Research Milestone R(11-1): Measure fluctuations responsible for turbulent ion and electron transpot

Results from NSTX indicate that the scalings of electron and ion energy transport with magnetic field and plasma current differ in the ST, and they also differ from high-aspect-ratio tokamak dependences. Understanding electron transport is particularly important as the electron channel is the dominant energy loss channel in NSTX plasmas, while ion transport commonly approaches neoclassical levels in H-mode plasmas. High-k scattering measurements have identified ETG turbulence as one candidate for the anomalous electron energy transport. However, low-k fluctuations may also contribute to electron and momentum transport. In addition to measuring high-k fluctuations, the low-k portion of the turbulent density fluctuation spectrum will be measured with a Beam Emission Spectroscopy (BES) diagnostic. Additional fluctuation measurements at long wavelength will be made using the upgraded reflectometer, interferometer and gas puff imaging systems. Experiments will be performed to vary plasma parameters such as collisionality, ExB shear, magnetic shear, plasma current, T_e/T_i and magnetic field to change the instability drive and damping of the various micro-instabilities (ITG, TEM, micro-tearing, and ETG) thought to possibly be responsible for anomalous energy transport. The k spectrum of the turbulence will be measured as function of plasma parameters and correlated with energy diffusivities inferred from power balance analysis.

Research Milestone R(11-2): Assess the dependence of integrated plasma performance on collisionality.

The high performance scenarios assumed for next-step ST devices such as NHTX and ST-CTF are based on operating at lower Greenwald density fraction and significantly lower pedestal collisionality than NSTX. Building on the research of the FY2010 boundary physics milestone R(10-3), Milestone R(11-2) would extend research on high-performance plasmas toward lower density and collisionality and systematically assess integrated performance (such as non-inductive current fraction, confinement, core and pedestal stability, pulse-duration, impurity content) of long-pulse H-modes. Two possible tools for accessing reduced plasma collisionality are the Liquid Lithium Divertor (LLD) and the upgraded HHFW system capable of higher power and with resilience to ELMs. Based on a successful demonstration of particle pumping in FY2010, the LLD would be utilized to vary plasma density and temperature by varying its pumping through control of parameters such as the strike-point position, flux expansion, the temperature, and thickness of the lithium layer. Further, the plasma integrated performance would be assessed as a function of boundary shape, in particular the strike point location and triangularity, to assess the possible trade-off between improved MHD stability (higher triangularity) and increased pumping efficiency (lower triangularity). Building upon recent successful electron heating by HHFW in low neutral beam power H-modes, the upgraded HHFW system will be used to heat electrons in order to decrease the collisionality and to increase non-inductive currents in high-power, long-pulse H-mode scenarios. The influence of these advanced pumping and heating capabilities on NSTX high-performance plasmas will be compared to time-dependent simulation codes such as

TSC and TRANSP to develop a predictive capability for advanced ST operating scenarios.

Research Milestone R(11-3): Assess the relationship between lithiated surface conditions and edge and core plasma conditions

The plasma facing components (PFC) of fusion devices play a key role in determining the performance of the fusion plasma edge and core by providing particle pumping and fueling and acting as a source of impurities. On NSTX, coating the divertor carbon PFCs with evaporated lithium has resulted in transient particle pumping, increased energy confinement, and suppression of edge localized modes (ELMs). To extend the duration of particle pumping, and to investigate the impact of liquid lithium on plasma performance, a liquid lithium divertor (LLD) will be installed in FY2010, and the relationship between lithiated surface conditions and edge and core plasma conditions will be determined. Deuterium pumping will be studied as a function of LLD temperature and divertor electron density and temperature, strike-point location, and flux expansion. Deuterium recycling will be measured with a Lyman-α AXUV diode array. An in-situ materials analysis particle probe situated near the LLD will provide data on surface composition in the outer divertor region. The measurements will be compared to retention models. The temperature evolution of the LLD surface will be measured to determine its heat transfer properties and allowable peak flux, and to relate the LLD surface temperature to the influx of lithium and hydrogenic species. Finally, lithium transport from the plasma edge to the core will be measured. This research will provide the scientific understanding of LLD operation necessary to begin to evaluate liquid lithium as a possible PFC solution for NSTX and next-step facilities.

Research Milestone IR(11-1): Assess RWM and rotation damping physics at reduced collisionality

The proposed operating scenarios of next-step STs such as NHTX and ST-CTF rely on sustaining beta values at or above the no-wall kink stability limit. NSTX has already demonstrated sustained operation above the no-wall limit utilizing toroidal rotation from co-injected neutral beams to stabilize the resistive wall mode (RWM). Passive RWM stabilization, dynamic error field correction and active feedback control of unstable RWMs were essential elements in achieving sustained high-normalized-beta operation. However, the lower density and significantly lower collisionality of next-step STs could make rotational stabilization of the RWM more challenging. Specifically, initial results from NSTX indicate that lower ion collisionality may increase the rotation needed to stabilize the RWM, and if neoclassical toroidal viscosity (NTV) scales as $1/\nu_i$ as predicted, the torques from plasma-amplified error fields will increase. Variations in equilibrium profiles and stability limits will be characterized as a function of density and collisionality. The damping torque from both resonant and non-resonant braking will also be characterized as a function of collisionality. Rotation profiles unfavorable for RWM stability will be determined by varying the plasma rotation with non-resonant magnetic braking. Several advanced numerical tools will be utilized to model the RWM control and stabilization physics (including MISK), plasma rotation damping, and plasma response effects. This research will aid development of a predictive capability for the passive and active suppression of error fields and resistive wall modes (RWM) for the ST and ITER.

IR(11-2) Assess pedestal and SOL response to externally applied 3D fields.

Three-dimensional (3D) fields are proposed in ITER to suppress ELMs and reduce time averaged heat flux. This research aims to improve understanding of the underlying physics of the pedestal and SOL transport and stability response to 3D fields, and use this understanding to optimize boundary plasma control. On NSTX, 3D fields are used to trigger ELMs in ELM-free discharges to reduce impurity and radiated power buildup, but the mechanisms for this triggering are not well understood. Experiments will be conducted to test transport and stability code predictions (e.g. XGC-0, EMC3-EIRENE, IPEC, and M3D). The divertor heat and particle flux profiles, as well as midplane profiles and fluctuations, will be measured during a variety of applied 3D fields. Trends from the calculations will be used to aid understanding and guide optimization of heat flux and ELM control in NSTX-U and ITER.

Research Milestone R(12-1): Enhance physics understanding of turbulent transport mechanisms by comparing theory and simulation to measured fluctuations

In order to understand the importance of various turbulence-driven transport mechanisms over a broad range of operating space and plasma conditions, the low- and high-k turbulence measurements will be compared with linear and non-linear instability calculations using numerical tools that include the set of benchmarked simulation codes with strong ongoing development efforts and user bases such as GYRO, GTS, GS2, GTC-NEO and other codes as they become available. Synthetic diagnostics that simulate NSTX measurements will be developed and built into these modern, high-performance simulation codes in order to identify the microinstabilities responsible for the observed turbulence through direct experiment-simulation comparisons of the fluctuating quantities and their spectral and spatial characteristics. Improved physics insight of how these instabilities affect electron and ion energy transport in the ST is highly desirable to reduce the uncertainty of extrapolation to next-step STs. This research also contributes broadly to a fundamental understanding of transport.

R(12-2): Assess very high flux expansion divertor operation

The exploration of high flux expansion divertors for mitigation of high power exhaust is important for proposed ST and AT-based fusion nuclear science facilities and for Demo. In this milestone, the controllability and plasma response to advanced divertor concepts including the “snowflake” and “x-divertor” configuration will be assessed. Divertor heat flux handling, pumping with the liquid lithium divertor, impurity production, SOL turbulence and their trends with engineering parameters will be studied. Edge pedestal stability, ELM characterization, core transport and confinement, as well as edge transport and turbulence will also be studied Measurements will be compared to analytic and numerical code predictions**.** This research will provide a significant impact on the present PMI concept development for both the ST and tokamak.

Research Milestone R(12-3): Assess confinement, heating, and ramp-up of CHI start-up plasmas

Elimination of the central solenoid is essential for ST-based nuclear fusion applications, and it would reduce the cost/complexity of all tokamak reactors. TSC simulations indicate that at the higher B_T and higher RF power anticipated in NSTX-U, RF coupling should be considerably higher than in NSTX, and this combined with NBI allows for the possibility of a fully non-inductive start-up, ramp-up and sustainment demonstration in NSTX-U. Methods to reduce low-Z impurities in NSTX allowed substantial progress in coupling the CHI-initiated discharges to induction, and these have been successfully coupled to induction in neutral beam heated H-modes in NSTX. While these results are favorable, the confinement properties of CHI start-up plasmas have not been characterized. Understanding CHI plasma confinement is important for projecting non-inductive start-up and ramp-up efficiency to next-steps. HHFW is the only available tool for heating these target plasmas in NSTX. Early HHFW heating (during ramp-up) of ohmic targets was demonstrated in FY2008 and will be further developed in FY2010. In FY2011-12, HHFW heating will be applied to a CHI initiated discharge transitioning to an inductive discharge to compare the confinement and heating efficiency versus OH-only targets. For the FY2012 milestone research, the HHFW heating and CD will be applied progressively earlier in the target plasma to increase the β_P and bootstrap fraction. The degree to which the OH flux consumption can be reduced toward zero (i.e. achievable level of non-solenoidal start-up and ramp-up) will be assessed. During 2011/2012, the possible utilization of an all metal divertor is expected to further improve CHI start-up as a result of a further reduction of low-Z impurities.

Research Milestone R(12-4): Investigate magnetic braking physics and develop toroidal rotation control at low collisionality

Plasma rotation and its shear affect plasma transport, stability and achievable bootstrap current, all needed for advanced operation scenarios, through the plasma poloidal beta and local profile shapes. In order to explore the role of rotation in transport and stability, the physics governing the plasma rotation profile will be assessed over a wide range of collisionality and rotation by exploiting the tools of NBI momentum input and resonant and non-resonant braking from externally applied 3D fields. The plasma collisionality will be varied using density control with the Liquid Lithium Divertor and electron heating by High Harmonic Fast Waves. Key aspects of this study include the behavior of the Neoclassical Toroidal Viscosity at low collisionality and rotation, and the detailed modeling of the plasma response to applied non-axisymmetric fields, including self-shielding. To accomplish this milestone, real-time rotation measurements will be developed in FY2011. The effectiveness of various inputs in achieving controllability of the rotation profile will be assessed in order to develop and implement optimized real-time rotation control algorithms in FY2012. In support of these goals, the IPEC code will be further developed to examine the impact of 3D fields on the plasma, and the more general theory will be converted to simpler models for the real-time rotation control. MISK code analysis will be used to determine rotation profiles that are optimized for plasma stability, and these profiles in turn will be used as targets for the rotation control system. This research will provide the required understanding of rotation control and plasma stability critical for NSTX-U, ITER and future burning STs.

Research Milestone IR(12-1): Assess predictive capability of mode-induced fast-ion transport.

Good confinement of fast-ions from neutral beam injection and thermonuclear fusion reactions is essential for the successful operation of ST-CTF, ITER, and future reactors. Significant progress has been made in identifying the Alfvénic modes (AEs) driven unstable by fast ions, and in measuring the impact of these modes on the transport of fast ions. However, theories and numerical codes that can quantitatively predict fast ion transport have not yet been validated against a sufficiently broad range of experiments. To assess the capability of existing theories and codes for predicting AE-induced fast ion transport, NSTX experiments will aim at improved measurements of the mode eigenfunction structure utilizing a new Beam Emission Spectroscopy (BES) diagnostic and enhanced spatial resolution of the Far-Infrared Reflectometer. NSTX will also make new measurements of the internal magnetic field structure of AEs using far-infrared polarimetry (if available) and improved measurements of the fast-ion distribution function utilizing a tangentially viewing Fast-Ion D-alpha (FIDA) diagnostic. In order to broaden the range of discharge conditions studied to those relevant to future devices, experiments will be conducted for both L-mode and H-mode scenarios. Specific targets for the experiment-theory comparison are those between the measured and calculated frequency spectra and spatial structure. Both linear (e.g., NOVA-K, ORBIT) and non-linear (e.g., M3D-K, HYM) codes will be used in the analysis.