The DIII-D Metal Rings Campaign: Characterizing tungsten sources, SOL transport, and its impact on high-performance scenarios

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The DIII-D Metal Rings Campaign utilized a novel isotopic W tracer technique in the outer divertor to gain unique insights into W sourcing and scrape-off-layer (SOL) transport in the presence of a predominantly low-Z (i.e., C) material background. Notably, it is observed that the W atomic escape probability from the divertor region depends crucially on both the W source location and the ELM behavior. For large ELMs at low frequency, expected during any phases of poor ELM mitigation on ITER, W leakage into the main SOL is approximately equally efficient from both the strike point (SP) and far-target region (i.e., 3-5 heat flux widths from the SP). In contrast, for small ELMs, the divertor W source at the SP became the dominant driver of upstream SOL contamination. On-axis electron heating effectively suppressed the core neoclassical pinch to ion diffusivity ratio in such scenarios, nearly completely eliminating core W accumulation, as observed in other W devices. Only marginal reduction of the pinch/ diffusivity ratio occurs during off-axis electron heating, so strong W accumulation persists. In the far-SOL, asymmetries observed in the W collection pattern along two sides of a midplane collector probe are consistent with the formation of a 'potential well' driven primarily by the ion temperature gradient force along flux tubes near the separatrix. These results are supported by DIVIMP modeling, which suggests W impurities accumulate near the plasma crown in the near-SOL, then diffuse radially outward and flow back downstream towards the target.

ELM-resolved spectroscopic measurements of the divertor W source support ERO modeling predictions that inter-ELM phases are dominated by W sputtering via C impurities. ERO-OEDGE quantitatively reproduces the observed W erosion profile in L-mode discharges only when inward ExB drift effects are included because a substantial fraction of the C impurity flux to the W surface is carried by these drifts. Empirical SDTrimSP sputtering modeling predicts that both D and C contribute substantially to W sourcing during ELMs because the measured average ion impact energy increases from below to substantially above the threshold for D→W sputtering. The implications of the Fundamenski-Moulton 'free-streaming' model for parallel heat and particle flux during ELMs on W sputtering are explored. Consistency is only observed between measurements and predictions of how ELM deposited energy density scales with W source when broadening of the divertor heat flux footprint and enhanced target electron densities (e.g., via increased neutral recycling) are taken into account. Both effects are directly observed. Post-mortem analysis of the W-coated divertor tiles indicated unipolar arcing also contributed to high-Z sourcing during ELMs and arcing activity correlated with ELM size.[1]

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