Particle balance and exhaust in Wendelstein 7-X

Thierry Kremeyer[1], J. Baldzuhn[1], D. Boeyaert[2],S. Brezinsek[3], P. Drews[3], C.P. Dhard[1], E. Flom[2], Y. Gao[1], V. Haak[1], M. Krychowiak[1], R. König[1], M. Jakubowski[1], D. Naujoks[1], F. Reimold[1], G. Schlisio[1], O. Schmitz[2], S. Sereda[2], V. Winters[1], and the W7-X Team

[1]*Max Planck Inst. for Plasma Physics, 17491 Greifswald, Germany*

[2]*University of Wisconsin - Madison, Madison, WI 53706, USA*

[3]*Forschungszentrum Jülich GmbH, IEK–Plasmaphysik, 52425 Jülich, Germany*

Particle control is of significant relevance for a nuclear fusion reactor as it affects a wide range of operational and safety aspects. The hydrogen fuel cycle inside the plasma vessel affects core plasma confinement, in-vessel components lifetime, fuel and therefore also tritium retention. Fueling and exhaust provide a path to high-density regimes, which are necessary for high performance and detached plasmas. The mission of the optimized stellarator Wendelstein 7-X is to demonstrate steady state, high performance plasmas. First experiments with the island divertor, a novel concept for heat and particle exhaust deliver exhilarating results including complete, stable detachment [1,2] as well as high-performance plasmas after a series of pellets, where the global energy confinement time transiently surpasses the empirical ISS04-scaling [3].
In this contribution, a comprehensive analysis of the hydrogen fuel cycle for attached and detached plasmas will be presented. The particle confinement time is relatively short, $\tau_P =$ 0.26 s [4]. As particles leave the plasma, 99 % of the outflowing ion flux is neutralized at the divertor target plates. These neutralized particles can recycle, be retained by the plasma-facing components, or be exhausted through the pumping ports behind the 10 divertor units. In attached divertor operation only approx. 4 % of the incoming ion flux in the divertor is collected through the pump gap into the sub-divertor. When transitioning into detachment, the sub-divertor pressure doubles; lower than hoped for, but enough to allow stable density operation by a balance between particle fueling and exhaust. Our gas balance calculations allow quantification of the particle sources and sinks associated with the plasma-facing components. H_α measurements reveal that 85% of the 5.2E+22 recycling particles per second ionize in the divertor region, while 15% recycle far away from the recycling surfaces in the main chamber [4].
Active fueling was conducted with multiple systems (divertor and main chamber gas injection, pellet, and neutral beam injection) to reach high performance plasmas and detachment. The fuelling efficiency of these systems varied and with up to 90% was highest for the NBI, pellets of up to 80% and the gas injection between 12% and 44%.
The gas injection system was successfully operated in feedback density control and offered reliable access to stable detached plasma states. During detachment, heat loads drop dramatically and particle loads onto the divertor targets decrease by 65%. The installed divertor cryo-pumps will allow improved pumping in the next campaign, and it is expected to allow for density control even with the upgraded NBI and pellet injection fueling, as well as the expected wall source.

References:

[1] Jakubowski et al	2021 Nucl. Fusion	https://doi.org/10.1088/1741-4326/ac1b68
[2] Schmitz et al	2021 Nucl. Fusion	https://doi.org/10.1088/1741-4326/abb51e
[3] Bozhenkov S et al	2020 Nucl. Fusion	https://doi.org/10.1088/1741-4326/ab7867
[4] Kremeyer et al	2022 *Nucl. Fusion*	https://doi.org/10.1088/1741-4326/ac4acb