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Global impurity migration in Wendelstein 7-X: ^{13}C Balance and footprint after the $^{13}CH_4$ injection experiment

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Material erosion, migration, and deposition are critical aspects for the design of plasma-facing components of current magnetic confinement fusion experiments and future fusion reactors. Impurities caused by eroded material decrease the performance of the device and can also cause an early termination of the discharge. Modeling tools are used to describe and predict material migration but need experimental benchmark data to validate the model. Therefore, a dedicated experiment with $^{13}CH_4$ injection was carried out in Wendelstein 7-X (W7-X) at the end of operation phase 1.2b, and the extracted divertor target elements were analyzed post-mortem [1].

About 4.1×10^{22} molecules of ^{13}C marked methane were introduced through a divertor gas puffing system during 30 consecutive and similar plasma discharges (“standard 5/5 island con-figuration”, P_{ECRH} ~5.5 MW, n_e ~5×10^{19} m^{-3}, T_e ~3 keV, total plasma duration ~330 s).

Afterward, a number of divertor target elements (TEs) from different toroidal locations were extracted for post-mortem analysis. This contribution presents, in particular, the results of the $^{13}C(d,p_0)^{14}C$ nuclear reaction analysis (NRA) on 23 of those (TEs).

Using more than 6000 individual measurements, the global ^{13}C deposition and migration footprint was reconstructed: Roughly 30% of the injected ^{13}C is deposited locally within a 5 cm radius around the injection holes. Additionally, toroidally striated ^{13}C deposition patterns, accounting for ~50% of the ^{13}C deposition, emerge on the half module where the injection took place: First, one striation along the outer strike line and, therefore, net ^{12}C erosion zone. Second, a strongly peaked striation is located at the ^{12}C net deposition zone where the magnetic island intersects the TDU. Third, a striation along the inner strike line with 100 times lower peak deposition. The remaining ~20% of ^{13}C are transported globally through the plasma across the machine and are also deposited along the strike lines’ and magnetic islands’ footprints. Extrapolating the NRA data to the whole TDU surface, a surprisingly high fraction of nearly 100% of the injected ^{13}C appears to be deposited. Furthermore, the ^{13}C distribution indicates a non-negligible amount of global transport and the strong influence of the magnetic topology on the migration. In contrast to the strike line pathway, the transport along the magnetic island’s O-point seems to employ a preferred direction.

The well-defined plasma conditions and the obtained migration footprint will provide excellent benchmark data for impurity tracing simulations such as ERO2.0 [2] or WallDYN and can be seen as a reference for impurity migration processes in a stellarator.

References

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