Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: Power Balance Studies at Varying Target T_e

OP-XP-204	**Revision:**	Effective Date: 2/6/02 *(Ref. OP-AD-97)* Expiration Date: 2/6/04 *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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ATI - Task Force Leader: D. Darrow	Date
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Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

Power Balance Studies at Varying Target T_e

1. Overview of planned experiment

The goal of this experiment is to assess the power balance of neutral beam heated discharges with both low and high target electron temperatures. Low target temperatures will be developed in a high density regime, and high target temperatures will be accomplished by early RF heating alone to heat the electrons with neutral beam injection then substituting for the RF, or by reducing the target density. The variation in target T_e will modify the partition of neutral beam power between the ions and electrons, as well as the thermal ion-electron collisional energy transfer, and the results will aid in understanding the overall picture of transport in auxiliary heated NSTX plasmas. Different documentation methodologies will be used for the high temperature targets, depending upon the success of maintaining high T_e after RF turn-off.

2. Theoretical/ empirical justification

The initial power balance studies of neutral beam heated NSTX plasmas have resulted in the enigma of high ion temperatures relative to the electron temperatures across most of the plasma profile, and especially in the outer portion of the discharge. This result appears inconsistent with the classical picture of collisional heating and energy transfer, as more total power is expected to heat the electrons than the ions since $E_{beam}/T_{e,crit}$~7, and the ion-electron energy transfer term can be a significant fraction of the total heating power (not accounting for other losses or energy gains). Without invoking modifications to the classical collisional terms (such as low aspect ratio corrections), this result leads one to suspect that some anomalous ion heating mechanism may be operative.

To arrive at a more complete picture of the energy transport in NSTX, it is necessary to modify plasma conditions in order to affect both the expected collisional energy transfer from the beam ions to the plasma and the collisional energy transfer between the thermal ions and electrons. One such way of doing this is to change either or both the electron temperature and the beam voltage. Changing the electron temperature can be accomplished by varying the plasma density, or by introducing RF power. High electron densities can result in T_i~T_e, thus effectively eliminating the dominance of the Q_{ie} term in the power balance. Previous experiments on NSTX have shown that HHFW alone can be effective in heating electrons to central temperatures in excess of 1.5 keV (over 3 keV) for HHFW pulses of 100 msec or more (Fig. 1). These temperatures are approximately double the ohmic target temperatures in NBI studies up to now. The higher temperatures after RF heating will result in more classical collisional heating of the ions than in previous experiments, as the critical temperature scales as approximately $15T_e$. At present, with target $T_e(0)$ values of about 0.6 keV, three times as much heating of the electrons than the ions takes place according to classical collisional considerations. For 2 keV target central electron temperatures, the beam heating of the electrons and ions would be approximately equal. At 55 keV beam energies and 2 keV central electron temperatures, 60% of the beam power would go to the ions.

Early RF heating followed by NBI has also been shown, at least from modeling studies during the design phase of the experiment, to yield the longest plasma current flattop durations (up to 0.5 sec). This is due to the reduced inductive and resistive flux consumption accompanying the higher T_e. Fig. 2 is a result of a TSC modeling run showing the discharge scenario modeling that we intend to use as a basis for part of this experiment. The attempt to lengthen the discharge pulse is a secondary objective of the experiment.

Whether the high T_e can be maintained after the RF turn-off or after the start of NB injection (during the RF) will determine the precise documentation methodology. If high T_e can be maintained, then the documentation of this condition, as outlined below in Phase II, will take place. If not, a different approach will be taken. In this "contingency" approach, closely spaced Thomson scattering pulses will be used to measure the change in the electron temperature at the onset of NB injection (no RF prelude) and carefully compared to estimates of both dW_e/dt and dW_i/dt from classical heating (TRANSP). This will be done at two different electron densities to vary the target temperature. The precise target density will be determined from the results of the ohmic density limit experiment.

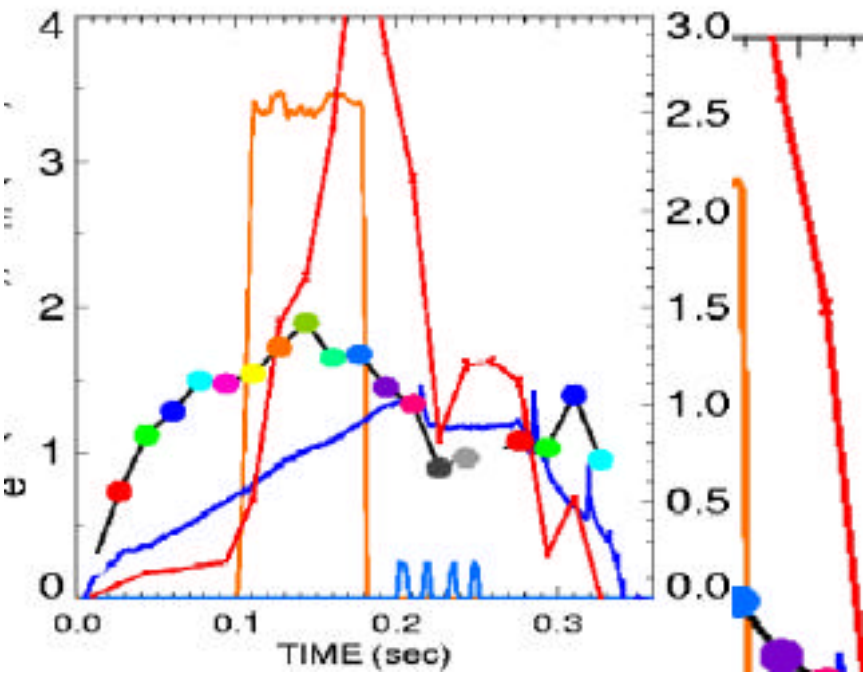

Figure 1

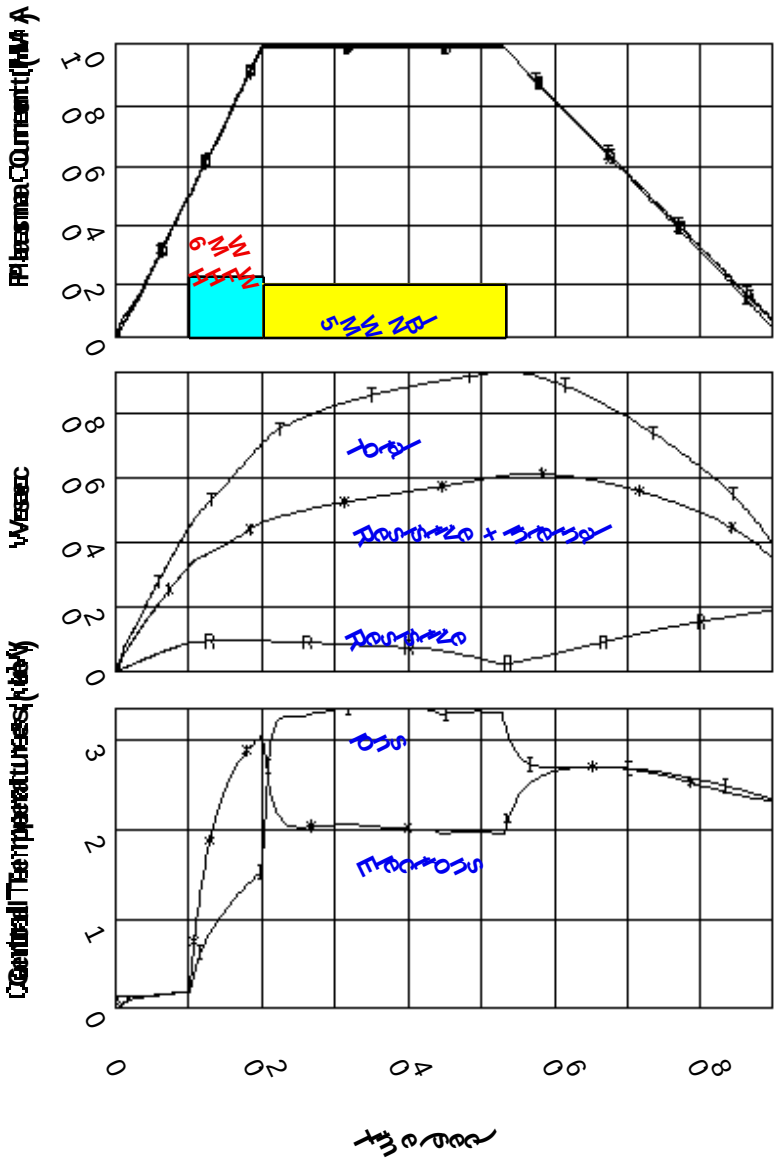

Figure 2

3. Experimental run plan

The base discharge for this XP during the NBI phase will be 106337, which is shown in Fig. 3. This discharge was a 0.9 MA, 4.5 kG, IWL, deuterium plasma with an elongation of approximately 1.6. The RF was turned on at 0.1 sec and lasted for 0.14 sec, during which time the electron temperature increased to 0.9 keV and remained steady at that value as the densitiy continued to increase. Of considerable note is that the T_e did not decrease as the neutral beams were turned on at 0.22 sec. For the high $T_e(0)$ portion of this experiment, the line integral density will be held to a value of ~2e10^{19} m^{-2} to allow the $T_e(0)$ to increase during the RF phase.

The experiment will consist of several phases:

Phase I: low target density (high T_e), RF on from 0.1 to 0.2 sec

The second phase of the documentation will be to attempt to vary the electron temperature by use of RF. The RF pulse (maximum available reliable power) will be turned on at 0.10 sec and will last for up to 100 msec. Target line <u>integral</u> densities during the RF phase will be approximately 2 x 10^{19} m^{-2}. If electrons are observed to heat on time scales shorter than 100 msec, the pulse will be shortened to the minimum acceptable time for $T_e(0)$ to reach >2 keV. At the line integral densities mentioned above, electron temperatures in excess of 3 keV were obtained (Fig. 1). We will attempt for the highest T_e possible. Ideally, the beam pulse would be turned on simultaneously as the RF pulse is turned off to avoid any RF-thermal or beam ion interactions. Depending on the electron energy confinement time (i.e., how long the electrons can maintain high temperature without cooling off), there may have to be some minimal overlap between the end of the RF pulse and the beginning of the NBI pulse (10 to 20 msec). If necessary, however, the RF heating will be maintained for a longer duration (into the NBI pulse), and the measured changes in the fast ion distribution, as measured by the NPA, will be taken into account during analysis. One NBI source will be used during the NBI phase (Source A), keeping beta low as to avoid MHD activity. Kinetic profile data will be taken during both the RF and the NBI pulse. We will run occasional pulses with short (≤20 msec) beam blips during the RF pulse (Source B) at t=0.130, 0.170 sec to measure the ion temperature. Assuming we achieve the high target temperature, a second condition will be to shorten the RF pulse in order to document at lower T_e. Another condition during this phase will be to operate with lower beam voltage to further reduce $E_{beam}/T_{e,crit}$ for a higher ion heating fraction).

Phase II: diagnose initial dW_e/dt; NB only

If no electron heating is observed during the early portion of the discharge, or if the high temperature cannot be maintained after the start of NBI, the experiment will move onto the Phase II fallback documentation, in which closely spaced MPTS pulses will be used to diagnose the initial dT_e/dt and compare to estimates for purely collisional heating. Here, it is important to ensure that the heating rate of the electrons is faster than that of ion-electron collisional energy transfer in order to isolate the heating from other modifying processes. From previous observations, the time scale of the former appears bounded by the MPTS time resolution of 30 msec (the actual heating rate may actually be faster; i.e., time scales of < 30

msec). Estimates of ion-electron collisional energy transfer rates give time scales of order 100 msec, thus satisfying the conditions for this documentation. The Phase I documentation will then take place after a successful RF-NBI coupling scenario has been developed. The Phase II documentation will be done at low and high density (2.5e19, 5e19 m^{-2}) in order to determine the initial electron and ion heating rates at two different target T_e's. The MPTS spacing will be approximately 5 msec, and the documentation will step the MPTS through the first 30 to 60 msec of the NB heating phase. The measured heating rates will be compared to calculations from TRANSP, based on collisional heating.

Phase III: high density, T_i~T_e (Q_{ie}~0)

In this phase, no RF heating will be used, just NBI. Discharges with target densities ~5 x 10^{19} m^{-3} will be developed in order to have T_i~T_e and eliminate, or reduce significantly the ion-electron coupling term. The precise target density will be determined from the results of the ohmic density limit XP

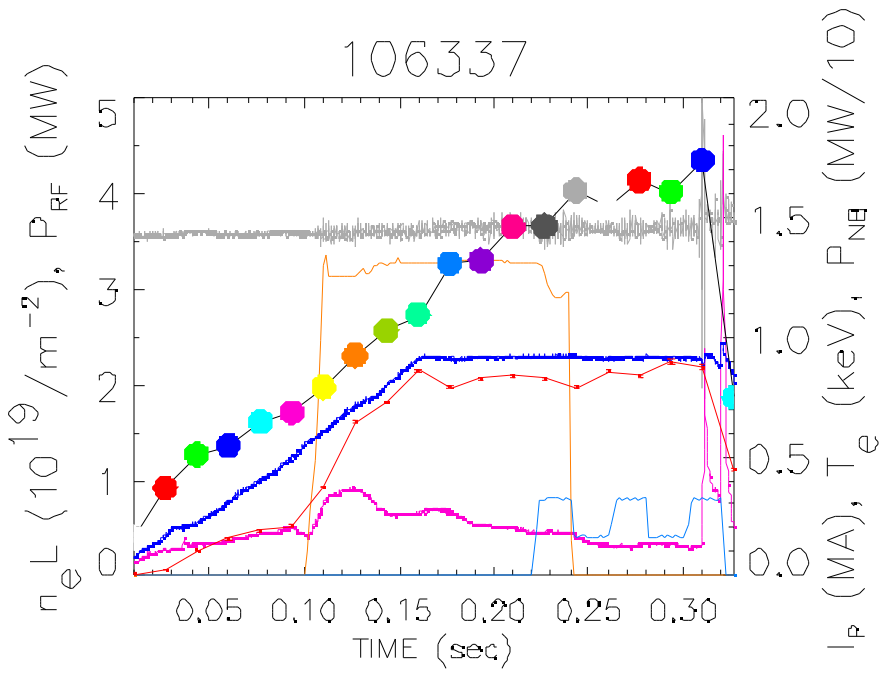

Figure 3

A suggested shot list is given below.

Phase	Condition	E_{beam} (keV)	Source	Info	# Shots
I	A	80	A	Establish discharge (100 msec RF pulse)	4
I	A	80	A	Document NBI phase*	2
I	B	80	A	Establish discharge (~50 msec RF pulse)	2
I	B	80	A	Document NBI phase**	2
I	C	55	A	Establish discharge (100 msec RF pulse)	2
I	C	55	A	Document NBI phase*	2
II	A	80	A	High density dT_e/dt	6***
II	B	80	A	Low density dT_e/dt	6***
III	A	80	A	High density documentation (T_e~T_i)	2

* Beam blips with source B at 0.130, 0.17 sec; RF pulse from 0.10 to 0.20 sec

** Beam blips with source B at 0.17 sec.; RF pulse from 0.15 to 0.20 sec

*** 5 msec separation between MPTS pulses, shifted by 5 msec every shot

Perform Phase II only if Phase I documentation conditions are unachievable.

Total # Shots (I & III) 16

Total # Shots (II & III) 14

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

see Physics Operations page

5. Planned analysis

EFIT, TRANSP, HPRT, CURRAY, TSC

6. Planned publication of results

APS, EPS, refereed publication

PHYSICS OPERATIONS REQUEST

Title: Power Balance Studies at Varying Target T_e **XP No.: 204**

Machine conditions (indicate range where appropriate):

TF: Flattop (kA) __53.4__ Flattop start/stop (s) _____

I_p: Flattop (kA) _900_ Flattop start/stop (s) _____

Position: R (m) _____ Z (m) _____ **Inner wall** / Single null / Double null

Gas: Prefill _D____ Puff __D____

NBI: Power (MW) _≤1.5 Start / stop (s) __.20___ Voltage (kV) _80/55_____

RF: Power (MW) _~4_ Start / stop (s) _.10-.20_____Frequency (MHz) _____

CHI: **Off** / Start-up / Ramp-up / Sustainment

If this is a continuation of a previous run or if shots from a previous run are similar to those needed, provide shot numbers for setup

Use 106337 as a basis; reduce target density to 2 x 10^{19} m^{-2}.

If shots are new and unique, sketch desired time profiles and shapes. Accurately label the sketch so there is no confusion about times or values. Attach additional sheets as required.

DIAGNOSTIC CHECKLIST

Error! Reference source not found. Power Balance Studies at Varying Target T_e Error! Reference source not found.**204**

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