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Complete H fuel cycle with the island divertor in Wendelstein 7-X

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A comprehensive analysis of the H fuel cycle, using experimental measurements aided by input from modeling, is presented for attached and detached plasmas. This analysis focuses on the particle transport processes in the Wendelstein 7-X island divertor is presented. This analysis allows an assessment of the status-quo and will quantify the optimization potential in particle collection, removal, and plugging for a future divertor design.
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 exciting results including complete, stable detachment 1,2.
The particle confinement time is relatively short, τP = 0.26 s 3. As particles leave the plasma, 99 % of the outflowing ion flux is neutralized at the divertor target plates, according to EMC3-EIRENE modeling4. 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, neutral channels along the targets open up5, increasing the collection to 12 %, but also decreasing the particle plugging from 85 % to 50 %. Our gas balance calculations allow quantification of the particle sources and sinks associated with the plasma-facing components6. Hα 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:
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