FY2011 Office of Fusion Energy Sciences Joint Theory-Experiment Research Milestone:

Responsible TSGs: Boundary Physics, Transport & Turbulence

Experiment:

Improve the understanding of the physics mechanisms responsible for the structure of the pedestal and compare with the predictive models described in the companion theory milestone. Perform experiments to test theoretical physics models in the pedestal region on multiple devices over a broad range of plasma parameters (e.g., collisionality, beta, and aspect ratio). Detailed measurements of the height and width of the pedestal will be performed augmented by measurements of the radial electric field. The evolution of these parameters during the discharge will be studied. Initial measurements of the turbulence in the pedestal region will also be performed to improve understanding of the relationship between edge turbulent transport and pedestal structure.

Theory:

A focused analytic theory and computational effort, including large-scale simulations, will be used to identify and quantify relevant physics mechanisms controlling the structure of the pedestal. The performance of future burning plasmas is strongly correlated with the pressure at the top of the edge transport barrier (or pedestal height). Predicting the pedestal height has proved challenging due to a wide and overlapping range of relevant spatiotemporal scales, geometrical complexity, and a variety of potentially important physics mechanisms. Predictive models will be developed and key features of each model will be tested against observations, to clarify the relative importance of various physics mechanisms, and to make progress in developing a validated physics model for the pedestal height.

FY2012 Office of Fusion Energy Sciences 3 Facility Joint Research Milestone:

Responsible TSGs: Transport & Turbulence

Conduct experiments on major fusion facilities leading toward improved understanding of core transport and enhanced capability to predict core temperature and density profiles. In FY 2012, FES will assess the level of agreement between predictions from theoretical and computational transport models and the available experimental measurements of core profiles, fluxes and fluctuations. The research is expected to exploit the diagnostic capabilities of the facilities (Alcator C-Mod, DIII-D, NSTX) along with their abilities to run in both unique and overlapping regimes. The work will emphasize simultaneous comparison of model predictions with experimental energy, particle and impurity transport levels and fluctuations in various regimes, including those regimes with significant excitation of electron modes. The results achieved will be used to improve confidence in transport models used for extrapolations to planned ITER operation.

NSTX FY2011 Research Milestones:

R(11-1): Measure fluctuations responsible for turbulent electron, ion and impurity transport

Responsible TSGs: Transport & Turbulence

The thermal transport scalings of electrons and ions with magnetic field and plasma current in NSTX H-mode plasmas have been found to be different from those of high-aspect-ratio tokamaks. Furthermore, recent experiments show that lithiated wall conditions can affect global confinement of NSTX H-mode plasmas and lead to different scalings with magnetic field and plasma current from un-lithiated plasmas. High-k scattering measurements have identified ETG turbulence as one candidate for the anomalous electron energy transport for both H and L-mode plasmas. However, low-k fluctuations and fast-ion-driven modes, e.g. GAE, may also contribute to electron transport. Furthermore, low-k fluctuations may also contribute significantly to momentum, ion thermal, and particle/impurity transport. In addition to measuring high-k fluctuations, the low-k turbulence and fast-ion-driven modes will be measured with a Beam Emission Spectroscopy (BES) diagnostic. Additional low-k fluctuation measurements will be made using the upgraded reflectometer, interferometer, and gas puff imaging systems. The turbulence k spectrum will be measured as function of plasma parameters and coupled with power balance analysis. Experiments on particle transport will be carried out by using gas puffs coupled with density measurements and low-k to high-k turbulence measurements. Impurity transport will be studied by coupling impurity puff and edge SXR measurements.

R(11-2): Assess ST stability dependence on plasma aspect ratio and boundary shaping

Responsible TSGs: Macro-stability, Advanced Scenarios and Control

Next-step ST conceptual designs assume aspect ratio $A \geq 1.6$ and/or high elongation (κ = 3-3.5) to maximize projected fusion performance. These aspect ratio and elongation values are higher than commonly accessed on NSTX ($A < 1.5$ and κ = 2.4-2.8), and to narrow this gap, NSTX Upgrade is designed to overlap next-step configurations by operating with higher aspect ratio (A=1.6-1.7) and κ up to 3. This combination of increased aspect ratio and higher elongation is projected to increase vertical instability growth rates by up to a factor of 3 and degrade kink marginal stability normalized beta by -0.5 to -1 relative to present NSTX performance. In this milestone, the integrated plasma scenarios previously developed in NSTX will be extended to plasma geometries closer to those of the Upgrade and next-step devices and the stability properties systematically explored. The maximum sustainable normalized beta will be determined versus aspect ratio (up to A=1.7) and elongation (up to 3) and compared to ideal stability theory using codes such as DCON and PEST. Both passive and actively-controlled RWM stability will be assessed both experimentally and theoretically using codes such as MISK and VALEN, and the viability of previously developed control techniques will be tested. The vertical stability margin will also be determined, and vertical motion detection and control improvements will be implemented. Boundary shape parameters (including squareness) will be varied to assess the impact of shaping and plasma-wall coupling on global stability. Edge NTV rotation damping is also expected to vary with aspect ratio and will be investigated. Plasma profile modifications and the impact on NSTX integrated performance (confinement, non-inductive fraction, pedestal stability, and recycling and divertor dynamics) will also be documented. Overall, these results will help guide stability control development for both NSTX Upgrade and next-step STs.

R(11-3): Assess very high flux expansion divertor operation

Responsible TSGs: Boundary Physics, Advanced Scenarios and Control

The exploration of high flux expansion divertors for mitigation of high power exhaust is important for NSTX-Upgrade, proposed ST and AT-based fusion nuclear science facilities and for Demo. In this milestone, high flux expansion divertor concepts, e.g. the "snowflake", will be assessed. The magnetic control, divertor heat flux handling and power accountability, pumping with lithium coatings, impurity production, and their trends with engineering parameters will be studied in this configuration. Potential benefits of combining high flux expansion divertors with gas-seeded radiative techniques and ion pumping by lithium will be explored. Two dimensional fluid codes, e.g. UEDGE, will be employed to study divertor heat and particle transport and impurity radiation distribution. Further, H-mode pedestal stability, ELM characterization, as well as edge transport will also be studied in the experiment and modeled with pedestal MHD stability codes, e.g., ELITE, and transport codes, e.g. TRANSP and MIST. This research will provide the foundation for assessing the extrapolability of high flux expansion divertors for heat-flux mitigation in next-step devices.

R(11-4): H-mode pedestal transport, turbulence, and stability response to 3D fields

Responsible TSGs: ITER/CC, Transport & Turbulence, Boundary Physics, Macro-stability

The use of three-dimensional (3D) magnetic fields is proposed to control the H-mode pedestal to suppress ELMs in ITER. However, the mechanisms for particle and thermal transport modification by 3D fields are not well understood. On NSTX, 3D fields are observed to trigger ELMs in ELM-free discharges and this triggering has been exploited to reduce impurity and radiated power buildup. The mechanisms for this triggering are also not well understood. As observed on other experiments, the plasma response to 3D fields in NSTX is sensitive to the edge q value – in particular, the threshold for triggering ELMs with applied n=3 fields varies non-monotonically with q_{95}. To better understand these findings, this milestone will explore possible mechanisms for modifying particle transport, thermal transport, and the resultant modifications to the pedestal kinetic profiles and ELM stability. Example possible mechanisms include: zonal flow damping, stochastic-field-induced E×B convective transport, and banana diffusion or ripple loss. Pedestal turbulence trends as a function of applied field will be measured with BES, high-k scattering, and gas-puff imaging. Edge particle transport will be measured using improved Thomson scattering, impurity injection, and edge SXR. If available, more flexible 3D field control will be used to vary the applied spectrum. The underlying 3D equilibrium is also a very important determinant of the 3D edge transport, and the transport and turbulence measurements combined with other edge measurements will be utilized to help infer whether the edge plasma response is predominantly ideal or resistive/stochastic in nature. These measurements and comparisons to theory will contribute to improved understanding of the transport and stability response of the pedestal to 3D fields for ITER.

NSTX FY2012 Research Milestones:

R(12-1): Investigate the relationship between lithium-conditioned surface composition and plasma behavior.

Responsible TSGs: Lithium research, Boundary Physics, Advanced Scenarios and Control

The plasma facing surfaces in a tokamak have long been known to have a profound influence on plasma behavior. The development of a predictive understanding of this relationship has been impeded by the lack of diagnostics of the morphology and composition of the plasma facing surfaces. Recently, a probe has been used to expose samples to NSTX plasmas and subsequent post-run analysis has linked surface chemistry to deuterium retention. However, with very chemically active elements such as lithium, more prompt surface analysis is likely required to characterize the lithiated surface conditions during a plasma discharge. In support of prompt surface analysis, an in-situ materials analysis particle probe (MAPP) will be installed on NSTX. The MAPP probe will enable the exposure of various samples to the SOL plasma followed by ex-vessel but in-vacuo surface analysis within minutes of plasma exposure using state of the art tools. The reactions between evaporated lithium and plasma facing materials and residual gases in NSTX will be investigated. Correlations between the surface composition and plasma behavior will be explored and compared to laboratory experiments and modeling. Measurements of fueling efficiency and recycling will be made. The results will deepen the understanding of plasma-wall interactions and inform the plans for particle control in NSTX-Upgrade.

R(12-2): Assess confinement, heating, and ramp-up of CHI start-up plasmas

Responsible TSGs: Solenoid-Free Start-up, Wave-particle Interactions, Advanced Scenarios and Control

Elimination of the ohmic heating (OH) solenoid is essential for proposed ST-based nuclear fusion applications. Coaxial helicity injection (CHI) is a leading candidate method for plasma initiation without an OH solenoid. Understanding CHI plasma confinement is important for projecting non-inductive start-up and ramp-up efficiency to next-steps. CHI initiated plasmas have been successfully coupled to induction H-mode plasmas with Neutral Beam Injection (NBI) heating. While these results are favorable, the confinement properties of CHI start-up plasmas have not been characterized. High-Harmonic Fast Wave (HHFW) and more recently NBI heating of low-current ohmic targets has been demonstrated and will be further developed. HHFW and/or early NBI heating will be applied to CHI targets coupled to induction to compare the confinement and heating versus non-CHI plasmas. Early NBI and HHFW heating and CD will be applied progressively earlier in the target to assess non-inductive sustainment, and the degree to which the OH flux consumed can be reduced will be quantified. Utilization of an all metal divertor could further improve CHI start-up and will also be characterized if such a divertor is present in NSTX. TRANSP and/or TSC will be used to both analyze and simulate the CHI experiments. This milestone informs the early auxiliary heating requirements for non-inductive start-up for NSTX Upgrade and for next-step ST facilities.

R(12-3): Assess access to reduced density and collisionality in high-performance scenarios

Responsible TSGs: Advanced Scenarios and Control, Macro-Stability, Boundary Physics

The high performance scenarios targeted in NSTX Upgrade and next-step ST devices are based on operating at lower Greenwald density fraction and/or lower collisionality than routinely accessed in NSTX. Collisionality plays a key role in ST energy confinement, non-inductive current drive, pedestal stability, RWM stability, and NTV rotation damping. Lower density and/or higher temperature is required to access lower ν^*. HHFW is a potential means of increasing electron temperature and reducing ν^*, and reduced fueling and/or Li pumping are effective and readily available tools for lowering ν^* through lower density. However, while D pumping from lithium has been observed, additional gas fueling is typically required to avoid plasma disruption during the current ramp and/or in the high β phase of the highest performance (i.e. highest confinement, beta, non-inductive fraction, etc) plasmas of NSTX . The goal of this milestone is to identify the stability boundaries, characterize the underlying instabilities responsible for disruption at reduced density, and to develop means to avoid these disruptions. Possible methods for stability improvement include changes in current ramp-rate (l_i and q(r) evolution), H-mode transition timing, shape evolution, heating/beta evolution and control, optimized RWM control and error field correction, fueling control (SGI, shoulder injector), and optimized Li pumping. This milestone will also aid development of MISK and VALEN stability models and TRANSP and TSC integrated predictive models for NSTX Upgrade and next-step STs.

IR(12-1): Investigate magnetic braking physics and develop toroidal rotation control at low collisionality *(incremental)*

Responsible TSGs: Macro-Stability, Advanced Scenarios and Control

Plasma rotation and its shear affect plasma transport, stability and achievable bootstrap current and thereby impact the performance of integrated ST scenarios. In order to explore the role of rotation in transport and stability, the physics governing the plasma rotation profile will be assessed over a range of collisionality and rotation by exploiting the tools of NBI momentum input and resonant and non-resonant braking from externally applied 3D fields. Possible tools for varying the plasma collisionality include using density/fueling variation, pumping by lithium, 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. A prerequisite for accomplishing the rotation control assessment of this milestone is the implementation of real-time rotation measurements 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 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 will in turn 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 next-step STs.

IR(12-2): Assess predictive capability of mode-induced fast-ion transport *(incremental)*

Responsible TSGs: Wave-Particle Interactions

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 Multi-Channel Reflectometer. Improved measurements of the fast-ion distribution function will be available 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, spatial structure and induced fast ion transport. Both linear (e.g., NOVA-K, ORBIT) and non-linear (e.g., M3D-K, HYM) codes will be used in the analysis. In addition, the newly developed full-orbit particle-following code SPIRAL will be adapted to the NSTX geometry and used to model fast ion losses by Alfvénic modes.