Topic: OV

# Overview of Physics Results from the National Spherical Torus Experiment*

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**Abstract:** Research on the National Spherical Torus Experiment, NSTX, targets the physics understanding needed to extrapolate confidently toward the goal of a steady-state Fusion Nuclear Science Facility, pilot plant, or DEMO based on the ST. The unique ST operational space is leveraged to test physics theories for next-step tokamak operation, including ITER. Present research has also examined implications for the coming device upgrade, NSTX-U, doubling field, plasma current and heating power to produce high beta plasmas at lower collisionality, $\nu$. In NSTX, an increase in energy confinement is observed as $\nu$ is reduced with data extended down to $\nu^*_e$ = 0.05 by lithium (Li) conditioning of first wall components. Nonlinear microtearing simulations predict reduced electron heat transport at lower $\nu$ and match the experimental electron diffusivity, $\chi_e$, quantitatively. A measured reduction in high-$k$ turbulence and computed $\chi_e$ are observed in H-mode, accentuated by Li wall conditioning. Plasma characteristics change nearly continuously with increasing Li evaporation: global energy confinement parameters improve, edge transport declines, and ELMs stabilize due to alteration of the density gradient outside of the pedestal, with no Li accumulation in the core. Beam-emission spectroscopy measurements indicate the poloidal correlation length of turbulence in the pedestal increases at higher $n_e$ and $\nabla n_e$, decreases at higher $T_i$, and $\nabla T_e$, and is consistent with generic low-$k$ turbulence. Global mode stabilization studies yield a new understanding of stability limits and are improving disruption avoidance. Stabilizing effects of collisional dissipation are reduced at lower $\nu$, but stabilizing resonant kinetic effects are enhanced. Combined radial and poloidal field sensor feedback significantly reduced $n$ = 1 perturbations and improved stability. The disruption probability due to unstable RWMs is reduced by more than a factor of three in low $l_i$ plasmas at high $\beta_N/l_i$ > 11. Greater instability seen at lower $\beta_N/l_i$ is consistent with decreased kinetic RWM stabilization at plasma rotation between stabilizing resonances. A model-based RWM state-space controller proposed for ITER, which includes a 3D model of plasma and mode-induced wall currents, has produced long-pulse discharges exceeding $\beta_N$ = 6.4, and $\beta_N/l_i$ = 13. Disruption precursor analysis for more than 2000 shots show 99% of disruptions can be predicted with ~10ms warning, with a false positive rate of only ~4%. Disruption halo currents can have significant toroidal asymmetry and can rotate toroidally at 0.5-2 kHz. In addition to Alfvénic modes, low frequency $n$=1 global kinks cause fast ion redistribution as measured by a fast ion $D_\alpha$ diagnostic. Full-orbit code calculations show redistribution from the core outward, and toward $V_{||}/V$ = 1, consistent with reduced CAE stability. The snowflake divertor configuration enhanced by impurity-seeded radiative detachment has demonstrated a significant reduction in steady-state and ELM divertor heat fluxes, high core plasma confinement with reduced core impurities, and stable operation. The peak divertor heat flux decreased from 7 MW/m$^2$ to less than 1 MW/m$^2$, providing the basis for the heat flux reduction required in NSTX-U. Experimental scenario development has accessed aspect ratio and boundary shaping planned for NSTX-U. Predictive TRANSP calculations project 100% non-inductive current (NIC) fraction at $I_p$ = 1MA, capability for an order of magnitude collisionality variation, and a factor of 3 reduction compared to NSTX for fully relaxed plasmas with $q_{min}$ > 1. NIC fraction up to 65% is experimentally reached. Coaxial helicity injection (CHI) has further reduced the inductive startup flux. L-mode plasmas ramped to 1MA require 35% less inductive flux when CHI is used. TSC simulations using CHI predict at least a doubling of the closed flux current for NSTX-U.

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