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# Modification of edge plasma profiles in ELM-suppressed discharges with lithium coatings in NSTX

R. Maingi[a], R.E. Bell[b], M.G. Bell[b], D.A. Gates[b], E.D. Fredrickson[b], S.P. Gerhardt[b], R. Kaita[b], S.M. Kaye[b], F.A. Kelly[b], H.W. Kugel[b], B.P. LeBlanc[b], D.K. Mansfield[b], J.E. Menard[b], D. Mueller[b], T.H. Osborne[c], S.F. Paul[b], R. Raman[d], S.A. Sabbagh[e], V.A. Soukhanovskii[f], T. Stevenson[b], and the NSTX research team

[a] *Oak Ridge National Laboratory, Oak Ridge TN, 37831 USA*
[b] *Princeton Plasma Physics Laboratory, PO Box 451, Princeton, NJ, 08543 USA*
[c] *General Atomics, San Diego CA, USA*
[d] *Univeristy of Washington, Seattle, WA USA*
[e] *Columbia University, New York, NY USA*
[f] *Lawrence Livermore National Lab, Livermore, CA USA*

**Abstract**

Reduction or elimination of edge localized modes (ELMs) while maintaining high confinement is essential for future fusion devices, e.g. ITER which has been designed for H-mode operation. An ELM-free regime was recently obtained in the National Spherical Torus Experiment (NSTX), following the application of lithium onto the graphite plasma facing components. The edge $n_e$ profile was observed to shift radially inward by several cm at fixed outer boundary radius. This inward shift is attributed to reduced recycling and core fueling. The edge $T_e$ profile was unaffected in the H-mode pedestal steep gradient region; however, the region of steep $T_e$ gradient extended radially inward by several cm following lithium coatings. Consequently, the edge $P_e$ profile broadened substantially. The edge $T_i$ was also increased, as was the edge toroidal rotation. These lithium-enhanced discharges exhibited an improvement in normalized energy confinement time of up to 50%, with no sign of ELMs up to the global stability limit when $\beta_N$ approached ~ 5.5.

## Experiment Details, Results, and Conclusions

As in other fusion research devices, ELMs are routinely observed[1] in nearly all H-mode discharges in the NSTX. In recent experiments in NSTX, however, it was observed that sufficiently thick lithium coatings resulted in complete ELM suppression[2,3,4,5]. Lithium evaporation is being evaluated as a particle control tool in NSTX, which in principle could provide density control for a variety of boundary shapes while enhancing the energy confinement[6]. The goal of this paper is to show the effect of lithium on discharge parameters, particularly edge density and temperature profiles; the resulting pressure profile modification is thought to be responsible for ELM suppression[7].

Lithium was introduced into the NSTX vacuum vessel between plasma discharges using a pair of overhead evaporators[4,5]. An overview of recent lithium coating results is presented in reference 8. With a high lithium evaporation rate (≥ 15 mg/min) and/or coating thickness (≥ 1 g)[3], the energy confinement increased such that the heating power needed to be reduced to avoid the global stability limit. The effect of thick lithium wall coatings on discharge characteristics is shown for three discharges (black: pre-lithium, red: post-lithium, low power, blue: post-lithium, intermediate power) in Figure 1. Panel 1b shows a step in neutral beam injected power from 2 to 3 MW at 0.45 sec in the post-lithium discharges; the post-lithium discharge with 4 MW of neutral beam injected power (NBI) disrupted shortly after $I_p$ flat-top (not shown). The post-lithium discharges showed reduced early density and dN/dt, although the eventual density in the lowest power discharge reached the same value as the reference discharge, partly because of the lack of ELMs (panel 1c). Panel 1d shows that the stored energy for the 2-MW post-lithium discharge was comparable to the 4-MW pre-lithium discharge, and that the energy confinement time normalized by the ITER-97 L-mode global scaling[9] was 50% higher in the post-lithium discharges (panel 1e). Following the 2 MW-3 MW step at 0.45 sec, a global MHD instability terminated the high performance phase (blue curve panel 1d). The radiated power was comparable out to 0.48 sec in these discharges, despite higher input in the pre-lithium discharge, i.e. the radiated power fraction increased during the ELM-free H-mode phase (panel 1f). Finally the divertor $D_\alpha$ emission was substantially lower in the post-lithium discharges, indicating reduced recycling, and all signatures of ELM activity vanished (panel 1g).

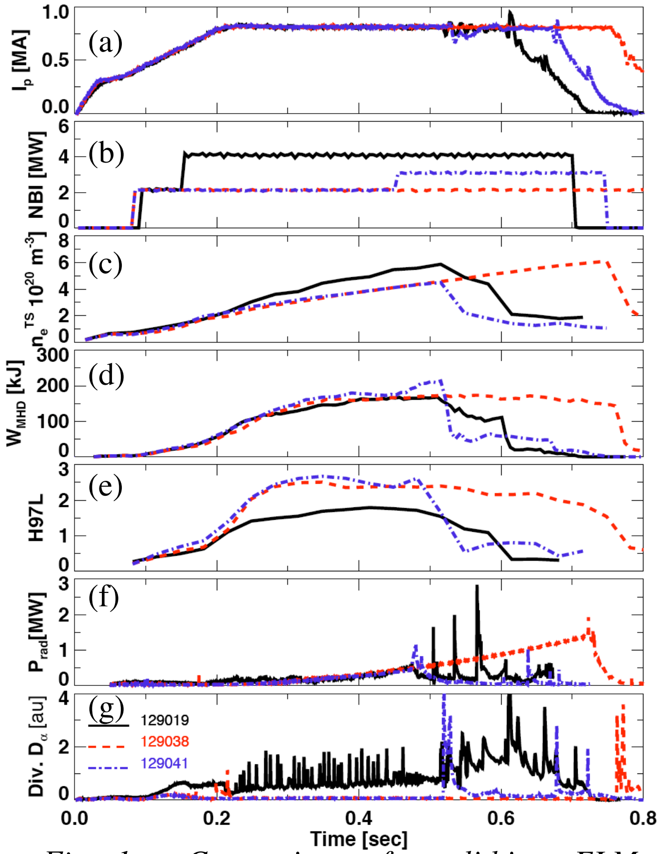


*Fig. 1 – Comparison of pre-lithium ELMy discharge (black), and two post-lithium discharges with different NBI power (blue, red): (a) plasma current $I_p$, (b) neutral beam injected power $P_{NBI}$, (c) line-average density from Thomson Scattering $n_e^{TS}$, (d) stored energy $W_{MHD}$, (e) confinement time relative to ITER97L scaling, (f) total radiated power $P_{rad}$, and (g) divertor $D_\alpha$ emission.*

The dramatic effect of lithium conditioning on the plasma kinetic profiles for the 2 MW (post-lithium) and 4 MW (pre-lithium) discharges from Figure 1 is displayed in Figure 2. The time slice at t=0.415 sec is displayed because the plasma – outer wall gap was nearly identical, and electron density and temperature ($n_e$, $T_e$) data from the Thomson Scattering diagnostic, and ion temperature ($T_i$) and toroidal rotation ($V_{tor}$) data from the charge-exchange recombination spectroscopy (ChERS) diagnostic were centered about the same time window to within 1 msec. In the pre-lithium discharge, the $T_e$ gradient increased outside of R=1.42 m, indicating that

R=1.42m was the top of the H-mode pedestal (panel 2a). While the $T_e$ gradient outside of R=1.42m was unaffected in the post-lithium discharge, the region of reduced gradient from R=1.36m-1.42m was eliminated; effectively shifting the entire profile upward. In contrast, the entire post-lithium $n_e$ profile appears to be shifted inward by about 2 cm, despite having the same plasma-wall gap (panel 2b), and the gradient is also reduced. This profile change is probably due to a reduction in core fueling from the lithium wall coatings, which is most likely a direct consequence of the 80-90% reduction in divertor recycling shown in panel 1g. The edge and core post-lithium $T_i$ values were increased (panel 2c), as was the edge $V_{tor}$ despite a lower $P_{NBI}$. Note that the reduction in core $V_{tor}$ was caused by this reduced $P_{NBI}$.

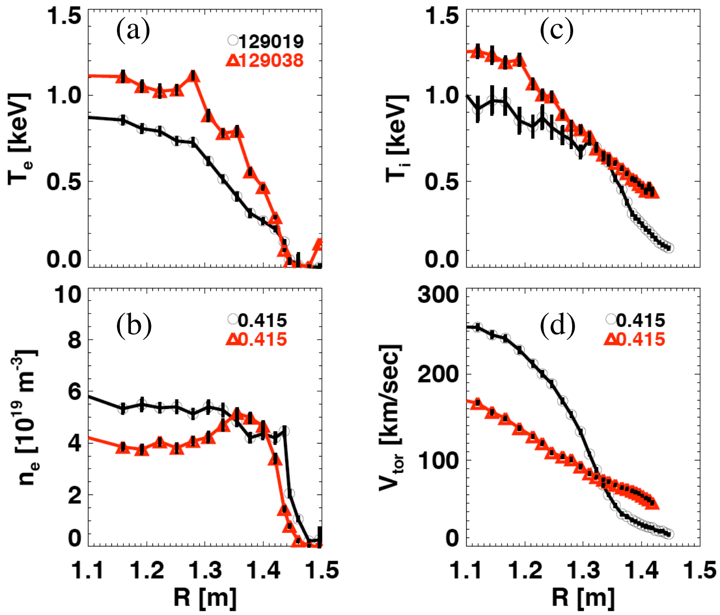


*Fig. 2 – Comparison of profiles from pre-lithium ELMy discharge (black), and post-lithium discharge (red): (a) $T_e$, (b) $n_e$, (c) $T_i$, and (d) $V_{tor}$.*

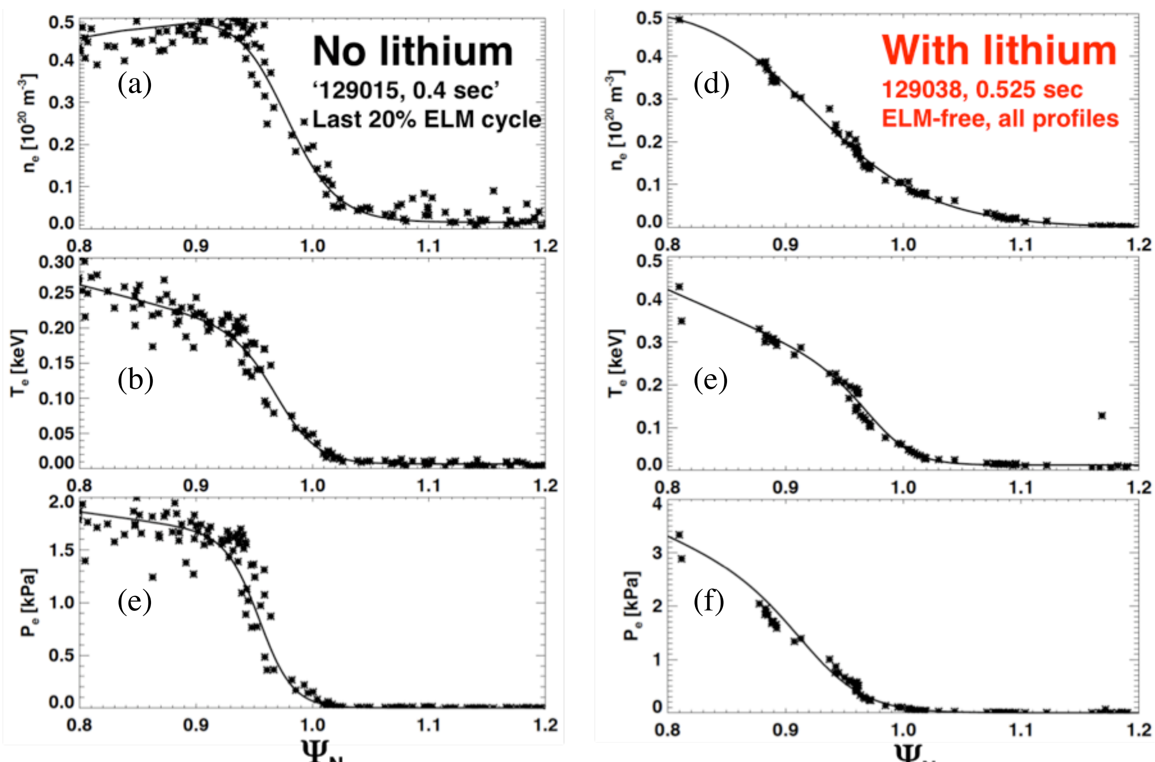


*Fig. 3 – Comparison of fitted plasma profiles from pre-lithium time slices (a-c) and post-lithium discharges (d-f). The pre-lithium profiles use multiple time slices in the last 20% of the ELM cycle from several identically programmed discharges, whereas the post-lithium profiles are from a single discharge over a 100ms window.*

As part of this study, five discharges with nearly identical programming and plasma characteristics were obtained before starting lithium evaporation. By using Thomson data from all five discharges over a narrow density/collisionality range, a number of good $n_e$, $T_e$ and $P_e$ profiles were obtained in the last 20% of the ELM cycle time. By mapping each one to an EFIT equilibrium, a composite pre-ELM profile representative of the pre-lithium discharges was constructed. Panels 3a-3c show those profiles, along with 'standard' modified hyperbolic tangent fits[10], showing the characteristic structure of the H-mode pedestal. Panels 3d-3f display the corresponding profiles for the post-lithium discharges; because the discharge is ELM-free, all of the profiles from a 100ms window can be utilized to construct the composite profile. Here the substantial modification of the $n_e$, $T_e$, and $P_e$ profiles and gradients from lithium coatings shown in Figure 2 is even more evident.

The inward shift of the $n_e$ profile with little change to the $T_e$ profile in the steep gradient region leads to broadening of the pressure profile, with an inward shift of the peak pressure gradient to smaller major radius and reduced magnetic shear. This inward shift is thought to be responsible for the ELM stabilization, as detailed in reference 7. The resulting discharges were ELM-free up the global $\beta_N$ limit when resistive wall modes are observed, i.e. the edge stability limit was completely obviated.

While the present lithium evaporators have provided an expeditious route to improved performance, a more complete divertor coating will be enabled by the liquid lithium divertor project, to be installed in NSTX in 2009/2010. The ultimate goal is achievement of the LiWall regime with very high pedestal temperatures and improved edge MHD stability[11].

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