Optimizing ion heating in D-T plasmas with three-ion ICRF scenarios: insights from JET and strategies for future tokamaks

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Achieving fusion-grade ion temperatures ($T_i \approx 15$ keV) is crucial for the performance of future fusion reactors. In ITER, radiofrequency heating of a few percent of ^{3}He ions is currently considered as the main option for increasing T_i with ICRF during the ramp-up [1-3]. However, due to the scarcity of ^{3}He alternative methods are under exploration. The three-ion T-(IMP)-D ICRF scenario suggests employing a small quantity of selected impurities (IMP) with $1/3 < (Z/A)_{imp} < 1/2$ as resonant absorbers [4]. Various low-*Z* and mid-*Z* impurities and their isotopes, including ^{7}Li, ^{9}Be, ^{11}B, ^{22}Ne, and Ar, meet this criterion with $(Z/A)_{imp} \approx 0.44$-0.46. Importantly, these impurities, with their higher atomic mass compared to ^{3}He ions, enhance the transfer of the absorbed RF power to bulk D and T ions through Coulomb collisions.

The efficiency of the three-ion T-(^{9}Be)-D ICRF scenario for heating D-T plasmas was demonstrated during the deuterium-tritium campaign DTE2 at JET in 2021 [5]. A substantial increase of ion temperature, from $T_i \approx 3$ keV to ~6 keV, was observed with the application of 2 MW ICRF, specifically when experimental conditions were chosen to locate the cyclotron resonance of intrinsic ^{9}Be impurities ($n_{Be}/n_e \approx 0.5$-1%) in the plasma core. The effectiveness of this novel ICRF scenario for core plasma heating and alpha-particle generation was independently confirmed by neutron and gamma-ray diagnostics [6].

However, a direct comparison of the performance of this ICRF scenario with other heating schemes was lacking after DTE2. This gap was addressed in dedicated heating experiments during the recent DTE3 campaign at JET, conducted at $B_t = 3.7$ T with a D-T mixture of approximately 50%-50%. These experiments combined 7.5 MW of NBI (deuterium) and 2.5 MW ICRF heating. At JET, only at this magnetic field the core ICRF resonance can be changed from ^{9}Be impurities to H minority ions by simply adjusting the ICRF frequency from 25 MHz to 55 MHz. The discussed set of comparison pulses was complemented with a 10 MW NBI-only plasma, characterized by dominant ion heating. Consistent with theoretical predictions, plasmas heated with the H minority scheme exhibited the highest electron temperature, while the pulse employing the three-ion ICRF scheme with core ^{9}Be resonance achieved the highest ion temperature. In this talk, we present the comparison of these DTE3 identity pulses, exploring various ion/electron heating sources, and supplement it with modeling results for heating deposition.

Currently, ITER is considering to switch from the Be/W to the full-W first wall [7], thus motivating the need to re-assess the potential of three-ion T-(IMP)-D ICRF scenarios in the absence of ^{9}Be. In this talk, we also evaluate promising impurities and the range of their concentrations for efficient bulk ion heating with ICRF in D-T plasmas at ITER.

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** See the author list of "Overview of T and D-T results in JET with ITER-like wall" by C.F. Maggi et al., to be published in Nuclear Fusion Special Issue from the 29th Fusion Energy Conference (London, UK, 2023)*
*** See the author list of "Progress on an exhaust solution for a reactor using EUROfusion multi-machine capabilities" by E. Joffrin et al., to be published in Nuclear Fusion Special Issue from the 29th Fusion Energy Conference (London, UK, 2023)*