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Termination of discharges in high performance scenarios in JET

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The termination of high performance plasmas in tokamak devices with high Z metal plasma facing components presents challenges related to the influx of heavy impurities which, if not kept under control, cause an increase of the radiative losses, radiative cooling and high probability of disruption.

A number of key players in these dynamics have been identified by intensive research performed after the first years of operation in tungsten machines as AUG and JET in preparation of ITER operation. Inward neoclassical convection related to the peaking of the density profile, poloidal asymmetries, plasma rotation and centrifugal effects, temperature screening, pedestal temperature, pedestal density and ELMs control are among them [1-3].

The objective of D-T fuelled plasmas with high neutron yield in stationary conditions, foreseen in the near future at JET, focuses the operations towards high performance in terms of thermal energy content and plasma current and consequently with higher disruption risk. The reduction of such risks is being pursued for the specific features of the two plasma scenarios being developed, baseline (β¬N ~1.8, q95 ¬~ 3) and hybrid (β¬N ~2–3, q95~4) [4]. The high plasma current (Ip≥2.5MA) experiments based on the baseline scenario performed in the high power campaign C36b (2016) had 65% overall disruptivity (Ip,disr≥1.0MA) with 49% pulses ending with a disruption at Ip,disr≥2.0MA. The high plasma current (Ip≥2.MA) experiments based on hybrid scenario of the same campaign had 39% overall disruptivity with 21% of the pulses ending with a disruption at Ip,disr≥2.0MA. The inspection of the corresponding databases for the recent C38 campaign (2019) reveals a significant reduction of the disruption rate. The overall disruptivity for baseline has been 34% with 27% at Ip,disr≥2.0MA. For hybrid the overall disruptivity has been ~9% (16% considering only the Ip≥2.MA database) with 5% at Ip,disr≥2.0MA. Such numbers are better understood by taking into account the necessary explorative nature of scenario development, and, in particular, the progressive adaptation towards the target parameters of higher plasma current, 3.5-4 MA for baseline and 2.2-2.8 MA at flat top for hybrid. The key elements developed to obtain a smooth termination of the high performances discharges in JET and their effectiveness in reducing the disruptivity are discussed in this contribution.

The analysis of the previous experimental campaign and the data so far collected in the present campaign indicate that the combination of edge and core W control is needed to obtain a safe plasma termination, with the optimized use of the available actuators: gas and pellet for ELMs control, ramp-down waveform of the NBI heating power while maintaining a relevant ICRH additional power, sweeping of the separatrix hitting point on the divertor to reduce the heat load and to decrease the W source. These elements, common for baseline and hybrids although with a different tuning [5], have been tested in the C38 campaign and some of them are represented in the pair of discharges in Fig.(1) where an impurity influx has been deliberately generated by drastically reducing the gas fuelling during the main heating phase.

With respect to the typical termination scheme previously adopted the gas fuelling has been increased to burst the ELM frequency in order to favor impurities removal at the plasma edge and to reduce the divertor temperature. The slow NBI power ramp-down delays the H-L transition. This needs to be tuned to shorten the free-ELMs phase at the ramp-down starting. At high current and high density the ICRH central heating may be inefficient to counteract the core impurity effect being dominantly ion heating. However, a significant core electron heating is obtained by increasing the H minority fraction during the ramp-down as shown in the figure, where the central electron temperature is recovered and the disruption avoided.

A further adaptation of the termination scheme may be required for the application to the higher plasma current D-T scenarios in development. Moreover, since the termination time cannot be foreseen in case of off-normal events, real-time tools are being implemented in a dedicate event detector to identify the nature of the off normal condition, e.g. core impurity accumulation or edge temperature collapse, and to start the termination phase with a real-time controlled response. The new detectors include real-time tomography which can estimate the amount of radiated power from different region of interest [6] and a Generative Topographic Mapping algorithm [7] aiming to compute the probability of disruptive evolution for core and edge radiative collapse respectively. A termination algorithm aiming to optimize the input power waveform during the ramp-down in order to keep a safety margin to overcome the radiative losses both in H and L mode is also being planned.

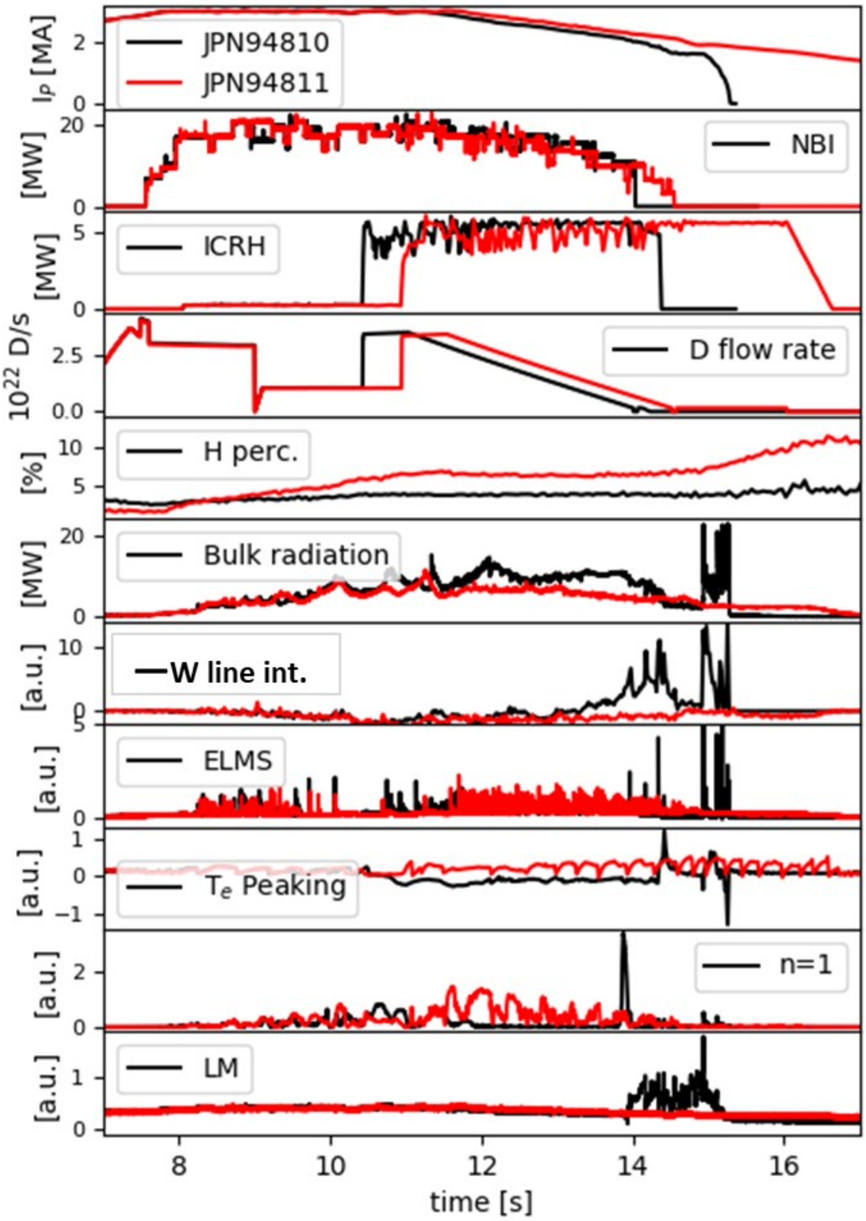

Figure 1: Time evolution of two baseline-like JET discharges. From top: Plasma current, NBI and ICRH power and radiative power, H minority ion concentration, gas fueling rate, bulk radiative power, W line intensity, ELMs trough BeII line intensity, electron temperature peaking, N=1 mhd activity, locked mode amplitude.

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