

The ITER baseline scenario on JET in D-T with Neon seeding

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INTRODUCTION

The last campaigns of the *Joint European Torus* (JET) have been devoted to support the ITER programme by operating in the closest conditions to those envisaged for ITER experiments. Among all the experiments done to address key physics aspects for future ITER operations [1, 2], during the last deuterium and deuterium-tritium campaigns, JET developed and optimized the Integrated Scenario [3], also known as the ITER baseline scenario, designed to operate at high plasma current (2.5 – 3.2 MA), high triangularity ($\delta_{av} = 0.35 - 0.38$), and in V-V divertor configuration to achieve partial detachment through Neon seeding [4, 5, 6]. During the DTE3 campaign the Scientific Team dedicated a significant number of experiments in optimising the scenario by varying the nominal fuelling rate and the Neon seeding rate, aiming at collecting a consistent dataset of experiments to highlight the effect of seeding both on the pedestal and in the core.

Experiments have been performed in DT at 2.5 MA and at 3.0 MA with neon (Ne) seeding aiming at demonstrating the same beneficial effect of Ne on confinement demonstrated in D [4, 7, 8]. Consistently with what observed in D, also DT plasmas with Ne seeding show a reduction of the edge electron density [Fig. 1], which is followed by an increase in electron and ion pedestal temperatures, propagated also in the core. The toroidal velocity results also increased in seeded pulses [3, 6].

In this contribution we are presenting the results of Integrated Modelling performed with JINTRAC imposing the boundary conditions of the simulation at the separatrix. This approach allows us to investigate the pedestal transport required to match the experimental profiles, and the ionization sources required to sustain the pedestal density. We are aiming at explaining the reduction of pedestal density, due to Ne seeding, with an increase of the pedestal particle diffusivity or with a reduction of the ionization sources. The results will help highlighting the interplay between fuelling (gas puffing and seeding) and transport in the plasma edge in the framework of previous studies [9, 10].

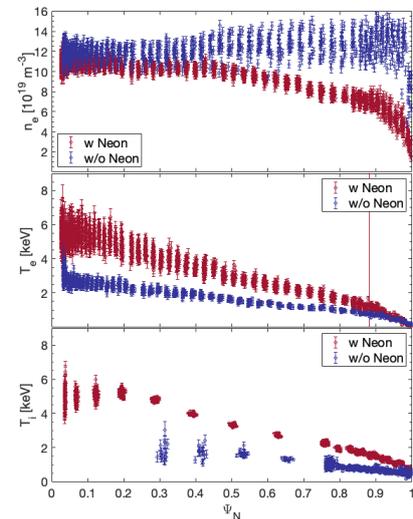


Figure 1: n_e and T_e profiles measured by HRTS, T_i measured by CXRS. The profiles have been mapped on the best available equilibrium from EFIT++ (determined with the full set of available magnetic measurements and pressure constrained). For edge CXRS diagnostics, only the periscope with the highest resolution at the edge has been selected and only points with relative errors $DT_i/T_i < 50\%$ CXRS and HRTS measurements have been shifted to achieve $T_e = 100$ eV at the separatrix.

MODELLING THE ITER BASELINE SCENARIO WITH AND WITHOUT NEON

In the framework of the multi-year activity of predictive modelling and of intense validation on multiple transport codes and reduced first-principle transport models [11, 12], we are now presenting the results on the ITER baseline plasmas produced in DTE3 at 3.0 MA.

We started modelling the unseeded pulse, and we modelled the Ne seeded pulses starting from the preliminary results obtained without Ne seeding. The three pulses share similar experimental setup, being Ne seeding the main difference, as it is shown in Table 1.

In JINTRAC [13], equipped with the QuaLiKiz transport model [14], we are predicting the D and T densities, the electron and ion temperatures and the plasma current density profiles. ESCO is evolving the equilibrium consistently with the evolution of the plasma kinetic profiles, while the impurity density profiles (i.e. n_{Be} , n_{Ni} , n_W and n_{Ne}) are evolved with SANCO. In the impurity mix composition we imposed the Nickel content estimated from spectroscopy, Be and Ne content measured by CX spectroscopy, and W content to match the bulk radiative power. PENCIL and PION are used for the determination of the heating deposition profiles, FRANTIC for the computation of the ionization sources. The boundary conditions are imposed at the separatrix, where we assumed $T_e = T_i = 100$ eV and $n_{e,sep}$ according to [15]. The pedestal is modelled with ELM average transport coefficients obtained scanning the thermal diffusivity χ and the particle diffusivity D to reproduce the experimental pedestal top and tuning the ionization sources.

As first step in this analysis we modelled the unseeded pulse JPN 104623 achieving a good agreement between the predicted and the experimental plasma kinetic profiles [Fig. 2]. Through the modelling performed we also determined the ELM average transport coefficients and the ionization sources found reproducing the pedestal height both in temperature and density.

Using the ELM average transport coefficients and the ionization sources from the unseeded case, we tried modelling the Ne seeded JPN 104594, which shares the same nominal gas puffing level with JPN 104623, including the Neon in the impurity mixture and imposing as initial conditions the experimental conditions. Without reducing the ionization sources or increasing the pedestal transport we cannot reproduce the plasma kinetic profiles. To achieve a good agreement with the plasma kinetic profiles [Fig. 2] we need a reduction of the ionization sources of around the 70% with respect to the unseeded pulse, or an increase of the pedestal particle diffusivity around a factor of 2.5. It's worth mentioning that even keeping the turbulent transport constant in the pedestal and reducing the ionization sources, we observe an increase

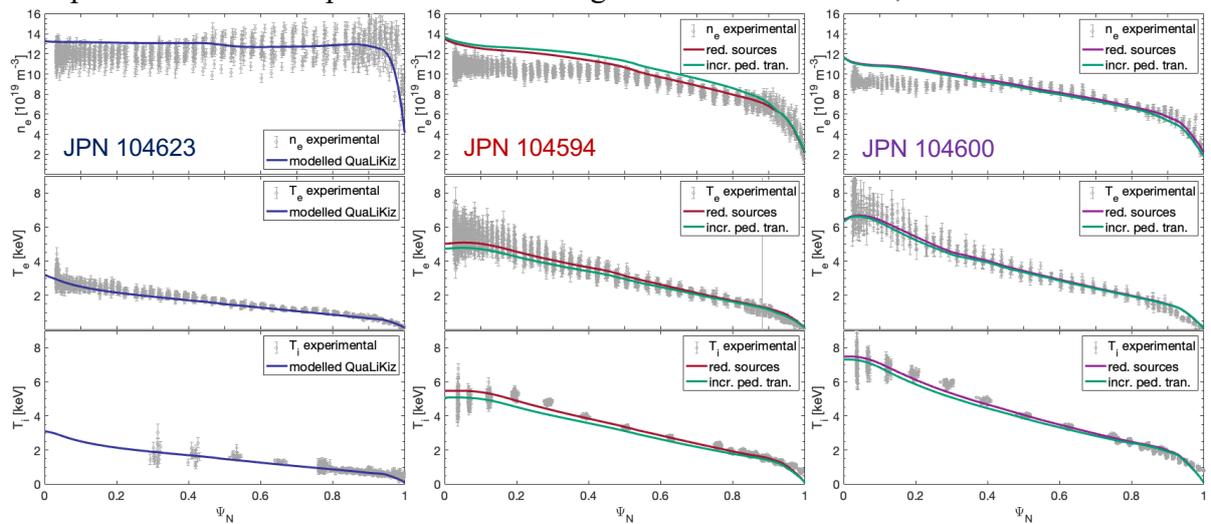


Figure 2: ITER baseline scenario on JET in DTE3 (3.0 MA / 2.9 T) [from left to right] **unseeded** (JPN 104623), **with Neon seeding [Ne]=1.35%** (JPN 104594), **with Neon seeding [Ne]=1.75%** (JPN 104600). Predicted plasma kinetic profiles compared to HRTS measurements for electron density and temperature, and to charge exchange spectroscopy for ion temperature.

of the overall pedestal transport related to the increase of the neoclassical transport induced by higher Z_{eff} .

To model the second Ne seeded pulse, JPN 104600, with a lower nominal gas puffing and a higher Ne seeding rate, we further modified the predictive simulations of the previous Ne seeded pulse increasing the Ne concentration, but we haven't been able to match with the predictions the experimental plasma profiles. To be in agreement with the experiment, a further reduction of the ionization sources (or a further increase in the pedestal transport) is needed. With respect to the unseeded pulse. In JPN 104600 the ionization sources need to be reduced more than 80% or the pedestal particle transport has to be increased above a factor of 2.5. Therefore, we observe a higher effect of Ne seeding on particle sources or pedestal transport in the pulse where the Ne concentration is higher.

Notably, light impurity density profiles (Be and/or Ne), predicted by QuaLiKiz – SANCO are in good agreement with

Table 1 Main plasma parameters of the modelled pulses.

JET pulse number	104623	104594	104600
Simulated time window [s]	12.5 – 13.6	13.0 – 14.5	14.5 – 16.3
T concentration [%]	52	54	54
B_t [T]	2.7	2.9	2.9
I_p [MA]	3.0	3.0	3.0
q_{95}	2.6	2.8	2.6
D gas [10^{22} s^{-1}]	2.8	2.8	2.1
T gas [10^{22} s^{-1}]	2.2	2.2	1.7
Neon gas [10^{22} s^{-1}]	0	1.5	1.6
Neon concentration [%]	0.04	1.35	1.75
β_N	1.5	2.0	2.1
P_{NBI} [MW]	24.8	27.7	29.3
P_{ICRH} [MW]	2.9	3.9	5.0
P_{rad} [MW]	6.6	10.2	10.5
$n_{e,0}$ [10^{19} m^{-3}]	12.3	11.5	9.7
$\langle n_e \rangle$ [10^{19} m^{-3}]	10.8	7.6	6.6
$T_{e,0}$ [keV]	3.1	5.5	6.7
$\langle T_e \rangle$ [keV]	1.2	2.3	2.6
$T_{i,0}$ [keV]	2.8	6.3	7.4
W_{th} [MJ]	5.5	8.0	8.3
neutron rate [10^{16} s^{-1}]	36.9	105.9	125.3
Z_{eff}	1.4	2.7	3.3

the charge exchange spectroscopy measurements both in unseeded and seeded pulses. In the unseeded pulse the predicted radiation profile follows the experimental reconstruction within the error bars. In the Ne seeded pulses we found the W to be still the main radiator, with the contribution of Ne to the total core radiation around the 30%. Even though the predicted radiation profile follows the flat shape of experimental reconstructions, the simulations do not capture the increase of radiation towards the magnetic axis neither the increase in the pedestal.

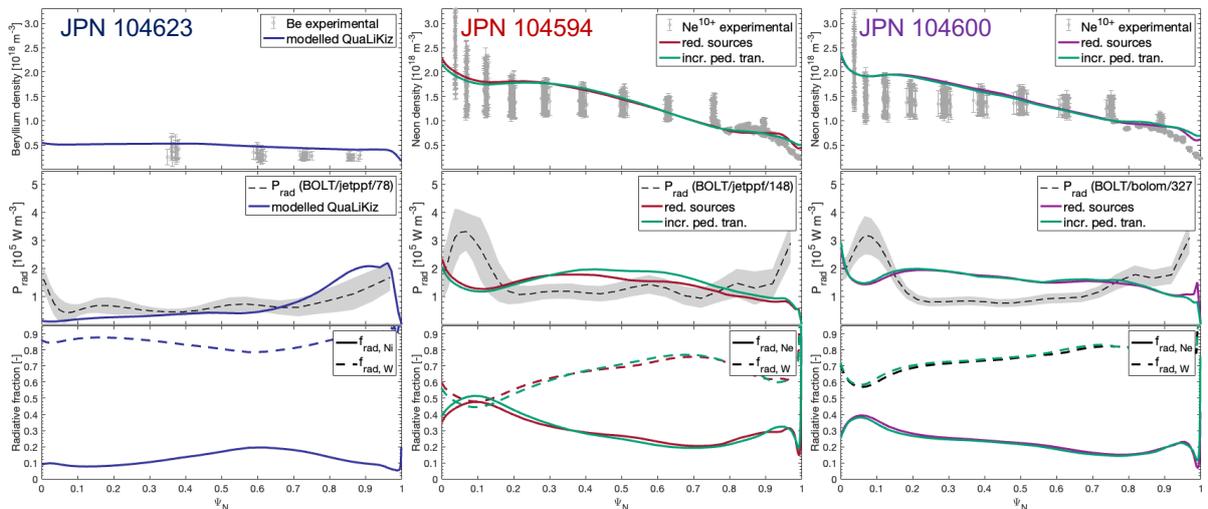


Figure 3: ITER baseline scenario on JET in DTE3 (3.0 MA / 2.9 T) [from left to right] unseeded (JPN 104623), with Neon seeding [Ne]=1.35% (JPN 104594), with Neon seeding [Ne]=1.75% (JPN 104600). Predicted light impurity density profiles compared to CX measurements, and predicted radiation profiles compared to bolometry reconstructions.

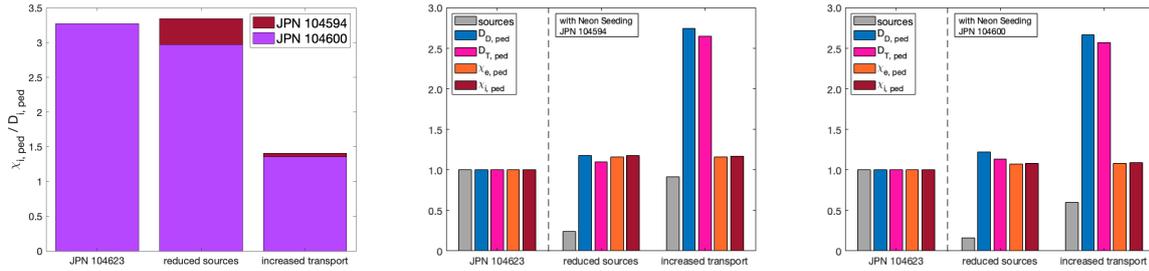


Figure 4: Comparison of ionization sources and pedestal transport coefficients normalized to the unseeded pulse (JPN 104623) [from left to right]: χ/D ratio in the pedestal, sources and pedestal transport in JPN 104594, sources and pedestal transport in JPN 104600.

CONCLUSIONS

The ITER baseline scenario with Neon seeding has achieved in DTE3 low divertor target temperatures with partial divertor detachment [5]. The Neon seeding allows the access to a regime characterized by lower densities at the edge [3, 4] with respect to the unseeded pulse. Predictive modelling performed with JINTRAC – QuaLiKiz at 3.0 MA with Neon seeding shows a good agreement between predicted and measured plasma kinetic profiles. Modelling results are demonstrating that the decrease of electron density, induced by Neon injection, can be explained both with a reduction of the ionization sources and with an increase of the pedestal particle diffusivity or, probably, with a combination of these two effects.

In the analysis performed, we find that the ionization sources from gas puffing are the dominant fuelling channel in the region $\psi_N \in [0.85, 1]$ in the unseeded pulse, while in Ne seeded pulses in the region $\psi_N \in [0.7, 1]$ due to the decreased pedestal density. These findings are highlighting the importance of modelling the pedestal region and the ionization sources, often neglected in transport studies where internal boundary conditions are imposed inside the plasma core.

The results obtained are in qualitative agreement with the analysis done on ITER baseline plasmas in D at 2.5 MA [16]. However, the reduction of the sources (or the increase in particle pedestal transport) seems to be higher in 3.0 MA D-T plasmas. Further analysis of 2.5 MA plasmas in D-T will help clarifying whether this could be related to the operations at higher plasma current or to the differences in the fuelling channels when producing the D-T mixture.

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