Topic: OV

NSTX Research Results in Preparation for NSTX-Upgrade Operation

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The National Spherical Torus Experiment (NSTX) is currently being upgraded to include a center stack capable of producing twice the toroidal field and plasma current (up to 1 T and 2 MA), and a second, more tangentially aimed neutral beam for current and rotation control, allowing pulse lengths up to 5 s. During the two-year construction period, NSTX physics analyses have addressed key topics that will allow NSTX-U to achieve the research goals critical to next step Spherical Tokamaks, such as a Fusion Nuclear Science Facility. These goals include accessing low collisionality and high beta, producing stable, 100% non-inductive operation and assessing PMI solutions to handle the high heat loads expected in the next-step devices.

Detailed gyrokinetic simulations have been performed to study transport of heat, particles and momentum in the core plasma. Electron heat transport is the dominant loss channel in NSTX-U, as it may be in future fusion devices. NBI-heated L-mode plasmas, which exhibited non-linear coupling between ion and electron-scale turbulence and strong effects of ExB shear [1], have been studied using the global, non-linear GTS code. GTS predicts strong ExB suppression of the ion scale turbulence, and it predicts ion thermal diffusivities comparable to those inferred from experiment. In RF-heated L-mode plasmas, electron-scale turbulence is seen to decrease following the RF turn-off, despite little or no change in either the temperature profiles or local equilibrium quantities, indicating the importance of "non-local" turbulence spreading. Quasi-linear estimates of impurity and momentum pinch numbers are at odds with experimental results. Both results indicate the need for non-linear, global gyrokinetic simulations, presently underway using GTS, GYRO and XGC1.

Studies of fast growing Ideal Wall Modes (IWM) using MARS-K indicate that including rotation and kinetic resonances is necessary for predicting experimental stability thresholds; otherwise, the IWM is predicted to become unstable at beta values higher than those observed. Extensions of work showing the importance of kinetic resonances on resistive wall mode (RWM) stability [2] have identified favorable ExB velocity profiles needed for disruption avoidance. A model-based rotation control algorithm using non-resonant neoclassical toroidal viscosity (NTV) from applied 3D fields, and a simplified kinetic RWM stability criterion will be used to improve disruption avoidance in NSTX-U for long-pulse operation. The physical characteristics of NTV, including the dependence on collisionality, behavior at reduced plasma rotation, and radial profile details are presently under analysis. A massive gas injection system will be implemented to probe the poloidal dependence of the gas penetration, including injection on the high field side and private flux regions. The DEGAS-2 code is being utilized to understand the dependence of gas penetration on SOL temperatures and densities.

ELM studies have shown that the peak heat flux increases with the size of the ELM, while the wetted area can decrease or increase, depending on the number of filaments in the heat flux footprint. n=3 3D fields, applied to the plasma to study the effect of this magnetic perturbation on divertor heat flux, showed a phase locking of the divertor footprint to the 3D fields for small ELMs, but not for large ones. The presence of the 3-D fields was found to lead to a reattachment of a detached plasma unless strong gas puffing was utilized [3]. Studies of Enhanced Pedestal (EP) H-modes focused on assessing whether this mode, with $H_{98y,2}$ values up to 1.7, could be the basis for stable operation in NSTX-U. Strong T_i gradients were associated with strong rotation shear and an E_r well in the pedestal region, and the experimentally inferred neoclassical ion thermal transport was confirmed by the XGC0 code. GS2 results showed the existence of TEM/KBMs in the steep gradient region, and that the ETG mode was a candidate for clamping the T_e profile just inside the separatrix.

Large, up to 20%, drops in the neutron rate due to TAE avalanches were studied by synthesizing the linear eigenmode structure computed by NOVA-K, mode displacement measured by the reflectometer diagnostic, and particle tracking by the ORBIT code. The neutron decrease was found to be due primarily to energy loss and a redistribution of fast ions, with the energy loss channeled back to the thermal plasma through the damping of the TAEs. First tests of a reduced transport model for fast ions due to TAEs has shown good agreement with experimental observations. This model, based on a phase space “kick” probability function, will be implemented in NUBEAM/TRANSP for both analysis and prediction.

AORSA-based full wave simulations of fast ion heating that include a finite SOL density show that RF power losses in the SOL increase significantly for both NSTX and NSTX-U plasma scenarios when the launched waves transition from being evanescent to propagating in the SOL. Large power losses in the SOL, which then follow field lines into the divertor region, are predicted when the wave propagates, consistent with experimental observations.

The physics of Coaxial Helicity Injection has been studied using the NIMROD code in 2D, and the simulations exhibit X-point and closed flux formation 0.5 ms after injector voltage and current turn-off. The simulated reconnection follows from a radial bi-directional pinch flow that is consisten with a 2D Sweet-Parker process. The simulations also show the importance of plasma resistivity and injector flux temporal dynamics and footprint [4, 5].

Lithium evaporation on graphite PFCs in NSTX has led to reduced recycling and enhanced performance. Lithium increases oxygen surface concentrations on graphite, and deuterium-oxygen affinity [6], which increases deuterium pumping and reduces recycling. Source studies showed that the low lithium level observed in the core of lithium-coated wall NSTX plasmas was due to both a high retention of lithium in the divertor region as well as a large neoclassical diffusivity, which governed the radial lithium transport in the edge region. Lithium coating lifetimes were studied with both graphite and molybdenum substrates on the Magnum-PSI test stand [7], with results showing a longer Li lifetime on molybdenum than on graphite. Lithium-coated molybdenum samples also exhibited a long-lived vapor cloud of lithium in front of the target, leading to the possibility of steady-state vapor-shielding of PFCs suggesting a novel divertor regime to be examined after the installation of a high-Z divertor in NSTX-U. Gross lithium erosion rates under high-flux, high-temperature conditions are found to be lower than in low-flux experiments suggesting maximum temperature limits for a lithium PFC in the divertor should be reconsidered.

Upgrade construction is moving on schedule with first operation of NSTX-U planned for Autumn 2014. The project status and operations plan will be given.

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