Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: Divertor heat flux reduction and detachment in NBI-heated plasmas		
OP-XP-605	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Author:	**V. A. Soukhanovskii**	Date
ATI – ET Group Leader:	**R. Maingi**	Date
RLM - Run Coordinator:	**R. Raman (S. Sabbagh)**	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 NBI-heated plasmas **OP-XP-605**

1. Overview of planned experiment

The goal of this experiment is to determine conditions of the outer divertor target heat flux reduction and detachment in the NBI-heated plasma operational space. The lower single null (LSN) plasma shape with elongation κ=1.9–2.0 and triangularity δ=0.5 will be used. The highest peak outer divertor heat fluxes (q < 4-7 MW/m^2) have been measured in this shape due to a low magnetic flux expansion (~ 3) at the outer strike point. Two techniques will be used to achieve the outer target heat flux reduction and detachment: raising density by means of D_2 injections, and raising edge radiated power by injecting an extrinsic impurity. 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 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.

2. Theoretical/ empirical justification

Previous divertor experiments in NSTX [1,2] 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. 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 locations radiative divertor conditions are apparently attained, whereas if D_2 is puffed in the lower divertor region 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 further. The Branch 5 injector will be used to puff deuterium in the lower divertor region in a steady-state manner to further study the partially detached regime. Midplane CD_4 injections will be used to increase divertor radiated power and achieve OSP detachment through divertor radiation simultaneously maintaining an H-mode confinement.

3. Experimental run plan

1. Setup an LSN (with PF2L coil) HFS-fueled plasma with elongation κ=1.9–2.0 and triangularity δ=0.5 and perform gas injection rate scan. Obtain several conditions at low, intermediate and high plasma density, with emphasis on the high-density part (15 - 20 shots)
   - Setup a discharge with 2 NBI sources at full energy, adjust the X-point height so that the inner strike point remains at 1-2 cm from the inner wall throughout discharge.
   - Example shots: 116484, 116485, 116488 (0.7 MA, 0.4 T RtEFIT-controlled shot)

- Use Branch 5 gas injector in FLO mode at several plenum pressures (1300 - 1800 T) to obtain injection rates 100 - 250 Torr l /s
- Add LDGIS injectors in series to obtain one LGDIS gas puff (fill pressure 100 - 200 Torr) s to directly compare to Branch 5 results
- 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}
  - (Conditional) In one discharge, turn off gas feed at 0.25-0.30 s
  - (Conditional) Run a helium discharge to de-saturate walls if necessary

(Note: if the limit of choking the plasma with gas is reached, proceed to CD_4 injections with configuration as in 1)

2. Perform CD_4 injections in increasing quantities (0.05 – 0.2 s duration pulses at a rate from 1 to 20 Torr l / s) into intermediate density two NBI source shot from 1. Monitor radiated power (10-15 shots).
   - Use Injector 3 for CD_4. Methane pulse start time 0.30 -0.35 s
   - Start with a CD_4 pulse at the rate of 1 Torr l / s, pulse duration 50 ms
   - Increase CD_4 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
   - 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 = 181000 Torr l. A modification of gas handling setup may be developed to reduce the loss of methane to pipe and plenum cycling and pumpout.
3. Conditional, time permitting - perform CD_4 injections at established in 2 rates into high density two NBI source shot from 1. Monitor radiated power.

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 and calibrated prior to the execution of this experiment.

5. Planned analysis

The following numerical tools will be used for data analysis: EFIT04, LRDFIT, UEDGE, ADAS, DEGAS 2, TRANSP, analytic two point divertor model.

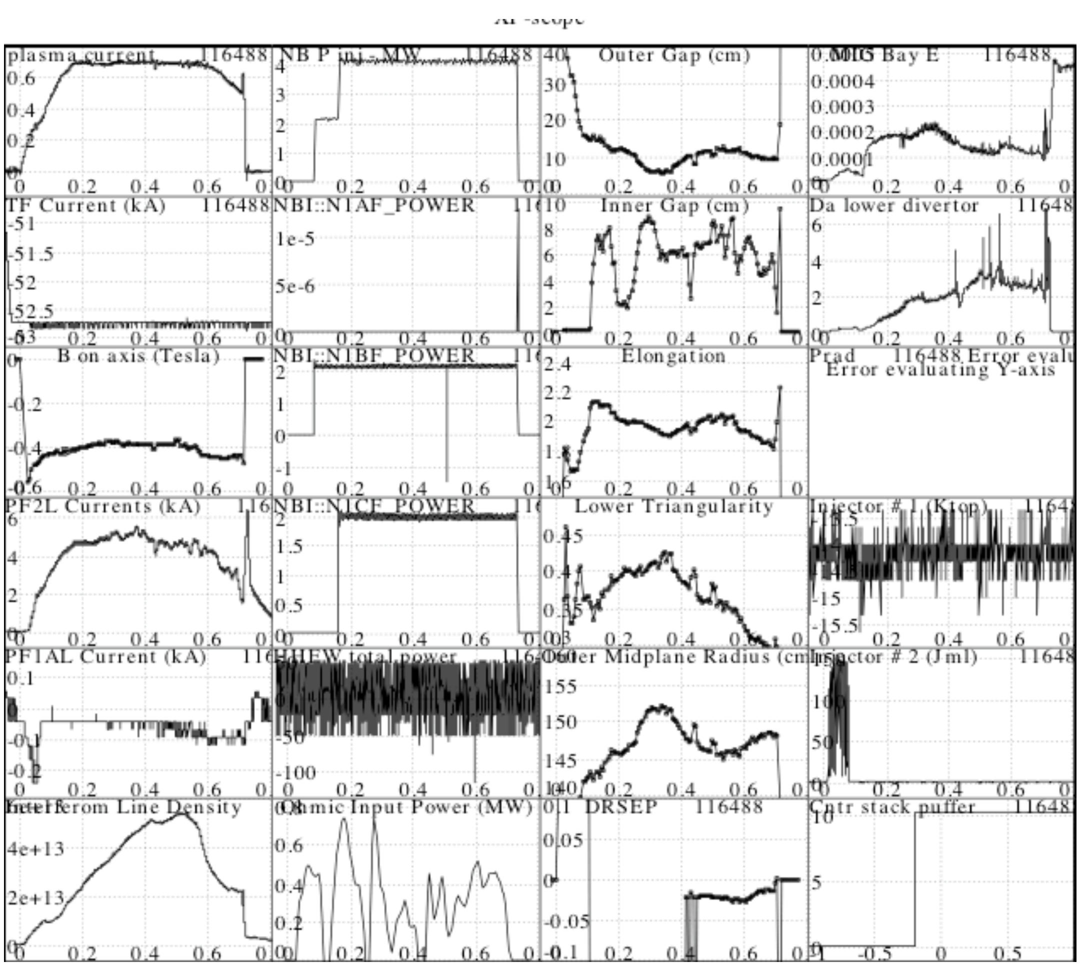
6. Planned publication of results

Results will be presented at the upcoming PSI, ITPA and/or IAEA meetings, and will be published in a refereed journal as appropriate.

References

[1] V. A. Soukhanovskii; R. Maingi; C. J. Lasnier, *et al.* "Particle and power exhaust in NBI-heated plasmas in NSTX", 32nd EPS Conference on Plasma Phys. (Tarragona, Spain, June 2005), *Europhys. Conf. Abstr.,* **29C,** pp P-4.016 (2005).

[2] V. A. Soukhanovskii et. al., GO3.00009: Dissipative divertor experiments in NSTX, 2005 47th Annual Meeting of the Division of Plasma Physics, October 24–28, 2005; Denver, Colorado



PHYSICS OPERATIONS REQUEST

Divertor heat flux reduction and detachment in NBI-heated plasmas **OP-XP-605**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **-52.5** Flattop start/stop (s): **-0.02/1.0**

I_P (MA): **0.7-0.8** Flattop start/stop (s): **0.12/0.6**

Configuration: **Lower Single Null**

Outer gap (m): **0.1**, Inner gap (m): **0.05-0.1**

Elongation κ: **1.9-2.0**, Triangularity δ: **0.5**

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): **0.6**

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

CHI: **Off**

Either: List previous shot numbers for setup: **116485, 116488**

<u>Gas setup</u>: CS Injector – D_2, 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 NBI-heated plasmas **OP-XP-605**

Diagnostic	**Need**	**Desire**	**Instructions**
Bolometer - tangential array	✓		
Bolometer array - divertor	✓		
CHERS	✓		Need in both deuterium and neon shots
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	✓		CAM1, CAM2: Dα, CAM3: Dβ, CAM4: Dγ
Filterscopes	✓		Use neon filter
FIReTIP	✓		
Gas puff imaging	✓		Measure turbulence in neon shots
High-k scattering			
Infrared cameras	✓		Divertor lower div., 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			