Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **RMPS below the ELM triggering threshold for impurity control**

OP-XP-1027	Revision:	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: J.M. Canik	Date
ATI – ET Group Leader:	Date
RLM - Run Coordinator:	Date

Responsible Division: Experimental Research Operations

RESTRICTIONS or MINOR MODIFICATIONS
(Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

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DATE: **3/10/10**

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1. Overview of planned experiment

This goal of this experiment is to test the possibility that 3D magnetic perturbations can be used to alter impurity transport without triggering ELMs. If successful, this would provide a means for impurity control that is more consistent with PFC operation in devices such as ITER. This will be tested using pulsed n=3 fields, based on previous observations of particle transport changes that were not linked to large triggered ELMs.

2. Theoretical/ empirical justification

Several experiments have observed that 3D magnetic perturbations can reduce plasma impurity content (*without* triggering ELMs, as has been done in NSTX). One example of this is the RMP ELM-suppression experiments in DIII-D, which show increased pedestal particle transport and no impurity accumulation, even in the absence of ELMs (T.E. Evans, *et al*, Phys. Plasmas **13** (2006) 056121). Impurity screening in ergodic edge magnetic fields has also been shown on the Tore Supra and TEXTOR limiter tokamaks, as wells as the W7-AS and LHD stellarators.

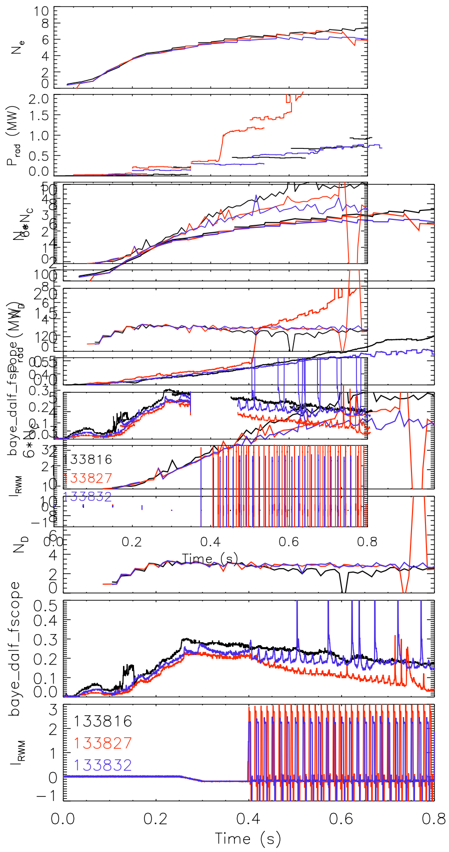

Figure 1: Time traces from a control shot (black), with 3 kA 3 ms n=3 pulses (red), and with 2.5 kA 4 ms pulses (blue)

NSTX RMP experiments have shown some evidence that n=3 fields can increase particle transport without triggering large ELMs. During XP943 (Optimization of ELM pacing), many discharges were taken using SPA pulses with magnitude of 3 kA and pulse widths of 4 ms, and varying pulse frequencies; this amplitude and width was quite effective at triggering ELMs. When either the duration or amplitude was decreased, the ELM triggering became unreliable. As shown in figure 1, in these cases large ELMs were not triggered, but the D_α emission did show an increase during the n=3 pulse. This implies increased particle transport through the edge, and is supported by measurements with the USXR system in bolometry mode, which also show an increase in edge emission during the n=3 field. As shown in figure 1, these discharges also show somewhat decreased total carbon content compared to a reference discharge. The impact on radiated power is less clear: in one discharge, the radiated power increases substantially when the n=3 pulses begin at 0.4 s. This increase is absent in the other discharge, however, suggesting that the increase was an abnormality. The goal of this XP is to tailor the n=3 waveform so that this transient increase in the particle transport is maximized while avoiding the triggering of large ELMs. If successful, this may be a superior method for impurity control during ELM-free H-modes, especially in larger devices such as ITER.

3. Experimental run plan

The conceptual starting point for this experiment is the discharges with very short n=3 pulses that triggered the "stochastic response". Since these affected particle transport without causing ELMs (or perhaps through very small ELMs), this response will be reproduced and optimized to diagnose it more thoroughly and test if impurity accumulation can be reduced. The discharge in which the stochastic response was observed previously used very aggressive SPA waveforms: 3kA triggering pulses, followed by 3 kA negative-going spikes, repeated at 77 Hz. To avoid undue stress on the RWM coils, this XP will attempt to reproduce this effect using a more conservative SPA waveform. The approach is to begin with lower SPA amplitudes to test if the particle transport can be increased prior to (and ideally avoiding) ELM onset. Since the ELM triggering time will be longer at lower SPA currents, the field can be applied for a longer time than the 3ms used in the previous experiments, so that even if the magnitude of the particle transport change is less at lower n=3 field, the time-integrated effect may be comparable. The magnitude and duration of the SPA pulses will then be scanned to optimize for impurity control.

The shot plan is as follows (14 shots total, for 1/2 day XP):

1. Produce reference discharge (no n=3 pulses) (2 shots)

    Reload 135182: I_p=0.8 MA, B_t=0.45 T, $\varkappa$=2.4, δ=0.7, P_{NBI}=4 MW, LiTER at 250 mg/shot

    Adjust lithium evaporation rate to ensure ELM-free conditions

2. Apply n=3 fields using 2 kA SPA pulses to reproduce stochastic response (3 shots)

    Begin with 8 ms pulses, repeated at 50 Hz, without negative-going spikes

    If no ELMs, increase pulse duration by 25%, else reduce to avoid ELMs

    If "stochastic response" is not observed, reload SPA waveform from 133827 (3kA, 3ms pulses at 77 Hz, with negative-going spikes), else repeat above step

        If response still not observed, switch to lower density discharge assuming LLD commissioning XP has produced one, repeat SPA waveform from 133827

3. Change amplitude of SPA pulses to 2.5 kA (3 shots)

    Keep pulse duration set to previous value

    If no ELMs, increase pulse duration by 25%, else reduce to avoid ELMs

    Repeat above step

4. Decision point, if Prad and Zeff have not been decreased with SPA pulses compared to control shot, jump to step 6. Else continue.

5. Optimize based on Prad and Zeff measurements from 2 kA and 2.5 kA sets of discharges (6 shots)

If impurity control is improved at 2.5 kA, then increase the SPA current to 3 kA pulses, again adjusting duration to avoid ELMs

Increase pulse frequency if duration is short enough to allow it

If impurity control is better is 2 kA, then reduce SPA current to 1.5 kA A, adjust pulse duration and frequency

Repeat this process as time permits

6. Alternative SPA waveform. If time-averaged impurity behavior has been unaffected by 3D fields, then attempt control using a new waveform.

Set initial SPA pulse at 3kA, 3ms in duration to initiate the stochastic response.

After large pulse, set SPA current to low DC level, scanning this level from 200 to 500 A to test if increased particle transport initiated by large pulse can be sustained at reduced SPA current

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

This XP requires a fully functioning NBI system, RWM coils configured as n=3, and LiTER. This XP would also benefit from pumping with LLD, contingent on a satisfactory target being developed during the LLD commissioning XP.

5. Planned analysis

EFIT/LRDFIT needed. Pedestal profile analysis using Python tools. IPEC and field line tracing for magnetic field structure under perturbation.

6. Planned publication of results

The results of this experiment will be included in an IAEA presentation on using 3D fields for impurity control.

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:

The reference discharge must be ELM-free, with sufficient flat-top for clear impurity accumulation.

Previous shot(s) which can be repeated: 135182

Previous shot(s) which can be modified:

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

I_{TF} (kA): **53** Flattop start/stop (s): **0/1**

I_P (MA): **0.8** Flattop start/stop (s): **0.15/1.2**

Configuration: **Limiter / <u>DN</u> / LSN / USN**

Equilibrium Control: **Outer gap / <u>Isoflux</u>** (rtEFIT) **/ Strike-point control** (rtEFIT)

Outer gap (m): **0.1** Inner gap (m): **0.05** Z position (m):

Elongation: **2.4** Triangularity (U/L): **0.7** OSP radius (m):

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

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

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

CHI: **<u>Off</u> / On** Bank capacitance (mF):

LITERs: Off / <u>On</u> Total deposition rate (mg/min): **40**

LLD: Temperature (°C):

EFC coils: Off/<u>On</u> Configuration: **<u>Odd</u> / Even / Other** *(attach detailed sheet)*

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		

Reciprocating probe √