Modification of Edge Profiles, Edge Transport, and ELM stability with Lithium in NSTX

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Rapidly growing instabilities known as Edge Localized Modes (ELMs) are commonly observed in high-confinement (H-mode) regimes in many toroidal confinement devices. The reduction or elimination of ELMs with high confinement is essential for the ITER, which has been designed for H-mode operation. Large ELMs are thought to be triggered by exceeding either edge current density limits (kink/peeling modes) and/or edge pressure gradient limits (ballooning modes)[1]. Edge stability calculations have indicated that spherical tokamaks should have access to higher pressure gradients and H-mode pedestal heights than higher aspect ratio tokamaks, owing to high magnetic shear and possible access to second stability regimes[2]. The use of lithium in NSTX has enabled access to such a high pedestal pressure regime, one in which the core stability limits with high normalized beta are observed with no sign of ELMs, as predicted by some models[3].

A regime with several of these characteristics was recently discovered in the National Spherical Torus Experiment (NSTX) following the application of Lithium onto the graphite plasma facing components between discharges[4]. ELMs were eliminated through growing periods of quiescence[5], with the resulting pressure pedestal widths increasing substantially[6]. The modification of the pressure profile originated mainly from reduced recycling and edge fueling, which relaxed the edge density profile gradients inside the separatrix, effectively shifting the profile inward by up to 2-3 cm (Figure 1a, 1b). Density profile modifications measured by two separate reflectometer systems have confirmed that the magnitude of the profile shift depends on the thickness of the lithium coating applied prior to the discharge[7]. In contrast, the edge electron temperature profile was unaffected in the H-mode pedestal steep gradient region at constant plasma stored energy; however, the region of steep gradients extended radially inward by several cm following lithium coatings. Consequently, the pressure profile width increased substantially, with the peak post-lithium ELM-free discharge gradients comparable to the pre-lithium ELMy discharge gradients (Figures 1c, 1d). The measured edge profiles in both the pre-lithium and post-lithium discharges were simulated with the SOLPS code, which indicated that both a reduction in recycling *and* a drop in the edge and SOL cross-field transport was required to match the post-lithium profiles. The latter is consistent with a clear reduction in the measured SOL turbulence, which is likely key in setting the SOL width.

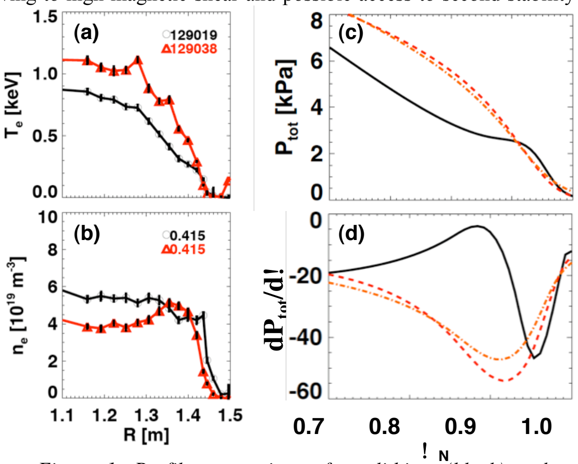

Figure 1: Profile comparison of pre-lithium (black) and post-lithium time slices (red, orange): (a) T_e, (b) n_e, (c) total plasma pressure P_{tot}, and (d) Pressure gradient. Panels (c) and (d) are from multiple time-slice profile fits. Note the inward shift in the density and pressure profiles.

Calculations with the PEST and ELITE codes have confirmed that the post-lithium discharge pressure profiles were farther from the stability boundary than the reference pre-lithium discharges, which were relatively close to the kink/peeling boundary (Figure 2). Indeed low-n (n=1-5) pre-cursors were observed prior to the ELM crashes in the reference discharges, consistent with the PEST and ELITE predictions. The resulting post-lithium discharges were ELM-free with a 50% increase in normalized energy confinement, up to the global N ~ 5.5-6 limit, where resistive wall modes were observed. While these ELM-free discharges ultimately suffer radiative collapse, pulsed 3-d magnetic fields can be used to trigger ELMs on-demand to control density and purge impurities as needed[8].

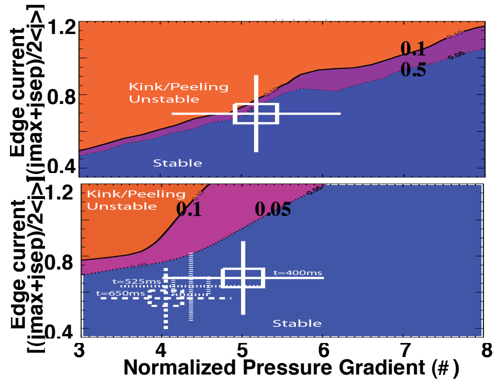

Figure 2: stability boundary[5] (blue to orange color transition) from ELITE code with fixed boundary kinetic EFITs for (a) pre-lithium discharge time-slice and (b) three post-lithium discharge time slices.

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