NSTX-U

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NSTX-U Waves & Energetic Particles Research Planning for 2012-2018

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NSTX-U WEP TSG Meeting

January 26, 2012

PPPL
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Goals & Agenda for this Meeting

- Provide input on WEP research for PAC, Five-Year Plan FY14-18
  - Discuss Facility Enhancement needs for WEP-TSG
- Discuss goals for WEP Research Milestones R(13-3), R(14-2)

Draft paragraph due by COB Monday 01/30

(Please send comments to G. Taylor, M. Podestà, N. Gorelenkov ASAP !)

- Agenda:
  1) Review draft FY13 & FY14 WEP milestones
  2) Discuss FY14-18 WEP research goals
  3) FY12-14 collaborations & modeling/theory supporting FY14-18 WEP research:
     - Development of finite-orbit width CQL3D – Yuri Petrov
  4) Critical facility/diagnostic upgrades that support long-term WEP research:
     - Microwave Diagnostics for NSTX-U – Neal Crocker
     - NSTX-U HHFW Studies – Joel Hosea
     - Proposal to return one pair of HHFW straps to end-ground – Phil Ryan

EP & HHFW NSTX-U Presentations

- PAC meeting (4/17-4/19) presentations to present key issues & needs for NSTX-U:
  - PAC talk dry runs completed by mid-March
  - Individual EP (Podestà) & HHFW (Taylor) PAC presentations
  - Goals/milestones for TSG (1 slide)
  - Research highlights/progress since January 2011 PAC meeting (6 slides)
  - FY12-13 collaboration plans (1-2 slides)
  - Plans for FY14-15 NSTX-U research (2 slides)
  - Linkage between collaborations & FY14-15 NSTX-U operation (1 slide)
  - Key diagnostics & facility upgrades needed for FY14-15 research (2 slides)
  - FY16-18 NSTX-U research goals (1-2 slides)
  - Major diagnostics & & facility upgrades needed for FY16-18 research (2 slides)

FY12-14 NSTX-U Research Milestones

	FY2012	FY2013	FY2014
Expt. Run Weeks:			12
Transport and Turbulence		Perform integrated physics+optical design of new high-k_θ FIR system	
Macroscopic Stability	Investigate magnetic braking physics and toroidal rotation control at low ν^* (with ASC TSG)		Assess access to reduced density and ν^* in high-performance scenarios (with ASC, BP TSGs)
Boundary and Lithium	Project deuterium pumping using lithium coatings and cryo-pumping	Assess relationship between lithium-conditioned surface composition and plasma behavior	
Waves+Energetic Particles		Perform physics design of ECH & EBW system for plasma start-up & current drive in advanced scenarios	Develop reduced models for *AE mode-induced fast-ion transport
Solenoid-free Start-up/ramp-up	Simulate confinement, heating, and ramp-up of CHI start-up plasmas (with HHFW TSG)		
Adv. Scenarios and Control			Assess advanced control techniques for sustained high performance (with MS, BP TSGs)
ITER Needs + Cross-cutting		Identify disruption precursors and disruption mitigation & avoidance techniques for NSTX-U and ITER	
Joint Research Target (3 facility)	Understand core transport and enhance predictive capability	Stationary regimes w/o large ELMs, improve understanding of increased edge particle transport	TBD

NSTX-U FY13 WEP TSG Research Milestone

R(13-3) Perform physics design of ECH & EBW system for plasma start-up & current drive in advanced scenarios:

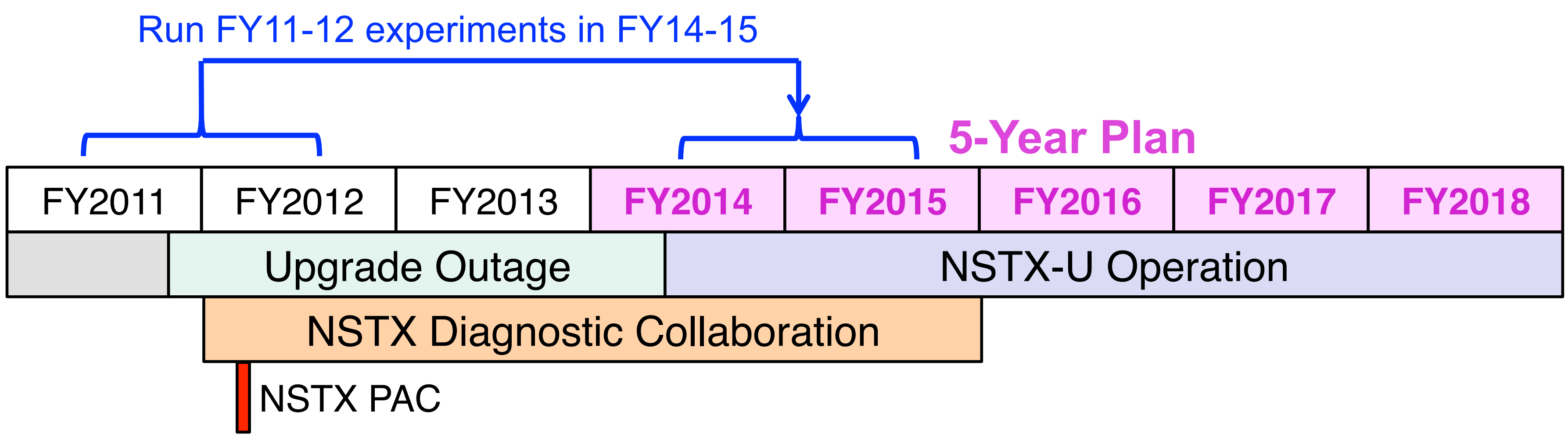
For a reactor-relevant ST operation it is critical to develop discharge initiation, plasma current ramp-up, and plasma sustainment techniques that do not require a central solenoid. Earlier ECH modeling of NSTX CHI startup plasmas with GENRAY and CQL3D predicted 25-30% first pass absorption. In addition, EBW startup experiments on MAST in 2009 showed good electron heating when the discharge became overdense. A few hundred kilowatts of coupled ECH/EBWH power in NSTX-U should heat a solenoid-free startup discharge sufficiently to allow coupling of 30 MHz high harmonic fast wave power, that will in turn generate non-inductive plasma current ramp-up. While pressure gradient-driven bootstrap current can provide a large fraction of the plasma current required to non-inductively sustain an ST plasma, an externally driven off-axis current may still be required to provide magnetohydrodynamic stability during the plasma current flat top. Electron Bernstein wave current drive (EBWCD) can provide this non-inductive current and thus may play a critical role in enabling high beta, sustained operation of ST plasmas. A 28 GHz ECH and EBWH system is being proposed for NSTX-U. Initially the system will use short, 10-50 ms, 0.5-1 MW pulses to support development of non-inductive startup scenarios. Later the pulse length may be extended to 0.2-0.5 s and the power increased to provide EBWH and EBWCD during the plasma current flat top. A mirror launcher will be used to couple microwave power to the plasma via the O-mode to the slow X-mode to the EBW mode (O-X-B). Previously B-X-O radiometric measurements on NSTX had yielded 50-60% EBW coupling efficiency from H-mode plasmas with the coupling losses being dominated by collisions near the B-X-O mode conversion layer, located in the plasma scrape off. The higher toroidal field on NSTX-U should yield higher scrape off temperatures and lower EBW collisional losses. EBW startup experiments are being planned on MAST for the summer of 2012 to extend the 2009 experiments to higher EBW power. Results from those experiments will support the design for the EBW startup system for NSTX-U. In 2012 and 2013 GENRAY and CQL3D ECH and EBWH modeling will be performed for NSTX-U plasma startup scenarios and for EBWH and EBWCD during the plasma current flat top for advanced NSTX-U plasma scenarios to support the physics design of the NSTX-U ECH/EBWH system.

NSTX-U FY14 WEP TSG Research Milestone

R(14-2) Develop parametric models for *AE-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 characterizing the Alfvénic modes (AEs) driven unstable by fast ions and the associated fast ion transport. However, models that can consistently reproduce fast ion transport for actual experiments, or provide predictions for new scenarios and devices, have not yet been validated against a sufficiently broad range of experiments. In order to develop a physics-based parametric fast ion transport model that can be integrated in general simulation codes such as TRANSP, results obtained from NSTX/NSTX-U and during collaborations with other facilities (MAST, DIII-D) will be analyzed. Information on the mode properties (structure of the eigenfunctions, amplitude, frequency) and on the fast ion response to AEs will be deduced from Beam Emission Spectroscopy, Reflectometers, Fast-Ion D-alpha (FIDA) systems, Neutral Particle Analyzers, Fast Ion Loss Probes and neutron rate measurements. The mechanisms responsible for AE-induced fast ion transport and the parametric dependence of transport on the mode properties will be assessed through experiment-theory comparison. Both linear (e.g., NOVA-K) and nonlinear (e.g., M3D-K, HYM) codes will be used in the analysis. In addition, gyro-orbit (ORBIT) and full-orbit (SPIRAL) particle-following codes will be used to characterize the fast ion loss and redistribution mechanisms. Based on the general parametric model, the possibility of deriving *reduced models that can* be readily implemented in existing codes such as TRANSP will then be assessed. For instance, the existing Anomalous Fast Ion Diffusion (AFID) model utilized in TRANSP could be improved by implementing methods to calculate the AFID coefficient consistently with the measured (or simulated) mode properties. Further improvements will also be considered, for instance to include a convective transport term in addition to the diffusive AFID coefficient in TRANSP.

Long-Term EP TSG Research Goals



Long-term WEP TSG Research Goals for FY14-18:

- Study effect of multiple, high frequency (>10 kHz), MHD modes and RF heating on fast-ion confinement
- Use RF heating to enable fully non-inductive RF+NBI H-mode plasmas

See backup slides for draft FY14-18 WEP research goals →

Draft FY12-14 WEP TSG Collaboration/Modeling Plans that Support FY14-18 WEP 5-Year Plan

Waves:

- FY12: Collaborate with MAST on EBW plasma start up experiments
- FY12-13: RF modeling HHFW for NSTX-U equilibria
- FY12-13: RF modeling EBW for NSTX-U equilibria
- FY12-13: Perform ICRF-only H-mode experiments on EAST
- FY12-13: ICRF+NBI H-mode experiments on DIII-D; study SOL power loss mechanisms
- FY12-13: ICRF+ECH & ICRH H-mode experiments
- FY13-14: Model reduced strap HHFW antenna for NSTX-U

Energetic Particles:

- FY12: SPIRAL modeling of high-frequency GAE/CAE modes, develop interface with HYM code
- FY12-13: Linear analysis of TAE scenarios for NSTX-U H-mode plasmas with NOVA code
- FY12-13: Collaborate with MAST and DIII-D on *AE experiments
- FY12-13: Identify optimal fast ion diagnostics for NSTX-U
- FY13: Extend M3D-K simulations to NSTX-U H-mode scenarios
- FY13-14: Develop parametric model for *AE-induced fast ion transport, R(14-2) – needed for NBI-CD in STs/ATs
- FY13-14: Finalize design of prototype CAE antenna and of upgraded ssNPA diagnostic

Backup Slides

Draft FY2014-18 Research Goals

Waves FY14 Goals

RF-HHFW:

- Heat low I_p plasma, achieve high non-inductive current fraction, improve coupling to NBI-heated H-mode plasmas
- Evaluate possible alternate HHFW configurations during outage & perform tests using test stand (if funds are available)
- *Explore physics basis for particle transport induced by EHO excitation* *(eg. What mode numbers, frequency, structure etc. is needed for preliminary design?)*

RF-ECH:

- Update design of ECH system plasma start-up support

**EHO research goals probably fall within another TSG (T&T?)*

Waves FY15 Goals

RF-HHFW:

- Heat CHI start-up plasma coupled to induction, sustain low I_p plasma 100% non-inductively, improve coupling to NBI-heated H-modes
- Assess HHFW performance at higher magnetic field and higher plasma density - especially compatibility with high-power NBI operations
- *Design EHO antenna using HHFW straps, or some other location*

RF-ECH:

- Implement short-pulse, high-power ECH system for plasma start-up support (0.5-1MW, 10-50ms)

Waves FY16 Goals

RF-HHFW:

- Utilize HHFW to assist start-up plasma formation - compare to short-pulse ECH
- Assess impact of HHFW electron heating on NBI current ramp-up
- Simulate/mock-up performance using reduced number of straps
- *Implement EHO antenna compatible with HHFW requirements*

RF-ECH:

- Test short-pulse, high-power ECH system for plasma start-up support and assess impact on close-flux current achieved, pulse-length extension, non-inductive fraction

Waves FY17 Goals

RF-HHFW:

- Modify HHFW antenna system to have reduced number of straps and test performance during I_p ramp-up and NBI H-mode
- *Test EHO antenna for impact on density/particle control*

RF-ECH:

- Test upgraded ECH system power and pulse-length for EBW heating studies (1MW, 0.2-0.5s)

Waves FY18 Goals

RF-HHFW:

- Utilize modified HHFW system heating and CD to optimize plasma start-up, ramp-up, and NBI sustainment

RF-ECH:

- Pending successful EBW heating results, further upgrade ECH system power and pulse-length for EBW heating studies (2-4MW, 1-5s),
- Project EBW CD performance to FNSF/CTF

Energetic Particles FY14-15 Goals

FY2014:

- Measure fast-ion transport with tangential FIDA, *AE eigenfunctions with BES and reflectometers
- Research Milestone R(14-2) [separate discussion]
- Test capability of prototype *AE antenna & finalize design of upgraded *AE antenna to measure stability properties of *AEs & to compare damping rates from models & theory:
  - Excite CAE/GAE, a unique capability for NSTX-U

FY2015:

- Use tangential + perpendicular FIDA to characterize distribution function modifications induced by *AE modes
- Measure *AE activity observed to be driven by more tangential 2nd NBI - compare to existing more perpendicular NBI
- Implement upgraded *AE antenna

Energetic Particles FY16-17 Goals

FY2016

- Optimization of *AE antennae design for efficient coupling to the plasma modes
- Simulate *AE activity driven by more tangential NBI, extend non-linear models to NSTX-U plasmas with 2nd NBI, compare numerical and theoretical simulations to new data
- *Extend simulations of avalanches to FNSF/Pilot sustainment phase*

FY2017

- Utilize *AE predictive capability to optimize/minimize *AE activity during non-inductive current ramp-up with 2nd NBI. Compare simulations to experimental results
- Measure stability properties of high-f *AE with upgraded antenna

Energetic Particles FY18 Goals

- Assess requirements for "fast-ion phase-space engineering" techniques through selective excitation of *AE modes

- *Extend simulations of *AE avalanches to FNSF/Pilot current ramp-up phase*
- *Assess implications for FNSF/Pilot design, in particular NBI injection geometry, expected current drive*