Sawtooth and Impurity Accumulation Control in JET Radiative Mantle Discharges

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**see appendix of the paper by J. Pamela "Overview of recent JET results", Proc. IAEA conference on Fusion Energy, Sorrento, 2000*

I – Introduction - JET radiative mantle experiments in the ELMy H-mode regime have produced high confinement plasmas with densities close to the Greenwald density [1]. This paper aims at understanding loss of confinement in plasmas with the septum configuration [2]. Experiments designed to understand the role of sawtooth crashes in re-distributing impurities are reported. Control of sawteeth activity resulted in quasi-steady state, high performance.

II - Loss of confinement in discharges with high impurity densities - In the septum configuration, the highest performance plasmas ($H_{97}*f_{GWD}$ 0.8) were obtained with 12 MW NBI heating, with two gas injection phases: an initial phase of continuous D_2 and Ar fuelling, followed by the "after-puff" phase when both gases injection rates are reduced. In the after-puff phase, confinement improves for 1-2 s, then either saturates or declines. In discharges with low or moderate Ar seeding, a quasi-steady state regime remains through to the end of the applied heating. However, at high Ar injection rates ($4x10^{21}$ el/s), the high confinement phase is transient (see fig. 1). The degradation in confinement coincides with two

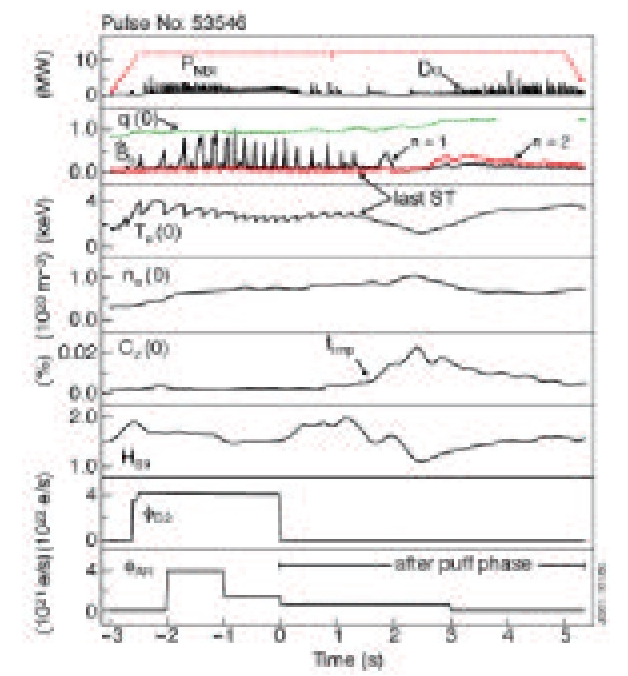

Fig.1-Overview of a discharge with high Argon density (P_{NBI}=12MW, Ip=2.5 MA , B_T= 2.5 T). Time=0 sec corresponds to the start of the after-puff phase.

phenomena: a) Ar accumulation in the plasma core (beginning at 1.5 sec in fig.1) and, b) disappearance of sawtooth.

The temporal evolution of Ar density profiles was derived from bolometry measurements for 50 discharges. The bolometer signals in the upper half of the poloidal cross section were Abel inverted with the assumption of poloidal symmetric radiation distribution. The core Ar is in coronal equilibrium. Thus the Ar concentration on axis is $C_Z = \dfrac{P_{rad}(0)}{n_e^{\,2}(0)L_u(T_e(0))}$ using the cooling rates L_u from Post [3]. In addition, for a few discharges, with low to moderated Ar levels, impurity densities were obtained from analysis of tomographically inverted soft ray emission profiles.

The correlation between impurity profile peaking and core MHD events indicated that the central Ar density increased when the amplitude of sawteeth crashes decreased (fig. 1). In discharges with a high Ar input, a sudden increase in central impurity concentration followed the cessation of sawtooth activity (figures 1 and 2).

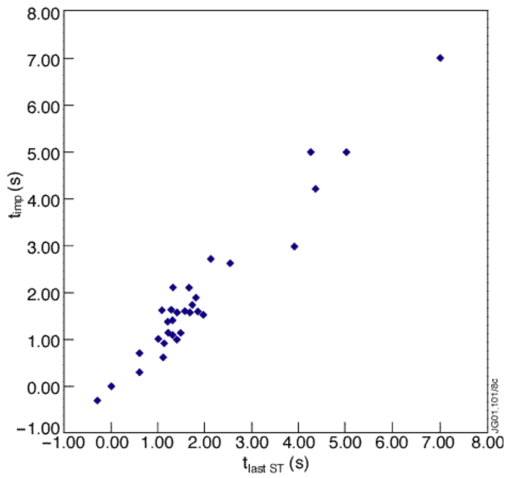

Fig.2 - Time of sudden increase in central impurity concentration versus time last sawtooth crash is observed. For t ≥5s, sawteeth were maintained throughout the heating and no impurity peaking was observed.

No correlation between Ar accumulation and ELM activity was found. In discharges with high Ar input, the ELM frequency decreases, and ELM-free periods (up to 0.5s) may be observed. Core impurity accumulation during the ELM-free periods, or following large type I ELMs was evaluated as a contributor to the confinement degradation. Bolometer data analysis indicated that central impurity accumulation occurred in a variety of ELM regimes, including Type III ELMs. Soft-X-ray emission indicated that following Type I ELMs the impurity density increases in the outer region of the plasma, typically within 20-30 cm from the edge.

III – Sawtooth Observations - The sawtooth period and amplitude obeyed the empirical relations with temperature, density and Zeff described in [4]. In the after-puff phase, the sawtooth amplitude is determined by the evolution of the central q-profile. Once the gas rate was decreased, q(0) increased and sawtooth suppression occurred when q(0) rose above unity. Magnetic equilibrium reconstruction as well as MHD mode analysis [5] indicate that near the time of sawtooh suppression the central q-profile is nearly flat and close to unity. After sawtooth suppression, equilibrium reconstruction with polarimetric measurements indicates reversed shear q-profiles (similar to observations in TEXTOR [6]).

The observation that sawtooth-free periods coincide with core impurity accumulation is similar to observations in TEXTOR [6] and ASDEX-U [7-8] experiments where an increase in central SXR emission during the absence of central relaxations such as sawtooth and fishbones also indicated an increase in impurity density. Fig. 3 shows that the effect of a sawtooth crash on impurities depends on the amount of impurities in the core. In the main gas–feeding phase (–1 to 0 sec in fig.3) the central impurity density increased at each sawtooth crash. Later, both sawtooth crashes and continuous core MHD modes flattened the impurity density profile (1-3 sec in fig 3, also in fig.4), as also observed in ASDEX-U [7].

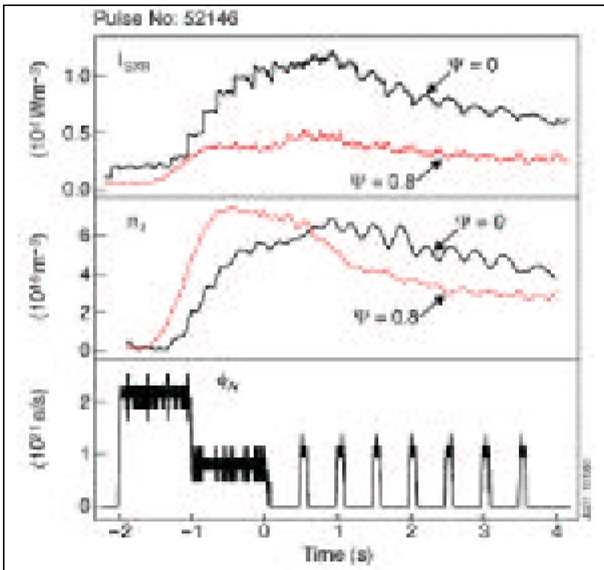

Figure 3 – SXR tomographic inverted signals and deduced impurity density, for a discharge with moderate Argon input. In this discharge sawteeth were maintained by addition of 3MW of ICRF heating to 12 MW NBI heating.

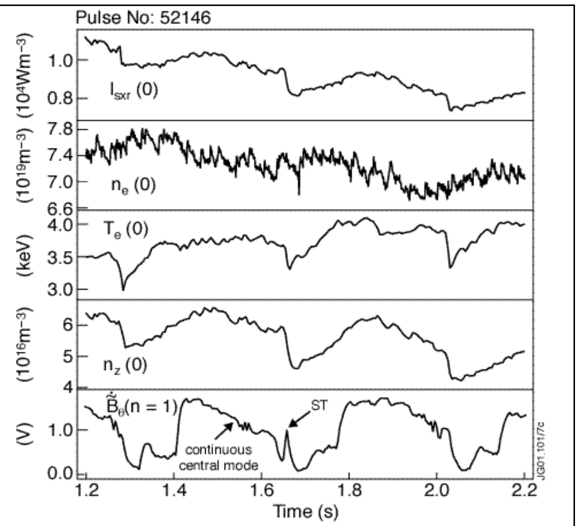

Figure 4 – Central SXR emission, electron density and electron temperature used to calculate the impurity density. The central impurity density was reduced during continuous n=1 MHD modes and sawtooth crashes.

IV – Experiments to maintain sawteeth - To keep q(0) below unity and maintain sawteeth, ICRF power (1-3MW) was added to the main NBI heating. The RF heating resonance layer was located on axis to increase the central electron temperature. Low RF power was used in order not to create a significant population of ICRF accelerated ions, thus avoiding sawtooth stabilisation by fast particles. Hydrogen was used as the minority species, with the antennas operated either in dipole, or with $-\pi/2$ phasing. In both configurations the central Te was increased, preventing q(0) increasing as fast as in the reference discharges. In these experiments, sawteeth were maintained and core impurity accumulation was not observed (fig. 5). Loss of confinement and density was also not observed (fig. 6). The beneficial aspect of ICRF heating on the avoidance of accumulation in RI-modes was previously observed in TEXTOR [9].

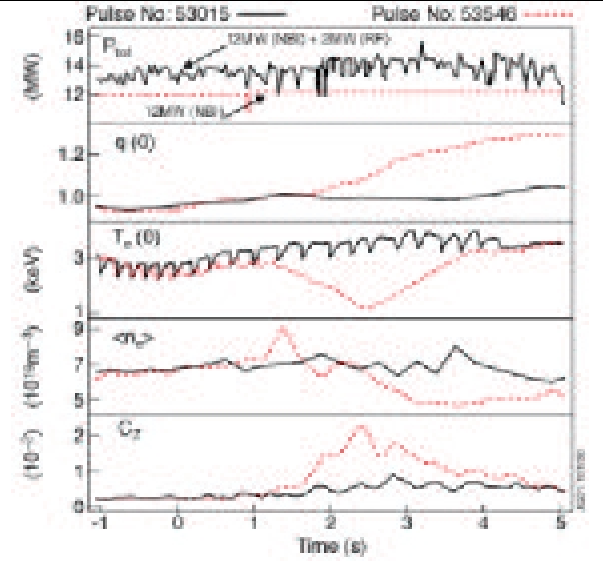

Figure 5 – Comparison of high Argon density discharge shown in fig.1 with a discharge where 2MW ICRF heating was added. In the latter, sawtooth was maintained and core impurity accumulation was not observed.

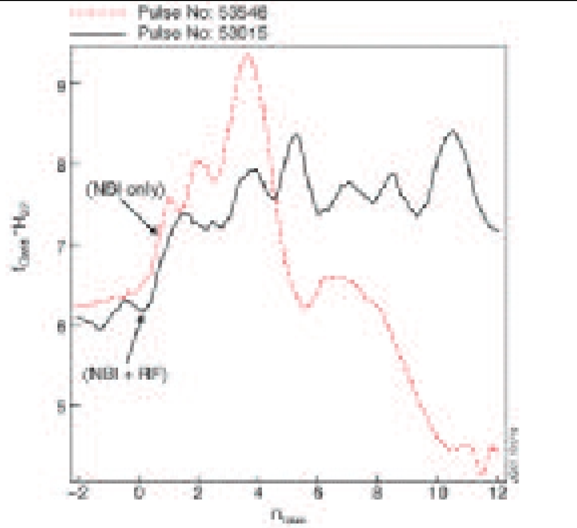

Figure 6 – The product $H_{97}*f_{GWD}$ for the discharges in fig. 5. In the discharge with the sawteeth maintained, $H_{97}*f_{GWD}$ ~0.8 lasted for several confinement times (n_{taue}=time/τ_E).

V Conclusions - Maintaining sawteeth using ICRF heating resulted in quasi-steady state, high performance plasmas with high Ar densities. Values of $H_{97}*f_{GWD}$~0.8, previously only lasting <1 τ_E at high Ar injection rates, were maintained for the duration of the heating(Δt~9τ_E). We conclude sawtooth plays an important role in preventing impurity accumulation.

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