Interpretative TRANSP analysis of JET baseline scenario: performance dependence on kinetic plasma parameters

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Introduction

The baseline scenario represents one of the most promising plasma states suitable for high-performance DT operation. This study focuses on the JET D-T baseline scenario ($Ip = 3.0\ MA$, $q95 = 3$, $\beta_N < 2$) from the DTE2 campaign, conducted in 2021, and the more recent 2023 DTE3 campaign. Specifically, we will analyze shot 99512 for DTE2 and shot 104461 for DTE3. The scenario is characterized by regular sawteeth core activity and pellet paced ELMs frequency in the 40Hz range. Both pulses have the same I_p and B_{tor}, but exhibit different beam fuels and net power: the DTE3 campaign utilizes pure Deuterium (D) beams with ~29 MW, whereas DTE2 employs a 50-50 DT beam mix with maximum ~24 MW. Additionally, in DTE3 the ICRH power also increases from ~2 MW to ~4 MW. Pulse 104461 features larger T_e and T_i (measured by ECE+HRTS and active CX spectroscopy, respectively) compared to 99512, in agreement with the increased input power. Also, the interferometric line integrated electron density results slightly higher. The 2 pulses have a comparable isotope mix (in the range of 50D:50T), based on the residual gas analysis diagnostics, and effective charge values (ZEFF) from visible spectroscopy are within 20% (1.5-1.8). Despite the increased temperature and density, the higher input power, and the pure D beams, the fusion performance obtained in the DTE3 pulse, measured by the neutron yield, is close to the 99512. In this work we analyze the possible cause of such differences, quantifying their relative contribution to the final result.

Interpretive TRANSP simulation of DTE2 pulse 99512

The TRANSP [1] simulation for 99512 exploits the optimized EFIT equilibrium, considering the total plasma pressure computed by a preliminary TRANSP run [2]. Beryllium (Be) concentration is set to 1% (minimum value according to ZEFF), and the Nickel (Ni) concentration is used as a free parameter to match the ZEFF. The calculated neutron rate shows an overestimation of about 20%, while the plasma energy is in good agreement with the experimental data. The neutron rate trend aligns with the experimental measurements until the first sawtooth at 9.26 seconds. After this point, the simulation deviates from the experimental measurements by about 13%. This discrepancy increases to 25% after the second sawtooth. As

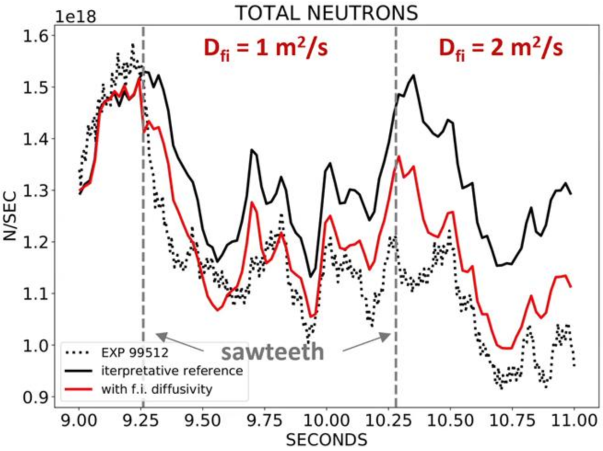

***Figure 1**: Comparison of neutron rates: experimental measurement (dotted line), TRANSP run reference (black line), and TRANSP run with Dfi (red line).*

highlighted in [3], there is a significant loss of beam fast ions in correspondence of the sawteeth. A proper modeling of the fast ion dynamics is beyond the scope of this work, but still, to address this effect, various levels of anomalous diffusivity for fast ions (D_{fi}) are tested. The results, shown in Figure 1, indicate that $D_{fi} = 1\ m^2/s$ between the first and second sawtooth reduces the discrepancy below 5%. However, to maintain a discrepancy below 10% after the second sawtooth, increasing Dfi $= 2\ m^2/s$ is necessary. It is important to note that an increase in the concentration of Be will reduce the required D_{fi} value.

Fusion performance from DTE2 to DTE3: extrapolation and experimental result

In preparation for the DTE3 campaign, the neutron rate is calculated starting from 99512 and modifying the beam fuel and power. The ICRH power is not modified. By changing the beam fuel from DT to D only, an increase in the neutron ratio of about 25% is obtained. Furthermore, by increasing the power from 23.5 to 28.5 MW, the increase reaches 40%. Despite this encouraging projection, the actual DTE3 pulse 104461 shows neutron rate values similar to those measured in 99512, yielding performance much lower than expected. To understand the reasons behind this performance, the TRANSP simulation of shot 104461 is performed, with similar settings used in the 99512 simulation. In this case (104461Q06), the neutron rate profile over time shows an overestimation of about 70% compared to the measurements, which is significantly higher than what is computed starting from DTE2 data, shown in Figure 2. This is because we are now using the actual kinetic profiles of 104461, along with the experimental NBI and ICRH power. This result prompts us to begin an analysis to understand why the experimental performance is so much lower than what is forecast by the TRANSP runs.

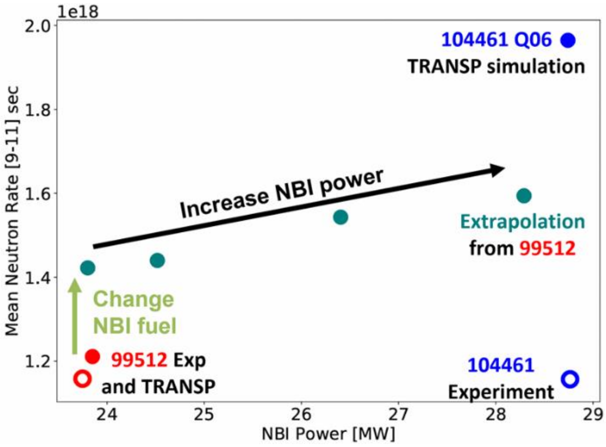

***Figure 2**: Mean neutron rate over the NBI power. The full dots represent the TRANSP simulation and the rings represent the experimental values.*

Analyses of the parameters that influence fusion performance

Starting from the reference TRANSP run 104461Q06, we aim to quantify the influence of three different effects on neutron yield: the dilution caused by impurities; the effect of the D beams