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Optimizing Performance of Hybrid and AT Discharges in Preparation for the ITER Like Wall

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E. Giovannozzi[1], M.N.A. Beurskens[2], A Boboc[2], A. Botrugno[1], M. Brix[2], J. Bucalossi[3], P. Buratti[1], G. Calabro[1], R. Cesario[1], C. Challis[2], I. Coffey[4], F. Crisanti[1], K. Crombe[5], T. Eich[6], J. Flanagan[2], D. Frigione[1], L. Garzotti[2], C. Giroud[2], E. Joffrin[3], M Kempenaars[2], E. De La Luna[7], P. Lang[6], T. Loarer[3], G. Maddison[2], C. Mazzotta[1], F. Orsitto[1], R. Pasqualotto[8], V. Pericoli[1], F. Rimini[9], M. Tsalas[10], O. Tudisco[1], M. Walsh[2], S. Wiesen[11], L. Zabeo[2] and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]Associazione Euratom/ENEA sulla Fusione, CP 65-00044 Frascati, Rome, Italy
[2]EURATOM-UKAEA Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK
[3]Association EURATOM-CEA, CEA/DSM/IRFM, Cadarache 13108 Saint Paul Lez Durance, France
[4]Department of Pure and Applied Physics, Queens University, Belfast, BT7 1NN, UK
[5]Department of Applied Physics UG (Ghent University) Rozier 44 B-9000 Ghent Belgium.
[6]Max-Planck-Institut für Plasmaphysik, EURATOM-Assoziation, D-85748 Garching, Germany
[7]Laboratorio Nacional de Fusión, Asociación EURATOM-CIEMAT, 28040, Madrid, Spain
[8]Associazione EURATOM-ENEA sulla Fusione, Consorzio RFX Padova, Italy
[9]EFDA Close Support Unit, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK
[10]Association EURATOM-Hellenic Republic, NCSR "Demokritos" 153 10, Agia Paraskevi Attica, Greece
[11]EURATOM association FZ-Julich, IEF-4, Plasmaphysics, D-52425 Julich, Germany
** See annex of F. Romanelli et al, "Overview of JET Results",*
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1. INTRODUCTION

Fuelling the AT scenario remains one of the main challenge for its operation in ITER. If the electron density at the last closed flux surfaces is not high enough (typically less $3\times10^{19}m^{-3}$), with the peak power loads on divertor targets will be unacceptable high for the given choice of plasma facing materials, namely Be and W. The JET first wall and divertor plasma facing components, currently made of carbon fibre-composite, will be substituted by similar plasma facing components made of beryllium and tungsten, thus the same material choice that will be installed in ITER [1]. With this new first wall, JET could address the fuelling issue for AT scenario [2,3] and also other limitation such as the neutral beam shine-through limits. Because of the metallic wall, the density control of the scenario is also likely to change. Therefore, recent experiments done in the last JET campaign with CFC, have been carried out with the aim of studying particle fuelling in Hybrid and AT scenario while preserving the confinement in order to obtain density level compatible with the operation with the ITER-Like Wall (ILW).

A series of experiments have been conducted injecting deuterium at different level and from different poloidal locations, as well as injecting pellets from the Low Field Side (LFS) and Vertical High Field Side (VHFS). The first experiments were aimed at documenting the difference between different gas injecting locations at a moderate gas influx. The second series of experiments extended gas rates to higher levels while the third series of experiments used pellet injection for comparing the effect of pellets during the main heating phase and during the transient phase at the start of the NBI heating.

2. GAS PUFFING

Gas was injected in hybrid scenario ($q_{95}=4$, $B_t=2MA$, $I_P=1.5$-$1.8MA$) [2] and Advanced Tokamak (AT) scenario ($q_{95}=4.6$, $B_T=2.7T$, $I_P=1.8MA$) from three different location around the machine wall. Two of the injection modules are located in the main chamber: one on the top of the machine, and one on the low field side at the mid-plane. The third gas injection point was through a circumferential ring of gas inlets in the inner divertor situated inside the private flux region of the magnetic configuration. D_2 was injected in two steps: about 6×10^{21} electrons per second in the first step and about 12×10^{21} electrons per second in the second step. Higher levels of gas injection have also been used in the hybrid scenario with a level of up to 30×10^{21} electrons per second. In all experiments, almost no effect was observed on the average density while the confinement was progressively degraded with increasing gas rate.

To compare the discharges the confinement factor H_{98Y2} is averaged during the first (6.7−8.3s) and the second step (8.8−10.4s), the result can be seen in fig.2, where a decrease of confinement with gas puffing rate is shown. When the gas injection is very high we can get to a situation where the discharge confinement factor H_{98Y2} degrades down to 1 and even lower, while in not fuelled discharges it could reach a value of 1.2. The energy stored in the pedestal $W_{ped} = 3V_{ped}P_{ped}$, as estimated by the High Resolution Thomson Scattering (HRTS) was also strongly affected by the gas injection. W_{ped} has been calculated by fitting the HRTS data close to the pedestal with a function like: $(Pr) = P_{Ped}/2((1+ax)\exp(-x) - \exp(x))/(\exp(-x)) + P_{ped}/2$ and ; $x = (R-R_{ped})/t$; R_{ped} is the position of the pedestal and t is its width, V_{ped} is the plasma volume inside the pedestal, the factor 2 is used to take into account the ions, assuming that their contribution is the same as that of the electrons. The effect of ELMS and gas puffing on P_{ped} can be seen on figure 3 where P_{ped} is plotted as function of the time from the previous ELM, the colours refer to the gas injection rate. The usual observation that the ELM frequency increases with increasing gas puffing is obtained again. Due to the higher ELM frequency the average pedestal pressure is lower at higher gas injection rate [4].

3. PELLET INJECTION

Pellets were injected during the main heating phase (fig.4) from the Vertical High Field Side (VHFS) and from the Low Field Side (LFS) injection location. Only VHFS medium size pellets (3×10^{21} electrons) had a visible impact on the plasma density, while LFS pellet are barely visible. This is related to the beam power (fig.5), pellet of the same size were injected from the low field size at high power (Pulse No: 77863, P_{NBI} = 21 MW), from the vertical high field size (Pulse No:77864, P_{NBI} = 21MW), and again from the low field size but with a much lower NBI power (Pulse No:76754 P_{NBI} = 6MW), in the last discharge pellet has been injected after a step down of NBI, density was not lost but the electron temperature decreased. This different behaviour is investigated in [5]. In both cases the normalised confinement H_{98Y2} decreases to about 1.0. For the VHFS injection, the decrease in confinement was not related to the edge only but the whole discharge was affected, the central temperature decreased and couldn't recover before the following pellet, while most of the density was already lost. LFS small pellets (2.2×10^{21} electrons) injected during a prelude phase which has only 3MW of NBI could be seen to provoke the typical fast density jump. They can increase the plasma density before the start of the full NBI power phase to a level slightly higher than that achievable with gas puffing only (fig.6). Later on, from 5s, as the temperature increases due to the NBI heating and a full H-mode is formed, pellets don't have anymore any marked effect on the central integrated density. Replacing the pellets with gas puffing at a comparable level (from one third to one fifth of the original pellet mass can get to the plasma) make the plasma have the same final density, at least after the H-mode is started. On figure 6 the density profile obtained by a smoothing of HRTS data shows the density profile at three times, after the first pellet, at the beginning of the high power phase, and during the density increase where the maximum difference between fuelled and not fuelled discharges was observed.

CONCLUSIONS

The effects of gas puffing and injection of pellets from different directions have been compared. Confinement degradation during gas puffing seems related to the decrease of the energy stored in the pedestal, but a contribution due to an increased transport in the central part of the discharges cannot be completely excluded. Pellets can increase the density of the discharge when injected before the main heating phase, their effect on the following high power phase is similar to that of gas puffing. Injecting pellet during the main heating decreases the confinement as well. VHFS pellet can get deeply into the plasma, while LFS pellets cannot get inside the pedestal. The injection of pellets and their effect on density, confinement and ELMS complement previous observation on gas injection effects [4]. The different penetration of LFS compared to VHFS pellets may also help to understand the role of drift and ELM triggering on the effective deposition profile. Even if pellet injection cannot solve all the issue related to fuelling, it will be an essential tool for density control in the next step nuclear fusion machine.

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REFERENCES

[1]. "Operational limits for the ITER-like wall in JET" V. Riccardo, to be published in Physica Scripta (proceedings of PFMC12).

[2]. "Improved Confinement in JET hybrid discharges" J. Hobirk et al. EPS2009

[3]. "Development of a steady-state scenario in JET with dimensionless parameters approaching ITER target values" J. Mailloux et al. EPS2009.

[4]. "Hybrid H-mode scenario with nitrogen seeding and type III ELMs in JET", Y. Corre et al., Plasma Phys. Control. Fusion **50** (2008) 115012

[5]. "Analysis of pellet fuelling, ablation and particle deposition at JET" Frigione et al. EPS2009 (P5.160).

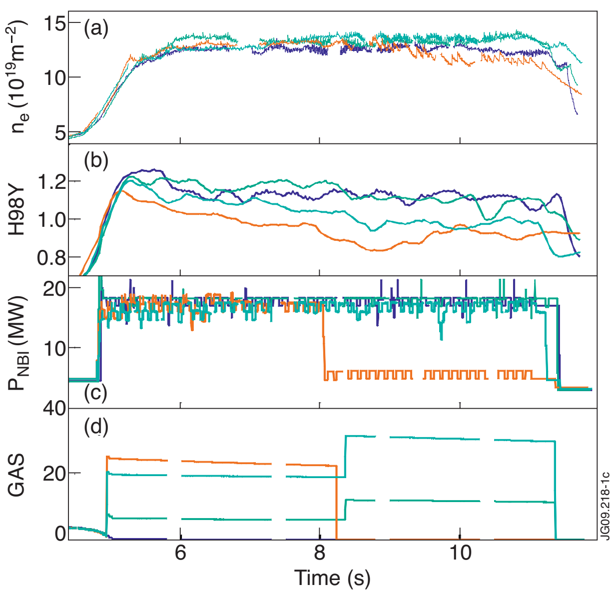

Figure 1: (a) Line integrated density; (b) H98Y confinement factor; (c) neutral beam power (d) and the injected gas level for four discharges: Pulse No's: 75954 (blue), 75962 (green, GIM 8), 76748 (red GIM 8), 76749 (cyan GIM 11).

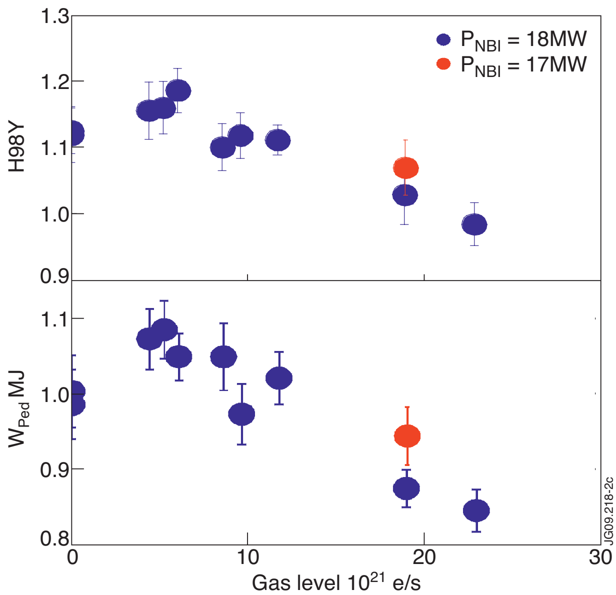

Figure 2: Normalized confinement and pedestal energy content as function of the gas injection rate for the hybrid discharges. The pedestal energy content is calculated assuming that the ion contribution is equal to the electron one.

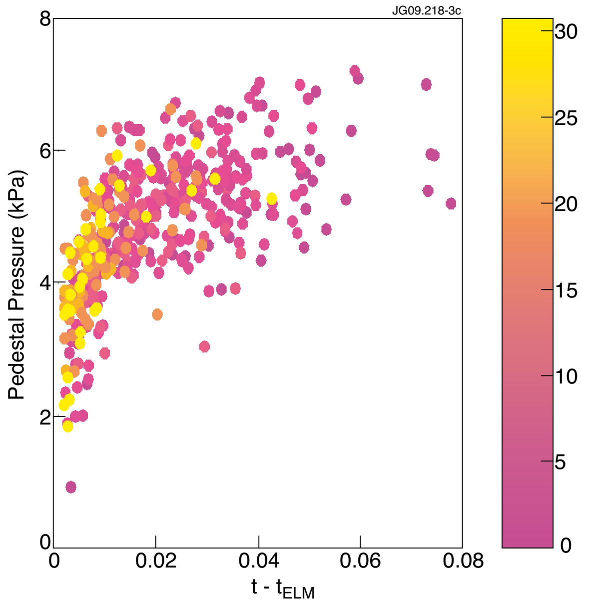

Figure 3: *Electron pressure at the top of the pedestal as function of the delay from the previous ELM. The color scale is related to the amount of injected deuterium.*

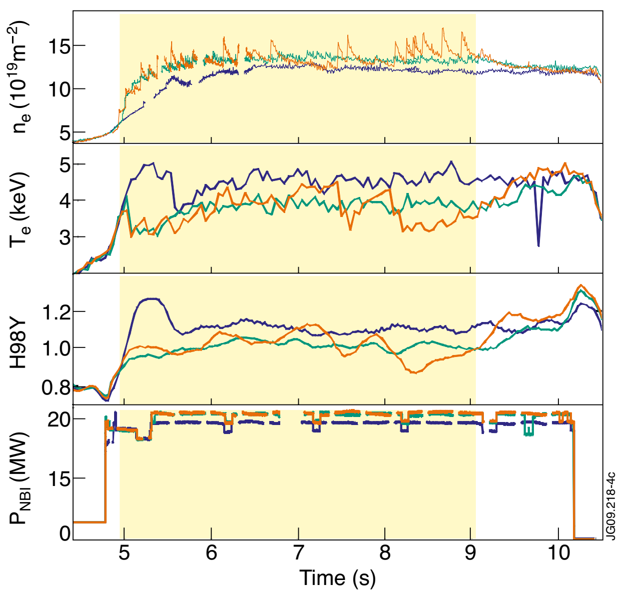

Figure 4: *Density, confinement factor (H98Y) and injected power for three discharges: Pulse No's: 77858 (blue) reference discharge, 77863 (green) LFS pellets, 77864 (red) VHFS pellets.*

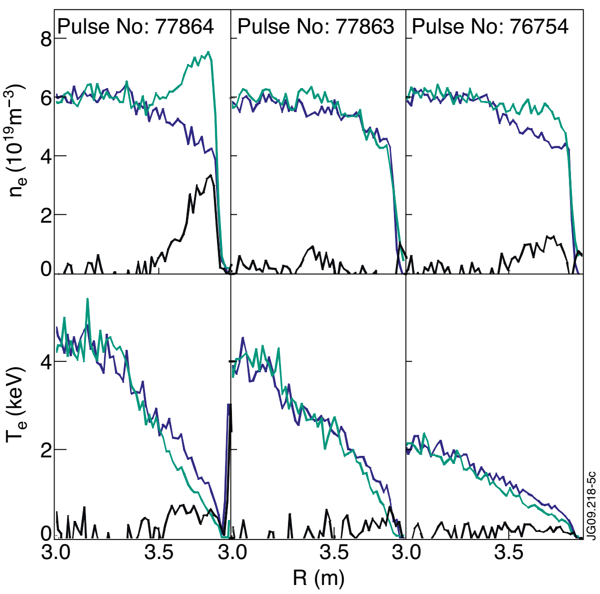

Figure 5: *Electron density and temperature after the pellet injection in three discharges Pulse No's: 77864 (VHFS P_{NBI} = 21MW, t = 7.4s) 77863 (LFS P_{NBI} = 21MW, t = 6s), 76754 (LFS P_{NBI} = 6MW, t = 9.3s). The blue line is before pellet injection, the green line is after pellet injection. The black line is the difference.*

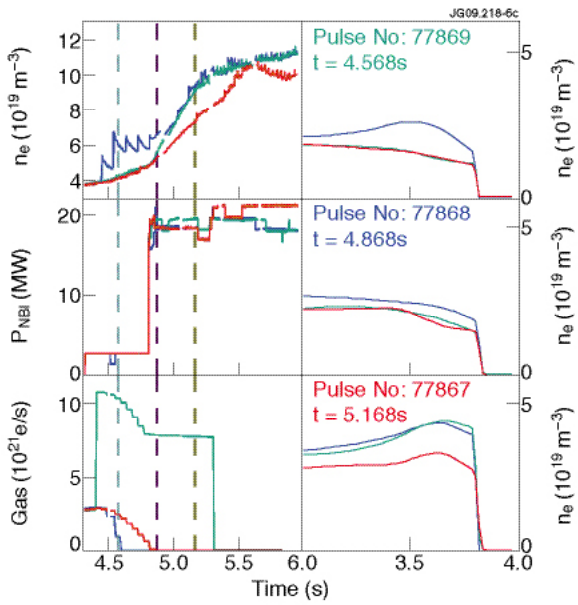

Figure 6: *density during the prelude phase for the Pulse No's: 77868 (blue), 77869 (green), and 77867 (red). Pellets were injected in Pulse No's: 77868, while 77869 was fuelled with gas puffing.*