). Given the potentially high disruption forces and the need of scenario development,the heating pulse length of some of the 3MA plasma was shorter than the 6s achieved subsequently. In those plasma, the density required 6/8 energy confinement times (≅3s)to reach its final value,and the ELM frequency f_{ELM} even longer. Although the evaluation of the plasma with short pulse length (≅3.5s) is more uncertain,they are included in the analysis.

2. RESULTS

All the characteristic signatures [1,2,3,4] of the mixed Type I/II ELMy regime are observed in the gas scan at 2.5MA/2.7T ($q_{95} \cong 3.6$).The first characteristic is the "anomalous "behavior of the Type I ELM frequency that, after the initial increase with increasing density (Type I ELMs, $f_{ELM} \sim 10^1$Hz), decreases in the density range where Type II ELMs are observed in the inter ELM period ($f_{ELM} \sim 10^0$Hz),and then increases again ($f_{ELM} \sim 10^1$Hz)as the collisionality increases,and mixed Type I/II and III ELMs can be present simultaneously. The transition to a steady Type III ELMs regime is observed at the highest fuelling rate. The second,and most notable characteristic of the presence of mixed Type I/II ELMs is the high density ($n_e/n_{GR} \cong 1$)that is achieved with good confinement (H98y ≅ 1),as shown in Fig.1 (red triangles).

H98y ≅ 1 at $n_e/n_{GR} \cong 1$ is comparable to the previous results with the ITER like configuration [1], at the same I_p and B_t. The third observation is that the high global confinement at high density is associated with high pedestal pressure, p_{ped}, at high density. The evolution of the parameters n_e, T_e (red circles) and T_i (red triangle)at the top of the H-mode pedestal for the gas scan at $q_{95} \cong 3.6$ are shown in Fig.2. The pedestal T_i is measured with Charge Exchange Spectroscopy, T_e with ECE while n_e is the edge line averaged density from the FIR interferometer. At low density, in the Type I ELMy regime,the pedestal pressure, p_{ped}, decreases with density,as typical for JET Type I ELMy H-modes [5]. This corresponds to an initial limited decrease of the total thermal stored energy, W_{th}. At high density,with mixed Type I/II ELMs, p_{ped} increases:ne increases at almost constant T_i (and

W_{th} increases). This increase of p_{ped} was observed previously with both for T_e [1] and T_i [6] data. When the fuelling is increased further, both n_e and T_i (and W_{th}) decreaseas the pedestal collisionality increases. The inter ELM Type II behavior is maintained, but with reduced confinement, and Type III ELMs also start to appear.

The good confinement with mixed Type I/II ELMs was achieved in all the power range explored. Plasma with lower P_{IN} require lower external fuelling to enter this regime and are more difficult to obtain,due to the tendency towards density peaking. The transition from the Type I to the mixed Type I/II ELMy regime is also characterized by a reduction of the ELM energy losses (f_{ELM} ΔW, where ΔW is the prompt energy loss per ELM averaged over, typically, 8-10 ELMs).

In Fig.3, the variation with density of the ELM energy losses normalized to the power to the separatrix (f_{ELM} $\Delta W/P_{sep}$) of the $q_{95} = 3.6$,2.5MA/2.7T, H-modes is compared with the $q_{95} = 3$ data at 2.5 and 3MA.For the $q_{95} = 3$ data,it is not possible to distinguish the ELM character by the variation of f_{ELM} with density, since only high density data are available at 2.5MA and only partial gas scans,at different PI_N, were carried out at 3MA. Fig 3 shows that, at $q_{95} = 3.6$ (red triangles),a large reduction of the energy loss by ELMs is observed at the transition from the Type I to the Type I/II ELMy regimes, in agreement with previous results [1]. The figure also shows that the normalized ELM energy losses at high density are reduced (or low)also in the $q_{95} = 3$ H-modes,indicating that their pedestal is in the Type I/II ELMy regime.

The mixed Type I/II ELMy regime is observed above a pedestal n_e of $\cong$80% n_{GR} (and pedestal collisionality $0.4 \leq \nu_{ped} \leq 0.65$). Although the scatter of the data is large, there seem to be a correlation between f_{ELM} $\Delta W/P_{sep}$ of mixed Type I/II ELMs and their p_{ped} (p_{ped} taken here as $\propto 2n_eT_i$), with higher pped for decreasing f_{ELM} $\Delta W/P_{sep}$. Another characteristic signature of the mixed Type I/II ELMy regime comes from the Fourier spectra of magnetic fluctuations [1, 5, 6]. The comparison,in Fig.4,of an H- mode with Type I ELMs and one with mixed Type I/II ELMs, at $q_{95} = 3.6$,shows an enhancement of the magnetic fluctuations in the low frequency (f<40kHz)range coincident with Type I/II ELMs,and a reduction in the high frequency range,as typically observed [1,3]. In Fig.5, the MHD fluctuation spectra of a $q_{95} = 3$ Type I ELMy plasma,and of two plasma at the same q95 and reduced f_{ELM} $\Delta W/P_{sep}$, are compared.Although this comparison at q95=3 does show the characteristic enhancement at lower frequencies,this is less pronounced than at higher q95.Both MHD and ELM loss measurements demonstrate that the mixed Type I/II ELMy regime is achieved at $q_{95} = 3$,but weaker Type II signature is seen in the MHD data.A weaker Type I/II MHD signature and decreased inter-ELM losses are also seen,at $q_{95} = 3.6$,in Type I/II ELMy plasmas with increased gas fuelling and collisionality (with reduced p_{ped}), indicating that an optimum density or collisionality range for good performance exist.

The global confinement and pedestal n_e-T_i of the $q_{95} = 3.6$ data with clear mixed Type I/II behavior are compared in Fig.1 and 2 with the results at $q_{95} = 3$: the 2.5MA/2.25T (black diamonds)and 3MA/2.7T (green circles). The comparison of the 2.5MA data at $q_{95} = 3.6$ and $q_{95} = 3$ show that with reduced q_{95} it was possible to achieve similar density but with lower energy confinement: H98y decreased from ≅1 to ≅0.9. The pedestal T_i of the 2.5MA at $q_{95} = 3$ is also lower than at $q_{95} = 3.6$. A similar reduction in global confinement at high density is observed when comparing the $q_{95} = 3.6$ with the 3MA data.The higher pedestal pressure at higher I_p results from higher pedestal ne,with lower or similar T_i. While the difference in H factor between the $q_{95} = 3.6$ $q_{95} = 3$ H-modes is not large (≅10%),the consistency between pedestal and global confinement data indicate that this is a real trend. For example, Pulse No's: 56146 (H98y ≅1,$q_{95} = 3.6$)and 58012 (H98y ≅0.9, $q_{95} = 3$)with the same I_p and similar input power and external fuelling,reach similar core ($n_e/n_{eGR} = 1$) and pedestal density. The main difference between the two shot is in the pedestal (and core) T_i, which is lower at $q_{95} = 3$. Consistently, the contribution of the pedestal stored energy, W_{ped},($W_{ped} \propto p_{ped}$)to the total stored energy is ≅50%for both discharges.

The ratio between pedestal and thermal stored energy is 0.4 to 0.5 for all the data,independent of the ELM type (for Type I and Type I/II ELMs)and of q_{95}. This suggests that the improved global confinement at high density is associated with the improved pedestal resulting from the change in the ELM behavior.In addition, Fig.4 shows that W_{ped} of the $q_{95} = 3$ plasmas at 2.5 and 3MA scales as $\propto I_p (T_i)$ 0.5 [6]. The scaling of the pedestal pressure with Ip (or stronger)results in similar global H factor.The pedestal data for a gas scan with the HT3 configuration at $q_{95} = 4.6$ (2.5MA/3.4T)are also shown in Fig.2 to demonstrate that the differences between the $q_{95} = 3.6$ and $q_{95} = 3$ cannot simply be attributed to a trend of decreasing local and global confinement with decreasing q95, since both pedestal and global [4]confinement are lower also at $q_{95} = 4.6$.At $q_{95} = 4.6$,the transition to Type III ELMs occurs at lower density. Those data are described in more detail in [4].All those observations indicate that the main difference between the $q_{95} = 3.6$ and $q_{95} = 3$ data derive from differences in the pedestal. The lower pped at lower q_{95} might be attributed to the weaker Type I/II ELM signature and weaker inter-ELM transport.It has to be noted however,that additional elements can, when combined, contribute to some further reduction in the H factor of the 3MA H-modes:the positive density scaling of the energy confinement (generally not observed in the data), some reduction of the central beam deposition at higher density, and sometimes the presence of a (4, 3) MHD mode (for comparison,a continuous (3, 2) mode reduces the confinement by 5-8%).

CONCLUSIONS

The good confinement at high density,previously reported with the ITER like configuration,has been obtained also in the configuration designed for high I_p (i.e., up to 3.5MA).The improved pedestal confinement at high density is associated with the transition from the Type I to the mixed Type I/II regime.The achievement of the Type I/II ELMy regime at the reduced δ of this configuration is probably facilitated by increased q_{95}. At $q_{95} = 3.6$, 2.5MA/2.7T, H98y δ1 at $n_e/n_{GR} = 1$ were obtained. The reduced pedestal and core confinement (H98y ≅0.9 at $n_e/n_{GR} = 1$) at reduced q_{95} ($q_{95} = 3$, $I_p = 2.5$ and 3MA) could be linked to the weaker Type II ELM character of the H-mode pedestal and reduced inter-ELM transport,since no trend of reduced confinement with q_{95} is seen for the Type I ELMy plasmas. Further experiments both at 3MA and 2.5MA,in particular more extensive density variation and the exploitation of higher P_{IN}, are planned.Those experiments should clarify if the reduced Type I/II signature is due to the reduced q_{95} of those plasmas,or if the optimum conditions for Type I/II have not been achieved yet (or both).The experiments at higher I_p (3.5MA/3.2T)and at higher q_{95} (2.5MA/3.45T and 3MA/3.45T), to confirm and clarify the trend of the data with I_p and q_{95},will require,for operation at high density,the higher PIN provided by the NB upgrade.

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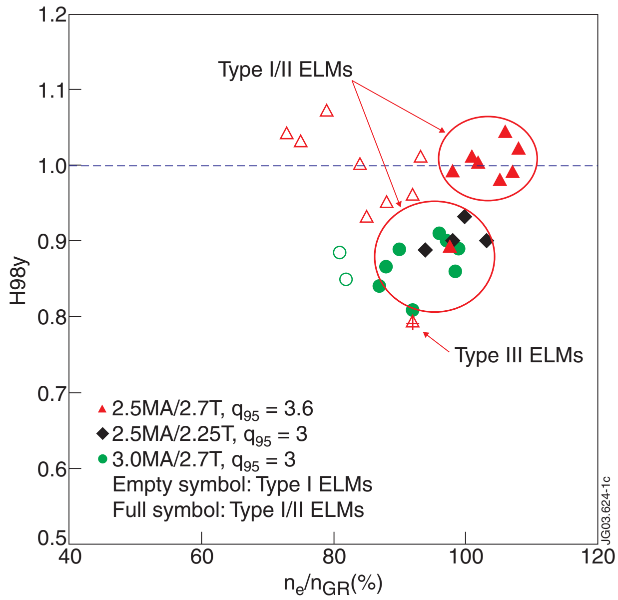

Figure 1: Confinement enhancement factor versus normalized density for ELMy H-modes with the HT3 plasma magnetic configuration.

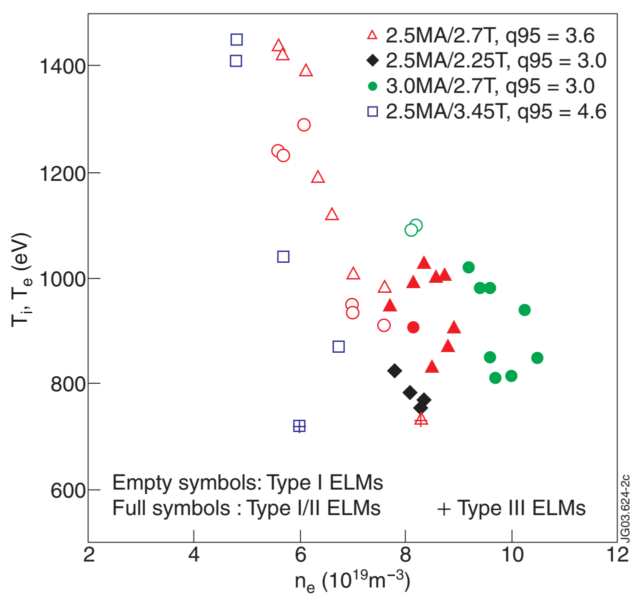

Figure 2: Pedestal temperature (T_i, T_e) versus pedestal density n_e. n_e from the outermost channel of the FIR interferometer (at R = 3.75m),Ti from Charge Exchange Spectroscopy (at a fixed position, R = 3.76-3.78m) and Te from ECE (at the pedestal top). Due to ECE cut-off,the Te data a e only available at low density at 2.5MA/2.7T: while at the lowest density $T_e > T_i$, at intermediate density $T_e \cong T_i$. The T_e value at the highest density(Type I/II ELMs)is underestimated:it is taken before the end of the ELM cycle(just before the ECE cuts-off).

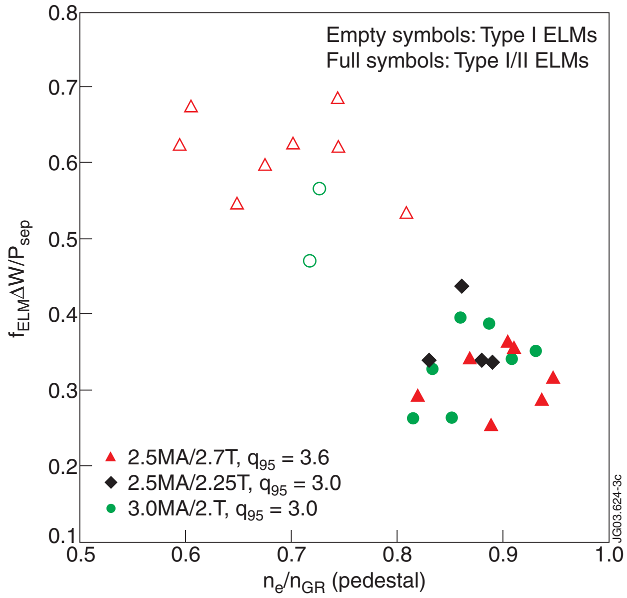

Figure 3: ELM ene gy losses normalized to the power to the separatrix versus normalized pedestal density for the gas scans at q_{95}=3.6 (2.5MA) and q_{95}=3 (2.5MA and 3MA)

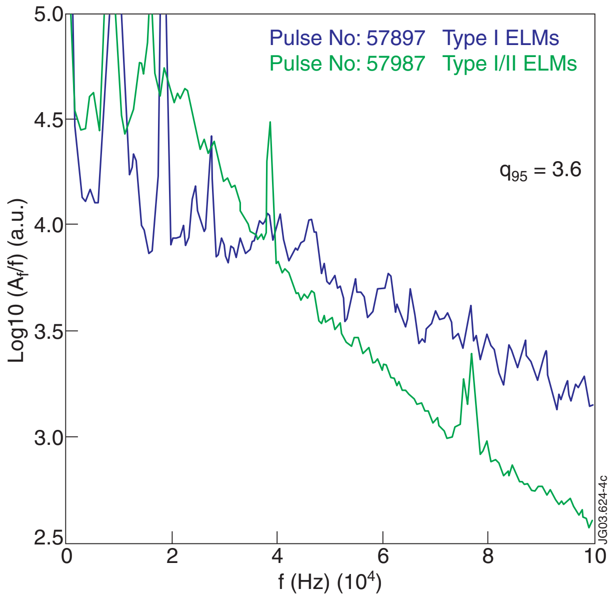

Figure 4: Spectra of the magnetic fluctuation in the inter-ELM period for Pulse No: 57987 (green) and Pulse No: 57897 (blue). An enhancement of the fluctuations in the low frequency range is observed with Type I/II ELMs.

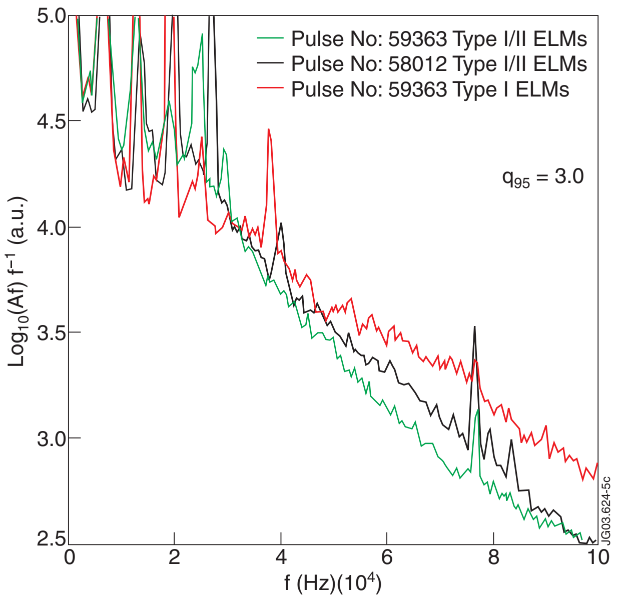

Figure 5: Spectra of the magnetic fluctuation in the inter-ELM period for Pulse No's: 59368 (red, 3MA/2.7T, Type I ELMs), Pulse No: 58012 (2.5MA/2.25T, Type I/II ELMs) and Pulse No: 59363 (3MA/2.7T,Type I/II ELMs)

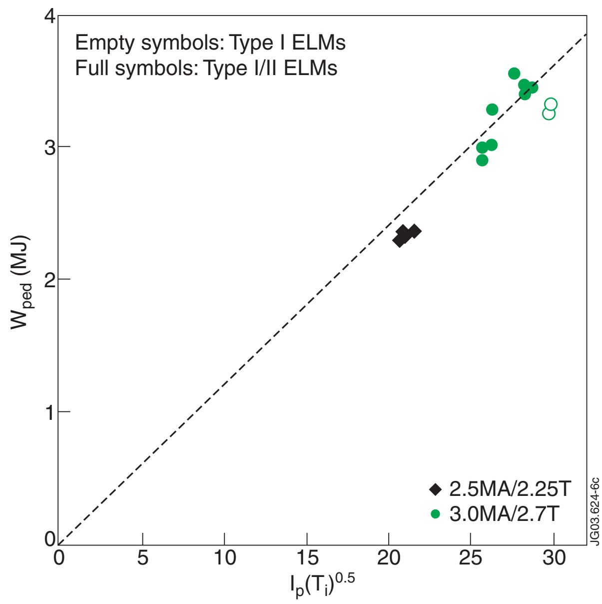

Figure 6: Pedestal stored energy ($\propto n_e T_i$) versus $I_p(T_i)$ 0.5, for the q_{95} = 3 ELMy H-modes at 2.5 and 3MA.