Princeton Plasma Physics Laboratory **NSTX-U Experimental Proposal**			
Title: **Assessment of NB-CD and pressure profile modifications by 2^{nd} NBI line**			
OP-XP-	Revision:	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*	
PROPOSAL APPROVALS			
Responsible Author: M. Podestà et al.			Date **03/12/2015**
SG, TSG or TF Leader (assigned by RC):			Date
Run Coordinator (RC):			Date
Responsible Division: Experimental Research Operations			
RESTRICTIONS or MINOR MODIFICATIONS (Approved by Experimental Research Operations)			

NSTX- EXPERIMENTAL PROPOSAL

TITLE: No. **OP-XP-**
AUTHORS: DATE:

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1. Overview of planned experiment

A new, more tangential Neutral Beam Injection (NBI) line has been installed on NSTX-U to improve NB current drive (CD) efficiency and to provide more flexibility for modifying current and pressure profile. The goal of this multi-TSG experiment is to perform a first assessment of the new operating regimes enabled by the 2nd NBI line, in addition to the more perpendicular NBI line already available on NSTX. The XP is divided in two parts, focusing on (i) NB-CD operating space with 1st+2nd NBI lines, and (ii) modifications of pressure profile by 2nd NBI line. Achieving these goals will provide a consistent set of data to fulfill the FY-15 Joint Research Target and the NSTX-U research milestone R15-2. It is expected that the main part of the experiment will be performed with boronized PFCs. A subset of the discharges will then be repeated with lithiated plasma-facing components (PFCs), with focus on the pressure profile dependence on NBI source mix.

2. Theoretical/ empirical justification

During the design phase of the NSTX Upgrade project, extensive effort has been dedicated to the optimization of the NB injection geometry of the 2nd NBI line, see *J. Menard et al., NF 2012* and *S. Gerhardt et al., NF 2012*. Predictions of the 2nd NBI performance have been obtained through modeling with the TRANSP code indicating, in general, higher current drive efficiency for the new (more tangential) NB sources. In addition, the possibility of varying the NBI mix from more on-axis to more off-axis is expected to provide enhanced flexibility in modifying the NB heating location, e.g. to broaden the pressure profile through off-axis heating.

All these predictions require extensive experimental validation, similarly to what has been done in the past on several devices (including NSTX) after major upgrades of the NBI system. Planned experiments on NSTX-U will proceed in two steps. First, consistency of experimental and predicted behavior is checked in a dedicated XP (coordinated by D. Liu, UCI). That XP focuses on basic aspects such as fast ion slowing down and neutron rate response under “classical” conditions, which will be compared with predictions from NUBEAM/TRANSP. Then, NBI physics is explored in the proposed XP for higher-performance H-mode plasmas to assess the new operating space achievable with thee combined 1st + 2nd NBI systems. The experiment includes scans of the NBI source mix for a limited set of Ip and Bt values (dedicated Ip/Bt scans are the goal of other XPs).

3. Experimental run plan

The experiment is divided in two parts, which specific focus on (1) NB-CD efficiency and (2) pressure profile modifications by varying the NBI source mix. For Part 1, a low-current Ip~700kA target scenario with P_{NB} up to 6MW is envisaged to maximize the non-inductive current fraction from the neutral beams. The target for Part 2 has higher current, Ip~1MA, for higher confinement. Part 2 will also provide data for a two-point Ip scan to extend the NB-CD study from Part 1. As time permits and discharge conditions allow, NB power will be increased up to 8MW in Part 2. A subset of discharges from Part 2 will then be repeated during a 1/2day session after the transition from boronized to lithiated PFCs.

When sources from the 2^{nd} NBI line are used, short (~20ms) pulses of source 1B are synchronized every 100ms with notches of the 2^{nd} NBI sources to obtain time evolution of ion temperature, toroidal rotation and Z_{eff} from CHERS measurements. (The optimum setup for NB blips/notches will be determined after the "CHERS assessment" XMP).

Discharges for both Part 1 and 2 are designed starting from a similar "template", see Fig. 2. The shot is divided into 4 phases, which include ramp-up and target set-up, plus two phases during which NBI parameters are varied. Ramp-up and target setup are kept identical for all discharges in order to have virtually the same initial conditions for the NB scans. Ideally, settings during ramp-up and set-up will be optimized to avoid/minimize low frequency MHD that was often observed in NSTX discharges. After that, NB mix and power are varied in two phases. Settings from 0.5sec to 1.0-1.3sec are aimed at collecting the highest-priority data to fulfill JRT-15 and Milestone R15-2. The exact duration of this phase will be determined depending on time scales for current and profile evolution. After 1.0-1.3sec, settings are varied again to collect additional, lower-priority data at – presumably – lower q_{min} and higher density values, in case the discharge lasts long enough.

Below is a detailed description of the run plan and discharge conditions for the two parts. For each condition, (at least) two shots are taken assess reproducibility and consolidate the database.

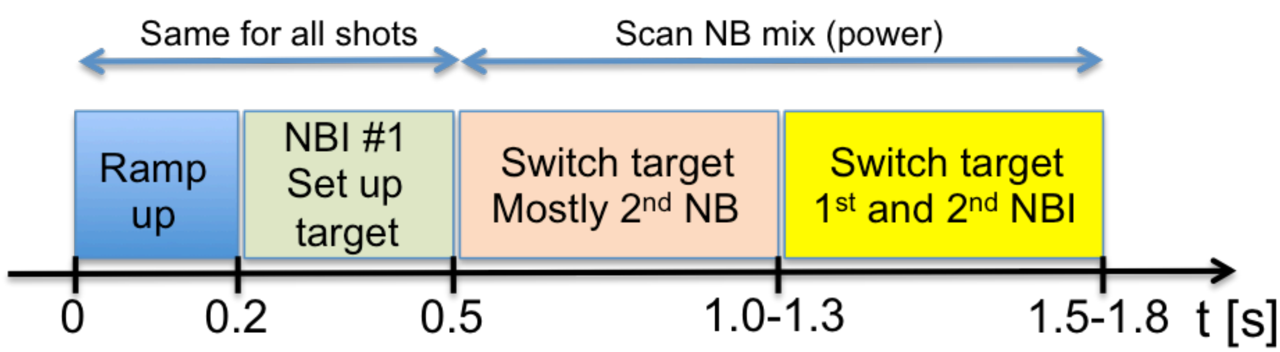

Fig. 1: Template discharge. Ramp-up and target set-up phases are the same for all shots, then NBI mix (and, possibly, power) are varied in two phases. Exact length of phase #3 is based on time scales for current and profiles relaxation, with additional constraints for CHERS, MSE diagnostics.

Part 1: NB-CD efficiency

Two conditions are explored in Part 1, with injected NB power during the steady-state phases of 4MW and 6MW. If time permits, a third set of discharges will explore NB-CD from the 2^{nd} NBI sources at reduced injection voltage ("4MW-equivalent" total P_{NB}), in anticipation of very-long pulses whose duration exceeds the allowed NB pulse duration at the nominal V_{inj}=90kV injection voltage (cf. Appendix #1). All discharges start with the same conditions of B_t=0.65T and I_p=700kA. The latter value of plasma current is chosen to maximize the NB-driven current fraction, but still retain fast ion confinement and stability that may be lost at even lower currents. A specific target will be selected after development of the "fiducial" NSTX-U discharge, in order to minimize shot development time for this XP.

NB source 1A is kept ON all the time for MSE measurements for all cases in Part 1. The proposed ramp-up and target set-up phases employ sources from the 1^{st} NBI line (see Table 1). This may be revisited as NSTX-U operations make progress in developing a reliable front-end, which may differ from what was used on NSTX. NB power in phases #1 and #2 is kept at ~4MW to reduce the drive for Alfvénic and other energetic-particle-driven instabilities. A short (~200ms) pulse from source 1C will be added at the beginning of the current flat-top, if required, to pre-heat the plasma and slow down the evolution of the q profile. The target value is q_{min}~1.5-2 at the beginning of phase #3 (~0.5sec).

NBI injection geometry is varied in phases #3 and #4 according to the list in Table 1.

NB-CD scan, 1 day

ID#	phase #1	phase #2	phase #3	phase #4	Notes
1	1A, 1B (, 1C)	1A, 1B	1A,1B	1A,1B	Reference for 4MW shots. Use NBI #1 only. Use 1C if additional pre-heating is required to slow down qmin evolution.
2	1A, 1B (, 1C)	1A, 1B	1A, 2C	1A, 2B	Part 1, 4MW shot, on-axis
3	1A, 1B (, 1C)	1A, 1B	1A, 2B	1A, 2A	Part 1, 4MW shot, intermediate
4	1A, 1B (, 1C)	1A, 1B	1A, 2A	1A, 2C	Part 1, 4MW shot, off-axis
5	1A, 1B (, 1C)	1A, 1B	1A, 1B, 1C	1A, 1B, 1C	Reference for 6MW shots. Use NBI #1 only. Use 1C if additional pre-heating is required
6	1A, 1B (, 1C)	1A, 1B	1A, 1C, 2C	1A, 2C, 2B	Part 1, 6MW shot, intermediate
7	1A, 1B (, 1C)	1A, 1B	1A, 1C, 2B	1A, 2B, 2A	Part 1, 6MW shot, intermediate
8	1A, 1B (, 1C)	1A, 1B	1A, 2C, 2B	1A, 2B, 2A	Part 1, 6MW shot, on-axis
9	1A, 1B (, 1C)	1A, 1B	1A, 2B, 2A	1A, 2C, 1B	Part 1, 6MW shot, off-axis
10	1A, 1B (, 1C)	1A, 1B	1A, 2C, 2B	1A, 2C, 2B	Part 1, 4MW-equiv. with sources 2C, 2B, 2A @65kV, on-axis
11	1A, 1B (, 1C)	1A, 1B	1A, 2C, 2A	1A, 2C, 2A	Part 1, 4MW-equiv. shot, intermediate
12	1A, 1B (, 1C)	1A, 1B	1A, 2B, 2A	1A, 2B, 2A	Part 1, 4MW-equiv. shot, off-axis
13	1A, 1B (, 1C)	1A, 1B	1A, 2B, 2A	1A, 2C, 2B	Part 1, 4MW-equiv. shot, intermediate

Table 1: List of conditions for Part (1) of the experiment. Light red background indicates required conditions. Light green background indicates shot that will be run if time allows. Two shots are planned for each condition.

Part 2: NBI mix effects on pressure profile

Part 2 is divided in two sessions: 1day early in the Run, with boronized PFCs, and 1/2 day later in the Run, after the transition to lithiated PFCs. All discharges start with the same nominal conditions as Part 1 but with higher current, I_p=1MA. Similarly to Part 1, discharges include two phases during the flat-top, with phase #3 including the highest-priority conditions of the experiment. Each condition is repeated twice to check reproducibility and consolidate the database.

To be discussed: if sufficient progress is made in the "low density start-up" XP, conditions #14 through #17 will be repeated at lower density to vary the NB absorption profile and assess pressure broadening and NB-CD vs. NBI mix for the low-density case. Cases #23 through #26 will move to lower priority.

The list of conditions for the two sessions is given in Table 2 (Boron-PFCs) and Table 3 (Li-PFCs). Note that Table 3 contains a sub-set of conditions from Table 2, with the goal of performing a direct comparison for the same NBI injection settings and assess differences with lithiated PFCs.

pressure broadening with boronized PFCs, 1 day

ID#	phase #1	phase #2	phase #3	phase #4	Notes
14	1A, 1B (, 1C)	1A, 1B	1C, 2A	1C, 2A	Part 2, 4MW shot, broad pressure, steady
15	1A, 1B (, 1C)	1A, 1B	1A, 2B	1A, 2B	Part 2, 4MW shot, intermediate peaking
16	1A, 1B (, 1C)	1A, 1B	2C, 2B	2C, 2B	Part 2, 4MW shot, most peaked
17	1A, 1B (, 1C)	1A, 1B	2C, 2B	1C, 2A	Part 2, 4MW shot, transition peaked -> broad
18	1A, 1B (, 1C)	1A, 1B	1B, 1C, 2A	1B, 1C, 2B	Part 2, 6MW shot, broad pressure
19	1A, 1B (, 1C)	1A, 1B	1A, 1B, 2C	1A, 1B, 2B	Part 2, 6MW shot, intermediate peaking
20	1A, 1B (, 1C)	1A, 1B	1A, 1B, 2B	1A, 1B, 2C	Part 2, 6MW shot, intermediate peaking
21	1A, 1B (, 1C)	1A, 1B	1A, 2C, 2B	1A, 2C, 2B	Part 2, 6MW shot, most peaked
22	1A, 1B (, 1C)	1A, 1B	1A, 2C, 2B	1C, 1B, 2A	Part 2, 6MW shot, transition peaked -> broad
23	1A, 1B (, 1C)	1A, 1B	1A, 1B, 1C, 2A	1C, 1B, 2A	Part 2, 8MW shot, broad pressure
24	1A, 1B (, 1C)	1A, 1B	1A, 1B, 2B, 2A	1A, 2B, 2A	Part 2, 8MW shot, intermediate peaking
25	1A, 1B (, 1C)	1A, 1B	1A, 2C, 2B, 2A	1A, 2C, 2B	Part 2, 8MW shot, intermediate peaking
26	1A, 1B (, 1C)	1A, 1B	1A, 1B, 2C, 2B	1A, 2C, 2B	Part 2, 8MW shot, most peaked

Table 2: List of conditions for the pressure profile scan in Part 2, to be run with boronized PFCs. Color coding is the same as for Table 1. Lower-priority shots from this Table will be run after the entire shot list from Table 1 is completed.

pressure broadening with Li-PFCs, 1/2 day

ID#	phase #1	phase #2	phase #3	phase #4	Notes
28	1A, 1B (, 1C)	1A, 1B	1C, 2A	1C, 2A	Part 2, 4MW shot, broad pressure, Li-PFC
29	1A, 1B (, 1C)	1A, 1B	1A, 2C	1A, 2C	Part 2, 4MW shot, intermediate peaking
30	1A, 1B (, 1C)	1A, 1B	2C, 2B	2C, 2B	Part 2, 4MW shot, most peaked
31	1A, 1B (, 1C)	1A, 1B	1B, 1C, 2A	1B, 1C, 2B	Part 2, 6MW shot, broad pressure, Li-PFC
32	1A, 1B (, 1C)	1A, 1B	1A, 1B, 2C	1A, 1B, 2B	Part 2, 6MW shot, intermediate peaking
33	1A, 1B (, 1C)	1A, 1B	1A, 2C, 2B	1A, 2C, 2B	Part 2, 6MW shot, most peaked

Table 3: List of conditions for Part 2, to be run with lithiated PFCs.

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

The XP requires reliable access to H-mode, with well-reproducible front-end. Sufficiently long pulse duration, at least 1-1.3sec with >0.8sec flat-top at both I_p=0.7MA and I_p=1MA, is needed.

All 6 NB sources must be operational. Operations of the 2nd NBI sources at E_{inj}=65kV is desired, but it is lower priority in the shot plan (to be discussed with NB operators). Neither RF nor CHI is required.

All profile diagnostics are needed: MPTS, CHERS, MSE. All fast ion diagnostics are needed: FIDA, ssNPA, sFLIP, (calibrated) neutron counters. Running CHERS and FIDA checkout XMPs is a pre-requisite to ensure correct operation of those systems during the XP.

Fluctuation diagnostics are desired to monitor MHD and EP-driven modes activity, and to complement the data set from the "I_p/B_t scan" XP: high-frequency Mirnov coils (HN and HF arrays), BES, reflectometers.

The proposed diagnostic list will be extended as per request from other TSGs.

5. Planned analysis

EFIT and LRDFIT for equilibrium reconstruction.

TRANSP for time-dependent modeling, including fast ion transport models to account for MHD activity (if any). Analysis with NOVA-K, ORBIT, possibly SPIRAL is also planned to assess MHD activity effects on fast ion transport and NB-CD.

6. Planned publication of results

JRT-15 Report, R15-2 Report, ITPA-EP Joint Experiment

Meetings: APS 2015, IAEA 2016.

A Nuclear Fusion paper is expected from the IAEA 2016 meeting. Other publications based on data from this database are expected, e.g. on Alfvén Eigenmode stability vs. NBI injection.

7. Estimated Neutron Production

Based on the number of shots, plasma current levels, and expected durations, estimate the maximum neutron production of this experiment. See calculator in Appendix #2 for this calculation.

# of Shots used in Estimate: 66 Estimated Total Neutron Production: 2.58e16

PHYSICS OPERATIONS REQUEST

TITLE: No. **OP-XP-**
AUTHORS: DATE:

Brief description of the most important operational plasma conditions required and any special hardware requirement:

All 6 NBI sources must be up & running. May need sources 2A, 2B and 2C at reduced voltage V_{inj}=65kV (tbd with NBI operators). Need profile diagnostics with in-between-shots analysis. Need reliable and reproducible H-mode plasmas with P_{NB}=4-6MW and flat-top duration of (at least) 1sec.

Previous shot(s) which can be repeated:

Previous shot(s) which to modify:

Machine conditions *(specify **ranges** as appropriate, strike out inapplicable cases)*

B_T Range (T): **0.65** Flattop Duration (s): **2**

I_P Range (MA): **0.7-1** Flattop Duration (s): **>1**

Configuration: **LSN**

Equilibrium Control: **Outer gap / Isoflux** (rtEFIT)

Outer gap (m): Inner gap (m): Z position (m):

Elongation: **~2.3** Triangularity (U/L): **~0.6** OSP radius (m):

Gas Species: **D** Injector(s): **tbd**

NBI Species: **D** Heating Duration (s): **1.5**

Voltage (kV) 50 cm (1C): 90 60 cm (1B): 90 70 cm (1A): 90

Voltage (kV) 110 cm (2C): 90/65 120 cm (2B): 90/65 130 cm (2A): 90/65

ICRF Power (MW): **n/a** Phase between straps (°): Duration (s):

CHI: OFF Bank capacitance (mF):

LITERs: ON (Part 2b only) Total deposition rate (mg/min): tbd

EFC coils: ON for error field correction

DIAGNOSTIC CHECKLIST [1]

TITLE: No. **OP-XP-**

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Beam Emission Spectroscopy		**X**
Bolometer – midplane array		
CHERS – poloidal		**X**
CHERS – toroidal	**X**	
Divertor Bolometer (LADA)		
Divertor visible cameras		
Dust detector		
Edge deposition monitors [2]		
Edge neutral density diag.		
Edge MIGs [2]		
Penning Gauges [2]		
Edge rotation diagnostic		**X**
Fast cameras – divertor [2]		
Fast ion D_alpha - poloidal	**X**	
Fast ion D_alpha - toroidal	**X**	
Fast lost ion probes - IFLIP		**x**
Fast lost ion probes - SFLIP	**X**	
Filterscopes [2]		
FIReTIP		
Gas puff imaging – divertor		
Gas puff imaging – midplane		
Hα cameras - 1D [2]		
Infrared cameras [2]		
Langmuir probes – divertor		
Langmuir probes – RF		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism		
Magnetics – Halo currents		
Magnetics – RWM sensors		

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
MAPP		
Mirnov coils – high f.	**X**	
Mirnov coils – toroidal array	**X**	
MSE-CIF		
MSE-LIF	**X**	
Neutron detectors [2]	**X**	
Plasma TV		
Reflectometer – 65GHz		
Reflectometer – correlation		
Reflectometer – FM/CW		
Reflectometer – fixed f		**X**
Reflectometer – SOL		
SSNPA [2]	**X**	
RF edge probes		
Spectrometer – divertor		
Spectrometer – MonaLisa		
Spectrometer – VIPS		
Spectrometer – LOWEUS		
Spectrometer – XEUS		
TAE Antenna		
Thomson scattering	**X**	
USXR – pol. Arrays		
USXR – multi-energy		
USXR – TG spectr.		
Visible Brems. det. [2]		

Notes:

[1] Check marks in this table do not guarantee diagnostic availability. Check with diagnostic physicists or research operations management to ensure diagnostic coverage.

[2] In some cases, a given line represents multiple diagnostics. For instance, there are multiple SSNPAs, multiple IR cameras, and multiple neutron detectors, multiple Langmuir probe arrays.

Appendix #1: Allowed Neutral Beam Power vs. Pulse Duration

Heating of the primary energy ion dump limits the beam duration to that given in the following table[1]:

Acceleration Voltage [kV]	MW per Source	MW per Beamline	Pulse Length [s]
65	1.1	3.2	8
70	1.3	3.8	7
75	1.5	4.5	6
80	1.7	5.1	5
85	1.9	5.8	4
90	2.1	6.4	3
95	2.4	7.1	2
100	2.6	7.7	1.5
105	2.8	8.4	1.25
110	3.0	9.0	1

Table A1: Beam power and pulse length as a function of acceleration voltage

Appendix #2: Table for neutron rate estimations:

Change only the blue cells					
I_p Range [kA]	Center of I_p Range [kA]	Number of Discharges	Typical Discharge Time [s]	Assumed Neutron Rate [N/s]	Fluence at this I_p [N]
$0<I_p\leq400$	200	0	0	0.00E+00	0.00E+00
$400<I_p\leq600$	500	0	0	1.00E+14	0.00E+00
$600<I_p\leq800$	700	26	1.5	2.00E+14	7.80E+15
$800<I_p\leq1000$	900	40	1.5	3.00E+14	1.80E+16
$1000<I_p\leq1200$	1100	0	1	4.00E+14	0.00E+00
$1200<I_p\leq1400$	1300	0	0	5.00E+14	0.00E+00
$1400<I_p\leq1600$	1500	0	0	8.00E+14	0.00E+00
$1600<I_p\leq1800$	1700	0	0	1.30E+15	0.00E+00
$1800<I_p\leq2000$	1900	0	0	2.00E+15	0.00E+00
Total # of Discharges		66		Total Fluence	2.58E+16

Table A2: Neutron Emission Rate Calculator. Double click to open in excel for automatic calculation. Change only the blue cells.

[1] J.E. Menard, et al., Nuclear Fusion **52**, 2012 (83015)