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Understanding tungsten divertor sourcing, transport and its impact on core impurity accumulation in DIII-D high performance discharges

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Using two toroidal rings of isotopically enriched tungsten-coated metal inserts in the predominantly carbon DIII-D divertor, detailed information on W sourcing, transport, and core contamination has been acquired over a range of high performance plasma conditions. W is the planned plasma facing material for the ITER divertor, but its contamination of the core plasma can have deleterious effects on fusion gain. To mitigate W core contamination in ITER and beyond, it is necessary to develop a comprehensive understanding of the W impurity pathway from the divertor into the core. Experiments were carried out on DIII-D featuring the first-ever use of distinct W isotope mixes in a fusion device, and were coupled to inductively coupled plasma mass spectrometry of removable midplane collector probes to determine the W leakage from localized regions in the divertor into the main chamber.

The evolution of W-C mixed-material surface layers in the divertor, formed via continual erosion and re-deposition of W and C ions, was also quantified via removable C inserts mounted on a divertor collector probe exposed during ~100 s of repeated L-mode discharges. Contrary to predictions from preliminary ERO modeling, W coverage was observed to be nearly constant with both major radius and exposure time on the inboard half of the probe near the outer strike point (OSP), while being much larger and increasing with exposure time at the outboard side in the far scrape-off-layer (SOL). Depth profiles from Rutherford backscattering spectrometry reveal thick mixed-material deposits on the outer half of the probe inserts, leading to higher than expected W retention in the redeposited C layers.

Edge-Localized-Mode (ELM)-resolved spectroscopic measurements of W sourcing conducted during H-mode discharges with high spatial resolution indicate, for the first time, that large ELMs shift the peak W erosion rate radially outwards, in additional to the broadening of the erosion profile because the ELM wetted area increases with ELM size similar to observations in the JET-C divertor [1]. Detailed analysis of intra-ELM W sourcing shows that C impurities and D fuel ions contribute equally to W divertor sourcing during ELMs, in contrast to JET-ITER-like Wall (ILW) where D ions were the main contributor [2].

High performance discharges (P_{AUX}=14 MW, H_{98}=1.6, β_N=3.7) with high ELM frequency (f_{ELM}~200 Hz) run during this campaign show roughly equal performance with similar scenarios run previously with the all-C divertor. These discharges exhibit low core W concentrations (few 10^{-5}) presumably due to flattening of the main plasma density profile via on-axis electron cyclotron heating (ECH), in line with the experience on other devices with high-Z plasma facing components [3]. In these discharges, W impurities are predominantly transported to the midplane from the OSP region rather than the far-SOL region. Conversely, in scenarios when f_{ELM} drops to 60 Hz, the W impurities are shown to transport equally from the OSP and far-SOL regions.

[1] Eich J. Nucl. Mater. 415 (2011)
[2] Guillemaut Phys. Scr. T167 (2016)
[3] Angioni Nucl. Fusion 54 (2014)

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