Status of Integrated Modelling of JET-ILW Plasmas with N_2 seeding

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1. Introduction

The N_2-seeding experiments at JET[1][2] were carried out in order to develop a type-I ELMy H-mode reference scenario for achieving Q=10 in ITER compatible with the wall materials (Be main chamber, W divertor) of active operation. One objective of the experiments was to reduce the steady-state divertor-target power load by introducing a radiating extrinsic impurity (N_2). An unexpected feature of N_2-seeding, in high-triangularity (δ) JET with an ITER-Like wall (JET-ILW) plasmas, was the observation of improved pedestal confinement at levels closer to those of JET with Carbon-Fibre-Composite Wall (JET-C) [2][3][4]. It has been suggested that the level of C and its associated radiation could have been a hidden parameter in the JET-C confinement behaviour of high-δ plasmas and that this could partially be recovered by N_2 seeding in JET-ILW[2].

Detailed integrated modelling (core and SOL) of these JET-ILW discharges, with and without N_2 seeding, may shed some light on the difference in plasma dynamics between high- and low-δ configurations and, in particular, the improvement in confinement with high-δ and N_2-seeding. It is important to compare the simulations with a set of experimental parameters in the core/edge/SOL to ascertain the main physics governing these plasmas has been captured correctly. This paper reports on the present results.

2. JINTRAC Simulation Settings

To initialise JINTRAC[5], JETTO simulations during the L-mode phases of the discharges were run for at least a few confinement times before coupling to EDGE2D. The coupling occurs well before the switch on of the neutral beams (absorbed power is calculated by PENCIL) and substantial increase of gas puffing rates (D_2 & N_2). The EDGE2D grid takes

* See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, US

into account the shape of the plasma, location of the strike points and plasma boundary. The puffing rates are set up according to experiment with a delay of 100ms to take into account the transfer time from gas valve to plasma boundary. The D_2 puff is located on the high-field side and N_2 puff on the low-field side. Be and W are both recycled impurities and their influxes are calculated by EIRENE through the sputtering rates. Wall recycling rates are set individually for each ion species, while the pump albedo is the same for all species and both vary between L-mode and H-mode as the wall gets saturated.

The L-H transition is triggered whenever the power crossing the separatrix is above the threshold set by the Martin scaling[6]. At this point the transport of both particles and heat is reduced from Bohm/GyroBohm to neoclassical within a fixed region (1-5cm) inside the separatrix. ELMs are triggered when the pressure gradient within the barrier region exceeds the ballooning-instability threshold. At this instant the transport in the barrier region is increased for a fixed duration to mimic the process in the experiment. So far only slow and small ELMs have been used to avoid code instabilites. The sawtooth-trigger rate is set to match experiment and each sawtooth is simulated by the Kadomtsev model.

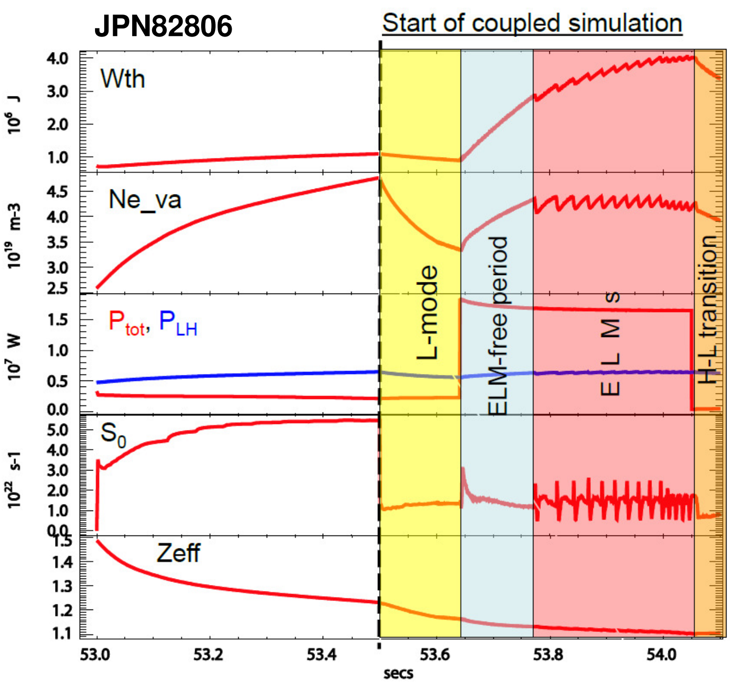

Figure 1: Proof-of-principle JINTRAC simulation with Be as intrinsic impurity of the high-δ N_2-seeding reference case from L-mode, through L-H transition and subsequent ELM-free period, ELMy H-mode and H-L transition. Shown from top to bottom are: total thermal energy, volume-averaged electron density, total and L-H transition threshold power, neutral D_2 source at the separatrix and the effective charge. The vertical dashed line indicates the start of the fully coupled core and SOL JINTRAC simulation.

3. Proof-of-Principle Simulation and Challenges to the Modelling

Figure 1 shows a proof-of-principle simulation with JINTRAC where we were able to model a high-δ reference pulse for N_2 seeding. The N_2-seeding experiments push the tokamak very close to operational boundaries such as the density limit, L-H transition (may cause dithering and numerical instabilities) and full detachment (requires improved and more CPU-demanding EIRENE version). These limits need to be tested in the simulations to make sure that the suite of codes is robust under the above circumstances. A further complication of the JET-ILW N_2-seeding experiments is the lack of prolonged steady-state phases. Even in L-mode matching the experimental plasma density, Be and W evolution with JINTRAC while applying the experimental gas-puff rate has proven non-trivial, especially when we try to match the SOL/wall properties to experiment. In H-mode there is, apart from the fast transient phenomena following each ELM, a gradual accumulation of W as seen in experiment. In the end, excessive impurity accumulation leads to a collapse of the H-mode barrier and return to L-mode.

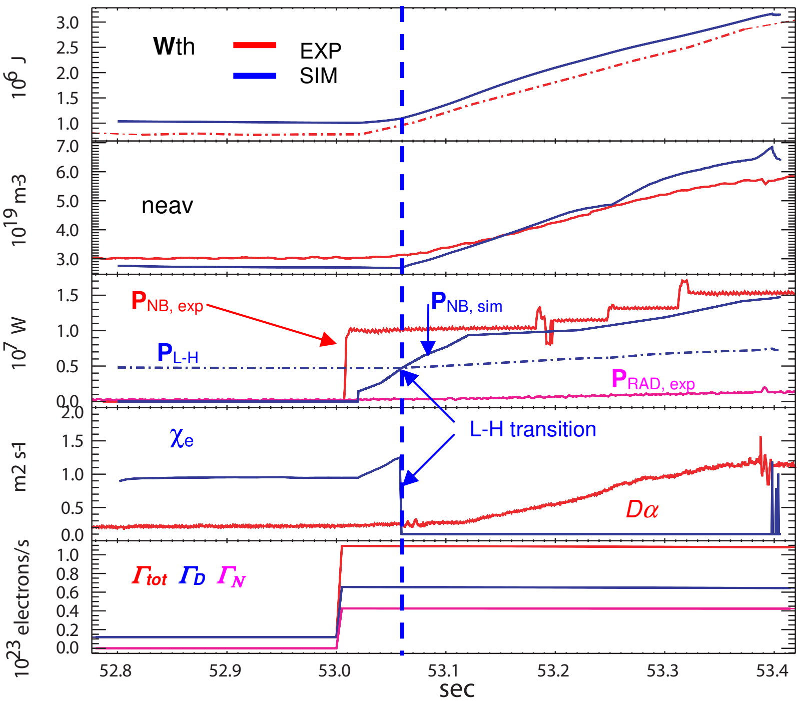

Figure 2: JINTRAC simulation (impurities: Be and N_2; P_{rad} from experiment) of the L-H transition and subsequent ELM-free period of JET-ILW high-δ plasma JPN83359. Shown from top to bottom are: total thermal energy; volume-averaged electron density; simulated total, L-H transition threshold and radiated power; simulated electron diffusivity and experimental D_α radiation; and applied puffing rates (equal to the experimental rates but time-delayed by 100ms to take into account the time-of-flight from gas valve to plasma boundary) of D_2 an N_2.

4. Simulation of N_2-seeded L-H Transition

JINTRAC was upgraded to handle three impurities only recently and final testing and validation is ongoing. All simulations until now only contain two impurities (Be & W or Be & N_2). We here present a simulation of L-H transition with N_2 seeding (Figure 2).

The L-H transition, in itself a sudden event that may destabilise the simulation, is further complicated by the simultaneous switch on of the neutral beams accompanied with a spike (from ~2.5-6.5*10^{22} electrons/s) in D_2 gas-puffing rate to protect the ILW, and N_2 seeding. The increase in gas puffing is so large that part of the density rise seen at the L-H transition can in fact be attributed to it and this has been shown in both our JINTRAC and JETTO simulations with the L-H transition model switched off. When we allow for L-H transition, this leads to a strong accumulation of particles just inside the separatrix (Figure

3), which we can reduce by imposing a particle pinch proportional to the particle diffusivity (proportionality constants 0.3-0.6 tested).

Although, the electron density at the outer midplane and outer target matches the experiment, the electron temperature at the targets is underestimated. This would cause reduced level of W sputtering if included in the simulation. The N_2 penetrates the barrier region where it peaks causing a local increase of the radiation density by almost two orders of magnitude above the unseeded case.

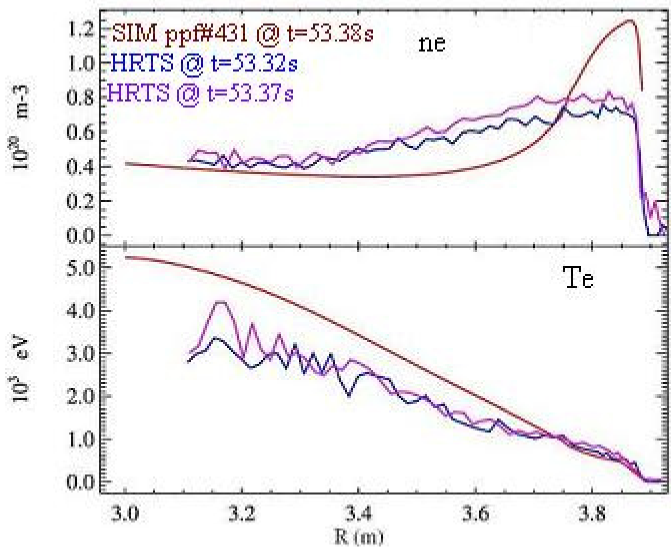

Figure 3: Electron density and temperature profiles at the end of the ELM-free phase of JPN83359. While hollow density profiles are observed in these experiments during the L-H transition, the density is rising smoothly from the magnetic axis to the pedestal rather than creating a spike in the pedestal region as seen in our simulations. This seems to indicate that the width of and transport in the H-mode barrier evolves in time after the L-H transition, rather than the instantaneous transition to a narrow, fixed, neoclassical-transport-only barrier normally applied in JINTRAC. Similarly, simulated N_2 and Be density profiles also accumulate in the barrier region (not shown), leading to a local peak in the radiation density.

5. Summary and Outlook

The dynamical evolution of JET-ILW N_2-seeded experiments is an extremely complicated process. We have achieved significant progress so far and next we will have to include all three impurities (Be, W & N) together, to obtain edge conditions closer to the experiment and to understand the particle transport during the ELM-free H-mode phase. This is crucial before a more accurate analysis of the impact on N_2 on confinement can be conducted.

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