EUROPEAN FUSION DEVELOPMENT AGREEMENT
JET

EFDA–JET–CP(04)03-35

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** See annex of J. Pamela et al, "Overview of Recent JET Results and Future Perspectives",*
Fusion Energy 2002 (Proc. 19th IAEAFusion Energy Conference, Lyon (2002).

Preprint of Paper to be submitted for publication in Proceedings of the
31st EPS Conference,
(London, UK. 28th June - 2nd July 2004)

ABSTRACT

The presence of an Internal Transport Barrier (ITB) in the plasma can dramatically affect the transport of fuel and impurity particles. However, effective control of the plasma density, fuel concentration and deuterium-tritium mixture is required to maintain fusion power. Dedicated experiments have been performed in JET to address these issues, using trace amount of tritium injected transiently to make it possible to determine separately the T diffusion and convection. Three fuelling methods were compared in otherwise similar ITB plasma conditions: T gas puffing, neutral T beam injection and T recycled from the wall.

1. EXPERIMENTAL SCENARIO AND NEUTRON DIAGNOSTIC

The plasmas used in these experiments have deeply negative shear, obtained by applying Lower Hybrid Current Drive (LHCD) shortly after the beginning of the current ramp-up. High Neutral Beam Injection (NBI) and Ion Cyclotron Resonance Heating (ICRH) power is applied ~1s before the minimum safety factor (qmin) reaches 3, and triggers an ITB seen simultaneously on the electron and ion temperature (T_e, T_i), and on the electron density (n_e). The plasma current (I_P) is ramped towards 3MA throughout most of the experiment, and the magnetic field ($B_T = 3.2T$) is constant. The LHCD and NBI waveforms were engineered to provide either a single ITB in the region of negative magnetic shear (Fig.1) or a double ITB by allowing a second barrier in the positive magnetic shear region (Fig.2). In Figure 1 and 2, ρ_{Te}^* is the ion Larmor radius at the sound speed normalised to the local T_e gradient scale length, $\rho_{Te}^* \geq 0.014$ corresponds to a clear ITB (determined empirically)[1] . Both types of ITB were produced with duration greater than the energy confinement time.

The evolution of the trace tritium is tracked using collimated horizontal and vertical neutron cameras that measure separately the DT and DD neutron emissivity [2, 3]. The number of lines of sight allows enough spatial resolution to give information from the regions inside and outside the core ITB and the outer ITB. The time resolution is 10ms. Figure 3(b)) shows the time of the maximum of the 14MeV neutron emissivity for the lines of sight of the horizontal camera, following a T gas puff, for three shots with ITBs at different location (illustrated on Fig.3(a)). This figure shows that the inward propagation of the tritium ions slows down at the ITB location, whether it is in the positive or negative magnetic shear region of the plasma. This illustrates how the presence of an ITB can affect the fuel transport. However, in order to understand the processes behind this effect, and to be able to extrapolate to a 50:50 DT plasma, a detailed transport analysis is required.

2. TRANSPORT ANALYSIS

In order to determine the T diffusion coefficient (D_T) and convection velocity (v_T), the neutron emissivity spatial and temporal evolution is fitted by the transport code UTC/SANCO [4], in which the more complete DT neutron calculations of TRANSP [5] have been used. Figure 4 shows the D_T and v_T that leads to the best fit to the neutron data, in comparison with the neo-classical diffusion coefficient and convection velocity predicted by NCLASS [6]. The experimental D_T falls to ≤ the neo-classical value at the location of the ITB, but is higher in the region enclosed by the ITB. The T inward convection velocity also decreases at the ITB location (from ~10m/s to ~0.3m/s), but remains larger than the neo-classical prediction. Note that the neo-classical transport contribution for T is different than for D, because T is in minority [6, 7]. This will have to be taken into account when extrapolating the results found here to 50:50 DT plasmas.

4. PRELIMINARY RESULTS OF COMPARISON OF FUELLING METHODS

The three fuelling methods have been compared in plasmas with similar parameters. Figure 5 shows T_i and n_e for Pulse No: 61328 (T recycled from the walls only), 61352 (T gas puff) and 61347 (neutral T beam blip). Figure 6(a) and 6(b) show the neutron emissivity profile for the same shots, for the horizontal and vertical camera respectively. The measurement is shown at 0.3s after the end of the T beam blip, which corresponds to the time where the fast T from the beam has become thermal, as calculated by TRANSP. In the case of the gas puff, the time shown corresponds to the time at which the T arrives in the core (0.4s after the beginning of the gas puff as shown in Fig.3). The total number of T atoms injected in the torus from the gas puff is higher than that injected with the beam blip, by $3.1\times10^{20} / 8.2\times10^{18}$ ~38. However, the DT neutron emissivity in the core (which is proportional to the T density in the observed temperature range) for the gas puff is only 1.6 times higher than for the T beam blip. Hence, in this case, the T beam blip is ~25 times more efficient than the gas puff in getting T ions into the plasma core. When comparing the fuelling scenario in plasmas with weaker ITBs (as in Fig.2 for example), it is found that, although the T beam is always more efficient than the gas puff for increasing the T in the plasma core, the difference between beam and gas fuelling is not as pronounced. This indicates that the relative efficiency of different fuelling methods depends on the confinement inside the plasma. These results are preliminary and the detailed transport analysis of these experiments to compare the fuelling scenarios more accurately, including for extrapolation to ITER, is in progress.

ACKNOWLEDGEMENT

This work was performed under the European Fusion Development Agreement, and funded partly by the UK Engineering and Physical Sciences Council and by Euratom

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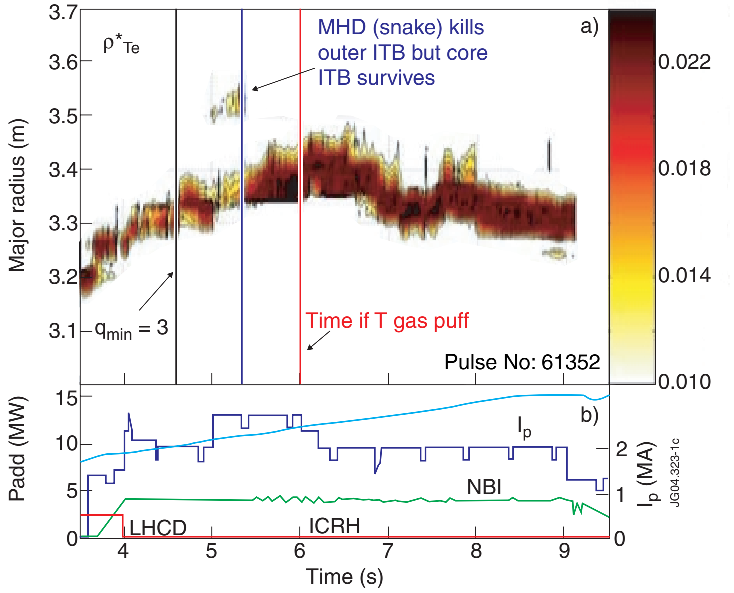


Figure 1.Time evolution a) ITB ($\rho^*_{Te} > 0.01$) and b) P_{ADD} and I_P for Pulse No: 61352.

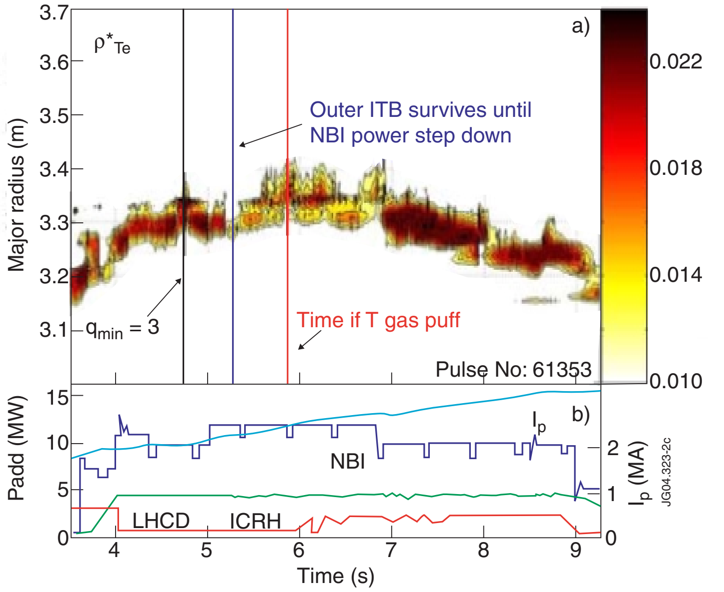


Figure 2.Time evolution a) ITB ($\rho^*_{Te} > 0.01$) and b) P_{ADD} and I_P for Pulse No: 61353.

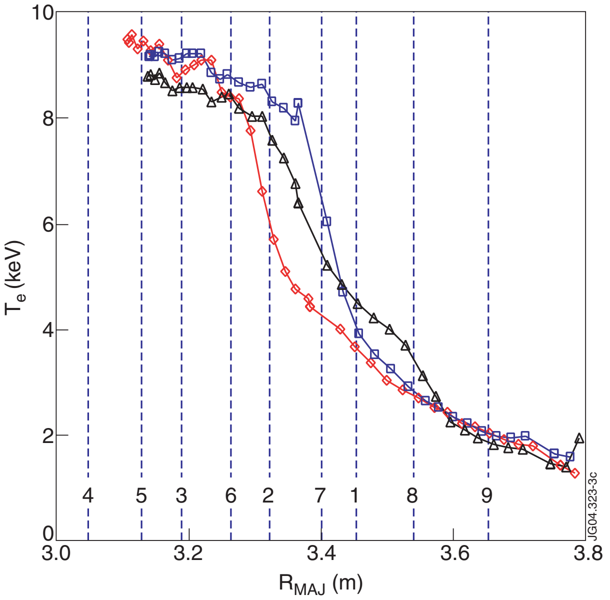


Figure 3(a) T_e for Pulse No's: 61351 (diamond), 61352 (square), 61353(triangle). The dashed lines show the lines of sight (hor. Camera).

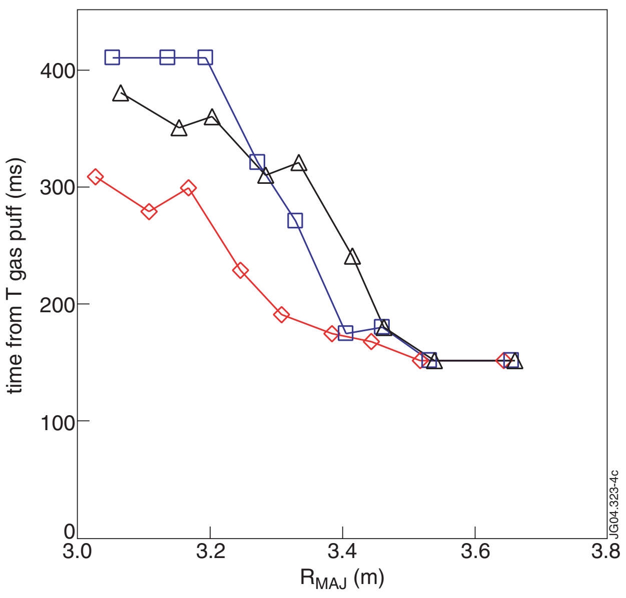


Figure 3(b) Time from T gas puff of the maximum of emissivity for the lines of sight of the horizontal camera.

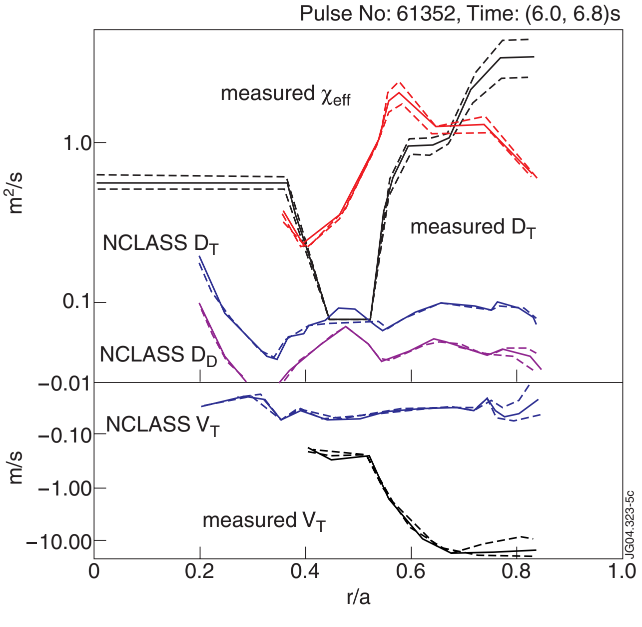


Figure 4. Measured D_T and v_T, in comparison to neo-classical prediction, a negative v_T indicates inward convection. The dashed lines represent the error bars.

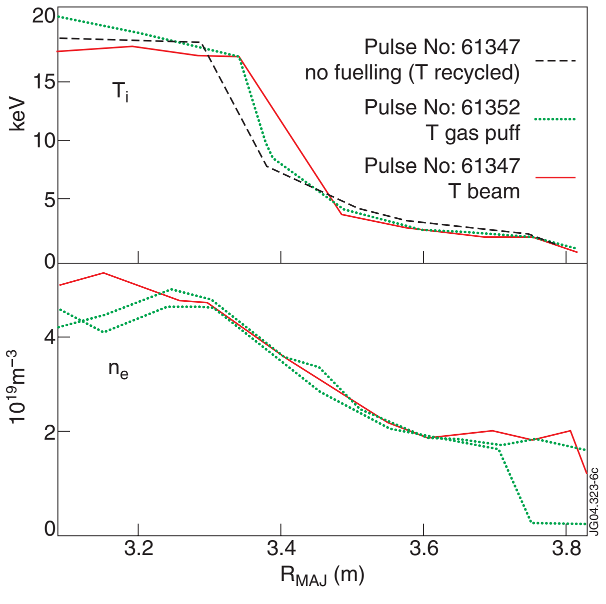


Figure 5. T_i and n_e profile for Pulse No's 61352 (full line), 61347 (dotted) and 61328 (dashed)

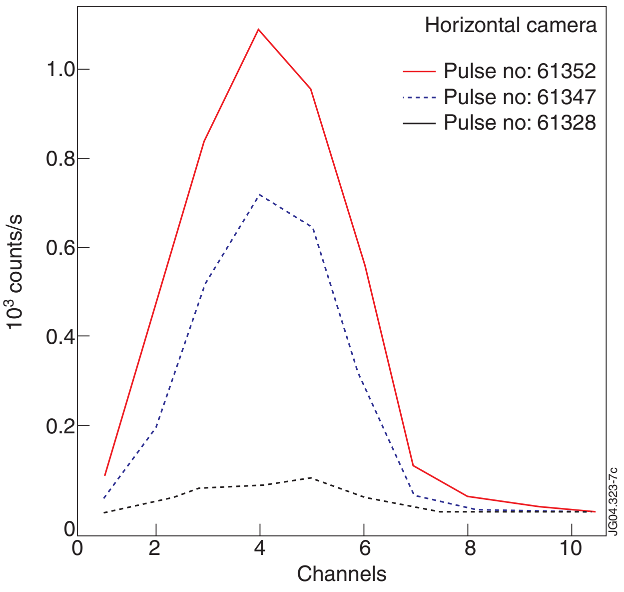
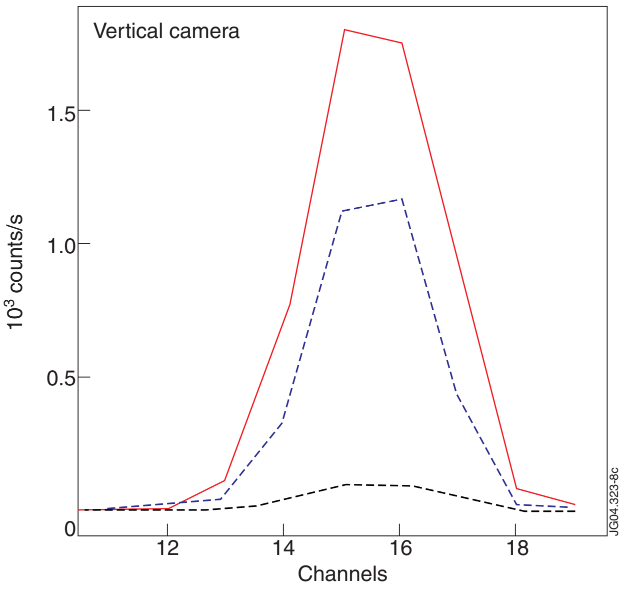


Figure 6(a) DT neutron emissivity measured by horizontal camera, for shots of Fig.5 Figure



6(b) DT neutron emissivity measured by vertical camera, for shots of Fig.5.