Stable, small plasmas in Wendelstein 7-X

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Recent operation phases of Wendelstein 7-X have witnessed a number of discharges where the plasma shrank significantly from its original size as a result of intense edge radiation from a several cm thick, visibly radiating mantle at the edge. In such discharges, the plasma remained stable in the shrunken state, completely decoupled from the plasma facing components, for many confinement times [1]. This behavior was observed with as well as without boronized walls [1, 2] although with different edge plasma densities. An analysis of such a discharge, which exemplifies a small and stable plasma with a radiating mantle, is presented. The intense edge radiation is triggered by a strong hydrogen puff. The SOL density rises sharply after the gas injection and the electron temperature decreases below 10 eV as seen from the Langmuir probe data. The conditions in the edge become conducive to higher level of low-Z impurity radiation. This creates a strong energy loss channel and makes the plasma shrink down to 62% of its original size, which in turn reduces the confinement time of the plasma as expected from the empirical scaling [3]. The plasma stays in this state for nearly 100 confinement times until the programmed termination of the discharge. During the stable, smaller state of the plasma, the particle and heat load on the plasma facing components are extremely small while the density and temperature in the core are $n_e \sim 4\ to\ 6 \times 10^{19}\ m^{-3}\ and\ T_e \sim 2.5\ keV$ respectively. A power balance model can broadly explain the observed behavior. This suggests that the small plasmas are a consequence of pushing the plasma past its Sudo-limit [4] and that at a given heating power there should be an inverse relation between the radius of the small plasma and its density. This relationship could indeed be found and by adapting the Sudo-limit to W7-X [5] the radii of the small plasmas could even be calculated quantitatively.

References:

1. Thomas Sunn Pedersen et al, Stellarator News, Issue 175, October 2021.
2. Pedersen, T.S. et al. Small, stable plasmas, fully decoupled from the PFCs in W7-X, Proceedings of the 62nd Annual Meeting of the APS Division of Plasma Physics, Nov. 2020.
3. H. Yamada et al Nucl. Fusion **45** 1684 (2005).
4. S. Sudo. et al., Nuclear Fusion, **30**, 11, (1990).
5. G. Fuchert et al., Nucl. Fusion **60**, 036020 (2020).