NSTX-U

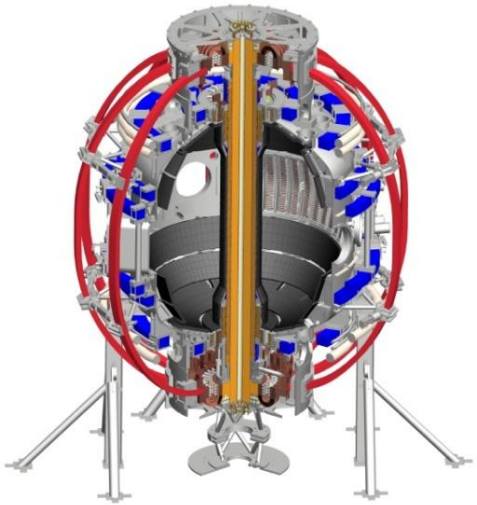
Supported by

U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U Program Update

J. Menard

NSTX-U Team Meeting
B318
October 4, 2013



Coll of Wm & Mary
Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Lehigh U
Nova Photonics
Old Dominion
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Tennessee
U Tulsa
U Washington
U Wisconsin
X Science LLC

Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
Chonbuk Natl U
NFRI
KAIST
POSTECH
Seoul Natl U
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Outline

- NSTX-U 5 Year Plan Review Report Overview
- Collaboration Solicitation for University and Industry
- Publish NSTX Review Papers from 5YP (?)

5 Year Plan Review Outcome (1):

- **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."

5 Year Plan Review Outcome (2):

- **A few overview comments from written report:**
  - "The strength of the proposed NSTX-U program lies in its potential to contribute to plasma physics understanding via model validation and development"
    - Access to unique physics regimes, the rich interplay among core/boundary/PMI physics and the good diagnostic set should enable fundamental contributions in a number of key research areas.
  - "The research plan for understanding and improving particle control for the ST was not clearly articulated, so it is hard to gauge the expected significance of the proposed research beyond the present operating regimes…"
    - The relative roles of PFC material choices, wall conditioning (including baking, boronization, and lithiumization), and pumping in providing density and impurity control for H-mode operation in the ST was not explained well, nor was the plan to resolve these roles.
    - There appear to be many questions still in play and the plans seem more trial and error rather than a systematic study of the role of ELMs, recycling, and impurity sources on particle control for the ST.

5 Year Plan Review Comments by Topical Area

- **Macroscopic stability**
  - …the NSTX team is in many ways leading the world effort on resistive wall physics, active and passive stability and control.
  - Efforts to compare theory and experiment for linear instability onset are quite impressive since it necessitates the inclusion of non-MHD physics in the fundamental model.
    - A quibble would be that this area could benefit from interaction with the extended MHD community to address nonlinear physics issues.
  - Non-axisymmetric control coils (NCC) will greatly enhance physics studies and control.
    - A more complete set of theory/modeling studies to understand how the added coils can affect various physics studies are encouraged.
  - Disruptions are an enormously important topic for the magnetic confinement community and NSTX-U is in a position to address a number of important aspects of this area.
    - Emphasis on disruption avoidance and mitigation is desired, but NSTX-U can also address some of the basic disruption physics properties as well.

5 Year Plan Review Comments by Topical Area

- **Transport and Turbulence**
  - With the excellent set of diagnostics tools (both equilibrium and fluctuations) and access to multiple advanced simulation codes, the NSTX-U team has an excellent opportunity to advance this primary goal of establishing a predictive capability through verification and validation.
  - The NSTX-U team is addressing the validation issue on a broad front and should set the standard for treating this issue in fusion plasmas.
    - The team should not be satisfied with implementing a conventional qualitative validation approach.
    - …it is critically important that the NSTX group work to improve validation science by developing quantitative validation metrics that take into account both the limitations of the measurements and the simulation codes
  - Fluctuation measurements are primarily limited to density fluctuations
    - Plans to develop/attempt internal measurement of magnetic fluctuations via Faraday-effect polarimetry will be implemented and represent an important new capability. Whether this is sufficient to validate codes is not clear.
    - No transformative measurements to determine multi-field quantities like the fluctuation-induced fluxes (particle, heat, momentum, etc.) are proposed.

5 Year Plan Review Comments by Topical Area

- **Boundary Physics**
  - Characterize, control, and optimize the H-mode pedestal performance, transport, and stability
    - Research program is strong… with plans to address a number of key physics questions towards developing first-principles understanding of the pedestal
    - Lithium has turned out to be a very interesting control knob, affecting the pedestal in a much more subtle way than originally envisioned
      - i.e., affecting the microturbulence via profiles changes rather than changing the convected power flows associated with neutral recycling though the boundary.
  - Divertor Physics: The principle focus is on developing heat flux mitigation strategies. These involve the use of snowflake divertor topologies (SF) and radiation in both the divertor and mantle regions.
    - The planned program makes good use of prior experience with SF in NSTX and the expertise of the experimental team
  - Particle Control: This is a critical research thrust for NSTX-U operations.
    - An important new tool is the proposed cryo-pumping system. The role that it is expected to play compared to the NSTX experience with Lithium pumping is appropriately addressed.
    - Cryo-pump motivation: provide particle removal while not suppressing ELMs

5 Year Plan Review Comments by Topical Area

- **Materials and PFCs**
  - There is a new understanding that vacuum conditions and contaminants largely determine the efficacy of Lithium as a hydrogen getter.
    - Near-surface chemistry conditions controls plasma-surface interaction; oxidation occurs rapidly under typical vacuum conditions
    - Thus, fully flowing Lithium, better vacuum conditions, and/or complete removal of carbon contaminants may be required to realize low recycling ($R < 0.5$) conditions with Lithium
    - This realization is largely driving the NSTX-U plan to transition towards Lithium on high-Z substrate surfaces and to pursue a possible Li vapor-shielding concept
  - The plan calls for an upgraded set of material erosion/redeposition diagnostics to be installed in NSTX-U, with specific locations determined by modeling….
    - This plan is appropriate and could lead to new understandings.
  - …Plans for investigating Lithium vapor-shielding as a potential tool for mitigating PMI are appropriate and…
    - have the potential to make fundamental contributions to this science area.

5 Year Plan Review Comments by Topical Area

- **Energetic Particles**
  - Energetic particle research is a strength of the NSTX-U program as the spherical torus is a device that is rich in energetic particle physics and the NSTX-U research team has vast experience in this area.
  - With NSTX-U, PPPL will likely have the control expertise to demonstrate Alfvén Eigenmode (AE) control.
    - The actuators include plasma shape, fueling, NBI and high harmonic fast waves (HHFW) for density and current density profile control, and NCC fields to vary plasma and mode rotation.
    - In collaboration with theory, it would be valuable to develop a predictive capability for the stability of AEs and then include this capability into the control system to learn how to navigate high performance regimes and avoid excessive fast ion loss due to AEs.

5 Year Plan Review Comments by Topical Area

- **Wave Heating and Current Drive**
  - Importance of power loss in the SOL plasma is recognized, and physics understanding is being developed.
    - Validation of upgraded codes will improve predictive capability, not only for NSTX-U but also for ITER and FNSF.
  - Given the essential need for non-inductive startup for FNSF-ST…
    - Acquisition of a 28 GHz gyrotron to provide capability for heating CHI plasmas to allow better absorption of HHFW, is important to the long-term program.
    - Allocation of appropriate resources will be important.
  - Non-linear physics and edge effects have been a major roadblock for efficient RF uses for many years, …
    - and it is unlikely that such significant progress can be accomplished in 3-4 years, with the proposed level of effort, including manpower (both for operations and physics studies) and proposed dedicated diagnostics.

5 Year Plan Review Comments by Topical Area

- **Plasma Formation and Current Ramp-up**
  - The detailed physics of how CHI works is not a settled topic.
    - This is an area where the research can benefit from close collaborations with the extended MHD projects. Beginning efforts are underway with NIMROD.
    - Comparisons between NSTX-U and MHD simulations are crucial to this physics mission. It is clear that this must be done in order to scale the NSTX-U results to fusion applications.
  - The role of the plasma guns was not discussed at length.
    - It is not clear how much emphasis this will be given in the upcoming NSTX-U research plan. Close collaboration with Pegasus colleagues is important to establishing the viability of the gun approach to non-inductive plasma startup.
    - Noting the potential uncertainties with CHI, it is important for the ST program to develop alternative strategies for non-inductive startup
  - Some experimental time should be invested in direct coupling of HHFW to CHI start-up plasma before 28 GHz ECH becomes available.
    - Start-up by outboard PF induction and ECH (tried briefly on NSTX, but with insufficient ECH power) and further ramp-up by HHFW is another start-up scenario worth trying.

5 Year Plan Review Comments by Topical Area

- **Plasma Sustainment: Advanced Scenarios and Control**
  - It will be quite important to optimize the re-start plan in order to get back to scientific productivity as early as possible
    - Plans for commissioning the new systems provided by the upgrade are well developed and appropriate.
  - It is difficult to judge how much time (and run time) will need to be devoted to relearn how the tokamak plasmas "behave".
    - One of the key aspects of relearning curve is particle (fuel, impurity) control.
  - Nevertheless, the addition of fine-tuned capability for current and rotation profile control in NSTX-U should provide greater flexibility for developing high performance ST scenarios
  - NSTX-U is expected to make major contributions in advanced scenario development.

5 Year Plan Review Comments on Proposed Facility Enhancements

- "The plans to install a divertor cryo-pump, a 28 GHz ECH system, and off-midplane non-axisymmetric control coils in base funding case are adequate."
  - "The addition of a divertor cryo-pump will be an excellent addition to their program."
  - "NCC will greatly enhance physics studies and control"
  - "Given the essential need for non-inductive startup for FNSF-ST, acquisition of a 28 GHz gyrotron to provide capability for heating CHI plasmas to allow better absorption of HHFW, is important to the long-term program"
    - Alternative viewpoint (devote NSTX-U operation to conventional tokamak physics):
      - "The proposed ECH/EBW system is primarily needed to achieve non-inductive start-up.
      - This goal is has little scientific or technical merit for conventional tokamaks.
      - Moreover, ECH/EBW heating systems are notoriously manpower intensive, and it is not clear where the required additional effort would come from."
- The proposed additions of the flowing liquid Lithium divertor and divertor Thomson scattering diagnostic are desirable.
  - Reassessment of the importance of the flowing Lithium divertor relative to other items covered under base funding is recommended.

FESAC facility prioritization for 2014-2024 ranked NSTX-U "(a) absolutely central" for enabling world-leading science

- Contributions critical to ITER
  - Energetic particle physics, where the new heating systems in NSTX-U will provide expanded ability to vary the velocity and spatial distribution of energetic ions in the plasma
  - Radiative divertor solutions to the ITER-relevant heat fluxes, impurity transport using multiple conditioning and PFC scenarios to enable control techniques to be developed in impurity-seeded ITER plasmas
- Developing new solutions for the plasma-material interface:
  - The ability to explore very high exhaust power density, high magnetic expansion, and liquid metals in the same device is unique in the world fusion program
- Establishing the physics basis for FNSF
  - With access to the highest magnetic field and heating and current drive power of any low aspect ratio tokamak, NSTX-U will be the leading device in the world program to assess the viability of this regime for FNSF applications

Collaboration Solicitation for University and Industry

- Collaboration proposals due to FES next Thursday = October 10, 2013 by 5PM EDT
- See solicitation, program letter for details, priorities
  - Diagnostic development/implementation NOT part of this solicitation
  - Next diagnostic solicitation will most likely be 2 years from now
- Record number of Records of Discussion (30+)
  - ~10 (40%) more than previous period

Publish NSTX Review Papers from 5YP (?)

- Fusion Science and Technology journal has standing offer to publish NSTX special issue that would summarize NSTX research achievements

- One idea is to use 5 year plan chapter text, i.e. all the research results/references that motivate the plans
  - Detailed plans would need to be removed from each chapter, but there could be one summary chapter that contains future plans

- I would like feedback from chapter authors / TSG leaders if they are willing to work on this (after APS)
  - Good for NSTX, good for authors, good for publications
  - Most of work already done, last chance before NSTX-U operation…