Role of the radiation opacity in divertor plasma detachment

A.A. Pshenov[1,2], A.S. Kukushkin[1,2], S.I. Krasheninnikov[3], E.D. Marenkov[2]
[1] *NRC "Kurchatov Institute", Moscow, Russian Federation*
[2] *National Research Nuclear University MEPhI, Moscow, Russian Federation*
[3] *University of California San Diego, San Diego, USA*

Transition to the detached divertor regime that allows lowering the peak heat loads to the divertor targets in an ITER size tokamak-reactor to the tolerable level of 5-10 MW/m^2 [1] is closely connected to the onset of the volumetric recombination process [2], which in turn requires low temperature $T_e \sim 1$ eV and high density $n_e \sim 10^{21}$ m^{-3}. Plasma in such conditions is opaque to the Lyman lines of the hydrogen isotopes [3] and radiation transport becomes an important part of the problem [4]. Radiation trapping results in both a reduction of the hydrogen "ionization cost" and a noticeable anisotropy of the heat fluxes associated with the photon transport inside the hydrogen recycling region [5]. Moreover, changes in the excited level populations modify the hydrogen ionization/recombination rates significantly and can even impose a stiff relation between the neutral and ion densities if the local thermal equilibrium (LTE) is reached.

Almost all studies conducted with 2D edge plasma transport codes presume that the edge plasma is fully transparent for the line radiation of both hydrogen and impurities. Self-consistent modelling of radiation trapping and its influence on the plasma parameters have been performed once in [6] for ITER divertor plasma with fixed power entering the scrape-off layer. It was shown that in spite of the significant changes in the divertor plasma profiles, the control parameters (such as the peak heat loads, the neutral pressure in the divertor, the impurity concentration at the separatrix, etc.) remain largely unaffected. (At least in the interval of the neutral pressure inside the divertor volume studied in this paper.) This, along with the extreme computational demands for such a self-consisted radiation transport treatment, served as an "excuse" to neglect radiation transport in further studies. Therefore, up to now, no in-depth study of the influence that the hydrogen line radiation opacity may have on divertor plasma detachment has been reported.

In this work we test the radiation transport block of the SOLPS code package [6] by comparing its results with the exact 1D slab solution of the Biberman-Holstein equation [7]. We study also the divertor plasma detachment process for a DIII-D-sized tokamak for two limiting cases of the plasma fully transparent and completely opaque for the Lyman lines of hydrogen by self-consistent modeling that accounts for hydrogen line radiation transport. We analyze the impact of the opacity on the divertor plasma parameters, on the global detachment threshold (i.e. the rollover of the total plasma flux to the divertor targets) and on transition to detachment inside specific flux tubes.

References

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