Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: **Development of high-κ scenarios with high non-inductive fraction and reduced impurity content.**		
OP-XP-1008	Revision:	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS	
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RLM - Run Coordinator: Eric Fredrickson	Date
Responsible Division: Experimental Research Operations	

RESTRICTIONS or MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **High-κ, f_{NI}, low impurity discharge development** No. **OP-XP-1006**
AUTHORS: **S.P. Gerhardt, et al.** DATE:

1. Overview of planned experiment

The goal of this experiment will be to develop discharge scenarios with a large non-inductive fraction and reduced impurity accumulation. The primary means of doing this will be to incorporate previously tested impurity control techniques into the high-κ target. If this is not successful, then some reduction of I_P will be attempted.

The target will be high-κ, lithium conditioned discharge 133964 (0.48 T and 700 kA); modifications to the shot will be made one it is reproduced. Impurity reduction techniques such as ELM pacing, divertor gas puff, and dr_{sep} optimization will be used, first sequentially and then combined. The compatibility of these techniques with the high-performance plasma state will be documented.

If this is not successful, then attempts at increasing f_{NI} by decreasing I_P will be made.

Time permitting, two additional steps are included to address other aspect of these discharge scenarios:

i) beam modulations will be used to further test/verify the TRANSP model for NB heating

ii) a brief kappa scan at fixed normalized current

2. Theoretical/ empirical justification

Experiments in 2009 demonstrated a largely reliable scenario with $<V_{loop}>_{flat-top}$~130 mV, with minimal MHD activity. These discharges has non-inductive current fractions of ~65-70%, but suffered from large levels of radiated power and impurity accumulation. This resulted in smaller values of β_P for a given density, compared to a more pure plasma. Also, the continued rise in impurities contributed to the ramping electron density. Other problem included a shut-off of the OH rectifier if it spent too much time on the positive side of zero, and some kicking-around of the outer gap.

(Potential) fixes are in hand for all these problems.

1) A number of impurity reduction techniques have been tested in NSTX (ELM pacing, divertor gas puff, dr_{sep} optimization).

2) The OH rectifier was given a longer time widow.

3) The rtEFIT basis vectors were improved.

4) More experience has been gained with SGI fuelling

5) We have an improved RWM control system.

3. Experimental run plan

The overall layout of the XP is to develop the high-q_{95}, high-β_P target, then make perturbations to it:

i) If Z_{eff} and P_{rad} are increasing (as in 2009), then implement impurity reduction steps.

ii) If the global stability is at issue, then implement a small optimization of the RWM feedback parameters and bring in β-control.

iii) If radiation and impurity accumulation are not a problem, then optimize the early fuelling.

iv) Do a test of beam modulation, to establish the difference in NB losses among the three sources in H-mode plasmas.

v) Test a reduced plasma current target.

3.1: Generate target

Reload discharge 133964, 300 mg Lithium, same beams as that day. Initial gas fuelling at the discretion of the physics operator.

Load RWM and mode-ID categories from shot 139514. This loads the "miu" algorithm, with 180 degree feedback phase.

Note that some number of shots will likely be required to establish a reproducible condition with lithium conditioning.

Check new discharge against reference for:

1) Early density evolution (increase/decrease LFS/HFS gas)
2) Early *AE modes (increase LFS/HFS gas if large modes are observed)
3) β_N, l_i, I_{OH} evolution (check against old shot as a measure of confinement and global performance)
4) Radiated power rise and Z_{eff}.

3.2: Reduce TF to 0.45 T

Load the TF waveform from a typical morning fiducial shot.

Extend I_p to fill the flat-top.

Check for onset of late n=1 mhd, changes to β_P and loop voltage.

Choose one of these conditions (B_T=0.44 or B_T=0.48) for the target in later discharges, with a preference for the slightly longer pulse.

Decision point #1

If global stability appears to be a problem (maybe due to improved confinement compared to last year), then go to "RWM Phase-Scan Contingency"

If impurity accumulation is an issue as last year, then go to section 3.3.

If neither of these is a problem, then go to section 3.5.

RWM Phase-Scan Contingency:

These discharges will use the new “miu” compensation algorithm. The shot selected above for RMW control settings has a 180 degree feedback phase. If the shot in this XP fails to run through because of rapidly growing modes, then implement a short scan of the RWM feedback phase parameter between 180 & 270 degrees. Otherwise skip this step.

B_P Feedback Phase	Shot
180	
270	
225	

3.3: Test three ideas for reduced impurity accumulation

Not all of these techniques will be tested. It will be a judgment call leading up to, and during, the run day, in determining which to test.

3.3.1 ELM Pacing: (4-6 shots)

Add n=3 triggering pulses as per the following table:

Pulses Start (msec)	Pulse Width (msec)	Pulse Frequency (Hz)	Pulse Amplitude (kA)	Shot
300	5	10	2 kA	

3.3.2 Divertor Puffing: (5 shots)

Use template shots 138768, 138769, from XP-1002. Likely good scenarios have 2500-3000 torr in the bay E gas injector, single pulse of ~100 msec duration, early in the shot. There is a ~100 msec delay between the injector firing and the gas entering.

Note that it may be necessary to reduce the HFS gas during discharges with divertor fuelling.

Pressure	Pulse Timing	Duration	Shot
2500	150	100	
2500			

3.3.3: dr_{sep} optimization: (5 shots)

Base discharge (133964) has dr_{sep}=-5 mm.

Scan dr_{sep} over a range -15 mm to 0 mm. Also, try to make change as early in the shot as will be tolerated.

shot	dr_{sep} (mm)	Time of dr_{sep} change	shot
	-5		
	0		
	-10		
	0		
	5		

3.3.4 Transition to the snowflake divertor: (5 shots)

A graceful means of transitioning to the snowflake divertor may be to start the plasma up diverting with PF-1A only, then transition to using PF-1AL, PF-2L, and PF-1B. The target shot has I_{PF-1A}/I_P=9/0.72=12.5 kA/MA. It is likely that the PF-1AL current will need to be rampd down, while the PF-1B and then PF-2L are ramped up.

Final PF-1A Current	Final PF-2L Current	Final PF-1B Current	shot

3.4: Test of combined efficacy. *(5 shots)*

Take best scenarios from 3.3 and attempt to combine them.

3.5: Improved fuelling scenario (5 shots)

The improved fuelling scenario is motivated by two observations:

i) Many NSTX discharges with lithium conditioning show many large TAE avalanches early in the shot, which can deleteriously modify the early current evolution. Raising the early density may help eliminate these modes.

ii) If the impurity accumulation is arrested, it may indeed be necessary to provide more D_2 fuelling.

Add SGI fuelling in order to prop up the early density evolution. Then reduce the HFS gas as appropriate. Note that the goal is NOT to eliminate the HFS gas, only to flatten the density evolution.

shot	Pulse Start Times	Pulse Durations	HFS Pressure

3.6: Test beam modulations in high-performance H-modes.

In successive shots, modulate each of the beams with 20 msec on/off times. Start of modulations should be sufficiently far into I_P flat-top that the shot is reliable, for instance 250 msec seems a reasonable time to start.

Source	Modulation time	Shots
A		
B		
C		

3.7 Variation of I_P

It may be desirable to attempt to increase the non-inductive fraction by further lowering the plasma current. Beware of excessive beam loss when I_P becomes too small.

Pick favorite scenario (likely without any complicating impurity elimination tricks), and reduce I_P. Things to be aware of:

i) Likely need to reduce the fuelling as I_P is dropped.

ii) Check that rtEFIT is staying sufficiently converged at lower Ip

iii) Be aware of risks associated with NB loss.

iv) The I^2t or overtime limit on the OH coil may be a problem.

I_P	Gas Parameters	Shots
600		

3.8 Kappa Scan at Fixed Normalized Current

There has been continued discussion of whether running at the highest kappa leads to degradation in confinement. Hence, conduct a small scan of the flat-top elongation in the preferred target condition.

Note that kappa can be scanned via changes of ~0.01 in the lower- and upper-outer squareness.

κ	UO Squareness	LO Squareness	Shots

Reference: Toroidal field waveforms for various field levels

B_T	Current	Flat-top End	Shots
0.47	56.2	1.17	133964
0.49	58.5	0.97*	124579
0.51	60.9	0.84*	121111
0.535	64.3	0.65*	125074

* Can possibly be shifted to provide additional duration…but be careful of coil heating!

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

This XP needs 6 MW of NB heated power, RWM control, and lithium evaporation at a rate of 250-300 mg per shot. Full profile diagnostics are necessary. Bay E injector should be prepared with 5000 Torr of D_2, and SGI on standby.

5. Planned analysis

MSE constrained equilibrium reconstructions will be required. TRANSP will be run in order to quantify the transport and non-inductive current components. The bootstrap and inductive currents will also be assessed using homegrown codes. Ideal stability may be computed with codes such as DCON.

6. Planned publication of results

These results will be presented at the 2010 IAEA FEC & APS meetings, and may contribute to presentations, conference papers and journal articles by Gerhardt, Canik, Scotti, and Soukhanovskii

PHYSICS OPERATIONS REQUEST

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(use additional sheets and attach waveform diagrams if necessary)

Brief description of the most important operational plasma conditions required:

Need: i) Dual LITER system, ii) 6 MW NBI, iii) all profile diagnostics, iv) RWM control

Previous shot(s) which can be repeated: 133964

Previous shot(s) which can be modified: 133964

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

I_{TF} (kA): **4.5-5.0 T** Flattop start/stop (s): **Full I^2t for the given current**

I_P (MA): **500-800 kA** Flattop start/stop (s): **As long as possible, consistent with TF**

Configuration: **near DN, maybe some up/down balance scans.**

Equilibrium Control: **Isoflux** (rtEFIT)

Outer gap (m): **10-15 cm** Inner gap (m): **~2-5 cm** Z position (m): **-1 to +1 cm**

Elongation: **2.5-2.7** Triangularity (U/L): **PF-1A Diverted** OSP radius (m): **~35-40 cm**

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

NBI Species: **D** Voltage (kV) **A: 90** **B: 90** **C: 90** Duration (s):

ICRF Power (MW): **0** Phase between straps (°): **NA** Duration (s): **NA**

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

LITERs: On Total deposition rate (mg/min): **rate for 250-300 mg/shot**

LLD: Cold Temperature (°C): **Cold**

EFC coils: On Configuration: **Odd**

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Beam Emission Spectroscopy		√
Bolometer – divertor		√
Bolometer – midplane array	√	
CHERS – poloidal		√
CHERS – toroidal	√	
Dust detector		
Edge deposition monitors		
Edge neutral density diag.		
Edge pressure gauges		
Edge rotation diagnostic		
Fast cameras – divertor/LLD		
Fast ion D_alpha - FIDA		
Fast lost ion probes - IFLIP		
Fast lost ion probes - SFLIP		
Filterscopes	√	
FIReTIP		
Gas puff imaging – divertor		
Gas puff imaging – midplane		
Hα camera - 1D		√
High-k scattering		√
Infrared cameras		√
Interferometer - 1 mm		
Langmuir probes – divertor		√
Langmuir probes – LLD		√
Langmuir probes – bias tile		
Langmuir probes – RF ant.		
Magnetics – B coils	√	
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		√
Magnetics – RWM sensors	√	
Mirnov coils – high f.		√
Mirnov coils – poloidal array		
Mirnov coils – toroidal array	√	
Mirnov coils – 3-axis proto.		

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
MSE	√	
NPA – E‖B scanning		√
NPA – solid state		√
Neutron detectors	√	
Plasma TV		√
Reflectometer – 65GHz		√
Reflectometer – correlation		√
Reflectometer – FM/CW		√
Reflectometer – fixed f		√
Reflectometer – SOL		√
RF edge probes		
Spectrometer – divertor		
Spectrometer – SPRED		√
Spectrometer – VIPS		√
Spectrometer – LOWEUS		√
Spectrometer – XEUS		√
SWIFT – 2D flow		
Thomson scattering	√	
Ultrasoft X-ray – pol. arrays	√	
Ultrasoft X-rays – bicolor		√
Ultrasoft X-rays – TG spectr.		√
Visible bremsstrahlung det.	√	
X-ray crystal spectrom. - H		√
X-ray crystal spectrom. - V		√
X-ray tang. pinhole camera		√