NSTX-U

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Program / Project Update, PAC Review of Program Letter for University and Industry Collaboration

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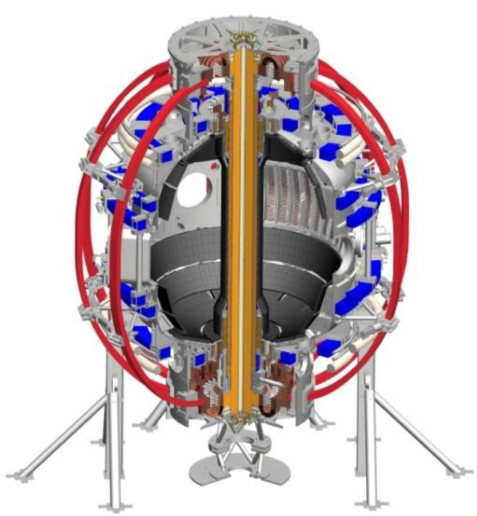
J. Menard
M. Ono, R. Strykowski

NSTX-U PAC-34 Teleconference
PPPL
July 30, 2013



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Agenda

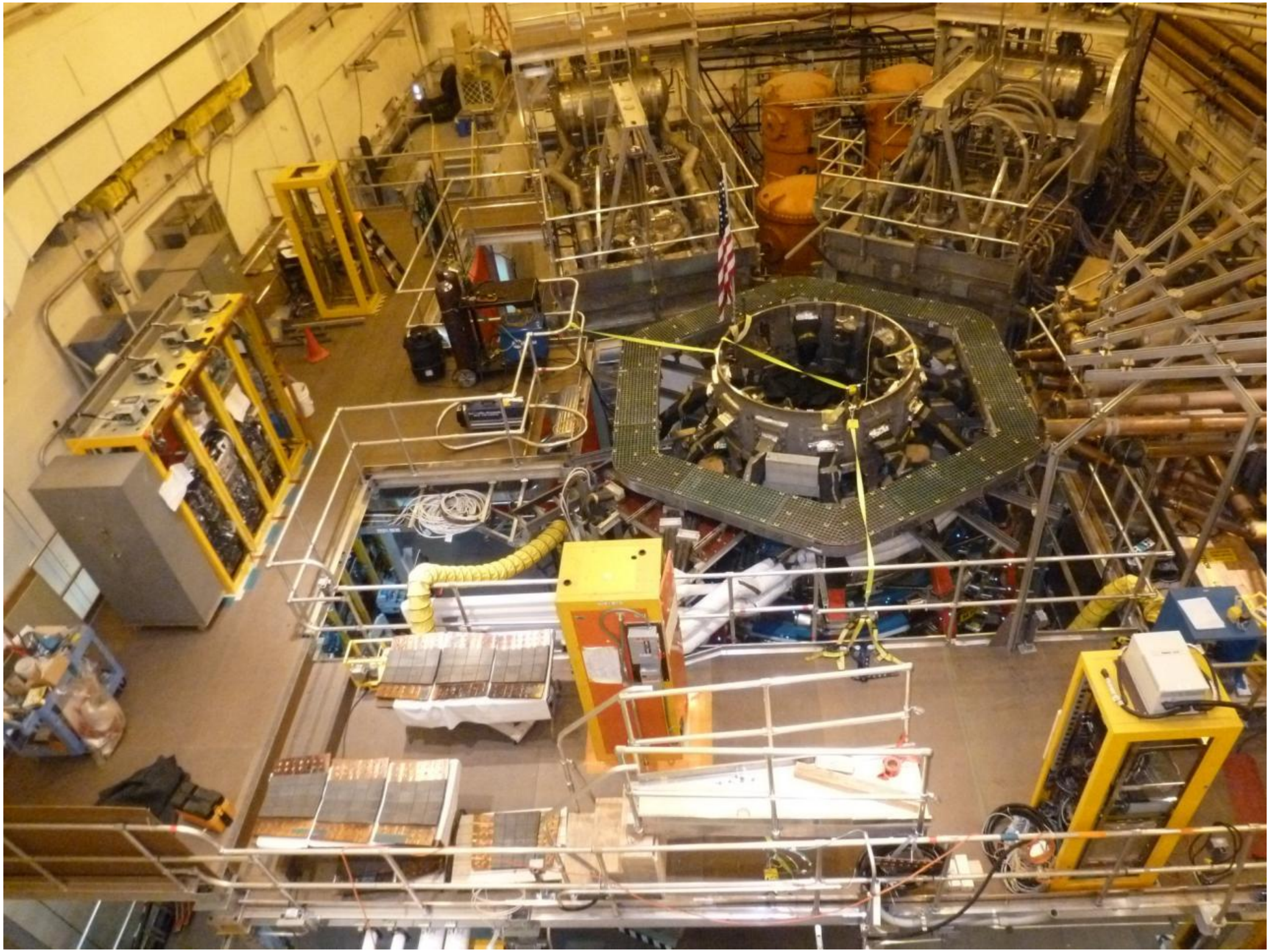
- Roll call, welcome new members, FES comments – J. Sarff, S. Eckstrand
  - 5-10 minutes
- Program / Project events since PAC-33 – J. Menard
  - 20 minutes
- Charge to PAC, Program Letter overview – J. Menard
  - 40 minutes
- PAC executive session – J. Sarff
  - 1 hour
- PAC verbal debrief to NSTX-U – J. Sarff
  - 20-40 minutes

Major assessments of NSTX-U since PAC-33:

- March: FESAC Subcommittee on the Prioritization of Proposed Scientific User Facilities for the Office of Science
  – Ranked importance of NSTX-U as “A” for “absolutely central”
- May: Positive debrief report of NSTX-U 5 year plan (2014-18)
  – “The quality of the proposed research is excellent, employing state-of-the-art diagnostics to obtain data that will be compared to theory using a wide variety of numerical models.”
  – “The proposed research addresses fundamental problems in magnetic fusion and will advance the state of knowledge in a number of areas.”
  – “The proposed research is essential for advancing the ST to a nuclear science mission.”
  – “NSTX-U will be a leading facility in the world fusion program, exploring unique physics of a low aspect ratio spherical tokamak, accessing high beta, large non-inductive current fractions, compact magnetic geometry, pushing to parameters not accessible to conventional tokamaks.”

PAC-33 advise was very helpful for preparing for NSTX-U 5YP review

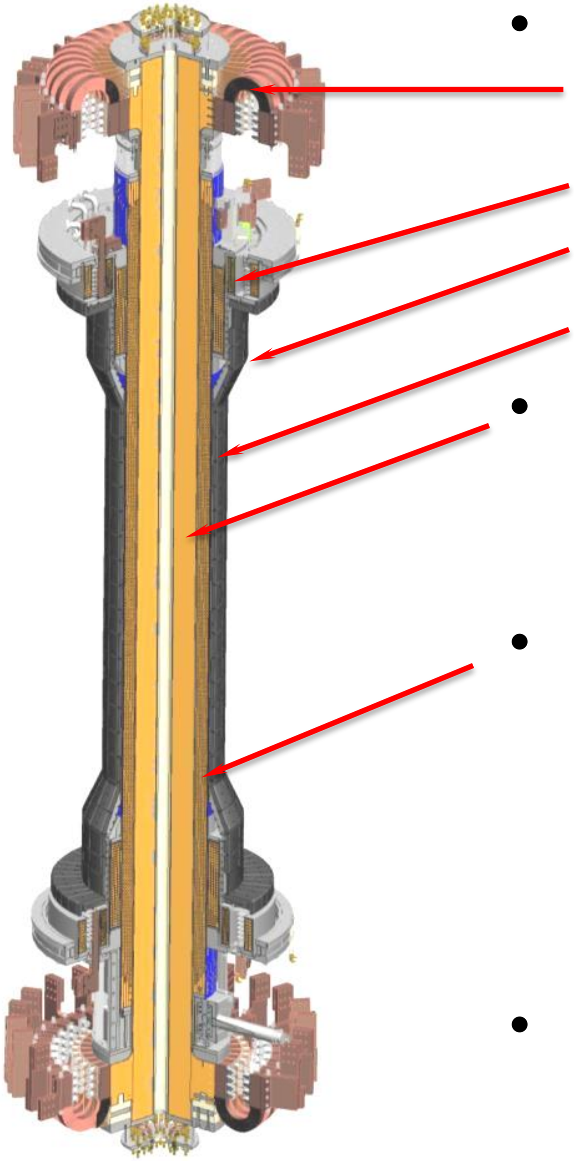
Good technical progress continues to be made on NSTX-U Project – still on cost and schedule



Neutral beam installation

- All 3 High Voltage Enclosures (HVEs) relocated to NSTX-U Test Cell
- NB water piping installation underway
- Electrical cable installation contract in procurement

Centerstack is the critical path and highest risk



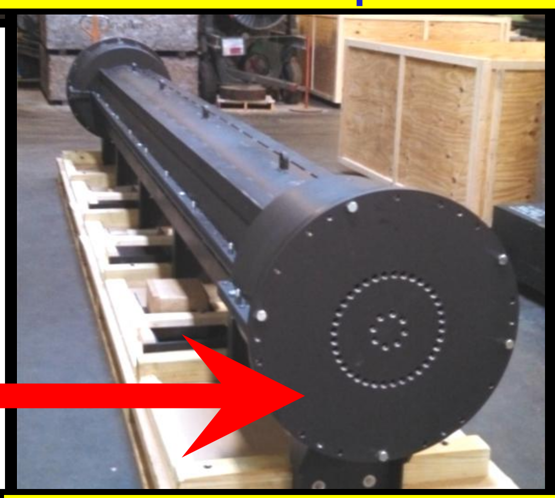
- **Components & Hardware**
  - Flex connectors – delivered
  - PF 1A,B,C coils – awarded
  - PFC Tiles – delivered and being machined
  - Casing – delivered
- **Inner TF Bundle**
  - VPI 4 Quadrants – **Completed**
  - VPI Full Bundle – ***August 2013***
- **OH Solenoid**
  - OH Conductor – delivered
  - Begin winding OH solenoid – ***September 2013***
  - OH Mold – ***Delivery August***
  - VPI OH – ***January 2014***
- **Centerstack Assembly**
  - Delivery to NSTX TC – ***May 2014***

Next step - CS Inner bundle assembly

Two of the 4 quadrants being sanded for final assembly

The assembly stand ready to receive the 4 quadrants

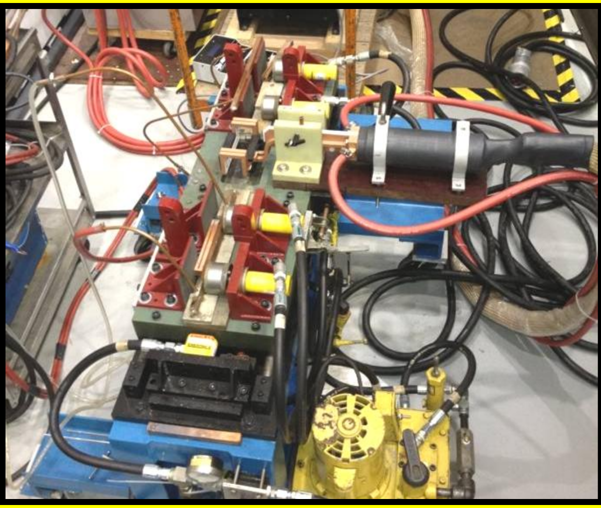
The full Inner TF mold positioned and leveled



The TF mold shown with the lid installed

OH Winding Assembly & Casing tile studs

The OH winding assembly being assembled for testing



The OH in-line braze unit tested and ready for use

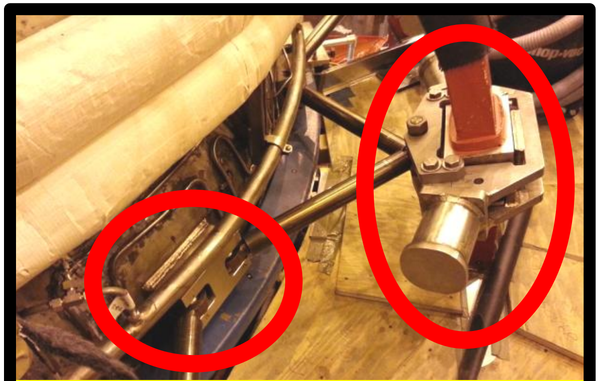
- The casing forms the inner part of the vacuum vessel and houses the inner TF/OH magnet.
- 500 Inconel studs being added to the outside surfaces.
- 696 Tiles with diagnostics will then be mounted.

Machine modifications making good progress

Umbrella Leg/arch Reinforcement

Umbrella/TF Reinforcements

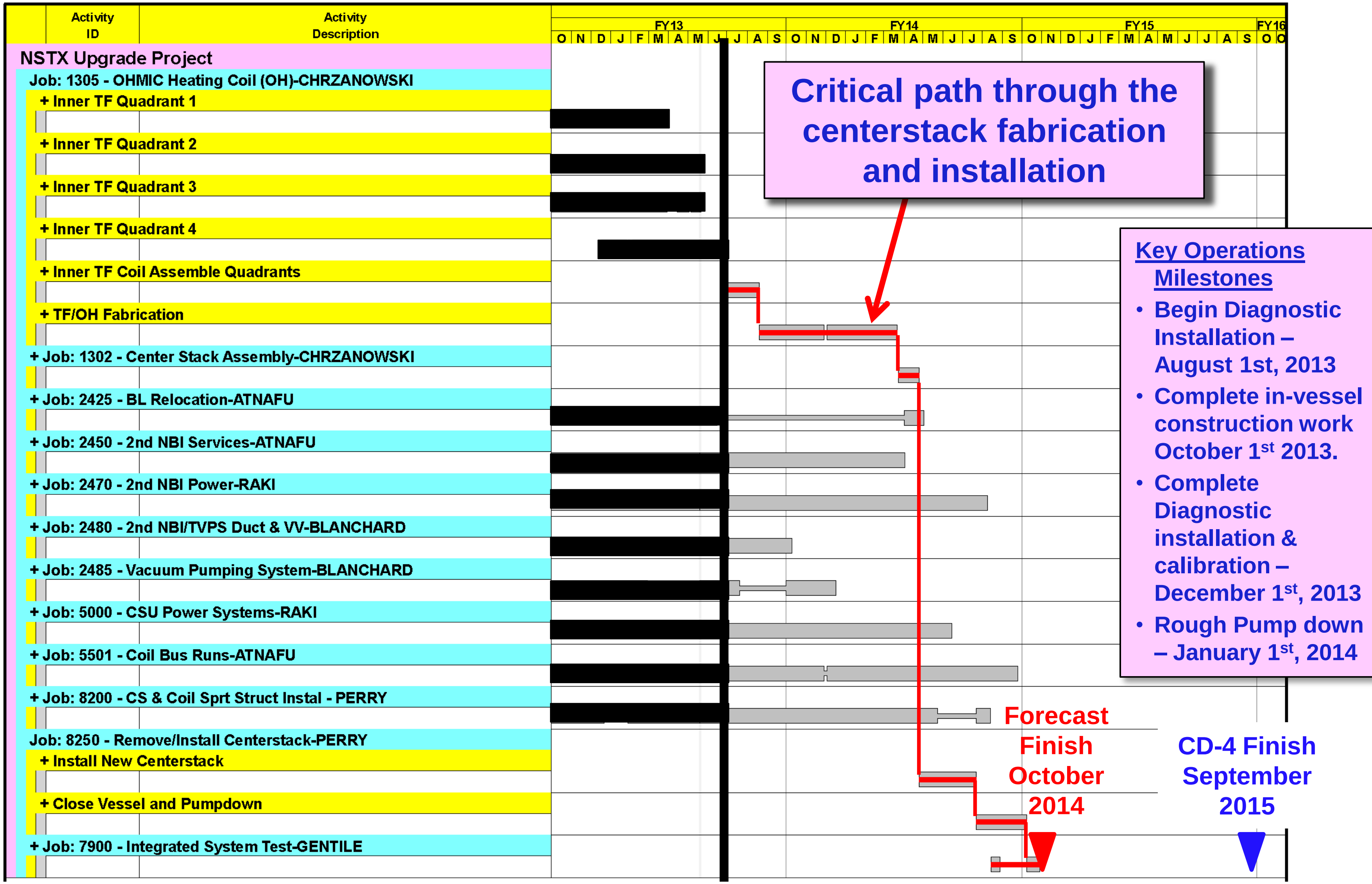
2 New Outer TF Coils Installed



TF Outer Leg Supports

Re-installation of cable trays
and racks underway

Project on track for October 2014 completion



Outline for Program Letter Discussion

- Guidance for University and Industry collaboration
- Charge to PAC-34
- Program Letter Overview
- Collaboration opportunities in Program Letter
- Summary

Considerations for FES solicitation for collaboration by Universities and Industry on NSTX-U

- FES solicitation cycle divided into 3 groups:
  - University & Industry → Diagnostics → National Laboratories
- DOE collaboration solicitation will be issued end of July
- Purpose of Program Letter is to convey more detailed status, priorities, contacts, opportunities for prospective collaborators
- NSTX-U Program Letter will be issued August 9, 2013

→ Request short written PAC report (2-4pp) by Aug. 6, 2013

- Like last year, grants will be for 4 years instead of the usual 3
  - Extended for FY2012/diagnostics to get 1st NSTX-U data
  - Implication: this collaboration period = FY14, 15, 16, 17
    - → Collaboration covers most of NSTX-U 5 Year Plan (2014-18)
- Expect next solicitation (diagnostics) will be delayed until summer of 2015 to synchronize, then go back to 3 year cycle

Charge to PAC-34

- Assess Program Letter from perspective of potential collaborator (using your PAC knowledge of NSTX-U)
  1. Does the letter properly represent NSTX program progress and the goals for utilization of NSTX-U, including schedule and expected performance?
  2. Are the priorities, background, and opportunities easily understood?
  3. Is there anything important missing? or that should be fixed or removed?

- Additional considerations for assessment of letter:
  – Letter is (purposely) sufficiently broad to attract new collaboration ideas
  – Research proposal recommendations are conveyed from Program to collaborator through comments section in "Record of Discussion"
  – Further, detailed hardware capabilities and preliminary requirements are agreed upon between the collaborator, the collaborator's research contact, and NSTX-U Program and Project directors using "Record of Discussion"

Program Letter Overview

- Program Letter "Research Priorities" strongly aligned with the 5 year plan research "Thrusts"
- Letter covers 6 topical areas:
  I. Macroscopic Stability
  II. Multi-Scale Transport Physics
  III. Plasma Boundary Interfaces
  IV. Waves and Energetic Particles
  V. Plasma Start-up and Ramp-up without a Solenoid
  VI. Advanced Operating Scenarios and Control
- Subsequent pages summarize the "Research Priorities" and "Key Collaboration Opportunities" from program letter

Research priorities for:

I. Macroscopic Stability

- I-1. Understand and advance passive and active feedback control to sustain internal and external macroscopic stability

- I-2. Understand 3D field effects on tearing layer physics and neoclassical transport, and provide the physics basis for 3D field utilization to improve macroscopic stability

- I-3. Provide stability physics basis for disruption prediction and avoidance, develop techniques for disruption mitigation, and understand disruption dynamics in high-performance ST plasmas

Key collaboration opportunities for:

I. Macroscopic Stability

- Extend sustainable β_N, β_N / l_i to long-pulse w/ RWM feedback
- Understand RWM kinetic stabilization, also internal kink, NTM
- Investigate resonant and non-resonant error field correction and locking/tearing responses to varied rotation, lower ν^*
  - Linear/non-linear modeling of layer dynamics, use 3D diagnostics
- Support 3D neoclassical transport and NTV studies
  - More self-consistent NTV codes, physics basis for NTV rotation control
- Assess off-midplane in-vessel 3D coil options with application to error field, NTV, RWM, RMP for ELM control in NSTX-U
- Develop reduced/real-time models to detect/avoid disruptions
  - MHD spectroscopy, observer techniques, real-time profile controllers
- New mass delivery methods, 3D diagnostics for mitigation
- Transport and stability physics during disruption
  - Thermal quench physics, transient heat loads, halo current models

Research priorities for:
II. Multi-Scale Transport

- II-1. Characterize H-mode global energy confinement scaling in the lower collisionality regime of NSTX-U
- II-2. Identify regimes of validity for instabilities responsible for anomalous electron thermal, momentum, and particle/impurity transport in NSTX-U
- II-3. Establish and validate reduced transport models (0D & 1D)

Key collaboration opportunities for:
II. Multi-Scale Transport

- Determine τ_E scaling vs B_T, I_P, P_{NBI}, ν_e*, β, ρ*, compare to NSTX
  - Identify mechanisms underlying observed confinement scalings
  - Exploit BES, high-k, polarimetry, reflectometry, compare to GK calcs
- Understand sources of anomalous electron thermal transport
  - Polarimetry/δB, perturbative gas puffs & laser blow-off, multi-energy SXR
- Study ion-gyro-scale T&T to understand relationship between the flow/shear and turbulence in core, improve understanding of momentum transport by turbulence and 3D magnetic fields
  - Exploit higher spatial resolution BES, study intrinsic rotation
- Explore particle/impurity transport from the edge to the core, linkages to inward momentum pinch physics
  - Utilize B_T, I_P, varied momentum deposition of NSTX-U
- Perform GK sims, develop synthetic diagnostics for high-k
- Develop/validate physics-based models of core e-transport
  - Drift wave, microtearing, kinetic ballooning, GAE/CAE

Research priorities for:

III. Plasma Boundary Interfaces

- III-1. Characterize, control, and optimize H-mode performance, transport, and stability

- III-2. Control divertor heat and particle fluxes, and recycling with a combination of innovative and proven techniques

- III-3. Develop lithium surface science for long pulse PFCs, including continuous vapor shielding

- III-4. Unravel the physics of tokamak-induced material migration and evolution

Key collaboration opportunities for:
III. Plasma Boundary Interfaces

- Assess pedestal vs I_P, B_T, P_{heat} with enhanced diagnostics
- Assess ELM triggering/suppression w/ 3D coils (existing, NCC) Li granule injection. Explore EPH, I-mode, QH modes
- As high-Z PFCs introduced, assess H-mode performance
- Investigate SOL heat, particle T&T, associated widths to lower ν^*, higher I_P, P_{SOL}. Compare snowflake to standard divertors
- Validate cryo-pump physics design, perform initial density control studies, assess H-mode performance, power exhaust
- Utilize diagnostics to identify in-situ/between-shot chemical compositions of Li coatings, connect to lab-based studies
- Assess vapor-shielding with application to heat-flux mitigation
  - Assist in deployment of Li-coated high-Z substrate, or flowing system
- Model/assess shot-to-shot erosion and re-deposition (QMBs)
  - Evaluate the impact of high-Z PFCs, different divertor configurations

Research priorities for:

IV. Waves and Energetic Particles

- IV-1. Develop capability to heat high-power neutral beam heated H-mode plasmas with fast waves and assess fast wave interaction with fast-ions

- IV-2. Develop fast wave, electron cyclotron, and electron Bernstein wave heating for non-inductive plasma current start-up, ramp-up and sustainment

- IV-3. Improve the ability to predict fast ion driven instabilities and the resulting fast ion dynamics using the expanded parameter space of NSTX-U

Key collaboration opportunities for:

IV. Waves and Energetic Particles

- Assess performance of fast wave antenna after boronization, and with optimized Li coatings to improve coupling
  - Utilize enhanced diagnostics: RF probes, IR cameras, fast-ions
  - Evaluate, mitigate RF power flows in SOL, divertors
  - Study interactions with NBI fast-ions at higher field and plasma current
  - Simulate reduced-strap (12 → 8 straps) fast wave antenna
- Assess/simulate viability of fast wave and EC/EBW heating for fully non-inductive I_P ramp-up
  - Measure EBW emission (synthetic aperture microwave imaging) and simulations of EBW H&CD to design an O-X-B heating system
- Support diagnostic operation/analysis for fast ion distribution, compare data to classical models (NUBEAM/TRANSP)
  - Assess impact on NBI-CD, assist 100% non-inductive development
- Characterize AE instabilities affecting fast ion confinement
  - Perform analysis/simulations of AE saturation, single vs. multi-mode

Research priorities for:

V. Plasma Start-up and Ramp-up without a Solenoid

- V-1. Develop helicity injection start-up with Coaxial Helicity Injection (CHI) and prepare for the use of point-source helicity injection

- V-2. Develop electron heating of low-I_P start-up targets using HHFW and ECH if it is available for both low-density and over-dense plasmas.

- V-3. Understand and optimize the non-inductive current ramp-up of low-current target plasmas driven by high-harmonic fast wave and/or neutral beam injection

Key collaboration opportunities for:

V. Plasma Start-up and Ramp-up without a Solenoid

- Experiment/analyze/simulate increasing closed-flux plasma current generated by coaxial helicity injection (CHI)
  - Utilize higher TF, new injector coils, higher injector voltage (≤ 2-3 kV)
- Provide simulations, experimental data (Pegasus) to support design/installation of plasma guns for point helicity injection
- 2D, 3D MHD/transport evolution simulations of HI start-up
- Support optimization of fast wave H&CD in low-current and low-density target plasmas prototypical of CHI target
  - Analysis/modeling/expts for heating low-I_P, low-T_e plasmas to ~1keV
  - Model the heating of very low temperature plasmas (30 eV) by 28 GHz ECH and HHFW for both low-density and over-dense plasmas.
    - If ECH becomes available, perform heating experiments vs target n_e, T_e
- Perform experiments, analysis, simulation for I_P overdrive
  - Experimentally investigate effects of fast-ion, MHD instabilities on overdrive using HHFW & NBI, support with data analysis and modeling

Research priorities and key collaboration opportunities for:

VI. Advanced Operating Scenarios

- VI-1. Develop, simulate, and implement advanced control algorithms in support of high-performance operating scenarios in NSTX-Upgrade.
  - Participate in scenario development, especially control of high-κ scenarios which may challenge vertical stability
  - Contribute to advanced control development
    - Participate in implementation of real-time diagnostics and control algorithms for rotation and current profile control
    - Experiments / analysis supporting real-time control of divertor heat-flux and PFC temperature for high-power, high-current operation
  - Implement real-time versions of existing diagnostic signals and/or develop control algorithms to detect the onset of plasma disruptions for triggering safe-shut-down and/or disruption mitigation systems

Summary

- Many exciting collaboration opportunities in Program Letter emphasizing utilization of new capabilities of NSTX Upgrade
  - Aligned with 5 year plan thrusts/priorities
- Thank you for helping to improve the Letter!