Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Characterization of the divertor heat flux width and the mid-plane SOL widths

OP-XP-815	Revision:	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: J-W. Ahn	Date
ATI – ET Group Leader: V. Soukhanovskii	Date
RLM - Run Coordinator: M. Bell	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Characterization of the divertor heat flux width and the mid-plane SOL widths**
No. **OP-XP-815**
AUTHORS: **J-W. Ahn, J. Boedo, R. Maingi, R. Maqueda, S. Zweben**
DATE: **Mar 27, 2008**

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1. Overview of planned experiment

This experiment aims to measure SOL plasma profiles (T_e, n_e, j_{sat}, and q_{target}) with operation parameters (*eg*, I_p, nebar, B_t, and power) scanned. The T_e, n_e, and j_{sat} profiles are measured by the mid-plane fast probe and the q_{target} profile is measured by the divertor IR camera. Various other diagnostics (GPI, FIReTIP, USXR, fast visible camera, etc) will also measure blob characteristics in the SOL plasma. All the measured profiles will be flux mapped to the mid-plane for comparison. The goal is to find out 1) the relation between various decay lengths at the target and at the mid-plane, 2) the dependence of SOL widths on the operation parameters and the development of SOL width scaling law for both near and far SOLs, and 3) the relationship between SOL widths and the blob characteristics.

2. Theoretical/ empirical justification

The electron temperature and heat flux SOL widths, λ_{Te} and λ_q respectively, have a conventional relation of λ_{Te}=7/2λ_q, assuming a dominant parallel electron heat conduction and a simple exponential function for the T_e and q_{target} profiles. However, it has been observed that the profiles have a long tail in the far SOL and this can be approximated by introducing an offset value in the exponential function, *ie* $a = a_0 + a_1 \exp\left(-\frac{R - R_{sep}}{\lambda_a}\right)$. If we use the offset exponential function for both T_e and q profiles and apply it to the parallel electron heat conduction equation in the near SOL, we obtain a new relation between λ_{Te} and λ_q,

$$\lambda_{Te,u} = \frac{7}{2}\lambda_q\left(\frac{T_{e,u} - T_{e0}}{T_{e,u} - Cq_0 T_{e,u}^{-5/2}}\right)$$

, where $C = \frac{7}{2}\frac{L_c}{\kappa_0}$, T_{e0} and q_0 are the offset T_e and q values, and κ_0 is the electron conduction coefficient. The measured value of λ_{Te}/λ_q differs from the new prediction by 17%, compared to the 26% difference from the conventional prediction. The use of offset temperature and heat flux values, T_{e0} and q_0, in the parallel e-conduction equation can be interpreted as a representation of relatively strong perpendicular heat transport.

On the other hand, the measured far SOL widths do not follow the expected relation neither for the sheath-limited ($\lambda_q^{-1} = \lambda_n^{-1} + 3/2\ \lambda_T^{-1}$) nor the conduction-limited (λ_{Te}=7/2λ_q) regime. While the measured λ_q is 9.8cm, the expected value is $2.6 < \lambda_q < 4.0$ cm (sheath-limited regime) and λ_q =3.3 cm (conduction-limited regime). One of the possibilities under consideration to explain the discrepancy is the long ion heat flux decay length.

The scaling of SOL widths with operation parameters (I_p, nebar, B_T, power, etc) is important for the extrapolation to the future machine such as NHTX in two ways; the near SOL scaling and the far

SOL scaling. The near SOL scaling is important to estimate heat flux onto the divertor target and therefore to evaluate power handling capabilities. The far SOL scaling is also important to estimate heat and particle flux onto the 1st wall and therefore to evaluate its interaction with the wall.

As for the near SOL scaling, the IR heat flux data has been already scaled with I_p and power [1] and the fast probe T_e and n_e profiles showed dependence on I_p, nebar, and power. However, the size of current dataset is limited and scaling laws have not been derived. The derived experimental scaling will be supplemented by the best fitting theoretical models to be identified by comparison of experimental data with analytic models. Currently the most comprehensive analytic SOL models are provided by a reference by J.W.Connor and G.F.Counsell [2]. This will provide useful information for the extrapolation of NSTX near SOL width data to NHTX.

The long tail of plasma profiles in the far SOL can be the result of intermittent perpendicular heat and particle transport, which is a subject of intense investigation in the boundary physics community. The degree of intermittent perpendicular transport can be characterized by the 'offset' value or by the decay length of a far SOL profile. The theory of intermittent perpendicular transport is still being developed and there is a need to develop empirical scalings to confirm the dependence of this transport on the operation parameters. This will provide an experimental basis to the theoretical investigation of the intermittent transport.

The last task of this experiment is to find a relationship between SOL widths and the blob characteristics. Blobs are expected to play an important role in the intermittent perpendicular particle and heat transport. Characteristics of blob such as fluctuation characteristics, blob velocities and directions, and the number of filaments, etc will be investigated in the relation with SOL widths as a function of operation parameters. This may provide useful input to the theoretical blob models currently under development (eg, at Lodestar).

As for the effect of flux change that the probe motion could cause, we have looked into the raw magnetic signals as well as the EFIT equilibrium results, to identify any possible deteriorating impact on the plasma. There was no noticeable change in any magnetic signal and EFIT equilibrium caused by the probe plunge, as well as in the magnetic signal from the SGI magnetic sensors, which is nearby the fast probe. We also investigated the TS Te and ne data to look for any change in Te and ne data, with no change identified. Therefore at this stage, there is no solid ground to expect a deteriorating impact on the plasma performance and the probe measurement caused by the probe plunge, although this will remain to be investigated in further detail.

[1] R. Maingi, C.E. Bush, R. Kaita, H.W. Kugel, A.L. Roquemore, S.F. Paul, V.A. Soukhanovskii, and the NSTX team, et. al., *Journal of Nuclear Materials* **363-365** (2007) 196

[2] J. W. Connor, G. F. Counsell, et. al., *Nuclear Fusion* **39** (1999) 169

Experimental run plan (in the order of priority)

- **6.5 min Glow, 12.5 min shot cycle, Turn off HFS fueling (1200Torr) at 290ms**
- **Turn off NBI src C well before the start of probe plunge to minimize the fast ion effect**

1. Establish a baseline shot: 125065 (note the NBI slight time change, by ~20ms)
   NBI time: A (150-330ms: 2MW), B (320-500ms: 1MW), C (190-290ms: 2MW)
   1MA, 0.55T, 1MW NBI
   Plunge time: Max penetration at 400ms (**4 shots**)

Decision point 1: to take low density point
NBI time: A (80-260ms: 2MW), B (250-500ms: 1MW), C (120-220ms: 2MW)
1MA, 0.55T, 1MW NBI
Plunge time: Max at 330ms (**4 shots**)

2. Start Ip scan
   NBI time: A (120-330ms: 2MW), B (320-500ms: 1MW), C (170-290ms: 2MW)
   Plunge time: Max at 400ms
   - 0.7MA, 0.385T, 1MW NBI (**4 shots**)
   - 0.8MA, 0.45T, 1MW NBI (**2 shots**)
   - 0.9MA, 0.495T, 1MW NBI (**2 shots**)

Decision point 2: to take 0.6MA point
NBI time: A (120-330ms: 2MW), B (320-500ms: 1MW), C (170-290ms: 2MW)
0.6MA, 0.355T, 1MW NBI
Plunge time: Max at 400ms (**4 shots**)

3. Start density scan
   NBI time: A (150-330ms: 2MW), B (320-500ms: 1MW), C (190-290ms: 2MW)
   1MA, 0.55T, 1MW NBI
   - nebar 4.5e19, plunge at 450ms (**4 shots**)

Decision point 3: HFS gas fueling (1200→1400Torr) or SGI for higher density
NBI time: A (150-330ms: 2MW), B (320-500ms: 1MW), C (190-290ms: 2MW)
1MA, 0.55T, 1MW NBI
Plunge time: Max at 450ms (**4 shots**)

4. Power scan (If time permitting)
   1MA, 0.55T, Plunge time: Max penetration at 400ms
   - 0MW: A (150-330ms: 2MW), B (320-330ms: 1MW), C (190-290ms: 2MW) (**4 shots**)
   - 0.5MW: (150-330ms: 2MW), B (320-330ms: 0.5MW), C (190-290ms: 2MW) (**4 shots**)

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

This XP requires a fully operational NBI system. We desire HeGDC between shots of ~ 6.5 minutes for a 12.5 minute repetition rate.

5. Planned analysis

The SOL widths will be analyzed from the data obtained from the fast probe and the IR camera, and relationships between the SOL widths will be investigated. The SOL widths data will be scaled with operation parameters to derive the scaling law and will be compared with analytic cross-field transport models. The GPI data will be analyzed to yield blob characteristics and this will be compared with SOL widths data to find relationships. EFIT will be necessary for the flux mapping of the profiles to the mid-plane.

6. Planned publication of results

Data and analysis for the relation of SOL widths will be presented at the PSI conference in May 2008 and be published in J. Nucl. Materials in 2009. SOL width scaling work will be published in an appropriate refereed journal.

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **63** Flattop start/stop (s):

I_P (MA): **0.7-1.0** Flattop start/stop (s): **0.15/1.0 (max)**

Configuration: **LSN**

Outer gap (m): **10cm** Inner gap (m): **5-10cm**

Elongation κ: **2.0** Upper/lower triangularity δ: **0.45**

Z position (m): **0.0**

Gas Species: **D** Injector(s): Inner wall Mid-plane

NBI Species: **D** Sources: **A/B/C** Voltage (kV): Duration (s): **<1sec**

ICRF Power (MW): Phasing: Duration (s):

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

LITER: On / Off

Previous shot numbers for setup: **125065 (LSN) (1.0MA / 63kA)**

127231 (0.9MA / 58kA)

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Bolometer – tangential array	√	
Bolometer – divertor		√
CHERS – toroidal	√	
CHERS – poloidal		√
Divertor fast camera	√	
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.	√	
Edge pressure gauges	√	
Edge rotation diagnostic	√	
Fast ion D_alpha - FIDA		√
Fast lost ion probes - IFLIP		√
Fast lost ion probes - SFLIP		√
Filterscopes	√	
FIReTIP	√	
Gas puff imaging	√	
Hα camera - 1D	√	
High-k scattering		√
Infrared cameras	√	
Interferometer - 1 mm		
Langmuir probes – divertor	√	
Langmuir probes – BEaP		√
Langmuir probes – RF ant.		
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
Magnetics – Pickup coils	√	
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 – ExB scanning		√
NPA – solid state		
Neutron measurements		√
Plasma TV		√
Reciprocating probe	√	
Reflectometer – 65GHz		√
Reflectometer – correlation		√
Reflectometer – FM/CW		√
Reflectometer – fixed f		√
Reflectometer – SOL		√
RF edge probes		
Spectrometer – SPRED	√	
Spectrometer – VIPS	√	
SWIFT – 2D flow		√
Thomson scattering	√	
Ultrasoft X-ray 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 fast pinhole camera		
X-ray spectrometer - XEUS		