Date: November 20, 2001

To: NSTX Research Team

From: Martin Peng & Ed Synakowski

Subject: Draft Update of FY02-03 Research Milestones

Motivation

The NSTX Research and Facility Operations Teams, together with the Pegasus, HIT-II, and CDX-U Teams, have achieved great results during FY01, as evidenced by the increasing numbers of the invited, the contributed oral, and the contributed poster papers presented at the 2001 APS DPP annual meeting just over two weeks ago. This progress, together with improved schedule estimates of key NSTX device and diagnostic capabilities, and the limited 12 experimental run weeks in FY02, have necessitated an update to the FY02 research milestones. This memo provides a draft update of these milestones as input to the NSTX Research Team in preparation for the upcoming FY02 ST Research Forum, scheduled for November 28-30, 2001. The Team's output from the Research Forum will provide important information for us to finalize these milestones in early December 2001.

The following summarizes the draft updates:

I) Milestone (02-1) on global stability is maintained while adding the study of the effects of significant field errors in the description.

II) Milestone (02-2) on plasma heat containment is maintained without any change.

III) A draft Interim Milestone (02-3A) on noninductive startup assist is introduced for FY02, while the full Milestone (02-3) is moved to FY03 and renumbered (03-4).

IV) A draft Interim Milestone (02-4A) on HHFW current drive are introduced for FY02, while the full Milestone (02-4) is moved to FY03 and renumbered (03-5).

The NSTX Program introduces the Interim Milestones to account for the high priority assigned to these research topics.

Draft Update of 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 β_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. Recently measured field errors in NSTX are being reduced and are expected to add complexity to the study. The properties of the global perturbations, including the effects of field errors, will be extensively measured, analyzed and compared with theoretical calculations. The new data and understanding will be crucial to making decisions on the need for and, if necessary, on the best techniques for active mode stabilization in NSTX. The data will also improve the reliability of projections of power density of future spherical torus devices, and will extend the existing database and understanding of global stability of toroidal fusion plasmas to very high β_T values.

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 electric field fluctuations are expected to be more important. Strong magnetic fluctuations may also increase plasma heat leakage via the electrons. Theory 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 ($\beta_T \sim 10\text{-}25\%$) 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 electric field 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)

02-3A) Test on NSTX innovative techniques for starting up plasma currents in toroidal fusion devices to prepare for a demonstration 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 and noninductively maintain large plasma currents up to 400 kilo amperes. Testing will begin of strategies for controlling CHI plasmas in order to couple them to plasmas sustained by magnetic induction and heated by radio-frequency waves. Information obtained will be crucial to the preparation of a future demonstration of this technique on NSTX, including combining this and other techniques 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.

02-4A) Test the effectiveness of using High Harmonic Fast Wave (HHFW) to drive plasma current via direct interactions with the electrons and/or fast ions to prepare for a quantitative assessment 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 via flexible control 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, while applying strong heating to increase plasma pressure and self-driven (bootstrap) current. Interaction of this wave with the fast ions introduced by injection of energetic deuterium will also be investigated. The efficiency of combined HHFW-driven and self-driven current will be estimated by comparing global measurements in modest current plasmas with theory. An understanding of the underpinning physics of HHFW and self 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.

Update of 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 β_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 β_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.

03-4) 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. (9/03)

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.

03-5) 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. (9/03)

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.