Researchers Observe a Further Enhancement of Energy Confinement in the National Spherical Torus Experiment

High-confinement mode or "H-mode" plasmas are routinely produced and studied in the National Spherical Torus Experiment (NSTX). However, in recent NSTX experiments, a second transition from H-mode has been observed, in which the edge plasma temperature and density increase further, producing even higher energy confinement.

Plasmas in the high-confinement mode, or "H-mode", play an important role in fusion energy research in tokamaks and spherical torus devices. Such H-mode plasmas are routinely produced and studied in the National Spherical Torus Experiment (NSTX) at the Princeton Plasma Physics Laboratory. H-mode plasmas achieve better confinement of the plasma energy, and they also develop a characteristic stairstep-like structure termed a "pedestal" in the plasma radial profiles near the edge, which both improves plasma stability and generates a larger fraction of the self-generated plasma current.

In an invited talk to be presented at the 47th Annual Meeting of the APS Division of Plasma Physics in Denver Colorado, David Gates will describe how, in recent NSTX experiments [1], a spontaneous additional improvement in H-mode plasmas has been observed, in which the plasma temperature and density in the edge plasma increased further, producing even higher confinement. Figure 1 shows an example of such a transition to an enhanced H-mode (indicated by the red-dashed line). This occurred well after the normal transition to the H-mode (shown by the black dashed line), and appeared to be triggered by the occurrence of a brief burst of magnetohydrodynamic (MHD) instability, indicated by the "spike" in the emission of light from the plasma edge at $t = 0.17$ s. The improvement in the energy confinement is evident in the behavior of the plasma stored energy, which began to increase even though the heating power of the neutral beams remained constant. The calculated energy confinement time was transiently up to 50% higher than normal H-modes in NSTX.

As shown in Figure 2, the electron and ion temperatures increased dramatically, by a factor of 2-3 during the enhanced H-mode phase relative to normal H-mode values at the top of the edge "pedestal". These temperatures in the enhanced H-mode created, for the first time in a spherical torus, a very low particle collision rate in the "pedestal". The normalized particle collision frequency actually approached the range expected for the International Thermonuclear Experimental Reactor. These discharges exhibit some similarities with an enhanced H-mode regime known as very high confinement or "VH-mode", reported from the DIII-D tokamak[2].

The enhanced H-mode phase was terminated when the ratio of the plasma pressure to magnetic field pressure reached a critical value. This value is about two-thirds of the best NSTX stability limit, but is not unexpected from theory because measurements revealed that almost no toroidal current was flowing in the innermost region of the plasma cross-section in the enhanced confinement phase. Future experiments will try to lengthen the duration of the enhanced H-mode phase, partly by modifying the current density profile to restore higher stability limits.

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[1] R. Maingi, *et al*., "Observation of an H-mode with Enhanced Confinement in the National Spherical Torus Experiment", *to be submitted to Physical Review Letters*.

[2] G.L. Jackson, *et. al., Physical Review Letters* **37** (1991) 3098.

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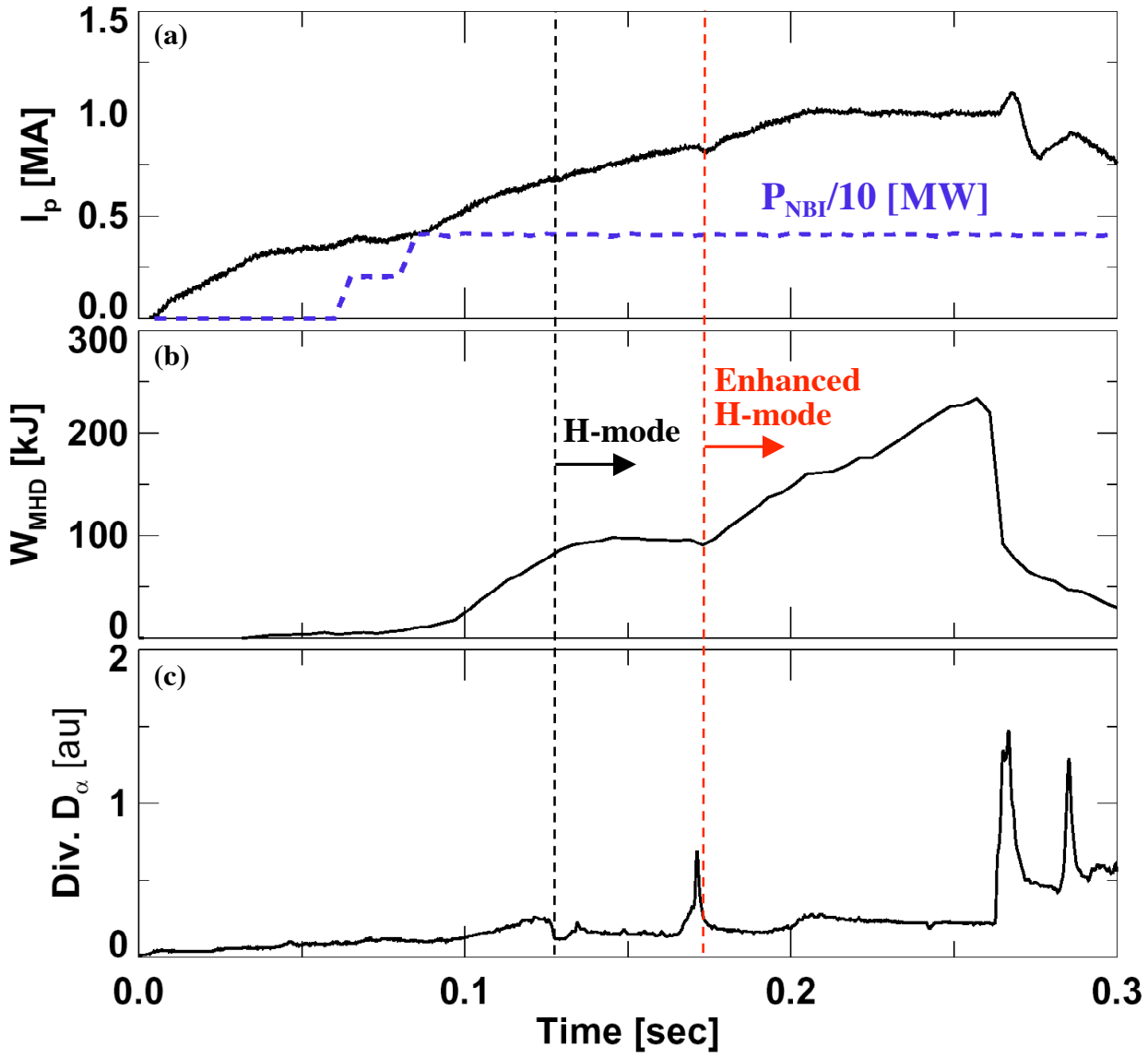

Figure 1. Time evolution of (a) toroidal plasma current (I_p) and neutral beam heating power (P_{NBI}); (b) plasma stored energy (W_{MHD}); and (c) the level of hydrogen light emission from the plasma edge. The transition to the normal H-mode occurred at t ~ 0.125 sec. The second transition to an enhanced H-mode occurred at t ~ 0.17 sec, following a burst of MHD instability marked by the elevated "spike" in the light emission.

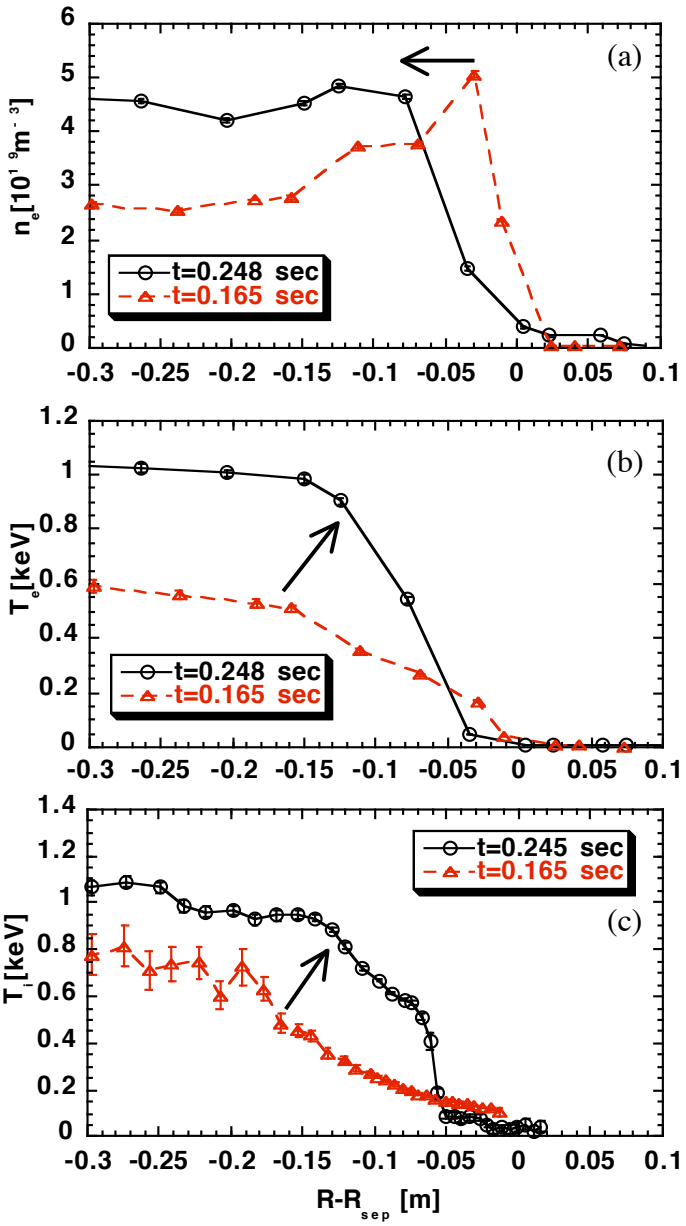

Figure 2 – Changes in the profiles of (a) electron density (n_e); (b) electron temperature (T_e); and (c) ion temperature (T_i). The quantities are plotted against the distance from the outer edge of the plasma determined by magnetic data. The density increased mainly in the interior of the plasma, whereas the temperatures increased substantially near the edge during the enhanced H-mode phase, and the width of the steep gradient region also increased.