Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: H-mode Power Threshold Scaling on NSTX

OP-XP-215	**Revision: 0**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

H-mode Power Threshold Scaling on NSTX

1. Overview of planned experiment.

The main goal of the experiment is to determine the dependence of the L-H threshold power (P_{th}) on B_t, n_e, and I_p in NSTX. Then we will compare the NSTX Pth parametric dependence with the scalings from the international H-mode database (IHMDB) and transport model (for example CPTM) based predictions. Also, the threshold scaling and other H-mode data will be added to the IHMDB. The main component of the XP will be facilitated by scans in B_t, n_e, and I_p. However, it must be kept in mind that these are not the only important parameters, and this small set was selected only due to limited run time. Other important parameters and conditions include the divertor configuration [upper single null (USN) and double null (DN) though important are not included in the main set] and plasma shape. These will be investigated should time permit. A secondary aim is to obtain profile and fluctuation data before, during, and after the L-H transition in order to study the H-mode physics of the ST. We will obtain data on the effect of local parameters T_e, T_i, V_φ and n_e (at the edge) on the threshold power.

2. Theoretical/Empirical Justification

The goals of the H-mode experiments on NSTX are to further understand H-mode phenomena by studies on a different toroidal configuration (the ST), expand the international H-mode database, and to be able to use H-modes as a tool to achieve the goals of the NSTX project. In order to do this we must determine the power required to obtain H-modes under a variety of operating conditions.

Recent studies on both NSTX and MAST indicate power thresholds significantly higher when compared to the International H-mode database, IHMDB, scaling. A recent scaling by Snipes is given by

$$P_{th} = 0.054\, n_e^{0.49}\, B_t^{0.85}\, S^{0.84} \qquad (1)$$

(where P_{th} = MW, n_e in units $10^{20}/m^3$, S = plasma surface area in m^2, B_t = toroidal field on axis in Tesla) obtained from a regression fit to the threshold data from the IHMDB. Another scaling is the ITER-EPS97 scaling:

$$P_{th} = 0.65\, n_e^{0.93}\, B_t^{0.86}\, R^{2.15} \qquad (2)$$

Data from the "single point" NSTX P_{th} study were compared to the two scalings in Equations (1) and (2), with P_{tot} = 2 MW and P_{Loss}(NSTX) ~ 1.1 MW. The first scaling, $P_{th} \sim R^{2.15}$, gave an NSTX threshold value of about 28 times the IHMDB value of 40 kW and the second, $P_{th} \sim S^{0.84}$, a value of about 5 times the IHMDB value (214 kW).

Many NSTX NBI heated H-modes were obtained with a gap-in size of ~ 2 cm. However, for this XP the magnitude of gap-in is not as important as obtaining a fairly reproducible value. There appear to be two main approaches for which H-modes were obtained. In the first, gap-in was increased gradually to ~ 2 cm, effectively without overshoot, and in the second gap-in was increased at a modest rate up to 5 to 8 cm and then gradually decreased to ~ 2 cm at which point the L-H transition was triggered. Figure 1 shows the time variation of kappa, gap-in, gap-out and other parameters for shot 106091, which is an example of the latter approach. In the first case the plasma was usually diverted late ($t \geq 170$ ms) and in the second case the plasma was diverted early ($t \simeq 130$ ms). Also, when diverted late the H-mode was ELM-free and when diverted early it was ELMy.

H-modes have been obtained reliably during the present run and a "start" shot similar to shot 106091 will be run. This shot was part of the "single-point" (in B_t/I_p space) threshold power study mentioned above. However, we are specifying that gap-in at L-H transition be somewhat constrained

to be fairly shot-to-shot reproducible. The programmable parameters which affect gap-in the most are kappa and gap-out. A kappa/gap-out program which resulted in a reproducible gap-in and reliable H-mode trigger is shown in Fig. 1 below. Therefore, the initial model shot will use nominally the kappa/gapout program found to be reproducible and reliable for obtaining H-modes. If Real Time Efit is available for feedback control, it will be used to help maintain plasma shape and gap-in and gap-out. This would be useful for the parameter scans, especially the B_t scan. The beams are to be run at a range of beam voltages so as to vary the NBI power.

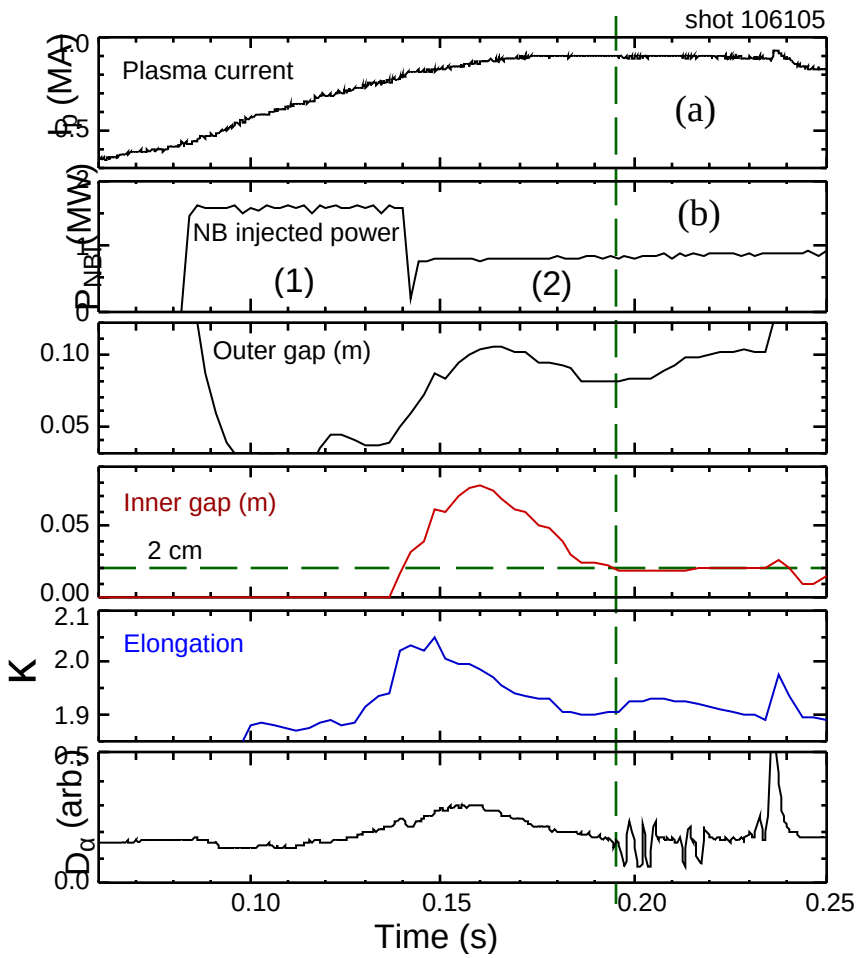


Figure 1: Time variation of the inner gap and κ for a successful L-H transition. D_α, NBI, and I_p are also shown.

As the power is lowered, we begin to make use of two beams, (1) and (2) (see Fig. 1b) one at full or elevated power and the other at a lower power using reduced beam voltage. The full power beam is basically for preheating.

Another diagnostic tool we plan to use this time are D_α signals T'ed off from the usual D_α detectors and input to the same fast digitizers used by the GPI system. These will be taking data with and without GPI. This will allow detection of higher frequency ELMs and also higher frequency dithers. It is possible that there were higher frequency dithers at powers slightly lower than the 840 kW NBI at "threshold" during the last run. These faster D_α signals could also better help in identifying H-modes through pre-L-H transition dithers, also seen on conventional tokamaks. When GPI is used the fast D_α signals will be on the same clock to help in correlation studies with the turbulent fluctuations data The faster D_α signal will also help in better resolving ELM frequency, shape, and amplitude. This run we will also be able to make use of the new LSN divertor , beam heated fiducial shot. This shot will have settings aimed at obtaining H-modes. This will give a daily check of the "readiness" of the discharge for H-mode access. We expect to have several days of these before this XP is run.

3. Experimental run plan

The XP will make use of ELMy or ELM-free H-modes. ELMy H-modes could provide two types of information: Threshold information based on power level at a set of parameters (B_t, n_e, and I_p) and effect on ELMs as the power level approaches the threshold level – they usually become more like dithers. We will begin with settings similar to those for shot 106091 (refer to Figure 2 below), or a better shot from the current run. If H-mode access at I_p > 900 kA becomes routine, then baseline I_p may be increased.

- Start: Source A @ 80 kV, Source B @ 65 kV and Source C as low as possible (~ 55 – 60 kV).
- Use Source A as early heating beam, t = 80 – 140 ms
- $n_e(1) = 1.5 \times 10^{13}/cm^3$, $n_e(2) = 2.5 - 3 \times 10^{13}/cm^3$, and $n_e(3)$ such that $n_e(1) < n_e(3) < n_e(2)$

1) Re-establish P_{th} from last run's "single point" study. (B_t = 0.45T/I_p = 900kA) (6 shots)

¾ Begin at P_b = 1.6 MW and scan down in power until P_b ~ 840 kW for P_{th} and one step below P_{th}. – These can be coarse steps. Begin with nebar = ne(1) ≈ $1.5 \times 10^{13}/cm^3$

¾ Below 700 kW (60 kV), will need pulse width modulation.

1. Initial start-up shots [Include a fiducial]
2. Set-up shots to get H-mode (Use Shot 106091 or other shot for best chance for H-mode).
   a. Set-up to get a reproducible gap-in.
   b. Used Source A for early heating and to obtain the P_b = 1.6 MW data at point 1 on Fig.2. Source C was used to get P_{th} using P_b ~ 840 kW at point 2.

(Point at B_t = 0.45 T / I_p = 900kA serves as the first point of the scan. See Fig. 2))

n_e at this point is $n_e(1)$

3. Establish P_{th}. Expect it to be ~ 840 kW, but could be slightly different.
4. Compare P_{th} with a modulated beam to that of a de-rated full-on beam.

2) TF scan at I_p = 900kA (12 – 14 shots)

1. Drop B_t to 0.30 T
   a. If still H-mode, decrease P_b in steps until no H-mode. Maintain $n_e(1)$ to within 10%.
   b. If there is no H-mode, increase P_b until obtain H-mode
2. (Higher B_t is important, so obtain data at B_t = 0.6T when it becomes available.)

3) Ne scan – Begin with initial B_t = 0.45T, Ip = 900kA (10 shots)

Obtain n_e (2) > n_e (1) using HFS gas puff @ 1000 torr + increase LFS fueling up to 100 ms (from scaling expect No H-mode)

a. If still H-mode, decrease P_b in step until no L-H transition
b. If there is no H-mode, increase P_b until obtain H-mode
c. Try a 3rd n_e if time permits. High Field Side @ 1000 torr, LFS same as $n_e(1)$

4) Ip Scan – Begin with setting of 1), except set Ip = 600kA (6 shots)

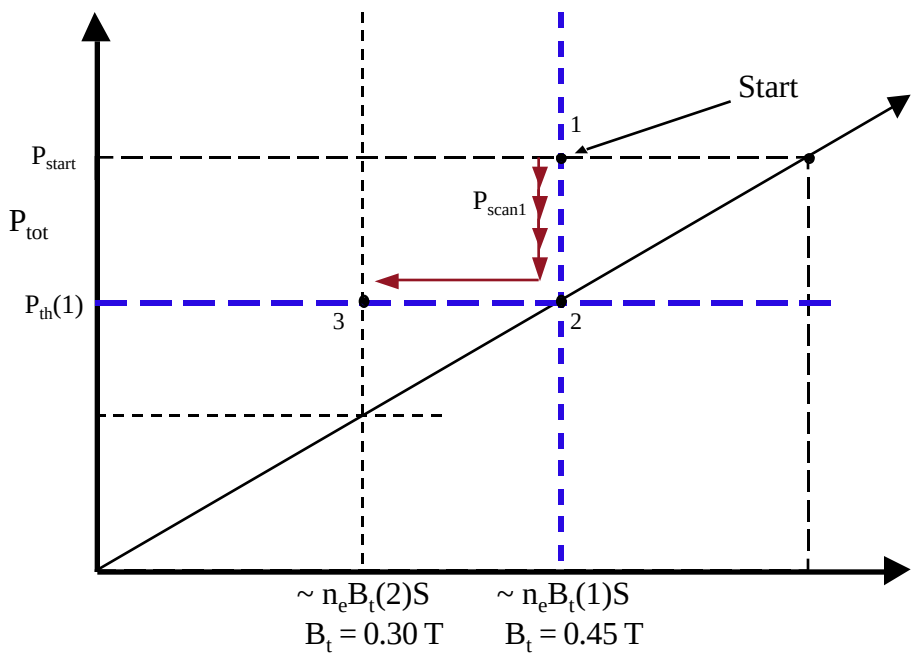
Drop Ip to 600 kA (see approach to point 3 on Fig. 4)

a. If still H-mode, decrease P_b in step until no L-H transition (may require modulated beam)
b. If there is no H-mode, determine if large change in other parameters (adjust and try again)

<u>Shots in order of priority (At lower single Null)</u>

1. Re-establish single point P_{th} at ~ 840 kW. ($n_e(1)$), I_p = 900 kA, B_t + 0.45 T.
2. Compare P_{th} with a modulated beam to that of a de-rated full on beam.
3. Obtain B_t point at 0.3 T, I_p = 900 kA.
4. Obtain point at $n_e(1)$, B_t = 0.45 T, I_p = 900 kA.
5. Obtain point at $n_e(2)$, B_t = 0.45 T, I_p = 900 kA.
6. Obtain point at $n_e(1)$, B_t = 0.45 T, I_p = 600 kA.
7. Obtain point at $n_e(3)$, B_t = 0.45 T, I_p = 900 kA.
8. Obtain point at $n_e(1)$, B_t = 0.60 T*, I_p = 900 kA.

$n_e(1)$ = nominal density = 1.5 x $10^{13}/cm^3$
$n_e(2)$ = High density maximum = 2.5 to 3 x $10^{13}/cm^3$
Choose a $n_e(3)$ such that $n_e(1) < n_e(3) < n_e(2)$



P_{thITER} (MW) = $0.54 \cdot n_e^{0.49} \cdot B_t^{0.85} \cdot S^{0.84}$

Figure 2: This shows a possible scheme for achieving the parameter scans. Shown are several paths in n_e, B_t, and S space.

Required machine, NBI, RF, CHI and diagnostic capabilities

1. The machine must be well conditioned with low oxygen levels and low neutral influx. Closely follow a boronization, or use boronization during run (plasma boronization still being evaluated).

2. Nominally operate at plasma currents between 600 and 900 kA, allow 1.0 MA or higher if H-mode reliability at higher Ip is found. Higher Ip goal will be at the discretion of the authors of the XP, i.e. if it is felt to be necessary for a complete data set at the time of the run. B_t will nominally be between 0.45 T and 0.30 T. Run at 0.6 T if time permits. Asking for (desire, but not an exact requirement) Gap-in and Gap-out controll to be like that of shot 106091 (or of a better H-mode if available).

3. NBI sources will be set as follows: Source-A at 80 kV, Source-B at 70 kV, and Source-C at 65 kV (can be dropped lower if needed, but keep at 65 kV for conditioning until lower value is required) for power control. Beam modulation will be used for additional power control. Run only NBI heating (no ICRF).

4. Thomson scattering, magnetics, filterscopes, bolometers, plasma TV are required

5. Desire CHERS, VB, VIPS, PHA, edge scanning reflectometer, USXR, GPI, Oak Ridge Reflectometer, NPA,

Planned analysis

1. The Main Goal: Determine dependence of P_{th} on n_e, B_t, I_p and compare with international database and CPTM scaling.

2. Expected but not required to run the XP: There should be data available which can be used to test several L-H transition theories (see Appendix). There is also expected to be data for edge pedestal studies. Plan to piggyback accumulation of turbulent fluctuation data which could help in interpretation of the experimental results.

3. Analysis to address transport and confinement issues; using EFIT, TRANSP, NCLASS …

Planned publication of results

The results of the power scaling will be presented at the 26th EPS Conference (17-21 June 2002). The power scaling plus physics will be published in a refereed journal. The scaling data will be entered into the International H-mode Database.

Appendix

Since the run time available for each XP is very limited this year, the approach in this XP is to be focused. The scope of the XP is on purpose limited, in order to obtain a cohesive and consistent set of data using a plan guided by the single objective of determining to parametric dependence of the threshold power. However, to be sure, we understand that the power and limited global parameters are not the full story. There are fundamental physics issues that must be kept in mind. These are not the focus of this XP, however, we should always keep in mind and strive to obtain as much profile and fluctuation data as possible. Especially just before the L-H transition. In this way as a side product we would be able to take a preliminary look at such issues as possible turbulence suppression by ExB flow shear, competition between velocity terms and the pressure term in flow shear, and some recent models of the L-H transition.

PHYSICS OPERATIONS REQUEST

Title: H-mode Power Threshold Scaling on NSTX XP No: 215

Machine conditions (specify ranges as appropriate)

I_{TF} (kA):**TF(T): 0.3 – 0.6 T** Flattop start/stop (s): _____/_____

I_P (MA): **0.6 – 1.0 (leave upper range open)** Flattop start/stop (s): **0.15 / 0.4**

Configuration: **Lower Single Null Diverted**

Outer gap (m): **5 – 10 cm**, Inner gap (m): **2-3 cm at L-H (See Fig. 4)**

Elongation κ: **1.8-1.9@L-H**, Triangularity δ: _____

Z position (m): **0.00** /// **(Swing of gap-in = 0 ↑ 8 ↓ 2 cm)**

Gas Species: **D_2**, Injector: **Outer Midplane (Inner Wall)**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **80/70/65**, Duration (s): **0.3 s**

ICRF – Power (MW): **0**, Phasing: **N/A**, Duration (s): _____

CHI: **Off**

Either: List previous shot numbers for setup: **106091 (or better H-mode if available)**

Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

Title: H-mode Power Threshold Scaling on NSTX **No. 215**

Diagnostic system	**Need**	**Desire**	**Requirements** (timing, view, etc.)
Magnetics	✓		
Fast visible camera	✓		
VIPS-1		✓	
VIPS-2		✓	
SPRED		✓	
GRITS		✓	
Visible filterscopes	✓		
VB detector		✓	
Midplane bolometer		✓	
Diamagnetic flux		✓	
Density interferometer (1mm)		✓	
FIReTIP interf'r/polarimeter		✓	
Thomson scattering	✓		
CHERS		✓	
NPA		✓	
X-ray crystal spectrometer		✓	
X-ray PHA		✓	
EBW radiometer		✓	
Mirnov arrays	✓		
Locked-mode detectors		✓	
USXR arrays		✓	
2-D x-ray detector (GEM)		✓	
X-ray tangential camera		✓	
Reflectometer (4 ch.)		✓	
Neutron detectors		✓	
Neutron fluctuations		✓	
Fast ion loss probe		✓	
Reciprocating edge probe		✓	
Tile Langmuir probes		✓	
Edge fluctuation imaging		✓	
H-alpha cameras (1-D)		✓	
Divertor camera (2-D)		✓	
Divertor bolometer (4 ch.)		✓	
IR cameras (2)		✓	
Tile thermocouples			
SOL reflectometer		✓	

PPPL EXPERIMENTAL PROPOSAL REVIEW CHIT Chit No. _____

XP TITLE: **_H-mode Power Threshold Scaling on NSTX** XP No. **215**_____

PROPOSER: _____ DATE OF REVIEW: _____

COMMENT / CONCERN / RECOMMENDATION

Name _____

REVIEW BOARD COMMENT / RECOMMENDATION

❑ REQUIRES ACTION / ❑ NO ACTION REQUIRED / ❑ OTHER _____

Run Coordinator _____ Date _____

PROPOSER'S RESPONSE

Proposer _____ Date _____

RUN COORDINATOR REVIEW OF RESPONSE

❑ APPROVE / ❑ DISAPPROVE RESPONSE

Run Coordinator _____ Date _____