NSTX Research Program Outline for FY 1999-2000

March 16, 1998

The National Spherical Torus Experiment (NSTX) is a national facility to test the fusion physics principles of the innovative spherical torus concept. NSTX is a major component of the restructured U.S. Fusion Energy Sciences Program to innovate in confinement concepts and to find a cost-effective route to an attractive fusion power source. As an alternative to tokamak, NSTX will contribute to understanding of plasmas in a new regime that promises order-unity beta, near neoclassical ion confinement, efficient noninductive startup and current drive, and dispersed divertor fluxes.

The NSTX Project has begun design and fabrication to deliver first plasma in April 1999 at a total project cost of $23.8M, utilizing facilities and equipment at PPPL valued over $100M. This facility will be capable of supporting the NSTX research mission, and will be flexible for improvements and upgrades as determined by new data. Important cost-effective enhancements, as recommended by the NSTX Program Advisory Committee (PAC) and interests in the research community, include a TFTR neutral beam injection system, a modern Thomson scattering system, and a new current profile diagnostic system.

The NSTX Research Program has begun preparation to build a nationally based Research Team to carry out the exciting scientific investigations of the spherical torus plasma, and fulfill its crucial role in the U.S. Fusion Energy Sciences Program. The NSTX PAC and the annual NSTX Research Forum have begun to draw from the broad expertise of the fusion community and develop the institutional and scientific elements of the NSTX Research Program. The Letters of Interest we received in January 1998 contain very good descriptions of prospective research collaboration on NSTX. These Letters of Interest encompass a wide range of research elements in all major scientific areas of interest and provide a solid basis for this NSTX Research Program Outline.

In this document we outline for FY 1999-2000 the scientific objectives, the priority among major scientific areas of investigation, and the relative emphasis among the scientific elements within each area. An overall progression of the NSTX Research Program is included to provide a forward-looking framework for this outline. Here we envision Phase I investigations (5/99–4/00) for Startup and Low Auxiliary Heating Power, Phase II investigations (5/00–9/01) for the First-Stability Regime relevant to Burning Plasma Physics and the Volume Neutron Source, and Phase III investigations (10/01 and beyond) for the highly optimized Advance Regimes relevant to economic Pilot and Power Plants.

1. NSTX Mission and Research Objectives

The mission of NSTX is to prove the physics principles for attractive near-term burning plasma test, the VNS, and the future Pilot and Power Plants. These applications, to be attractive, will entail

- Ultra high beta, high confinement, and high bootstrap current fraction simultaneously and in steady state,
- Noninductive current startup and maintenance to eliminate the Ohmic solenoid and minimize device size, and
- Dispersed power and particle fluxes to permit practical plasma facing components

NSTX is also part of broader research in ST, including

- Exploration in configurations, such as for extremely low aspect ratios using the Pegasus experiment at Univ. Wisconsin,
- Testing Coaxial Helicity Injection (CHI) noninductive startup, such as the HIT-II experiment at Univ. Washington, and
- Testing RF-only noninductive startup, such as the CDX-U at PPPL.

There is also high interest in understanding the physics relationship between the ST and the Compact Torus (CT) plasmas. CT plasmas include the Spheromak (the Sustained Spheromak Physics eXperiment being built at LLNL), the Field Reversed Configuration (FRC, Univ. Washington), and the Reversed Field Pinch (RFP, Univ. Wisconsin).

The overall NSTX Research Program Plan is summarized in Figure 1 below. The program for FY 1999-2000 will cover the Phase-I research and the beginning of the Phase-II research.

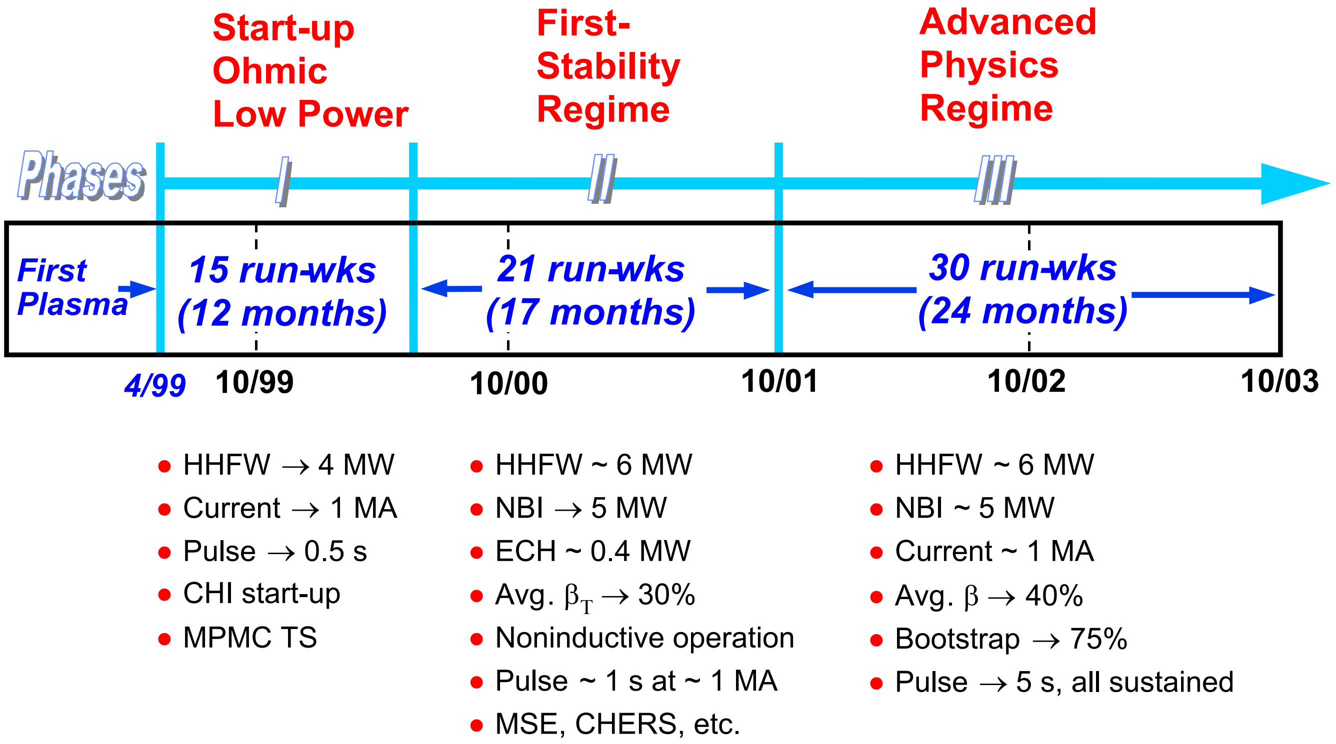

Figure 1. NSTX Research Program Plan

The scientific objectives for the three phases of the NSTX Research Program are:

Phase I: Startup and Ohmic/Low Auxiliary Power Operational Space (5/99–4/00)

- Explore and establish operational space
- Characterize initial Ohmic and low power limits in confinement and stability
- Test and develop HHFW heating scenarios
- Test and develop CHI current initiation scenarios

Phase II: Heating and Noninductive Operations for Startup and Moderate Beta (First-Stability Regime, Relevant to Burn Physics and VNS) (5/00–9/01)

- Establish noninductive CHI startup techniques
- Introduce and test ECH and EBW startup techniques
- Establish confinement scaling heated to moderate beta
- Study local transport and turbulence properties
- Investigate transport barrier formation
- Investigate plasma SOL properties for x-point divertor and natural divertor configurations
- Study approaches to MHD limits at moderate beta
- Explore and characterize current drive during sustainment phase

Phase III: Start-up, Heating and Current Drive at Full Capability (Advanced ST Physics Regime, Relevant to Pilot and Power Plants) (10/01 and beyond)

- Achieve full noninductive startup and sustainment operation at high power for several seconds
- Control of plasma edge and core transport barriers for good confinement
- Achieve and maintain high beta
- Investigate unique features in ST plasma edge and SOL under high power densities

2. Priority for NSTX Science Research Activities for FY99

Within the present DOE guidance, the FY99 NSTX Science Research resource is to cover

- PPPL's NSTX research
- Advanced diagnostics
- Collaborators' NSTX research and contributed diagnostics and tools
- RF research support by CDX-U

The relative emphases among the major scientific areas for FY99 research, consistent with the NSTX PAC advice, are given below. The emphases cover experimental research as well as preparation for experiments in future years.

Scientific Areas	Emphasis (%)	PAC Advice

1) Inductive and CHI Current Formation and Sustainment	13	M
2) RF and NBI Heating and Current Drive	18	H
3) Magnetics and Stability Limits	15	H
4) Plasma Transport and Fluctuations	20	H
5) Divertor, Scrape-Off Layer, Power and Particle Handling	13	L
6) Enabling Activities and Crosscutting Diagnostics	12	
Management	9	
Total	100	

3. Emphasis and Balance among Research Elements within Scientific Areas

The relative emphasis among the "Research Elements" within the "Scientific Areas" for Phases I and II is provided in the tables below, consistent with the recent advice of the NSTX PAC. The "Collaboration Emphasis" for each of the "Research Elements" for Phases I and II is based on our present understanding of what would be the most cost-effective for the overall national research program. This information should be helpful but does not introduce any restriction nor imply any limitation in how a prospective collaborator should prepare proposals to DOE. Scientific elements for Phase III research will be developed based on the outcome of research from Phases I and II.

It may be helpful to note that a "Research Emphasis" of High (H), Medium (M), or Low (L) identified for a "Research Element" indicates the relative amount of national science resource appropriate for this "Research Element" within a "Scientific Area." A "Collaboration Emphasis" indicates how much emphasis in collaboration would be appropriate for a "Research Element," in our present understanding.

1) Inductive and CHI Current Formation and Sustainment

(Phase I Emphasis ~13%)

P-I	P-II		P-I	P-II
Research Emphasis		Research Elements	Collab. Emphasis	
H	L	Inductive formation of plasma, EC preionization	M	M
H	L	CHI plasma formation studies	H	M
	H	Combined CHI startup, inductive sustainment at moderate beta		H
	M	Initial studies of CHI current drive during current sustainment		H
	L	Ramp-up via bootstrap current overdrive		M
	L	Initial assessment of bootstrap current drive during sustainment		M
	L	Preliminary studies of effective configurations for plasma formation and sustainment – Ultra low aspect ratio formation – High aspect ratio – Lower q		L

2) RF and NBI for Heating and Current Drive

(Phase I Emphasis ~18%)

P-I	P-II		P-I	P-II
Research Emphasis		**Research Elements**	**Collab. Emphasis**	
H	H	Develop HHFW modeling tools, integrate into analysis codes (absorption by ions, RF-driven plasma rotation, RF/NBI interaction, etc.)	H	M
H	H	HHFW heating and current drive tests at moderate (P-I) and high (P-II) power (coupling, launcher-sheath-edge interactions, power deposition, etc.)	M	H
L	M	ECH and EBW noninductive startup planning and preparation (P-I), and tests (P-II)	H	M
L	H	Preparation for fast ion experiments (RF and NBI) (P-I), NBI heating and current drive tests (assess fast ion losses) (P-II)	M	M
	M	Understanding heating profiles – Perturbation in RF heating – Fast ion transport		L
	M	Early HHFW injection to assist current ramp-up		M
	M	Modeling advanced RF techniques		M

3) Magnetics and Stability Limits

(Phase I Emphasis ~15%)

P-I	P-II		P-I	P-II
Research Emphasis		Research Elements	Collab. Emphasis	
H	L	Equilibrium reconstruction for post-pulse analysis, including tool development	M	M
H		Plasma ramp-up and operation – Error fields – Resistive current penetration – Axial and vertical stability – Runaways	L	
M	H	MHD operation limits (P-I) and stability limits (P-II) – Ideal and wall effects – Resistive wall modes – Mode control – Neoclassical tearing modes – ELMs, IREs, sawteeth – Locked modes – Disruptions and halo currents	M	H
M		Preliminary assessment of ideal MHD stability	M	
L	M	Assessment of mode control	M	H
	M	Fast ion driven instabilities – Alfven eigenmodes – FLR stabilization of sawteeth, ideal modes – Sawtooth effects on fast ions		M
	M	Effects of sheared rotation		M

4) Plasma Transport and Fluctuations

(Phase I Emphasis ~20%)

Research Emphasis		Research Elements	Collab. Emphasis	
P-I	P-II		P-I	P-II
M	M	Characterize global confinement – ⟨ne⟩, Ip, heating power, plasma shape (A, κ, etc.) dependencies – Local heating	L	L
L	H	Parallel transport and resistivity, RF (P-I) and NBI (P-II)	L	M
M	H	Preparation for (P-I) and carry out (P-II) local transport studies – Electron vs. ion thermal flows – electron particle diffusion – relation between particle and energy transport	M	H
M	H	Design/scoping studies for core fluctuation diagnostics (P-I); investigate low-k and high-k fluctuations, core transport barriers (P-II)	H	H
M	H	Edge plasma transport and barrier studies – Fluctuation, scale length characterization – Pedestal characteristics	M	M
	M	Computation and theory comparison Kelvin-Helmhotz instabilities; Neoclassical transport and plasma stability; Microinstability and nonlinear analysis; Gyrokinetic simulation on local particle and energy fluxes; Stability of Pressure with neoclassical ions; Transport simulation of temperature profiles using temperature at edge; Gyrofluid and gyrokinetic models with T, n dependence on fluxes; Modeling edge and core transport barrier formation		H

5) Divertor, Scrape-Off Layer, Power and Particle Handling

(Phase I Emphasis ~13%)

P-I	P-II		P-I	P-II
Research Emphasis		Research Elements	Collab. Emphasis	
H	M	Wall Conditioning, Recycling and Impurity Control – Achieve reliable operation – Develop method for density control – Assess edge particle sources and sinks	H	M
M	H	Heat Flux and Power Balance – Prevent damage to first wall materials – Power accountability in SOL and divertor – Modeling for extrapolation to high power	H	H
M	M	Edge and SOL characterization – Produce database for comparison with theoretical models – Study edge transport barrier mechanisms	H	H

6) Enabling Activities and Crosscutting Diagnostics

(Phase I Emphasis ~12%)

P-I	P-II		P-I	P-II
Research Emphasis		Research Elements	Collab. Emphasis	
H	L	Multi-pulse, multi-chord Thomson scattering	L	L
H	M	Current Profile Diagnostics	H	M
H	H	Plasma control	M	M