The role of plasma-atom/molecule interactions on power, particle and momentum balance during detachment

K. Verhaegh, B. Lipschultz[a], B.P. Duval[b], B. Dudson[a], A. Fil, O. Février[b], D.S. Gahle, J.R. Harrison, D. Moulton, O. Myatra[a], A. Perek[c], C. Theiler[b], M. Wensing[b], the EUROfusion MST1 team[d] and the TCV team[e]

Culham Centre for Fusion Energy, Culham Science Centre, OX14 3DB, UK
[a] York Plasma Institute, University of York, United Kingdom
[b] Swiss Plasma Centre, EPFL, Lausanne, Switzerland
[c] DIFFER, Eindhoven, The Netherlands
[d] See the author list of S. Coda et al. 2019 Nucl. Fusion, 59 086020
[e] See the author list of B. Labit et al. 2019 Nucl. Fusion, 59 112023

kevin.verhaegh@ukaea.uk

The process of detachment development is controlled by a range of atomic and molecular processes. There is currently no consensus regarding the relative importance of momentum and power loss, the role of molecular reactions or the sequence of various processes observed during detachment. More specifically, it remains unclear whether the target ion current, I_t reduction, seen during detachment, results from reductions in ion sources; increases in ion sinks, or both. Experimental studies of these issues are limited by what can be extracted from measurements.

We have developed and applied new analysis techniques to D^0 Balmer line emission that addresses some of these limitations, generating quantitative estimates of: (a) the *atom-derived* ion source and ionisation cost [1] (ion sinks/recombination has been addressed for over 20 years [2]); (b) the contributions of *molecular processes* to ion sources/sinks and the power balance.

Applying these techniques to TCV divertor detachment [3] indicates that, in the first phases of detachment (target temperature, T_t ~ 5eV), the observed decrease in I_t results from a reduction in the ion source driven by both an increased cost of ionization and a reduction in the power available for ionization (due to increased upstream impurity radiation) [2,3]. During a density ramp to detachment, there are further reductions in the power reaching the target region reducing T_t (≤1 eV) and increasing electron-ion recombination (EIR, <15 % I_t) ion sink. This is consistent with SOLPS modeling results [3,4]. In contrast, the EIR ion sink is negligible during N_2-seeding ramps to detachment, an observation common to several existing tokamaks [2, 3, 5]. We show that the reduction in EIR is due to higher T_t / lower target densities during detachment when compared to an upstream density ramp [3].

A second mystery of detachment through upstream density ramps, common across tokamaks, is that after the detachment onset the measured D_α intensity increases while I_t drops. Our analysis technique (b) shows that the enhancement in D_α intensity is caused by *molecular contributions to the D_α emission from D_2^+ & D^-* on TCV. In addition, reactions with D_2^+, D^- result in: 1) significant ion sinks (<35 % I_t) through Molecular-Activated Recombination (MAR) which occurs after the detachment onset (T_t ~ 2-3 eV) but before the start of EIR (T_t ≤1 eV), which remains weaker; 2) excited atom radiation which can account for up to 50% of *all hydrogenic radiation;* 3) significant enhancements to n=3-6 Balmer lines. For TCV, at least, we thus conclude that the influence of plasma-molecule interactions on particle and power balance can be significant. This has important implications for interpretation of divertor Balmer line spectra as well as divertor modeling codes where the treatment of molecules is immature.

[1] K. Verhaegh, et al. PPCF (2019) 61; [2] B. Lipschultz, et al. Phys. Plasmas (1999) 6; [3] K. Verhaegh, et al. Nucl. Fusion (2019) 59; [4] A. Fil et al, submitted to PPCF; [5] B. Lomanowski, et al. Nucl. Mater. Energy (2019)