Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Dependence of metallic impurity accumulation on I_p and the outer gap in the presence of lithium deposition**

OP-XP-950	Revision: **0**	Effective Date: **6/9/09** *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: Stephen F. Paul, Stefan Gerhardt	Date: 05/28/2009
ATI – ET Group Leader: Charles Skinner, Robert Kaita **Lithium TSG**	Date
RLM - Run Coordinator: Roger Raman, Eric Fredrickson	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Dependence of metallic impurity generation in the presence of lithium deposition** No. **OP-XP-950**
AUTHORS: **Stephen F. Paul, Stefan Gerhardt** DATE: **05/28/2009**

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1. Overview of planned experiment

This experiment is intended to examine the dependence of impurity accumulation on the major metallic impurity sources in NSTX. Operations in the presence of lithium, deposited on plasma facing components, have resulting in many shots exhibiting strong impurity accumulation. (see S.F. Paul, C.H. Skinner, J.A. Robinson, B. LeBlanc, H.W. Kugel, *J. Nuc. Mat*., vol. 390-391, pp. 211-215). Accumulation results from a complicated interaction between changes in impurity transport (thought to result from the suppression of ELM's) and changes in impurity generation. This experiment is designed to investigate the dependence of impurity generation on certain operational parameters. One hypothesis is that impurity accumulation may be observed only with lithium because the reduction in the neutral gas blanket that normally surrounds the plasma. The presumption is that the freshly deposited lithium covers the graphite tiles, acting as a pump for the neutral deuterium, and thus the reduced neutral atom density allows a greater the particle flux to reach the limiter. One way to reduce the effect of the gas blanket is to reduce its depth by simply scanning the width of the outer gap. Another lever involves change the fast ion flux from the beams, by running at two different plasma currents and different beam geometries. This experiment consists of a series of scans in the outer gap width in ELM-free 4-MW H-mode discharges with lithium evaporation with the following conditions:

1. Scan the outer gap in a 1.1-MA discharge using NBI sources A and B. This scan is performed at high plasma current, designed to minimize the loss of fast ions by keeping the width of banana orbits of trapped fast-ions small. Particles orbits close to the magnetic axis (where the banana width is largest according the formula):

   $$\delta_{Ba} = \frac{mv}{qB_\theta}\epsilon^{1/2}$$

   have the largest banana widths. A large outer gap keeps the magnetic axis farther from the plasma facing components. The expectation is that accumulation of metallic impurities will decrease when the outer gap is increased.

2. Vary the outer gap in a 700 kA discharge using NBI sources A and B. This scan is run at a current where the loss of fast ions is much greater. The expectation is that accumulation of metallic impurities will be even greater, because the low current effects compounds the gap width effects.

3. Attempt to isolate the effect of the beam geometry. For the conditions in scans #1 and #2, replace source C with B, or vice versa.

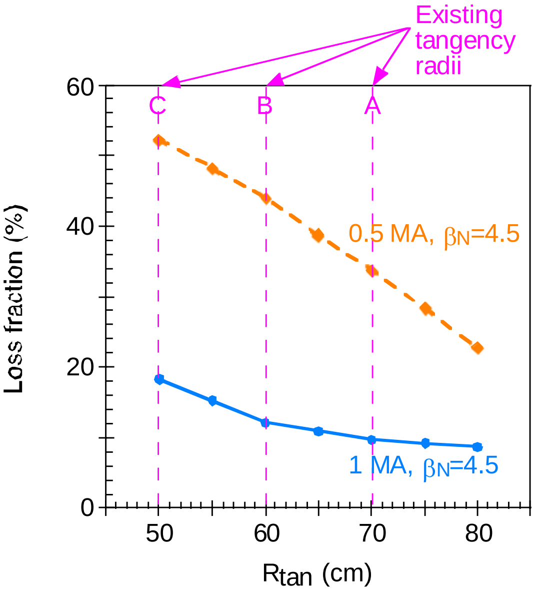
4. For a case with impurity accumulation, use a small LFS D_2 puff in order to test the effects of adding back the "gas blanket."

5. Optional beam timing scan if time permits: For the same conditions chosen in scan #3, source A and B will be injected *later* to see how rapidly the impurity generation is reduced, owing to less injected power during the ramp-up of the plasma current.

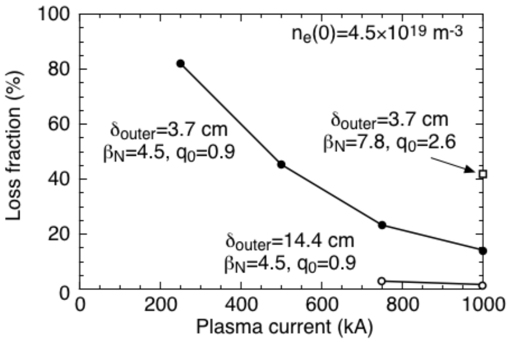
The detailed shot lists for these scans are discussed in Section 3.

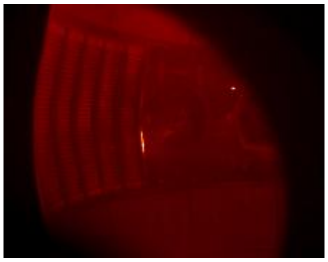
2. Theoretical/ empirical justification

Impurity generation from plasma facing components is particularly severe when the flux contains a substantial number of lost fast ions, as fast particles are particularly adept at sputtering. Models of energy from fast ion losses that are incident on the limiters and metallic walls of NSTX show that a fast ion flux can heat up plasma facing components and, in extreme cases, cause unacceptable damage. In some cases, the models predict a fast ion energy flux of 11 MW/m^2 on the side of the HHFW antenna. (D. S. Darrow, "Fast Ion Loss on NSTX", NSTX Results Review, September 20, 2001). Calculation of the beam ion loss rate shows a strong dependence on I_p and R_{tan} of the beamline, with particles from the beam source with largest tangency radius (source A) confined best. These effects are substantial; the beam ion models show that for source C, the fast ion loss fraction increases from 20% to 50% with I_p at 1 MA and .5 MA respectively. At .5 MA differences in R_{tan} lead to fast ion losses of 50% vs. 35% when injecting with source C vs. source A. Thus, three main tools are used in this experiment to vary the lost fast ion flux. The outer gap-width is the main independent variable and two different conditions of plasma current and beam geometry are scanned to amplify the anticipated variances. Beam loss modeling in model NSTX equilibria and density profiles without lithium show that the overall beam ion loss fractions (averaged over all 3 beam sources) for a 1 MA plasma show that operating with a 14 cm outer gap results in about a 1% loss fraction, whereas operating with a 4 cm outer gap results in a ~15% loss fraction. At I_p = 750 kA, the variation loss fraction is greater; from 25% to 2%. The graph also shows that substantial changes in the loss fraction are seen as well when q_0 and β_N are varied.



Beam ion loss rate model shows strong dependence on I_p and R_{tan} of beamline





There are indications of energy deposition from fast ion losses in NSTX. Photographs of the NSTX RF antenna limiter during NBI with source C (shot 133799; 600 to 601 ms) show the glowing edge of the limiter. Though this could be simply H_α emission, the persistence of the light after the shot indicates that the glowing is a small component of the blackbody radiation due to the limiter's being heated to high temperatures. Erosion of metal surfaces has been shown to be dependent on the temperature of the substrate. (see R.P. Doerner, M.J. Baldwin, R.W. Conn, *J. Nuc. Mat.*, vol. 290-293, March 2001, pp. 166-172, and references therein.) According to Ricky Maqueda, the glowing ceased when source C was not used, even with the same NBI power. A goal of this experiment is to examine how varying the amount of lost beam ion flux modified the impurity content of the plasma. In this experiment we plan to use only two beam sources, thus allowing the swapping of sources so that the differences in beam ion losses (and fast-ion induced impurities) associated with the difference beam geometries can be investigated.

3. Experimental run plan

The experiment consists of a scan in the outer gap in ELM-free 4-MW fiducial–like H-mode discharges with lithium evaporation, starting with a standard outer gap. If ELM-free H-modes cannot be obtained because of insufficient lithium deposition, then the experiment will be halted. Plasma equilibria will be more susceptible to instabilities from n=0 and n=1 modes as the plasma is moved away from the outboard passive stabilizing plates. Pressure-driven modes n=1 will be minimized by limiting β_N via keeping the total NBI power below 4 MW, while n=0 vertical modes will be avoided by keeping the internal inductance of the plasma below threshold levels.

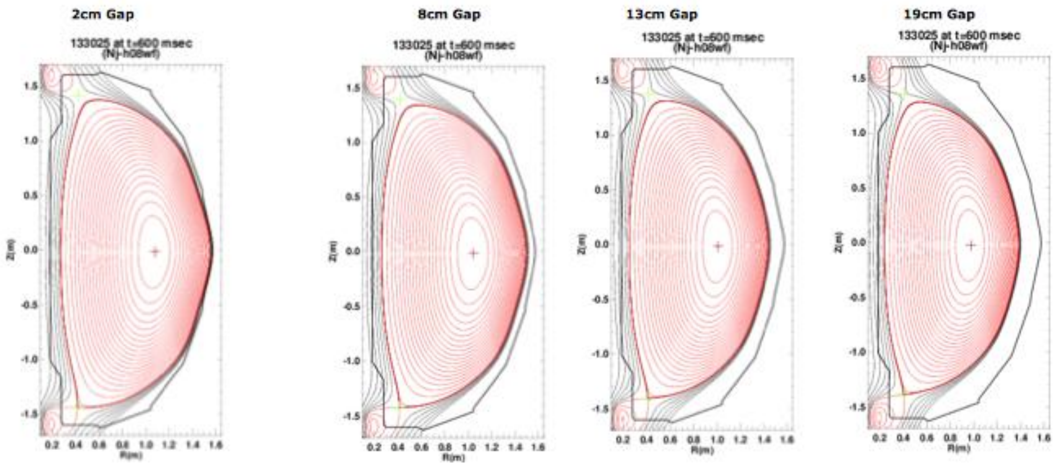
The scan in the outer gap necessitates other changes, e.g., the minor radius, position of magnetic axis, and inner gap will change as well. This will be tolerated as the main effect is expected to be the interaction leading to generation of metals is between the outboard region of the plasma and limiters/steel walls. Proximity of the plasma to the center stack is presumed to be of secondary importance.

The following is the expected shot list, performed in order of priority. At least 6-8 shots are required to draw conclusions.

1. (6-8 shots) Outer gap scan from 5 to 20 cm in 5 cm intervals in a 700-kA, 4.5 kG discharge using NBI sources A and C. Again, standard conditions will be maintained through the L->H-transition and then the gap is ramped to the desired value. Repeat each shot, replacing source C with source B. If *no* change is seen and MSE is not needed for the entire shot duration, sources B and C can be tried with intermittent beam blips on source A for obtaining MSE data.
2. (6-8 shots) Outer gap scan from 5 to 20 cm in 5 cm intervals in a 1.1-MA, 4.5 kG discharge using NBI sources A and B. Standard conditions will be maintained through the L->H- transition (115-125 msec). Following the transition, the gap will be ramped to the desired value over a period of 100-150 msec. The shot duration needs to be 0.7 sec after the H-mode transition. If this cannot be attained at 1.1 MA, reduce the plasma current to 1 MA. Repeat each shot, replacing source B with source C.
3. Take an I_P/gap pair from steps 1 & 2 in which significant impurity accumulation is observed. While keeping early LFS and HFS gas the same as in the previous scans, add a small amount (starting at 5 torr-l/sec) of LFS D_2 shortly after the H-mode, in order to mimic the missing hypothesized gas blanket.

A disruption in the middle of the scan is not expected to adversely affect the results of the experiment. Though metal impurities may be sprayed around the PFC's, with continual lithium evaporation the effect of this should last only through the next shot and is considered to be of secondary importance.

Another concern is that the divertor strike points move around as the outer-gap is scanned in a shot with other parameters held steady. Equilibria were calculated for various shot parameters resulting in a scan of the outer gap from .02 to .19 m. With the currents in PF-1A and PF-3 held approximately fixed, and PF-5 adjusted from -9.1 to -10.5, the major radius is shifted from .8 to .95 m, and the plasma elongation varied from 2.2 to 2.3, but the location of the strike points varies by only a few cm.



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

- Plasma operation at .7 and 1.1 MA, 4.5 kG, LSN.
- 4-MW NBI with all three sources available, each at 90 keV
- LiTER operation with adequate deposition (starting at 150-200 mg/shot) to insure ELM-free H-modes with I_p = 1.1 MA.
- No CHI, no RF.
- In addition to those diagnostics listed in the diagnostic checklist, the LowES XUV spectrometer (80 – 200 Å spectral range) is required.
- Confirm that the plasma TV camera and/or the GPI camera is observing the RF limiter so that any glowing from high heat flux is recorded.
- Keeping q_0 and $\beta_N$constant is desirable to isolate the effects of plasma current and gap width, however the beam ion loss fraction can be calculated for any combination of parameters. Therefore the correlation between beam ion loss and impurity accumulation can still be examined.

5. Planned analysis

1. EFIT analysis and normal plasma control system is required.
2. Mean-free-path of collisions of fast-ions with neutrals needs to be calculated
3. Banana orbit widths of fast ions (averaged over the divergence of the beams used in each scan) for each plasma current need to be calculated. Ideally the outer extent of the average banana orbit at 1.1 MA extends beyond the plasma boundary by less than 10 cm (the middle point for the outer gap scan) and at .7 MA, it extends beyond the plasma boundary by more than 10 cm.

6. Planned publication of results

Results to be published at next PSI meeting (2010).

PHYSICS OPERATIONS REQUEST

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(use additional sheets and attach waveform diagrams if necessary)

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

- 1 and .7 MA LSN plasmas with lithium deposition.
- ELM-free H-mode discharges at least .8 sec in duration, preferably > 1 sec.
- 4 MW NBI

Previous shot(s) which can be repeated: 133816

Previous shot(s) which can be modified: 133025

Machine conditions *(specify ranges as appropriate, strike out inapplicable cases)*

I_{TF} (~~kA~~): 4.5 kG Flattop start/stop (s):

I_P (MA): .7 to 1.1 Flattop start/stop (s):

Configuration: **LSN**

Equilibrium Control: **Isoflux** (rtEFIT)

Outer gap (m): **5-20 cm** Inner gap (m): Z position (m): **-0.02**

Elongation κ: ~2.3 Upper/lower triangularity δ: 0.7/0.45

Gas Species: **D** Injector(s): #1 and #2

NBI Species: **D** Voltage (kV) **A: 90** kV **B:** 90 kV **C:** 90 kV Duration (s): 1.5

ICRF Power (MW): 0 Phase between straps (°): Duration (s):

CHI: **Off** Bank capacitance (mF):

LITERs: On Total deposition rate (mg/min): **adequate to suppress ELM's, starting at 150 -200 mg/shot.**

EFC coils: On Configuration: **Odd**

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

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

Note special diagnostic requirements in Sec. 4

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