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Spectroscopic investigations of island plasma parameters and impurity enrichment in the W7-X island divertor

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The island divertor concept implemented at W7-X is currently one of the extensively investigated concepts for the power and particle exhaust for a future quasi isodynamic stellarator power plant. In the latest experimental campaign (OP2.3), W7-X demonstrated successful feedback control of radiative detachment via impurity seeding based on real-time measurements of the total radiated power via Bolometry. This capability marks an important step toward reactor-relevant power exhaust scenarios, where strong impurity radiation in the divertor is required to protect plasma-facing components. At the same time, future fusion reactors must limit the impurity content in the core plasma to sustain the fusion reaction. Impurity enrichment ($c_{imp,SOL}/c_{imp,core}$) is the performance parameter that characterizes the divertors ability to retain impurities and allow larger divertor concentrations without hampering core performance.
This contribution presents measurements and validation thereof of local plasma parameters in the W7-X divertor plasma based on line-ratio spectroscopy for Neon and Nitrogen. Results suggest that W7-X operates at relatively low Scrape Off Layer (SOL) electron densities ($1 - 5 \times 10^{19}$ m^{-3}) compared to other devices (e.g., AUG, JET) that typically operate with electron densities $> 10^{20}$ m^{-3}.
We show that transport cannot be neglected in the ionization balance in the W7-X island. The strong deviations from local equilibrium are likely driven by the low SOL densities and the open geometry of W7-X increasing among others processes the importance of neutral transport. For concentration estimates not only the local plasma parameters, but also the ionization balance is important. The inferred impurity concentrations in the divertor plasma are cross-validated using a newly installed time-of-flight (ToF) mass spectrometer in the sub-divertor volume part of the diagnostic residual gas analyzer (DRGA). To assess the enrichment parameter, the data is compared to core concentrations obtained via Charge Exchange Recombination Spectroscopy (CXRS) during diagnostic NBI phases.
We discuss two exemplary discharges seeded with Neon in the standard magnetic configuration. No significant enrichment is observed for Neon in detached conditions
($c_{imp,SOL}/c_{imp,core} \approx 1$). Ongoing work aims to extend the analysis to additional Neon cases and other seeded impurities such as Nitrogen and Argon. Notably, elevated edge electron densities diagnosed via Stark broadening and the presence of recombination radiation are observed in discharges with high core density and heating power. Such conditions could help to retain impurities in the SOL, limiting core contamination, and will therefore be investigated further.
Future experiments and divertor design optimizations (e.g., improved baffling to enhance neutral pressure) may offer pathways to achieve better impurity enrichment in stellarator island divertors. The present contribution provides a new toolset to study and quantify these effects in present day stellarators and beyond.

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