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L-H Transitions and the H-mode Edge in the National Spherical Torus Experiment (NSTX)

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I. Introduction: Long Pulse High Performance H-modes on NSTX.

H-modes are being applied effectively in experiments aimed at achieving the high β goals of NSTX. Toroidal β_t as high as 32 % has now been obtained in H-mode plasmas in NSTX. The H-mode access space has been expanded significantly during the past year as a result of recent improvements in wall conditioning, magnetic configuration and operational scenario development. These include full implementation of a 350 °C bake out capability, routine application of boronization, and reduction of magnetic field errors. Previous H-modes reported from spherical tori have been of modest duration [1,2,3]. L-H mode transitions have been obtained in lower single null (LSN) and double null (DN) divertor geometries but not yet in either upper single null diverted or center stack limited discharges. Although H-modes are obtained with either RF or NBI heating, only results for NBI heated H-modes will be reported here. The parameter ranges for H-mode access in

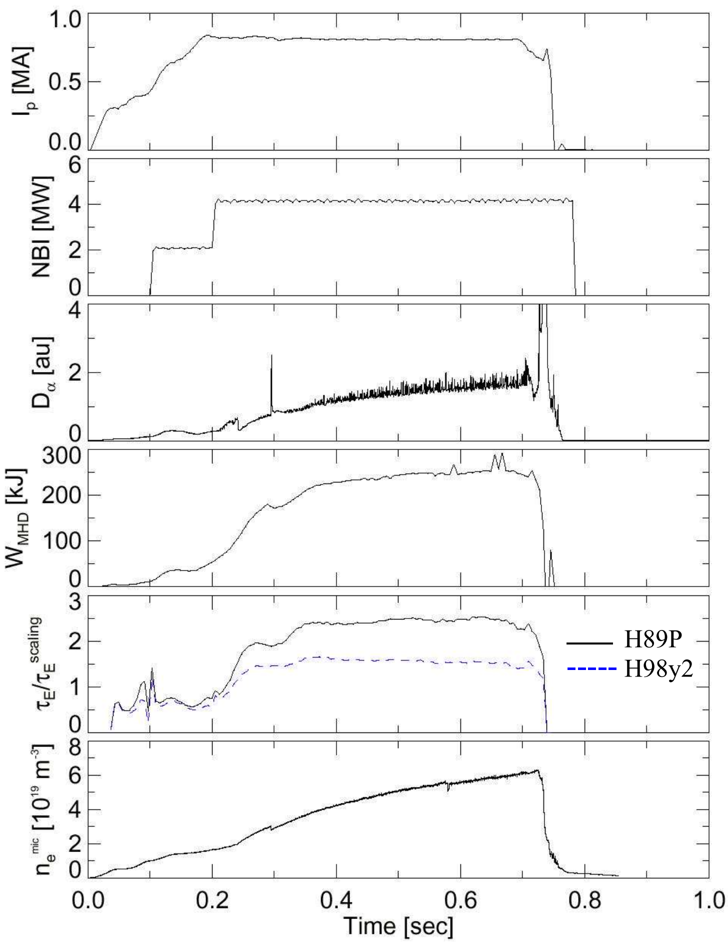

Fig. 1 Time variation of parameters for a long pulse high performance H-mode.

NBI heated plasmas with aspect ratio ~1.3 and elongation $1.6 < \kappa < 2.3$ can be summarized as follows: $0.3 < B_t < 0.6$ T, $0.6 < I_p < 1.2$ MA, $0.33 \leq P_{NBI} \leq 7$ MW. The duration of H-modes in NSTX has been extended by an order of magnitude: an H-mode duration > 500 ms has been obtained in a plasma with beta-poloidal $\beta_P \approx 1.3$ and a substantial fraction of bootstrap-driven current.

Time traces for a high performance H-mode obtained by optimizing the configuration are given in Fig.1. The drop in D_α signaling the L-H transition is at t ~ 0.220 s. More recently, H-mode plasmas in NSTX have benefited from higher neutral beam voltages and power, and higher toroidal field. In an H-mode obtained at I_p = 1.2 MA, B_t = 5.5 kG using 7 MW of NBI, a stored energy of 390 kJ was produced with β_t ~ 20 % and β_p ~ 0.95.

II. Edge Fluctuations during NSTX H-modes.

There are clearly similarities between the dynamics of the L-H-mode transition and the ensuing H-mode behavior for ST's and conventional aspect ratio tokamaks. Following the transition, there is a reduction in the turbulent fluctuations seen on several diagnostics. The gas puff imaging (GPI) diagnostic [4] which is sensitive to density fluctuations in the vicinity of the plasma boundary at the outboard midplane has revealed clear differences between the edge turbulence in H- and L-mode plasmas. Generally L-

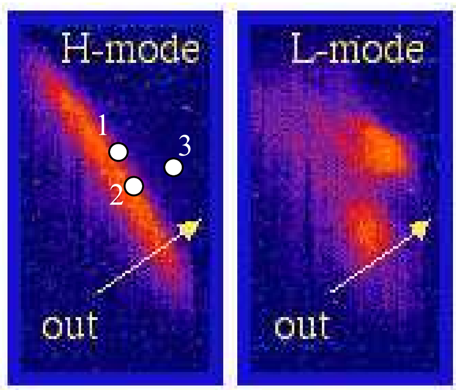

Fig.2: Images of edge turbulence in NSTX taken in HeI(587.6 nm) light with an exposure of 1µs. These views shows a 15 cm x 30 cm region of the plasma edge in the plane perpendicular to the magnetic field, and with the outer wall toward the upper right. The plasma is relatively quiescent in the H-Mode (left), but highly turbulent in the L-Mode (right),which often shows small "blobs" which move outward in radius.

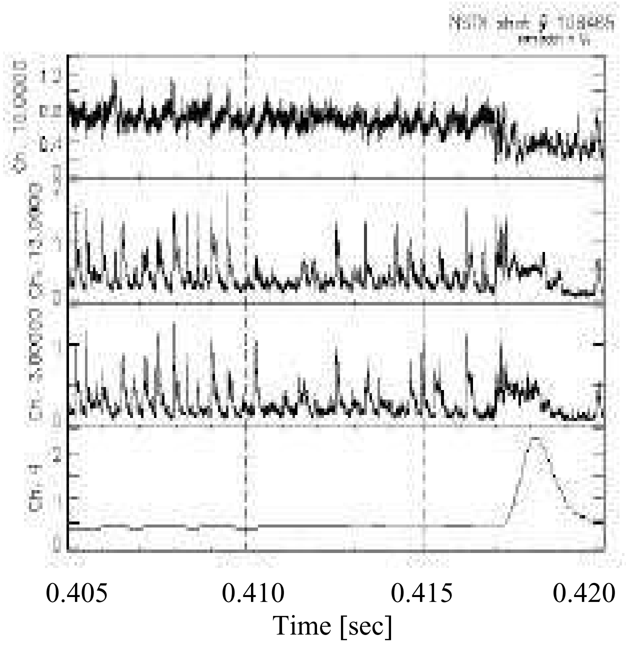

Fig.3: Time dependence of the GPI light emission from the three regions shown in Fig. 2 (top three traces), compared with the standard D_α light monitor (bottom). There are many intermittent bursts visible during the ELM-free period, probably corresponding to a series of blobs forming in this region and moving outward.

mode (and Ohmic) plasmas have a very turbulent spatial structure with a typical size scale of 3-7 cm, often developing isolated “blobs” of increased emission which move in both the radial and poloidal directions. H-mode plasmas usually have a more quiescent edge, at least within the region in which GPI can measure, as illustrated in Fig. 2. However, many H-mode plasmas in NSTX also exhibit blobs which form intermittently and move outward, even during ELM-free periods. Evidence of this is shown in Fig. 3 which presents the D_α emission from a standard chordal measurement and from three fast photodetectors viewing along chords approximately tangential to the local B-field in the vicinity of the separatrix. During the period when the slow signal appears quiescent, the fast detectors reveal frequent small bursts which are the signatures of the blobs seen in the 2-D images. The rapid bursts actually become suppressed during the large ELM spike on seen on the slower detector. Thus, there appears to be no obvious link between the ejection of the blobs and the large ELMS. Sometimes during H-modes, a short burst of coherent oscillations is observed in the GPI image with a poloidal wavelength of about 20 cm and a period of about 10 kHz.

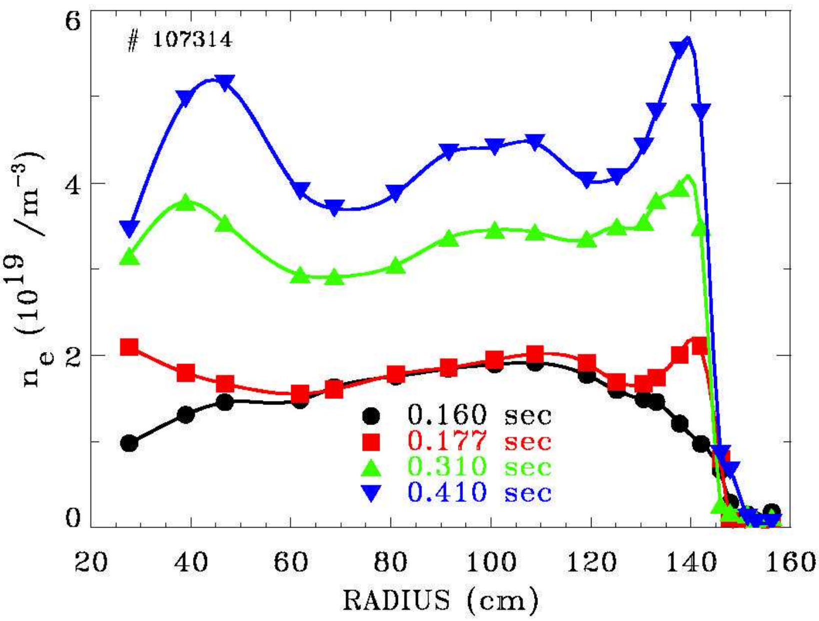

Fig. 4: Electron density profiles at several different times during a long pulse H-mode, showing development of the ears. Note t=0.16sec is in the L-mode phase.

At the L-H transition, both the Thomson scattering measurements and a scanning reflectometer show a rapid increase in the edge density. The addition of spatial channels to the multi-pulse Thomson scattering diagnostic has confirmed earlier reports that the density profile develops localized peaks, referred to as “ears”, near the edge during the H-mode, An example is shown in Figure 4.

III. Power Threshold Experiments.

NSTX has obtained H-modes in both the LSN and DN configurations. While power threshold data have been obtained for both configurations, most of the detailed parameter scans were carried out in LSN. It was found, however, that for similar discharge conditions (B_T=0.45 T, I_p=0.9 MA), the auxiliary heating power required for a transition into the H-mode could be over a factor of two greater for DN than for LSN plasmas. Furthermore, it was observed that the line-average density required for an L-H transition in DN plasmas (~4 × 10^{13} cm^{-3}) was greater than that required in LSN plasmas (~2.5 × 10^{13} cm^{-3}). No transition was observed in these DN plasmas at the lower density (2.5 × 10^{13} cm^{-3}) even at the higher powers.

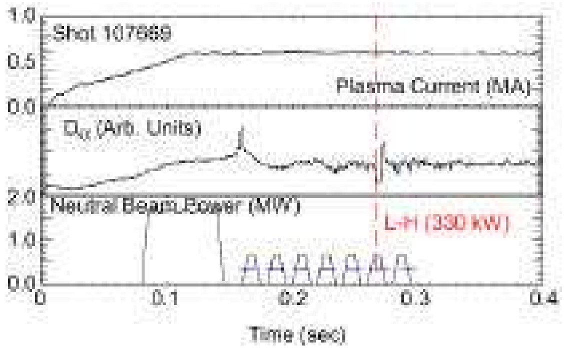

Fig. 5 Time history of NSTX discharge exhibiting the lowest power threshold to date.

Fig. 5 shows an NSTX discharge at 600 kA and 0.45 T with a short H-mode phase whose power threshold was 330 kW, representing the lowest power threshold obtained to date. As can be seen in the figure, the beams blocked for 20 msec every 20 msec; the 330 kW represents the average beam power during this period, given by $P_{NBI,max}/2$. This was found to be a good characterization of the average beam power by investigating H-mode access requirements with and without similarly blocked beams at higher powers. The power threshold can be quantified by the value of P_{loss}/P_{scal}, where P_{loss} is the power lost through the separatrix at the time of the L-H transition, and is defined as $P_{NBI}+P_{OH}-dW_p/dt$, where the latter term is the time rate of change of the plasma stored energy. P_{scal} is the threshold scaling given in [5], which includes an inverse aspect ratio dependence derived from the inclusion of MAST data in the threshold database. For this discharge, $P_{loss}/P_{NBI} \sim 2 - 2.5$.

In summary, long duration high performance H-modes are realized on NSTX. Intriguing edge fluctuation phenomena are observed using GPI and must be investigated further. Power threshold values are not inconsistent with those predicted from a scaling that includes an aspect ratio dependence. Continued running of NSTX and regular conditioning could possibly lead to a further lowering of the L-H power threshold in NSTX.

Acknowledgements

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