§48. Density Limit Study in LHD

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So-called Sudo density limit scaling has been often used to discuss the operational density limit of helical plasmas. The Sudo scaling is defined by; n_c^{Sudo} (10^{20} m^{-3}) = 0.25 $(PB/(a^2R))^{0.5}$, where P (MW), B (T), a (m) and R (m) are the total heating power (P_{tot}), the magnetic field strength, the minor radius and the major radius, respectively [1]. It should be noted that strongly peaked density profiles are not in the scope of the Sudo scaling. This scaling is based on the power balance between the heating power and the radiation loss that is proportional to n_e^2. In LHD, radiative collapse is triggered even at a small radiation loss fraction of ~30 %. On the other hand, sustainable complete detachment, named *the Serpens mode*, has been found in LHD [2], and the radiation loss fraction ranges from 30 to 100 % at complete detachment. It is therefore difficult to determine a threshold radiation loss fraction that triggers radiative collapse.

Detachment in LHD proceeds as described below. When the density is increased by hydrogen gas puffing, the hot plasma boundary, $\rho_{100\mathrm{eV}}$, given as the normalized minor radius where T_e = 100±50 eV, gradually decreases. When $\rho_{100\mathrm{eV}}$ decreases to 1, *complete detachment* takes place and the ion saturation current begins to decrease at all the measured divertor tiles. In contrast to tokamaks, but similar to W7-AS, there are no clear indications of *high recycling* prior to detachment. As the edge T_e decreases, hydrogen volume recombination takes place and the ionization front moves from the ergodic region to the closed-flux-surface (CFS) region. The effective fueling efficiency for neutral particles is improved at complete detachment. This is due to the better particle confinement in the CFS region, where particle diffusion perpendicular to the flux surfaces is important, compared with that in the ergodic region, where parallel particle transport through the open field lines dominates. To avoid an excess of density increase that leads to radiative collapse, it is necessary to decrease the fueling rate. Therefore, the density that results in $\rho_{100\mathrm{eV}} = 1$ corresponds to the maximum density achievable under the attached condition. It is possible to increase the density further beyond this critical density, under the completely detached condition. The Serpens mode begins when $\rho_{100\mathrm{eV}}$ decreases to ~0.9.

Shaded regions in Fig. 1 denote the density regimes for complete detachment, where $<n_e>$ and the edge electron density, $n_e^{100\mathrm{eV}}$, defined by the density at $\rho_{100\mathrm{eV}}$, are plotted against P_{tot}. High-density reaching 2.2 n_c^{Sudo} is sustainable in the Serpens mode plasmas. Higher densities as high as 3.5 n_c^{Sudo} are achieved by applying pellet injection, although these are transient. Even in these pellet-fueled plasmas, $n_e^{100\mathrm{eV}}$ are similar to those obtained in the gas-fueled plasmas at the threshold for complete detachment ($\rho_{100\mathrm{eV}}$ ~ 1.0). The high $<n_e>$ achieved in pellet-fueled plasmas are resultant of the strongly peaked density profiles (see Fig. 2). The ratio of $<n_e>/n_c^{\mathrm{Sudo}}$ linearly increases with a peaking factor defined by $<n_e>/n_e^{100\mathrm{eV}}$, which reaches ~4 in pellet-fueled plasmas. In detached plasmas, $n_e^{100\mathrm{eV}}$ are larger than in the attached plasmas, although the maximum peaking factor achieved so far is less than 2.

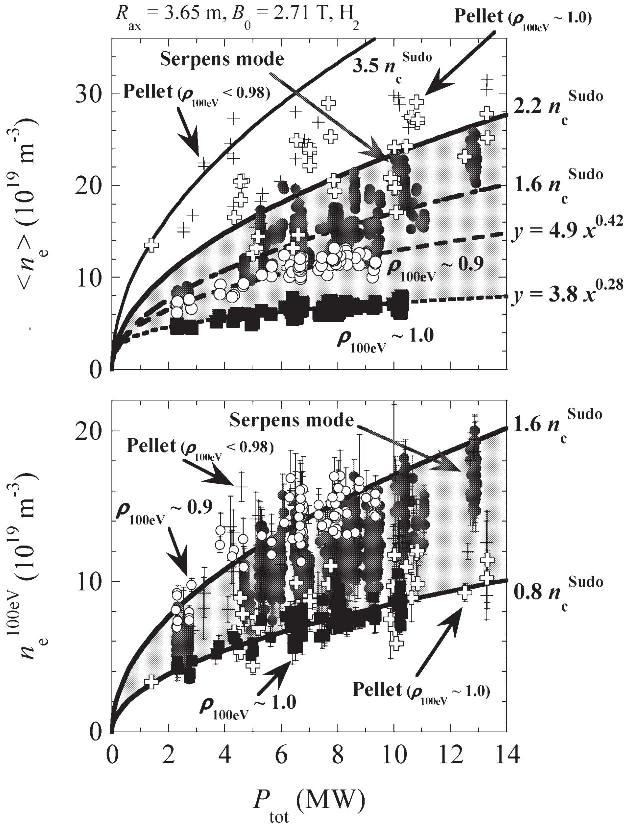

Fig. 1. P_{tot} v.s. (a) $<n_e>$ and (b) $n_e^{100\mathrm{eV}}$.

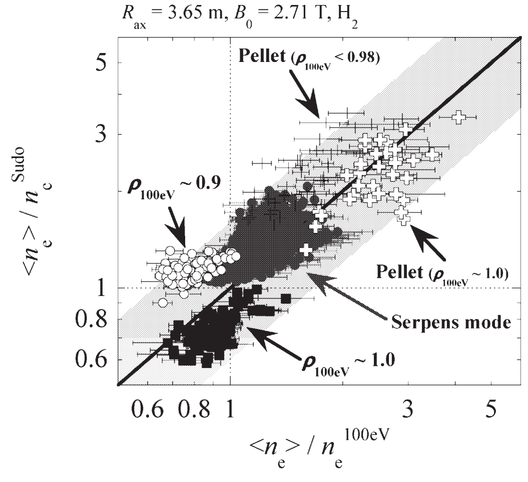

Fig. 2. $<n_e>/n_c^{\mathrm{Sudo}}$ v.s. $<n_e>/n_c^{100\mathrm{eV}}$.

References

[1] S. Sudo *et al.*, Nucl. Fusion **30**, 11 (1990).
[2] J. Miyazawa *et al.*, Nucl. Fusion **46**, 536 (2006).