**Princeton Plasma Physics Laboratory**

# NSTX Experimental Proposal

**Title: Ohmic Density Limits**

| | | |
|---|---|---|
| **OP-XP-203** | **Revision:** | Effective Date:<br>*(Ref. OP-AD-97)*<br>Expiration Date:<br>*(2 yrs. unless otherwise stipulated)* |

## PROPOSAL APPROVALS

| | |
|---|---|
| **Author: S.M. Kaye** | Date 1/15/02 |
| **ATI - Task Force Leader: D. Darrow** | Date 1/15/04 |
| **RLM - Run Coordinator: R. Maingi** | Date |

**Responsible Division: Experimental Research Operations**

**Chit Review Board** (designated by Run Coordinator)

**MINOR MODIFICATIONS** (Approved by Experimental Research Operations)

# Ohmic Density Limits in NSTX

## 1. Overview of planned experiment

The overall goal of this experiment is to continue exploration of density limits in NSTX ohmic plasmas utilizing the new inner wall gas feed capability and assessing the role of high-temperature bakeout. Previous studies on NSTX indicated difficulty in raising the density above the Greenwald limit. Deuterium plasmas achieved densities up to 60% of the Greenwald limit and Helium plasmas up to 80% of the Greenwald limit in the earliest studies. These numbers increased to 80% and 120% of the Greenwald limit, respectively, after boronization and with the use of Helium gas puffer installed for use with the visible fast camera. The purpose of this experiment is to continue these studies to assess the effects mentioned above. Scans will be restricted to deuterium plasmas. Bakeout/error field reduction will be assessed by first using the "outside" gas feeds and comparing to previous results. Then, the ability to increase density further by using the inner wall feed will be assessed by comparing to the results with the outer gas feeds. A toroidal field scan will be done to help determine whether the Greenwald or Murakami scaling sets the density limit.

## 2. Theoretical/ empirical justification

Testing the q and density limits is a standard method for mapping out the operational limits of experimental devices. The operational limits can be manifest in several ways. For high density limits, the plasma can exhibit a radiative collapse, REs, or simply a saturation in density.

The density limit has been expressed by two scalings, the Murakami-Hugill scaling in which

$$n_e \leq cB_T/R \qquad \text{where} \quad q_{cyl}=2.5\, a^2 B_T\, f(\kappa)/RI_p \text{ and } f(\kappa)=(1+\kappa^2)$$

and the Greenwald limit, in which

$$n_e \leq I_p/\pi a^2.$$

In some devices, it was found that the MH limit had a dependence such that

$$n_e R/B_T \leq 2/q_{cyl} \qquad \text{where} \quad q_{cyl}=2.5\, a^2 B_T\, f(\kappa)/RI_p \text{ and } f(\kappa)=(1+\kappa^2)$$

If this relation holds, the MH and GW density limits differ only through the elongation, for other parameters being constant,

$$n_{e,MH}/n_{e,GW} = 0.8\pi/f(\kappa)$$

so that a distinction between the two limits can be best attempted at high elongation.

The explicit dependence on toroidal field in the MH scaling could be tested as well. At constant $I_p$, the density will not depend on the toroidal field if the GW (or, almost equivalently, the MH ~$2/q_{cyl}$) dependence holds.

Previous experiments performed on NSTX indicate that the Greenwald is an adequate guide for the density limits. These experiments were performed in both deuterium and helium ohmic plasmas, before and after boronization campaigns. Fig. 1 shows the results of these experiments.

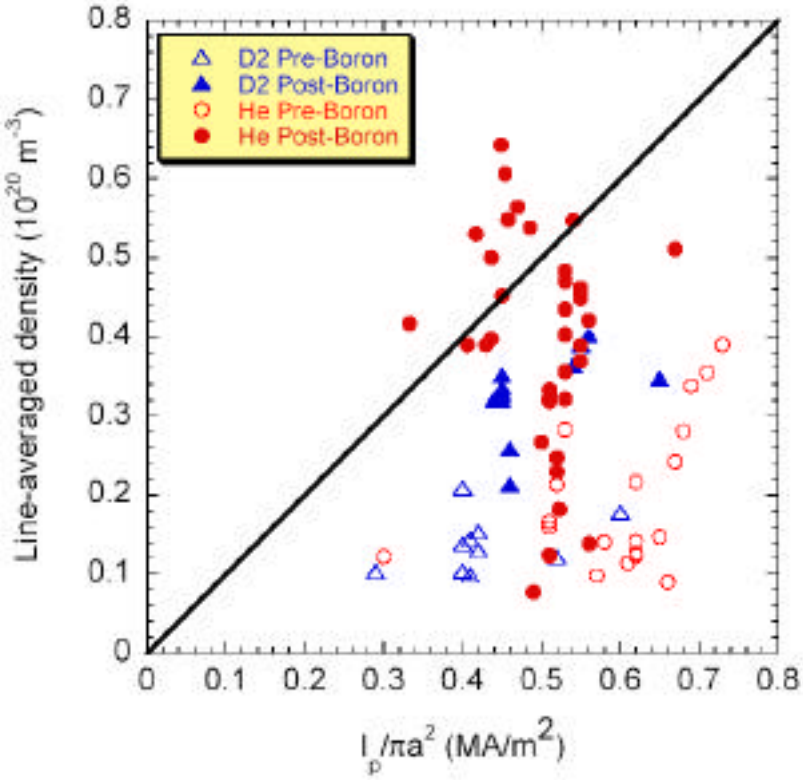


Fig. 1 Previous density limit results

As can be seen, the helium plasmas typically achieved higher densities than the deuterium ones, and higher densities, above the Greenwald limit, were obtained after the boronization campaigns. Operation above the Greenwald limit in helium plasmas was fairly routine using the fast camera Helium gas puffer, indicating the importance of the type and location of the gas feed in exploring these limits. No dedicated toroidal field scans were performed to test the importance of this parameter.

## 3. Experimental run plan

This XP consists of several parts testing the density limits. Density limits will be tested in deuterium ohmic plasmas at several different currents using first the outside and then the inner

wall gas feeds separately (and then together, if necessary, to maximize density). For each condition, we will start at modest gas feeds (about half of the maximum voltage for each feed), and then increase until the density or fueling limit is reached. Fast camera, reflectometer, USXR and magnetics probes will be used to monitor changes in MHD behavior as the density limit is approached.

A minimum of two shots for each sequence is required. Helium glow between some shots may be desirable.

| Sequence | Gas Feed | $I_p$ | $B_T$ | $q_{cyl}$ | Min. # Shots |
|---|---|---|---|---|---|
| 1 | Outer | 0.8 MA | 0.3 T | 2.1 | 2 |
| | | 0.6 | | 2.9 | 2 |
| | | 0.4 | | 4.3 | 2 |
| 2 | Inner | 0.8 | 0.3 | 2.1 | 2 |
| | | 0.6 | | 2.9 | 2 |
| | | 0.4 | | 4.3 | 2 |
| 3 | Inner(+ Outer?) | 0.8 | 0.45 | 2.9 | 2 |

Table I  Density limit exploration

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

Ohmic plasmas are required.

<u>Required diagnostic capabilities</u>

• fullest complement of magnetic diagnostics and Ip measurements for plasma control and equilibrium reconstruction

• fast visible camera

• density measurement

• impurity measurements

• fast Mirnov coils, USXR, reflectometer (MHD assessment)

• $D_\alpha$ measurements

• locked mode measurement

• runaway electron detection

## 5. Planned analysis

EFIT analysis of the plasmas is required. This tool will enable us to characterize the global plasma conditions at the time the respective limits are reached. In particular, the EFIT calculations will allow us to determine which definition of q ($q_{cyl}$, $q_{\psi}$, etc.) is fundamental to characterizing the operational boundary.

## 6. Planned publication of results

The results of the investigation will be presented at conferences and written up and submitted to a refereed journal for publication once the experiment is completed.

# PHYSICS OPERATIONS REQUEST

**Title: Operational Limits** **XP No.:**

Machine conditions (indicate range where appropriate):

**TF**: Flattop (kA) _≤ 54 Flattop start/stop (s) _____

**$I_p$**: Flattop (kA) _≤ 800 Flattop start/stop (s) _____

**Position**: R (m) __0.85 Z (m) __0.00 **Inner wall** / Single null / Double null

**Gas**: Prefill __$D^+$____ Puff __ $D^+$__

**NBI**: Power (MW) _____ Start / stop (s) _____ Voltage (kV) _____

**RF**: Power (MW) _____ Start / stop (s) _____ 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

Desire generic OH flattop with elongation of 1.8.

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

**Title:** **XP No.:**

| | | Need | Desire | Special requirements |
|---|---|---|---|---|
| **Magnetics** | Flux loops, B-coils | x | | |
| | Passive plate diag. | | | |
| **$n_e$ and $T_e$** | Interferometer | | x | |
| | Thomson Scattering | x | | |
| **$T_i$** | CHERS | | | |
| | NPA | | x | |
| **Spectroscopy** | $H\alpha$ | x | | |
| | SPRED (UV)/GRITS | x | | |
| | VIPS (H/D ratio) | | x | |
| | X-ray PHA | | | |
| | Visible Bremsstrahlung | x | | |
| **Particles** | NPA | | x | |
| **Fluctuations** | Mirnov Coils | x | | |
| | X-ray Array | x | | |
| | Reflectometer | | x | |
| **Edge** | Bolometer | x | | |
| | Plasma TV | x | | |
| | IRTV | | x | |