Isotope mixture control in the high density regime by pellet injection at ASDEX Upgrade

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The all-metal-wall tokamak ASDEX Upgrade is equipped with a versatile pellet launching system. Offering an injection set up similar to that foreseen for EU-DEMO, one of its major tasks is to investigate reactor relevant aspects of core particle fuelling. A future fusion power plant has to operate at high core densities with a D:T isotope mixture of about 1:1 in order to harvest a maximum of fusion power. To access accordingly high densities beyond the Greenwald density n_{Gw} fuelling by pellets, mm-sized bodies of solid fuel, is required. This approach must happen in a controlled manner, raising the core density while keeping edge density sufficiently low to avoid confinement degradation. Hence, the challenge of the task is to develop both suitable plasma scenarios and effective tools capable of simultaneously controlling the density profile and the isotope fraction in the core.

ASDEX Upgrade deploys a sophisticated control system, providing full feedback control of the pellet launcher. The reactor relevant D/T scenario was mimicked by using H/D. To enable for isotope fraction control, the pellet lauching system was modified to produce H_2/D_2 pellets, delivering pellet trains with a constant H/(H+D) fraction of 0.5 ± 0.03. Pellet injection can alter the isotope mixture in plasma as requested; after equilibration a 1:1 H:D ratio was established in the plasma, as confirmed by spectroscopy and residual exhaust gas analysis. In addition, pellet actuation allows for operation at high core densities.

Hence, our experiments proved pellet actuation can yield access to the high density regime while simultaneously establishing and maintaining the requested H/D isotope ratio.

A database containing key parameters was created for the set of experiments dedicated to pellet based isotope fraction control and their pure D reference discharges. It covers plasmas with a H/(H+D) fraction in the range 0 – 0.8 and core densities up to 1.8 x n_{Gw}. For the energy confinement, degradation with increasing core density was observed. An increasing H fraction correlates with lower energy confinement. However, the latter correlation does not fit well to the smooth transition with the average ion mass M as predicted by e.g. the scaling $H98(y,2) \sim M^{0.19}$. Conversely, small fractions of H were found to cause a significant reduction. This observation demands further consideration for its potential consequences since e.g. for the engineering design of the H removal system in the EU-DEMO fuel cycle a 2 % contribution of H to the plasma particles has been mooted as acceptable. From our data, there is also strong indication of an increasing H content significantly reducing the particle confinement. The same pellet actuation shows a pronounced lower density build up in cases with a significant H fraction in comparison to their pure D counterparts. In addition, analysis of the density evolution after pellet injection shows a distinct shortening of the pellet particle sustainment time for the HD compared to the D pellets.