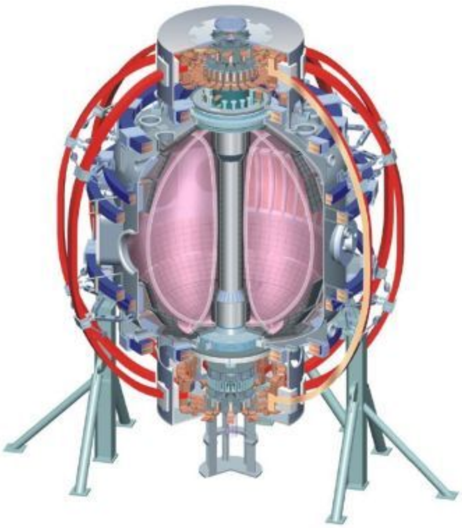
Discussion of NSTX research milestones for FY2011-12

J. Menard, S. Kaye

NSTX Meeting
PPPL – B318
December 10, 2010



Schedule

- Finalize FY11-12 milestones/priorities – Dec 2010
- NSTX PAC Meeting – Jan 26-28, 2011
- NSTX Research Forum for FY2011-12 – Mar 2011
- Begin NSTX FY2011-12 operations – Apr 2011
  - May start 1-2 months later than this – TBD
- No vent planned between FY11 and FY12 runs
- Complete FY12 run – Apr 2012
- Begin outage for major Upgrade – summer 2012

FY2011-12 TSG definition nearly complete

Run coordinator	Deputy run coordinator
S. Sabbagh	M. Bell

TSG	Leader - experiment	Deputy - experiment	Leader - theory and modelling
Boundary	V. Soukhanovskii	A. Diallo	D. Stotler
Lithium	C. Skinner	M. Jaworski	D. Stotler
Transport	Y. Ren	H. Yuh	TBD
MHD	J.-K. Park	J. Berkery	R. Betti
HHFW/EP	G. Taylor	M. Podestà	TBD
SFSU	R. Raman	D. Mueller	TBD
ASC	S. Gerhardt	M. Bell	E. Kolemen
ITER urgent needs, cross-cutting & enabling	J. Menard	R. Maingi	A. Boozer

NSTX Near Term Facility Plan

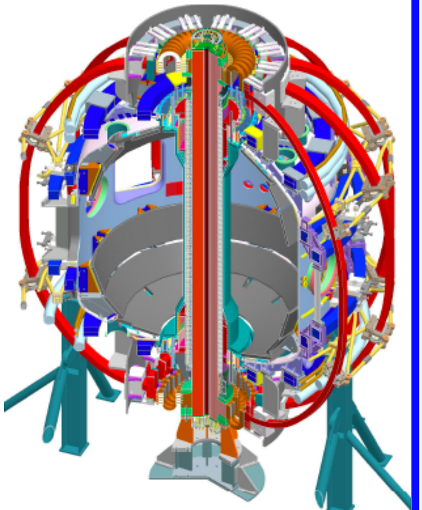
ARRA Funding Significantly Enhances Research Capability

◉ **ARRA**

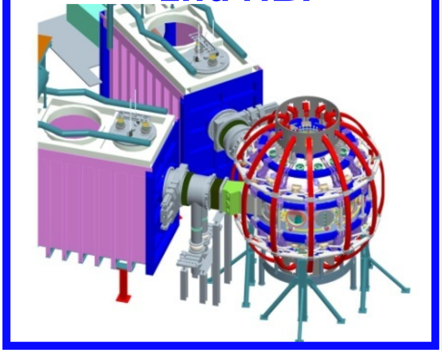
	FY 10	FY 11	FY 12
Run Weeks Base / Increment	1 14	4 10	12
Heating & CD	● HHFW Antenna Upgrade	● HHFW ELM Avoidance	
MHD and ASC	● β control (NBI)	◉ 2nd SPA Supplies ● Real-time rotation?	● Real-time rotation control?
T&T	● Upgraded FIReTIP (UCD) ● BES (U. Wisconsin)	◉ MPTS Extra channels ◉ MSE-LIF (Nova Photonics)	
Boundary / Li	● LLD (SNL) ● PMI Probe ● Lithium CHERS ● Divertor Spectrometer (LLNL)	◉ Enhanced LLD ● Materials Analysis Particle Probe (MAPP) (Purdue)	
Energetic Particles	● Two-Color Fast IR Camera (ORNL) ● Upgraded reflectometry (UCLA)	● Tangential FIDA(UCI)	
Start-Up	● CHI Absorber Control Coils (U. Washington)		

Upgrade Outage FY 2012-14 →

New Center-stack



2nd NBI



Overview

- This meeting:
  - We will go through each milestone in bulletized form
    - Most have been defined/wordsmithed previously – several have not
    - Are any key elements missing? (ideas/diagnostics/codes)
    - Are we sufficiently well prepared to meet these milestones?
  - Should milestone ordering/years be swapped?
  - Are there better milestones that should replace these?
- Finalize milestone topics/titles/elements/content by Dec 17
- Finalize milestone text by Dec 23
- Finalize TSG "priorities" (see research forum page) by Jan 7
- Hold TSG meetings/e-mail as necessary to complete
- Need all this before the PAC
  - PAC prep will begin in early January

Previous FY2011-12 NSTX research milestone

	FY2010	FY2011	FY2012
Expt. Run Weeks:	15 w/ ARRA	4 10	12
1) Transport & Turbulence		BES, High-k Measure fluctuations responsible for turbulent ion and electron energy transport	BES, High-k Compare measured turbulence fluctuations to theory & simulation
2) Macroscopic Stability	Assess sustainable beta and disruptivity near and above the ideal no-wall limit		
3) Boundary/Lithium Physics	Assess H-mode characteristics as a function of collisionality and lithium conditioning	BES, High-k, LLD, Assess relationship between lithiated surface conditions and edge and core plasma conditions	Snowflake, LLD, MPTS Assess very high flux expansion divertor operation
4) Wave-Particle Interaction	Characterize HHFW heating, CD, and ramp-up in deuterium H-mode		
5) Solenoid-free start-up, ramp-up			CHI, HHFW, NBI Assess confinement, heating, and ramp-up of CHI start-up plasmas
6) Advanced Scenarios & Control		LLD, HHFW Assess integrated plasma performance versus collisionality	LLD, HHFW, NBI Investigate physics and control of toroidal rotation at low collisionality
Joint Research Targets (3 US facilities):	Understanding of divertor heat flux, transport in scrape-off layer	MPTS, MSE-LIF Characterize H-mode pedestal structure	BES, High-k Draft: Understand core transport and enhance predictive capability

Latest Draft FY2011-12 NSTX research milestones
(several topics/dates subject to change)

	FY2010	FY2011	FY2012
Expt. Run Weeks:	*15 w/ ARRA*	*4* *10*	*12*
1) Transport & Turbulence		*BES, High-k* ***Measure fluctuations responsible for turbulent energy transport***	*BES, High-k* ***Compare measured turbulence fluctuations to theory & simulation***
2) Macroscopic Stability	***Assess sustainable beta and disruptivity near and above the ideal no-wall limit***	*2nd SPA, advanced RWM control* ***Assess impact of increased aspect ratio on ST stability*** *(with ASC TSG)*	
3) Boundary/Lithium Physics	***Assess H-mode characteristics as a function of collisionality and lithium conditioning***	*Snowflake, MPTS, LLD* ***Assess very high flux expansion divertor operation*** *(with ASC TSG)*	*MAPP, BES, High-k, LLD* ***Assess relationship between lithiated surface conditions and edge and core plasma conditions***
4) Wave-Particle Interaction	***Characterize HHFW heating, CD, and ramp-up in deuterium H-mode***		
5) Solenoid-free start-up, ramp-up			*CHI, NBI, HHFW* ***Assess confinement, heating, and ramp-up of CHI start-up plasmas*** *(with WPI/HHFW TSG)*
6) Advanced Scenarios & Control			*SGI, LLD, HHFW* ***Assess access to reduced density and ν^* in high-performance scenarios*** *(with BP, LR, MS TSGs)*
7) ITER urgent needs, cross-cutting		*BES, High-k, 2nd SPA* ***H-mode pedestal transport and turbulence response to 3D fields*** *(cross-cutting with T&T, MS, BP)*	
Joint Research Targets (3 US facilities):	***Understanding of divertor heat flux, transport in scrape-off layer***	*MPTS, MSE-LIF* ***Characterize H-mode pedestal structure***	*BES, High-k* ***Understand core transport and enhance predictive capability***

Some guidance to TSGs for milestone writing

- Have intro sentence why topic important for fusion/ST
- Highlight a few recent results/progress for context
- Discuss remaining physics questions to be addressed
- State diagnostics/facility resources to be utilized
- State theory/modeling/analysis requirements

- Milestone is *not* a research report
- Be specific enough so it is clear what and how research will be done, but not overly specific
  - Give the milestone flexibility wherever possible
- Target ≤ 200 words (1 PPT slide in 18pt Arial font)
  - Makes FWP and research forum page much more readable/useful
  - Save the details for the research forum and generating XP ideas

FY11 Milestones

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

- ST thermal transport scalings different from those of high-aspect-ratio tokamaks. Lithiated wall condition can also lead to different scalings.
- High-k scattering measurements have identified ETG turbulence
- However, low-k fluctuations and fast-ion-driven modes, e.g. GAE, may also contribute to electron transport.
- Low-k fluctuations may also contribute significantly to momentum, ion thermal, and particle/impurity transport.
- Low-k portion of the turbulent density fluctuation spectrum and the radial profile of fast-ion-driven modes will be measured with BES. Turbulence will also be measured with reflectometer, interferometer, and GPI
- The k spectrum of the turbulence will be measured and correlated with energy diffusivities inferred from power balance analysis.
- Experiments on particle transport will use gas puffs coupled with density measurements and low-k to high-k turbulence measurements.
- Impurity transport will use impurity puff and edge SXR
- Results will form comprehensive dataset for R(12-1) and FY12 JRT

R(11-2): Assess impact of increased aspect ratio on ST stability

- Next-step ST designs commonly assume high elongation (κ = 3-3.5) and aspect ratios above A=1.65.
- The combination of increased aspect ratio and higher elongation is projected to increase vertical instability growth and reduce β_N limits
- Plasma scenarios previously developed in NSTX will be extended to plasma geometries (including squareness) much closer to those of the Upgrade and next-steps and the stability properties systematically explored.
- The maximum sustainable β_N will be determined versus aspect ratio and (high) elongation and compared to ideal stability theory and simulation
- Both passive and actively-controlled RWM stability will be assessed both experimentally and theoretically using codes such as VALEN and MISK, 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.
- Edge NTV rotation damping is also expected to vary with aspect ratio and will be investigated and compared to existing NTV theory and modeling.
- Results will guide MHD control improvements for Upgrade, next-steps

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

- 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” and “x-divertor” configurations, will be assessed.
- The magnetic control, divertor heat flux handling and power accountability, pumping with lithium coatings, impurity production, turbulence, and their trends with engineering parameters will be studied in these configurations.
- 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.
- H-mode pedestal stability, ELM characterization, edge transport and turbulence will also be studied and modeled with pedestal MHD stability codes, e.g., ELITE, and transport codes, e.g. TRANSP and MIST.
- Informs PFC requirements for NSTX Upgrade high-heat-flux 2MA plasmas

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

- 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 understood.
- The mechanisms for ELM triggering as observed on NSTX are also not well understood. But, as observed on other experiments, the plasma response to the 3D fields in NSTX has recently been found to be sensitive to the edge q value (NSTX exhibits a “resonant” behavior in q_{95}) for ELM triggering.
- To better understand these findings, this milestone will explore possible mechanisms for modifying transport, such as zonal flow damping, stochasticity-induced ExB convective transport, banana diffusion/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.
- More flexible field control enabled by the 2nd SPA (if available) will be used to vary the applied 3D field spectrum.
- Potentially high impact for ITER if any clear trends are observed

FY12 Milestones

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

- Low- and high-k turbulence measurements will be compared with linear and non-linear instability calculations to better understand the importance of various turbulence-driven transport mechanisms over a broad range of operating space and plasma conditions
- Tools will include aset of benchmarked simulation codes such as GYRO, GTS, GS2, GTC-NEO
- Synthetic diagnostics that simulate NSTX measurements will be developed and built into these modern, high-performance simulation codes in order to identify the micro-instabilities 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 thermal 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 momentum and particle/impurity transport.

R(12-2): Assess the relationship between lithiated surface conditions and edge and core plasma conditions

- 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 attempt to extend the duration of particle pumping, a liquid lithium divertor (LLD) was installed and commissioned in FY2010.
- Deuterium pumping will be studied as a function of LLD temperature and divertor electron density and temperature, strike-point location, and flux expansion. These measurements will be compared to retention models.
- An in-situ materials analysis particle probe (MAPP) situated near the LLD will provide data on surface composition in the outer divertor region under various plasma conditions.
- 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.
- Improves understanding of Li PFCs, informs Upgrade particle control plans

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

- Elimination of the OH solenoid is essential for ST-based nuclear fusion applications, and would reduce the cost/complexity of all tokamak reactors.
- 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 and NBI-heated H-mode. CHI start-up confinement has not been characterized.
- HHFW and recently NBI heating of low-current ohmic targets was demonstrated in 2008 and 2010 and will be further developed in FY2011-12.
- In FY2011-12, HHFW and early NBI heating will be applied to CHI → OH discharges to compare the confinement and heating versus non-CHI plasmas.
- For the FY2012 milestone, early NBI and HHFW heating and CD will be applied progressively earlier in the target to assess non-inductive sustainment
- In particular, the degree to which the OH flux consumed can be reduced toward zero will be assessed.
- TRANSP and/or TSC will be used to analyze/simulate the experiments.
- Informs early heating requirements for NICD start-up for Upgrade, next-steps

R(12-4): Assess access to reduced density and collisionality in high-performance scenarios

- The high performance scenarios targeted in NSTX Upgrade and next-step ST devices are based on operating at lower Greenwald density fraction and 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 T is required to access lower ν^*
- Reduced fueling and/or Li pumping is readily available tool for lower ν^*
- However, while D pumping via LiTER evaporation (and possibly LLD operation) has been observed, additional gas fueling is typically required to avoid plasma disruption during the current ramp and/or in the high β phase.
- This milestone will characterize the underlying instabilities responsible for disruption at reduced density and attempt to avoid these instabilities
- Possible methods for stability improvement include changes in current ramp-rate (l_i and q(r) evolution), H-mode timing, shape evolution, improved evolution/control of heating, beta, EFC , fueling (SGI), and pumping (Li).
- This data set would greatly aid development of TRANSP and TSC integrated predictive models in preparation for NSTX Upgrade and next-step STs

Possible FY12 incremental/alternative milestones

IR(12-1): 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 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 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 can 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 next-step STs.

IR(12-2): 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.

IR(12-3): 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(12-4): 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(12-1) 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 FY2011, 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.

Draft milestone text

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

- 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. Recent experiments have also shown 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 portion of the turbulent density fluctuation spectrum and the radial profile of fast-ion-driven modes 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. The k spectrum of the turbulence will be measured as function of plasma parameters and correlated with energy diffusivities inferred from 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 impact of increased aspect ratio on ST stability

- Next-step ST designs commonly assume high elongation (κ = 3-3.5) and aspect ratios above A=1.65. Similarly, NSTX Upgrade will have higher aspect ratio (A=1.6-1.7) and κ up to 3. In contrast, NSTX typically operates with A < 1.5 and κ = 2.4-2.8. The 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 by $\Delta\beta_N \approx -0.5$ to -1. In this milestone, the integrated plasma scenarios previously developed in NSTX will be extended to plasma geometries much closer to those of the Upgrade and next-steps and the stability properties systematically explored. The maximum sustainable β_N will be determined versus aspect ratio and (high) elongation 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 VALEN and MISK, 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 variations – in particular squareness – will be varied to asses 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.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

- 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” and “x-divertor” configurations, will be assessed. The magnetic control, divertor heat flux handling and power accountability, pumping with lithium coatings, impurity production, turbulence, and their trends with engineering parameters will be studied in these configurations. 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. H-mode pedestal stability, ELM characterization, as well as edge transport and turbulence 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 a significant impact on the present PMI concept development for both the ST and tokamak.

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

- 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 the 3D fields in NSTX is sensitive to the edge q value – in particular NSTX exhibits a “resonant” behavior in q_{95} for ELM triggering. To better understand these findings, this milestone will explore possible mechanisms for modifying particle and thermal transport, such as zonal flow damping, stochastic-field-induced ExB 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. These measurements and comparisons to theory will contribute to improved understanding of ELM control for ITER.

R(12-1): Enhance understanding of turbulent transport 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 thermal 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 momentum and particle/impurity transport.

R(12-2): 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 attempt to extend the duration of particle pumping, and to investigate the impact of liquid lithium on plasma performance, a liquid lithium divertor (LLD) was installed in FY2010. Deuterium pumping will be studied as a function of LLD temperature and divertor electron density and temperature, strike-point location, and flux expansion. The measurements will be compared to retention models. An in-situ materials analysis particle probe situated near the LLD will provide data on surface composition in the outer divertor region under various plasma conditions. 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 necessary to aid evaluation of liquid lithium as a possible PFC solution for NSTX and next-step facilities.

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

- Elimination of the OH solenoid is essential for ST-based nuclear fusion applications, and would reduce the cost/complexity of all tokamak reactors. 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 and NBI-heated H-mode. While these results are favorable, the confinement properties of CHI start-up plasmas have not been characterized. HHFW and recently NBI heating of low-current ohmic targets was demonstrated in 2008 and 2010 and will be further developed in FY2011-12. In FY2011-12, HHFW and early NBI heating will be applied to CHI → OH discharges to compare the confinement and heating versus non-CHI plasmas. For the FY2012 milestone, early NBI and HHFW heating and CD will be applied progressively earlier in the target to assess non-inductive sustainment. In particular, the degree to which the OH flux consumed can be reduced toward zero will be assessed. Utilization of an all metal divertor could improve CHI start-up and will be characterized if present in the machine. TRANSP and/or TSC will be used to analyze/simulate the experiments.

R(12-4): Assess access to reduced density and collisionality in high-performance scenarios

- 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, and 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^*. Reduced fueling and/or Li pumping are readily available tools for lowering ν^* through lower density. However, while D pumping via LiTER evaporation (and possibly LLD operation) has been observed, additional gas fueling is typically required to avoid plasma disruption during the current ramp and/or in the high β phase. This milestone will characterize the underlying instabilities responsible for disruption at reduced density and attempt to avoid these disruptions. Possible methods for stability improvement include changes in current ramp-rate (l_i and q(r) evolution), H-mode timing, shape evolution, heating/beta evolution and control, improved fueling control (SGI), and varied pumping. This milestone will also aid development of TRANSP and TSC integrated predictive models for NSTX Upgrade and next-step STs.