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

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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 steady-state outer divertor target heat flux reduction and detachment in the NBI-heated H-mode plasma operational space in two lower single null (LSN) configurations. These configurations are a lower-end elongation/triangularity LSN shape with κ=1.8–2.0 and δ<0.5, referred hereforth as the PF2L shape, and 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. 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

The highest peak outer divertor heat fluxes (typically q < 4-7 MW/m^2) are measured in plasmas with the PF2L shape, which is more challenging from the heat flux handling point of view. The PF1A shape is used in the long-pulse early H-mode scenario because of its improved stability. Typical peak outer divertor heat fluxes in this shape are 2-4 MW/m^2. 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. 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 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 fashion 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. Heat flux reduction and detachment in PF2L LSN plasmas with D_2 puffing
   - Setup an LSN (with PF2L coil) HFS-fueled plasma with elongation κ=1.9–2.0 and triangularity δ=0.5 and perform a gas injection rate scan (up to 15 shots)
   - Wall conditions should permit reproducible H-mode access
   - Use 2 NBI sources at full energy (80 kV). Start with A, B and adjust as needed
   - 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 50 - 250 Torr l /s
   - Add LDGIS injectors in series or in FLO mode to obtain one LGDIS gas puff (fill pressure 100 - 200 Torr) s to compare with 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) Run a helium discharge to de-saturate walls if necessary
2. Heat flux reduction and detachment in high elongation/triangularity (PF1A) LSN plasmas with D_2 puffing (up to 15 shots)
   - Setup an LSN (with PF2L+PF1A coils) HFS-fueled plasma with elongation κ=2.2–2.5 and triangularity δ=0.5-0.7 and perform a gas injection rate scan
   - Wall conditions should permit reproducible H-mode access
   - Use 2 NBI sources at full energy (80 kV). Start with A, B and adjust as needed
   - Example shots: 116318 (0.7 MA), 116313 (0.75 MA), 117577 (0.80 MA)
   - Use Branch 5 gas injector in FLO mode and/or LDGIS at several plenum pressures (1300 - 1800 T) to obtain injection rates 50 - 250 Torr l /s
3. Heat flux reduction and detachment in PF2L LSN plasmas with CD_4 puffing (up to 15 shots)
   - 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 (10-15 shots)
   - Wall conditions should permit reproducible H-mode access
   - Use Injector 3 for CD_4. Methane pulse start time 0.30-0.35 s, pulse duration 0.05 – 0.200 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/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
- Conditional, time permitting - perform CD_4 injections at established in 3 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

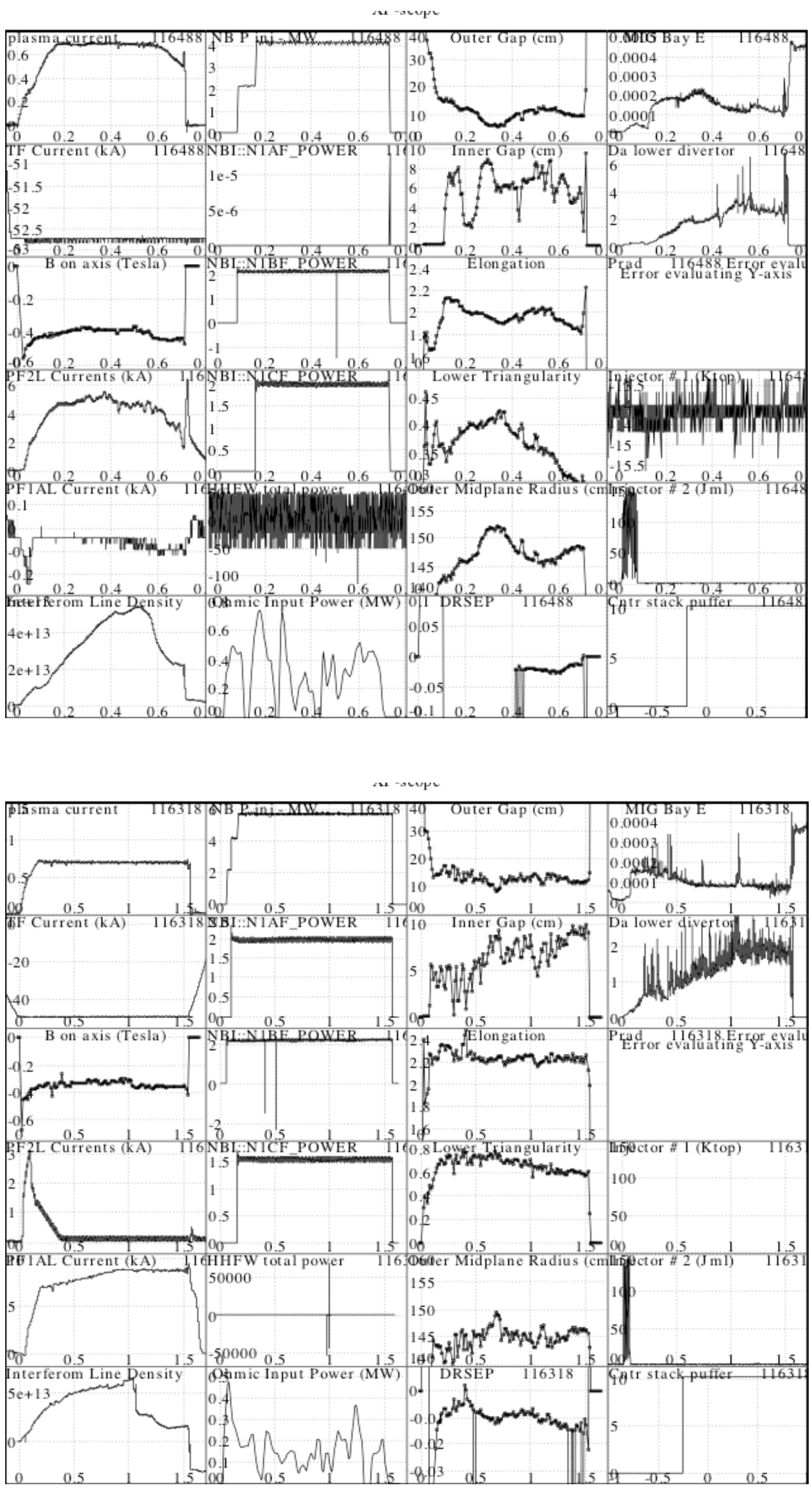

Figure 1. Example shots: 116488 (top) and 116318 (bottom)

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: **116488 and 116318**

Gas setup: 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	✓		
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	✓		
FIReTIP	✓		
Gas puff imaging	✓		Measure turbulence during detachment
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			