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Application of three-ion ICRF scenarios for optimizing ion heating in the ramp-up phase in future tokamaks

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The success of magnetic confinement fusion as energy source relies crucially on reaching high temperatures for the fuel D and T ions. In a fusion reactor, plasma heating with waves in the ion cyclotron range of frequencies (ICRF) is the only system capable to provide a large fraction of bulk ion heating. Furthermore, in view of better understanding non-linear physics of alpha heating in ITER and future reactors, generation of MeV-range ions with ICRF and studying different mechanisms on how fast ions impact the plasma dynamics becomes progressively more important. Recent progress with the development of three-ion ICRF scenarios have expanded the use of these scenarios from dedicated ICRF studies [1] to a flexible tool with a broad range of applications [2].

In order to maximize bulk ion heating of D-T ≈ 50%-50% plasmas and increase Ti in the ramp-up phase with ICRF, ITER foresees the injection of a few percent of 3He ions [3]. Because 3He is a scarce gas, using the three-ion T-(IMP)-D ICRF scenario with a small amount of selected impurities (IMP) with $1/3 < (Z/A)_{imp} < 1/2$ as resonant absorbers was proposed in [4]. A fairly large number of low-Z and mid-Z impurities and their isotopes with $(Z/A)_{imp} \approx 0.44$-0.46 satisfy this criterion, including 7Li, 9Be, 11B, 22Ne, and Ar. Since these impurities have a higher atomic mass than 3He ions, they transfer an even larger fraction of the absorbed RF power to bulk D and T ions via Coulomb collisions.
The potential of 7Li and 9Be impurities ($n_{imp}/n_e \approx 1\%$) to absorb RF power efficiently in D-T plasmas was demonstrated at TFTR and recently at JET-ILW [5]. In particular, in recent JET-ILW experiments with the three-ion T-(9Be)-D ICRF scheme, a strong increase of Ti with ICRF was observed, in line with theoretical predictions. The experimental demonstration of this scenario at JET-ILW thus allows to extend the list of potential applications of three-ion ICRF scenarios in ITER and future fusion reactors.

At the moment, ITER is considering to switch from the Be/W to the full-W first wall, thus motivating the need to re-assess the potential of three-ion T-(IMP)-D ICRF scenarios in the absence of 9Be. In this contribution, we evaluate promising extrinsic impurities and the range of their concentrations for efficient bulk ion heating in D-T plasmas, with a focus on the plasma parameters in the ramp-up phase. We also discuss the potential of these novel ICRF scenarios for their applications in future high-magnetic field and high-beta spherical tokamaks [6, 7].

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