# Backup Information for NSTX Presentations

## At

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**I. NSTX FY 2001-2003 Research Milestones**

**II. FY 2001-2003 NSTX Contributions to the FESAC Goals and 5-Year Objectives, and Relationship to IPPA Implementation Approaches**

**III. NSTX U.S. Collaboration and Cooperation Researchers**

**IV. Postdoctoral, Graduate, and Undergraduate Researchers Working on NSTX Topics**

## NSTX FY 2001-2003 RESEARCH MILESTONES

March 2001

The NSTX Research Milestones for FY 2001-2003 are organized to achieve the NSTX Proof of Principle mission, to develop the scientific basis to realize the promise of high-efficiency magnetic containment of high temperature fusion-relevant plasmas produced in the innovative and cost-effective Spherical Torus configuration. The NSTX mission is consistent with the goals and objectives defined by the recent "Report of the FESAC Panel on Priorities and Balance." In particular, the 5-Year Objective 2.1 for the FESAC Goal #2 ("resolve outstanding scientific issues and establish reduced-cost paths to more attractive fusion energy systems by investigating a broad range of innovative magnetic confinement configurations.") is to "make preliminary determination of the attractiveness of the Spherical Torus, by assessing high-beta stability, confinement, self-consistent high-bootstrap operation, and acceptable divertor heat flux, for pulse lengths much larger than the energy confinement times." These milestones are also relevant to the other goals and objectives recommended by FESAC. The milestones are further updated in accordance with the near-term Spherical Torus Implementation Approaches suggested by the recent Integrated Program Planning Activity, which aims to achieve the 5-year objectives of the FESAC Goals.

In the following we provide plain-English description of the FY 2000 – 2003 milestones, assuming the baseline funding for FY 2001 – 2003. If the requested incremental funding for FY 2002 – 2003 were obtained, two incremental research milestones could be accelerated into FY 2003.

FY00 Research Milestones:

00-1) Operate a novel magnetic fusion confinement device, the National Spherical Torus Experiment, with 0.5 mega-ampere plasma currents approaching 0.5-second pulse lengths and 1-megampere currents for shorter pulses. (9/00)

This milestone was completed on schedule. The basic plasma operational conditions needed to achieve the NSTX FY01-03 milestones was established.

00-2) Investigate on NSTX innovative techniques for initiating plasma current, which can be utilized to simplify and reduce the cost of future spherical torus devices. (9/00)

Coaxial Helicity Injection (CHI) deposits current directly at the chamber edge. Theory suggests that this current can be transported into the chamber through the breaking and reconnecting of magnetic field lines. The intriguing physics mechanisms of this technique have been observed in the HIT and the HIT-II experiments at the University of Washington, and are similar in nature to the physics responsible for the formation of solar flares. These mechanisms will be investigated on a larger scale on NSTX using improved plasma control techniques, to initiate noninductively plasma currents approaching 200 thousand amperes. Successful noninductive startup (along with a means for current sustainment) would eliminate the need for a solenoid on the central column and thereby would simplify the spherical torus concept, leading to a major reduction in the size and cost of a fusion device.

This milestone was completed on schedule by producing via CHI alone plasma currents up to 260 kilo-ampere in up to 200-ms pulses in NSTX. The basic understanding was established to enable development during FY01-03 of CHI induced plasma currents up to 500 kilo-ampere and the related investigations of noninductive startup.

00-3) Begin investigation of a new powerful radio-frequency technique to heat spherical torus plasmas to high temperature. (9/00)

Due to relatively high plasma density and low magnetic field, spherical torus plasmas in NSTX are expected to possess a large plasma dielectric constant (commonly called an "over-dense" condition). This over-dense plasma condition can often prevent plasma waves near natural resonance frequencies from propagating into the plasma core. However, radio-frequency waves at large multiple of the natural ion rotation frequency are predicted to possess favorable wave propagation and strong wave energy absorption by electrons even in the highly over-dense plasmas expected in NSTX. The resulting electron heating and related new physics properties will be investigated at high radio-frequency heating power (up to four million watts) and at high plasma current (up to 1 million amperes) for the first time.

This milestone was completed with the delivery of up to 4 MW of HHFW power into the NSTX plasma in October 2000. Strong absorption and heating of the electrons (from about 500 eV to 1000 eV) were observed when large rf power was applied. The initial results provided data needed to prepare for rf-related research during FY01-03.

<u>FY01 Research Milestones:</u>

01-1) Measure and analyze the containment properties of plasma energy within strongly heated NSTX plasmas. Good containment of energy will enable increased fusion gain in future spherical torus experiments. (9/01)

Energy containment studies will be performed for the first time in spherical torus plasmas at high currents (up to one million ampere) and at high ratios of average plasma-to-toroidal magnetic pressure ($\beta_T \sim 20\%$). The investigations will begin by applying strong plasma heating via injection of neutral beams of energetic deuterium and/or of RF power, together with extensive measurements of the hot NSTX plasma core. The effects on confinement by the strongly curved magnetic field lines and the high pressure gradient relative to the modest magnetic field pressure, particularly in the peripheral region unique to the spherical torus plasma, will be measured and analyzed for the first time. Modes of plasma operation showing differing properties of energy containment will also be explored and documented. The new data will also extend the existing database and understanding of energy confinement of toroidal fusion plasmas.

01-2) Measure and analyze how high-power radio-frequency waves with slow propagation velocity interact with and heat high-temperature spherical torus plasmas. (9/01)

As the spherical torus plasma in NSTX is heated to higher temperature and pressure, the wave propagation velocity in the direction of the magnetic field slows down toward the electron thermal velocity, while the wavelength perpendicular to the magnetic field shrinks to the size scale of ion gyration around the magnetic field. The competition between the electron and the ion interactions with the wave is therefore important to the understanding of wave interactions that are unique to very high-$\beta_T$ fusion plasmas. In NSTX, radio-frequency waves at high multiples of the natural ion rotation frequencies will be launched to investigate how an increased interaction with the ions could reduce the wave-electron interactions and alter how the plasma can be heated and how plasma current can be driven. Very high power (up to six million watts) will be launched for the first time in NSTX with extensive measurements and analysis to clarify the relevant wave-plasma interaction properties at currents up to one million ampere and $\beta_T$ values up to ~20%.

FY02 Research Milestones:

02-1) Measure and analyze the global stability of spherical torus plasmas at high ratios of plasma pressure to magnetic pressure without applying active external control. (9/02)

Spherical torus plasmas in NSTX have been predicted to be stable against large-scale fluid-like perturbations at high ratios of average plasma-to-toroidal magnetic field pressure $\beta_T$ up to 25% without active external stabilization. In theory, the global stability results directly from the increase in favorable magnetic curvature in the unique peripheral region of the spherical torus plasma, and if verified experimentally, would allow a very high efficiency of utilization of the applied magnetic field. The properties of the large-scale perturbations will be extensively measured, analyzed and compared with theoretical calculations. The new data and understanding will be crucial to decisions on the need, and if so, the best techniques for active mode stabilization in NSTX, make possible reliable projections of power density for future spherical torus devices, and extend the existing database and understanding of global stability of toroidal fusion plasmas.

02-2) Assess the effects of very high ratio of plasma pressure to magnetic pressure and plasma flow on plasma heat loss in spherical torus. (9/02)

Theoretical calculations suggest that high plasma-to-magnetic pressure ratio (beta) can cause the magnetic field to fluctuate more with microscopic plasma turbulence than low beta, where the electrical field fluctuations are expected to be more important. Strong magnetic fluctuations may increase plasma heat leakage via the electrons. Theory also suggests that strong shear in plasma flow can accompany the high beta and strong field line curvature unique to the spherical torus plasmas, and/or a large external momentum input (such as from the injection of energetic beams of deuterium in NSTX). A strong flow shear have been seen to reduce the larger-scale microscopic turbulence associated with heat leakage via the ions, but is less likely to modify the smaller-scale microscopic magnetic turbulence that may be associated with heat leakage via the electrons. Heat fluxes in NSTX plasmas will be inferred from plasma profile measurements and analyzed over a wide range of beta ($\beta_T$ ~ 10-20%) and flow shear. Trends in the ratio of ion to electron thermal heat fluxes will be compared with predictions from theoretical calculations that account for the relatively large ion orbits and the relatively small electron orbits. External heating with varied momentum input will be used to help separate the effects of externally driven flow shear from the internal high beta driven flow shear, the magnetic field fluctuations from the electrical charge fluctuations, and the electron heat leakage from the ion heat leakage. Understanding of the physics underpinning these mechanisms of heat loss will enable future investigations of plasmas with simultaneously high beta and high plasma containment efficiencies. (9/02)

02-3) Demonstrate on NSTX innovative techniques for starting up plasma currents in toroidal fusion devices that will allow these devices to be made simpler, run longer, and cost less to construct. (9/02)

The initiation of plasma current by noninductive techniques is of crucial importance to the attractiveness of future spherical torus devices. The innovative technique of Coaxial Helicity Injection (CHI) will be utilized to initiate noninductively large plasma current up to 500 kilo ampere. Improved control of plasma position and parameters will be implemented together with extensive measurements to carry out this test. Data on compatibility of CHI with magnetic induction and plasma heating via injection of radio-frequency wave and neutral beams of energetic deuterium will also be collected. The information will be crucial to future investigations on NSTX into combining this and other current drive methods to ramp up and maintain plasma currents for longer durations. Successful noninductive-assist methods for startup will help minimize the central solenoid magnets, simplify the spherical torus concept, and lead to a major reduction in the size and cost of fusion devices.

02-4) Assess the effectiveness of using High Harmonic Fast Wave (HHFW) to drive plasma current via direct interactions with the electrons and/or fast ions in high-temperature spherical torus plasmas. (9/02)

Maintenance of plasma current by noninductive means represents one of the most important mission elements of the NSTX Program and is of common interest to magnetic fusion energy sciences research. High power HHFW with an increased wavelength in the direction of the magnetic field and flexible control of direction will be launched with a fast propagation velocity along the magnetic field line. This wave is expected to maximize momentum transfer to the electrons and drive plasma current noninductively. Interaction of this wave with the fast ions introduced by injection of energetic deuterium will also be investigated. The efficiency of current drive will be assessed by comparing the measurements with theory. An understanding of the underpinning physics of HHFW current drive and the techniques to ensure reliable operation at high power levels will contribute to future investigation of spherical torus plasmas sustained for longer durations in NSTX.

FY03 Research Milestones:

03-1) Measure and analyze the dispersion of edge heat flux and assess the impact on plasma facing component requirements under high heating power in NSTX. (9/03)

Understanding of the interaction between the plasma edge and the first wall and plasma facing components is critical to the success of containing any small-size high-temperature plasma with high power density. The spherical torus plasma introduces uniquely stronger and more favorable variations in the geometry and strength of the magnetic field in the edge region, which is expected to disperse the plasma exhaust over a larger wall area and reduce the power flux to the first wall. Detailed investigation of the edge plasma will be carried out when large heating powers and several edge diagnostics and wall treatment techniques on NSTX are introduced. Measurements and theoretical modeling of diffusion, convection, and turbulence processes will be compared in detail to guide the investigation. Successful dispersal of plasma exhaust power over large wall areas will enable more powerful and compact spherical torus experiments and fusion devices at reduced costs.

03-2) Explore and characterize spherical torus plasmas having simultaneously good plasma containment and high plasma-to-magnetic pressure ratio for durations much larger than the energy containment times. (9/03)

Simultaneously enhancing the plasma containment and raising the plasma-to-magnetic pressure ratio has been an overarching goal for magnetic fusion research and is an crucial mission element of the NSTX program. Experimental tests and extensive measurements will be carried out in NSTX to determine how to achieve the integration of high average toroidal $\beta_T$ (up to 25%) without the application of active mode control, good plasma containment times, and large plasma self-driven "bootstrap" current (up to 40% in fraction of total current) for increased durations (much larger than energy containment times). Results of research during FY02 will provide information critical to the completion of this milestone. The new results of this research will provide information crucial to the subsequent investigations towards increasing plasma containment and the plasma-to-magnetic pressure ratio even further by utilizing active external stabilization. They will also extend the existing database and understanding of plasma containment and global stability of toroidal fusion plasmas to new regimes of plasma $\beta_T$ and energy containment.

03-3) Measure and analyze the effectiveness of using a combination of noninductive techniques to assist in startup and sustainment of plasma pulse lengths up to 1 s. (9/03)

The investigation of the spherical torus plasma properties appropriate for enabling plasma pulse durations up to 1 s using noninductive assist is a crucial mission element of the NSTX program. The experience and understanding in current startup and maintenance using Coaxial Helicity Injection, radio-frequency wave, pressure gradient (bootstrap current), and magnetic induction will be combined to create the plasma conditions that minimize the dissipation of the solenoid magnet flux while permitting increased plasma pulse durations. Extensive measurements and analysis of the interactions among these current drive techniques will be carried out over a range of plasma parameters and conditions to establish a basis to begin the development of the plasma conditions that enable the extension of the plasma pulse toward 5 s during FY04-06.

Additional Milestones Contingent on Incremental Funding:
Under the requested incremental funding, additional research milestones can be included into FY03, while portions of the FY03 baseline milestones can be accelerated into FY02. These added research milestones will be updated based on the results of research during FY01-03.

Incremental-1) Measure and analyze the effects of energetic ion driven instabilities on the physics mechanisms that limit the high ratios of plasma-to-applied toroidal field pressure ($\beta_T$ ~ 25%) and high energy containment efficiency in spherical torus plasmas. The spherical torus plasma, as in all high beta plasmas, is uniquely characterized by fast ions of supra-Alfvén velocities and with large radius of gyration relative to plasma size that could potentially lead to new plasma behaviors of interest. Comparison with theory will contribute to the scientific understanding of these effects needed to consider future experiments with similar energetic ion properties.

Incremental-2) Measure and analyze the effects of very large plasma flow (of the order of plasma sound and Alfvén velocities) on MHD plasma equilibrium and global stability at very high ratios of plasma-to-applied toroidal field pressure ($\beta_T$ > 25%). Such large relative plasma flows can happen only to very high beta plasmas such as the spherical torus. An understanding of the underpinning interactions between plasma flow and macroscopic stability is expected to be important to the investigation of the noninductive sustained plasmas in NSTX.

**FY01-03 NSTX Contributions to the FESAC Goals and 5-Year Objectives, and Relationship with IPPA Implementation Approaches**

Martin Peng for the National NSTX Team, March 2001

The FY01-03 NSTX research milestones address, either primarily or secondarily, several of the goals and 5-year objectives recommended by FESAC for the magnetic confinement research of Fusion Energy Sciences. The National NSTX Program proposes two research milestones for FY01 (01-1, 01-2), four research milestones for FY02 (02-1, 02-2, 02-3, 02-4), and three research milestones for FY03 (03-1, 03-2, 03-3). The following table provides a summary of the NSTX contributions to these goals and objectives.

| FESAC Goals | 5 Year Objectives | Contributing NSTX Research Milestones |
|---|---|---|
| 1. Advance fundamental understanding of plasma, the fourth state of matter, and enhance predictive capabilities, through comparison of well-diagnosed experiments, theory and simulation | 1.1 Turbulence and Transport: Advance understanding of turbulent transport to the level where theoretical predictions are viewed as more reliable than empirical scaling in the best-understood systems. | (01-1) Measure and analyze the containment properties of plasma energy and fuel within strongly heated NSTX plasmas. Good containment of energy and fuel will enable increased fusion gain in future spherical torus experiments. [Secondary]<br>(02-2) Assess the effects of very high ratio of plasma pressure to magnetic pressure and plasma flow on plasma heat loss in spherical torus. [Secondary]<br>(03-2) Explore and characterize spherical torus plasmas having simultaneously good plasma containment and high plasma-to-magnetic pressure ratio for durations much larger than the energy containment times. [Secondary] |
| | 1.2 Macroscopic Stability: Develop detailed predictive capability for macroscopic stability, including resistive and kinetic effects. | (02-1) Measure and analyze the global stability of spherical torus plasmas at high ratios of plasma pressure to magnetic pressure without applying active external control. [Secondary]<br>(02-3) Demonstrate on NSTX innovative techniques for starting up plasma currents in toroidal fusion devices that will allow these devices to be made simpler, run longer, and cost less to construct. [Secondary]<br>(03-2) Explore and characterize spherical torus plasmas having simultaneously good plasma containment and high plasma-to-magnetic pressure ratio for durations much larger than the energy containment times. [Secondary] |

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| | 1.3 Wave-Particle Interactions: Develop predictive capability for plasma heating, flow and current drive, as well as energetic particle driven instabilities, in power-plant relevant regimes. | (01-2) Measure and analyze how high-power radio-frequency waves with slow propagation velocity interact with and heat high-temperature spherical torus plasmas. [Secondary]<br>(02-4) Assess the efficiency of using High Harmonic Fast Wave (HHFW) to drive plasma current via direct interactions with the electrons and/or fast ions in high-temperature spherical torus plasmas. [Secondary]<br>(03-3) Measure and analyze the effectiveness of using a combination of noninductive techniques to assist in startup and sustainment of plasma pulse lengths up to 1 s. [Secondary] |
| | 1.4 Multiphase Interface: Advance the capability to predict detailed multiphase plasma-wall interfaces at very high power- and particle-fluxes. | (03-1) Measure and analyze the dispersion of edge heat flux and assess the impact on plasma facing component requirements under high heating power in NSTX. [Secondary] |

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| 2. Resolve outstanding scientific issues and establish reduced-cost paths to more attractive fusion energy systems by investigating a broad range of innovative magnetic confinement configurations. | 2.1 Spherical Torus: Make preliminary determination of the attractiveness of the Spherical Torus (ST), by assessing high-beta stability, confinement, self-consistent high-bootstrap operation, and acceptable divertor heat flux, for pulse lengths much greater than energy confinement times. | The NSTX FY01-03 research milestones have been designed to address this objective.<br>(01-1) Measure and analyze the containment properties of plasma energy and fuel within strongly heated NSTX plasmas. Good containment of energy and fuel will enable increased fusion gain in future spherical torus experiments. [Primary]<br>(01-2) Measure and analyze how high-power radio-frequency waves with slow propagation velocity interact with and heat high-temperature spherical torus plasmas. [Primary]<br>(02-1) Measure and analyze the global stability of spherical torus plasmas at high ratios of plasma pressure to magnetic pressure without applying active external control. [Primary]<br>(02-2) Assess the effects of very high ratio of plasma pressure to magnetic pressure and plasma flow on plasma heat loss in spherical torus. [Primary]<br>(02-3) Demonstrate on NSTX innovative techniques for starting up plasma currents in toroidal fusion devices that will allow these devices to be made simpler, run longer, and cost less to construct. [Primary]<br>(02-4) Assess the efficiency of using High Harmonic Fast Wave (HHFW) to drive plasma current via direct interactions with the electrons and/or fast ions in high-temperature spherical torus plasmas. [Primary]<br>(03-1) Measure and analyze the dispersion of edge heat flux and assess the impact on plasma facing component requirements under high heating power in NSTX. [Primary]<br>(03-2) Explore and characterize spherical torus plasmas having simultaneously good plasma containment and high plasma-to-magnetic pressure ratio for durations much larger than the energy containment times. [Primary]<br>(03-3) Measure and analyze the effectiveness of using a combination of noninductive techniques to assist in startup and sustainment of plasma pulse lengths up to 1 s. [Primary] |

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| | 2.2 Reversed Field Pinch: Begin determination of the attractiveness of the Reversed-Field Pinch (RFP) by assessing self-consistent confinement and plasma current sustainment. | (01-2) Measure and analyze how high-power radio-frequency waves with slow propagation velocity interact with and heat high-temperature spherical torus plasmas. [Secondary]<br><br>(02-4) Assess the efficiency of using High Harmonic Fast Wave (HHFW) to drive plasma current via direct interactions with the electrons and/or fast ions in high-temperature spherical torus plasmas. [Secondary]<br><br>(03-3) Measure and analyze the effectiveness of using a combination of noninductive techniques to assist in startup and sustainment of plasma pulse lengths up to 1 s. [Secondary] |
| | 2.4 Resolve key issues for a broad spectrum of configurations at the exploratory level. | The NSTX FY01-03 research milestones can contribute helpful information to concept exploration experiments in their effort to address this objective. [Secondary] |
| 3. Advance understanding and innovation in high-performance plasmas, optimizing for projected power-plant requirements; and participate in a burning plasma experiment. | 3.1 Assess profile control methods for efficient current sustainment and confinement enhancement in the Advanced Tokamak, consistent with efficient divertor operation, pulse lengths >> energy confinement times. | (03-1) Measure and analyze the dispersion of edge heat flux and assess the impact on plasma facing component requirements under high heating power in NSTX. [Secondary]<br><br>(03-2) Explore and characterize spherical torus plasmas having simultaneously good plasma containment and high plasma-to-magnetic pressure ratio for durations much larger than the energy containment times. [Secondary] |
| | 3.2 Develop and assess high-beta instability feedback control methods and disruption control/amelioration in the Advanced Tokamak, for pulse lengths >> energy confinement times. | (02-1) Measure and analyze the global stability of spherical torus plasmas at high ratios of plasma pressure to magnetic pressure without applying active external control. [Secondary]<br><br>(03-2) Explore and characterize spherical torus plasmas having simultaneously good plasma containment and high plasma-to-magnetic pressure ratio for durations much larger than the energy containment times. [Secondary] |

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| 4. Develop enabling technologies to advance fusion science; pursue innovative technologies and materials to improve the vision for fusion energy; and apply systems analysis to optimize fusion development. | 4.1 Develop enabling technologies to support the goals of the scientific program outlined above, including advanced methods for plasma measurements, heating, current drive, flow control, and fueling. | (01-2) Measure and analyze how high-power radio-frequency waves with slow propagation velocity interact with and heat high-temperature spherical torus plasmas. [Secondary]<br><br>(02-4) Assess the efficiency of using High Harmonic Fast Wave (HHFW) to drive plasma current via direct interactions with the electrons and/or fast ions in high-temperature spherical torus plasmas. [Secondary]<br><br>(03-1) Measure and analyze the dispersion of edge heat flux and assess the impact on plasma facing component requirements under high heating power in NSTX. [Secondary] |
| | 4.2 Advanced Design: Perform a range of advanced MFE and IFE design studies to support the goals of the scientific program; assess the role of fusion energy in the context of all energy systems. | The results of NSTX FY01-03 research milestones will help update the ST physics assumptions used in advancing the design concept of future ST fusion devices. [Secondary] |

These NSTX research milestones further are coherent with the IPPA Measure of Progress and Implementing Approaches for **3.2.1: Spherical Torus**, as summarized below:

| **Measure of Progress** | **Implementation Approaches** | **Coherent NSTX Research Milestones** |
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| Progress will be measured by the degree of understanding of the processes and techniques that extend plasma pressure, improve plasma confinement, and allow sustained plasmas in a spherical torus concerning candidate devices for studying burning plasmas and/or testing fusion-nuclear components. | 3.2.1.l Achieve Efficient Heat and Particle Confinement: Assess the efficiency of heat and particle containment as functions of externally controllable parameters of strongly heated spherical torus plasmas with high pressure, modest magnetic field and strong field line curvature. Understand core turbulence and effect its suppression to reveal limiting confinement (corrected neoclassical transport) mechanisms under large plasma flow and large flow gradients. However, very high beta also increases the potential virulence of electromagnetic turbulence to challenge the effectiveness of turbulence suppression by sheared flow observed routinely in the tokamak. | (01-1) Measure and analyze the containment properties of plasma energy and fuel within strongly heated NSTX plasmas. Good containment of energy and fuel will enable increased fusion gain in future spherical torus experiments.<br>(02-2) Assess the effects of very high ratio of plasma pressure to magnetic pressure and plasma flow on plasma heat loss in spherical torus. |
| | 3.2.1.2 Verify Stability of Large Scale MHD Perturbations: Characterize the stability of large-scale magnetohydrodynamic fluid perturbations in spherical torus plasmas of high pressure and modest magnetic field with average toroidal betas up to 25% and with self-generated, or bootstrap, current fractions up to 40%, without active control of plasma instabilities and profiles. Assess requirements for plasma profile and large-scale mode control to increase beta, bootstrap current fraction and plasma pulse duration. As the sound speed approaches the Alfvén speed at very high beta, mass flow begins to alter significantly the equilibrium and stability properties of the plasma, challenging the conclusions of static equilibrium, which is well established in tokamak research. | (02-1) Measure and analyze the global stability of spherical torus plasmas at high ratios of plasma pressure to magnetic pressure without applying active external control. |

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| | 3.2.1.3 Heat High-beta Over-dense Plasmas: Investigate wave-particle interaction resulting from new radio-frequency wave launchers (such as the high harmonic fast wave) to heat and to control plasmas of very high dielectric constant. Assess the integration of intense heating by radio frequency waves and the injection of neutral particle beams in creating and maintaining high-beta spherical torus plasmas. The fast beam ion speed in the ST will far exceed the Alfvén speed, likely enhancing the Toroidal Alfvén Eigenmode instabilities and the associated dispersion of the energetic ions from the plasma core. | (01-2) Measure and analyze how high-power radio-frequency waves with slow propagation velocity interact with and heat high-temperature spherical torus plasmas. |
| | 3.2.1.4 Test Plasma Startup With Noninductive Techniques: Characterize the integration of noninductive plasma startup via magnetic reconnection such as using Coaxial Helicity Injection (CHI) with other noninductive and inductive current drive techniques. Investigate a number of noninductive techniques to start and to increase the plasma current in ST plasmas while at the same time minimizing magnetic flux and helicity injection. | (02-3) Demonstrate on NSTX innovative techniques for starting up plasma currents in toroidal fusion devices that will allow these devices to be made simpler, run longer, and cost less to construct.<br><br>(02-4) Assess the efficiency of using High Harmonic Fast Wave (HHFW) to drive plasma current via direct interactions with the electrons and/or fast ions in high-temperature spherical torus plasmas.<br><br>(03-3) Measure and analyze the effectiveness of using a combination of noninductive techniques to assist in startup and sustainment of plasma pulse lengths up to 1 s. |

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| | 3.2.1.5 Disperse Edge Heat Flux at Acceptable Levels: Study the dispersion of edge heat flux over a range of externally controllable parameters and estimate the plasma facing component requirements under high heating power in the spherical torus magnetic geometry. Determine the ability for managing intense energy and particle fluxes in the edge geometry and for increasing pulse durations significantly beyond the energy confinement time. Most elements of the physics on the edge open field lines are shared between the ST and the tokamak, while the ST introduces stronger variations of the magnetic field strength along the field lines, that are closer to the magnetic mirror. The "toroidal mirror" configuration also tends to have large flux expansion in the divertor region, likely extending the physics research to new parameter regimes. | (03-1) Measure and analyze the dispersion of edge heat flux and assess the impact on plasma facing component requirements under high heating power in NSTX. |
| | 3.2.1.6 Integrate High Confinement and High Beta: Test spherical torus plasmas having both high confinement and high beta for times much longer than the energy confinement times, without active stabilization. Determine the ability for extending the established operating regimes towards simultaneously higher confinement and higher beta using active control of plasma instabilities and profiles. Assess the requirements for integrating high confinement and high beta for long pulse durations with and without active control of instabilities and profiles, to prepare for the succeeding implementation of the 10-year ST objectives. Begin to evaluate physics properties and design options for the moderate-pulse burning plasma mission and for the long-pulse component testing mission in support of the Goal 3 ten-year objectives. | (03-2) Explore and characterize spherical torus plasmas having simultaneously good plasma containment and high plasma-to-magnetic pressure ratio for durations much larger than the energy containment times. |

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| | 3.2.1.7 Explore Spherical Torus Issues in Directed Laboratory Experiments: Use small and mid-sized laboratory experiments to explore and develop understanding of a variety of issues relevant to future development of the ST concept and/or to general plasma science and technology. Some of these issues are: (i) current drive based on novel helicity injection concepts; (ii) extrapolation of ST physics to the limit of near-unity aspect ratio; (iii) nature of the transition region between externally controlled tokamak-like and self-organized spheromak-like behavior as the stabilizing toroidal magnetic field is reduced; (iv) development of radio frequency wave heating, current drive, and diagnostic techniques relevant to over-dense plasmas; and (v) tests of novel technology for plasma-wall interaction control. | The Pegasus, HIT-II, and CDX-U experiments carry out this Implementation Approach. NSTX cooperates with these experimental efforts and contributes to their progress. |

# NSTX U.S. Collaboration and Cooperation Researchers

(Updated March 5, 2001)

| Institution | Research Topic | Home-Site Lead | Collaboration Lead and Members | |
|---|---|---|---|---|
| Columbia U | MHD Studies | Jerry Navratil<br>Navratil@columbia.edu | Steve Sabbagh<br>Jerry Navratil<br>Franco Paoletti<br>Jim Bialek<br>Wubiao Zhu | ssabbagh@pppl.gov,<br>Navratil@columbia.edu,<br>fpaoletti@pppl.gov,<br>jbialek@pppl.gov, |
| | Stellar X-Ray Spectroscopy (DOE Astrophysics funded) | Steve Kahn<br>skahn@astro.columbia.edu | Steve Kahn<br>Ehud Behar | skahn@astro.columbia.edu, |
| General Atomics | Coaxial Helicity Injection (CHI) Equilibrium Reconstruction | John Ferron<br>ferron@gav.gat.com | Mike Schaffer<br>Lang Lao | schaffer@gav.gat.com,<br>lao@LEGACY.gat.com, |
| | Radio Frequency Physics | | Bob Pinsker | pinsker@gav.gat.com, |
| | Plasma Control* | | John Ferron<br>Ben Penaflor<br>David Piglowski | ferron@gav.gat.com, |
| Johns Hopkins U | Ultra-Soft X-Ray (USXR) Diagnostics | Michael Finkenthal<br>mike@eta.pha.jhu.edu | Dan Stutman<br>Michael Finkenthal<br>Branimir Blagojevic<br>Robert Vero | dstutman@pppl.gov,<br>mike@eta.pha.jhu.edu, |
| LANL | Fast visible & infrared imaging | Glen Wurden<br>wurden@lanl.gov | Ricardo Maqueda<br>Glen Wurden | Maqueda@lanl.gov,<br>wurden@lanl.gov, |
| | Macroscopic Stability Modeling (Theory funded) | Alan Glasser<br>ahg@nimrod.lanl.gov | Alan Glasser | ahg@nimrod.lanl.gov, |
| LLNL | Edge, Scrape-Off Layer Modeling | Gary Porter<br>Porter2@llnl.gov | Gary Porter<br>Marvin Rensink | Porter2@llnl.gov, |
| | Boundary Plasma Stability & Turbulence | | Xueqiao Xu | xxu@llnl.gov, |
| | Stellar X-Ray Spectroscopy (DOE Astrophysics funded) | Peter Beiersdorfer<br>beiersdorfer@llnl.gov | Peter Beiersdorfer<br>Gregory Brown | beiersdorfer@llnl.gov,<br>brown86@llnl.gov, |
| Lodestar | Boundary Plasma Stability & Turbulence (Theory funded) | Dan D'Ippolito<br>dasd@lodestar.com | Jim Myra<br>Dan D'Ippolito | myra@lodestar.com,<br>dasd@lodestar.com, |

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| MIT | Electron Cyclotron Heating-Electron Bernstein Wave Modeling | Miklos Porkolab<br>Porkolab@psfc.mit.edu<br>Ian Hutchinson<br>hutch@psfc.mit.edu<br>Earl Marmar<br>marmar@psfc.mit.edu | Abe Bers<br>Abhay Ram | bers@mit.edu,<br>Abhay@psfc.mit.edu, |
| | Ion Cyclotron Radio Frequency Modeling | | Paul Bonoli | Bonoli@psfc.mit.edu, |
| | Edge Measurements | | Spencer Pitcher | csp@psfc.mit.edu, |
| NASA Glen Research Center | Direct Fusion Propulsion Concept (NASA funded) | Craig Williams<br>lvcraig@lerc.nasa.gov | Craig Williams | lvcraig@lerc.nasa.gov, |
| Nova Photonics | Motional Stark Effect (MSE) Diagnostics | Fred Levinton<br>flevinton@pppl.gov | Fred Levinton<br>Jill Foley | flevinton@pppl.gov, |
| NYU | Transport and RF Heating Theory (Theory funded) | C S Chang<br>cschang@pppl.gov | C S Chang | cschang@pppl.gov, |
| ORNL | Radio Frequency Launcher & Experiments (VLT funded in part) | David Rasmussen<br>rasmussenda@ornl.gov | David Swain<br>David Rasmussen<br>Phil Ryan<br>Joey Barnes<br>Hanna Smith | swaindw@ornl.gov,<br>rasmussenda@ornl.gov,<br>ryanpm@ornl.gov, |
| | ECH/EBW Mode Conversion Plasma Initiation, Heating, Current Drive | | Tim Bigelow<br>John Wilgen | bigelowts@ornl.gov,<br>wilgenjb@ornl.gov, |
| | Edge Experiments | Peter Mioduszewski<br>mioduszewspk@ornl.gov | Rajesh Maingi<br>Peter Mioduszewski | rmaingi@pppl.gov,<br>mioduszewspk@ornl.gov, |
| | Transport Simulation | | Wayne Houlberg<br>Par Strand | houlbergwa@ornl.gov, |
| | Coherent laser radar metrology (VLT Funded), Particle exhaust design, | Madhavan Menon<br>menonmm@ornl.gov | Madhavan Menon | menonmm@ornl.gov, |
| Princeton Scientific Instruments | Fast Tangential X-Ray Imaging (SBIR funded) | John Lowrance<br>lowrance@prinsci.com | John Lowrance<br>S. Von Goeler | lowrance@prinsci.com, |
| SNL | Plasma Facing Material (VLT Funded) | Mike Ulrickson<br>maulric@sandia.gov | Richard Nygren<br>Mike Ulrickson | renygre@sandia.gov,<br>maulric@sandia.gov, |
| | Material Surface Analysis (VLT Funded) | William Wampler<br>wrwampl@sandia.gov | William Wampler | wrwampl@sandia.gov, |

| | | | | |
|---|---|---|---|---|
| UC Davis | Far-InfraRed Tangential Interferometer/Polarimeter (FIReTIP) | Neville Luhmann<br>Luhmann@ucdavis.edu | Bihe Deng<br>Neville Luhmann<br>Kwan-Chul Lee<br>Bryan Nathan<br>Huijuan Liu | bhdeng@ucdavis.edu,<br>Luhmann@ucdavis.edu, |
| UC Irvine | Energetic Particle-Plasma Interactions | Bill Heidbrink<br>heidbrin@apollo.gat.com | Bill Heidbrink | heidbrin@apollo.gat.com, |
| UCLA | Reflectometry | Tony Peebles<br>peebles@gav.gat.com | Shige Kubota<br>Tony Peebles<br>X nguyen<br>Grad student<br>Undergrad student | skubota@physics.ucla.edu,<br>peebles@gav.gat.com,<br>xnguyen@ee.ucla.edu, |
| UCSD | High Harmonic Fast Wave Modeling | Charlie Baker<br>cbaker@iter.ucsd.edu | T K Mau | mau@fusion.ucsd.edu, |
| | Fast Probe | Stan Luckhardt<br>sluckhardt@ucsd.edu | Jose Boedo<br>Stan Luckhardt | jboedo@fusion.ucsd.edu,<br>sluckhardt@ucsd.edu, |
| | Far SOL Turbulence & Transport (Theory Funded) | Sergei Krasheninnikov<br>skrash@mae.ucsd.edu | Alexander Pigarov<br>Sergei Krasheninnikov | apigarov@fusion.ucsd.edu,<br>skrash@mae.ucsd.edu, |
| U Washington | Coaxial Helicity Injection | Tom Jarboe<br>Jarboe@aa.washington.edu | Roger Raman<br>Tom Jarboe<br>Brian Nelson<br>Alan Redd<br>Dave Ovris<br>Ralph Ewig | raman@aa.washington.edu,<br>Jarboe@aa.washington.edu,<br>nelson@hit.aa.washington.edu,<br>redd@aa.washington.edu, |
| **Total National Collaboration Team Members** | | | **74** | |

**Post Doctoral (P), Graduate (G), and Undergraduate (U) Researchers Working on NSTX Topics**

(Updated March, 2001)

| Institution | Name | P | G | U | Topic | Mentor |
|---|---|---|---|---|---|---|
| Columbia U | Wubiao Zhu | | 1 | | Resistive wall mode | Sabbagh |
| | Ehud Behar | 1 | | | X-ray spectroscopy | Steve Kahn |
| GA | None | | | | | |
| JH U | Branimir Blagojevic | 1 | | | Miniaturized USXR arrays | Finkenthal |
| | Robert Vero | | 1 | | USXR tomography | Stutman |
| LANL | None | | | | | |
| LLNL | None | | | | | |
| | Gregory Brown | 1 | | | X-ray spectroscopy | Beiersdorfer |
| Lodestar* | None | | | | | |
| MIT | None | | | | | |
| Nova | Jill Foley | | 1 | | MSE-LIF | Levinton |
| NYU* | None | | | | | |
| ORNL* | Par Strand | 1 | | | Plasma rotation and confinement | Houlberg |
| | Joey Barnes | | | 1 | Antenna measurements | Swain |
| | Hanna Smith | | | 1 | Antenna measurements | Swain |
| PPPL (NSTX) | Darin Ernst | 1 | | | Between-shot TRANSP | Kaye |
| | Clarisse Bourdelle | 1 | | | Micro-turbulence and transport | Synakowski |
| | Jerome Lewandowski | 1 | | | Gyrokinetic simulation | Lin |
| | Soukhanovski Vlad | 1 | | | Spectroscopy measurements | Skinner |
| | Adam Rosenberg | | 1 | | HHFW | Menard |
| | Jef Spaleta | | 1 | | | CK Phillips |
| | Brent Jones | | 1 | | | Taylor |
| | Danica Wyatt | | | 1 | Energetic particle orbits | Darrow |
| PSI* | None | | | | | |
| SNL* | None | | | | | |
| UC Davis | Kwan-Chul Lee | 1 | | | Development, maintenance, and operation of FIReTIP | Luhmann, Park |
| | Bryan Nathan | | | 1 | Mechanical design of FIReTIP | |
| | Huijuan Liu | | 1 | | FIReTIP mixer preamplifier/bias boards | Luhmann |
| UC Irvine | None | | | | | |
| UCLA | Shige Kubota<br>Postdoc<br>Undergrad | 1 | 1 | 1 | Density profile and fluctuation measurements via reflectometry | Peebles |
| UCSD* | None | | | | | |
| U Wash | David Ovris<br>Ralph Ewig | | 1 | <br>1 | CHI design studies for NSTX<br>CHI startup modeling for NSTX | Jarboe |
| **Total** | | **10** | **9** | **6** | | |

*Indicates cooperation in NSTX research involving expertise funded separately and in part by OFES Theory and Virtual Laboratory of Technology (VLT, covering Enabling Technology, Advanced Design, and Chamber Technology).