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Extrapolating performance of negative triangularity plasmas in reactors via confinement scaling

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Plasmas with a poloidal cross-sectional shape featuring negative triangularity (NT) are emerging as a potential candidate for operation in nuclear fusion reactors thanks to an easier path towards the core-edge integration solution [1]. Although the thermal energy confinement time in NT plasmas is observed to be comparable to that in positive triangularity (PT) H-mode plasmas, first of a kind experiments on DIII-D have evidenced different confinement scaling with the normalized gyroradius ρ_* and collisionality υ_*, along with comparable scaling with plasma rotation [2]. As opposed to standard H-mode regimes follow a "core-first" approach which maximizes the core stored energy by optimizing the overall magneto-hydro-dynamic (MHD) stability of the plasma, the NT configuration adopts a "wall-first" approach which prioritizes power handling provided that the core stored energy reaches a minimum target. While power exhaust constraints are paramount for the viability of a NT reactor, the overall fusion performance and associated costs for a reactor depend on the confinement levels achieved at reactor conditions. Experiments on DIII-D used an ad-hoc reinforced outer-wall allowing operation at high auxiliary power using diverted plasmas with the largest achievable value of negative triangularity. Controlled parametric dependencies varied one given parameter of interest while maintaining constant other non-dimensional quantities such as normalized pressure, ion to electron temperature ratio, plasma effective charge or safety factor. Experiments varying ρ^* inferred a near Bohm scaling for the thermal confinement with the thermal transport for ions being closer to Bohm than that for electrons. The collisionality scan evidenced a near zero dependence on υ_*. The results from the non-dimensional scaling experiments indicate a closer resemblance of NT plasmas to L-mode scaling in PT configurations.

Varying the injection angle of neutral beams at fixed power resulted in a ~20% reduction in thermal energy confinement time when the auxiliary torque decreased from co-current to near-balanced values. Plasmas maintained excellent MHD stability and low impurity confinement also at the lowest external torque levels achieved. More specifically, the beam auxiliary power compatible with low torque injection allowed plasmas to reach β_N=2 without the appearance of confinement deteriorating NTMs, while the particle to energy confinement ratio was measured to be near unity.

Local nonlinear gyro-kinetic simulations quantitatively reproduce the experimentally inferred values of thermal and particle transport at various radii as well as the impact of rotation, thereby increasing confidence in extrapolations to future devices based on first principle modelling [3].

Similarity experiments are being conducted on the TCV tokamak to compare results to DIII-D and extend the ρ_* range accessible. Results will be reported first at this conference.

In summary, results reported herein present both challenges and attractive features to the scalability of the NT scenario to reactors.

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