Dimensional Isotope Scaling of Heat and Particle Transport between JET Deuterium and Tritium L-mode Plasmas

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The JET tokamak has the unique capability to perform experiments with tritium. The tritium confinement is 12-25% better than the deuterium confinement in JET L-mode plasmas, depending on experimental conditions. Understanding the isotope mass scaling between the JET deuterium versus tritium L-mode plasmas is the main scope of this paper. Recently, a positive mass dependence of global confinement (sum of core and pedestal) in favour of tritium is reported in the JET type I ELMy H-mode plasmas (1) and in the pedestal (2). In L-mode plasmas, a ~25% improvement in global confinement and local transport by performing a dimensionless isotope match was found (3). This paper concentrates on the isotope mass scaling of transport and confinement between deuterium and tritium L-mode plasmas, in particular on the scaling in the dimensionally matched deuterium-tritium pair. Detailed comparisons of particle transport and edge neutral fuelling between this engineering D versus T isotope match are performed with the gas puff modulation analysis. The gyro-kinetic GENE simulations are extended up to $\rho_{tor} = 0.95$ to understand better the origin of the isotope scaling.

The dimensional isotope identity experiment between deuterium $n_D/(n_H + n_D + n_T) = 0.95$ and tritium $n_T/(n_H + n_D + n_T) = 0.98$ plasma is illustrated in figure 1. All the engineering parameters (I_p, B_t, n_e, P_{nbi}) are the same between the two dimensionally matched pulses. Gas puff modulation technique, seen on the third panel from top, was exploited here as the tool to study the electron particle transport in detail and to quantify the isotope scaling in electron particle transport channel and in edge neutral fuelling. There are no neo-classical tearing modes or other MHD instabilities, except sawtooth, present in this deuterium-tritium pair with $Z_{eff} = 1.5 - 1.65$.

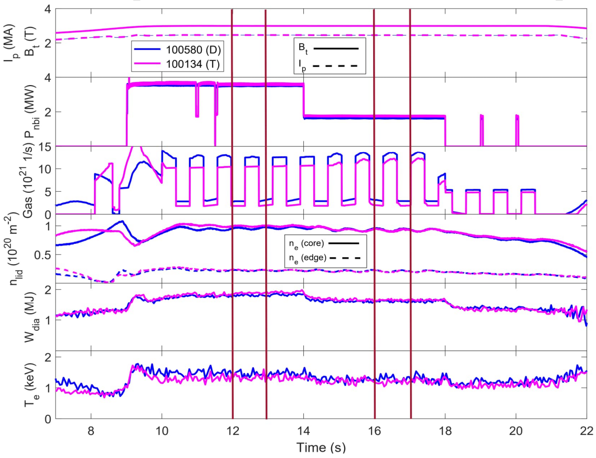

Figure 1. Key time traces of the deuterium (blue, #100580) and tritium (magenta, #100134) discharges. The vertical bars indicate the times for averaging the profiles at two different NBI power levels.

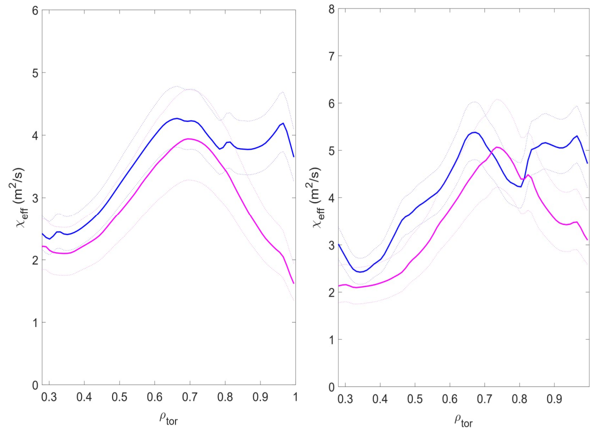

Figure 2. Effective one-fluid diffusion coefficients for the deuterium discharge (blue, #100580) and the tritium discharge (magenta, #100134) at two different NBI power levels, P_{nbi} = 1.7MW (left panel) and P_{nbi} = 3.5MW (right panel). The dotted lines show the error bars of the estimates.

The energy confinement time $\tau_{E,th}$ is 0.27s (P_{nbi}=1.7MW) and 0.22s (P_{nbi}=3.5MW) for the deuterium pulse and correspondingly 0.30s (P_{nbi}=1.7MW) and 0.26s (P_{nbi}=3.5MW) for the tritium pulse, yielding 11% and 13% improvement in confinement in favour of the tritium pulse. The local power and particle balances, heat and particle fluxes and the effective heat and particle diffusion coefficients are calculated with TRANSP and JINTRAC. The effective one-fluid diffusion coefficients ($\chi_{eff} = (q_e + q_i)/(n_e \nabla T_e + n_i \nabla T_i)$ at both the NBI power levels including the error bar estimates are shown in figure 2. Consistently with the global energy confinement, the effective one-fluid diffusion coefficients show the positive isotope scaling favouring the tritium plasma, in particular toward the edge region of the plasma is well outside the error bars. Decomposition of the effective one-fluid diffusion coefficients into the three separate transport channels reveals that the confinement improvement in tritium originates dominantly from the electron heat transport channel.

The density response, based on the JET density profile reflectometry with a sub-ms time resolution, to gas puff modulation is almost identical between the deuterium and tritium discharges as illustrated in figure 3 (4-6) This strongly suggests the same particle transport between D and T, concluding that there is no isotope scaling observed in the particle transport channel, at least $\rho_{tor} <$ 0.9, in these JET L-mode plasmas. The EDGE2D-EIRENE simulations indicate about 15% better neutral penetration across the separatrix in deuterium plasma at comparable separatrix densities resulting in the ionisation profiles that are correspondingly higher in the deuterium plasma.

In order to understand possible reasons for the large isotope scaling between deuterium and tritium, local linear and non-linear gyro-kinetic flux-tube GENE simulations have been performed in the plasma edge region at $\rho_{tor} = 0.95$. Non-linear GENE simulations of the tritium pulse (#100143) are compared in figure 4 with a "numerical D" case with all data from the tritium pulse except the isotope mass set from $A = 3$ to $A = 2$. GENE shows a strong edge isotope effect, a factor of 2 found both in the ion and electron heat fluxes, in favour of tritium at $\rho_{tor} = 0.95$, much stronger than at $\rho_{tor} = 0.6$. The linear eigenvalues at ion-scales indicate a continuous TEM/ITG branch which rotates in the electron diamagnetic direction for the relevant wave numbers contributing to the nonlinear fluxes.

To conclude, the tritium confinement is 12-25% better than the deuterium confinement in JET L-mode plasmas, originating mainly from (a) the electron heat transport channel, (b) from the L-mode edge part of the plasma and (c) a combined turbulent, neo-classical and fueling effects. GENE is qualitatively consistent with the experimental observations; it finds around 7% improvement for tritium in the core plasma and a larger one at the edge, and a larger improvement in the electron heat transport channel. However, isotope effects cannot be easily generalised as they depend on the plasma regime and plasma parameters. Even in the L-mode case, the isotope effect at the edge plasma may significantly differ from the isotope effect in the core plasma. Furthermore, the isotope scaling influences different transport channels in a different way under different plasma conditions.

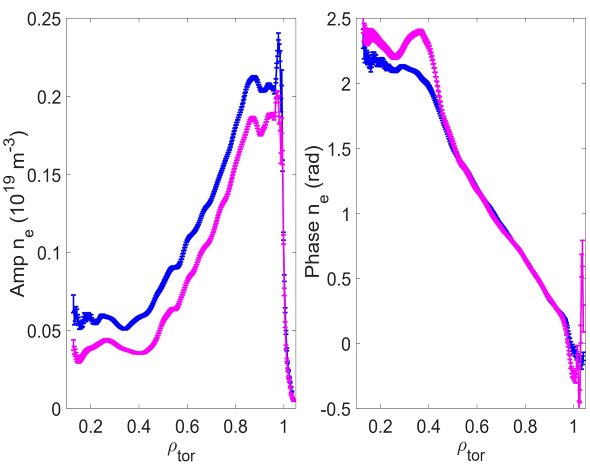

Figure 3. The amplitude (left) and phase (right) profiles for deuterium (blue, #100580) and tritium (magenta, #100134) for the dimensionally matched isotope scaling discharges.

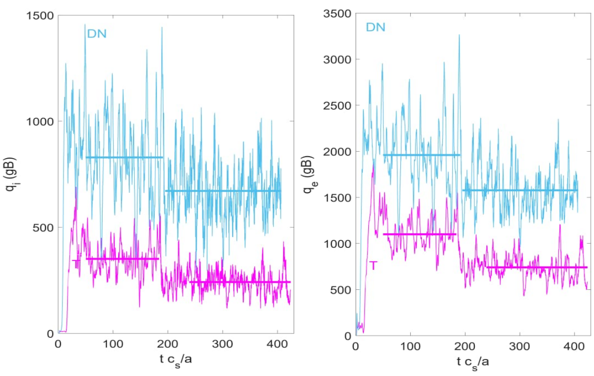

Figure 4. Non-linear ion (left) and electron (right) heat fluxes qi and qe in gyro-Bohm units as a function normalised time tc^s/a, for the tritium discharge no. 100134 (magenta) and numerical deuterium (blue), at ρtor = 0.95. The time until 200 exclude the E × B flow shear in the GENE simulations and after 200 the E × B flow shear is switched on.

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