Impurity Concentrations and Radiated Power in the DIII-D Divertor

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Calibrated measurements of radiated power constituents and local plasma conditions in the DIII-D divertor reveal the inter-ELM intrinsic carbon impurity fraction to be 4.5±1.0% in attached H-mode conditions, falling to 0.4±0.1% in detached conditions, a 10X drop and a significant departure from a fixed fraction assumption. Despite vastly different background plasma conditions the absolute impurity density in the divertor remains about the same in both cases, as does the fraction of total power radiated by the carbon (~40%). In contrast, the upstream impurity fraction reduces by only 2X with a ~30% drop in absolute impurity density. UEDGE modelling with a full physics drift model similarly shows a reduction in divertor impurity concentration in detachment but limited to <3X drop. Integrated emission radiance in the 45-170 nm spectral region is found to account for 95% of the total radiated power from the plasma. Cases spanned the divertor "T_e cliff"[1], attached with $T_{e,OSP,peak}$=20±4 eV, and, with only 5% higher $\langle n_e \rangle$, detached with $T_{e,OSP,peak}$=1.0±0.3 eV.

Divertor Thomson scattering (DTS) was used for a unique, direct measurement of electron temperature and density, with sweeps of the X-point and targets to build up a 2D profile, and ADAS for simulation of the emission intensities. Intensity calibrated, vertically-viewing EUV/VUV spectroscopy provides line data for dominant line emissions from the plasma. Tangential visible cameras confirm spatial details of hydrogenic and impurity emissions for higher-n transitions at visible wavelengths. Visible and EUV/VUV spectroscopy, as well as the DTS measurements are at the same major radius in the machine.

While the impurity fractions measured in DIII-D are similar to results from JT-60U[2] and JET[3] where plasma conditions are determined spectroscopically, the cases here (B_T=-2.1 T ($\mathbf{B}\times\nabla\mathbf{B}$ into the divertor), I_p=1.3 MA, P_{inj}=2.5 MW) show a reduced role of recombination of C^{3+} near the X-point in detachment. The EUV/VUV spectrum suggests that ~20% of the measured spectrum is unaccounted-for by line emissions alone, leading to a hypothesis that broadband molecular emissions of deuterium (D_2 Lyman-Werner bands) may be present but unresolved with the current instrument. Analysis presented will include state-of-art collisional radiative modelling, and will include analysis with nitrogen injection for radiative detachment control. A new high resolution VUV instrument on DIII-D, will also be applied to monitor molecular emissions. These results provide critical benchmarks for code validation and detachment scalings, insight into divertor/scrape-off-layer (SOL) impurity transport, and reveal how efficiently the intrinsic impurity can be complemented with extrinsic sources.

1. A. McLean, et al., J. Nuc. Mater. **463** (2015) 533.
2. T. Nakano, *et al.*, J. Nuc. Mater. **390-391** (2009) 255.
3. M. Bernert, *et al.*, J. Nuc. Mater. **12** (2017) 111.

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