Main Ion Isotope dependence of impurity transport in ion and electron-heating dominated H-mode plasmas in the DIII-D tokamak

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The global particle confinement time for medium-Z impurities is significantly shorter in hydrogen plasmas compared with dimensionally similar deuterium plasmas[1], while the isotopes also have starkly different responses to electron vs. ion heating mix. In this work, we present the first systematic comparison of impurity transport coefficients in hydrogen and deuterium plasmas for the purpose of validation of gyrokinetic and gyrofluid transport codes. The first non-active phases of ITER Pre-Fusion Power Operation (PFPO-1 and PFPO-2) will be operated with hydrogen and helium plasma to minimize neutron production. These phases will also provide a basis for predictions of transport in later deuterium and tritium plasmas. Understanding the isotope scaling of particle and validation of impurity transport codes is thus crucial for reliable predictive modeling. A recent experiment on DIII-D tokamak compared impurity transport in hydrogen ELM-y H-mode plasmas with a deuterium reference case[2] matching the kinetic profiles. ECH and NBI power scans performed during the discharge significantly reduces impurity confinement time τ_{imp} in deuterium from 300ms in the NBI heated to 120ms in the NBI+ECH heated case, while in hydrogen τ_{imp} remains at 100ms independently of the heating mix. Impurity transport coefficients, quantified by a Bayesian inference using AURORA code[3], explains the lack of τ_{imp} variation in hydrogen by a high core impurity diffusion in hydrogen plasmas, which is only slightly increased by ECH heating. In contrast, mid-radius impurity diffusion in deuterium is increased with additional electron heating by an order of magnitude (Fig. 1a, 1b). Normalized gradients of midradius impurity density are nearly identical for the H and D plasmas, and the profile shapes change from peaked in the ECH heated plasma to hollow in NBI heated plasma. Turbulent particle transport is modeled by the gyrofluid TGLF model and by the quasilinear CGYRO model. Quasilinear CGYRO properly reproduces the trend in turbulent impurity diffusion over the heating scan, but underestimates the increase of diffusion from deuterium to hydrogen plasmas (Fig. 1c). CGYRO and TGLF models indicate that the direct effect of isotope on impurity transport is negligible. The transport is mostly affected by indirect changes of plasma parameters associated with the isotope change, for instance changes in profile gradients, higher electron-ion heat exchange in hydrogen, and less effective beta stabilization of particle flux in hydrogen. In this presentation, we will discuss differences between the hydrogen and deuterium reference cases, Bayesian inference of impurity transport coefficients, TGLF+NEO modeling, and quasilinear CGYRO modeling.

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References

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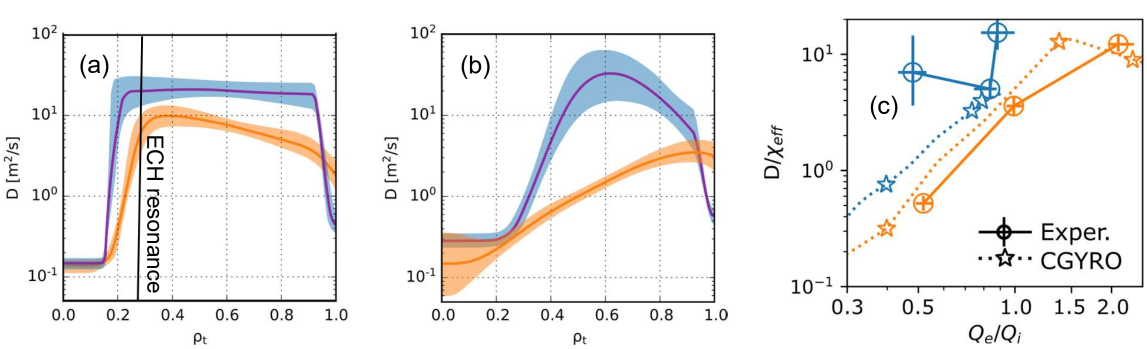

Figure 1 Inferred experimental profile of impurity diffusion coefficient D in ECH+NBI heated (a) and NBI only heated case (b), where blue line is in H and yellow in D plasma. In plot (c) are mid-radius values of D/χ_{eff} and Q_e/Q_i are compared between experiment and quasilinear CGYRO model.