NSTX Program Letter
on Research Collaboration by National Laboratories
for FY 2007-2009

Introduction

This NSTX Program Letter provides updated information about NSTX topical research priorities and collaboration opportunities during the upcoming three years (FY 2007-2009). This information is useful for the preparation of proposals from national laboratories in response to the Office of Science Notice *Fusion Research on National Spherical Torus Experiment*, which will be issued in early August 2006. Researchers from national laboratories have carried out about one-third of the collaborative research on NSTX. This Program Letter suggests specific collaboration opportunities, as well as broader areas of research, in order to encourage proposals that address the research areas on NSTX. These research areas were described in the NSTX Five-Year Plan[1] and the FESAC Facilities Report[2] last year. In the Appendix to this Letter, these areas are cross-referenced to the ten-year goals in the FESAC Priorities Report as additional background information.

The NSTX Program Advisory Committee reviewed this Program Letter on July 18, 2006. Its advice was incorporated in the final version.[3]

NSTX Mission

The *programmatic* mission of NSTX is to evaluate the attractiveness of a compact Spherical Torus (ST) configuration—such as a Component Test Facility[4] (CTF)—in reducing cost, risk, and development time for practical fusion energy; to contribute to the physics basis for an ST-based DEMO device; and to use the special properties of NSTX in order to resolve key burning plasma physics issues anticipated in ITER. The NSTX programmatic mission thus addresses two of the long-term goals of the Office of Fusion Energy Sciences: viz., configuration optimization, and developing a predictive capability for burning plasmas. Both ITER participation and also CTF development are included in the DOE 20-year strategic plan for the Fusion Energy Sciences Program.[5]

In support of the above programmatic mission, the *scientific* mission of NSTX is to advance fusion plasma science by understanding the special physics principles of the Spherical Torus (ST). Due to its low aspect ratio, the ST is characterized by strong magnetic field curvature and by high β_T (the ratio of the average plasma pressure to the applied toroidal magnetic field pressure). The ST, with its unique properties, thus extends and complements the normal aspect

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[1] http://nstx.pppl.gov/Pages_folder/research_folder/5YrPlan.html.

[2] http://www.ofes.fusion.doe.gov/more_html/FESAC/FacilitiesVol1.doc and http://www.ofes.fusion.doe.gov/more_html/FESAC/FacilitiesVolume2_v3.pdf.

[3] http://nstx.pppl.gov/nstx/NSTX_Program_Letter (available August 4, 2006).

[4] Recent information on the concept of compact CTF is available in Peng et al., IEEJ Transaction **125** (2005) 1 and Peng et al, Plasma Phys. Control. Fusion **47** (2005) B263. CTF plasmas are expected to be similar in nature to ITER driven steady-state plasmas, for which $f_{BS} \sim 0.5$ and $\beta_N \sim 0.5\ \beta_{Nlimit}$.

[5] http://www.sc.doe.gov/bes/archives/plans/SCSP_12FEB04.pdf.

ratio, lower β_T tokamak in addressing the overarching scientific issues in magnetic fusion energy science.

NSTX Research Priorities and Key Collaboration Opportunities for FY 2007-2009

This section briefly lists the research topics of high priority in the NSTX Program during FY 2007-2009 and then highlights key collaboration opportunities for which collaborative research proposals are solicited. The NSTX priorities and collaboration opportunities are organized according to the six categories used in the FESAC Priorities Plan. For each category a key person is listed, who may be contacted for further information.

The list of research priorities is guided by the NSTX programmatic and scientific missions and by its schedule of milestones, subject to anticipated funding during FY 2007-2009. The key collaboration opportunities highlighted below were determined on the basis of several factors: what the NSTX Program considers to be necessary; what it thinks could be contributed by other national laboratories; and what is currently being carried out through diagnostic grants and university/industry grants and by the PPPL team. Proposals for innovative collaboration activities beyond the ones listed in this Program Letter are also welcomed; such proposals might be motivated by the list in Appendix A. All proposals will be considered by means of the normal DOE peer review process, according to the criteria described in the solicitation announcement.

I. ***Macroscopic Plasma Physics*** – the role of magnetic structure in plasma confinement and the limits to plasma pressure in sustained magnetic configurations.

Contact: Jon Menard (jmenard@pppl.gov)

I-1. *Characterize the effectiveness of closed-loop Resistive Wall Mode (RWM) control and the dependence on rotation with the use of ITER-like control coils.*

I-2. *Characterize the stability of shaped, toroidally rotating plasmas above the "no-wall" pressure limits with error field correction relevant to CTF.*

I-3. *Characterize modes that tear magnetic field surfaces and limit plasma pressure and energy confinement as the plasma pressure increases above the "no-wall" limit.*

Key Collaboration Opportunities:

- Tearing mode mitigation and control.

II. ***Multi-Scale Plasma Physics*** – physical processes that govern the confinement of heat, momentum, and particles in plasmas.

Contact: Stan Kaye (skaye@pppl.gov)

II-1. *Study local high-k turbulence (i.e., with scale lengths perpendicular to the magnetic field smaller than the local thermal ion gyro-radius) when plasma conditions are varied.*

II-2. *Characterize the relationship between local high-k turbulence and electron heat transport.*

II-3. *Measure poloidal rotation and determine radial electric field shear at low aspect ratio and compare with theory for low-k turbulence suppression and transport barrier formation.*

II-4. *Characterize plasma rotation and momentum transport in sustained high-beta plasmas relevant to ITER and CTF.*

Key Collaboration Opportunities:

- Extension of neoclassical framework to low aspect ratio, large gyroradius, high rotation shear regimes.
- Measurement and analysis of turbulence from ion to electron gyro-scales.

III. *Plasma Boundary Interfaces* – the interface between fusion plasma and its lower temperature plasma-facing material surroundings.

Contact: Bob Kaita (rkaita@pppl.gov)

III-1. *Characterize the effects of lithium wall coating on recycling and particle control.*

III-2. *Characterize the edge/divertor at low plasma collisionality with ITER-level heat fluxes and relevance to CTF.*

III-3. *Assess the requirements of edge heat and particle control with ITER-level heat fluxes and relevance to CTF, for time scales beyond the current redistribution times.*

Key Collaboration Opportunities:

- ELM control and mitigation.
- H-mode access and pedestal optimization.
- Advanced techniques for power handling and recycling control, particularly with the use of lithium to pump particles and modify the scrape-off layer, including supporting modeling.
- Advanced techniques for core fueling.
- Two- and three-dimensional plasma boundary physics modeling, including turbulent transport and intermittency.

IV. *Waves and Energetic Particles* – the use of waves and energetic particles to sustain and control high-temperature plasmas.

Contact: Gary Taylor (gtaylor@pppl.gov)

IV-1. *Measure, identify, and characterize instabilities driven by super-Alfvénic ions.*

IV-2. *Characterize the transport of supra-Alfvénic fast ions due to fast-ion driven oscillations relevant to ITER and CTF.*

IV-3. *Characterize the physics of interaction between the edge plasma region and the externally launched fast plasma waves at high ion cyclotron harmonic frequencies (n=10-15) to determine conditions that enable effective heating and current drive.*

IV-4. *Characterize the physics of mode conversion between electron Bernstein waves in the over-dense plasma and externally propagating electromagnetic waves, to determine conditions for heating and current drive in over-dense plasmas.*

Key Collaboration Opportunities:

- Experimental and/or theoretical characterization of wave-plasma interactions near the plasma edge during high-harmonic fast wave injection.
- High-harmonic fast wave core propagation and absorption, heating, and current drive efficiency.
- Experimental and/or theoretical studies of electron Bernstein wave coupling, mode conversion, propagation, heating, and current drive.
- Measurements of the fast ion distribution and transport in phase space.
- Hardware development and scoping studies for high-harmonic fast waves and electron Bernstein waves.

V. *Start-up, Ramp-up and Sustainment without Solenoid* – the physical processes of magnetic flux generation and sustainment.

Contact: Mike Bell (mbell@pppl.gov)

V-1. *Characterize the operating conditions that allow transition from Coaxial Helicity Injection plasmas to standard inductively and non-inductively sustained toroidal plasmas.*

V-2. *Characterize conditions for solenoid-free ramp-up to substantial plasma currents via heating and current drive by neutral beam injection and high harmonic fast wave.*

Key Collaboration Opportunities:

- Innovative start-up, ramp-up, and sustainment techniques via high-harmonic fast waves, electron Bernstein waves, and neutral beam injection, including electron heating of plasmas produced by coaxial helicity injection.
- Control and modeling of plasmas produced by coaxial helicity injection.

VI. *Physics Integration* – the physics synergy of external control and self-organization of the plasma.

Contact: Dave Gates (dgates@pppl.gov)

VI-1. *Characterize the evolution of long-pulse plasmas in high-beta, high-bootstrap-fraction, sustained conditions relevant to CTF and advanced operations in ITER, and how these plasmas could be achieved through a variety of tools, with integration of physics issues in categories I-V.*

Key Collaboration Opportunities:

- Advanced scenario and modeling development, including experimental verification, from start-up to the high-beta phase.

Appendix: FESAC Priorities Panel 10-Year Goals	Relevant NSTX Research
Macroscopic Plasma Physics	
1. Understand the coupled dependencies of plasma shape, edge topology, and size on confinement in a range of plasma confinement configurations.	1. I-1, 2
2. Identify the mechanisms whereby internal magnetic structure controls plasma confinement.	2. I-3
3. Identify the effects and consequences on confinement of large self-generated plasma current.	3. VI-1
4. Learn how to control the long scale-length instabilities that limit plasma pressure.	4. I-1, 2
5. Understand and control intermediate to short wavelength modes responsible for limiting the plasma pressure, particularly at the edge, and extrapolate their effects to the burning plasma regime.	5. III-2
6. Understand the equilibrium pressure limits in a range of magnetic configurations, including the effects of islands, stochastic magnetic fields, and helical states.	6. I-3
7. Understand and demonstrate the use of self-generated currents and mass flows to achieve steady-state high-pressure confined plasmas and improve fusion energy performance.	7. VI-1
8. Understand how external control can lead to improved stability and confinement in sustained plasmas in a range of magnetic configurations.	8. I-1, 2
9. Understand the pressure limits and confinement properties in configurations where magnetic turbulence controls the distribution of the equilibrium magnetic field and for similar configurations with reduced turbulence. Assess their prospects for study in more collisionless plasma regimes for possible extrapolation to practical sustained burning plasmas.	9. V-1,2
Multi-Scale Transport Physics	
1. Develop predictive capability for ion thermal transport using simulations validated by comparison with fluctuation measurements.	1. II-2
2. Identify the dominant particle transport mechanisms, including the conditions under which pinch/convective processes compete with diffusive processes.	2. II-3
3. Identify the dominant mechanisms for momentum transport and their relationship to thermal transport.	3. II-3, 4
4. Understand generation of flow shear, regulation of turbulence, and self-consistent profile dynamics and local steepening, and to identify conditions and thresholds for edge and core barrier formation.	4. II-3, 4
5. Identify the dominant electron thermal transport mechanisms, including the role of electromagnetic fluctuations, short-scale versus long-scale turbulence, and spectral anisotropy.	5. II-1, 2
6. Identify the dominant driving and damping mechanisms for large-scale and zonal flows, including turbulent stresses and cascades.	6. II-3
7. Identify the dominant mechanisms by which turbulence generates and sustains large-scale magnetic fields in high-temperature plasma.	7. V-1
8. Identify the mechanisms and structure of magnetic reconnection, including the role of turbulent and laminar processes, energy flow, and the production of energetic particles.	8. I-3, V-1
9. Identify the conditions for onset of island growth and the factors controlling saturation and coupling with transport.	9. I-3

Appendix: FESAC Priorities Panel 10-Year Goals	**Relevant NSTX Research**
Plasma Boundary Interfaces	
1. Predict the expected magnetohydrodynamic stability and plasma parameters for the ITER H-mode edge pedestal with high confidence. This is a time-sensitive issue relevant to the success of ITER	1. III-2
2. Identify the underlying driving mechanisms for mass flow and cross-field transport in the scrape-off-layer plasma, in H-mode attached and detached plasmas.	2. III-3
3. Resolve the key boundary-physics processes governing selection of plasma-facing components for ITER. This is a time-sensitive issue relevant to the success of ITER.	3. III-1
4. Complete the evaluation of candidate plasma-facing materials and technologies for high-power, long-pulse fusion experiments. This is a time-sensitive issue relevant to the success of ITER.	4. III-1
Waves and Energetic Particles	
1. Develop the capability to design high-power electromagnetic wave launching systems that couple efficiently and according to predictions for a wide range of edge conditions.	1. IV-3
2. Produce, diagnose in detail, and model with nonlinear, closed-loop simulations the macroscopic plasma responses produced by wave-particle interactions, including localized current generation, plasma flows, and heating, in both axisymmetric and non-axisymmetric configurations.	2. IV-1, 2
3. Develop long-pulse radio-frequency wave scenarios for optimizing plasma confinement and stability and to benchmark against models that integrate wave coupling, propagation, and absorption physics with transport codes (including microturbulence and barrier dynamics) and with magnetohydrodynamic stability models.	3. IV-4
4. Improve analysis and models to match the experimental measurements and scale the understanding to predict the dynamics of energetic particle-excited modes in advanced regimes of operation with high pressure, inverted magnetic shear, and strong flow.	4. IV-1
5. Identify the character of Alfvén turbulence and the evolution of the energetic particle distribution in a nonlinear system, which can be used to predict alpha-particle transport in a burning tokamak experiment; and to evaluate and extrapolate energetic particle behavior in present-day confinement systems to reactor parameters.	5. IV-2
Fusion Engineering Science	
1. Deliver to ITER the blanket test modules required to understand the behavior of materials and blankets in the integrated fusion environment.	1.
2. Determine the “phase space” of plasma, nuclear, material, and technological conditions in which tritium self-sufficiency and power extraction can be attained.	2. V-1, 2, VI-1
3. Develop the knowledge base to determine performance limits and identify innovative solutions for the plasma chamber system and materials.	3. III-1, 2, 3
4. Develop the plasma technologies required to support U.S. contributions to ITER.	4. III-2
5. Develop the plasma technologies to support the research program.	5. VI-4