NSTX Program Letter for CY 2005 – 2007

September 15, 2004

Introduction

This Program Letter describes for CY 2005-2007 the research objectives, the overarching scientific theme areas of investigation, and a list of research elements within each scientific area of the National Spherical Torus Experiment (NSTX) Program on which collaboration during CY 2005-2007 is particularly encouraged. The Program Letter is submitted to the Office of Fusion Energy Sciences as an input to support the DOE review and selection[1] of a fraction of the NSTX national collaboration team. The Program Letter is also available as information helpful to the present and prospective NSTX research collaborators in the broad fusion community.

DOE Office of Science Strategic Plan for Fusion Energy Sciences Program

The NSTX Research Program, supported by DOE funding, has since 1999 built a nationally based research team to carry out the exciting scientific investigations of the spherical torus plasma. The NSTX Program aims to fulfill an important role in the DOE Office of Science's Strategic Plan for the Fusion Energy Sciences Program,[2] to "*determine the most promising approaches and configurations to confining hot plasmas for practical fusion energy systems*." The spherical torus introduces opportunities to test the scientific basis of fusion plasmas extended to order-unity beta, near-sonic and Alfvénic plasma flow, supra-Alfvénic fast ions, over-dense plasmas, minimized magnetic flux content, and strong in/out asymmetry of the plasma edge. Research on NSTX thus widens the scientific domain of toroidal fusion plasmas, and thereby contributes to "*develop a fundamental understanding of plasma behavior sufficient to provide a reliable predictive capability for fusion energy systems*." The research substantially extends the tokamak database and thereby contributes to the physics optimization of ITER, which aims to "*demonstrate with burning plasmas the scientific and technological feasibility of fusion energy.*" Progress in plasma science in this extended physics regime further contributes to the verification of promising configurations that enable compact and reduced-cost fusion devices, contributing to "*develop the new materials, components, and technologies necessary to make fusion energy a reality.*"

Themes Presented by FESAC Priorities Panel

It is further appropriate to organize NSTX research of this extended physics regime of fusion plasma around the Overarching Themes presented by the FESAC Panel on Program Priorities in its interim report,[3] which are to

1) Understand the dynamics of matter and fields in the high temperature plasma state.
2) Create and understand a controlled, self-heated, burning starfire on earth.
3) Make fusion power practical.

The FESAC Panel interim report indicates that a number of specific scientific themes within magnetic confinement fusion contribute extensively to the Overarching Themes:

1) Understand the role of magnetic structure on plasma confinement and the limits to plasma pressure in sustained magnetic configurations.
2) Understand and control the physical processes that govern the confinement of heat, momentum, and particles in plasmas.

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[1] http://www.science.doe.gov/grants/FAPN04-24.html
[2] http://www.science.doe.gov/sub/Mission/Strategic_Plan/Feb-2004-Strat-Plan-screen-res.pdf
[3] http://www.mfescience.org/fesac/

3) Learn to use energetic particles and electromagnetic waves to sustain and control high temperature plasmas.
4) Learn to control the interface between a 100-million-degree plasma and its normal temperature surroundings.

Progress in these thematic areas will in time establish the scientific basis required to predict the integrated properties of steady-state burning plasmas, in ITER and possible future practical devices for testing the material and engineering sciences for fusion power.

NSTX Five-Year Research Plan[4]

In June 2003 DOE convened an international panel to review the NSTX Five-Year Research Plan, which was strongly endorsed by the panel. This plan aims to understand, control, and optimize the ST plasmas, and extend the knowledge base of plasma science, by establishing the tools for carrying out sustained high pressure plasma operations. In the plan, the present phase of research in FY 2004 would explore the physics of passive limits to identify the needed control tools. The next phase of research in FY 2005-2006, if adequately funded with a 10% increment over the FY 2004 level, would test advanced control of sustained high pressure plasmas and develop scenarios for initiating them without the benefit of a central solenoid. The succeeding phase of research in FY 2007-2008 would integrate the new physics results to optimize the sustained high pressure plasmas. The logic and vision described in this plan may provide information helpful to the consideration of proposals to conduct research collaboration on NSTX.

The impact of lower funding than indicated in the 5-year plan will be to stretch the research plan in time proportionately, roughly, to the inverse of lowered fraction of run weeks relative to the planned 20 run-weeks per year. Assuming a baseline level of 14 run-weeks per year and extending from the progress made in FY 2004, the NSTX Program will, during CY 2005-2007, focus on strengthening the scientific basis of the extended physics regime mentioned above, using advanced control techniques and diagnostic systems.

Priority Research Elements for Collaboration during CY 2005-2007

The NSTX National Team will address the challenging scientific topics identified in the above-mentioned campaigns, thereby contributing directly to the achievement of the Office of Science's Strategic Goals for Fusion Energy Sciences.[2] The tables contained in this Program Letter provide a description of the research elements in which research collaboration is encouraged, in order to form a strong and well-focus NSTX National Research Team.

These research elements were selected on the basis of our present understanding of what would be the most effective for the advancement of the overall NSTX National Program, in absence of specific proposals. This information should be treated as indicative of NSTX needs, but not restrictive for proposals to DOE by prospective collaborators.

About one-third of the NSTX research collaboration effort is subject to proposal review in CY 2004 for renewal in CY 2005.[1] It is in this context that research elements that best complement the present on-going activities are included in the following tables. Collaborations on major diagnostic systems will be subject to proposal review in CY 2005 for renewal in CY 2006, and collaborative research involving the national laboratories will be subject to proposal review in CY 2006 for renewal in CY 2007.

Since 1997, the NSTX Program Advisory Committee (PAC) has advised on the priorities of all elements of the NSTX Program, including the priorities and balance in the national collaborative

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[4] http://nstx.pppl.gov/DragNDrop/NSTX_Five_Year_Plan/5Yr_Plan_Final/

research that represents a major component of the overall NSTX Program. This Program Letter takes into account detailed advice received from the NSTX PAC during its recent 16th meeting.[5]

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[5] http://nstx.pppl.gov/DragNDrop/PAC_16/

1) Understand the role of magnetic structure on plasma confinement and the limits to plasma pressure in sustained magnetic configurations.

Research Elements
Develop equilibrium reconstruction and tool development for between-pulse and post-pulse analysis – Take into account sonic flow, energetic ions, very high beta, and other non-ideal affects important for low aspect ratio – Integrate diagnostic data to obtain accurate equilibrium – Identify effects of bootstrap and diamagnetic currents
Develop real-time plasma control capability for important ST objectives, including: – Solenoid-free current initiation, ramp-up, and sustainment scenarios/techniques – Precise control for highly shaped plasma
Characterize and understand effects on neoclassical tearing modes and on other internal stability modes from: – Plasma profiles – Sheared sonic flows – Externally driven, localized currents – Low aspect ratio
Characterize and understand effects on external beta-limiting modes from: – Nearby passive conductors – External and plasma-induced non-axisymmetric fields – Plasma rotation and its damping – Active non-axisymmetric magnetic field modifications – Plasma shape modifications – Low aspect ratio
Characterize and understand effects on H-mode pedestal and ELM properties from: – Edge stability – Flow effects on edge phenomena – Low aspect ratio
Characterize and understand magnetic reconnection and stability associated with – Co-axial helicity injection – Outer poloidal-field-only plasma initiation

2) Understand and control the physical processes that govern the confinement of heat, momentum, and particles in plasmas.

Research Elements
Characterize and understand low- and high-k core plasma turbulence mechanisms in a variety of confinement regimes – Includes linear and nonlinear gyrofluid and gyrokinetic simulations taking into account the effects of sonic flows and order-unity β
Characterize and understand low- and high-k edge plasma turbulence mechanisms in a variety of confinement regimes – Include flows, field structure, and electromagnetic effects
Update and apply neoclassical transport model to low aspect ratio plasmas – Sonic flows – Flow shear – Radial electric field effects – Finite orbit effects – Very high beta
Characterize and understand core transport coefficients and fluxes and their parametric dependences in a variety of confinement regimes – Including transport barriers, driven and spontaneous flows, etc. – May include both dimensional and dimensionless approaches

3) Learn to use energetic particles and electromagnetic waves to sustain and control high temperature plasmas.

Research Elements
Characterize and understand EBW coupling, power deposition, and current drive – Emission – Launching – Mode conversion – Propagation – Absorption by passing and trapped electrons – Current generation – Effect of electron transport on current drive efficiency
Characterize and understand HHFW coupling, power deposition, and current drive – Launching, launcher-sheath-edge interactions – Propagation, absorption by electrons, hot thermal ions, and fast ions – Current generation – Linear mode conversion, nonlinear mode coupling – Effect of electron transport on current drive efficiency
Characterize and understand NBI power deposition and current drive – Effect of finite gyroradius and large guiding center orbits – Resulting effects on fast ion driven bootstrap currents – Effects of fast ion driven instabilities on driven currents
Characterize and understand current initiation and current ramp-up by rf waves (HHFW and/or EBW), and the transition to NBI-driven plasma – Breakdown modeling – Control system development – RF heating of electrons on open flux surfaces – RF heating at low electron temperatures
Characterize and understand interactions between fast-ion driven modes and the fast ions, including effects of: – Fast ion energies, density, and profiles – Plasma profiles – Low aspect ratio

4) Learn to control the interface between a 100-million-degree plasma and its normal temperature surroundings.

Research Elements
Characterize and understand the plasma edge, including – Plasma particle and heat fluxes, recycling, and impurity fluxes – ELMs and edge transport barriers (H-mode pedestal) – Erosion and re-deposition of divertor and first wall materials – Plasma power distribution – Edge & SOL turbulence, including the intermittent ejection of filaments and "blobs" – Low aspect ratio effects, including in/out asymmetry – Plasma edge configurations and conditions, including conditions governing access to radiative divertor regimes
Develop control of ELMs and non-diffusive transport – Investigate methods for controlling ELM size while maintaining high plasma performance – Understand heat fluxes to the secondary null in single null plasmas
Characterize and understand the effects of wall treatment on in-vessel materials – Lithium coating – Boronization – Carbon composites, boron-nitrite, aluminum, etc. – Dust formation and distribution