Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: Investigation of perturbative electron transport vs. magnetic shear using pellet injection		
OP-XP-534	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*
PROPOSAL APPROVALS		
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Responsible Division: Experimental Research Operations		
Chit Review Board (designated by Run Coordinator)		
MINOR MODIFICATIONS (Approved by Experimental Research Operations)		

NSTX EXPERIMENTAL PROPOSAL

Investigation of perturbative electron transport vs. magnetic shear using pellet injection

Overview of planned experiment

We propose joint transport and boundary physics experiments having two main goals:

(i) development of low-Z pellet injection as a tool for perturbative heat and particle transport studies in the core and edge of NSTX plasmas

(ii) Investigation of perturbed electron transport vs. magnetic shear using controlled 'cold pulses' induced by shallow pellet injection.

The pellet edge perturbation will first be optimized for both H-mode and L-mode discharges and the magnetic shear then varied to see its effect on the perturbed electron transport. In these initial experiments the shear will be varied by means requiring little discharge development, mainly beam source change and timing. The Ultrasoft X-ray (USXR) poloidal system in the 'multi-color' configuration will be used in conjunction with Multi-point Thomson Scattering (MPTS) to monitor the pellet penetration and for an assessment of the cold pulse propagation. The Li pellet injection will also serve to provide first light to another transport relevant diagnostic under development at JHU, the Li III Telescope for pellet seeded BES. Finally, the proposed experiments will be followed up the next run using a dedicated fast T_e diagnostic, the tangential multi-color array built by JHU.

2. Theoretical/ empirical justification

Perturbative studies have long played a role in investigating how electron transport responds to fast changes in the electron temperature gradient (see e.g., the work by Fredrickson et al. at TFTR). Recently, such studies were performed at JET using also shallow pellet injection. The results enabled developing a phenomenological model of electron transport supporting the 'critical gradient' paradigm. Assuming gyro-Bohm normalization, this model parameterizes the 'stiffness' of the electron transport through three quantities, the 'stiff' or 'turbulent' χ_s, the 'threshold' κ_c and the residual χ_0 (see e.g., Garbet et al PPCF 2004):

$$\chi_T = \chi_s q^{1.5} \frac{T}{eB}\frac{\rho_s}{R}\left(\frac{-R\partial_r T}{T}-\kappa_c\right)H\left(\frac{-R\partial_r T}{T}-\kappa_c\right)+\chi_0 q^{1.5}\frac{T}{eB}\frac{\rho_s}{R}$$

This model appears to have quite broad experimental support in tokamaks. It is therefore of interest to investigate its applicability on NSTX, where electron transport is the dominant channel. In particular, since experiments in low density L-modes suggest a strong correlation between electron transport and magnetic shear, it would useful to start by investigating the effect of changes in the magnetic shear on the 'critical gradient' parameters. The first estimates of 'cold pulse' propagation in NSTX H-modes using Type-I ELM perturbations and the USXR system indicate a picture which could be consistent with the 'critical gradient' paradigm, with very fast propagation of the T_e perturbation in the region of large gradient, followed by a slowing down of the pulse towards the core where T_e flattens (Fig. 1).

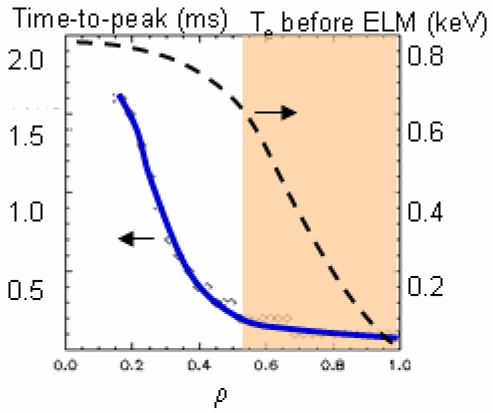

Fig. 1 Propagation of cold pulse from Type-I ELM as measured by USXR analysis. Fast propagation occurs in the region of large Te gradient,with a slow down in the inner plasma.

Initial estimates of pellet injection effects have been obtained in high density H-modes, in which all the beams have been switched off for 30 ms to allow pellet penetration into the pedestal. A full beam notch was used because it was surmised that the fast ion population at the edge prevents the Li pellet penetration. It was found that a 1.7 mg Li pellet arriving about 10 ms after beam turn-off does indeed produce a large T_e perturbation in the pedestal, resembling a large Type-I ELM (see e.g., shots 115589 and 115872). The discharge ended shortly after the injection. Since the pellet was injected at the end of the shot, it is not clear however whether the plasma collapse is entirely attributable to the injection. Nevertheless, injection without, or with only a minimal beam notch and with a reduced pellet impact, needs to be developed for transport studies.

3. Experimental run plan

The aim of the run plan is to produce in low power L-mode and high power H-mode plasmas *free of Type-I ELMs*, peripheral (about r/a > 0.7) T_e perturbations of measurable magnitude (around few tens of percent), but without having a major impact on other main plasma parameters, such as the magnetic equilibrium, core current profile, density profile, rotation and heating profile. As such, we will try with priority to optimize the pellet perturbation without using beam notches, or using only a minimal (in time and power) beam notch. If this will not be possible, we will nevertheless use full beam notches, shown earlier to allow effective pellet penetration. For quantitative monitoring of the pellet perturbation between shots we will use the MPTS profiles timed about 3 ms after pellet penetration into the plasma, while the USXR profiles will be used for a qualitative assessment of the pellet deposition and perturbation.

Finally, we will use with priority the highest velocity (150 m/s) pellets, in order to produce a fast (~ 1 ms) perturbations, since T_e profiles appear to respond on this time scale in NSTX. A lower velocity (75 m/s) will nevertheless be tried if the perturbation has to be reduced.

(1) According to the above priorities, we will start with relatively large (2 mg, or ~10% of plasma particle inventory in H-mode) pellets injected at the highest speed in discharges without beam notches. If the perturbation is too large, the pellet size and speed can be decreased by factors of up to three and two, respectively. If on the contrary, the perturbation is too small, we will start introducing short (10 ms) beam notches. (The experience so far suggests that timing the pellet so that it reaches the plasma edge at the end of a 10 ms beam notch is adequate). First we will try notching one source, and if not sufficient, more than one source. As the beam power is notched, we will however decrease the pellet size or velocity, for a more moderate pellet impact.

(2) The pellet optimization and transport measurements will be interleaved, in the sense that once an optimal injection condition is established, the same shot will provide the desired cold pulse propagation data.

(3) For low power and density L-mode plasmas we will try Li pellet injection, since Li has lowest Z and likely ablates more easily in the low density L-mode edge. For high power and density H-mode plasma we will use with priority B pellets, which have higher Z and should be more resistant to ablation in the dense H-mode edge. *C pellets will also be tried in H-modes, both to produce the desired* T_e *perturbation and to see if one can increase in this way the core C*

concentration for improved CHERS signals. If possible, we will try to save run time by injecting the C pellet after the perturbation from the first pellet (B) has subsided (we estimate ~ 150 ms). Since B and C should give comparable perturbations, this might also decrease the chance of missing the shot due to the pellet injector misfiring.

(4) Since discharge development time is limited, we will use as main scenarios discharges already developed in the 2005 run. As L-mode baseline we will use the reversed shear shot 115734 developed by F. Levinton (Src. A at 90 kV, 4.5 kG, 1 MA, DND). As an H-mode baseline we will use *Type-I* ELM-free shot 117577 (*Src. A, B and C* at 90 kV, 4.5 kG, 0.8 MA, LSN), developed by J. Menard. Alternately, ELM-free shot *115872* (Src. A and B at 90 kV, 4.5 kG, 1 MA, LSN) earlier developed by J. Menard will be used.

(5) We choose an injection time of ~ 360 ms for L-mode case and 400 ms for H-mode case, since MHD and transport stable conditions are consistently observed around this time. Eventual beam notches will therefore be between ~350-360 ms and 390-400 ms, respectively.

(6) Once the pellet injection is optimized and the cold pulse data obtained for a given discharge scenario and magnetic shear profile, we will proceed to cold pulse measurements in changed magnetic shear configurations, for both the L-mode and H-mode cases. To change the shear profile we will try 'lower-impact' approaches than moving early the beam injection, or very fast I_p ramp, as was done in XP411. This because attempts to increase the magnetic shear reversal by such means met with limited success in the 2005 run and our discharge development time is limited.

6a. Changed q-profiles in L-mode could be obtained by simply changing the beam source. For instance, in XP411 it was observed that source C produces much narrower electron ITBs (and therefore likely narrower region of shear reversal), than source B. Another venue could be to moderately increase the density in the early stage of the heating, as was one in XP223. The lower heat input per particle seems to be conducive to a flatter q-profile (TRANSP).

6b. In H-mode two simple strategies for varying the shear profile can be tried. One will be to delay the beam injection and the H-mode onset, thus having the current 'frozen' in a different profile than for the early H-mode onset. This approach is suggested by comparing the T_e profiles and evolution in e.g., shot 112032 and shot 117424. The other approach would be to follow the 'natural' evolution of the q-profile in a shot like 115500, where the MSE constrained EFIT indicates an increasing shear reversal between 200 and 400 ms. The pellet injection would in this case be delayed in e.g., 100 ms increments, to probe electron transport at various times and therefore q-profiles.

(7) Time permitting, other transport conditions will be investigated, such as beam power and I_p scans. Also, it would be interesting to compare pellet perturbations with Type-I ELMs.

(8) For reproducibility assessment, two shots per condition will be obtained

The proposed shot list and decision points are shown in Table I.

B and C pellets in Type-I ELM-free H-mode 117577:

0.8 MA, LSN, Src. A+B+C 90 kV,

$t_{inj\ 1}$=400 ms, $t_{inj\ 2}$=550 ms

Pellet	10 ms beam notch at t_{inj}-10 ms	Pellet mass (mg)	Velocity (m/s)	No of shots
B and C	**no / no**	**2/2**	**150/150**	**2**
If successful, continue with B and C pellets each shot. If not use just one pellet at 400 ms.				
C	**no**	**2**	**150**	**2**
B	**no**	**1**	**150**	**2**
B	**no**	**0.5**	**150**	**2**
if perturbation too small				
B	**Src. C**	**2**	**150**	**2**
B	**Src. B+C**	**2**	**150**	**2**
C	**Src. B+C**	**1**	**150**	**2**
B	**All sources**	**0.5**	**150**	**2**
C	**All sources**	**0.5**	**75**	**2**

Li and C pellets into low n_e L-mode 115734:

1 MA, DND, Src. A at 90 kV

t_{inj}=360 ms

Pellet	**10 ms beam notch at t_{inj}-10 ms**	**Pellet mass (mg)**	**Velocity (m/s)**	**No of shots**
Li	**no**	**2**	**150**	**2**
C	**no**	**2**	**150**	**2**
Li	**no**	**1**	**150**	**2**
Li	**no**	**0.5**	**150**	**2**
if perturbation too small				
Li	**Src. A**	**1**	**75**	**2**
Li	**Src. A**	**0.5**	**75**	**2**

Total = 30 shots

Time permitting, apply optimized pellet injection with changed shear conditions and compare pellet perturbation with Type-I ELM perturbation

Changed shear in L-mode	
Replace Src. A with Src. C in 115834	**2**
Changed shear in H-mode	
Delay all beams in 117577 by 100 ms, inject at 400 ms	**2**
Pellet vs. Type-I ELM	
Inject pellets in-between Type-I ELMs, using as baseline 117410	**4**

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

(1) All neutral beams operational at 90 kV

(2) LPI loaded with 0.5, 1 and 2 mg Li, B and C pellets

(3) MPTS and/or pellet timing synchronized for measurement at ~3ms after pellet deposition, as indicated by the low energy USXR array

(4) CHERS operational and synchronized for measurement before and after beam the blip between 350-360 ms

(4) MSE operational and synchronized for measurement before and after the beam blip at 350-360 ms

(5) USXR arrays in multi-color configuration: Hor. Up - Ti04, Hor. Down - Be10, Re-entrant Be-100

(6) Plasma TV camera with Li /B filters and FO bundle monitoring the pellet injection

(7) NPA in fast T_i mode, for estimate of relative T_i change following injection

(8) SPRED operational

(9) Bolometer array operational

(10) Visible light spectroscopy / fiberscopes for Li and B lines desirable

(11) X-ray pinhole camera desirable

5. Planned analysis

Fast EFIT for equilibrium changes. T_e cold pulse propagation and pellet deposition profile from analysis of USXR data. Routines for χ_e^{pert} estimate from E. Fredrickson and LHD cold pulse model (Inagaki et al, PPCF 2004). Fast TRANSP analysis using USXR T_e profiles and assuming T_i profiles measured by CHERS, modulated with the relative change measured by NPA may be possible. GS2 linear stability analysis before and after pellet injection is also of interest.

6. Planned publication of results

APS/DPP 2005, High Temperature Plasma Diagnostic Conference, publication in a refereed journal.

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **53 kA** Flattop start/stop (s): **-0.02/1.0 s**

I_P (MA): **0.8-1.0** Flattop start/stop (s): **0.12-0.22/0.8 s**

Configuration: **LSN for 117577, DND for 115834**

Outer gap (m): **5-10 cm**, Inner gap (m): **1-6 cm**

Elongation κ: **2-2.5**, Triangularity δ: **0.5-0.7**

Z position (m): **0.00**

Gas Species: **D / He**, Injector: **CS Midplane, Outer Midplane**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **90/90/90 kV**, Duration (s): **1s**

ICRF – Power (MW): ____, Phasing: **Heating / CD**, Duration (s): ______

CHI: **On / Off**

Either: Previous shot numbers for setup: **117577 as H-mode baseline (with 115872 as backup) and 115734 as L-mode baseline (with 115731 as backup)**

Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

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Diagnostic	Need	Desire	Instructions
Bolometer - tangential array	✓		
Bolometer array - divertor			
CHERS	✓		
Divertor fast camera			
Dust detector			
EBW radiometers			
Edge deposition monitor			
Edge pressure gauges			
Edge rotation spectroscopy			Only available by special request of T. Biewer @ MIT
Fast lost ion probes – IFLIP			
Fast lost ion probes – SFLIP			
Filtered 1D cameras			
Filterscopes		✓	Li and B filters
FIReTIP			
Gas puff imaging			
High-k scattering			
Infrared cameras			
Interferometer – 1 mm			
Langmuir probes - PFC tiles			
Langmuir probes - RF antenna			
Magnetics – Diamagnetism			
Magnetics – Flux loops	✓		
Magnetics – Locked modes			
Magnetics – Pickup coils	✓		
Magnetics - Rogowski coils	✓		
Magnetics - RWM sensors			
Mirnov coils – high frequency		✓	
Mirnov coils – poloidal array		✓	
Mirnov coils – toroidal array		✓	
MSE	✓		
Neutral particle analyzer	✓		Fast Ti mode
Neutron Rate (2 fission, 4 scint)			
Neutron collimator			
Plasma TV	✓		Li and B filter
Reciprocating probe			
Reflectometer - FM/CW			
Reflectometer - fixed frequency homodyne			
Reflectometer - homodyne correlation			
Reflectometer - HHFW/SOL			
RF antenna camera			
RF antenna probe			
Solid State NPA			
SPRED		✓	
Thomson scattering - 20 channel	✓		
Thomson scattering - 30 channel			
Ultrasoft X-ray arrays			
Ultrasoft X-ray arrays - 2 color	✓		
Visible bremsstrahlung det.		✓	
Visible spectrometers (VIPS)		✓	
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray pinhole camera		✓	