Local turbulent impurity transport suppression in NBI heated W7-X plasmas measured by CXRS

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Abstract

The precise monitoring of the impurity content and the understanding of the transport mechanisms is crucial for future fusion reactor operation due to the associated restrictions to the operational parameter space via dilution and increased radiative losses. While impurity transport in previous reactors of stellarator type such as LHD [1] or W7-AS [2] was dominated by unfavorable inward-directed neoclassical transport, the optimization of the W7-X magnetic field geometry [3] lead to dominant turbulent diffusive impurity transport in plasmas heated by electron cyclotron resonance heating (ECRH) [4]. Despite its optimization allowing for low levels of neoclassical impurity transport only, carbon profiles in certain operational scenarios of W7-X heated by neutral beam injection (NBI) were found to exhibit significant neoclassical transport properties inside $\rho = 0.5$ [5].

A standard approach to analyse impurity density transport in the confined plasma region is given by charge exchange recombination spectroscopy (CXRS) [6]. To allow for a holistic treatment of CXRS intensities including radiation from charge exchange reactions with halo neutrals [7], the neutral transport code pyFIDASIM [8] is applied to the W7-X NBI system.

Using a pyFIDASIM based impurity analysis scheme recently implemented at W7-X [9], impurity density profiles of individual charge states in plasmas heated by ECRH and NBI are analysed with respect to their transport properties. By comparison of experimental profiles and results from one-dimensional transport modeling, turbulent transport parameters are inferred.

Steady state plasmas of medium density heated by 4 MW of ECRH are found to exhibit flat impurity profiles dominated by turbulent transport with v/D being restricted below $0.3\,\mathrm{m}^{-1}$ within the error bars. Due to a low sensitivity of the imposed CXRS based transport analysis for steady state plasmas, the turbulent diffusion coefficient is loosely restricted to $0.1{-}5.0\,\mathrm{m}^2\,\mathrm{s}^{-1}$ based on profiles of fully ionized C, N, O, and Ne. Diffusion levels measured using LBO are well contained within this parameter range [4].

In case of plasmas with pure NBI heating, C^{6+} and Ar^{16+} profiles are observed to develop a central impurity accumulation over time. After an initial phase of flat density profiles, local gradients in the impurity density profiles appear inside $\rho = 0.45$. Comparison of experimental and simulation data indicates a suppression of the turbulent diffusion below the neoclassical diffusion level in the formed impurity density gradient region. Key characteristics in the experimental density time trends are only reproduced by the region of turbulence suppression growing in time, hinting towards a gradual spread of the suppression over the course of the discharge. The neoclassical transport of the high Z impurity argon is found to be sensitive to a change in the plasma profiles induced by a short ECRH pulse while the carbon transport is found not to be significantly altered. The disparity in impurity transport between turbulence dominated ECRH plasmas and the complete local suppression of turbulence in NBI heated discharges is subject to further investigations in the upcoming W7-X campaigns.

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