Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Z-scaling of impurity transport in beam heated NSTX H-mode discharges**		
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PROPOSAL APPROVALS

Authors: L. F. Delgado-Aparicio et al.	Date: May 26, 2006
ATI – ET Group Leaders: M. Bell, K. Tritz	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)

Z-scaling of impurity transport in beam heated NSTX H-mode discharges

L. F. Delgado-Aparicio, D. Stutman, K. Tritz and M. Finkenthal (The Johns Hopkins University)
R. E. Bell, M. Bell, R. Kaita, S. Kaye, H. Kugel, B. P. LeBlanc, S. Paul, L. Roquemore and D. Smith (Princeton Plasma Physics Laboratory)
F. Levinton, H. Yuh and R. Maqueda (Nova Photonics)
R. Maingi, C. Bush (ORNL)
V. Soukhanovski (LLNL)
S. Kubota (UCLA)

1. Overview of planned experiment

We propose to perform a dedicated study of the Z-scaling of impurity transport in NSTX H-modes by using deuterated-methane and neon gas puffs as well as vitreous carbon pellet injection. We will first attempt injection into ELM-free H-modes by applying brief (50-200 ms) gas puffs at the edge, as has been done previously for the L-modes. If impurity screening is strong and the diffusivity low, it is possible however that impurities will penetrate only in the outer plasma. To assess the convective transport deeper in the core we will then use different gas-puff pulses including the possibility of the SGI, as well as pellet injection. The time evolution of the added impurity should give us information about the average magnitude and Z-scaling of the convective velocity for ranges of time in the order of few hundred milliseconds. The same time evolution study could be made in a shorter time-scale by the use of (~ 0.25 and 0.55 mg) vitreous carbon pellet injection using the Lithium Pellet Injector (LPI). In order to follow the evolution of the perturbed profiles, the poloidal USXR arrays and the new tangential optical array developed at The Johns Hopkins University will be used in a “multi-color” mode.

Four basic single-parameter scans are proposed for the experiment using one H-mode baseline shot (NSTX: 120909), at 1MA, 4.5 kG, CS gas at 900Torr, and the three (A, B & C) NBI sources timed at 60ms, 80ms and 145ms (all at 90keV), with a total of 6 MW:

a) A gas-puff length scan with the plenum pressure at ~ 100-400 Torr and gas valve pulses of Δt~50, 100 and 200ms.

b) A pellet, size vs. velocity optimization scan, with masses in the order of 0.25 mg and 0.55 mg at full and half speed.

c) A pellet timing scan in order to asses impurity transport at later times ($t_{pellets}$~0.3, 0.55, 0.8).

d) A ρ-scaling at fixed q-profile, and repeating the optimized injection technique at different times as done in c).

2. Theoretical/empirical justification

Impurity transport has been studied in NSTX mainly in beam heated L-mode plasmas, using Neon injection and the (diode based) USXR poloidal arrays. While thermal ion transport in H-mode is well characterized (being generally in the neoclassical range), less is known about impurity transport. The carbon profiles obtained by the Charge Exchange Recombination Spectroscopy (CHERS) diagnostic have been in recent years consistently hollow in ELM-free H-modes, suggesting the existence of an outward convective velocity. A preliminary transport estimate based on impurity transport simulations of the intrinsic carbon profiles from CHERS, suggests neoclassical diffusivity near the pedestal and an outward convective velocity in the order of 0.5 m/s. The neoclassical transport theory predicts that in certain collisionality regimes, the cross-field particle flux of impurities would be directed down the main ion temperature gradient, resulting in a phenomenon known as “temperature screening”. This screening effect consists in the appearance of an outward convective velocity that scales approximately linear with Z, while the diffusivity is only weakly dependent on impurity species. We observe that NSTX is very well suited for the study of such neoclassical effects, due to the large ion gyroradius, the typically flat n_e profiles with strong ion temperature gradient observed in beam heated H-modes, and the estimated reduction of turbulent transport. The Z-scaling of convective impurity transport is also very important for the future of the ST concept as well as for ITER, where “temperature screening” is invoked to shield the plasma core from high-Z impurities such as molybdenum and tungsten.

During this 2006 NSTX campaign though, the carbon profiles for the ~ 1.0 second high power (6MW) H-modes, have shown a strong core peaking at later times suggesting a rather classical effect of strong impurity peaking proportional to n_i^Z or a neo-classical effect different than the typical impurity shielding for the neoclassical “banana” regime with ν^*_i<1. This discrepancy could result from either non-flat density profiles or due to the main ions & impurities confined in other neoclassical regimes like the Pfirch-Schlutter for instance. Due to this difference on impurity profiles from past years, we are also proposing a systematic study of the Z-scaling of impurity transport in beam heated NSTX H-mode discharges at different times (e.g. hollow and peaked carbon profiles at early and later times within the same discharge).

As a result of the gas injections, a time-averaged value of the impurity diffusivity and convective velocity could be obtained in the time-scale on which the gas penetrated to NSTX core. With the pellet injection on the other hand, a more localized measurement in time of the above quantities can be performed since the core impurity density gradients generated by the pellet are stronger and the analysis for the impurity diffusivity and convective velocity can be made during the 30-50 ms after the pellet arrival. To measure the evolution of the impurity profiles we will use the newly developed tangential “optical” (scintillator-based) SXR array and the poloidal (diode-based) USXR diode arrays filtered for edge and core charge states, the tangential bolometer array, as well as the CHERS carbon system. The contribution of injected impurities to the SXR emission will be obtained by subtracting the intrinsic background from reference discharges, as has been done in recent years for the L-mode impurity transport study.

3. Experimental run plan

A) Gas (CD_4 and Ne) injections:

For an assessment of the carbon and neon gas penetration in NSTX H-modes, we will perform scans with deuterated methane (CD_4) and neon gas-puffs with plenum pressures at 100 - 200 Torr and pulse lengths Δt ~ 50, 100 and 200ms. We will use NSTX shot 120909 (or 120157, 120406) as a baseline H-mode; 3 source, 4.5 kG, 1 MA, long pulse DND. The gas puff will begin at 350 ms when the plasma electron density, ~ 5×10^{19} m^{-3}, and temperature, ~ 800 eV, are constant, with a central carbon density ~ 1.6×10^{18} m^{-3} and ion temperature and 1.2 keV. Because we need to subtract the background in the USXR data, a baseline shot should precede every gas injection shot. A total of twelve shots will be needed to perform the six-shots-per gas scan at three gas pulse ranges as seen in Table 1.

In the event that the ~ 50 ms gas-puff pulses (or shorter) are enough to perform the impurity transport studies (i.e., the core signals are considerably above the background level measured in the reference baseline shot) and there is no need to further test the longer gas pulses, we will decide during the experiment to switch to a scan of the initial timing of the gas puff initial (e.g., 0.3, 0.55 and 0.8 s, Table 2).

B) Pellet injections:

For an assessment of the vitreous carbon pellet injection into an NSTX H-mode, we will repeat first the baseline shot and then perform a scan of pellet masses and velocities (see Table 3). After optimizing the injection with 0.25 or 0.5 mg vitreous carbon pellets at half ($v_f/2$) or full (v_f) speed, we will perform a scan of the injection time for a first assessment of the change in D and V with time.

C) ρ scaling:

The neoclassical impurity particle diffusivity ($D_I^{neo} \propto \rho_i^2 \nu_{ID} q^2$) and thus the convective velocity ($v_I^{neo} \propto D_I^{neo} Z / L_{n_i,T_i}$) depend strongly on the product of the main-ion gyro-radius and the safety factor. We will perform a gyro-radius scaling of the C impurity transport at constant q-profile, using pellet injection as well as reducing the toroidal field and the plasma current from their original values of 4.5 kG and 1MA, to 3.6 kG and 0.8 MA, and then increasing them to 5.0 kG and 1.11 MA (5.5 kG and 1.22 MA if permitted, see Table 4). Finally, we will repeat the scan of the timing of the optimized carbon pellet injection as done in B).

Baseline + gas inj. @ 350 ms ($\Delta t \sim 50$ ms)	2 shots
Baseline + gas inj. @ 350 ms ($\Delta t \sim 100$ ms)	2 shots
Baseline + gas inj. @ 350 ms ($\Delta t \sim 200$ ms)	2 shots
Total (x2 to include both Ne, CD_4)	***12 shots***

Table 1. Shot matrix for gas (CD_4 and Ne) injections

Baseline + gas inj. @ 300 ms ($\Delta t \sim 50$ ms)	2 shots
Baseline + gas inj. @ 550 ms ($\Delta t \sim 50$ ms)	2 shots
Baseline + gas inj. @ 800 ms ($\Delta t \sim 50$ ms)	2 shots
Total (x2)	***12 shots***

Table 2. *Optional* shot matrix for the gas (CD_4 and Ne) injection timing

Baseline + ¼ mg vitreous carbon @ v_f and 300 ms	2 shots
¼ mg vitreous carbon @ $v_f/2$ and 300 ms	1 shots
½ mg vitreous carbon @ $v_f/2$ and 300 ms	1 shots
½ mg vitreous carbon @ v_f and 300 ms	1 shot
Optimized pellet @ later time (550 ms)	1 shot
Optimized pellet @ later time (800 ms)	1 shot
Total	***7 shots***

Table 3. Matrix shot for the pellet optimization injection (v_f and $v_f/2$ refer to the full and half-full pellet speeds).

C pellet in 3.6 kG, 0.8 MA, 6 MW shot @ 550 ms	2 shots
C pellet in 5(5.5) kG, 1.1(1.2) MA, 6 MW shot @ 550 ms or latest time consistent with available TF, I_p flattop	2 shots
Total	***4 shots***

Table 4. Shot matrix for the ρ-scaling. Time permitting, a pellet time scan will be also executed

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

(1) All neutral beams operational at 90 kV.

(2) Gas Injection System with both neon and deuterated methane available on LFS valves.

(3) LPI loaded with 0.55 and 0.25 mg vitreous carbon pellets for an estimated maximum of 11 shots; inject at half speed and full speed in H-modes.

(4) Supersonic gas injector available with neon, if required.

(5) Three-color tangential optical SXR array (Be 10, Be 100, Be 350 filters).

(6) USXR arrays in two-color configuration: Hor. Up – Be5, Hor. Down - Be10, Re-entrant Be-100.

(7) Other diagnostics as specified in list.

5. Planned analysis

The impurity density profiles will be inferred from analysis of USXR and tOSXR data. Fast EFIT for equilibrium changes. Use of MIST simulations to map the contributions from the neon and carbon spectrum to the USXR & tOSXR detectors. Use of multi-color ratios to address possible variations on the electron temperature during gas and pellet injections. Fast TRANSP analysis, using USXR & tOSXR T_e profiles and assuming T_i profiles measured by CHERS could be possible. NCLASS will be used to assess neoclassical transport. Correlation with GS2 linear stability analysis before and after pellet injection are of interest.

6. Planned publication of results

TTF 06-07, APS/DPP 2006, publications in a refereed journal.

PHYSICS OPERATIONS REQUEST

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **-53, (-65)** Flattop start/stop (s): **-0.02 / 1.4 (0.8)**

I_P (MA): **1.0** Flattop start/stop (s): **0.2 / 1.2**

Configuration: **DND**

Outer gap (m): **0.10**, Inner gap (m): **0.06**

Elongation κ: **2.25**, Triangularity δ: **0.7 – 0.8**

Z position (m): **0.00**

Gas Species: **D, Ne, CD_4**, Injector: **CS Midplane, Outer Midplane (SGI)**

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

ICRF – Power (MW): **Off**

CHI: **Off**

Shot numbers for setup: **120406 or 120157**

DIAGNOSTIC CHECKLIST

Z-scaling of impurity transport XP-613

Diagnostic	Need	Desire	Instructions
Bolometer - tangential array	✓		
Bolometer array - divertor			
CHERS	✓		Synchronize to pellet timing
Divertor fast camera		✓	
Dust detector			
EBW radiometers			
Edge deposition monitor			
Edge pressure gauges		✓	
Edge rotation spectroscopy			
Fast lost ion probes – IFLIP		✓	
Fast lost ion probes – SFLIP		✓	
Filtered 1D cameras			
Filterscopes		✓	C, Ne filters
FIReTIP		✓	Pellet density perturbation
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	✓		Synchronize to pellet
Neutral particle analyzer		✓	Fast Ti mode
Neutron Rate (2 fission, 4 scint)	✓		
Neutron collimator			
Plasma TV	✓		C, Ne filters
Reciprocating probe			
Reflectometer - FM/CW			
Reflectometer - fixed freq. homodyne quadrature		✓	
Reflectometer - homodyne correlation		✓	
Reflectometer - HHFW/SOL			
RF antenna camera			
RF antenna probe			
Solid State NPA			
SPRED		✓	
Thomson scattering - 20 channel	✓		6ms laser separation around pellet
Thomson scattering - 30 channel		✓	
Ultrasoft X-ray arrays poloidal -2 color	✓		
Visible bremsstrahlung det.	✓		
Visible spectrometers (VIPS)		✓	
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray pinhole camera		✓	
Tangential Optical SXR Array (OSXR)_	✓		
Fiber optics with beam splitters for D_α and C II		✓	