HEATING D IONS TO OPTIMAL D-T FUSION ENERGIES WITH ICRF WAVES

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Thermonuclear reactors rely on the bulk Deuterium and Tritium fuel ions to reach sufficiently high temperatures for efficient fusion energy production. In such conditions the fusion-born alpha particles are expected to produce sufficient heating to sustain the 'burning' plasma without the need of excessive auxiliary plasma heating, except for MHD, impurity transport and current-drive control. Another approach is to heat one of the fuel ions to supra-thermal energies using neutral beam injection (NBI) or with ion cyclotron resonance frequency (ICRF) waves while keeping the other ion species at lower temperatures than the ones required for efficient thermonuclear fusion. This is commonly referred to in the literature as beam-target fusion, where the 'beam' particles are either the neutral beam injected ions or the fraction of the bulk fuel ions that are accelerated to high energies by ICRF heating, or both. This regime is not efficient for a steady state thermonuclear reactor, since the auxiliary power P_{aux} has to be applied continuously thus limiting the fusion gain $Q_{fus}=P_{fus}/P_{aux}$, but it can be interesting for achieving the burn-through conditions faster reactor test facilities such as ITER [1] and BEST [2] and is particularly attractive for neutron source devices designed for plasma material research, such as the Volumetric Neutral Source (VNS) [3].

The second approach was explored in the JET-ILW tokamak during the final DTE3 campaign. Tritium-rich hybrid-like plasmas with low core collisionality were heated with D-NBI an ICRH resonating with the D ions in the plasma core [4]. These experiments led to the world-record fusion energy ever produced in a tokamak (E_{fus}=69MJ), with approximately 12.5MW of fusion power produced for 5s with P_{NBI}=30MW and P_{ICRH}=5.5MW (#104522, Fig.1). This scenario was chosen after prior numerical simulations had shown that this regime was the most promising for

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enhancing the D-T fusion reactions in JET, since the injected D-NBI ions as well as the acceleration of the D-bulk and D-NBI ions by ICRF brought a substantial amount of the D population to energies close to the maximum cross-section for D-T reactions [5]. Neutron spectroscopy measurements as well as numerical simulations show that ~80% of the D-T power comes from NBI+ICRF driven 'beam'-target reactions in this case. Heating Tritium ions instead would require a higher T-NBI injection energy and stronger T-bulk ICRF acceleration to reach similar fusion yield, because of the mass effect. Going from a 20:80 D:T plasma composition to 50:50 D:T showed a clear decrease in the beam-target fusion yield, not because of the lower ICRF heating efficiency with large D ion fractions but due to a combination of weaker D acceleration and less T target ions for the fast D ions to collide with. This was the first time that fundamental D heating was applied to a 50:50 D:T plasma, which is relevant for its potential application in ITER [6].

The physics governing the generation of the fast D ion tails generated by NBI+ICRF heating in these experiments and their impact on the total D-T fusion yield in JET-ILW will be discussed based on state-of-the-art numerical simulations using the Heating & Current Drive (H&CD) modules of the European Transport Solver (ETS) [7]. The results will be benchmarked against the experimental findings for the T-rich and for the 50:50 D:T plasmas investigated, highlighting the optimal conditions for beam-target neutron generation. Preliminary simulations of ICRF heating of Deuterium ions for ITER and VNS will also be shown, with particular attention on the fusion enhancement produced when applying fundamental D ICRF heating to these plasmas with different isotope compositions.

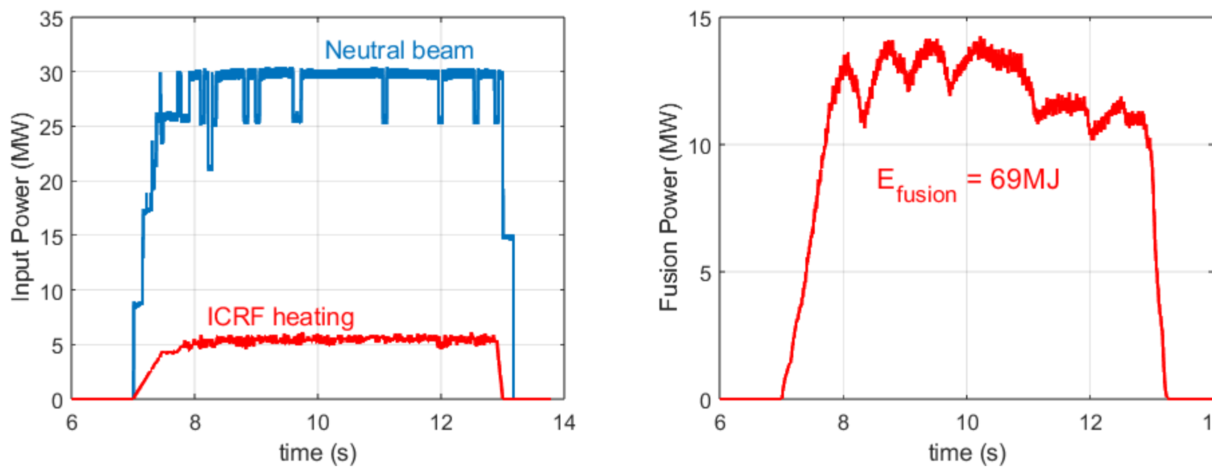

Figure 1: D-T fusion energy record pulse in JET-ILW (#104522): T-rich hybrid-like plasma with 30MW D-NBI and 5.5MW ICRH with fundamental D resonance heating. B_0=3.86T, I_P=2.5MA, n_{e0}=8x10^{19}/m^3, T_{e0}=10keV, T_{i0}=12keV.

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