Topic: EX-D

The role of lithium conditioning in achieving high performance, long pulse H-mode discharges in the NSTX and EAST devices

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In this paper, the role lithium wall conditioning on the achievement of high performance, long pulse discharges in the National Spherical Torus Experiment (NSTX) and the Experimental Advanced Superconducting Tokamak (EAST) is documented. Common observations include recycling reduction, confinement enhancement, and elimination of ELMs. In NSTX, lithium conditioning typically resulted in ELM-free operation with impurity accumulation, which was ameliorated e.g. with pulsed 3D fields to trigger controlled ELMs. Active lithium conditioning in EAST discharges has overcome this problem, producing an ELM-free H-mode with controlled density and impurities.

Lithium wall conditioning ('dose') was routinely applied onto graphite plasma facing components between discharges in NSTX, partly to reduce recycling [1]. The global effects are shown in Figure 1, which compares the evolution of a reference ELMy discharge, with an intermediate lithium dose (orange, ELMy), and one with high dose, that stabilized ELMs (blue). Note that the black and orange colored discharges were optimized for pulse length, but the blue discharge was not optimized. Nonetheless, the higher lithium dose resulted in reduced density ramp rate, comparable normalized pressure β_N, and substantially higher confinement relative e.g. to the H97L scaling law. Radiated power was not well controlled; hence, 3-D fields for controlled ELM triggering were developed [2].

In EAST extensive lithium wall conditioning is done via evaporators prior to a run day, and this was integral to achievement of the first [3] and record long H-mode discharges [4]. During the course of a run day, the state of the lithium coating can vary, and thus active conditioning via a lithium dust injector was sometimes employed for real time conditioning. Figure 2 compares the

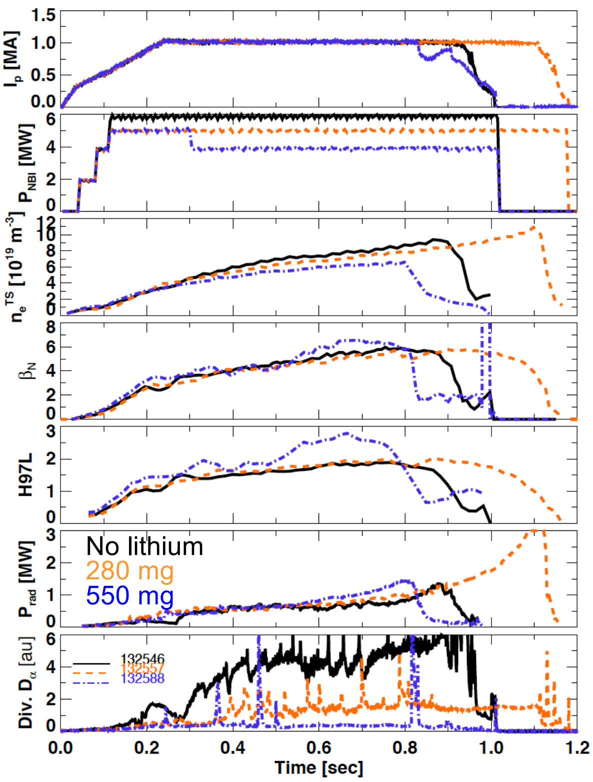

Figure 1: evolution of discharge parameters for a reference ELMy discharge and two discharges with different lithium dose in NSTX

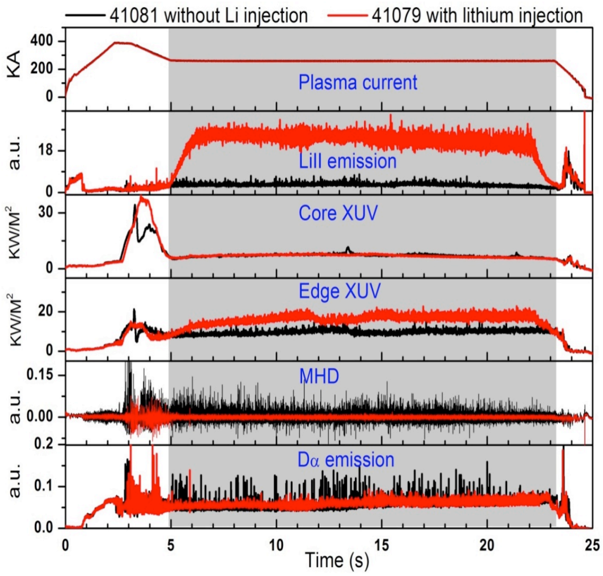

Figure 2: evolution of discharge parameters for a reference ELMy discharge and one with active lithium conditioning in EAST

evolution of a reference ELMy discharge and one with active lithium dust injection for 18 seconds (shaded period of the red discharge). As in NSTX, large ELMs were eliminated. The radiated power and edge soft X-ray emission was indeed higher in the discharge with active conditioning, but these and the line-averaged electron density were controlled, in contrast to the NSTX observations.

While the low frequency MHD activity was reduced with active lithium in EAST, a mid-frequency mode ~ 50 kHz appeared. This mode seems to provide the additional particle and impurity transport to avoid the typical accumulation in the ELM-free H-mode. [needs verification and figure]

Both devices observe improving performance with increasing lithium conditioning. This has been quantified in NSTX for a number of conditions and boundary shapes, and will be the subject of a coming systematic assessment in EAST. Figure 3 displays data from discharges during the NSTX dose scan sequence as a function of lithium dose for discharges with high and medium triangularity and elongation. Reduced recycling (via D_α emissions) from the divertor and center stack regions, as well as reduced midplane neutral pressure was observed; the magnitude of reduction increased with the pre-discharge lithium dose. Furthermore, improved energy confinement, both raw τ_E and H-factor normalized to scalings, with increasing lithium dose was also observed.

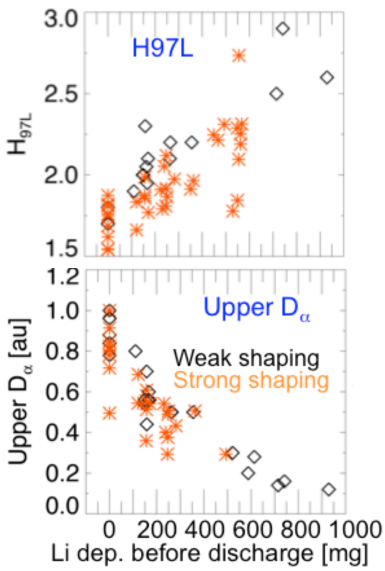

Figure 3: comparison of H97L confinement factor and divertor D_α emission pre-discharge lithium dose in NSTX.

The midplane edge plasma profiles were dramatically altered with lithium conditioning in NSTX, and this alteration is central to the stabilization of ELMs. The edge n_e gradient was reduced into $\psi_N = 0.95$, but greatly increased for $0.7 < \psi_N < 0.95$. The edge T_e gradient was increased for $\psi_N < 0.95$, and the edge T_i increased markedly. The role of lithium in profile modification, which underlies the ELM elimination, is now described: lithium reduces the recycling source, and the edge n_e gradient for $\psi_N > 0.95$ is reduced at roughly constant $D_\perp$. The edge T_e for $\psi_N > 0.95$ did not increase with the reduced n_e gradient; thus, the overall P_e gradient for $\psi_N > 0.95$ was reduced, which reduced the drive for kink/peeling and ballooning modes. Larger pressure gradients for $\psi_N < 0.95$ were observed, but these are not destabilizing to peeling/ballooning modes. An important factor of the observed ELM elimination is the apparent clamping of the edge T_e gradient. If the T_e gradient had been unclamped, the drop in the n_e gradient might well have occurred at constant pressure gradient, which would have had a more subtle effect on edge stability, via only the different dependences of the bootstrap current on the n_e and T_e gradients. The actual mechanism of improved deuterium retention with increasing dose appears to be related to lithium's ability to getter oxygen [5]. High levels of oxygen are bound in the lithium surface layer in a graphite matrix, and the oxygen effectively captures the incoming deuterium flux.

In summary, the results from both devices demonstrate the common benefits of lithium conditioning. The new observation on EAST of a quasi-steady discharge devoid of large ELMs improves the prospects for the applicability of lithium conditioning for future devices, removing one of the obstacles to progress in NSTX experiments.

*Research sponsored in part by the U.S. Dept. of Energy under contracts DE-AC02-09CH11466 and in part by the National Nature Science Foundation of China under Contract No. 11021565 and the National Magnetic Confinement Fusion Science Program of China under Contract Nos. 2010GB104001, 2010GB104002, 2011GB101000, 2011GB107001, 2012GB101001, 2013GB107003 and 2013GB106003.

References:

[1] Kugel, H.W., *et al. Phys. Plasmas* **15,** 056118 (2008).
[2] Canik, J.M., *et al. Phys. Rev. Letts.* **104,** 045001 (2010).
[3] Xu, G.S., *et al. Nucl. Fusion* **51,** 072001 (2011).
[4] Li, J.G., *et al. Nature Phys.* **9,** 817 (2013).
[5] Krstic, P., *et al. Phys. Rev. Letts.* **110,** 105001 (2013).