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Modeling Fuel Retention in Tungsten Plasma-Facing Materials under Realistic Tokamak Operation including Plasma Impurities

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To date, the primary method for fuel retention estimates in next step devices has been based on projection of laboratory data with input from gas balance and post-mortem analysis. The use of a large database minimizes risk, but the static nature of the retention data is not amendable to making projections under varied conditions. One recent example would be the failure of predicting how the physicochemical changes incurred at W surfaces from N2, Ne, Ar impurity seeding would affect T-inventory. We present an alternative method by parameterizing the hydrogen trapping and release processes at the near surface by the solute hydrogen concentration. This solute concentration and the effects of various impurities on it are directly measured from laboratory ion driven permeation experiments with W. It allows extraction of key hydrogen transport parameters such as diffusivity or recombination coefficients, allowing physics-based modeling of hydrogen desorption or transport behavior.

The data is summarized in the form of a solute concentration-temperature diagram. For impurity-free case, the concentration is fixed by plasma parameters and scales linearly to the incident flux (i.e. diffusion limited) up to divertor relevant fluxes (˜1e24 D/m2s). Noble gas impurities (He, Ne, Ar) result in a 20-50% reduction. With C impurities, the concentration at T < 700 K is controlled by precipitation effects effectively decoupling the concentration from changes in plasma parameters. For N impurities, co-deposition of D with N controls the solute concentration at T < 650 K while diffusion limited at T > 650 K. Extrapolating to divertor relevant fluxes predict a factor of 10 difference in inward transport at 750 K, which is supported by factor of 10 difference in retention results from D and D+N exposures at Magnum-PSI.

The introduction of solute concentration as a physical parameter allows for adopting a more physically sound model to improve our estimate and prediction of fuel retention in future burning plasma machines. The method lends itself to self-consistently model additional transport processes like recycling or steady state permeation to the coolant, which from an engineering point of view provides a necessary link for optimizing both plasma and material response in a fusion reactor.

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