Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Divertor heat flux reduction and detachment in highly shaped plasmas

OP-XP-708	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Author:	**V. A. Soukhanovskii**	Date 02/08/2007
ATI – ET Group Leader:	**V. A. Soukhanovskii**	Date
RLM - Run Coordinator:	**D. Gates (M. G. Bell)**	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Divertor heat flux reduction and detachment in highly shaped plasmas **OP-XP-708**

1. Overview of planned experiment

The goal of this experiment is to determine conditions of the steady-state outer divertor target heat flux reduction and detachment in the NBI-heated H-mode plasma operational space in a higher-end elongation/triangularity LSN shape with κ=2.2–2.5 and δ=0.5-0.7, referred hereforth as the PF1A shape. Two techniques will be used to achieve the outer target detachment: raising scrape-off layer density by means of D_2 injections, and raising edge radiated power by injecting an extrinsic impurity (CD_4 or N_2). In the first part of the experiment deuterium will be injected in the lower divertor region. In the second part of the experiment deuterated methane or nitrogen will be injected in increased quantities to yield P_{rad}/P_{in} up to 0.5 to obtain the outer target detachment. Divertor measurements, such as the D_α, D_β, D_γ brightnesses, heat flux (from IR cameras), radiated power, divertor Langmuir probe I_{sat} and neutral pressure will be monitored for signs of detachment. The goal is to determine the injected gas quantity necessary to establish radiative and/or detached (partially detached) divertor conditions, simultaneously retaining good core plasma quantities (MHD, confinement, impurity level).

2. Theoretical/ empirical justification

Previous divertor experiments in NSTX [1, 2, 3] with deuterium and neon puffing demonstrated that the outer divertor peak heat flux can be reduced by 50-80 % and simultaneously H-mode confinement can be maintained. These experiments have been conducted using the PF2L shape. The experiments revealed a strong dependence of the plasma performance and divertor heat flux reduction on a gas puffing location. When deuterium is puffed in the midplane or private flux region locations at rates 20-160 Torr l /s, radiative divertor conditions are apparently attained. When deuterium is puffed in the divertor at 200 - 450 Torr l /s, a partially detached divertor state can be achieved. Midplane neon injections apparently lead to the radiative mantle type heat exhaust since NSTX divertor temperature in the heat flux limited regime was too low for neon to radiate effectively. This experiment will study divertor heat reduction and detachment in high elongation/triangularity LSN shape (κ<2.5 and δ~0.7). This shape has shown great promise toward achieving CTF-like parameters (β_t, β_n, bootstrap and non-inductive current fraction) [4]. Because of large poloidal magnetic flux expansion, divertor peak heat flux is reduced in this shape by a factor 2-3 in comparison with the low triangularity/elongation shape. The Branch 5 and the LDGIS injectors will be used to puff deuterium in the lower divertor region in a steady-state fashion to further study the radiative and partially detached divertor regimes. Midplane CD_4 or N_2 injection will be used to increase divertor radiated power and to attempt the OSP detachment through divertor radiation simultaneously maintaining H-mode confinement.

3. Experimental run plan

1. Heat flux reduction and detachment in high elongation/triangularity (PF1A) LSN plasmas with D_2 puffing (up to 25 shots)
   - Setup an LSN (with PF2L+PF1A coils) HFS-fueled plasma with elongation κ=2.2–2.5 and triangularity δ<0.75 (3 shots)
   - Wall conditions should permit reproducible H-mode access. (Optional) Run a helium discharge to de-saturate walls if necessary
   - Perform a gas injection rate and location scan (up to 20 shots)
   - Use 2 NBI sources at full energy (80 kV). Start with A, B and add C as needed
   - Example shots: 120339 (0.7 A), 117577 (0.80 MA), 119645 (0.8 A)
   - Use LDGIS injectors in series at several plenum pressures (1300 - 1800 T) to obtain injection rates 50 - 600 Torr l /s (~ 10 shots)
   - Use Branch 5 gas injector in FLO mode at several plenum pressures (1300 - 2500 T) to obtain injection rates 50 - 160 Torr l /s (~ 10 shots)
   - In one high density discharge, turn off NBI at the time when n_e is high (> 6 x 10^{19} m^{-3}) to obtain high density low input power condition for about 50 ms
     - Greenwald density for I_p=0.8 MA is n_G = 5.5 x 10^{19} m^{-3}
   - Use GPI diagnostic and edge reciprocating probe in 2-5 shots with divertor gas puffing to obtain edge turbulence data
   - Use Supersonic gas injector (SGI) instead of divertor gas puffers to obtain radiative / detached divertor conditions (optional, time permitting)
   - Use 3 NBI sources at full energy (80 kV) (optional, time permitting). Example shots: 119622 (0.8 MA), 121120 (0.7 MA)

2. Heat flux reduction and detachment in high elongation/triangularity (PF1A) LSN plasmas with CD_4 or N_2 puffing (up to 10 shots, optional, time-permitting)
   - Perform CD_4 injections in increasing quantities (from 1 to 20 Torr l / s) into intermediate density two NBI source shot from 1. Monitor radiated power (10 shots)
   - Wall conditions should permit reproducible H-mode access
   - Use Injector 3 for CD_4 or N_2. The gas pulse start time is 0.30-0.35 s, pulse duration 0.05 – 0.300 s
   - Start with a imurity gas pulse at the rate of 1 Torr l / s, pulse duration 50 ms
   - Increase impurity gas injection rate to 20 Torr l / s in steps of 1-2 Torr l / s, increase the pulse duration from 50 ms to 200 ms, in accordance with plasma behavior and the flat-top length obtained (expect shortening due to increased plasma resistivity (Z_{eff}) and higher ohmic flux consumption). Monitor plasma radiated power
   - Conditional, time permitting - perform an impurity gas injection at established in 3 rates into a high density two NBI source shot from 1. Monitor radiated power
   - A 10 liter bottle of CD_4 has been reserved for this experiment. The quantity of methane in the bottle is 10 liter x (350 psi x 51.71 Torr/psi) = 181000 Torr l. A modification of gas handling setup may be developed to reduce the loss of methane to pipe and plenum pressure cycling and pumpout

– Run a standard fiducial as a last shot of the day to evaluate post-CD_4 wall conditions

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

Physics Operations Request and Diagnostic Checklist are attached.

Diagnostic capabilities: Tile Langmuir probes, IR cameras, main plasma and divertor bolometers, and the D_α, D_γ cameras should be operational. Lower divertor Langmuir probe locations are (major radii, m): 0.2775, 0.4952, 0.7970, 0.9110, 1.0170.

Branch 5 Injector in FLO mode must be tested prior to the execution of this experiment.

5. Planned analysis

The following numerical tools will be used for data analysis: LRDFIT, UEDGE, ADAS, DEGAS 2, TRANSP, analytic two point divertor model.

6. Planned publication of results

Results will be presented at the upcoming EPS, APS meetings, and will be published in a refereed journal as appropriate.

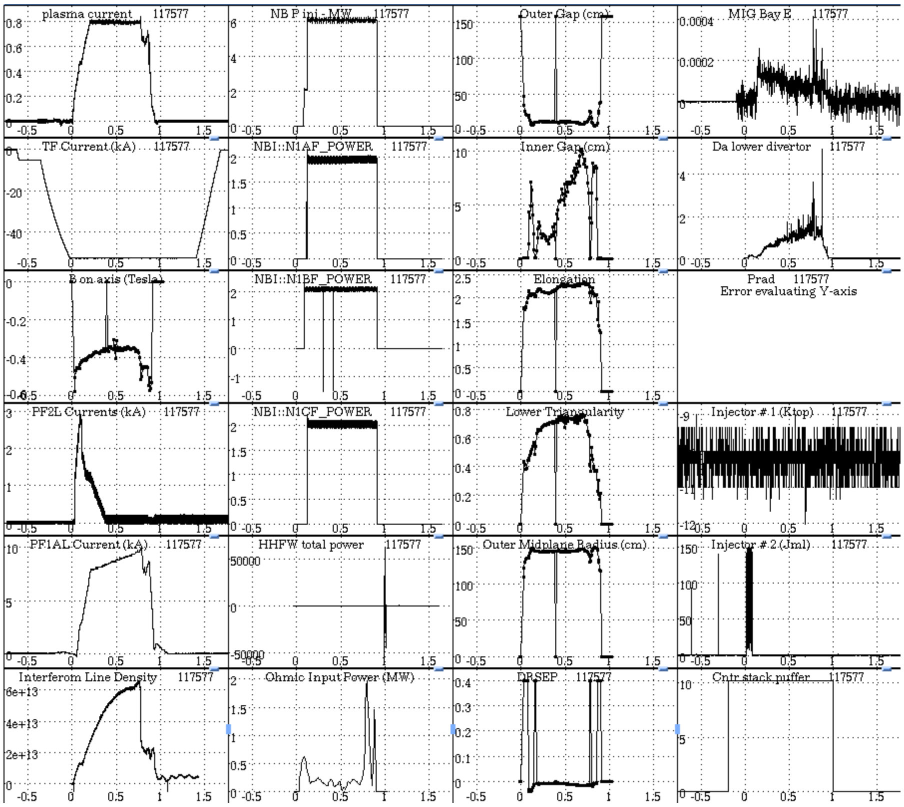
References

[1] V. A. Soukhanovskii, R. Maingi, R. Raman, R. E. Bell, C. Bush, R. Kaita, H. W. Kugel, C. J. Lasnier, B. P. LeBlanc, J. E. Menard, S. F. Paul , A. L. Roquemore, and the NSTX Team, “Divertor Heat Flux Reduction and Detachment in NSTX”, IAEA FEC 2006 (Chengdu, China 2006), to be submitted to Nuc. Fusion, 2007

[2] V. A. Soukhanovskii, R. Maingi, R. Raman, R. E. Bell, C. Bush, R. Kaita, H. W. Kugel, C. J. Lasnier, B. P. LeBlanc, J. Menard, S. F. Paul, A. L. Roquemore, and the NSTX Research Team, "Divertor heat flux reduction and detachment experiments in NSTX", *J. Nucl. Mater.*,to appear, 2007.

[3] Soukhanovskii, VA; Johnson, DW; Kaita, R; Roquemore, AL, "Electron density measurements in the National Spherical Torus Experiment detached divertor region using Stark broadening of deuterium infrared Paschen emission lines", *Rev. Sci. Instrum.,* **77,** 10F127, (2006).

[4] J. E. Menard et. al., “Recent physics results from NSTX”, IAEA FEC 2006 (Chengdu, China 2006), submitted to Nuc. Fusion, 2007


plasma current 117577
NB P inj - MW 117577
Outer Gap (cm)
MIG Bay E 117577
TF Current (kA) 117577
NBI::N1AF_POWER 117577
Inner Gap (cm)
Da lower divertor 117577
B on axis (Tesla)
NBI::N1BF_POWER 117577
Elongation
Prad 117577
Error evaluating Y-axis
PF2L Currents (kA) 117577
NBI::N1CF_POWER 117577
Lower Triangularity
Injector # 1 (Ktop) 117577
PF1AL Current (kA) 117577
HHFW total power 117577
Outer Midplane Radius (cm)
Injector # 2 (Jml) 117577
Interferom Line Density 117577
Ohmic Input Power (MW)
DRSEP 117577
Cntr stack puffer 117577

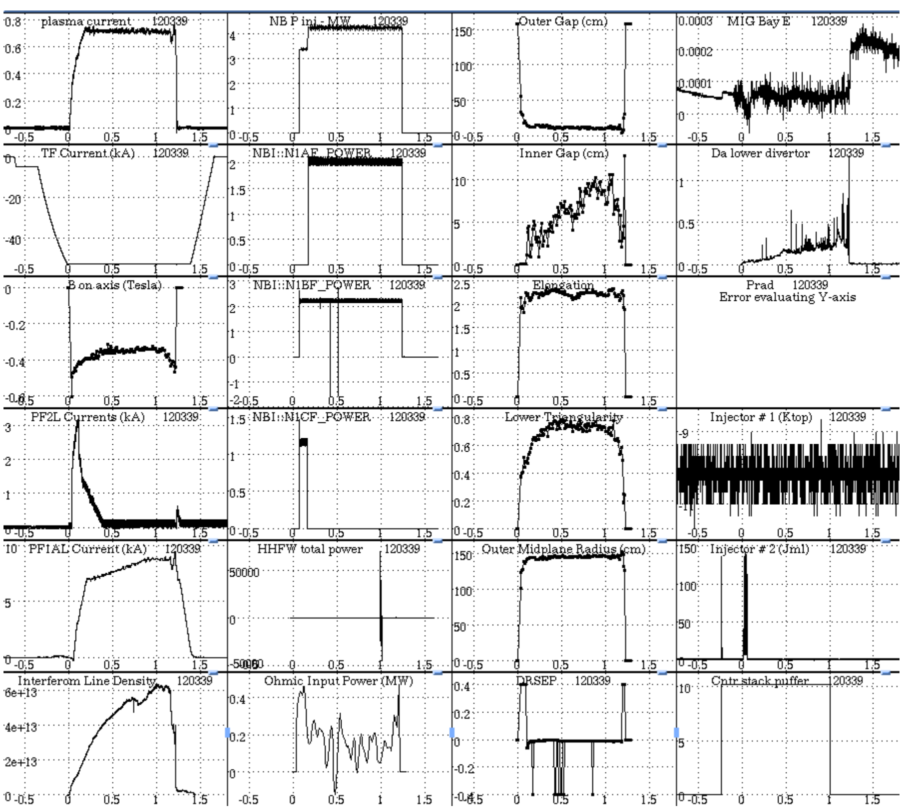

plasma current 120339
NB P inj - MW 120339
Outer Gap (cm)
MIG Bay E 120339
TF Current (kA) 120339
NBI::N1AF_POWER 120339
Inner Gap (cm)
Da lower divertor 120339
B on axis (Tesla)
NBI::N1BF_POWER 120339
Elongation
Prad 120339
Error evaluating Y-axis
PF2L Currents (kA) 120339
NBI::N1CF_POWER 120339
Lower Triangularity
Injector # 1 (Ktop) 120339
PF1AL Current (kA) 120339
HHFW total power 120339
Outer Midplane Radius (cm)
Injector # 2 (Jml) 120339
Interferom Line Density 120339
Ohmic Input Power (MW)
DRSEP 120339
Cntr stack puffer 120339

Figure 1. Example shots: 120339 (0.7 A), 119645 (0.8 A)

PHYSICS OPERATIONS REQUEST

Divertor heat flux reduction and detachment in highly shaped plasmas **OP-XP-708**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **-52.75** Flattop start/stop (s): **-0.02/1.2**

I_P (MA): **0.7-0.8** Flattop start/stop (s): **0.12/0.9**

Configuration: **Lower Single Null**

Outer gap (m): **0.10-0.13**, Inner gap (m): **0.05-0.0.08**

Elongation κ: **2.2-2.3**, Triangularity δ: **0.72-0.74**

Z position (m): **0.00**

Gas Species: **D / He / CD4**,

Gas Injector: **Midplane / Inner wall / Lower Dome/Branch 5**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **80**, Duration (s): **0.8-1.0**

ICRF – Power (MW): **0**, Phasing: **Heating / CD**, Duration (s): _____

CHI: **Off**

Either: List previous shot numbers for setup: **119645, 120339**

Gas setup: CS Injector – D_2 at 1300 Torr, LDGIS - D_2, Injector 1 – He, Injector 2 – D_2, Injector 3 - CD_4,

Injector Bay B High Flow - D_2 or He for GPI

DIAGNOSTIC CHECKLIST

Divertor heat flux reduction and detachment in highly shaped plasmas **OP-XP-708**

Diagnostic	**Need**	**Desire**	**Instructions**
Bolometer - tangential array	✓		
Bolometer array - divertor	✓		
CHERS	✓		
Divertor fast camera	✓		View the X-point region with Dα filter
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	✓		CIII, Dα, Dγfilters
Filterscopes	✓		
FIReTIP	✓		
Gas puff imaging	✓		Measure turbulence during detachment
High-k scattering			
Infrared cameras	✓		Divertor & CS
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			
Neutron Rate (2 fission, 4 scint)			
Neutron collimator			
Plasma TV	✓		Dα filter when requested, no filter otherwise
Reciprocating probe	✓		Operate on several shots when requested
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)	✓		Chords: inner, outer divertor and CS
X-ray crystal spectrometer - H		✓	
X-ray crystal spectrometer - V		✓	
X-ray PIXCS (GEM) camera			
X-ray pinhole camera			
X-ray TG spectrometer			