NSTX-U

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

Update on NSTX Upgrade Program

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For the NSTX-U Team

NSTX-U Team Meeting
PPPL B318
June 26, 2012

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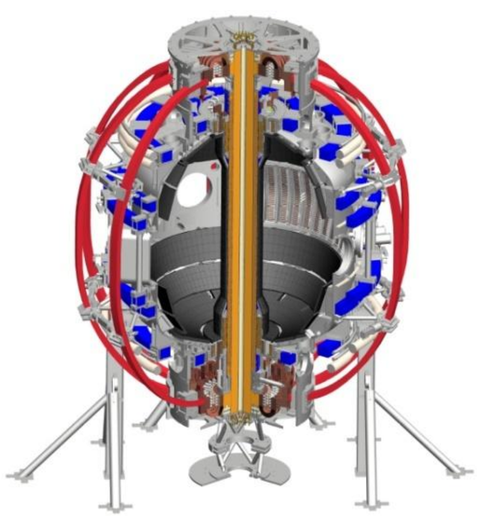

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Outline

- Summary of PAC-31 report
- Next-steps for 5 year plan proposal prep
- FESAC charge, and opportunity for input

Overall PAC comments (1)

- The PAC is particularly impressed by the progress and breadth of the advanced scenario and control modeling
- Other highlighted program achievements:
  - Improved theoretical understanding of micro-tearing instability and its role in governing heat transport, which complements growing experimental evidence
  - Further increase in energy confinement with lithium evaporation; this improvement is not yet saturated
  - Identified the role of oxygen in increasing deuterium retention for a lithium-graphite surface
  - Measured the fast ion redistribution from MHD instabilities, and initiated full-orbit calculations to understand the physics
  - Detailed analysis of the NSTX disruption database has been undertaken, including development of warning algorithms that predict 99% of disruptions

Overall PAC comments (2)

- The PAC is very pleased to see that the NSTX team has initiated a substantial design effort for a cryo-pump.
  - initial results suggest that a cryo-pump compatible with device and plasma performance requirements could be constructed"
- The PAC remains impressed by the comprehensive approach to understand the role of lithium coatings, including
  - Improved measurement and analysis capabilities on NSTX
  - Supporting "lab" (or test-stand) experiments, collaboration with LTX and other fusion experiments, and theory and modeling
  - Clearly the NSTX Program is a world leader in Li coating research

Overall PAC comments (3)

- The PAC remains concerned that a solution to obtaining stationary plasmas suitable for the stated high-level objectives has not been identified for NSTX-U.
- A key measure of success for the NSTX-U upgrade will be attaining plasmas with low collisionality, for which density control is the strongest leverage.
  - The cryo-pump is not certain, neither in design nor funding, and deuterium pumping on metal substrates is known to be different than for carbon substrate, the present plasma-facing component (PFC) material of NSTX.
  - We note that the PFC and plasma-wall-interaction (PWI) research plan calls for the eventual use of metal substrates in NSTX-U, both molybdenum and tungsten.

Overall PAC recommendations (4)

- The PAC is also concerned that the 5-year program plan has potential competing priorities with regard to the implementation of the PFC and particle control upgrades to support the three highest level goals:
  - FNSF scenario development, divertor heat flux control solutions, and exploring the role of plasma collisionality in ST performance.
- The PAC recommends that the NSTX-U Team develop an implementation strategy that provides definitive results at minimum risk on each of these goals, even if that requires deferral of one with respect to the others. This strategy should be developed in the 5-year plan and presented at the next PAC meeting

Specific PAC recommendations: Boundary Physics

- The PAC suggests that a much clearer plan is needed to better clarify the evolution from carbon to all-metal walls.
- The PAC also notes that the 5-year transition from an all-carbon machine to an all-metal machine is very ambitious, especially considering the possible reduction in key staff in coming years.
- A more systematic evaluation of the PFC assessment plan is needed to determine whether all of the steps described are needed. One suggestion to consider is elimination of Mo phase and go directly to W.
- The PAC also recommends that the NSTX-U team review and prioritize the divertor diagnostic capability that will be needed for NSTX-U to fully understand the snowflake configuration.
- Research of high-Z impurity shielding in the edge and SOL plasmas and active control of the core accumulation will be essential…
  - Control methods, such as gas puffing, central heating, and possibly new ideas should be investigated together with developments of spectroscopic measurement and transport modeling.

Specific PAC recommendations: Lithium Research

- Reduction of peak heat flux with Li deposition was documented, as well as narrowing of heat-flux radial profile for same power as no-Li discharges
  - If possible, more data analysis should be performed and more modeling to build a consistent picture – including the possible role of Li in the detached divertor plasma obtained in the snowflake configuration that yields very low peak heat flux.
- The observed development of a small-ELM-like regime on some discharges following the cessation of Li deposition is very interesting, especially because such discharges show low impurity accumulation, presumably due to the returning edge MHD fluctuations.
  - The result suggests an optimum Li coverage exists to allow such regimes. More analysis of such discharges is encouraged
- *Years 1-2 operation:* Establishing the pumping capability of Li with fuller device coverage should be a high, early priority, as well as clarifying the role of Li in low heat flux operation with the snowflake divertor.
- *Years 3-5 operation:* The use of flowing Li on only one toroidal segment is sure to complicate understanding, and perhaps operation, of the device.
  - There should be a clarification by NSTX staff whether this strategy is based on ease of retracting or removing the module if there is a problem, or is a cost-saving measure.

Specific PAC recommendations: Macro-Stability

- Plans for the first 4 years of operation of NSTX-U seem appropriate. In particular, year 1 focuses on reestablishing previous capabilities and mastering changed features such as error fields and shape controls.
- Year 2, by contrast, begins the exploitation of new capabilities such as the off-axis NBI and SPAs. The diagnostic development efforts, such as real-time velocity measurements, look particularly promising.
- A notable feature of the plan for years 3-5 of NSTX-U is the relatively low profile of 3D studies (R12-1), despite:
  - (i) the identification of this area as a priority by FES
  - (ii) the important new capabilities that the Upgrade will provide, particularly as regards reduced-collisionality regimes of operation and the elucidation of differences in the response to RMP in NSTX and DIII-D.
- The PAC assumes that the absence of this topic from the presentations is a consequence of reduced manpower caused by our previous request for a study on cryo-pump design.
- We hope to see this subject receive renewed attention in the future. In particular, we endorse the plans for the NCC coils and strongly support the planned inclusion of the plasma response in the design efforts.

Specific PAC recommendations: Transport & Turbulence

- Endorsement: The NSTX-U team is developing a highly coherent research approach in turbulence and transport studies in which global confinement properties, local transport levels, and turbulence characteristics are investigated experimentally and a consistent physical understanding is sought by means of comprehensive theoretical models and related numerical tools.
- In the framework of gyrokinetic modeling of turbulence, it is suggested to move towards increasingly realistic simulations, including:
  - the impact of rotational shear on micro-tearing
  - the impact of an additional C impurity species in conditions of large Z_{eff}
  - consider the impact of these effects on the collisionality scaling, particularly in the case that correlations between parameters are present in the experiments.
- A critical aspect on which particular efforts are suggested to be dedicated is the role of low-k turbulence in producing particle (electron and impurity) and momentum transport.
- Consider development of a model for *AE induced electron heat transport during outage phase (in collaboration with the TSG on Energetic Particles) to be tested against past NSTX results and to be applied then to NSTX-U.

Specific PAC recommendations: Waves + Energetic Particles

- The analysis of NSTX-U scenarios with respect to the expected fast ion physics is important due to the importance of the contribution of the ST in this area with respect to ITER/DEMO physics.
  - Modeling should be used to guide NSTX-U research plan as well as diagnostic strategy
  - The PAC is concerned that the proposed time line is not aggressive enough with only one research milestone in FY 2014, not reflecting the importance of the field with respect to NSTX-U and other future tokamaks. The PAC recommends to accelerate the time line in particular w.r.t. developing simplified models of the *AE induced fast ion transport.
- The NSTX RF team should turn increasing attention to modeling NSTX-U discharges. In particular,
  - Modeling of the SOL behavior at higher field and modeling of the interaction between the HHFW and the new NBI should be undertaken. Addition of new SOL diagnostics should be considered where appropriate to further evaluate the effects of RF in the SOL
  - Modeling of performance of HHFW for achieving fully NI operation in NSTX-U including minimum temperature requirements for heating the CHI plasma should be performed.
- The team should complete the conceptual design of the ECH/EBW system.
  - In addition, a physics basis for ECH in the start-up plasma, e.g. density limit, power requirements, etc. should be performed taking advantage of MAST and other expts
  - The role of EBW heating in fully NI ops should be re-assessed for parameters of NSTX-U

Specific PAC recommendations: Solenoid-free start-up

- The projected scenarios heavily rely on ECH to bridge the gap between CHI target plasma and desired conditions for HHFW coupling. The PAC endorses ECRH (> 1 MW, 28 GHz) for current start up during the initial phase of NSTX-U operation. This would
  - Greatly enhance start-up and current ramp-up capabilities for direct application of NBI or preheating to >400 eV to facilitate HHFW coupling.
  - This new RF capability could also be used for non-inductive EBW start-up to current levels comparable to CHI start-up alone.

- This possibility and impact on the NSTX-U design should be investigated further to strengthen the physics case for a 28 GHz ECRH system.

- The PAC supports further MHD modeling using TSC, NIMROD, TRANSP, and possibly M3D-C1, in support of NSTX-U, and recommends further exploring the compatibility of low li CHI target plasmas with ECH and HHFW during the initial start-up phase.

Specific PAC recommendations: Adv. Scenarios & Control

- Participation on snowflake divertor expts on DIII-D is highly encouraged.
- In addition, we recommend that NSTX-U staff pursue participation in off-axis neutral beam current drive and fully non-inductive scenario research on DIII-D (and other devices as appropriate) to develop hands-on experience in preparation for future experiments on NSTX-U.
- During years 3-5 after outage, extension of NSTX-U operation to fully non-inductive operation and I_P = 2 MA also are appropriate. As part of this plan, the PAC encourages NSTX-U management to establish a program-level objective of demonstrating fully non-inductive operation with Ip > 0.6 MA.
- An important aspect of this capability will be the requisite density control and the PAC encourages the testing of advanced density control techniques that can provide this capability.
- The PAC is concerned with what appears to be competing priorities with respect to assessing collisionality effects on transport, scenario development, and PFC research.   It is the PAC's belief that density control is a critical enabling tool for the first two of these.

Schedule for 5 year planning preparation

- April/May: Presented initial ideas to PAC-31, got feedback
- June-July 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

Near-term schedule for 5 year plan preparation

- By June 30: J. Menard will distribute overall chapter outline including main topics and tentative lead/responsible authors
- First ½ of July: TSG leaders will further modify/extend outline and hold TSG meetings as needed to discuss
- Second ½ of July: Team-wide meeting(s) led by JEM and all TSG leaders to review/finalize the overall 5 year plan outline
- July/August: Initiate chapter writing
  - First task (by end of August) for each chapter writer will be to draft a chapter introduction summarizing how NSTX-U research program will:
    - Support burning plasma science
    - Address critical challenges for long-pulse/steady-state operation including plasma-wall interactions and materials
    - Address fusion materials science and harnessing fusion power (i.e. FNSF)

Goal: NSTX-U 5 year plan chapter introductions will also serve as info for FESAC sub-panel charged with prioritization

- From W. F. Brinkman – Director Office of Science, DOE – April 13, 2012

  "I therefore ask FESAC to consider the following charge related to scientific priorities for magnetic fusion. Please assume that the ITER project is ongoing, will be until the end of this decade, and is supported separately from the rest of the program…"

1. "…Focus on research that supports burning plasma science and that addresses critical challenges for long-pulse/steady-state operation including plasma-wall interactions and materials, prioritize among and within the FY2013 elements of the non-ITER magnetic fusion portion of the Fusion Energy Sciences program. Assume funding at the FY2013 Presidential budget request level of effort…"
2. Considering the same focus as in (1), again prioritize the elements of the non-ITER part of the magnetic fusion portion of the FES program, but assume a restoration of the budget to the 2012 level…
3. Prioritize elements of a U.S. program w/ substantially enhanced emphasis on fusion materials science…. Consider 5 yr period following roll-off in ITER project construction funding... Assume that research on fusion materials science and harnessing fusion power will capture much of this increase…