NSTX-U Supported by U.S. DEPARTMENT OF ENERGY Office of Science

NSTX-U Team Meeting - Program Update

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CompX
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INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Lehigh U
Nova Photonics
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UC Irvine
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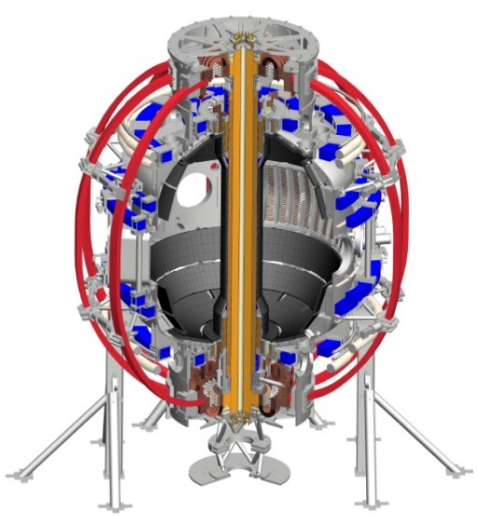
U Tulsa
U Washington
U Wisconsin
X Science LLC

J. Menard

NSTX-U Program Director

PPPL, B318
February 11, 2014



Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
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Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
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CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

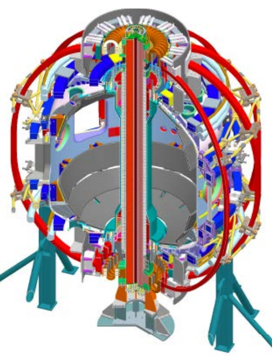
Upcoming NSTX-U Program Events

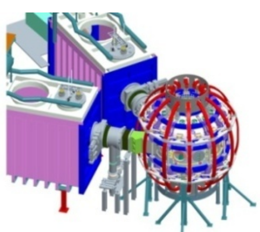
- FY2014-16 Field Work Proposal (FWP) preparation → budget planning meeting (BPM) on April 2, 2014
- Presentations by NSTX-U collaborators on research plans
  - April/May 2014 ~ 0.5-1.5 days
  - National labs, University and Industry (assuming outcome is known)
- NSTX-U PAC-35 meeting – June 11-13, 2014
  - Get PAC input either on FY2015 run plan prep OR advice on how to respond to any significant delays + feedback on collaboration activities
- "Workshop" with team to identify ways to enhance university involvement in NSTX-U program – July-Sep 2014
  - Beneficial to NSTX-U program, addresses notable outcome: "Expand engagement with university scientists to enhance NSTX-U program"
- Research Forum for FY2015 run
  - Most likely September or December - depends on CS installation/CD-4
  - Optimally 2-4 months before start of physics/research campaign

FWP motivates consideration of 5 year plan tools assuming base funding with extended outage deferred ½ year

	2014	2015	2016	2017	2018
	Upgrade Outage		1.5 → 2 MA, 1s → 5s		
Run Weeks:		16	16	0 – few?	16
Start-up and Ramp-up		Upgraded CHI for ~0.5MA		1 MW ECH/EBW	up to 0.5 MA plasma gun
Boundary Physics				Lower divertor cryo-pump	High-Z PFC diagnostics
Materials and PFCs		High-Z tile row on lower OBD		High-Z tile row on cryo-baffle	Full high-Z lower OBD
Liquid metals / lithium		Li granule injector	Upward LiTER		LLD using bakeable cryo-baffle
MHD		MGI disruption mitigation		Partial NCC?	Enhanced MHD sensors
Transport & Turbulence		δB polarimetry	High k_θ		
Waves and Energetic Particles		1 coil AE antenna	4 coil AE antenna		Charged fusion product
Scenarios and Control		Establish control of: Snowflake, $\bar{n}_e$	Rotation	q_{min}	Divertor P_{rad}

New center-stack





2nd NBI

Issue:

Extended outage shifted at least 6 months due to later CD-4 than assumed for 5YP

- Extended outage duration and scope need to be considered carefully:
  - May be important to run during FY2017 to operate for 4 of 5 years during 5YP
  - Unlikely all 3 major upgrades (ECH, cryo, NCC) can be implemented at same time and get run time during FY17

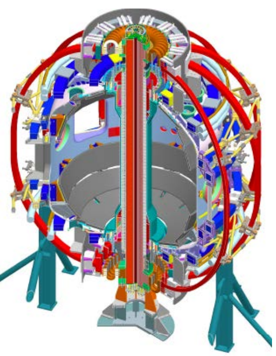
Possible 5 year plan tools with 5YP base funding with extended outage deferred 1 year

	2014	2015	2016	2017	2018

Upgrade Outage | **1.5 → 2 MA, 1s → 5s**

Run Weeks: 16, 16, 14, 14

New center-stack



Start-up and Ramp-up
- Upgraded CHI for ~0.5MA
- 1 MW ECH/EBW
- up to 0.5 MA plasma gun

Boundary Physics
- Lower divertor cryo-pump
- High-Z PFC diagnostics

Materials and PFCs
- High-Z tile row on lower OBD
- Full high-Z lower OBD

Liquid metals / lithium
- Li granule injector
- Upward LiTER
- LLD using bakeable cryo-baffle

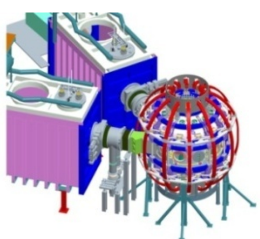
MHD
- MGI disruption mitigation
- Enhanced MHD sensors
- Partial NCC

Transport & Turbulence
- δB polarimetry
- High k_θ

Waves and Energetic Particles
- 1 coil AE antenna
- 4 coil AE antenna
- Charged fusion product

Scenarios and Control

Establish control of:
- Snowflake
- $\bar{n}_e$
- Rotation
- q_{min}
- Divertor P_{rad}



2nd NBI

- **For 1 year deferral of extended outage:** would try to accelerate ECH/EBW, enhanced MHD sensors, and q_{min} control (if ready)
- Consolidate lower OBD conversion to high-Z (i.e. do full conversion in 1 step?)

Draft FY2015-16 FWP milestones for base and incremental

	FY2014	FY2015	FY2016
Expt. Run Weeks:	0	16 / 20	16 / 20
Macroscopic Stability	R14-1 **Assess access to reduced density and ν* in high-performance scenarios** (with ASC, BP TSGs)		
Transport and Turbulence		R15-1 **Assess H-mode τ_E, pedestal, SOL characteristics at higher B_T, I_P, P_{NBI}** (with BP, M&P, ASC, WEP TSGs)	IR16-1 **Assess τ_E and local transport and turbulence at low ν* with full range of B_T, I_P, and NBI power**
Boundary Physics		**Develop snowflake configuration, study edge and divertor properties** (with ASC, TT, MP) IR15-1	R16-1 **Assess heat-flux mitigation and PFC response using advanced divertor configurations at high power density** (Joint BP and MP)
Materials & PFCs			
Waves+Energetic Particles	R14-2 **Assess reduced models for *AE mode-induced fast-ion transport**	R15-2 **Assess effects of NBI injection on fast-ion f(v) and NBI-CD profile** (with SFSU, MS, ASC TSGs)	R16-2 **Assess fast-wave SOL losses and core thermal and fast ion interactions at increased B_T, I_P**
Solenoid-free Start-up/ramp-up		**Assess CHI & low-I_P FW heating at higher B_T, test NBI+BS I_P ramp-up** (with WEP, ASC TSGs) IR15-2	R16-3 **Develop high-non-inductive fraction NBI H-modes for sustainment and ramp-up** (Joint ASC + SFSU)
Adv. Scenarios and Control	R14-3 **Assess advanced control techniques for sustained high performance** (with MS, BP TSGs)	R15-3 **Develop physics+operational tools for high-performance discharges** (with CC, ASC, MS, BP, M&P TSGs)	
ITER Needs + Cross-cutting			
Joint Research Target	**Quantify plasma response to non-axisymmetric (3D) magnetic fields in tokamaks**	**Quantify impact of broadened current and pressure profiles on tokamak confinement and stability**	**Assess MGI disruption mitigation, disruption warning and avoidance (+ additional theory contribution?)**

Summary

- Draft milestone elements have been defined for FY16 FWP by topical science groups + program leadership
- Let us know of issues/changes to FY2016 milestone elements by this week Friday
- TSGs requested to please provide draft milestone text by COB next Wednesday

R(15-1): Assess H-mode energy confinement, pedestal, and SOL characteristics with higher B_T, I_P and P_{NBI}

- H-mode studies in NSTX showed range of important scalings:
  - Global energy confinement exhibits a favorable scaling $B\tau_E \sim 1/\nu^*_e$
    - This strong ν^*_e scaling unifies disparate engineering scalings with boronization ($\tau_E \sim I_p^{0.4} B_T^{1.0}$) and lithiumization ($\tau_E \sim I_p^{0.8} B_T^{-0.15}$)
  - H-mode pedestal pressure increases with $\sim I_P^2$
  - Divertor heat flux footprint width decreases as $\sim 1/I_P$
- Core and boundary confinement regimes will be extended to 2.5× higher $B_T \times I_P$ and 2× higher P_{NBI} + varied tangency radius
  - The relationship between H-mode confinement and pedestal structure with increasing $I_{p,}$ B_T and P_{NBI} will be determined
    - Focus on ν^* dependence of core τ_E, β dependence of pedestal width
    - Utilize low-k turbulence diagnostics + gyrokinetic simulations to interpret
  - The scaling of the divertor heat flux profile with higher I_p and P_{NBI} will also be measured to characterize SOL widths, peak heat fluxes
    - Will provide basis for required heat flux mitigation at highest power, current

R(15-2): Assess effects of NBI parameters on the fast ion distribution function and neutral beam driven current profile

- Experiments will be carried out to systematically characterize the fast-ion population from the new 2nd NBI:
  - Utilize single-source scenarios at low NBI power to compare fast ion behavior with classical models (e.g. NUBEAM in TRANSP) in the absence of fast ion driven instabilities
  - Vary the injection tangency radius and beam voltage
  - Determine thresholds for onset of low-f fast-ion instabilities, and onset of avalanche behavior
  - Characterize evolution of fast-ion density using perpendicular and (new) tangential fast-ion D-alpha diagnostics, SSNPAs, neutrons
  - In higher-NBI-power experiments, document the inferred non-inductive current profile and associated beam-driven current profile
  - Time permitting, also document fast-ion behavior with the 2nd NBI including scenarios with MHD instabilities (core kink and tearing), externally imposed 3D fields, and additional Fast Wave (FW) heating

R(15-3): Develop the Physics and Operational Tools for Obtaining High-Performance Discharges in NSTX-U

- Lay foundation for full operational scenario goals by developing needed physics and operational tools using:
  - Toroidal fields up to ~0.8 T, plasma currents up to ~1.6 MA
  - Improved applied 3D field capabilities from additional power supplies
  - Range of plasma facing component (PFC) conditioning methods, and advanced fuelling techniques (SGI, B/Li, ELM pacing, LGI, …) .
- Develop higher-A, high elongation ($2.8 < \kappa < 3.0$) plasma shapes anticipated to result in high non-inductive fraction
  - Optimize vertical stability control
  - Assess and implement low-n error-field correction, expand the RWM control and dynamic error field correction strategies (PID, state-space)
  - Use resonant field amplification measurements, ideal MHD stability codes, kinetic stability analysis to evaluate the no-wall/with-wall limits
- Assess non-inductive current drive fraction across range of toroidal field, plasma density, boundary shaping, NBI params

R(16-1) Assess heat-flux mitigation and PFC response using advanced divertor configurations at high power density

- Access highest I_P (2MA), and $\lambda_q \sim 1/I_P$ → very high heat fluxes
- Assess amelioration of peak heat flux using (combinations of):
  - Magnetic balance – DND vs. SN
  - Partial detachment
  - High flux expansion - snowflake/X-divertor operation
- Implement PCS control of inter-X-point distance, X-point orientation, and flux expansion (if not completed in FY2015)
- Test hypothesis (UT-Austin) that convergence/divergence of SOL magnetic flux impacts full-detachment-front stability
- Measure impact of ELM-control techniques (3D fields, injected granules, etc) on transient heat fluxes vs. inter-ELM values
- Assess thermal/mechanical performance and high-Z impurity generation of TZM/W tile row (to be installed for FY16 run) vs. incident heat and particle flux and low-Z coatings

R(16-2) Assess fast-wave SOL losses and core thermal and fast ion interactions at increased field and current

- Important to NSTX-U start-up/ramp-up and ITER FW heating
- AORSA simulations suggest increased SOL power loss occurs when RF field amplitude in SOL is enhanced due to plasma in front of antenna being propagative vs. evanescent
  - Increased B_T and/or lower density should reduce E-field and losses → utilize higher field and improved density control available in FY16
  - RF probes and upgraded Langmuir probes will be used to test for the presence of SOL RF fields, and ideally distinguish them from the effects of plasma heating.
- Once SOL losses are sufficiently well characterized, core wave absorption from ions will be assessed:
  - Evaluate the synergy between NB and FW in H-mode discharges that include plasmas with the new more tangential NB lines on NSTX-U
  - Look for significant FW heating of thermal ions predicted by full wave simulations at the higher toroidal fields attainable in NSTX-U

R(16-3) Develop high-non-inductive fraction NBI H-mode scenarios for sustainment and ramp-up

- Goal is to increase non-inductive current fraction toward 100% (or above if possible)
  - Focus on beam-heated H-modes with inductive ramp-up for target
  - High non-inductive duration goal: 1-2 current redistribution times
  - Vary q_{95} and beam source and power: $f_{BS} \sim q_{95}{}^{*} \beta_N$
    - Higher TF capability → 1T important for these studies
  - Vary q_{min} and κ to optimize stability and confinement to maximize f_{BS}
  - Upward LiTER, granule injector may aid density/impurity control
- Vary partial-inductive initial I_P value to assess achievable non-inductive fraction vs. initial current
  - Will inform non-inductive ramp-up scenario development
  - Informs achievable pulse-length vs. flat-top current for all experiments
- Provide data on confinement properties of high-non-inductive fraction plasmas for future/further optimization

IR(16-1): Assess τ_E and local transport and turbulence at low ν^* with full confinement and diagnostic capabilities

- Builds on R(15-1) to assess confinement dependence field, current, and ν^* over widest range accessible
  - $B_T \rightarrow$ 1T, $I_P \rightarrow$ 2MA, P_{NBI} up to 15MW, improved density control
- Additional tools available in FY16 to facilitate this milestone
  - New high-k scattering should be available for ETG measurements – k_r and k_θ for initial assessment of turbulence anisotropy
  - Polarimetry should be available in FY15 or 16 for initial μ-tearing data
  - Upward LiTER to maximize Li-wall pumping and confinement
- Provides initial dataset for distinguishing between micro-tearing vs. ETG/other via dependence on ν^*

NSTX-U JRT-2016 support: Assess MGI disruption mitigation, disruption detection and avoidance

- Study gas assimilation efficiencies for MGI injection from multiple poloidal locations and evaluate impacts on divertor heat loads and halo currents.
  - Understand gas penetration and assimilation physics by performing extended gas dynamics modeling, e. g. DEGAS-2 code
- In parallel, develop algorithms for real-time MGI triggering based on disruption warning system such as locked mode sensors, state-space observers and RFA.
- Assess operation and control techniques in producing stable high-performance plasmas, and document disruption rates
  - Produce stable plasmas at high normalized beta with pulse lengths exceeding those of past NSTX plasmas
  - Determine effectiveness of NSTX-U tools: enhanced EFC, RWM stabilization, q and rotation control techniques (open or closed loop)