Compatibility of high-Z impurity accumulation with high plasma performance in ECR-heated W7-X plasmas

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In the neoclassically optimized W7-X stellarator, particle and energy transport has so far been dominated by turbulent transport, especially in gas-fueled plasmas generated by ECRH, where the transport time for impurities is much shorter than predicted by neoclassical theory and the energy confinement time is somewhat below the ISS04 stellarator scaling [1-4]. During these experimental programs (usually lasting ~10 s), no evident impurity accumulation has been observed up to now.

Recently, plasma phases with prominent radiation from the inner plasma region have been revealed by bolometer tomography in two long-pulse discharges (up to ~50 s; ECRH power 1.2 MW in the initial phase and later halved), which were performed shortly after wall boronization during the first divertor operational phase. In such discharges, gas refueling is alternately turned on and off. The radiation intensities (at r/a~0.3) are comparable to that at the plasma edge (r/a≥0.8), which is usually associated with intrinsic low-Z impurities (typically carbon from the plasma facing components). Spectroscopic diagnostics show an increasing of high-Z impurity content (mainly Fe ions) and their accumulation in the plasma core. During the accumulation phases of a few seconds long, a clear increase of the effective ion charge (Z_{eff} ~1.8) has been observed. At the same time, the plasma stored energy is increasing (also the ion temperature exceeds the typical limitation of ~1.5 keV [5]) and the energy confinement time is reaching the ISS04 scaling. This scenario remains in a quasi-steady state for several tens of seconds and occurs at different power levels in the respective experimental programs. Further analyses show that 1) a common condition for the occurrence of this scenario is the peaking of the plasma density profile which has a low edge plasma density ($<1.0\times10^{19}$ m^{-3}); 2) this scenario favors a plasma phase fueled solely by recycling neutrals from the divertors, without any additional gas-fueling. The impurity accumulation observed is believed to be a neoclassical effect as a result of turbulence suppression which is driven by density gradient increments [6] (similar to pellet injection experiments at W7-X [7]). The electrostatic instabilities at ion scales are analyzed through linear gyrokinetic simulations; the transport of impurities is studied using radiation profiles measured with bolometers. Detailed results are presented and the sources of high-Z impurities are discussed.

References:

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