General Comments

- The PAC congratulates the NSTX-U team on successfully solving many key technical challenges associated with the Upgrade project. The work is 87% complete, and while the schedule is tight, there is good probability that CD-4 will be achieved by Jan 2015, and full 18 weeks of operation completed in FY 2015.

- The PAC congratulates the Team for undertaking many successful collaborations during the Upgrade period. The impact is clear in key metrics for scientific productivity (papers, talks, etc). The collaborations on other facilities (DIII-D, C-Mod, MAST, EAST, KSTAR, MAGNUM-PSI) are reported helpful and welcome. These collaborations have brought back to NSTX-U new ideas and capabilities, e.g., advanced plasma control.

- The PAC is very pleased to see the strengthened connection between the NSTX-U program and PPPL Theory through the new Partnership. (More on this later)

- We applaud having younger members of the NSTX-U team represent the program as presenters. They are a talented and energetic crew who are a clear asset to the NSTX-U program.

Comments on 1st Charge Question (1)

1. *Assess the operational preparation and research priorities and preliminary plans for the first two run-years of NSTX-U with emphasis on the first run year.*

- The overall plan for bringing up an essentially new device with great new capabilities is good. However, we have a few recommendations below.

- The past practice of relatively short-term scheduling is likely insufficient for the NSTX-U program. We recommend adopting a longer term run schedule planning process to:
  - Better support integrated and increased collaboration
  - Help develop the rationale that drives the hardware schedule
  - Optimize the first year of operation, which is clearly very tight

- Particle control remains a critical issue in achieving low collisionality, long pulse, discharges in NSTX-U. We strongly recommend developing a clear plan to understand particle transport, sources, and sinks to ensure confidence in the design and implementation of the cryo pump. Such a plan will also increase confidence in achieving important metrics that validate the primary motivation for the upgrade within the first two years of operation.

Comments on 1st Charge Question (2)

- While it is clear there is eagerness to test NSTX-U new capabilities, we urge thorough investigations of the steps from bare surface to boronization to added lithium:
  - Another cut at the very informative time chart presented by S. Gerhardt that factors in diagnostic/control capabilities required for each step is strongly advised. Research readiness defined by TRANSP is necessary but not sufficient to understand the impact of various wall conditions.
  - Develop metrics for gauging success at each step in wall condition.
  - A thorough plan and anticipated schedule should be ready prior to the Research Forum.
  - Note that the next opportunity for careful diagnosis of steps in wall conditions will not occur until 2018.

(see also the detailed comments by topical area)

Comments on 2nd Charge Question (1)

2. *The NSTX Program has been asked by DoE Fusion Energy Sciences (FES) to develop and implement ideas to "Expand engagement with university scientists to enhance the NSTX-U program". Please comment on and/or expand the preliminary set of ideas (to be presented at PAC-35) to make NSTX-U more attractive and/or available to university scientists – including early career researchers and students..*

- We applaud the concerted effort to engage NSTX collaborators in a fruitful discussion on this important issue, which is really a larger fusion community issue.

- The suggestions identified for FES and PPPL action are good examples that are either essential to stabilize or to improve the environment for university collaborations on NSTX. (J. Menard slides 40-43)

- The NSTX-U Innovative Research Award (NIRA) is a good idea that should implemented, and if targeted exclusively to university researchers, would increase university collaborations 10-20% beyond that which is currently underway. We note the university-based collaborations are already substantial, e.g., totaling 76 individuals. In considering support of Ph.D. student research, more than 3 years might be necessary.

Comments on 2nd Charge Question (2)

- Establishing a university program dependent primarily on collaboration at a major facility is compelling but very challenging. There are few such programs in existence in the fusion program. PPPL and/or FES could help facilitate the establishment of such programs, for example:
  - The base for university collaboration is a faculty member(s), who is responsible for the supervision of Ph.D. education. This base is often greatly enhanced by the addition of professional scientists/engineers.
  - Tenure typically demands demonstration of scientific leadership in addition to scientific productivity. Structuring scientific management of the NSTX program to include university faculty/researches would demonstrate leadership and integrate the university with less concern for additional financial support. (They become core members of the team.)
  - Competition for tenured faculty positions is fierce. Guaranteed financial support for startup and initial salary can significantly influence hiring decisions. PPPL and/or FES could seek to establish tenure-track positions through such support, perhaps targeting universities in close geographic proximity.

- We recommend PPPL/NSTX help drive a national conversation on the role of universities in fusion and plasma physics research, together with other labs and universities.

Comments on 3rd Charge Question (1)

3. *Comment on progress and plans for establishing and expanding the partnership between the NSTX-U program and the PPPL theory department.*

- The PAC was impressed with the results of the very productive partnership that was initiated in order to increase the participation of the PPPL theory Department in the NSTX-U project. We congratulate the co-leaders of the partnership (Amitava Bhattacharjee and Stan Kaye) along with the participating theorists and NSTX-U team members for making that initiative so successful.

- It is the opinion of the PAC that the studies performed as a result of the collaboration initiative were, on balance, more beneficial than the studies they replaced.

- The PAC recommends that PPPL maintain the partnership regardless of the continuation of the incremental funding that was used to seed it. This should be a high priority.

Comments on 3rd Charge Question (2)

- We note that the description that was given of the partnership presented it as asymmetrical, in as much as theorists bore the burden of proposing projects that were of interest to the NSTX-U team. Sustaining the partnership without continued funding would require an equal investment of goodwill and interest from both sides in order to identify projects of mutual interest.

- In order to encourage the theory-experiment partnership, we recommend that the NSTX-U team include details of theory and modeling requirements for an experiment when proposals are made

- PAC suggests that the NSTX-U / Theory partnership produces a set of target milestones for theory work in the next three FYs (like slide 13 from Jon Menard's talk) especially highlighting the synergy with the experimental milestones. Please also show the long-term planning for modeling development on a timeline, like slide 12 from Masa Ono's talk. We look forward to seeing such milestones at future PAC meetings.

Advanced scenarios and control (I)

- The progressive build-up of the NSTX-U operation and control capabilities during FY15 and FY16 is clear.
  - And well aligned with the 5 year Plan for NSTX-U.

- The extensive preparation of key systems for NSTX-U operation is noted.

- The commissioning schedule prior to FY15 operation is aggressive.
  - Scheduling of the 18 week run plan should continue to take into account completion of key systems.
  - Especially for scenario development and their control

Advanced scenarios and control (II)

•The preparation for control of the current profile and rotation (involving collaborators) has been excellent (R14-3 milestone).

•Particle-density control will have new capabilities (gas valves, impurities, density measurements). Priority should be given to:

(a) What set of tools can provide particle control in NSTX-U's longer,

higher power plasmas, and

(b) developing the necessary basis for a cryopump.

•In the area of disruption prediction, avoidance and mitigation NSTX-U could provide important information for ITER.

- This aspect should be given immediate emphasis, in preparation for JRT in 2016 and ITER final design review.

•The PAC encourages coordination of the study, optimization and control of NBCD at NSTX-U and DIII-D.

Non-inductive start-up and ramp-up

NSTX-U plans to address a major challenge for FNSF-ST by demonstrating solenoid-free startup:

- 0 kA → ~400kA: Coaxial Helicity Injection (CHI)
  - Previously demonstrated to 200 kA in NSTX… should scale ×2 in new device

- ~400kA→ flat top: FWCD+NBCD+bootstrap
  - Can be tested/ developed from inductive startups

- Several challenges are acknowledged and addressed by the NSTX-U Team
  - Keeping the CHI target clean and avoid contact with the walls
  - CHI target is too cold for handoff to HHFW and NBI
    - Heat with ECH (requires new development of 28GHz gyrotron capability)
  - Compatibility between HHFW and NBI (fast wave heats beam ions)
  - Modeling with NIMROD, TSC, TRANSP, have started

Non-inductive start-up and ramp-up: Recommendations

- Plan for 2015-16 appears to address the right issues
  - Limits of CHI plasma formation should be determined as soon as possible
    - Determine maximum achievable current with solenoid current ➔ 0, closed flux surfaces, low impurity content
  - Prioritize sufficient run time to HHFW and NBCD experiments at 300-400 kA to develop coupling scenarios.
  - Handoff to full current ramp scenario from CHI startup will probably have to wait for ECH

- Expedite gyrotron development with intention of supplying heating power to the cold CHI plasma as soon as possible
  - This appears to be the critical path to full NI ramp-up demonstration

- Continue numerical simulations:
  - With more realistic assumption for HHFW coupled power
  - Predictions/interpretation for 300-400 kA full NI CD experiments

PFCs: Li, High-Z Materials: Plans and priorities for first two years of NSTX-U operation (FY15-16) [1]

We appreciate the schedule for installation of high-Z tiles according to previous PAC recommendations. The material probe (MAPP) is important for PWI study without influence of discharge history. There is excellent work on the fundamental surface science, e.g. with Princeton U. and DIFFER Magnum-PSI, included in the research thrusts.

Following are suggestions concerning the 5-Year Plan Research Thrusts and Near Term:

Comment on Thrust MP-1: Li surface-science in Laboratory will be further extended

Li coatings at high temperature closer to NSTX-U wall operation conditions, e.g. with D irradiation, will elucidate effects on hydrogen dynamic retention.

Comment on Thrusts MP-1, 2: Systematic study of Li surface-science in NSTX-U

Whereas commissioning and plasma confinement studies by wall conditioning such as Li injector (LITER) will be required, systematic investigation of Li effect (amount/coverage) on SOL/divertor and pedestal plasma is important, i.e. providing enough time of initial operation on Li-free conditions for **FY15**.

PFCs: Li, High-Z Materials: Plans and priorities for first two years of NSTX-U operation (FY15-16) [2]

The PAC suggests evaluating particle balance under different Li coating conditions:
providing unique database, as Li will be reduced in **FY16** for high-Z study.

Systematic MAPP studies correlating with plasma performance are recommended; encouraging closer coupling with modeling (WallDYN) collaboration and coordination with plasma edge diagnostics.

More quantitative evaluation of various Li coverage and uniformity on the control of recycling and reduction in sputtering is recommended.

Comment on Thrusts MP-2: Physics understanding of tokamak-induced material migration and evolution

Code development is key aspect for this thrust in **FY15-**:
close coordination with collaborators using WallDYN and other surface-response modeling needs to be established, coupled to edge plasma codes.

PFCs: Li, High-Z Materials: Plans and priorities for first two years of NSTX-U operation (FY15-16)3/3

Comment on Thrust MP-3: Establish the science of continuous vapor-shielding

Provide enough coordination with surface-response models and plasma edge models to elucidate the role of Li coatings at high temperature on high-Z substrates.

Additional comment: active study of high-Z transport and control

The present plan would provide useful data on the mechanical stability of the new tiles, but minimal information for PMI.
The coverage (presently only 1 row in FY16) should be discussed and considered more before FY16 installation. The detailed shaping of W-lamellae should be also considered. There are different options to consider:

- Expand the poloidal coverage to more than one toroidal row in FY16
- Try toroidally separated high-Z tiles at various wall locations to better validate the lamellae design in a variety of loading conditions, including small-scale melting has tended to be the most limiting factor in W solid deployment.

Study of W transport and control, such as melting layer and accumulation control, will be necessary before major replacement of wall PFC (FY19). These results will also contribute to ITER/ITPA R&D.
In addition, installation of the laser blow-off system for FY16 would allow important controlled injection of high-Z to study its transport throughout the discharge.

Boundary: SOL & Divertor Observations

- Continuation of snowflake concept, both through DIII-D collaboration and increasing integration of modeling, is very positive.

- For NSTX-U start, the proposed diagnostic set is appropriate to both support the NSTX-U overall mission and advance the edge physics
  - The development of DTS would be a very welcome addition
  - Continue to evolve and enhance the PMI measurement tools

- Overall continue to encourage and involve boundary modeling as new results come in from NSTX-U.

- The stated near-term 2015 priority is on heat flux control
  - However the near-term priority for the NSTX-U program is actually particle control, not heat flux control, since it appears unlikely that administrative energy limits will be surpassed.

Boundary: SOL & Divertor Recommendations

- The issue of achieving stationary particle/density control should be the highest priority in the near-term for SOL/divertor.
  - This may be mutually compatible with the snowflake development and its ability to achieve high-recycling divertors in a variety of shaping anyway.
  - Should fold-in characterization of SOL width with B, Ip, a, etc.

- Assure the necessary near-term effort to fully characterize the requirements and feasibility of the cryopump through measurement and modeling.
  - The cryopump installation will be perturbing to the NSTX-U schedule, but will likely be the central tool in obtaining the device mission goal of stationary high-performance.

- Continue to assess and prioritize an enhanced PMI and divertor diagnostic set, in time for the 2017 outage

Pedestal Research – General comments

Goal: Develop predictive capability for pedestal structure and evolution for FNSF

- Good recognition of high importance to understand scaling studies for pedestal and ELM behavior
- FY13-14 activities have aided readiness
  - Time response of n_e and T_e measured during post-ELM recovery in DIII-D
  - Magnetic fluctuations related to KBM in C-Mod pedestal
  - Study of KBM and other modes for NSTX with GENE
  - Led 2013 JRT on enhanced confinement without large ELMs
- Coupling of pedestal to SOL/divertor/materials appreciated; particle control likely involves all of these
- Basic diagnostics in place: MPTS, BES, bolometers, ME-SXR
- Linear analysis of short wavelength pedestal microstability: GENE, …
- Continue global nonlinear microturbulence development with XGC1, including electromagnetic effects

Pedestal Research – PAC comments

Specific comments/questions

- Identify/articulate some fiducial NSTX discharges for early pedestal comparisons
- Development of fundamental understanding of strong role of lithium on pedestal structure should be a high priority; more integrated model
- Particle transport (D and impurities) important to measure & model
- Encourage possible enhancement of pedestal-capable diagnostics; wave scattering, E_r (CHERS), etc.

Pedestal Research – PAC comments

Specific comments/questions – continued

- LH-transition studies plans should be articulated
- Consider more comparison with MAST, esp. pre-lithium conditions
- What is expected for KBM growth for Upgrade parameters
- Low-n ELM stability can/should be addressed by existing MHD codes
- Between-ELM and full ELM modeling could be done with M3D-C1 and/or BOUT++ as well as JOREK; theory partnering

Turbulence and Transport, General Comments

- The PAC congratulates the NSTX Upgrade Team for the recent important results
  - Turbulence measurements across the L-H transition and comparison with lin. GK
  - Test of reduced models for μT turbulence
  - Development of increasingly realistic descriptions of GAE and CAE electron heat transport
  - Extensions in the physics description of momentum transport (including the application of global codes)

- The PAC applauds the strong links which are being built between experimental and theoretical research in this topical area, and acknowledges the specific consideration which has been given to the suggestions included in the last PAC report (in particular emphasis to GAE/CAE transport and application of global models).

- The PAC is pleased to learn that a strong link between exp. and theoretical investigations is already envisaged in the planning of FY15-16 research activities (including major theory upgrades, e.g. e.m. extension of global codes)

Turbulence and Transport, assessment of operational plan and research priorities for FY15 and 16

- The PAC acknowledges that the research plans are well aligned with the 5 –year thrusts and leverage the increased scientific possibilities offered by the upgrade

- The PAC agrees with the hierarchy of investigations towards lower collisionality and higher beta plasma regimes which range from the empirical characterization of global confinement properties to local investigations of multiple transport channels with the aid of multi-scale multi-field (from FY16) fluctuation diagnostics

- However, the PAC is concerned that in FY15-16 insufficient emphasis is given to experimental studies of particle transport, and related validation of models

- As already underlined in the PAC33 report, particle transport plays a critical role towards the development of stationary scenarios for long-pulse opearation (e.g. BS fraction and high-Z impurity control)

Turbulence and Transport, specific suggestions

- Higher priority should be given to particle transport perturbative experiments (assessment of feasibility, continue collaboration with CCFE for comparative analyses between NSTX-U and MAST)

- Main plasma (electron) particle transport be considered as essential element for multi-channel transport investigations

- Emphasis given to prediction of temperature profiles be extended to prediction of density profiles, e.g., does a neoclassical particle transport model really reproduce the experimental observations, in which regimes, in the core, in the pedestal?

- (FY16) Increased understanding of particle transport be considered also to investigate the possibility of developing control schemes for the density profile shape for FY17+ operation.

Recommendations for Macrostability (1)

- Overall, the stability program is in excellent shape (one of the strongest stability programs in the world) with strong links to theory. Well done!

- RWM kinetic damping: Since NBI is main tool for changing fast ion distribution, NBI torque will also vary. PAC suggests the team do modelling of the various mixes of rotation/fast ion profiles that can be achieved at sufficiently high beta and predict RWM damping rates

- Error fields: PAC supports the high priority given to error field correction in FY15. We recommend you utilize different metrics other than delta B minimization for DEFC (e.g., minimize braking etc as used for NCC design) and then utilize the best metric for error field correction routinely. (There is scope to feed into the new rotation profile controller too).

Recommendations for Macrostability (2)

- NTMs: More emphasis should be given to NTM stability in preparation for high-Z wall, esp developing tools to suppress the mode given strong high-Z peaking observed with NTMs in JET. For long pulse with metal walls, this could be an additional driver for the ECH/EBW program

- The NCC would be a valuable tool for NSTX-U for EFC, rotation tailoring, pedestal/ELM control amongst others. PAC agrees with the prioritization with respect to other enhancement projects, i.e., following the cryo pump and gyrotron

- PAC encourages sufficient incremental funding to realize the NCC as soon as possible, noting the risk that beginning work in 2017 for installation and realisation after that may reduce the international impact

Energetic Particle (EP) Research

Overall Goals

1. **Develop predictive/interpretive tools for *AEs and fast ion dynamics, validate against experiments.**
2. **Assess requirements for fast ion phase space engineering through selective excitation/suppression of *AE modes**

FY15 Milestone R15-2:

Assess effects of NBI parameters on fast ion distribution function, NB driven current profile.

FY15 OFES Joint Research Milestone:

Quantify impact of broadened current and pressure profiles on confinement and stability.

FY16 Milestone R16-3:

Assess fast-wave SOL losses and core thermal/fast ion interactions at increased B_t and current.

EP Research: Recommendations (1)

- Raise the priority of physics experiments aimed at understanding ways to control AEs because these experiments would have high impact on ITER and FNSF.
  - NSTX-U team have very interesting results on AE stabilization by mode coupling, HHFW heating and applied 3d fields.
  - These potential control tools should be characterized and modelled with high priority since understanding ways to control AEs would have high impact in the field.
  - The PAC recommends prioritizing control over characterization.

- Measurements of losses with 3d fields are expected in piggy-back experiments.
  - Due consideration should be given to this aspect when planning the experiments, and development of the modelling required to compare to loss detection should be carried out, e.g., tracking particles in 3d fields including plasma response – perhaps via collaborations?

EP Research: Recommendations (2)

- A clear plan for experiments using the antenna in FY15/16 should be developed and presented to the PAC at the next meeting:
  - Having a TAE antenna will be a particularly valuable tool (recognizing that it will take some time to commission).
  - Should identify high value/leverage physics and prioritize.
  - For instance, dedicated experiments looking at the beta-damping of AEs would be very important for ST-FNSF.

NSTX-U RF Research

Goals/milestones:

FY2015 Goal:

Assess antenna performance and characterize field-aligned FW losses in SOL

FY16 Milestone R16-3:

Assess fast-wave SOL losses and core thermal/fast ion interactions at increased B_t and current.

RF research: Recommendations (1)

- Develop additional simulation and diagnostic capability to address SOL losses.
  - Good large computational simulation effort is in place but identification of the waves in the simulation would influence potential antenna modifications.
  - Magnetic probes would be extremely important to experimentally verify the modes potentially responsible for power loss.
- A clear plan for experiments, simulation, and theoretical should be developed to evaluate viable RF scenarios to heat and drive current in NSTX-U and ST-FNSF.
  - NSTX-U team has some examples of good HHFW heating but current drive seems to be lagging.
  - Utilize HHFW in piggyback to evaluate whether power can be coupled in ramp-up
  - HHFW and EBW are possible options. Using simulations, investigate higher harmonic fast waves.
- Develop a plan to evaluate and improve HHFW antenna performance (lower SOL losses) specifically aimed at antenna modification.
  - Current plan is to repeat previous measurements with additional diagnostics.
  - Develop set of modifications to pursue dependent on simulations and experimental data.

RF research: Recommendations (2)

- Develop a set of metrics to allow evaluation of antenna performance and how boronization, Li injection, and other conditions impact antenna performance.
  - The antenna performance seems to be significantly limiting HHFW utilization.
  - A vacuum maximum voltage of 25 kV is too low.
- Target RF simulation validation that is unique to NSTX-U.
  - HHFW interaction with fast ions could be well diagnosed in NSTX-U due the suite of available diagnostics.
  - Comparison to AORSA with a SOL is lower priority.
- Plan for ECH/EBW needs to be better articulated. The presentation at this PAC meeting was not sufficient to evaluate the preparation and plan for the ECH/EBW.
  - Gyrotron is pivotal. The non-inductive ramp-up is critical for the program so identification gyrotron to purchase/borrown is paramount.