Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Injection of Lithium Powder in NSTX

OP-XP-913	**Revision: 1**	**Effective Date: 6/24/09** ***(Approval date unless otherwise stipulated)*** **Expiration Date: 6/24/11** ***(2 yrs. unless otherwise stipulated)***

PROPOSAL APPROVALS

Responsible Author: D. K. Mansfield	**Date 6/24/09**
ATI – ET Group Leader: C. Skinner	**Date**
RLM - Run Coordinator: R. Raman	**Date**
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: Injection of Lithium Powder in NSTX **No. OP-XP-913**

AUTHORS: D. K. Mansfield, A.L. Roquemore, R. Maingi, H. Kugel **DATE: 6/24/09**

---

1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

This work will explore the potential of Li powder to improve plasma performance and/or reduce plasma density. This is a follow-up experiment to OP-XP-828 which was partially completed in July 2008.

2. Theoretical/ empirical justification

Brief justification of activity, including supporting calculations as appropriate. Describe *briefly* any previous or related experiments.

There are at least 3 reasons to attempt the injection of lithium aerosol into NSTX. They are in order of importance:

(1) Density control: Recent experiments involving the shuttered LITER system on NSTX have demonstrated the effectiveness of "just in time" Li coatings for improving plasma performance. Moreover, while the LITER experiments have reduced the rate of rise in the plasma density, a secular density rise is still apparent. Experiments on TFTR with injected lithium aerosols suggest that the introduction of Li powder (a dry aerosol) into the SOL of an NSTX H-Mode plasma would lead to improvements in plasma performance which were similar to those demonstrated during the LITER experiments while simultaneously causing a reduction in the plasma density. If such improvement in performance can be demonstrated, it will allow NSTX to have a more flexible Li conditioning capability than is presently available. Such a system could then be incorporated into an advanced performance scenario most likely involving a high elongation, high triangularity discharge that at least begins to *approach* a double null configuration. In this type of discharge, there may be some advantage to introducing lithium into the upper divertor in addition to the lower divertor, thus depositing Li near both x points simultaneosuly. Our experience (XP 828) with injecting lithium from above Bay I showed that a substantial fraction of the injected lithium will be transported along open field lines terminating in the upper divertor.

(2) Resupply LLD: If a steady flow of lithium aerosol can be evaporated in the edge of a stable discharge with an outer strike point at the future location of the LLD, then it is conceivable that such a flow of particles could be used to re-supply the LLD. In particular, because some fraction of the evaporated lithium will follow the open field lines that terminate in the vicinity of the LLD, injecting Li aerosol into the SOL could offer a highly efficient way to resupply the LLD in real time.

(3) Interaction with ELMs: If injected lithium particles could be used to perturb the plasma edge /SOL in such a way that small grassy or randomly-phased ELMS appeared, then such ELMS could conceivably purge the core of accumulated impurities brought on by lithium conditioning with LITER.

During XP-828, several interesting and salutary phenomena were observed when aerosol injection took place before the L-H transition. These phenomena include the reduction of OH consumption, the transient appearance of extremely flat density and Te profiles with steep edge gradients, the suppression of impurity influx into the plasma core and the transient suppression of ELMs. These phenomena were, however, only seen during one discharge (130389) and that discharge had two non-standard features: (1) it was driven into the H-mode with early beam overdrive (6MW NBI, terminating at 100 ms – See Fig 2) and (2) it did not receive a center stack gas puff. Further, XP-828 employed He glow and was run near the end of the 2008 experimental campaign when there was a large amount of residual evaporated Li from the LITER use prior to XP-828. Assigning any of the salutary features described above solely to aerosol injection is, therefore, problematic.

The aim of XP-913, therefore, is to document the effects of lithium powder injection while addressing as many of the points discussed above (theoretical / empirical justification) as practical. The primary objective of this experiment, however, will be to determine whether or not the salutary effects observed briefly during XP-828 are reproducible and solely a consequence of Li aerosol injection rather than a consequence of the large amount of residual evaporated lithium from LITER use prior to XP-828. To that end we propose using the standard NSTX fiducial discharge (for example 129012 or 130388) with the following difference: a brief period of NBI overdrive will be employed for entry into the H-mode. As we progress during the experiment, the center stack gas puff will be decreased to the lowest level that will still permit a viable H-mode discharge.

3. Experimental run plan

Describe experiment in detail, including decision points and processes.

The experiment will be divided into two sections. The first section will be devoted to reproducing 130389 and to understanding the role of the CS gas puff during Li aerosol injection. This first section will be comprised of ~10 discharges. At the end of those ten discharges a decision will be made. If we are successful in reproducing 130389 then we will forego the second section of the XP and, instead, continue to try to optimize the performance of the discharges under study.

The second section will explore the potential of using aerosol injection into CS-limited discharges to deposit Li on the center stack and will be comprised of ~10 discharges (total: ~20 discharges = 1.0 days).

In all cases, He glow will be used as needed. Further, triggering of the Li powder dropper will begin at 650 ms before plasma breakdown so that the train of Li particles will arrive at the NSTX midplane at t = 0. Any needed adjustment to this timing will be made by viewing the plasma TV.

During section #1 of the experiment we plan to reproduce and expand the performance of shot 130389. A shot similar to the standard NSTX fiducial (129012) will be used as the XP-913 baseline discharge. This shot (130388) will have a CS gas puff and will be driven into the H-mode with NBI overdrive. The first use of aerosol injection will begin after establishing this No-Li discharge. The first discharge will employ a CS gas puff and uniform flux (Fig 1) of Li aerosol at 10 mg/s. Injection will begin well before the L-H transition, essentially at t ~ 0 (although the plasma will not expand enough to encounter the vertical stream of Li particles until ~ 25 ms). The flux of Li particles will then be increased systematically over the next three discharges from 10 mg/s to 20mg/s to 35mg/s to 50 mg/s. If successful, identical discharges will then be attempted at a reduced rate of CS gas puffing until finally the CS gas puff will be eliminated while Li is being injected at the highest rate – Max Rate1 - as determined during the first part of section #1. In addition to trying to reproduce shot 130389 from XP-828, the purpose of this part of the XP is to establish whether or not Li aerosol injection can facilitate successful operations without use of CS gas injection (i.e. can LFS Li aerosol fuelling be used to replace LFS gas puffing in the absence of CS gas fuelling?).

Decision Point: Having demonstrated the reproducibility of 130389 with no CS gas puff - or not having done so - a choice of which Li conditioning tactic and/or which aerosol flux temporal profile to employ will be made.

Case 1: If 130389 (without CS gas) is reproducible, then we will proceed to vary and optimize the temporal profile of Li injection into No-CS gas puff discharges employing Li flux profiles B and C (Fig 2).

Case 2: If 130389 is not reproducible, then we will use limiter discharges to coat the CS with lithium and investigate the effect of that pre-conditioning on subsequent fiducial discharges with CS gas puff.

In Case 1, a systematic attempt will be made to improve plasma performance by injecting Li aerosol with temporal flux profiles different from those used to this point in the experiment. The choice of temporal profile will be dictated by which aspect of performance seems to be mostly likely to be affected based on the data taken to this point in the experiment. Further any increase to the Li influx above the maximum 50 mg/s described in the main body of the XP will be accomplished using the second dropper located on Bay C if available.

In Case 2, an attempt to exploit a Li "training" discharge taken before the shot of interest to investigate whether or not Li can be deposited preferentially on the CS by injecting a large amount (10 – 50 mg) of Li aerosol into an Ohmic discharge that is limited by the CS (Fig 3). The residual effects of the Li deposited in this manner would then be exploited on the following high-power discharge.

Table 1 Shot list for the 1st section of XP-913 (reproduce 130388 & 89)

XP913 Shot No.	Dropper Rate mg/s (Max)	Aerosol Temporal Profile	Total Lithium (mg)	Nominal HeGDC (min)
Establish reproducible fiducial (130388)				
1 (130388)	0	N/A	0	6
2 (130388)	0	N/A	0	6
Subsection #1 systematic Li injection into 130388 overdriven fiducial If discharge does not tolerate a particular aerosol influx level, adopt highest successful rate (Max Rate 1), repeat and proceed				
3 (130388)	10	A	10	6
4 (130388)	20	A	30	6
5 (130388)	35	A	65	6
6 (130388)	50	A	115	6
7 (130388)	Max Rate 1	A	165 (max)	6
Adopt max flux rate (mg/s) from above (Max Rate 1) and lower CS gas flux by 50%				
8 (130388)	Max Rate 1	A	215 (max)	6
9 (130388)	Max Rate 1	A	265 (max)	6
Eliminate CS gas puff and repeat at Max Rate 1				
10 (130389)	Max Rate 1	A	315 (max)	6
11 (130389)	Max Rate 1	A	365 (max)	6
Decision Case 1: If successful vary flux profiles and continue Case 2: If unsuccessful proceed to section #2 of XP				
12 (130389)	30-10 mg/s	B	395 (max)	6
13 (130389)	40-10 mg/s	B	435 (max)	6
14 (130389)	50-10 mg/s	B	485 (max)	6
15 Repeat	Best Rate	B	535 (max)	6
16 (130389)	10-30 mg/s	C	565 (max)	6
17 (130389)	10-40 mg/s	C	605 (max)	6
18 (130389)	10-50/mg/s	C	655 (max)	6
19 Repeat	Best Rate	C	705 (max)	6

Table 2 Shot list for the 2nd section of XP-913 to Assess Li coating of CS

Section #2 Establish limiter discharge (118980), determine max tolerable influx of lithium (Max Rate 2) then use the lithium deposited into a training shot to benefit the shot of interest – diverted fiducial – which also receives Li (at Max Rate 1) and has a CS puff (139088).				
11 (Limiter)	0	N/A	365 (max)	6
12 (Limiter)	0	N/A	365 (max)	6
13 (Limiter)	0	N/A	365 (max)	6
14 (Limiter)	10 mg/s	D	375 (max)	6
15 (Limiter)	30 mg/s	D	405 (max)	6
16 (Limiter)	50 mg/s	D	455 (max)	6
17 (Limiter)	Max Rate 2	D	505 (max)	6
18 (130388)	Max Rate 1	A	555 (max)	6
19 (Limiter)	Max Rate 2	D	605 (max)	6
20 (130388)	Max Rate 1	A	655 (max)	6

4. Required machine, NBI, RF, CHI and diagnostic capabilities

Describe any prerequisite conditions, development, XPs or XMPs needed.
Attach completed Physics Operations Request and Diagnostic Checklist.

5. Planned analysis

What analysis of the data will be required: EFIT, TRANSP, etc.?

EFIT, TRANSP as appropriate. A comparison of XP 913 results to XP 923 (H. Kugel) and XP 828 will be performed.

6. Planned publication of results

What will be the final disposition of the results; where will results be published and when?

J. Nuclear Material

PHYSICS OPERATIONS REQUEST

TITLE: Injection of Lithium Powder in NSTX **No. OP-XP-913**
AUTHORS: D. K. Mansfield, A.L. Roquemore, R. Maingi, H. Kugel **DATE: 6/24/09**

Describe briefly the most important plasma conditions required for the XP:

This is a standard fiducial shot with the exception that the plasma is driven into H mode by a brief period of NBI overdrive. It is, therefore, important that all three sources be available for this XP. We are simply trying to reproduce 130388 and/or 130389.

List any pre-existing shots: Section 1: 130388 & 130389 Section 2 (if needed): 118980

Equilibrium Control: Gap Control / rtEFIT(isoflux control):

Machine conditions ***(specify ranges as appropriate, use more than one sheet if necessary)***

I_{TF} (kA):-53 **Flattop start/stop (s): -0.01/1.1**

I_P (MA):0.8 **Flattop start/stop (s): 0.2/1.0**

Configuration: Limiter / ~~DN~~ / LSN / ~~USN~~ ***(strike out inapplicable cases)***

Outer gap (m): **Inner gap (m):** **Z position (m):**

Elongation κ: **Upper/lower triangularity δ:**

Gas Species: D **Injector(s): CS mid, OM#2**

NBI Species: D Voltages (kV or off) A: 90 B: 90 C: 90 Duration (s): 1

ICRF Power (MW): 0 **Phasing:** **Duration (s):**

CHI: Off / ~~On~~ **Bank capacitance (mF):**

LITERs: Off / ~~On~~ **Total deposition rate (mg/min):**

EFC coils: Off/On **Configuration:Odd / Even / Other** ***(attach detailed sheet)***

DIAGNOSTIC CHECKLIST

TITLE: Injection of Lithium Powder in NSTX **No. OP-XP-913**

AUTHORS: D. K. Mansfield, A.L. Roquemore, R. Maingi, H. Kugel **DATE: 6/24/09**

Note special diagnostic requirements in Sec. 4

Diagnostic	Need	Want
Bolometer – tangential array	x	
Bolometer – divertor		x
CHERS – toroidal	x	
CHERS – poloidal	x	
Divertor fast camera	x	
Dust detector		x
EBW radiometers		
Edge deposition monitors	x	
Edge neutral density diag.	x	
Edge pressure gauges	x	
Edge rotation diagnostic		x
Fast ion D_alpha - FIDA		x
Fast lost ion probes - IFLIP		x
Fast lost ion probes - SFLIP		x
Filterscopes	x	
FIReTIP	x	
Gas puff imaging		x
$H\alpha$ camera - 1D	x	
High-k scattering		
Infrared cameras	x	
Interferometer - 1 mm		
Langmuir probes – divertor		x
Langmuir probes – BEaP		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism	x	
Magnetics – Flux loops	√	
Magnetics – Locked modes	x	
Magnetics – Pickup coils	√	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		
Magnetics – RWM sensors		
Mirnov coils – high f.	x	
Mirnov coils – poloidal array	x	
Mirnov coils – toroidal array	x	
Mirnov coils – 3-axis proto.		x

Note special diagnostic requirements in Sec. 4

Diagnostic	Need	Want
MSE		x
NPA – ExB scanning		
NPA – solid state		
Neutron measurements	x	
Plasma TV	x	
Reciprocating probe	x	
Reflectometer – 65GHz	x	
Reflectometer – correlation	x	
Reflectometer – FM/CW	x	
Reflectometer – fixed f	x	
Reflectometer – SOL	x	
RF edge probes	x	
Spectrometer – SPRED	x	
Spectrometer – VIPS	x	
SWIFT – 2D flow		x
Thomson scattering	x	
Ultrasoft X-ray arrays	x	
Ultrasoft X-rays – bicolor		x
Ultrasoft X-rays – TG spectr.		x
Visible bremsstrahlung det.	x	
X-ray crystal spectrom. - H	x	
X-ray crystal spectrom. - V	x	
X-ray fast pinhole camera		x
X-ray spectrometer - XEUS		x

Also need Loweus and Xeus

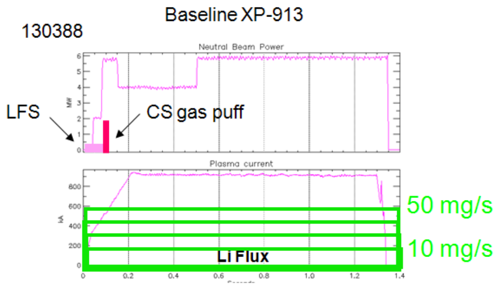

Fig.1: Li flux profile A

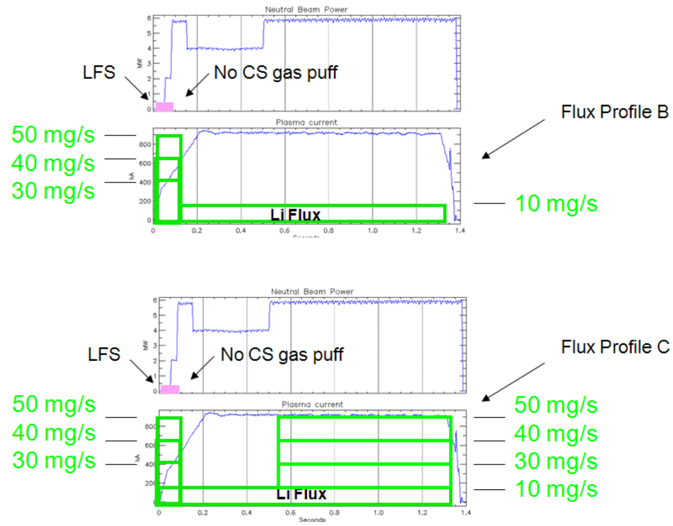

Fig. 2: Li flux profiles B and C

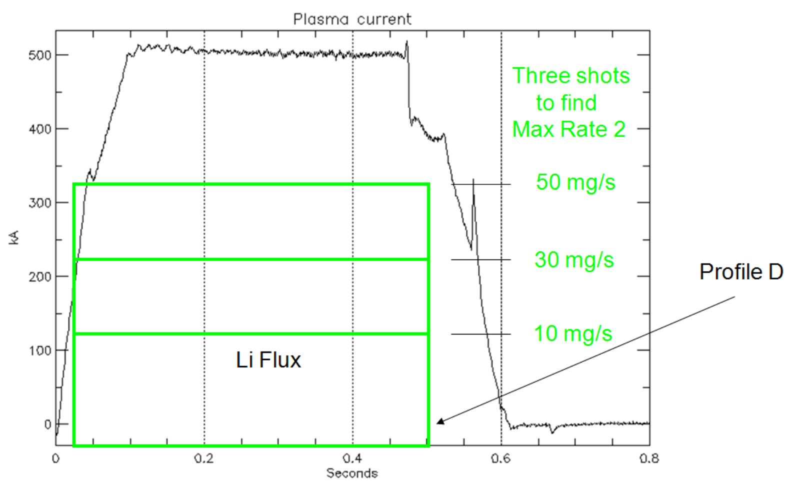

Fig. 3: Li flux profile D