PLASMA CONTROL EXPERIMENTS IN JET DEUTERIUM-TRITIUM PLASMAS

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The Joint European Torus (JET) has the unique capability of operating with Deuterium-Tritium (DT) fuel mixture, as required in nuclear fusion power plants. A 3rd experimental campaign (DTE3) using a DT fuel mixture, and building on the experience from the two previous DT campaigns (DTE1 (1997)[1] and DTE2 (2021)[2-3]), was executed in the autumn of 2023. In this campaign a series of advanced real time controllers, which are likely to be essential in nuclear fusion reactors, have been exploited. The operational issues that these controllers addressed were the entry into and exit from burn, the entry into and exit from H-mode, the control of the plasma exhaust during the H-mode phases of a plasma discharge, and the identification of under-performing plasma discharges (dud).

Controlling the D/T fuel ratio in a reactor could be an ideal tool to assure that the transition to and from burn occurs as desired. Hence demonstrating active D/T ratio control in the plasma core is of great importance. Fig. 1 shows two examples of successful, closed loop control of the D/T ratio on JET [4]. In these discharges, the Tritium was injected via gas valves, while the Deuterium was injected via a gas valve (left plot) or using a Deuterium pellet injector (right plot), while the D/T ratio was calculated using the ratio of D and T visible spectroscopy lines measured in the outer divertor lines of sight [5]. The realtime algorithm controls at the same time the isotope ratio and the total injected gas rate, in order to avoid altering other plasma physics quantities while executing isotope control. The response of DT neutron rate to the D/T ratio change, at constant injected power and plasma condition, is a demonstration of the effectiveness of this controller [6].

While controlling the isotope ratio, it is important to assure that the total plasma radiation remains moderate. On JET this radiation is dominated by the influx of heavy impurities, and avoiding this influx is key to remaining in a good quality H-mode. This can be achieved controlling the entry into and exit from H-mode. The exit from H-mode is particularly difficult to handle, as reducing the input power, while the plasma radiation or density is too high, leads to a radiative collapse. A real time algorithm has been used in JET DT plasmas, which modifies heating power and fuelling to assure that the plasma remains in H-mode as long as required, before executing a controlled exit from H-mode.

For tokamak fusion reactors, acceptable divertor target conditions can be achieved by maintaining a detached divertor plasma. In this regime, there is significant mitigation of power and particle fluxes impacting the divertor targets. Given that plasma conditions are varying during the discharge, real-time control algorithms that actively assess the exhaust plasma state are required to continuously adjust actuator actions to evolving reactor conditions and disturbances.

During JET DD and DT experiments, the dynamics and control of the tokamak heat exhaust have been controlled through the X-point radiator (XPR) vertical control [7]. The dynamic identification of control relevant exhaust dynamics allowed for systematic design of an exhaust controller, which has been used in standard operations for specific detachment characterization experiments.

In JET DT pulses, dud detector has been extensively used to terminate scenario development pulses, that were not reaching the expected plasma performance. Metrics based on the H98 and the Rnt/Wp2 have been monitored during the plasma evolution and if their values were below a certain threshold, the plasma was terminated safely. This has allowed the optimal use of the limited tritium and neutron budget [8, 9]. After DTE2 operation, the originally designed dud detector for JET baseline plasmas has been revisited in the so-called innovative dud

detector [5,6], to include a metric on the power above the PLH threshold. This has been motivated by the radiation runaway events that affected most of the baseline scenario plasmas.
In this contribution, the key role of JET in developing burning plasma control will be presented including the challenges encountered, the lessons learned and the main control achievements.

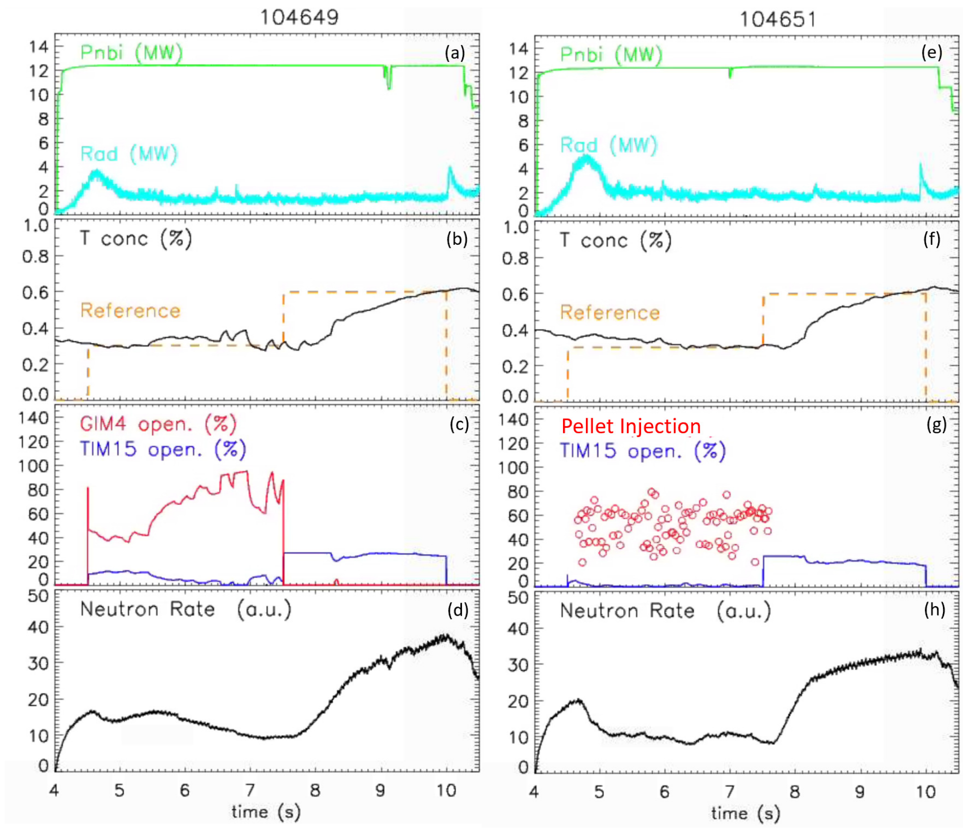

FIG.1. Time behavior of (a-e) NBI power (in green) and radiation (in cyan), (b-f) Tritium concentration and the corresponding real-time request (in orange), (c-g) Deuterium (in red) and Tritium (in blue) valve opening (on the left) while Deuterium pellet (in red) and Tritium (in blue) valve opening, (d-h) neutron rate in 1.4 MA, 1.8 T discharges performed in JET where the Deuterium-Tritium mixture controller has been tested.

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