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Lithium calms the edge plasma in the National Spherical Torus Experiment

New insight has been gained on the governing physics of edge plasma relaxations, which have been suppressed by coating the plasma facing surfaces with Lithium in the National Spherical Torus Experiment. In addition techniques to re-introduce controlled edge plasma relaxations on demand with 3-D magnetic fields have been refined, leading to improved control of the plasma characteristics.

Controlled thermonuclear fusion reactors are designed so that they will produce fusion reactions in the center of the plasma, which would also heat up the core plasma as the fast fusion products share their energy with the background plasma. In present day fusion research experiments, this central heating is simulated by injecting power from external sources, such as neutral beams. The efficiency by which plasmas retain this heat input is measured by the energy confinement time. In the early 1980's, a phenomenon was discovered in which the energy confinement time was observed to spontaneously double; this mode of operation was termed 'H-mode' for high confinement mode. A common observation in H-mode discharges across nearly all fusion research facilities was that the plasma showed signs of periodic relaxation events, which were named Edge Localized Modes or ELMs. These ELMs prevent buildup of contaminants and help to control the plasma density by ejecting impurities and fuel from the edge plasma region. When imaged with visible cameras, these ELMs were shown to consist of spiraling, ribbon-like filaments, similar in appearance to surface waves in hydrodynamics. The negative aspects of these ELMs include a small, sometimes transient reduction of the energy confinement time, and the occurrence of periodic heat pulses to the plasma-facing components (PFCs). These aspects of ELMs are a very serious concern for future fusion devices, such as the ITER, if the individual ELMs each result in a substantial loss of the plasma stored energy, which could lead to a concentrated heat pulse and PFC damage. On the other hand, H-mode discharges without ELMs ('ELM-free H-mode') were shown to be transient because both impurities and fuel remained in edge plasma for too long, resulting in an increase in the radiation from the plasma and an eventual thermal collapse as the plasma cooled. One solution for existing devices and future reactors is to use very frequent, small-amplitude ELMs to provide impurity control without large heat pulses.

In the National Spherical Torus Experiment (NSTX), several innovations have been refined to obtain new insight into the physics of ELMs, and these results will be presented in a series of talks at the 2009 APS Division of Plasma Physics conference. A couple of years ago, specially designed ovens were placed inside the NSTX vacuum chamber to coat the carbon PFCs with lithium. While the lithium coatings improved the energy confinement time by slowing the electron thermal transport in the edge plasma, they also somewhat surprisingly suppressed the periodic ELMs, which were present in pre-lithium discharges. Over the past year, detailed analysis was performed on the edge plasma profiles both with and without the lithium wall coatings. While the plasma temperature very near the periphery was unchanged, the plasma density and its radial gradient were reduced. As a result, theoretical calculations showed that the edge plasma pressure profile was shifted in a way that made the plasma more stable to edge plasma relaxations. The periodic heat loads from ELMs as measured with a new fast-framing, infrared camera were dramatically reduced, as shown in Figure 1.

To remedy the high impurity retention, a pulsed 3-D magnetic field was imposed using a set of coils just outside the vacuum vessel, to magnetically trigger ELMs. This pulsed magnetic field is in addition to the magnetic field used to confine the plasma. The added magnetic field was in the radial direction and varied around the plasma circumference, with three sinusoidal periods around the plasma circumference. The technique was successful: the magnetic field was used to trigger ELMs on demand, flush impurities, and improve the discharges. The results of these studies were used to improve high performance plasmas with magnetically triggered ELMs-on-demand.

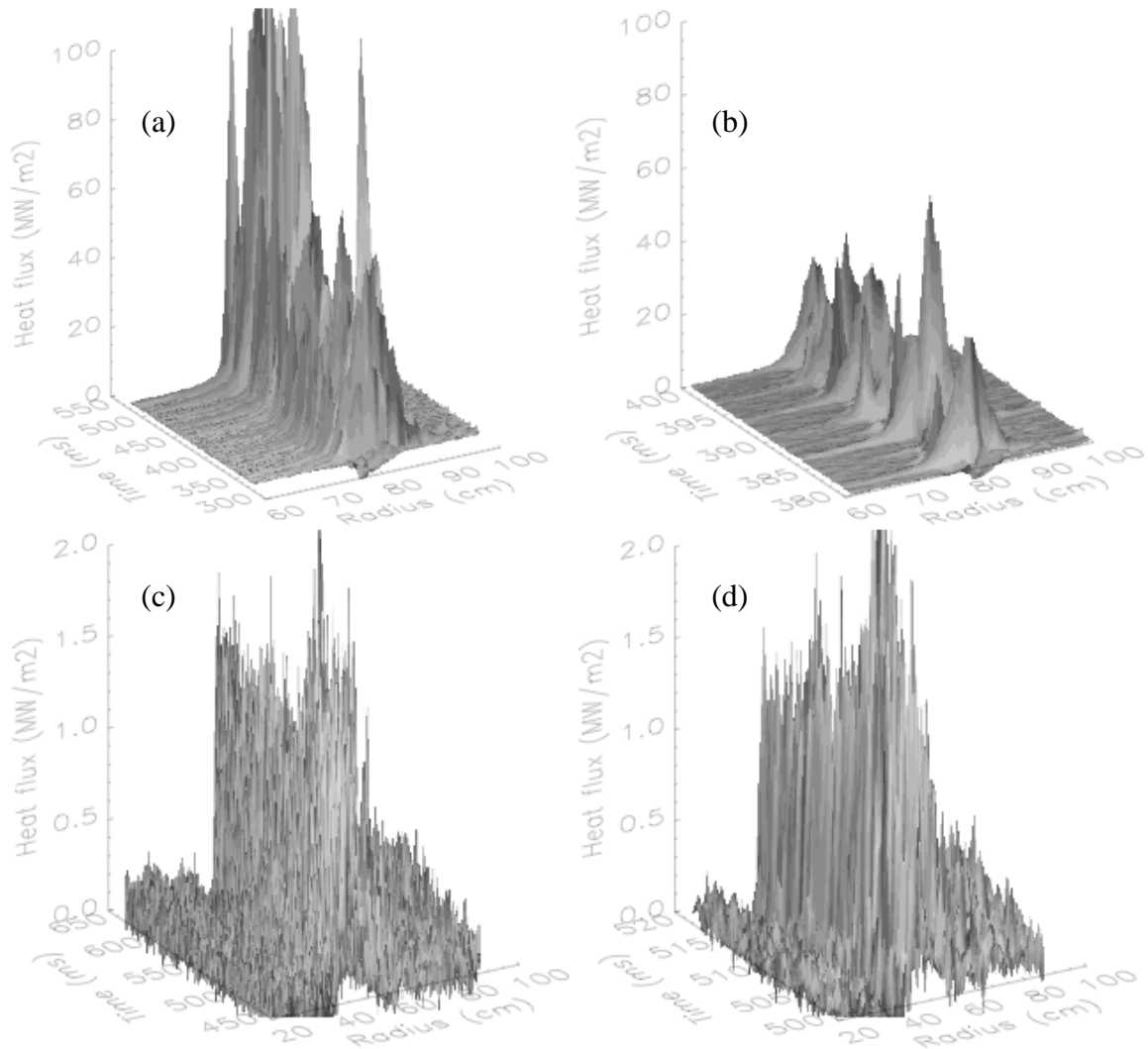


Fig. 1 – the heat flux to the plasma facing surfaces in the bottom of NSTX from a pre-lithium ELMy discharge (panels (a) and (b)), along with a post-lithium ELM-free discharges (panels (c) and (d)). Panels (b) and (d) are expanded time bases of panels (a) and (c) to show individual ELMs. Note that the maximum scale of the ELMy discharge is 50 times higher than the ELM-free discharge. The data were obtained from a new, fast-framing infrared camera.

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