October 1, 2002

Dr. Robert J. Goldston, Director
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Subject: Report of the 13th NSTX Program Advisory Committee Meeting, September-October 2002

Dear Rob:

The NSTX Program Advisory Committee (PAC) met at the Princeton Plasma Physics Laboratory on September 31 through October 1, 2002 (agenda attached). Our activities at this thirteenth meeting of the PAC focused on two areas in response to your charge to the committee (copy attached): (1) to comment on the FY 2003—2004 NSTX research plan; and (2) to advise the on NSTX 5-year research plan.

The PAC commends the NSTX team on the many exciting results which they have achieved since our last meeting. This includes new facility and diagnostic capabilities — heat flux profiles at the divertor plates, edge profiles from probes, CHERS, improved Thomson time/space resolution — and on achieving higher β — a maximum of β_T of 34% with β_T of 17% in sustained discharges (this volume average translates to >75% central beta), $\beta_N/l_i \approx 10$, and diamagnetic plasma (which is the reactor scenario). In addition the NSTX team has doubled the plasma's stored energy (to 400 kJ) and achieved a higher plasma current (up to 1.5 MA). We commend the NSTX management on their selection of strong Experimental Task Force leaders and the recent additions to the scientific leadership. Finally, the PAC notes the greatly improved NSTX web site (nstx.pppl.gov).

Comments on the ST Theory Report

At the PAC-11 meeting last year, in commenting on the ST Theory Panel report, the PAC requested that the new ST Theory Coordinator (Dr. Manickam) present a report at a subsequent PAC meeting. He did so at this meeting, describing theory work that had been presented at the recent Results Review Meeting.

One of the comments last year was that ST theory coverage was inadequate. Judging from Manickam's report, this situation seems to have improved. NSTX is to be congratulated for this development. Much of the theory work that he described seems to be work still in progress; we look forward to seeing further results.

The PAC comments of last year also asked programmatic questions about prioritization and categorization of theory issues, integration of effort, student involvement, SciDAC linkage, etc. Manickam did not specifically address these questions in his report, but later during the meeting he submitted an informative written response which is included as an appendix (attached).

Charge #1 — The FY '03 NSTX Research Plan

Do the FY03 research goals and facility plans take advantage of the FY02 progress and the opportunity for increased run time? Do they address the IPPA 5-year objectives for the ST in an appropriate manner?

Our first charge was to comment on the FY '03 NSTX Research plan. We begin by commending both the NSTX program management on their thorough preparation of an experimental plan which included both plans for a full 21 run-weeks and reduced runtime scenarios (see viewgraph 44 in Stan Kaye's presentation). The PAC joins the NSTX management in the hope that that funding will be available for a full 21 run-week NSTX experimental program in FY '03. However, the reduced runtime scenarios illuminate the proposed research priorities and were the focus of our deliberations. The PAC noted with approval the high priority given to sustaining high-β and high τ_E simultaneously for times long compared to the energy confinement time, and for using non-inductive current drive to assist in startup and sustainment of pulses for more than 1 second. The first of these milestones demonstrates the advantage of the ST configuration over conventional tokamaks, while the second address the key feasibility issue — how to drive current without a solenoid — for ST reactors. It is the opinion of the PAC that the best way to sustain $\beta\tau_E$ for long times is to address "interactions among resonant error field response, correction fields, and rotation". Hence, the PAC was puzzled by the proposal to delay this milestone by one year in the reduced funding scenario.

Both of these high-priority milestones will benefit from measurements of the current profile via the motional Stark effect, where the emitted light is a result of either collisionally induced florescence (CIF) or laser induced florescence (LIF). The PAC believes that CIF data is critical for '03 program. Current profile measurements using CIF in '03 will determine q(0) (a big swing item in equilibrium reconstruction and, hence, comparisons between NSTX experimental results and MHD stability theory) and will be important for analysis of HHFW CD experiments. Since CIF addresses immediate problem the need for an LIF system was discussed. The PAC concluded that the LIF system is necessary to resolve ambiguity between B_p and E_r. and to make local measurements of |B| (which translates into measurements of the pressure gradient). These measurements are important for both accurate equilibrium reconstruction and for understanding core turbulence.

The PAC discussed each of the six research areas (Heating and Current Drive, CHI, Transport, MHD, Integrated Scenario Development, and Boundary Physics) with the following recommendations:

1.1) Heating and Current Drive.

The highest priority of the HHFW program for FY03 is to increase the reliability with which power is coupled to NSTX plasmas. Improvement of HHFW system reliability requires both antenna diagnostics and modifications. In the last maintenance period the antenna feedthroughs and the boron nitride plates at the front of the antenna were modified to improve the reliability of coupling of HHFW to the plasma. Diagnostics aimed at quantifying the effect of these modifications (and characterizing this more precisely than just observing what voltage/power can be achieved) should be added at the earliest possible opportunity. The HHFW heating efficiency has not been very reproducible. An improvement in the understanding of HHFW coupling is needed to provide confidence in future antenna modifications and in the design of HHFW launchers for new facilities.

The NSTX program has begun serious consideration of an electron Bernstein wave (EBW) heating system. MAST is trying EBW, and will soon have results on heating. NSTX should watch, and learn from these results. The main effort in FY ’03 on NSTX in support of EBW is measurements of EBW emission. These measurements will help in determining the proper frequency for the EBW heating system. The PAC notes that NSTX may want to operate at a magnetic field of 4.5 kG, which would also affect the EBW frequency. Definition of the EBW system frequency may drive a need for tube development, so it is important to do the emission measurements in '03. NSTX has the appropriate detector. It is important that the needed run time is made available.

1.2) Co-Axial Helicity Injection

The HIT-II experimental results relative to co-axial helicity injection (CHI) are very encouraging. In HIT-II a CHI-initiated plasma was coupled to OH to achieve a 140 kA discharge. In this coupled discharge the CHI adds 40 kA to discharge relative to what is achieved in HIT-II with OH alone. Finally, the HIT-II CHI current persisted after CHI was turned off.

The NSTX CHI system has been recently been modified to address problems with absorber arcs by installing an improved insulator and an additional coil to improve the poloidal field null within the absorber gap. The PAC is looking forward to hearing results from this improved system at our next meeting.

Gas and impurity problems have also been addressed. The neutral density in NSTX CHI plasmas is now similar to that of OH plasmas. While HIT-II did not see major difference in impurities between CHI and ohmic plasmas, the role of impurities in CHI-initiated discharges in NSTX still needs to be assessed.

The theory support and analysis tools are now greatly improved. This includes results from a version of EFIT with current on open field lines, ESC, and TSC. The PAC trusts that these codes will be routinely used for analyzing CHI experiments in the future. Additional theoretical support should include exercising M3D (as modified by Tang) for exploring reconnection mechanisms, and comparisons with NIMROD, which is used in analysis of reconnection on spheromak and RFP experiments at other institutions. PPPL should identify a person to work with Sovinic to apply NIMROD to the modeling of CHI experiments on NSTX.

The PAC encourages continuation of a well-coordinated theory effort on this challenging problem. In addition, the PAC encourages T_e measurements of CHI plasmas since T_e peaking is clear signature of closed flux surfaces, and the PAC looks forward to experiments in which RF current drive (and heating) are applied immediately to CHI-initiated plasmas (could this be included in the FY '03 run plan?). Finally, the PAC continues to encourage a strong commitment to the development and evaluation of CHI as a means of initiating and sustaining the plasma current in NSTX.

1.3) MHD

There has been great progress to data: β_T of 34%, β_T of 17% in a sustained discharge (and we note that this volume average translates to a central β greater than75%). $\beta_N/l_i \approx 10$, and the demonstration of diamagnetic plasmas (which is the reactor scenario).

Regarding the FY ’03 experimental plan, the PAC notes that NSTX has installed sensors for resistive wall mode (RWM) detection and mode control studies. However, NSTX is up against the β-limit now, and the FY ’03 experimental plan is not focused on doing better. It will be 2 years before active feedback is really working. Further delay is undesirable even on reduced budget scenario. Midplane error-field correction and control coils outside vessel could be installed during the run, if it is determined that such coils will be adequate for RWM control. While power supply requirements still need to be defined, the PAC believes that the NSTX project should proceed expeditiously with the addition of control coils (Columbia University will supply the design). While this is a budget issue in reduced funding scenario, the PAC believes that since NSTX has already installed sensors, they should go ahead with the active coils as soon as possible.

1.4) Transport and Turbulence

There has been substantial progress in the area of transport and turbulence. The PAC was pleased to see progress toward ST confinement law, measurements of T_e, and n_e with Thomson scattering, measurements of T_i with charge exchange recombination spectroscopy (CHERS), and measurements of core density fluctuations with the UCLA reflectometer (providing information about both frequency spectra and radial correlation lengths).

The PAC looks forward to the first data from the high-k scattering diagnostic (expected in FY ’03) and the imaging reflectometer (which we hope to see in ’04). It is important that kinetic TRANSP analysis of NSTX shots becomes routinely available, as this will enable coupling between the NSTX experiment and the broader core transport and turbulence community.

1.5) Boundary Physics

The PAC was pleased to see measurements of the heat-flux on the NSTX divertor plates, and looks forward to data with better radial resolution which is in prospect for the '03 experimental campaign. The PAC was encouraged by initial measurements of the edge density and temperature profiles. However, further improvements to the edge profile diagnostics are required to make contact with the edge transport and turbulence community. Thomson scattering does not yet provide enough channels across the H-mode pedestal to really resolve the density and temperature pedestal. The reflectometer is able to resolve the H-mode density pedestal. However, large density fluctuations make measurements of the edge density profiles in L-mode problematic. The reciprocating probe gives both n_e and T_e with good spatial resolution. However, the failure of the electron temperature to rise as this probe crossed the (attributed?) separatrix location raises questions about the equilibrium reconstruction in the data shown to the PAC. The PAC appreciates the many demands on the NSTX diagnostic systems and the limited number of channels for both the Thomson scattering and CHERS systems. We encourage the NSTX team to increase the edge resolution when the Thomson scattering system is expanded to 30 channels (in ’04) and when the CHERS system is expanded to 51 channels, and we look forward to routine availability of edge profile data from NSTX shots.

1.6) Integrated Scenario Development

The PAC approves of the emphasis that this thrust area has placed on achieving a higher product of $\beta\tau_E$. In defining this measure of performance we note that the poloidal field is comparable to the toroidal field in spherical tokamaks. As a result a more appropriate measure of the plasma pressure for comparison to other tokamaks is $\beta=p/\langle B_T^2+B_P^2\rangle$ (rather than $\beta_T=p/\langle B_T^2\rangle$), and we encourage the NSTX team to report their results using β defined with the total magnetic field. With regard to increasing β — the PAC believes that the most promising means of increasing β is through a combination of the use of active coils (for resistive wall mode stabilization), and increasing the plasma elongation (to broaden the pressure profile and lower l_i). The PAC also notes the surprising result that H-mode transitions in NSTX do not always result in an increase in the energy confinement time. Clearly, there is much left to be understood about energy confinement in STs, and we encourage the NSTX team in their studies.

Charge # 2 — The NSTX 5-year Plan

Our second charge was to advise you on the (draft) NSTX 5-year research plan which is to be reviewed in June 2003.

> *Are the key elements of the NSTX 5-year research goals, diagnostic upgrade, physics analysis, and facility upgrades appropriate in addressing the IPPA 10-year objectives for the ST, taking into account the possible future development path for ST’s?*

Ed Synakowski did an excellent job in presenting the (draft) NSTX 5-year research plan. The PAC believes that a decision by the DoE to fund the NSTX 5-year research plan will be largely motivated by the contribution which ST's can make as a fusion energy concept, by the potential the ST configuration shows as the basis for a Component Test Facility, and as an experimental platform for obtaining a deeper understanding of the physics of toroidal plasmas. In the worst case (that is, all we get is "deeper understanding" of toroidal plasma physics) the proposed NSTX 5-year experimental program is a good investment. In the better cases (that it leads to an ST power reactor or an ST-based Component Test Facility) it is a great investment. These potential contributions of the ST to the world fusion program serve to motivate the choice of research priorities.

The emphasis in this 5-year plan on increasing $\beta\tau_E$ builds appropriately on the strength of ST configuration. The PAC also approves of the plan to do current ramp-up to high β_P by '06. It is appropriate to emphasize research on this potential show-stopper for the development of the ST as an energy source or a Component Test Facility.

NSTX has become a mature experimental facility and, over the period covered by this 5-year plan, NSTX will be a major experimental facility within the US program. As such, it is important that the 5-year plan address the "nuts and bolts" aspects of expanding the interactions between NSTX and the larger community. This includes such things as routine kinetic TRANSP analysis of NSTX shots (basic to any interactions with the transport and turbulence communities), improved resolution of the plasma edge (basic to interactions with the plasma boundary and edge turbulence communities), and generally insuring the routine availability of "blessed" NSTX data. The plan should also address the theory needs for the next 5 years. For example, co-axial helicity injection is a particularly complex problem, which would benefit from a concerted theoretical investigation. Theory can provide valuable support for steady-state ST operating scenarios and techniques for current ramp-up without solenoid. Electron Bernstein wave heating and current drive, which involves delicate tradeoff between launch angle and experimental profiles, might benefit from further modeling efforts. Finally, the PAC was intrigued by the possibilities of the proposed lithium module, and would like to hear more about it at a future meeting.

The PAC thanks the PPPL management and the NSTX program for their hospitality and looks forward to the next PAC meeting, to be held at PPPL in January of 2003.

Sincerely yours,

William M. Nevins, Chairman
for the NSTX Program
Advisory Committee

National Spherical Torus Experiment
Program Advisory Committee
13th Meeting

Agenda

Princeton Plasma Physics Laboratory
Conference Room LSB-318
September 30 – October 1, 2002

Monday, September 30, 2002

8:30	Coffee & Donuts	
8:50	Goldston	Welcome and Charge to the PAC
9:00	PAC Executive Session	
9:15	Priester	Comments from DOE
9:20	Nevins	Agenda
9:25	Manickam	ST Theory Results and Plans
9:55	Peng	NSTX Organization & Action Items

I. FY02-03

10:05	Coffee Break	
10:15	M. Bell	FY02 Experimental Results Break
12:00	Lunch and PAC Caucus	
1:00	Kaye	FY03 Experimental Plan
2:45	Coffee Break	
2:55	Levinton	MSE CIF and LIF plan
3:35	PAC Caucus	
6:00	Adjourn	
6:30	PAC Party at the home of Rich and Mary Katherine Hawryluk	

Tuesday, October 1, 2002

8:30	Coffee & Donuts	

II. Five-Year Plan

8:45	Synakowski	Research Elements of Five-Year Plan
10:00		10 minute Coffee Break
10:55	PAC Caucus	
12:00	Lunch during Caucus	
2:30	Nevins	Briefing for PPPL Director
3:00	Adjourn	

National Spherical Torus Experiment
Program Advisory Committee
13th Meeting

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CHARGE

The NSTX Program and Project achieved better than expected progress during FY02 relative to key research milestones, which are guided by the IPPA 5-year objectives for the ST. Also, the President has requested additional support from Congress for operating the large facilities, providing an opportunity for advancing our research program, if Congress appropriates the funds. This progress and opportunity for increased operation has impacted the planning of the FY03 research campaign and the development of the NSTX 5-year plan. I therefore ask the PAC to advise me on the following questions:

1) Do the FY03 research goals and facility plans take advantage of the FY02 progress and the opportunity for increased run time? Do they address the IPPA 5-year objectives for the ST in an appropriate manner?

The NSTX Team has started to develop a draft 5-year plan, the formal review of which is scheduled for June 2003. This plan should address the IPPA 10-year objectives for the ST. Though the details of the 5-year plan remain to be developed, I ask the PAC to advise me on the direction the plan is taking:

2) Are the key elements of the NSTX 5-year research goals, diagnostic upgrade, physics analysis, and facility upgrades appropriate in addressing the IPPA 10-year objectives for the ST, taking into account the possible future development path for ST's?

Input requested by Jim VanDam on actions taken in response to PAC's recommendations

Prioritization and Outreach

This is difficult, as we do not have significant funding to direct towards specific work areas. We rely to a fair extent on the interest we can generate in the topical areas. Non-inductive CD is a top priority, and we have many people working on RF modeling and CHI, more than in other topical areas. Several groups are working on Boundary Physics, even though we would not have indicated that to be highest priority.

We have made several efforts at educating the community about the interesting problems in ST physics and emphasized our priorities in these talk, S,. Kaye at Sherwood, J. Manickam at the International Varenna-Lausanne Fusion Theory Workshop. We have received positive feedback from such efforts. A couple of examples are the work of Betti's group and F. Jenko's interest in looking at NSTX data.

Generic vs. Specific issues

Major studies relating to flow in MHD codes, finite beta and scale-length issues in turbulence studies, revisiting neo-classical transport theory are underway. It is premature to identify any single significant new level of understanding.

Existing vs new theory tools

We have made some inroads here with new tools, e.g. incorporating flow in equilibrium calculations, first principles study of CHI, additional neoclassical development, the development of HYM which will lead to non-linear calculations of AE stability. Helped to fund improvements to the treatment of RWMs in VALEN. Need to do more with non-linear micro-instability calculations. Existing tools are being used more routinely; e.g. the RF codes are being integrated into TRANSP.

Consolidation of personnel (chunks)

Manickam's fraction raised from 0.25 to 0.40 . There is still a difficulty in allocating big chunks for individuals partly because of funding limitations and because of their previous commitments. On the other hand, we are getting more than our share out of theorists who have become interested in a subject (e.g. White, Park, Gorelenkov).

We still recognize the importance of having larger chunks of those who are doing longer-term development work to make them more responsive to our needs.

Integration (Manickam)

Manickam has been recognized in the lab organizational chart and has become a member of the Theory Steering Committee to promote ST related studies

Student involvement

Rosenberg is doing thesis work on fast ion/RF interactions at PPPL, Guazzotto at UR, Betti's student, is working on rotation effects on equilibrium and stability. He will work with PPPL to modify the NOVA code to include rotation. Zhao from Columbia is working on rotation damping physics in RWM plasmas, specific run time allocated.

SCIDAC linkage

The RF SciDac met recently to assess the state of their modeling work. Fundamental assumptions in the models are being reviewed. As the codes reach maturity the ST program will take advantage of their success.

The Fusion Collaboratory is another likely resource which needs to be explored.

<u>White paper - where it went ? update ?</u>

White paper was distributed to the National Theory Steering Committee.

We will be reviewing the status of theory and modeling efforts to identify areas which might need additional resources. Update from the Results Review and Theory Forum.