Edge Transport and Quiescent H-mode Plasmas in DIII-D at Q=10 Equivalent Fusion Performance.

A.M. Garofalo[1], A. Bortolon[2], J.M. Hanson[3], J.R. King[4], N.C. Logan[2], G.R. McKee[5], C. Paz-Soldan[1], C.M. Samuell[6], W.M. Solomon[1], D. Truong[5], F. Turco[3], D.B. Weisberg[1], T.M. Wilks[7]. Email: garofalo@fusion.gat.com

[1]General Atomics, P.O. Box 85608, San Diego, California 92186-9784, USA
[2]Princeton Plasma Physics Laboratory, Princeton, NJ 08540, USA
[3]Columbia University, New York, NY 10027, USA
[4]Tech-X Corporation, Boulder, CO 80303, USA
[5]University of Wisconsin – Madison, Madison, WI 53706, USA
[6]Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[7]MIT Plasma Science and Fusion Center, Cambridge, MA 02139, USA

The "quiescent H-mode" (QH-mode) regime has been shown to operate without ELMs at ITER's values of collisionality and beta, and provides excellent energy confinement (better than standard H-mode) even at the very low plasma rotation expected in ITER, with particle and impurity transport provided by edge coherent or broadband oscillations. Non-linear MHD simulations of the pedestal reproduce many QH-mode characteristics, and suggest that a fluctuation-induced density transport larger than the thermal transport derives from a difference in the phase of the density and temperature perturbations relative to the perturbed normal flow. Such phase differences have been measured on DIII-D by a new ultra fast charge exchange recombination spectroscopy diagnostic.

Recent DIII-D experiments have achieved stationary QH-mode operation in an ITER similar shape for many energy confinement times at simultaneous ITER relevant values of beta, normalized confinement, and safety factor, that is at normalized fusion performance equivalent to Q=10 operation in ITER. While initially these results were limited to large counter-Ip torque from neutral beam injection, recently the operating space has been extended to low NBI torque < 2 Nm. Similar to previous observations at higher safety factor, the energy confinement improves at lower counter-Ip torque because of an increase in the ExB shear inside the edge pedestal. The improved confinement at lower torque/rotation is common to different types of edge conditions: ELMing, QH-mode with coherent EHO or broadband MHD, wide pedestal or not, as long as the edge rotation is in the counter-Ip direction.

At the q_{95}~3 of the ITER baseline scenario, QH-mode operation with a coherent EHO is prevented at low NBI torque by locking of the EHO. However, it was found that the coherent EHO is replaced by broadband MHD oscillations, favorable to low torque operation, when the plasma-wall outer gap is reduced. On the other hand, a small outer gap can bring back the ELMs, depending on the energy of the NBI. When low torque is achieved by using near balanced co-Ip and counter-Ip NBI, the outer gap becomes populated by trapped, confined, counter-Ip fast ions. ELMs may be triggered when this mantle of fast ions, whose thickness increases with the ion energy, starts to interact with the outer wall. An optimal outer gap width with reduced NBI energies have allowed Q=10 QH-mode at counter-Ip NBI torque as low as ~1.5 Nm. At this point, further reduction in torque is not limited by the return of ELMs, but by core MHD activity, requiring optimization of the discharge trajectory. Supported by the US DOE under DE-FC02-04ER54698[1], DE-AC02-09CH11466[2], DE-FG02-04ER54761[3], DE-FC02-06ER54875[4], DE-FG02-08ER54999[5], DE-AC52-07NA27344[6], DE-FG02-94ER54235[7].