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**See Annex of J. Pamela et al., "Overview of Recent JET Results and FuturePerspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

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ABSTRACT.

Advanced scenarios featuring Internal Transport Barriers (ITBs) need to be extended to densities towards the Greenwald value in order to demonstrate their reactor relevance. It is difficult to access this regime since NBI deposition becomes less efficient in injecting particles and torque into the plasma core and high additional current drive power must be applied to maintain the optimized magnetic shear needed for stabilizing the turbulence. Steep internal density gradients, created by pellets, can substantially contribute to turbulence stabilization, and can efficiently drive the off axis bootstrap current that keeps the magnetic shear small or negative. This paper describes experiments performed on JET aimed at the production of high density ITBs by means of pellet injection. The basic scenario is illustrated in Fig.1. After a LH prelude, aimed at producing a reversed shear configuration, a pre-fuelling gap of about 1s follows which can be ohmic or heated with a moderate amount of NBI power (~4MW). During this gap, pellets are injected in order to prepare a high density target for the main heating phase characterised by the injection of a comparable amount of NBI and ICRH power. When conditions are optimised, high density barriers are formed at similar electron and ion temperatures. These barriers can last several hundreds of milliseconds and tend to decay either due to MHD events or to the flattening of the density profile. Attempts to refuel the ITB during the main heating have given encouraging results.

RESULTS

With the recipe described above, at the start of the main heating phase internal barriers have been formed with core densities near or beyond the Greenwald value with T_e close to T_i (Fig.2). These barriers start to form at a toroidal rotation frequency which is about four times lower than in standard ITB discharges [2,3]. This already points out the possibility that the density gradient is partially substituting the flow shearing rate in the role of stabilizing the ITG turbulence for the barrier formation. Experience shows that both the preparation of an optimized q-profile and an efficient pellet fuelling are essential to the formation of these internal barriers. Experiments done in similar conditions with and without LH prelude or pellets have led to the formation of a barrier only when both were present (Fig.3). An analysis of turbulence stabilisation of the type reported in reference [4], gives a quantitative explanation of this experimental evidence in terms of synergy between the density gradient and magnetic shear in the reduction of the ITG growth rate. Figure 4 shows the case of two shots having the same magnetic shear profile due to LH prelude but different density gradients since only one of them was fuelled with pellets: the latter formed a barrier in the region where the flow shearing rate exceeded the ITG linear growth rate. A complementary case shows that if pellets are present in two discharges giving similar density profiles, LH prelude is needed to attain the same stabilizing conditions. This last case, however, has poor statistics and needs more experimental data to be confirmed. The issue of turbulence stabilisation has also been addressed by means of a gyrokinetic code and results are reported in reference [5].

The gap between LH prelude and main heating is needed for injecting pellets that otherwise would be ablated in the plasma periphery by the fast electrons created by LH. First experiments were made with an ohmic gap: the q profile, that keeps reversed at the end of the gap in absence of pellets, becomes flat or slightly reversed in the central region after pellet injection but is still different from the case without LH prelude. When applying some NBI power (~ 4MW) during the gap higher densities were achieved and it was possible to better control the current profile which remained hollow also after pellet injection due to the longer current diffusion time. In spite of the higher temperature, even moderate speed pellets (80 m/s) kept being efficient in fuelling the core before the main heating phase. Figure 5 shows q-profiles at the beginning of main heating in the different cases. The recipe found allows to independently control the current and density profiles thus opening the possibility of further investigation on their individual role in the ITB physics.

After the barrier formation a strong bootstrap current is driven by the steep density and temperature gradients: in one of these shots, an interpretative analysis done with JETTO code, including constraints with MSE experimental data, shows that a total bootstrap current of the order of 0.5MA has been driven corresponding to about 25% of the total current. This helps in making the q-profile more reversed.

Attempts have been made to fuel the already formed barrier during the main heating phase. The barrier is not destroyed as long as pellets do not penetrate inside it [6]. There is a clear evidence of edge fuelling while the issue of weather these pellets contribute in making the core density decay time longer needs further investigation.

CONCLUSION.

Internal transport barriers with core density close to the Greenwald value and Te~Ti have been formed at JET using pellet injection as a fuelling tool. These barriers are obtained at low toroidal rotation due to the moderate neutral beam power employed. Both of these features go into the direction of ITER requirements. Synergy between a flat/reversed q profile, obtained by LH pre-heat, and density gradients produced by pellets, is needed to enter this regime. The new scenario is a significant step forward with respect to the former Pellet Enhanced Performance (PEP) since now it is possible to independently control the current and density profiles opening the perspective of a better understanding of ITB physics. Attempts to re-fuel the discharge during the main heating have been made showing that barriers are not destroyed if shallow pellets are injected. Clear edge fuelling is observed in these cases. There are also indications of a slower central density decay time but further investigations are needed about this item. A simplified turbulence stability analysis has confirmed the synergy between q-profiles and density gradients in triggering these ITBs.

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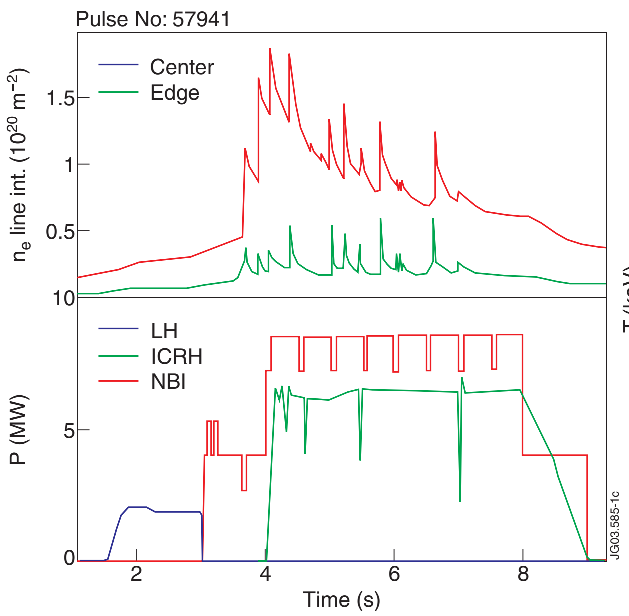

Figure 1: Typical waveforms of ITB pellet fuelled scenario. Pre fuelling pellets are injected during a low NBI heated gap between a LH prelude and the main heating phase starting at t = 4s. In this case other pellets are also injected at >4s

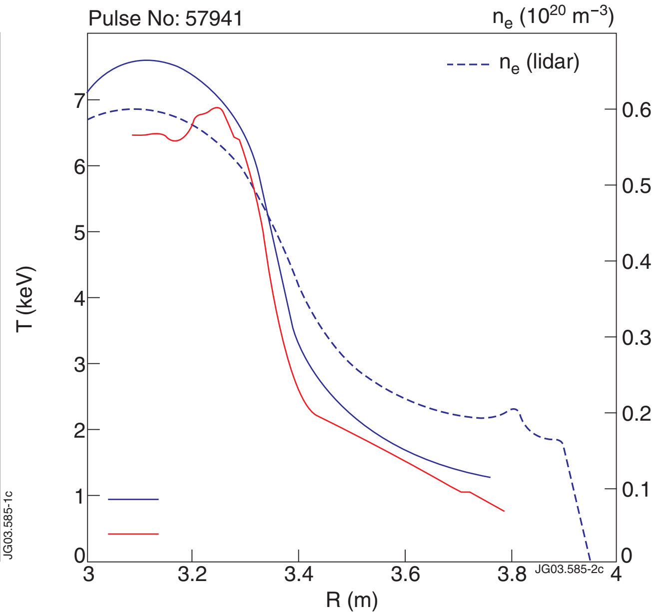

Figure 2: density and temperatures profiles of an high density ITB. The core density is at the Greenwald value (0.6×10^{20} m^{-3}) and electron and ion temperatures are close to each other.

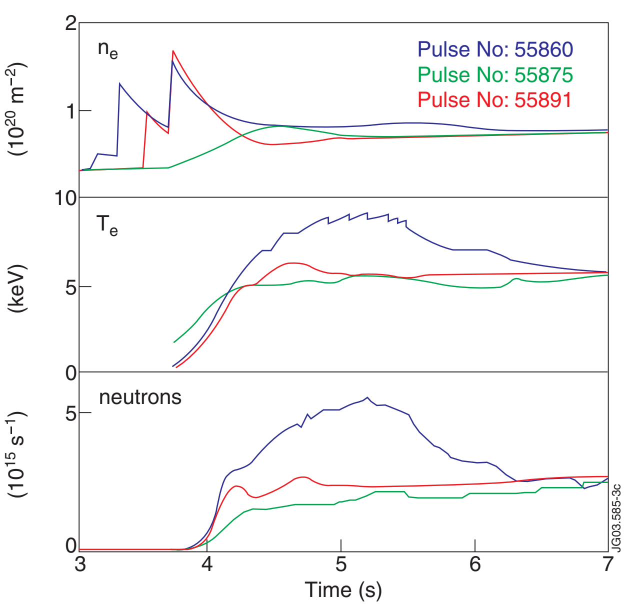

Figure 3: Three shots are compared here. Barrier formation, marked by the larger Te and neutron rate, occurs only in Pulse No: 55860 where both LH preheat and pellets were present. In the other two either pellets were absent (Pulse No: 55875) or LH (Pulse No: 55891)

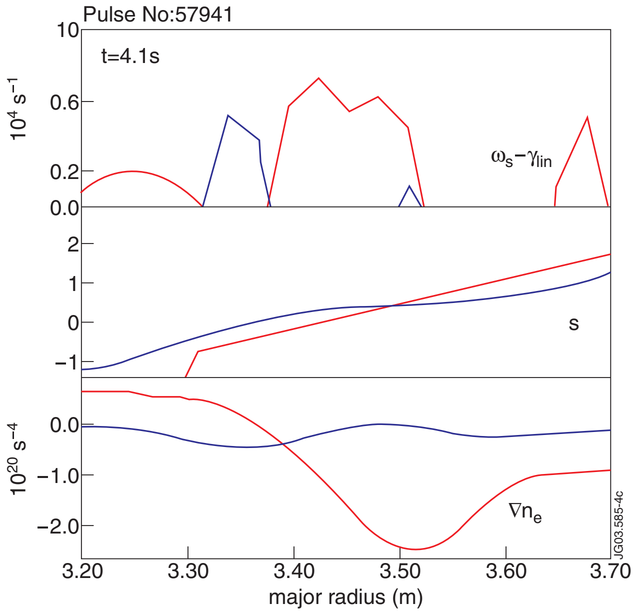

Figure 4: turbulence stability analysis for two discharges having a similar magnetic shear but different density profiles due to pellets injected only in Pulse No: 57941 . ITG turbulence is stabilised over a large area (ω_s-γ_{lin}> 1) in this shot that develops a barrier.

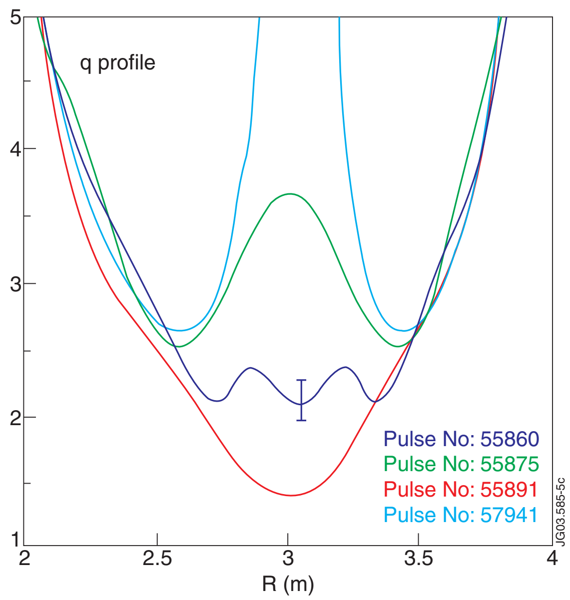

Figure 5: q-profiles before the main heating phase. Pulse No's: 55860 (LH+Pellets), 55875 (LH only), 55891 (Pellets only) both with an ohmic gap. Pulse No: 57941 (LH + Pellets) with 4MW NBI gap.