Contribution ID: **20** Type: **25 min Oral**

Preparation of long pulse divertor operation at Wendelstein 7-X

Wednesday, 16 November 2022 09:25 (25 minutes)

A fusion reactor based on a stellarator design has the advantage of easier access to long pulse scenarios. In fact, one of the main goals of Wendelstein 7-X (W7-X), the largest advanced stellarator in the world, is to demonstrate the steady-state capabilities of the stellarator line. Therefore, in the recent campaign, a number of experiments were performed in order to prepare long pulse operations, addressing issues like the development of stable detachment, control of the heat and particle exhaust, and the influence of leading edges on plasma performance. The heat and particle exhaust in W7-X is realized with help of an island divertor, which utilizes large magnetic islands at the plasma boundary. This concept shows very efficient heat flux spreading and favorable scaling with input power.

A highlight of the recent campaign was a robust detachment scenario through either intrinsic carbon or seeded impurities (Ne, N2). Detachment allowed removing of a large fraction of power loads due to direct contact of divertor target plates with the plasma while reaching neutral pressures at the pumping gap entrance yielded the particle removal rate close to the values required for stable density control in steady-state operation. Before the onset of detachment, the values of the downstream electron density are significantly higher ($1.2 - 1.4 \cdot 10^{20}$ m^{-3}) than electron densities near the separatrix ($n_{\mathrm{e,sep}}$ is in the range $4 - 6 \cdot 10^{19}$ m^{-3}). This difference between upstream and downstream density indicates that the divertor operates in the high recycling regime. This detachment regime is characterized by low impurity concentration ($Z_{\mathrm{eff}} = 1.5$) in the plasma and high neutral pressure (p_n 0.1 Pa) in the subdivertor volume. Estimates of total pumping rate for detached discharges at ca. $0.6 \cdot 10^{21}$ [atoms/s] show that at these neutral pressures particle exhaust is at the level required for steady-state operation. This was sufficient for stable density control in the discharges fueled either with gas injection or pellets. Both systems will be used for long pulse operation in the upcoming experimental campaigns.

A series of experiments were performed to study the behavior of intrinsic impurities as well as seeding low and highly recycling species to enhance plasma radiation. Overall W7-X shows good impurity control in low and high density discharges with Te/Ti > 1. We have found that despite high influx of carbon into the SOL during discharges with dedicated overloading of the leading edges, the plasmas remained stable. Line-of-sight averaged Zeff stayed below 1.5 throughout the discharge and radiation increased at the plasma edge only.

The results presented in this work form a promising outlook on the overall steady-state compatibility of the detached island divertor concept in future experiments and a stellarator-based reactor.

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Session Classification: PWI session

Track Classification: Plasma Wall Interactions, Exhaust and Control