INVESTIGATION OF IMPURITY BEHAVIOUR IN THREE-ION ICRF SCENARIOS IN H-D AND D-T PLASMAS AT JET

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The three-ion ICRF (Ion Cyclotron Resonance Frequency) heating scenario is a promising method for enhancing plasma heating and fast ion generation in fusion devices like ITER [1]. This approach exploits the presence of three ion species with distinct charge-to-mass ratios to create highly efficient wave absorption and localized energy deposition. By carefully tuning the wave-plasma interactions, the three-ion scenario may help mitigate impurity accumulation, a key challenge for ITER operations. Understanding how this heating method affects impurity behaviour, including impurity generation, accumulation, and redistribution, is critical for optimizing operational scenarios in ITER and essential for achieving high-performance plasmas. This study investigates impurity behaviour in three-ion ICRF scenarios in hydrogen-deuterium (H-D) and deuterium-tritium (D-T) plasmas at the JET-Be/W wall, providing valuable insights relevant to future ITER operations, particularly for its non-activated hydrogen phases as well as its D-T operational scenarios. This study specifically investigates the impact of antenna phasing on impurity behaviour in the D-(^{3}He)-H ICRF scheme, using the ICRF frequency of 33 MHz to heat ^{3}He ions as the minority species in H-D mixed plasmas. This scenario is distinguished by the efficient absorption of RF power by a small fraction of ^{3}He ions, with concentrations around n(^{3}He)/n_e ~ 0.2 % [1]. Experiments were performed in H-mode with magnetic field B_T = 3.2 T, plasma current I_p = 2 MA. The ICRF power was changed in three (1 MW, 2 MW and 4 MW) or two (4 MW, 5 MW) power steps in one discharge with a constant NBI power of 2.2 MW. By varying the relative phasing of the four straps on the JET A2 ICRF antennas, the spectrum of the parallel wave number ($k_\parallel$) is modified, resulting in a change of the way ICRF power is absorbed by the plasma. Discharges with 'dipole' (0 π 0 π); 'symmetric dipole' (0 π π 0); +90 deg., -90 deg., and 'optimized dipole' phasing were compared. Spectroscopic diagnostics, bolometry, and edge plasma measurements are employed to analyze impurities source and transport. Focus is given to the experimental observations of plasma radiation, high-Z (tungsten, W), mid-Z (nickel, Ni) and low-Z (beryllium, Be) impurities in plasmas. The obtained results showed that the Ni concentration (c_Ni) (presented in Fig.1) increased with heating power and varied with different antenna phasing. For comparison discharge with NBI power only was executed. Lower impurity content was observed for only NBI power. The effect of antenna phasing on the behaviour of Be I and c_Ni impurities exhibited distinct trends (see Fig.2) as a function of the parallel wave number $k_\parallel$. An increase in $k_\parallel$ led to a higher Be source, whereas the Ni concentration decreased. A similar behaviour of Ni was previously observed in JET plasmas with the carbon wall [3], suggesting a consistent underlying mechanism influencing Ni transport. For W and total radiated power, the influence of antenna phasing is less pronounced. Since both Be and Ni contribute to W sputtering, their opposing trends in response to antenna phasing may mitigate its overall impact on W behaviour and radiation losses. The soft X-ray (SXR) radiation measurements from channels close to the magnetic axis were an indicator of the observed sawtooth (ST) instabilities. The longest sawtooth period 850 ms was recorded for a +90° antenna phasing at an ICRF power of

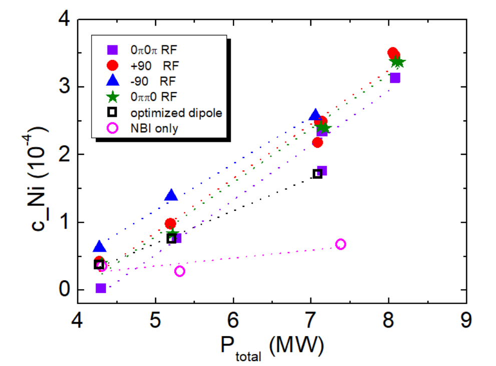

Fig.1 Ni concentration as a function of total heating power for different antenna phasing.

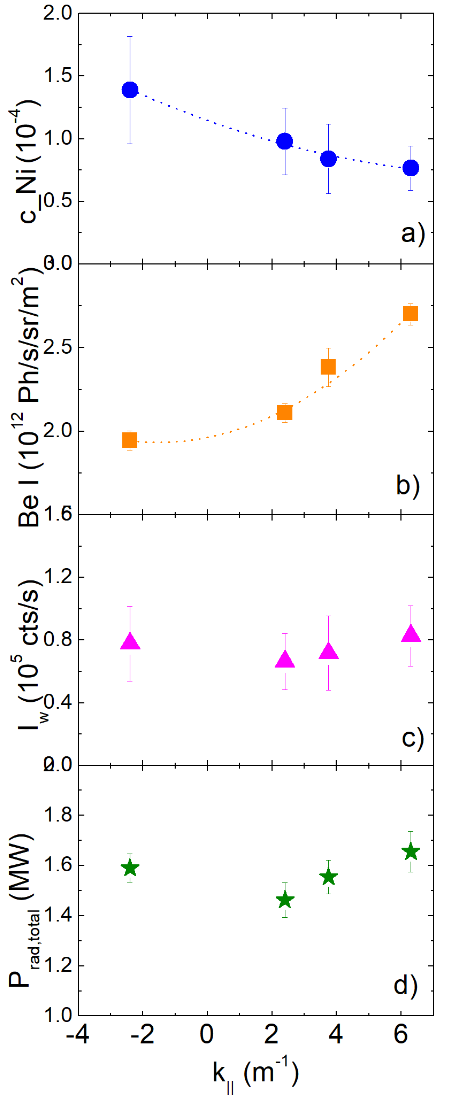

Fig.2 Ni concentration, Be I line intensity, I_W and total radiated power as a function of the parallel wave number $k_{\parallel}$.

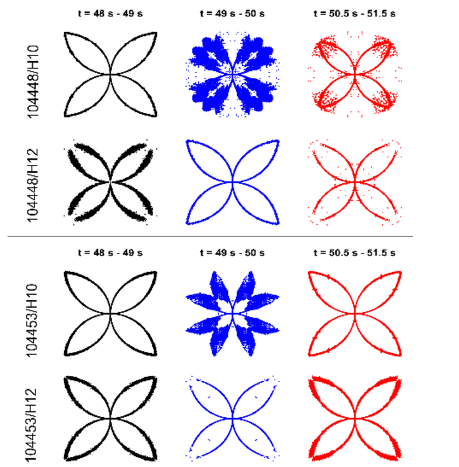

Fig. 3 The SDP plots for SXR channels H10 and H12 for the 3 selected time windows for #104448 and #104453 discharges.

4 MW. Additionally, the sawtooth period decreases up to 140 ms with a reduction in RF power at 1 MW.

The influence of two different 3-ion ICRF scenarios on impurity behavior was studied in a 50%-50% D-T plasma. The D-(H)-T scenario utilized the fundamental cyclotron resonance of minority hydrogen ions at 55 MHz, while the D-(^{9}Be)-T scenario involved the first harmonic (n=1) resonance of beryllium-9 impurity ions at 25 MHz. Identical plasma conditions were maintained with B_t = 3.7 T, I_p = 2 MA, and a constant auxiliary heating power of P_{NBI} + P_{ICRH} = 10 MW. The study employed alternating modulation of P_{ICRH} = 0 or 2.5 MW. The first scenario is characterized by dominant electron heating, leading to an increase in T_e, whereas the second scenario primarily facilitates bulk ion heating [5]. In discharge #104453 with D-(H)-T ICRF scenario, a higher Ni concentration is observed, as confirmed by data from vacuum ultraviolet VUV and SXR spectroscopy. Additionally, this scenario exhibits an increased signal from the SXR cameras. Conversely, in D-(^{9}Be)-T ICRH scenario, a higher Be influx and greater W content are detected, leading to a slightly elevated total radiated power. Overall, impurity levels are higher during ICRH compared to the NBI-only phase, highlighting the influence of radiofrequency heating on impurity transport and plasma composition. The Symmetrized Dot Pattern (SDP) analysis [4] for characteristics of the ST oscillation were performed using the SXR signals from the horizontal channels, at the magnetic axis r/a=0 (H10) and the sawtooth inversion radius r/a=0.3 (H12). The SDP approach is convenient to summarize the time dynamics into a single 2D normalized plot. During NBI+ICRF heating the main pattern of SDP for H10 is very similar to the one of a sinusoid or slowly time-evolving signal, which corresponds to the phase of plasma pressure build-up in the core after an ST crash. Besides, each individual dot represents a single ST crash. The position of the dot on the plot depends on the SXR signal intensity before and after the crash. The SDP for H12 are characterized by open legs, which are the signature of the fast blips observed after each ST crash on this channel. Different patterns are observed during NBI only. The development of high-frequency oscillations suggests an underlying plasma instability linked to the excitation of a fishbones. Results from recent experiments demonstrate that impurity release can differ significantly depending on the 3-ion ICRF scenario which must be considered in the development of heating scenarios in ITER.

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