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Recent advances in ICRF heating of mixture plasmas: survey of JET and AUG experiments and extrapolation to JET-DT and ITER

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This contribution summarizes recent theoretical and experimental developments of a novel 'three-ion species' heating scheme that have opened new promising avenues for the application of ICRF in fusion plasmas. Following successful proof-of-principle demonstration on the Alcator C-Mod and JET tokamaks [1], this scenario has also been recently established on AUG. A small amount of 3He ions (~1% and below) was injected into H-D plasmas to absorb RF power and heat the plasma. In JET experiments, effective plasma heating was observed both at extremely low 3He concentrations of ~0.1-0.2% (maximized fast-ion content) and at moderate concentrations of ~1-1.5%. We further enhanced the efficiency for fast-ion generation and plasma heating by changing the configuration of ICRH antennas from dipole to +pi/2 phasing. Heating AUG plasmas with this ICRF scenario requires 3He ions to be less energetic than in JET. The combination of moderate 3He concentrations of ~1% and off-axis 3He resonance was successfully applied to reduce fast-ion energies and thus improve confinement of RF-heated ions in AUG. ICRH modeling with the state-of-the-art codes SCENIC [2] and TORIC-SSFPQL has been used extensively to validate JET and AUG experimental observations.

In a next-step, we also successfully demonstrated effective heating of JET H-D mixtures using the fast injected D-NBI ions as resonant 'third' species [3]. The scenario was tuned such that D-NBI ions with injection energy of 100keV absorbed most of launched RF power and were accelerated with ICRF up to ~2MeV. The observed ten-fold increase in the neutron rate and its temporal evolution were successfully reproduced with the time-dependent TRANSP modeling. The established technique of accelerating NBI ions in mixture plasmas to higher energies can be applied to generate alpha particles in D-3He plasmas and to maximize D-T fusion reactivity.

Finally, we conclude with a discussion of the application of these novel ICRF scenarios for future JET-DT and ITER operations [4].

[1] Ye.O. Kazakov, J. Ongena, J.C. Wright, S.J. Wukitch et al, *Nature Physics* **13**, 973-978 (2017)

[2] J.M. Faustin et al, *Plasma Phys. Control. Fusion* **59**, 084001 (2017)

[3] J. Ongena, Ye.O. Kazakov et al, *EPJ Web Conf.* **157**, 02006 (2017)

[4] M. Schneider, J.-F. Artaud, P. Bonoli, Y. Kazakov et al, *EPJ Web Conf.* **157**, 03046 (2017)

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