Eighth Report of the National Compact Stellarator Experiment
Program Advisory Committee
November 14, 2006

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The National Compact Stellarator Experiment (NCSX) Program Advisory Committee (PAC) met on November 9-10, 2006 to advise the Director of the Princeton Plasma Physics Laboratory, Robert Goldston, on several items (Charge appended): the research goals and plans for the first NCSX experimental campaigns (FY09 and FY11), plans for the first NCSX research forum in December, a plan to operate NCSX every other year alternating with NSTX, and the relevance of the NCSX research plan to the Aries-CS identified R&D needs. The Committee was additionally asked to comment on a potential modification to the definition of CD-4 (MIE project completion). After an introduction and overall update of the project by Hutch Neilson and an overview of the Aries-CS study by Jim Lyon, Mike Zarnstorff presented the proposed Research Plans. This was followed by detailed presentations on the specific preparations for electron-beam mapping of the magnetic structure, transport studies, edge physics studies, and general diagnostics preparation.

The Committee wants to commend the Project for the significant progress in the fabrication of the NCSX device. All components for the vacuum vessel are on site and in preparation for assembly. Six of the eighteen modular coils have been completed through the epoxy impregnation stage, all of the modular coil winding forms have been cast, and production is moving at an acceptable pace to meet the CD-4 target date. Contracts are in place for fabrication of the toroidal field coils and potential difficulties in device assembly are being addressed through R&D work at the laboratory and through an external peer review of the project's assembly plans.

The NCSX research mission is important for the advancement of the compact stellarator concept and the understanding of 3D plasma physics for MFE. The exciting goals that were presented for the FY09 and FY11 experimental campaigns, if realized, will make significant progress toward accomplishing key goals of the U.S. compact stellarator program.

The PAC noted that the Project has not updated the Recommendations Log from PAC-7 (although many of these have been addressed). The PAC recommends updating of this document.

FY09 Program Goals and Redefinition of CD-4

The key objective in the FY09 period is completion of the MIE project with CD-4 and the electron beam mapping of the attained magnetic field structure. The present definition of CD-4 is production of a plasma by an ohmic current at 25 kA in a field produced by the modular coils of B=0.5 T. The project has asked the committee for advice on alternate methods (specifically ECH-produced plasmas) to confirm that the Project has completed device fabrication. It is the committee's opinion that formation of the first plasma by other means, including ECH, is a reasonable modification of the CD-4 goal. It is up to the project in consultation with DoE to define what these reasonable parameters might be, or other mutually agreed upon means for producing this first demonstration plasma for project completion.

The 28 GHz ECH option presented involved the use of existing operating equipment available at ORNL. The project should be careful of the needs and costs of installing and interfacing this system to NCSX, to be sure cost savings by this method over installation of PF-4 can be realized. The project's plans for production of the first plasma must ensure with a high level of confidence that the CD-4 goal is met.

The production of the first plasma, coupled with electron beam mapping of the base configuration, is defined as completion of the device. The purpose of mapping is to identify deviations of measured field line puncture plots from the predicted ones to arrive at a best estimate of a new coil model. This will be used as a basis for equilibrium modeling, and may help in future decisions on where to place trim coils. Additional methods, such as the mutual inductance method should be pursued as an additional check of the coil locations. In operation, NCSX has considerable flexibility in magnetic configuration through variation of currents in the modular coil types and PF coil types. A nomenclature should be developed prior to extended experimental campaigns to clearly identify machine operating modes.

If NCSX can use power supplies to provide continuous operation at low field (~0.05 – 0.1 T), most survey-type field mapping can be carried out much faster, with either wand or screen method. The wand might be preferable due to permission of larger number of toroidal transits with less beam scattering. Also, though not in the definition of completion of the project, the mapping capability should be continued as needed into later terms in the project as new PF coils & trim coils are added in preparation for FY11 operation. Additionally, numerous combinations of independent coil currents are envisioned for flexibility, and mapping could isolate potential problems in these configurations.

The Auburn group is trying to invert beam mapping data from CTH to indicate which coils are likely to be responsible for the observed deviation from predictions should they be observed. They are finding that mapping at the same symmetry plane in two different field periods gives a very good basis for comparison, particularly for poloidal coils and

low-order shifts. Experiments in HSX showed this method was also helpful in determining symmetry breaking terms in the magnetic field spectrum. The committee strongly suggests that NCSX hold open the option to map in two different field periods

FY 11 Program Plans

In response to the PAC's query about the FY11 research plan, the NCSX team has prepared a clear list of goals with realistic priorities accompanied by a table showing the relationship of specific heating and diagnostics systems to physics areas. The team is to be commended for this research plan and for the choice and prioritization of the appropriate diagnostics. A vertical Thomson laser beam arrangement as proposed may impact profile measurements in configurations with a shifted axis position. If necessary, an alternate arrangement should be considered. Additionally, while a SX-multicamera system may not be affordable in the FY11 timeframe, the project should consider a single camera with more than 20 channels which could be implemented in a cost-effective manner. The PAC also suggests that beginning the assessment of the role of the stellarator field in suppressing disruptions be considered in the list of highest priority goals as early in the program as practicable.

The consensus of the PAC is that the complete OH (PF1, PF2 and PF3)/shaping coil (PF3, PF4 and the other poloidal field coils) set be installed for FY11 operations. The PAC also remarks that if resource limitations dictate an early choice between installation of the complete OH (PF1, PF2, PF3) and an increase of ECH power (to 600 kW at 70 GHz), that this decision be taken in light of its impact on the stated FY11 goals in confinement and stability studies and the assessment of divertor/SOL characteristics for activities which impact planning for FY13 operation. The project's top three "level one goals" for FY11 include the investigation of "the effect of 3D equilibrium on SOL characteristics and contact footprint." The PAC is concerned that not having the full set of PF coils operational in FY11 could impact operational flexibility and potentially compromise this element of the research plan. The PAC recommends that the NCSX team assess the impact of the loss of the OH coils on the shape flexibility and accessible divertor configurations before a decision is made exchanging this coil set for the 600 kW ECH option. Additionally, if PF4 is deferred due to redefinition of CD-4, program planning must ensure this coil is available for FY11 operation if it plays a major role in plasma shaping.

Research forum plans

NCSX will hold its first Research Forum on December 7-8, 2006. PPPL has considerable experience in running such forums. The Committee feels it is essential to make clear to the participants the scheduling of the potential collaboration activities relative to the planned NCSX physics program. Specifically, it should be clear which elements will be done in-house, when funds might become available and also how and when collaborators should propose these activities (e.g. through subcontracts with PPPL or through the field work proposal process). Collaborations should factor in the alternate year operation of NSTX and NCSX discussed below.

Alternate year operation with NSTX

The PAC commends the PPPL/ORNL team for developing an alternating run-year research plan for NCSX and NSTX as a creative way forward in spite of highly constrained funding. Having a dedicated team investigate toroidal physics in two novel magnetic configurations side-by-side – hopefully using a common set of analysis and theory tools – should provide new physics insight into both devices. 3D magnetic field effects (error fields, islands, locked modes), neoclassical viscosity, confinement, stability, and disruption physics are obvious examples of scientific overlap that can be investigated with significant overlap and synergy.

However, the PAC does note several potential draw-backs to the alternating run year plan. First, there is the potential for large management overhead to effectively organize the run schedules, data analysis, conference attendance, and publications of results from the two devices. Further, the multi-machine and/or sharing of diagnostics has the potential to (further) create two classes of people – those responsible for moving and operating diagnostics, their calibration, and run support, and those who will analyze and publish the data and results from both machines. Management is advised to make the responsibility of dual-machine support as fair as possible, while balancing this against the need to make sure good experiments, data analysis, and publications are produced by both devices.

There is significant concern about the impact of NSTX/NCSX alternating run-years; in particular on the first full research year of NCSX, FY11. For instance, any significant delay in implementation of a crucial diagnostic needed to achieve the highest priority research goals in FY11 could cross machine-year boundaries and effectively delay the research program by 2 years. Contingency plans for the schedule and diagnostic implementation are needed in anticipation of delays. For example, for measuring the impact of increased effective ripple on rotation and transport, alternative (potentially simpler) diagnostics should be considered for measuring rotation. Can x-ray crystal spectroscopy, Mach probes and/or edge spectroscopy (like NSTX's Edge Rotation Diagnostic) be exploited should the CER and/or the DNB be delayed?

Also, FY10-11 is a unique and crucial time in the ramp-up of NCSX capabilities needed to carry out the FY11 campaign. It is important that the NCSX funding profile be supported at least at the levels presented to the Committee. Operational flexibility between machines during this ramp-up phase could prove to be very important, and contingency plans for schedule slippage should be developed to not adversely impact both devices. The project should explore with DoE possible variations to the strictly alternating schedule and the possibility of some additional funding in FY10 to facilitate the physics startup of NCSX while maintaining operation of NSTX. Additionally, there is a projected increase of ~$12M for joint operations between FY08 and FY12 in the plan presented, although the Five-Year SC budget plan provides only inflationary increases over this period for non-ITER program elements. Contingency planning should factor in impacts of various possible budget levels.

Finally, questions were also raised about how many new researchers can be expected to participate in NCSX. Up to 12 new scientific positions (by FY11 or later) could become available beyond the NSTX National Team as per budget estimates presented to the Committee. The PAC recommends that these positions be used to broaden the NCSX research program to the extent possible. The Committee notes and commends that hiring and hiring plans at both PPPL and ORNL are including younger scientists with stellarator experience.

Aries-CS Identified Research Topics and Theory

NCSX research can address many of the Aries-CS identified R & D topics and support the development of the stellarator configuration. NCSX should have a broad impact on the overall fusion program including tokamaks and ITER. The NCSX project should be complimented on the definition of its experimental program to support these issues.

The NCSX experimental contributions depend essentially on a strong theory/computation program. The NCSX Team has identified its specific needs for analysis tools and theory development as outlined in the PPPL Theory 5-Year Plan presented. The PPPL and ORNL team members could together exploit the natural synergies that exist in the theory/computation efforts on the NCSX and NSTX experimental programs. Additional efforts must continue to engage theory and computational activities from those relevant but not presently active in these programs and to encourage DoE support of this research.

This recommendation is an extension of the July 2004 Pac recommendation: "Secure adequate theoretical and computation support in the near term for developing the specific NCSX experimental plans and activities. Consider the methods to provide DoE guidance on theory and modeling needs of the NCSX project."

Recommendations

- Update the Recommendation Log from PAC-7
- Ensure that first plasma for CD-4 can be achieved with a high level of confidence
- Ensure beam-mapping capability through all coil upgrades of the device; strongly suggest multiple toroidal locations
- Investigate alternate designs of the Thomson system which would permit full profiles with variation in magnetic axis position.
- Assess the impact on shaping and SOL studies in FY11 of the loss of the ohmic system (PF1,2,3) before making a decision on 600 kW 70 GHz ECH
- Ensure that PF-4 is available for FY11 operation if it plays a major role in plasma shaping/SOL structure
- Develop contingency and opportunity plans for joint NSTX/NCSX operation in the event of delays and/or funding profile changes
- Continue efforts to broaden participation of theory and computational efforts in 3-D fusion science