Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Divertor heat flux reduction and detachment in highly-shaped high-performance plasmas**		
OP-XP-814	Revision:	Effective Date: Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS	
Responsible Author:	Date
ATI – ET Group Leader:	Date
RLM - Run Coordinator:	Date
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Divertor heat flux reduction and detachment in highly-shaped high-performance plasmas** No. **OP-XP-814**

AUTHORS: **V. A. Soukhanovskii** DATE: **Mar 25, 2008**

1. Overview of planned experiment

The goal of this experiment is to study a steady-state partially detached divertor (PDD) regime in the NBI-heated H-mode plasma operational space in a higher-end elongation / triangularity lower single null (LSN) and double null (DN) shapes with κ=2.3–2.4 and δ=0.5-0.7. Two techniques will be used to obtain the outer strike point detachment: raising scrape-off layer density by means of D_2 injections, and raising edge radiated power by injecting an extrinsic impurity (helium). In the first part of the experiment deuterium will be injected in the lower divertor region. In the second part of the experiment helium will be injected in increased quantities to yield a high 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 brightness profiles, heat flux profiles from IR cameras,core and divertor radiated power, divertor Langmuir probe I_{sat} and neutral pressure will be measured and analyzed for signs of heat flux reduction, recombination, power and momentum loss, and an X-point MARFE formation. The goal is to determine the injected gas quantity necessary to establish PDD conditions, simultaneously retaining good core plasma quantities (MHD, confinement, impurity level).

2. Theoretical/ empirical justification

Presently, divertor geometry and radiative (detached) divertors are considered candidate techniques for steady-state mitigation of divertor heat flux and erosion of divertor material in ITER and future fusion plasma devices. Previous NSTX divertor peak heat flux reduction experiments conducted ina lower-end elongation κ = 1.8-2.0 and triangularity δ = 0.4-0.5 LSN configuration confirmed model predictions of a limited access to detachment. Recent experiments conducted in high-performance plasmas with a high flux expansion divertor demonstrated that divertor peak heat flux reduction and detachment access may be facilitated naturally in the highly shaped ST configuration. Improved plasma performance approaching the performance level of CTF with high β = 15-25 % and a high bootstrap current fraction 45-50 % sustained for several current redistribution times has been achieved in highly-shaped LSN plasmas with higher end κ = 2.1-2.4 and δ = 0.5-0.7. Access to detachment was demonstrated in highly shaped plasmas using additional D_2 injection at $\Gamma < 9.8 \times 10^{21}$ s^{-1} and divertor radiation from intrinsic carbon and residual helium. The proposed experiment will attempt to reproduce these results under controlled conditions (no helium) in LSN and DN configurations, and with a controlled helium injection.

3. Experimental run plan

Part 1. Heat flux reduction and detachment in high elongation / triangularity LSN plasmas with D_2 injection (similar to XP 709) (10-15 shots)

1. Setup an LSN HFS-fueled plasma with elongation κ = 2.2 – 2.4 and triangularity δ < 0.75 (2-3 shots) with highest possible I_p and 5 kG TF for highest divertor peak heat flux and edge field angle suitable for GPI turbulence measurements
   - Wall conditions should permit reproducible H-mode access with 2 NBI sources.
   - Use 3 NBI sources at full energy (80-90 kV)

- HFS plenum pressure is 1000-1300 Torr
- rtEFIT control will be used
- Use 126968 (1MA / 4.5 kG / 6 MW) as a template shot
- Other example shots from 2008: 127745 (0.9 MA/ 4.5 kG, 6 MW NBI); 126958 (1.0 MA / 4.5 kG / 4 MW); 127740, 127760 (1.1 MA/ 4.5 kG, 4-6 MW)
- Example shots from 2007: 125277 (1.0 MA, 4 MW NBI), 125280 (1.0 MA, 6 MW NBI). 125281 (1.2 MA, 6 MW NBI), all 4.5 kG TF
- Configuration will be adjusted to obtain *drsep* ~ -1.0 cm, outer gap ~ 10 cm, R_{OSP} ~ 40 – 45 cm, triangularity ~ 0.8, elongation 2.2-2.3

2. Perform a scan of gas injection rate and/or times (5 shots). Use new Bay E lower divertor gas injector. As a backup option, may use Branch 5 injector and the PZV4/4a valve to inject gas in the outer SOL close to outer strike point. Gas delay is about 0.100 s. Use a 10 ms pre-pulse to improve the flow rate.
   - Use Bay E lower divertor gas injector in flow mode at several plenum pressures to obtain injection rates 50 - 160 Torr l /s as shown in Table 1

Number	Plenum pressure	Injection time wrt t0 in PCS (s)	Gas pulse duration (s)
1	2500	0.300	0.100
2	5000	0.300	0.050-0.100
3	2000	0.300	0.100

- In one high density discharge, turn off NBI at the time when n_e is high (> 5 x 10^{19} m^{-3}) to obtain high density low input power condition for 50 - 200 ms
- Use GPI diagnostic to obtain edge turbulence data ion some shots
- Optional, time-permitting: attempt to obtain PDD conditions at 1.2 MA / 6 MW
- Optional, time permitting: Use Supersonic gas injector (SGI) instead of divertor gas puffers to obtain radiative / detached divertor conditions (main density ramp)
- Optional, time permitting: Use 2 NBI sources at full energy (80-90 kV) and best gas injection scenario to obtain detachment data at lower input power.

Part 2. Heat flux reduction and detachment in high elongation / triangularity DN plasmas with D_2 injection (similar to part 1) (10 shots)

Repeat the best gas injection scenario in DN shots. Optional, time permitting - scan down gas injection rate using plenum pressure increments of 1000-1500 Torr.

Part 3. (Optional, time permitting) Heat flux reduction and detachment in high elongation / triangularity LSN plasmas with He injection (similar to part 1) (up 10 shots)

1. Setup an LSN HFS-fueled plasma with elongation $\kappa = 2.2 - 2.4$ and triangularity $\delta < 0.75$ (2-3 shots)
2. Perform He injections in increasing quantities (from 5 to 20 Torr l / s) into intermediate density 3 NBI source shot from Part 1. Monitor radiated power (10 shots)

- Wall conditions should permit reproducible H-mode access
- Use Injector 3 for He
- The gas pulse start time is 0.300-0.400 s, pulse duration 0.05 – 0.300 s
- Start with a helium gas pulse at the rate of 10 Torr l / s, pulse duration 50 ms. Total amount of helium 0.5 Torr l / s
- Increase impurity gas injection rate to 100 Torr l / s in steps of 10-20 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.

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.

Gas injectors (Bay E lower divertor, Branch 5, SGI) 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 0D and 1D divertor models.

6. Planned publication of results

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

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

I_{TF} (kA): 52.8 Flattop start/stop (s): 0.0 – 1.35

I_P (MA): 1.0 (0.9, 1.1) Flattop start/stop (s): 0.2 - 1.0 (0.23 – 0.53 actual)

Configuration: **LSN, DN**

Outer gap (m): **10 cm** Inner gap (m): **6-8 cm**

Elongation κ: **2.20-2.3** Lower triangularity δ: **0.8**

Z position (m): **0.0**

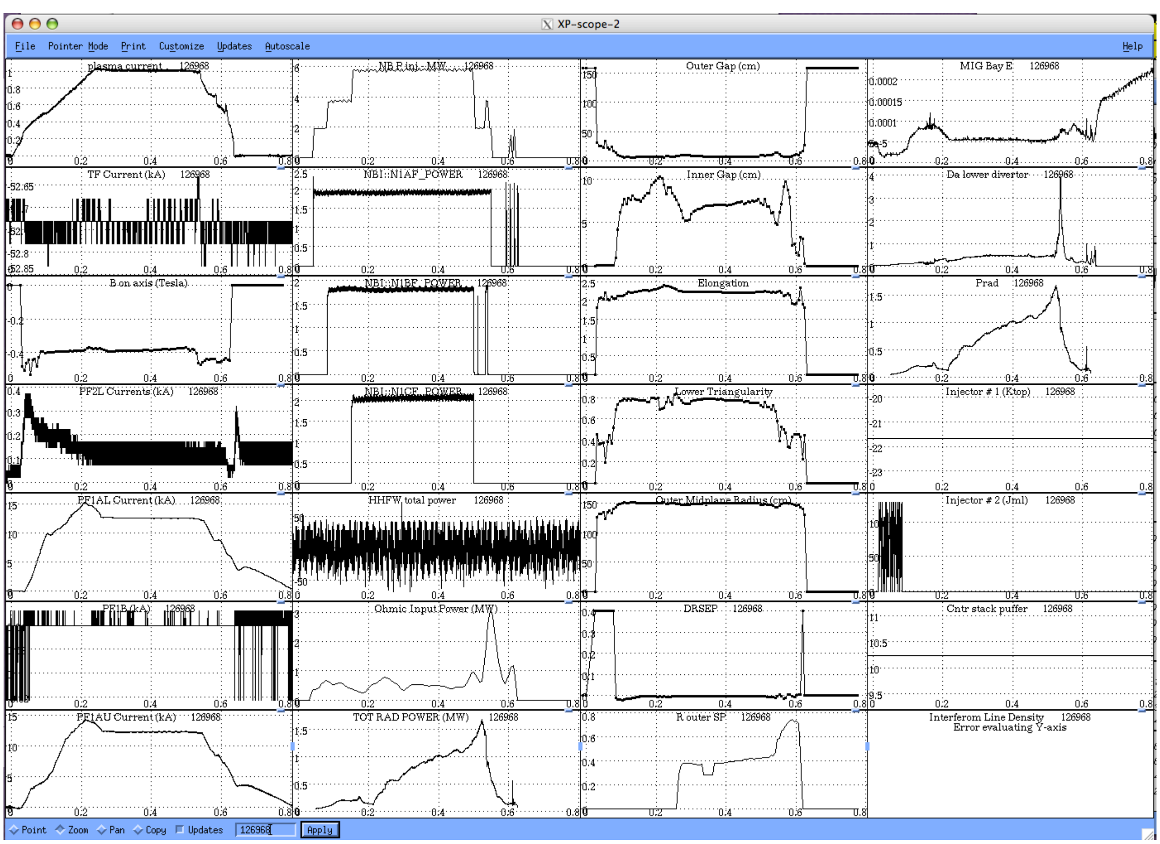
Gas Species: **D_2** Injector(s): HFS, Bay E Lower Divertor, SGI

NBI Species: **D** Sources: ABC Voltage (kV): 80-90 Duration (s): 1 s

ICRF Power (MW): None Phasing: Duration (s):

CHI: **Off** Bank capacitance (mF):

LITER: Off



DIAGNOSTIC CHECKLIST

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Diagnostic	Need	Want	Conditions
Bolometer – tangential array	x		
Bolometer – divertor	x		
CHERS – toroidal	x		
CHERS – poloidal	x		
Divertor fast camera		x	
Dust detector		x	
EBW radiometers			
Edge deposition monitors		x	
Edge neutral density diag.			
Edge pressure gauges	x		
Edge rotation diagnostic	x		
Fast ion D_alpha - FIDA			
Fast lost ion probes - IFLIP			
Fast lost ion probes - SFLIP			
Filterscopes	x		
FIReTIP	x		
Gas puff imaging	x		
$D\alpha$, $D\gamma$, CIII cameras - 1D	x		
High-k scattering			
Infrared cameras	x		
Interferometer - 1 mm			
Langmuir probes - divertor	x		
Langmuir probes - BEaP		x	
Langmuir probes – RF ant.			
Magnetics – Diamagnetism		x	
Magnetics - Flux loops		x	
Magnetics - Locked modes		x	
Magnetics - Pickup coils		x	
Magnetics - Rogowski coils		x	
Magnetics – Halo currents			

Diagnostic	Need	Want	Conditions
Magnetics - RWM sensors			
Mirnov coils – high f.			
Mirnov coils – poloidal array		x	
Mirnov coils – toroidal array		x	
Mirnov coils – 3-axis proto.			
MSE		x	
NPA – ExB scanning			
NPA – solid state			
Neutron measurements			
Plasma TV	x		
Reciprocating probe			
Reflectometer – 65GHz			
Reflectometer – correlation			
Reflectometer – FM/CW			
Reflectometer – fixed f			
Reflectometer – SOL		x	
RF edge probes			
Spectrometer – SPRED	x		
Spectrometer – VIPS	x		
SWIFT – 2D flow		x	
Thomson scattering	x		
Ultrasoft X-ray arrays	x		
Ultrasoft X-rays – bicolor		x	
Ultrasoft X-rays – TG spectr.		x	
Visible bremsstrahlung det.	x		
X-ray crystal spectrom'r - H			
X-ray crystal spectrom'r - V			
X-ray fast pinhole camera			
X-ray spectrometer - XEUS			