NSTX-U

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NSTX-U Program Update

J. Menard

NSTX Physics Meeting
B318
January 16, 2012

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CompX
General Atomics
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Nova Photonics
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ORNL
PPPL
Princeton U
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SNL
Think Tank, Inc.
UC Davis
UC Irvine
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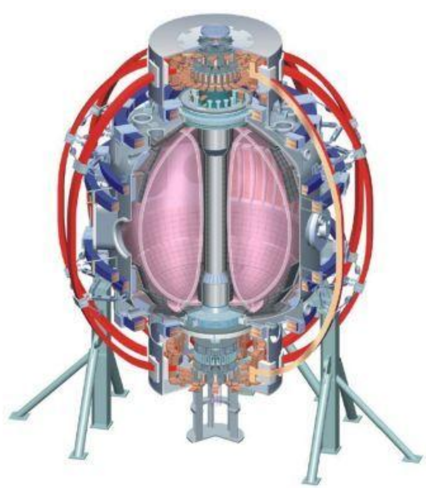
U Washington
U Wisconsin



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
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NIFS
Niigata U
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JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
NFRI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

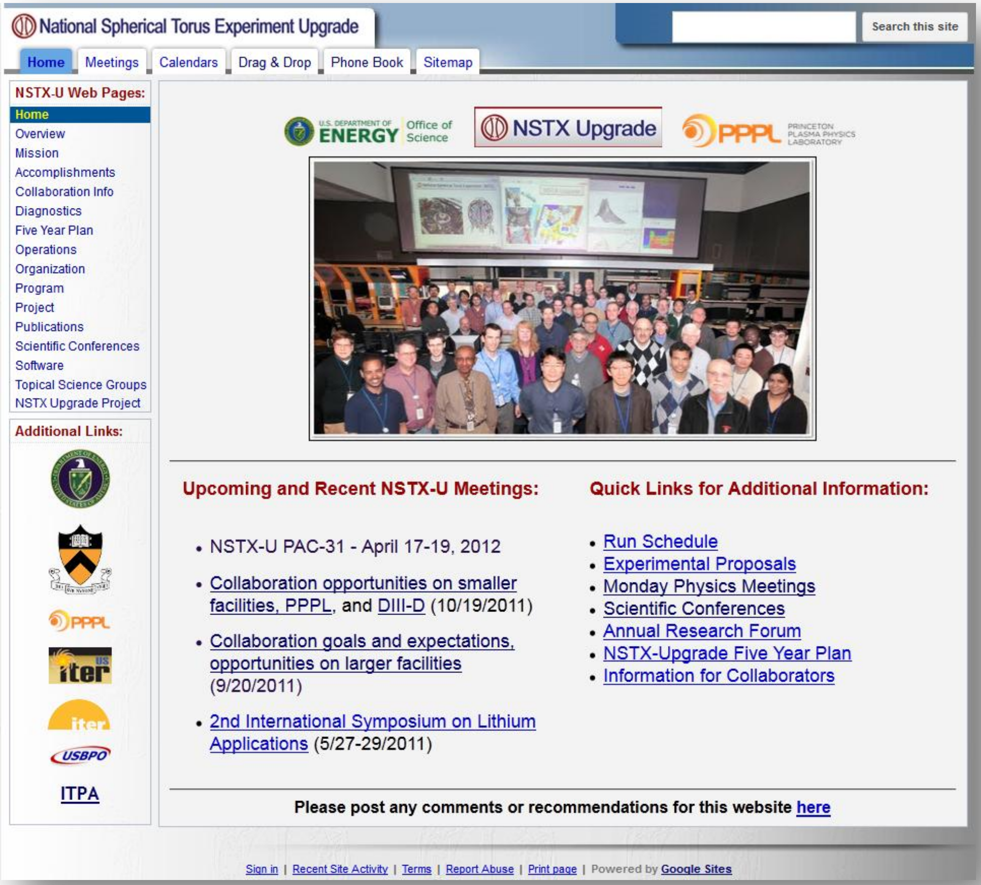
Outline

- New NSTX → NSTX-U website
- Discussion of FY2012-14 Milestones for FWP
- Discussion of PAC meeting preparation
- Longer-term = 5 year plan preparation

New website for NSTX-U

- NSTX-U has been approved for construction → will be making the name-change to NSTX Upgrade (aka NSTX-U).
- There is now new website (using Google sites): **nstx-u.pppl.gov**

  - You are the beta testers - please test the site & provide feedback:
    - Please use comments page link on bottom of home-page, or send an e-mail to Joanne Savino (jsavino@pppl.gov)
  - nstx.pppl.gov and nstx-upgrade.pppl.gov will eventually redirect to this new site
  - New site points to info in Drag&Drop on nstx.pppl.gov, and much of that will be transferred to Google.
  - D&D will likely be kept (still useful)



Discussion of FY2012-14 Milestones for FWP

- NSTX was supposed to run 20 run weeks July 2011-Feb 2012.
- FY12 milestones were written assuming new run time and data
- NSTX-U still needs field work proposal (FWP) for FY2012-14 and the associated milestones and deliverables for DOE
- Original FY12 milestones:
  - JRT-2012: Develop improved understanding of core transport and enhanced capability to predict core temperature and density profiles.
  - R(12-1): Investigate the relationship between lithium-conditioned surface composition and plasma behavior.
  - R(12-2): Assess confinement, heating, and ramp-up of CHI start-up plasmas
  - R(12-3): Assess access to reduced density and collisionality in high-performance scenarios
  - IR(12-1): Investigate magnetic braking physics and develop toroidal rotation control at low collisionality *(incremental)*
  - IR(12-2): Assess predictive capability of mode-induced fast-ion transport *(incremental)*
- Some have recommended having 2-3 milestones per year since NSTX-U will not be operating, and to emphasize collaboration

PAC report executive summary highlighted divertor/PMI issues/planning and preparation for NSTX-U:

- The NSTX Team should install the full complement of inner-divertor molybdenum tiles before the next run period and devote sufficient run time and research effort to evaluate the impact of the tiles, both with and without Li deposition.
- Before deposition of Li, the **PAC recommends re-establishment of an ELMing H-mode baseline with boronized carbon (and Mo) plasma facing surfaces.** The purposes of these experiments are (i) to observe density and impurity control with more conventional ELM regimesand plasma material interactions, (ii) to contrast and better understand the impact of Li in NSTX, and (iii) to provide discharge performance characteristics that will inform your divertor planning for the NSTX Upgrade.
- During these pre-lithium runs, take the opportunity to demonstrate two-feed antenna, fullpower HHFW heating and demonstrate the compatibility of HHFW with NBI and your NSTX Upgrade discharge targets.
- Since a primary focus of the NSTX Upgrade five-year plan must be the demonstration of stationary, high-performance, non-inductive spherical torus (ST) discharges that will inform next-step fusion development choices, the **PAC suggests the NSTX Team launch a serious cyropump and divertor geometry design study and develop an alternative to insure against uncertainties associated with the use of any next generation LLD in the NSTX Upgrade.**
- **Finally, in time for the PAC-31 meeting, the PAC asks that the NSTX Team describe their planning for the post April 2012 outage activities including design and scoping studies for the upgrade project, planning for start-up and initial discharges, and longer-term discharge scenarios needed to achieve the project goals. The PAC sees an opportunity to optimize how personnel will be assigned, how collaborators will contribute, and how best to use the many experts on the NSTX Team to continue ST research and maximize preparations for the Upgrade.**

NSTX 2009-13 5 year plan mid-term review comments were overall quite positive, but there are areas that need more work (a few examples below):

- "Current-ramp up scenarios with combined CHI and HHFW do not seem to be mature even in present NSTX operation. In the upgrade, the additional current-drive tool is a tangential neutral beam, but there will be no plasma guns or ECH as additional sources of current.
  - There is a need for additional modeling of discharge evolution in NSTX-U, so that plans for the physics program for the upgrade are grounded in predictable performance.
  - Current ramp-up and sustainment work is perhaps the least developed of the research areas on NSTX (which reflects the difficulty of the task).
  - Such research should be a priority of the NSTX team members as they collaborate with on other facilities during the shutdown for the upgrade."
- "The use of lithium wall coating for longer pulse length of NSTX-U is questionable as lithium coating does not produce steady-state densities in shorter NSTX pulses."
- "For the Liquid Lithium Divertor (LLD), no clear plan was presented for either additional research or analysis of possible upgrades. There is a need to come to some conclusions as to the use of the LLD, the upgrades that are required and what the research strategy should be employed after the upgrade.
  - For example, is the pumping from the use of Li/LLD sufficient for NSTX-U?"

Draft proposal for FY2012-14 Milestones for FWP (1)

- FY2012
  - JRT-2012: Develop improved understanding of core transport and enhanced capability to predict core temperature and density profiles
    - Unchanged – already accounted for NSTX not operating
  - R(12-1): Investigate the relationship between lithium-conditioned surface composition and plasma behavior.
    - Perform MAPP work locally (LTX and labs), collaborate on EAST/HT-7 for new lithium data
  - R(12-2): Assess confinement, heating, and ramp-up of CHI start-up plasmas
    - Simulate with TSC and TRANSP – TSC already underway, start from previous TRANSP calculations for NSTX-U
- FY2013:
  - JRT-2013: Evaluate stationary enhanced confinement regimes without large Edge Localized Modes (ELMs), and to improve understanding of the underlying physical mechanisms that allow increased edge particle transport while maintaining a strong thermal transport barrier.
    - Unchanged – already accounted for NSTX not operating
  - R(13-1): Assess access to reduced density and collisionality in high-performance scenarios
    - Physics design of cryo-pumping system for NSTX-U + experiments on EAST, DIII-D, KSTAR?
    - Time-dependent simulations of profile evolution (?) + simulations of stability vs. profiles - could also use existing data
  - R(13-2): Investigate magnetic braking physics and develop toroidal rotation control at low collisionality
    - Braking data from collaborations on KSTAR, DIII-D, MAST + v_ϕ control development on DIII-D for NSTX-U (?)

Draft proposal for FY2012-14 Milestones for FWP (2)

- FY2014
  - JRT-2014: Not yet defined
    - Could include data from initial NSTX-U operation – depends on status of Upgrade project
  - R(14-1): Assess predictive capability of mode-induced fast-ion transport
    - Collaboration on/with MAST, develop reduced model for FI redistribution from *AE, avalanches
  - R(14-2): Assess advanced stability control techniques for sustained high performance
    - Could involve assessment of 3D field coils for NSTX-U in collaboration with MAST, KSTAR, DIII-D, EAST for physics and engineering basis, also possibly J(r) or snowflake profile control (on DIII-D for NSTX-U), …

- Many additional ideas will come from 5 year planning process
- Will obviously be influenced by how much NSTX-U will operate in FY2014

- Please send your ideas/plans for analysis and experiments for research goals and milestones ASAP
  - Need to finalize ideas and draft paragraphs in ~10 days = January 26

Likely PAC charge topics/questions

- NSTX-U team scientific productivity during Upgrade outage
  - Analysis, publications, present and upcoming milestones
- NSTX-U team participation and utilization of collaboration with other facilities to prepare for NSTX-U operation and contribute to fusion science generally
- Preliminary ideas and preparation for 5 year plan:
  - Initial operation of NSTX-U = 2014-15
  - Longer term: later stages of 5 year plan = 2016-18

Draft PAC-31 agenda – day 1

Tuesday, April 17, 2012

• 1:00	Coffee & Cookies, PAC Executive Session	
• 1:15	Stewart Prager	Welcome and charge to the PAC
• 1:20	Steve Eckstrand	Comments from DOE
• 1:25	John Sarff	PAC member introductions, agenda and plan of meeting
• 1:30	Steve Sabbagh	NSTX results and analysis highlights since last PAC
• 2:00	Jon Menard	Program Overview – FY2011-12, collaboration, 5 year plan
• 3:00	Coffee Break	
• 3:15	Masa Ono	Upgrade Project Status, Facility/Diagnostic Overview
• 4:15	John Canik	NSTX-U cryo-pumping design progress, particle control plans
• 4:45	John Sarff	PAC Executive Session
• 6:00	John Sarff	Feedback and questions for NSTX team
• 6:15	Adjourn	

Draft PAC-31 agenda – day 2

Wednesday, April 18, 2012

• 8:00	Coffee & Donuts	
• 8:30	John Sarff	Any updates on questions from PAC to NSTX-U team
• 9:00	V. Soukhanovskii	Boundary Physics Progress and Plans
• 9:30	Charles Skinner	Lithium Research Progress and Plans
• 10:00	Coffee Break	
• 10:15	Jong-Kyu Park	Macroscopic Stability Progress and Plans
• 10:45	Yang Ren	Transport and Turbulence Progress and Plans
• 11:15	Mario Podesta	Energetic Particle Physics Progress and Plans
• 11:45	Gary Taylor	High-harmonic Fast Wave Progress and Plans
• 12:10	Roger Raman	Solenoid-free Start-up and Ramp-up Progress and Plans
• 12:35	Stefan Gerhardt	Advanced Scenarios and Control Progress and Plans
• 1:05	Lunch	
• 2:00	NSTX Team	Response to PAC questions
• 3:30	Coffee Break	
• 3:45	PAC Executive Session	
• 5:30	John Sarff	Feedback and questions to NSTX team (as requested)

Draft PAC-31 agenda – day 3

Thursday, April 19, 2012

- 8:30 Coffee & Donuts
- 8:40 John Sarff Final NSTX team response to PAC questions
- 9:00 PAC Executive Session
- (12:00 Lunch and PAC Executive Session)
- 12:45 John Sarff Debriefing
- 1:30 Adjourn

Draft outline format for PAC presentations from TSGs: ~25 minutes → ~17 content slides

- Overview – goals and/or milestones for your TSG – 1 slide
- FY2011-12 research highlights/progress from your research area (newest/most important/best since last PAC in Jan 2011) – 6 slides
- Collaboration plans (NSTX team wide) in your respective research area for 2012-2013 – 1-2 slides
- Outline of plans for first 1-2 years of research on NSTX-U (FY2014-2015) – 2 slides
- Discuss linkages between collaboration and first 1-2 years of NSTX-U operation – 1 slides
- Discussion of key diagnostics and facility upgrades needed to achieve FY2014-15 research goals – 2 slides
- Brief overview of research goals for 2016-2018 (last 3 years of 5 year plan) – 1-2 slides
- Brief overview of major diagnostics and facility upgrades needed to support research goals for 2016-2018 – 1-2 slides

Rough timeline for PAC preparation

- I will be in Asia 2nd half of March, and there are numerous ITPA and other meetings in late March/early April →
  - Want nearly all of the PAC dry runs to be done by mid-March (at least first version of talk) with final tweaks being done in early April
- TSGs should hold meetings mid Jan – mid Feb to discuss key issues/needs for PAC preparation:
  - Results since last PAC, collaboration plans, key diagnostic and facility needs for initial Upgrade ops (2014-15), same for longer term (2016-18)
  - Facility upgrades for very long term have not yet been discussed for the various groups, and should be a key topic for your meeting(s)
  - Masa and I can help lead the discussions if needed

→ **PAC dry-runs first 2 weeks of March**

- **At January 30 NSTX-U physics meeting**, J. Menard will lead group discussion to get opinions on how best to stage the **long-term NSTX-U PFC and lithium/liquid metal program**

Draft schedule for 5 year planning preparation

- Jan-Mar 2012 – define physics program, needed diagnostic and facility upgrades for initial ops (2014-15) and 2016-18
- April 2012 – get initial feedback from PAC on long-term plans
- May 2012 – formulate/finalize plan elements and outline, identify/finalize authors, begin writing chapters
- October 2012 – First drafts of plan chapters due
- Nov-Dec 2012 – internal review/revision/editing of plan
- Jan/Feb 2013 - 5 yr plan presentation 'dry-run' to PAC-33
- Plan presented to Review committee and FES Mar/Apr 2013

Backup material – FY12 milestone text

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.

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.