NSTX Program Letter on Diagnostic Collaboration Opportunities for FY 2006-2008

Draft July 25, 2005

Introduction and Purpose of Program Letter

This NSTX Program Letter provides updated information about NSTX research priorities and diagnostic collaboration opportunities during the upcoming three years (FY 2006-2008). It supports the Office of Science Notice DE-FG01-05ER05-20 *National Spherical Torus Experiment – Innovative Measurements of Spherical Torus Plasmas*, expected to be issued in early August, by providing information useful for the preparation of proposals in response to this Notice.

The NSTX Program Advisory Committee (PAC) reviewed the Program Letter on July 26, 2005, and provided advice, which was incorporated into the Program Letter. The names of the current members of the NSTX PAC are listed in:
http://nstx.pppl.gov/DragNDrop/NSTX_Program/NSTX_PAC_MEMBERSHIP-FY05.pdf.
The Program Letter will be available on August 15 at:
http://nstx.pppl.gov/nstx/NSTX_Program_Letters/.

Mission of NSTX

The *programmatic* mission of the National Spherical Torus Experiment (NSTX) is (1) to determine the attractiveness of the spherical torus for reducing cost, time, and risk of the development of practical fusion energy, through scientific investigations, and (2) to contribute broadly to fusion energy sciences, including the resolution of important burning plasma physics issues anticipated in ITER when appropriate.

The *scientific* mission of NSTX is to advance fusion plasma science by determining and understanding the physics principles of the Spherical Torus, which is characterized by strong magnetic field curvature and high β_T (the ratio of the average plasma pressure to the applied toroidal magnetic field pressure) due to its low aspect ratio. These unique properties complement those of normal aspect ratio tokamaks in addressing the overarching scientific issues in magnetic fusion energy science, such as turbulence and transport, macroscopic MHD stability, wave-particle interactions, solenoid-free generation and sustainment of magnetic flux, and plasma interface with the surrounding environment.

More details of the NSTX program are provided in the peer-reviewed five-year research program for NSTX (for the period starting in FY2004), available at http://nstx.pppl.gov/Pages_folder/research_folder/5YrPlan.html.

The low toroidal field and high plasma pressure (relative to magnetic pressure) of a spherical torus result in plasmas with different parameters from those in conventional aspect ratio tokamaks. This in turn leads to new challenges for making certain measurements and to new requirements for other measurements. The following sections provide a brief description of the topical areas of NSTX research. For each of these areas, the required enhanced measurement capabilities are described, together with the measurements already in operation or under development.

Projected NSTX Goals for FY 2006-2008

The projected NSTX goals for FY 2006-2008 can be grouped by the following scientific topics:

I. **Transport and Turbulence** – physical processes that govern heat, particle, and momentum confinement
II. **Macroscopic MHD Stability Properties** – role of magnetic structure on plasma pressure and bootstrap current
III. **Wave-Particle Interactions** – role of electromagnetic waves and of energetic particles and associated driven modes in sustaining and controlling hot plasmas
IV. **Startup, Ramp-up and Sustainment Processes** – physical processes of magnetic flux generation and sustainment
V. **Boundary Physics** – interface between fusion plasmas and normal temperature surroundings
VI. **Physics Integration Processes** – physics synergy of external control and self-organization

The NSTX goals for FY 2006 – 2008 are listed below. These, together with a brief description of each of these goals, the measurement needs, the diagnostics already in operation or under preparation, and examples of diagnostics for desirable additional measurements in support of these goals are provided in Table I. *This table provides the information basis to indicate the priority, timeliness, and complementarity of the desired new measurement capabilities on NSTX.*

I. FY 2006 – 2008 Goals in Transport and Turbulence

- *Characterize the effects of variations in the magnetic shear and gradients in* T_e *on electron transport in low-aspect ratio plasmas.*
- *Measure short wavelength turbulence in the plasma core in a range of plasma conditions.*
- *Assess the correlation between measured and calculated high-k turbulence spectra, and the measured electron thermal conductivity.*

II. FY 2006 – 2008 Goals in Macroscopic MHD Stability

- *Produce and characterize strongly shaped, rotating, low aspect ratio plasmas close to the "wall-stabilized" pressure limits with error field correction.*
- *Characterize the effectiveness of active feedback control of resonant error fields (Sept. '06) and pressure-limiting global modes (Sept. '07) using closed-loop control of currents in ex-vessel correction coils.*

- *Identify and characterize modes that tear magnetic field surfaces and limit plasma pressure and energy confinement as the plasma pressure increases toward the “wall-stabilized” limit.*

III. FY 2006 – 2008 Goals in Wave-Particle Interactions

- *Assess the effects of supra-Alfvénic fast inos and the instabilities* they excite *on driven current in the plasma core.*
- *Compare data on supra-Alfvénic fast ion driven modes with non-linear simulations of these modes.*
- *Characterize the interaction between the edge plasma region and the launched High Harmonic Fast Waves (HHFW), and determine plasma and wave launch conditions that permit efficient heating and current drive via HHFW.*
- *Characterize the diffusion and loss of supra-Alfvénic fast ions due to fast-ion driven oscillations in low-aspect ratio, high-beta plasmas.*
- *Longer term goal: Elucidate the electron Bernstein wave (EBW) mode conversion physics critical to enabling EBW heating and current drive.*

IV. FY 2006 – 2008 Goals in Startup, Ramp-up and Sustainment

- *Assess the conditions in which a substantial amount of closed poloidal magnetic flux is created via Coaxial Helicity Injection.*
- *Test conditions for solenoid-free ramp-up of plasma to substantial plasma current.*

V. FY 2006 – 2008 Goals in Boundary Physics

- *Characterize the plasma edge pedestals and scrape-off layer of low-aspect ratio, high confinement, high P/R plasmas.*
- *Characterize the effectiveness of lithium pellet injection and tile coating in controlling fuel recycling from the plasma facing components.*
- *Assess the long-pulse plasma conditions and operational requirements of edge heat and particle control of low-aspect ratio, high-confinement, high P/R plasmas.*

VI. FY 2006 – 2008 Goals in Physics Integration

- *Characterize strongly shaped low-aspect ratio plasmas with high fractions of self-driven current and low toroidal induction voltage for durations that allow internal currents to redistribute.*
- *Benchmark and improve physics models and the time-dependent simulation codes with data from high-performance plasmas characterized by large self-driven current, high pressure relative to the applied toroidal field, and low toroidal induction voltage.*
- *Characterize strongly shaped low-aspect ratio plasmas with high fractions of bootstrap current and zero toroidal induction voltage (solenoid-free) for durations that allow internal currents to redistribute.*

Present Measurement Capabilities on NSTX and Examples of Desirable Additional Measurement Capabilities

The projected FY 2006–2008 NSTX research goals, the present measurement capabilities in operation and under development, and examples of desirable additional measurement capabilities are provided in Table I. The present Experimental Task Group Leaders and Co-leaders for each of these topics are also indicated in the Table; they are available as contacts to discuss possible additional information that should be provided by the NSTX Program, as future addenda to the Program Letter.

The information in Table I aims to assist a prospective or continuing collaboration researcher in determining the priority, timeliness, and complementarity of a proposed diagnostic collaboration on NSTX. The NSTX Program is interested in collaborations that provide new diagnostic systems, and continue operation of existing collaboration diagnostic systems in support of the NSTX milestones. The Program recommends the distinction and inclusion of these two types of diagnostic collaboration in proposals by the present diagnostic contributors to DOE.

Diagnostic instruments on NSTX are provided by a broadly based research team, which includes scientists from many of the leading U.S. fusion research institutions and PPPL. Many are essential to making key measurements on NSTX of, for example, current profile, MHD and fast ion driven mode structures, turbulence at electron scales in the core, and turbulence in the edge and scrape-off layer. Further, certain existing diagnostic collaborations are critical to meeting the near term milestones in the NSTX plan. These include Motional Stark Effect diagnostics for transport, stability, fast ion, and current drive studies; scattering diagnostics for high-k turbulence studies; soft X-Ray tomography for stability, edge, and fast ion studies; edge probes and reflectometry for boundary physics studies; and interferometry array for location of core fast ion modes.

Table II provides a description of the measurement capabilities that are already in operation, including those via diagnostic collaborations, or are under active development on NSTX by the NSTX Team. Table III provides information about capabilities on NSTX capable of supporting active diagnostics. Questions about present and developing NSTX diagnostics should be directed to Dave Johnson (djohnson@pppl.gov) and Bob Kaita (rkaita@pppl.gov).

Table I. Projected FY06-08 NSTX Research Goals and Measurement Needs

Transport and Turbulence – Physical processes that govern heat, particle, and momentum confinement Contacts: Stan Kaye (skaye@pppl.gov) and Dan Stutman (dstutman@pppl.gov)		needed plasma measurements	routine operation (not comprehensive), under active development, ***EXAMPLES of potential future diagnostics***
Characterize the effects of variations in the magnetic shear and gradients in T_e on electron transport in low-aspect ratio plasmas.	The ability to vary both the magnetic shear and the electron temperature gradients in high beta plasmas at low aspect ratio offers a unique possibility to elucidate the roles of these properties in altering the electron heat transport as possible beta-induced electromagnetic effects emerge. NSTX is in a strong position to research this topic since electron thermal conduction is the dominant energy transport channel in many of its high performance plasmas. This research will first characterize the variations in the measured electron energy transport with the q-profiles, using the newly available Motional Stark Effect (MSE) diagnostic to provide a reliable determination of the q-profile. Higher resolution electron temperature profiles will be available with additional channels of the laser Thomson Scattering diagnostic, facilitating the study of the effects of changing magnetic shear on the electron temperature gradient, and, in turn, the effect of the electron temperature gradient on transport. A new multi-color soft X-ray diagnostic will provide the fast electron temperature profile change measurements necessary for determining the perturbative transport coefficients. Low-k correlation reflectometry will provide information on core density fluctuation levels, while MSE will provide information on coherent magnetic fluctuations (up to ~100 kHz) in the finite-beta NSTX plasma core.	equilibrium reconstruction	magnetic sensors + profile diagnostics
		$q(R)$, $E_r(R)$	MSE/CIF
			MSE/LIF/DNB
		$n_e(R)$, $T_e(R)$	TS (with improved resolution)
		fast $T_e(R)$	poloidal multicolor x-ray arrays
			EBW radiometry
			tangential multi-color x-ray arrays
		fast $n_e(R)$	FIReTIP
		$T_i(R)$, $v_{tor}(R)$, $v_{pol}(R)$, $n_c(R)$, $E_r(R)$	toroidal CHERS
			edge Doppler spectroscopy
			poloidal CHERS
		impurity transport (He, Ne, etc.)	***tunable CHERS***
		low-k density fluctuations	heterodyne reflectometry
			BES (D)
			BES (impurity seeded)
			imaging reflectometry
			phase contrast imaging
		B fluctuations	***microwave poloidal polarimetry***
			MSE
		flow fluctuations	***BES***
Measure short wavelength turbulence in the plasma core in a range of plasma	Experiments on NSTX have indicated that electron thermal conduction can vary widely and can often dominate over ion thermal conduction in high-confinement and high-beta plasmas. Gyrokinetic analysis indicates that short wavelength microinstabilities may play a strong role in such cases. Tangential microwave scattering will be	same as above plus:	
		high-k fluctuations	tangential microwave scattering
			radial microwave scattering

conditions.	available on NSTX to measure the short-wavelength turbulence properties over a wide range of conditions. These measurements will be used to test predictions from state-of-the-art theory and computation, especially as they pertain to the heat loss by the electrons due to short wavelength turbulence. In FY2006 measurements of the density turbulence radial wave number spectra on electron scales and extending towards ion scales (2 - 20 cm^{-1}) will be carried out over a wide range of these gradients. These plasmas will likely have neutral-beam-driven toroidal flow shearing rates up to a megaHertz and toroidal betas up to ~30%. Diagnostics to measure the plasma density, ion temperature, electron temperature, ion flow velocity, magnetic field line pitch, and radial electric field will be needed to provide data as input to theory codes. These codes will be used to predict turbulence characteristics and the ensuing electron transport, for comparison with the experimental measurements.		***phase contrast imaging***
Assess the correlation between measured and calculated high-k turbulence spectra, and the measured electron thermal conductivity.	In FY2007 a detailed investigation will begin to determine the parametric dependence of the turbulence-induced local electron thermal conductivity in the NSTX plasma core. Physics of interest will include the presence or absence, in strongly shaped, collisionless, high-beta, low-aspect-ratio plasmas, of the electron temperature gradient (ETG) driven turbulence, its possible nonlinear consequence in the form of "streamers" in the radial direction, and the micro-tearing fluctuations. The correlation of these simulated fluctuations with the electron heat conduction inferred from transport analysis of a suite of plasma measurements will be determined over a range of plasma conditions of interest.	same as above plus:	
		radial streamers	tangential microwave scattering ***phase contrast imaging*** ***BES*** ***Imaging reflectometry***

Macroscopic MHD Stability – Role of magnetic structure on plasma pressure and bootstrap current Contacts: David Gates (dgates@pppl.gov) and Steve Sabbagh (ssabbagh@pppl.gov)		needed plasma measurements	routine operation, under active development, ***EXAMPLES of potential future diagnostics***
Produce and characterize strongly shaped, rotating, low aspect ratio plasmas close to the “wall-stabilized” pressure limits with error field correction.	Large-scale, pressure driven plasma instabilities normally seen at very high pressures are restrained by plasma rotation, amplified by the asymmetries in the magnetic field, and can be mitigated by counteracting perturbations produced by field-correction coils. The interactions among these properties will be studied as very high-beta plasmas approaching the “wall-stabilized” limits are produced and maintained for periods longer than the timescale for the stabilizing eddy currents in the walls to decay naturally. Detailed measurements of internal magnetic field pitch angle will be made to strengthen present theoretical calculations of these modes for comparison with the observed mode behavior. The data from poloidal and toroidal arrays of magnetic field sensors and plasma profiles will be used in these analyses to determine the dependence of the critical rotation frequency for stabilization of the RWM on plasma parameters,	equilibrium reconstruction	magnetic sensors + profile diagnostics
		high spatial res. pedestal pressure profile (5 mm)	improved TS resolution
			thermal atomic beam spectroscopy
		high spatial res. pedestal current profile (5 mm)	MSE/LIF/DNB
		passive plate eddy currents	***Rogowski coils on plates and on connections to vessel***
		locked mode/RWM amplitude, phase	***locked mode, RWM sensor coils***
		q(R), E_r(R)	MSE/CIF
			MSE/LIF/DNB
		n_e(R), T_e(R)	TS
		fast T_e(R)	poloidal multicolor x-ray arrays
			EBW radiometry
			tangential multi-color x-ray arrays
		fast n_e(R)	FIReTIP
		low (m,n) MHD modes	poloidal multicolor x-ray arrays
			fast tangential x-ray pinhole camera
			low frequency Mirnov coils
		T_i(R), v_{tor}(R), v_{pol}(R), n_c(R), E_r(R)	toroidal CHERS
			edge Doppler spectroscopy
			poloidal CHERS
		fast particle pressure	***neutron collimator***
			D_α spectroscopy

Characterize the effectiveness of active feedback control of resonant error fields (Sept. '06) and pressure-limiting global modes (Sept. '07) using closed-loop control of currents in ex-vessel correction coils.	As the pressure in strongly shaped NSTX plasmas is raised toward and sustained near the "wall-stabilized" ideal limit for durations longer than the time scales of eddy current decay in the nearby wall, the stabilizing effects on the Resistive Wall Modes (RWMs) from resonant error field correction and strong plasma rotation are expected to change. Active feedback on the amplitude of the resonant error fields may be effective in maintaining stability of such plasmas. The effectiveness of using feedback control of the resonant field errors for the lowest toroidal mode numbers will be characterized over a range of plasma conditions, profiles, shapes, rotation frequencies, and feedback control parameters (current amplitude, toroidal rotation frequency, and phase lag). Of particular interest will be the interplay among plasma rotation, error fields, and RWM as the "wall-stabilized" pressure limit is approached.	same as above

Identify modes that tear magnetic field surfaces and limit plasma pressure and energy confinement as the plasma pressure increases toward the "wall-stabilized" limit.	Experiments will be carried out in rotating high-performance plasmas well above the "no-wall" pressure limit. External magnetic coils will be used to measure the toroidal and poloidal mode numbers. The amplitude of edge magnetic fluctuations will provide a constraint on the mode amplitude/island width. Measurements of the internal mode structure will discriminate between tearing and kink modes and indicate possible coupling between them. These internal diagnostics include multi-chord multi-time Thomson scattering, a fast scanning EBW radiometer system (a DOE-supported advanced diagnostic development), and soft x-ray cameras. The electron temperature profile evolution and fluctuations so measured will provide a direct indication of the radial mode structure for comparison with theory and simulation for interpretation. For H-mode plasmas the density profile is expected to be relatively flat, likely limiting the spatial resolution of local soft x-ray emission measurements. These data, coupled with the plasma profiles and EFIT equilibrium reconstruction that accounts for large rotation and q-profiles measured via the MSE, will be used to benchmark the predictive capability of theory and simulation codes.	same as above	
Wave-Particle Interactions – Role of electromagnetic waves, modes, and energetic particles in sustaining and controlling hot plasmas Contacts: Cynthia Phillips (ckphillips@pppl.gov) and Randy Wilson (jwilson@pppl.gov)		needed plasma measurements	routine operation, under active development, ***EXAMPLES of potential future diagnostics***
Assess the effects of supra-Alfvénic fast ion driven instabilities on driven current in the plasma core.	Experiments will be carried out where the neutral beam driven current is maximized, such as in moderate density, high electron temperature plasmas. Toroidal Alfvén eigenmodes (TAE) and energetic particle modes (EPM) are expected to be excited with a relatively sharp threshold in the beam energy, and hence the degree to which the fast ions become supra-Alfvénic. By operating just above and below this threshold, the current profile evolution can be	equilibrium reconstruction	magnetic sensors + profile diagnostics
		low (m,n) MHD modes - $\Delta\varepsilon_{xray}$	poloidal multicolor x-ray arrays
		low (m,n) MHD modes - ΔB	low frequency Mirnov coils
		high frequency instabilities-ΔB	fast Mirnov coils on outer wall
			fast 2-D Mirnov coils on CS

	compared in otherwise very similar discharges, correlated with the presence and absence of these modes. The Motional Stark Effect (MSE) diagnostic will be used to measure current profile evolution. Recent analysis of the onset of the sawtooth-like core reconnection instability when q(0) reaches unity provided independent validation of this measurement. Mirnov coils, soft x-ray cameras, heterodyne reflectometers, and far-infrared tangential interferometers will be used to characterize these modes. The scanning and solid-state neutral particle analyzer (NPA) diagnostics will be used to monitor fast ion transport, assisted by the fast lost ion probes (FLIP, SFLIP) and neutron diagnostics.	high frequency instabilities-Δn_e	heterodyne reflectometer
			FIReTIP
		$q(R)$, $E_r(R)$	MSE/CIF
			MSE/LIF/DNB
		$n_e(R)$, $T_e(R)$	TS
		$T_i(R)$, $v_{tor}(R)$, $v_{pol}(R)$, $n_c(R)$, $E_r(R)$	toroidal CHERS
			edge Doppler spectroscopy
			poloidal CHERS
		fast $T_e(R)$	poloidal multicolor x-ray arrays
			EBW radiometry
			tangential multi-color x-ray arrays
		fast $n_e(R)$	FIReTIP
		fast ion distribution	scanning NPA
			SSNPA
			D_α spectroscopy
		absolute fast ion loss	FLIP, SFLIP
		neutron source strength	fission chamber
			fast scintillator detectors
		neutron source profile	prototype neutron collimator
			multi-channel neutron collimator
Compare data on supra-Alfvénic fast ion driven modes with non-linear simulations of these modes.	Experimental data collected in the 2005 campaign from high performance regimes with supra-Alfvénic-ion driven instabilities will be used to benchmark M3D and HYM simulations and guide the code development. Data from the Fast Ion Loss Probe (FLIP, SFLIP) on the energy and pitch angle of the lost fast ions, and from the scanning Neutral Particle Analyzer (NPA) on the distribution of the fast ions in energy, pitch-angle, and position, will be used to correlate with the responsible modes. Data on mode structure from the Mirnov magnetic coil arrays, fast ultra-soft x-ray cameras, the heterodyne reflectometers and tangential interferometers will be compared with calculations using the HYM and M3D extended MHD codes.	same as above	

Characterize the interaction between the edge plasma region and the launched High Harmonic Fast Waves (HHFW), and determine plasma and wave launch conditions that permit efficient heating and current drive via HHFW.	Initial results in FY2004 indicated the existence of strong ion heating in the plasma edge region by the RF fields launched from the HHFW antenna. These investigations will continue using edge probes and edge rotation diagnostics (ERD) to look for likely edge RF heating mechanisms due to decay waves resulting from nonlinear coupling in the presence of large plasma gradients. In addition reflectometry will be used to monitor wave penetration deeper than the plasma periphery. Electromagnetic sensors will be used to look for the presence of far-field sheaths which can be driven by surface waves propagated away from the launchers. Variations in the edge plasma parameters and antenna phasing and geometry will be explored to determine approaches to maximize the overall effectiveness of the HHFW heating and current drive.	equilibrium reconstruction	magnetic sensors + profile diagnostics
		q(R), $E_r(R)$	MSE/CIF
			MSE/LIF/DNB
		$n_e(R)$, $T_e(R)$	TS
		$T_i(R)$, $v_{tor}(R)$, $v_{pol}(R)$, $n_c(R)$, $E_r(R)$	toroidal CHERS
			edge Doppler spectroscopy
			poloidal CHERS
		near-field surface waves	RF probe at antenna
			SOL reflectometer
		far-field surface waves	***far field RF probe***
		wave propagation inside LCFS	***reflectometer***
			phase contrast imaging
		SOL density fluctuations	SOL reflectometer
		RF driven sheaths	***isolated tiles or tile Rogowskis***
Characterize the diffusion and loss of supra-Alfvénic fast ions due to fast-ion driven oscillations in low-aspect ratio, high-beta plasmas.	Experiments will be performed in high performance regimes where supra-Alfvénic-ion driven instabilities are predicted to enhance fast ion diffusion and loss, as well as in regimes chosen to optimize the effectiveness of the necessary diagnostics. A new collimated neutron detector will be used to measure the profile of neutron emission from which the fast-ion birth profile can be inferred. The Neutral Particle Analyzers (NPA and SSNPA) will be used to measure the distribution of the fast-ion population that remains confined in the plasma, from which the changes in fast-ion distribution caused by the instabilities can be inferred and correlated with the presence of fast-ion driven instabilities. The energy and pitch angle of fast ions lost from the plasma will be measured directly with the Fast Lost Ion Probe (FLIP, SFLIP). The fast-ion driven instabilities will continue to be characterized with diagnostics which include the fast soft x-ray cameras, the heterodyne reflectometers and the multi-channel far infrared tangential interferometer polarimeter (FIRe-TIP).	equilibrium reconstruction	magnetic sensors + profile diagnostics
		low (m,n) MHD modes - $\Delta\varepsilon_{xray}$	poloidal multicolor x-ray arrays
		low (m,n) MHD modes - ΔB	low frequency Mirnov coils
		high frequency instabilities-ΔB	fast Mirnov coils
		high frequency instabilities-Δn_e	heterodyne reflectometer
			FIReTIP
		q(R), $E_r(R)$	MSE/CIF
			MSE/LIF/DNB
		$n_e(R)$, $T_e(R)$	TS
		$T_i(R)$, $v_{tor}(R)$, $v_{pol}(R)$, $n_c(R)$, $E_r(R)$	toroidal CHERS
			edge Doppler spectroscopy
			poloidal CHERS
		fast $T_e(R)$	poloidal multicolor x-ray arrays
			EBW radiometry

			tangential multi-color x-ray arrays
		fast $n_e(R)$	FIReTIP
		fast ion distribution	scanning NPA
			SSNPA
			D_α spectroscopy
		fast ion loss	FLIP, SFLIP
		neutron source strength	fission chamber
			fast scintillator detectors
		neutron source profile	prototype neutron collimator
			multi-channel neutron collimator
Longer Term Goal: Elucidate the electron Bernstein wave (EBW) mode conversion physics critical to enabling EBW heating and current drive.	A critical issue for implementing EBW heating and current drive is to establish a resilient technique to efficiently couple rf power to EBWs in the plasma. Recently, the AORSA-1D full wave code has been modified to solve the EBW mode coupling in a 1-D slab geometry. The launch polarization was adjusted to obtain the maximum EBW coupling efficiency as a function of the poloidal and toroidal wavenumber of the incident microwave power [n_{pol} and n_{tor}, respectively]. Efficient coupling of near-circularly polarized microwave radiation was found for a launched electromagnetic wave		
		equilibrium reconstruction	magnetic sensors + profile diagnostics
		$q(R)$, $E_r(R)$	MSE/CIF
			MSE/LIF/DNB
		$n_e(R)$, $T_e(R)$	TS (with improved resolution)
		EBW coupling efficiency	fixed dual polarization EBW radiometer
			remotely aimable EBW radiometers viewing multiple harmonics

	with $n_{pol} = \pm 0.35$ and $n_{tor} = \pm 0.3$ at 28 GHz. Since the mode conversion process is reciprocal studying mode-converted thermal EBW emission with absolutely calibrated radiometers allows experimental benchmarking of the numerical modeling predictions of EBW coupling efficiency for specific values of n_{pol} and n_{tor}. Obliquely-viewing, dual polarization radiometry has been successfully employed on NSTX to evaluate the coupling efficiency of 16-18 GHz thermal EBW emission. An EBW coupling efficiency 80±20% was achieved in good agreement with ~ 65% coupling efficiency predicted by a model that included a 1-D full wave calculation of the EBW mode conversion layer, radiometer antenna pattern modeling and 3-D EBW ray tracing and deposition modeling. Thermal EBW emission at 16.5 GHz was consistent with the near-circular polarization predicted by modeling. Thermal EBW radiometric studies on NSTX are currently being extended to 20-40 GHz to test EBW coupling efficiency predictions from AORSA-1D at 28 GHz.		
Startup, Ramp-up, and Sustainment – Physical processes of magnetic flux generation and sustainment Contacts: Roger Raman (raman@aa.washington.edu) and Michael Bell (mbell@pppl.gov)		needed plasma measurements	routine operation, under active development, ***EXAMPLES of potential future diagnostics***
Assess the conditions in which a substantial amount of closed poloidal magnetic flux is created via Coaxial Helicity Injection.	The priority of current CHI experiments is demonstration of initial current persistence. The capacitor bank voltage, toroidal field and injector flux will be optimized to produce the highest possible start-up currents. The CHI-produced plasma will then be coupled to induction from the central solenoid to demonstrate compatibility of this new method with the conventional inductive method. The CHI produced plasma will also be ramped up using induction from the outer PF coils to a level where neutral beams and HHFW could be applied to sustain the current. In other complementary experiments we will apply voltage to the SOL of preformed discharges to investigate relaxation current drive and to study the physics of SOL profiles during edge	equilibrium reconstruction	magnetic sensors + profile diagnostics
		fast visible images	fast visible cameras
		$q(R)$, $E_r(R)$	MSE/CIF MSE/LIF/DNB
		$n_e(R)$, $T_e(R)$	TS
		$T_i(R)$, $v_{tor}(R)$, $n_c(R)$, $E_r(R)$	toroidal CHERS
		$v_{pol}(R)$, $E_r(R)$	poloidal CHERS
		neutral pressure at various locations	pressure gauges
		edge ΔB	edge dynamo probe
		fast (~0.5 ms) edge	MSE/LIF/DNB

	biasing.	n_e, T_e, q, E_r profiles	***thermal atomic beam spectroscopy***
			fast edge Doppler spectroscopy
		reconnection phenomena near injector	***toroidal Mirnov array near lower x-point region***
		induced currents in passive plates	***halo current Rogowski coils***
		MHD m,n mode structure	poloidal multi-color x-ray arrays
Test conditions for solenoid-free ramp-up of plasma to substantial plasma current.	Different combinations of RF, neutral beam, bootstrap drive, and external PF induction techniques will be studied to test effective current ramp-up from an initially low level to substantially higher plasma currents in NSTX. The science of poloidal-field-only startup of the plasma current has been and will continue to be a major goal of NSTX.	same as above	
Boundary Physics – Interface between fusion plasmas and normal temperature surroundings Contacts: Bob Kaita (rkaita@pppl.gov) and José Boedo (jboedo@fusion.ucsd.edu)		needed plasma measurements	routine operation, under active development, ***EXAMPLES of potential future diagnostics***
Characterize the plasma edge pedestals and scrape-off layer of low-aspect ratio, high confinement, high P/R plasmas.	The relationship of edge pedestal height, width, and gradient to the plasma edge fluxes, parameters, and configurations will be studied with improved spatial resolution in measurements using laser Thomson scattering, fixed probes, scanning probes, edge impurity spectroscopy, and reflectometry of microwave pulses. The impact of edge-localized modes and reconnection events on the edge and divertor and its distribution with conditions in the edge and scrape-off layer (SOL) will also be investigated. In addition, the balance between diffusive and convective cross-field transport will be studied with improved edge turbulence diagnostics. Also, filtered cameras, an array of fixed divertor Langmuir probes, a divertor bolometer, and a fast time response infrared camera will be implemented for more detailed measurements in the divertor region. Results will be compared with numerical calculations of the edge pedestal and SOL regions based on a collection of MHD stability (e.g., ELITE), and	equilibrium reconstruction	magnetic sensors + profile diagnostics
		q(R), E_r(R)	MSE/CIF
			MSE/LIF/DNB
		n_e(R), T_e(R)	TS (with improved resolution)
			fast scanning midplane probe
			thermal atomic beam spectroscopy
		fast T_e(R)	***edge tangential multi-color x-ray arrays***
		fast n_e(R)	FIReTIP
		T_i(R), v_{tor}(R), v_{pol}(R), n_c(R), E_r(R)	toroidal CHERS
			edge Doppler spectroscopy (with improved resolution)
			fast scanning midplane probe
			poloidal CHERS
		neutral pressure at	pressure gauges

	fluid steady-state (e.g., UEDGE), and time-dependent (e.g., BOUT) models.	various locations	hydrogen sensors
			MSE/LIF
		n_e, T_e at divertor target	fixed divertor tile probes
			dense pack probe arrays
		n_e, T_e in divertor	***fast scanning divertor probe***
			divertor TS
		radiated power in divertor	divertor bolometer
			high resolution divertor bolometer
		divertor target surface temperature	IR cameras
			fast IR camera
		impurity concentration in edge and divertor	visible filterscopes
			divertor visible/UV Doppler spectroscopy
		SOL and edge fluctuations	gas puff imaging
			SOL reflectometer
			fast scanning edge probe
		SOL and divertor flows	***Doppler spectroscopy***
			2D tangential Doppler imaging
			Mach probes
		HFS edge $n_e(R)$, $T_e(R)$, fluctuations	***JxB swing arm probe***
		SOL $T_i(R)$ anisotropy	***gridded energy analyzer***
		images of ELM dynamics	filtered fast cameras
		n_e, T_e fluctuations at divertor target	***dense pack probe arrays***
Characterize the effectiveness of lithium pellet injection and tile	Starting with plasma-facing surfaces well-conditioned via helium discharges, lithium pellets will be injected into ohmically heated plasmas systematically varied from inboard-limited to fully diverted configurations, to coat the plasma-interacting graphite tiles in NSTX.	same as above plus:	
		lithium deposition thickness	quartz micro-balances
			sample exposure (DIMES) probe
		sheaths	fixed divertor Langmuir probes

coating in controlling fuel recycling from the plasma facing components.	The effects of activated lithium coating on subsequent deuterium-fueled plasmas in varying configurations will then be documented and characterized. Of key interest in this research are detailed comparisons of fueling rates, deuterium, lithium, and carbon radiation, recycling, diffusion, and migration between discharges with and without lithium coating. A suite of spectroscopic, infrared and soft x-ray diagnostics will be applied for this purpose. The concomitant changes in the plasma core and edge properties will also be measured and documented, for ohmically and neutral beam heated L-mode and H-mode plasmas in inboard-limited and diverted plasma configurations. The results will clarify the location, surface area, and thickness of lithium coating needed to derive substantial benefits of lithium coating on graphite tiles, and guide the operation of a subsequent lithium evaporator aimed at achieving similar benefits more effectively. Understanding the science of a liquid lithium surface and its interactions with the boundary plasma is expected to be an important goal for FY 2008-2010.	SOL currents	***Rogowskis on divertor and passive plates***
Assess the long-pulse plasma conditions and operational requirements of edge heat and particle control of low-aspect ratio, high-confinement, high P/R plasmas.	Heat and particle fluxes from H-mode, high P/R (up to 8-14 MW/m on NSTX) plasmas will be characterized over a range of ELM conditions, using a suite of plasma edge, scrape-off layer, and plasma facing component measurements. The effects of lithium coating on the edge fluxes will be measured, together with the potential benefits on core plasma properties. The effects and compatibility of a high-density, radiative edge with long-pulse high-performance plasmas will be explored to assess its effectiveness in mitigating the high edge heat fluxes. The effects of the varying ELM conditions will be documented to determine its role in determining these fluxes and affecting the balance between cross-field and parallel transport in the SOL. Operating regimes that show improved plasma core conditions with adequate control of the ELMs and edge fluxes will be characterized and documented.	same as above	
Physics Integration – Physics synergy of external control and self-organization		needed plasma measurements	routine operation, under active development, ***EXAMPLES of potential future diagnostics***

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Characterize strongly shaped low-aspect ratio plasmas with high fractions of self-driven current and low toroidal induction voltage for durations that allow internal currents to redistribute.	High-confinement and high-beta plasmas are sustained for increased duration by avoiding deleterious MHD and providing more of the total plasma current with non-inductive sources (bootstrap, HHFW, and NBCD), thereby reducing the inductive current fraction. In the 2005 run period the plasma elongation will be increased using the modified PF1A coil to broaden the current profile and increase the bootstrap current fraction. The early heating and H-mode transition developed in the 2004 run period will be used to elevate the safety factor, keeping q > 1 for long periods, and allow the tailoring of the current profile by varying the timing of the transition. Routine use of the MSE diagnostic to measure the safety factor will enable correlating its evolution with MHD and transport features. Broad pressure profiles provide higher ideal beta-limits, and optimization of the pedestal and ELM regime will be attempted to access high confinement and high beta, which in turn enhance the bootstrap and diamagnetic current sources. Efforts will begin to examine the impact of lower toroidal fields, which is necessary to reach the very high beta, long pulse integrated scenario target. Lower toroidal fields increase beta, which will challenge the regime of strong n>0 external kink modes, RWMs, and their stabilization.	equilibrium reconstruction	magnetic sensors + profile diagnostics
		locked mode/RWM amplitude, phase	locked mode, RWM sensor coils
		$q(R)$, $E_r(R)$	MSE/CIF
			MSE/LIF/DNB
		$n_e(R)$, $T_e(R)$	TS
			fast scanning midplane probe
		fast $T_e(R)$	poloidal multicolor x-ray arrays
			EBW radiometry
			tangential multi-color x-ray arrays
		fast $n_e(R)$	FIReTIP
		low (m,n) MHD modes	poloidal multicolor x-ray arrays
			low frequency Mirnov coils
		$T_i(R)$, $v_{tor}(R)$, $n_c(R)$, $E_r(R)$	toroidal CHERS
		$v_{pol}(R)$, $E_r(R)$	poloidal CHERS
Benchmark and improve physics models and the time-dependent simulation codes with data from high-performance plasmas	This research will couple the free-boundary plasma evolution simulation of the TSC code to state-of-the-art heat, particle and momentum deposition modeling of the TRANSP code. In parallel, the gyrokinetic theory-based models for micro-turbulence and transport, such as the non-linear GS2 and GYRO codes, will be benchmarked against the experimental data from Milestone R(05-5) on turbulence and transport. Data of high-performance plasmas, from Milestone R(05-2) on physics integration, will be used to benchmark and update	same as above plus:	
		n_e, T_e at divertor target	fixed divertor tile probes
			dense pack probe array
		n_e, T_e in divertor	***fast scanning divertor probe***
			divertor TS

characterized by large self-driven current, high pressure relative to the applied toroidal field, and low toroidal induction voltage.	the time-dependent scenario simulation from the TSC. Data of the plasma edge properties, from Milestone R(05-4) on boundary physics, will be used to determine appropriate boundary conditions for the time-dependent scenario simulation. Finally, an improved numerical plasma structure model will be implemented to improve the realism of time-dependent MHD stability simulations. The updated TRANSP and TSC codes will be applied to making improved predictions of future high-performance plasmas in NSTX and ITER.		
Characterize strongly shaped low-aspect ratio plasmas with high fractions of bootstrap current and zero toroidal induction voltage (solenoid-free) for durations that allow internal currents to redistribute.	In this study, strong shaping of the plasma cross section will be combined with neutral-beam and radiofrequency wave power to augment the current produced internally from the pressure gradient. The condition of zero loop voltage at the plasma edge will be studied to enable characterization of the remaining magnetic flux diffusion properties in the plasma core. The "bootstrap" current, *i.e.* the current driven internally by the radial pressure gradient in collisionless toroidal plasmas, has been identified to be particularly important in a spherical torus such as the NSTX. Such plasmas would be extended from the high-confinement discharges already produced in NSTX at ~800 kA in which up to 60% of the toroidal current has been sustained by a combination of the bootstrap effect and the current driven by the tangentially injected neutral beams (NBI). Enhanced shaping of the plasma cross-section, improvements in the confinement, and optimization of the plasma profiles will be applied to match the driven current profile with that required for MHD stability at the high pressure required to enhance the bootstrap current. Possible synergistic effects between the current drive mechanisms will be investigated to determine the optimal plasma operation scenarios in this investigation.	same as above	

Table II. NSTX Measurement Capabilities – July 2005

(black = routine operation, blue = under active development)

Physics Measurement	Typical range and coverage	Spatial; Temporal Resolution	Typical Precision	Available Diagnostic Techniques	Comment	Contact
Coil currents		follow pulse shape.	0.5%	Rogowski coil on buswork	For EFIT equilibrium reconstruction	J. Menard – PPPL
Plasma current, I_p,		0.1 ms	1.0%	2 Rogowski coils around plasma outside vacuum vessel	For EFIT reconstruction	J. Menard – PPPL
Plasma position		10 mm absolute 1 ms	3 mm with RTEFIT	2D and 3D solenoids inside vv, flux loops inside and outside vv	For EFIT reconstruction	J. Menard - PPPL
Plasma kinetic energy	> 10 kJ	1 ms	1 kJ	diamagnetic loop	EFIT constraint, uses TF coil	M. Bell - PPPL
Electron density line integrals	>2x10^{11} cm^{-2}	500 kHz	2x10^{11} cm^{-2}	tangential interferometry, polarimetry (FIReTIP)	FIR laser with retro-reflectors in 4 tangential chords (2 additional under dev)	K. C. Lee – UC Davis
		500 kHz		1 mm radial interferometer	1 mm reflected from center stack	S. Kubota - UCLA
Electron density profile	5x10^{11} - 5x10^{14} cm^{-3}	3.0 cm core, 0.9 cm edge, 2 30 Hz lasers	>3%	Thomson scattering	60 Hz Nd:YAG, laser nearly radial on horizontal midplane, 30 of 48 channels implemented	B. LeBlanc - PPPL
	2x10^{12}– 3x10^{13} cm^{-3}	40 kHz	~ 1 cm	reflectometry FM/CW	13 – 50 GHz swept; 40 kHz sweep rate (cannot be used at same time as correlation system)	S. Kubota - UCLA
	.02-1.6x10^{13} cm^{-3}	1 kHz		reflectometry (SOL)	6 - 36 Ghz swept system, 1 kHz sweep rate	J. Wilgen - ORNL
	0.1-1.6x10^{13} cm^{-3}	1.5 mm, 2 ms per point, 60 ms per profile		fast scanning midplane probe	18 cm below midplane, τ_{insert}<100 ms, τ_{dwell} =2-50 ms, 10 tips	J. Boedo - UCSD
Electron temperature profile	0.003 – 5 keV	3.0 cm core, 0.9 cm edge, 2 30 Hz lasers	>3%	Thomson Scattering	2 - 30 Hz Nd:YAG lasers nearly radial on horizontal midplane, 30 of 48 spatial channels implemented	LeBlanc - PPPL
				fast scanning midplane probe	see above	J. Boedo - UCSD
	0.1-5 keV	4 cm, < 100 kHz	5% (rel)	tangential multi-color sxr arrays	3 color/ 16 spatial channels, CsI:Tl phosphor and PM arrays	L. Delgato - JHU
				imaging horizontal x-ray crystal spectrometer	requires Ar injection, spherical crystal with 2D multi-wire proportional counter	M. Bitter - PPPL

				EBW radiometer	oblique X-mode (dual polarization) 20-40 GHz (have also used 16 – 18 GHz) aiming adjustable between runs	G. Taylor- PPPL J. Kaughman. J. Wilgen - ORNL
Ion temperature profile	0.02 – 5.0 keV	3.0 cm core, 0.5 cm edge, 10 ms	≥ 2%	toroidal CHERS	51 channels system using C VI with heating beam, dedicated background view	R. Bell - PPPL
		~3.0 cm (R=139-158 cm), 10 ms	≥ 2%	edge Doppler spectroscopy	7 channels from tangential view and 6 channels from vertical view of outer midplane edge. Uses intrinsic C III, C IV, and He II.	R. Bell - PPPL
	0.2 – 5.0 keV	2.5 cm, 5 ms	≥ 5%	scanning neutral particle analysis	horizontal and vertical scan, profile requires vertical scan, L-mode beam heated discharges only	S. Medley - PPPL
		5 cm, 20 ms		imaging horizontal x-ray crystal spectrometer	vertical profile ±30 cm, requires Ar injection, spherical crystal with 2D multi-wire proportional counter	M. Bitter - PPPL
Plasma rotation profile	-100 km/s to +300 km/s	3.0 cm core, 0.5 cm edge, 10 ms	≥ 2%	toroidal CHERS	see above	R. Bell - PPPL
		see above	≥ 2%	edge Doppler spectroscopy	see above	R. Bell - PPPL
		3.0 cm core, 0.5 cm edge, 10 ms		poloidal CHERS	up and down views of heating beam and dedicated background views	R. Bell - PPPL
		see above		edge Doppler spectroscopy	see above	R. Bell - PPPL
				imaging dual vertical x-ray crystal spectrometer	dual system to separate toroidal and poloidal components, requirese Ar injection, spherical crystals, 2D multi-wire proportional counters	M. Bitter - PPPL
B field pitch (for determination of q(R) using EFIT)		3 cm core, 2 cm edge, 10 ms (target 5 ms)	≥ 0.2°	motional Stark effect based on collisionally-induced-fluorescence (MSE/CIF)	8 of 19 channels implemented, presently applies correction for toroidal rotation, requires heating beam source A.	F. Levinton, H. Yu - NOVA
		target - 3 cm core, 2 cm edge, 10 ms	target ≥ 0.2°	motional Stark effect based on laser-induced-fluorescence (MSE/LIF) using DNB	requires compact, radial DNB	F. Levinton, J. Foley - NOVA
Profile of the radial Electric field		3 cm core, 2 cm edge, 10 ms		MSE/CIF and MSE/LIF	see above; requires heating source A and DNB	F. Levinton, H. Yu, J. Foley - NOVA

		3.0 cm core, 0.5 cm edge, 10 ms		toroidal and poloidal CHERS	see above; requires heating beam	R. Bell - PPPL
		3.0 cm, 10 ms		edge Doppler spectroscopy	may need helium	R. Bell - PPPL
	10V–30kV/m	1.5 mm, 1 µs		fast scanning midplane probe	see above, edge only	J. Boedo - UCSD
Radiation profile		8 cm, 0.2 ms		toroidal bolometer array	tangential view, 19 AXUV diode array	S. Paul - PPPL
		8 cm, 5 ms		divertor bolometers	4 foil bolometers viewing divertor from outside	S. Paul - PPPL
Z_{eff}		line integral	10% abs.	visible continuum sensor	single filter -spectroscopy chord, R_{TAN}~60 cm, λ=FILL IN VALUE	C. Skinner - PPPL
		3.0 cm core, 0.5 cm edge, 10 ms	≥ 5% in (Z_{eff}-1)	toroidal CHERS	see above, assumes C only impurity	R. Bell - PPPL
Impurity concentrations	C^{+5} conc.	3.0 cm core, 0.5 cm edge, 10 ms	20% abs.	toroidal CHERS	see above	R. Bell - PPPL
	H/D ratio, detachment signature, line emission	Integral; 10 ms	5% (rel)	Visible (VIPS) survey spectrometer	several sightlines coupled via fiber to 0.5 M Czerny-Turner; 3500-11000Å, CCD detector	B. Stratton, C. Skinner - PPPL
	O/C ratio, impurity influx	Integral; 15 ms	5% (rel)	VUV (SPRED) survey spectroscopy	100 – 1100Å with 2 gratings, radial midplane view, microchannel plate with CCD readout	B. Stratton, C. Skinner - PPPL
	Z≥6 ions (C, O, Cu, Ne, Ar, Kr)	5 cm; 5 ms for impurities	15% abs	filtered poloidal sxr arrays	1 vertical array (16 ch); 2 horizontal arrays (32 ch); discrete AXUV diode arrays	K. Tritz - JHU
		r/a~ .08, 100 ms	15% abs	TGI spectrometer	12 chord transmission grating imaging spectrometer; 10Å – 300Å CMOS detector	D. Stutman - JHU
Low (m,n) MHD modes, sawteeth, locked modes, and disruption precursors	ΔB/B = 10^{-4} – 10^{-1}, (0,0)<(m,n) < (5,10)	poloidal DC – 250 kHz toroidal DC – 2 MHz		low frequency Mirnov coils outside plasma	12 toroidal, 24 poloidal	J. Menard - PPPL
		5 cm; < 300kHz bw		filtered poloidal sxr arrays	1 vertical array (16 ch); 2 horizontal arrays (32 ch); discrete AXUV diode arrays	K. Tritz - JHU

				fast tangential soft x-ray pinhole camera	uses various foils and apertures, phosphor and demagnifying image tube with PSIV camera ($5x10^5$ frames/sec for 300 frames)	B. Stratton - PPPL
		4 MHz		quadrature reflectometer	30, 42, 49 GHz	S. Kubota - UCLA
		500 kHz		Neutron scintillator array	plastic scintillators with PM tubes 1-ZnS; 3 BC400	L. Roquemore - PPPL
				dynamo probe on fast scanning midplane probe		J. Boedo - UCSD
High frequency instabilities (MHD, fast ion modes)	$\Delta B/B \leq 10^{-2}$, $\Delta n/n \leq 10^{-2}$, $n = 10 – 50$, $\Delta\phi \leq 10^{-2}$	5 MHz		Mirnov coils outside plasma	B_T and B_P	E. Fredrickson – PPPL
		5 cm; < 300kHz bw		filtered poloidal sxr arrays	1 vertical array (16 ch); 2 horizontal arrays (32 ch); discrete AXUV diode arrays	K. Tritz - JHU
	1.1, 2.2, $3x10^{13}cm^{-3}$	4 MHz		quadrature reflectometer	30, 42, 49 GHz	S. Kubota - UCLA
	$>2x10^{11}$ cm^{-2}	500 kHz	$2x10^{11}$ cm^{-2}	tangential interferometry, polarimetry (FIReTIP)	FIR laser with retroreflectors in 4 tangential chords (2 additional)	K. C. Lee – UC Davis
	$>2x10^{11}$ cm^{-2}	500 kHz	$2x10^{11}$ cm^{-2}	1 mm radial interferometer	1 mm reflected from center stack	S. Kubota - UCLA
Core turbulence		10 ms sweep time		correlation reflectometry	26-40 Ghz (for peaked density profiles and low density discharges)	S. Kubota - UCLA
		$-20 cm^{-1}<k_r<20 cm^{-1}$, $\Delta R \sim 5$ cm	$\Delta n/n$ >0.1%	high-k scattering	tangential microwave scattering at λ= 1 mm, 5 detector channels viewing r/a ~ 0.3-0.8	E. Mazzucat0, H. Park, D. Smith - PPPL
		> 2 cm dependent on final geometry	$\Delta n/n$ >1%	usxr telescope BES	multilayer mirror telescope viewing core lithium beam emission. Needs lithium	D. Stutman - JHU
Edge turbulence	10% -100% Δn_e, $\Delta\phi$	1.5 mm, 1 µs		fast scanning midplane probe	see above	J. Boedo - UCSD
	ΔT_e	1.5 mm, 1 µs		fast scanning midplane probe	see above	J. Boedo - UCSD
		~ 1 cm for r/a> 0.8, <500 kHz		gas puff imaging	Supported by gas puff manifold. Various fast cameras used	S. Zweben – PPPL, R. Maqueda - NOVA
	B, ΔB .01 – 100G	1 mm, 2 µs		dynamo probe tip on fast scanning probe	all components	J. Boedo - UCSD

Edge recyling and impurity influx		2 kHz		filterscopes	5 upper divertor, 5 lower divertor, 12 midplane CS. filters include $H_{\alpha,\beta,\gamma}$, CII, CIII, LiI, BII,	V. Soukhanovskii – LLNL, R. Maingi – ORNL, C. Skinner - PPPL
		0.2 ms/frame		1D CCD cameras	2 lower divertor, 1 midplane CS, 1 radial horizontal view of lower divertor	V. Soukhanovskii – LLNL
		1.5 cm sightline separation		high resolution divertor fiber view	32 channels viewing inner and outer divertor from top, channel separation at divertor 1 – 3 cm. Used with filterscopes and visible spectrometers	V. Soukhanovskii - LLNL
Edge and SOL flows	Mach .1-2	1.5 mm, 1 μs		fast scanning midplane probe	see above	J. Boedo - UCSD
	helium	1 cm, 10 kHz		paired interference filter Doppler spectroscopy	uses fiber views of gas puff manifold	S. Paul - PPPL
Dust monitoring		1 kHz	sens. 1μg/cm^2	electrostatic grid detector	biased fine pitch PC grid, pulse counting electronics, Bay C bottom	C. Skinner - PPPL
First wall deposition		2 sec continuous		quartz microbalances	three QMBs (top, bottom, midplane), 2 shuttered, Inficon XTM/2	C. Skinner - PPPL
Spectroscopic n_e , T_e in divertor		1.5 cm sightline separation		visible filterscopes viewing lower divertor	see above	V. Soukhanovskii - LLNL
n_e , T_e at target	3 - 50 eV			Langmuir probes	flush-mount probes embedded in carbon tiles (3 inner div, 4 outer div.- upper and lower, 8 on CS)	C. Bush - ORNL
Neutron source profile				neutron collimator	multiple sight lines through plasma core region	L. Roquemore - PPPL
Neutron flux monitors		1 ms	5% rel. 25% abs.	fission chambers	2 U^{235} detectors with x26 sensitivity ratio	l. Roquemore - PPPL
		0.2 μs	<5% rel.	scintillator detectors	plastic scintillators with PM tubes 1-ZnS; 3 BC400	L. Roquemore - PPPL
RF driven surface waves				high-frequency Langmuir probe	located between antenna segments,	R. Wilson – PPPL, J. Wilgen - ORNL
Mode conversion efficiency of EBW emission				EBW radiometer	see above	G. Taylor - PPPL
Gas pressure at several locations				Penning gauges	1 in lower devertor, 1 in upper divertor, 1 in pumping duct with spectroscopy, 1 below lower divertor with spectroscopy	R. Raman – U. Wash

				micro-ion gauges	4 at midplane, 1 top, 1 in pumping duct	R. Raman – U. Wash
				in-vessel ion gauges	2 gauges use field during shot	R. Raman – U. Wash
Gas composition in vacuum ducts	typ A = 1-100, ΔA=1, between pulses	1 minute mass sweep	10^{-11} torr typical sens.	Residual gas analyzer	In Bay L pumping duct, differentially pumped system	W. Blanchard - PPPL
Runaway electrons		10 ms	30%	hard X-ray detector	at start-up and thermal quench	L. Roquemore, K. Hill - PPPL
First wall filtered visible images	Kodak	182x239	8 bit	1 kHz	cameras share various views: • top view of lower divertor • tangential view of lower divertor • fish eye radial view of entire plasma • 3 tangential midplane views including one view near pellet port • view of gas puff manifold along B field	C. Bush - ORNL
	Kodak		8 bit	1 kHz		L. Roquemore-PPPL
	PSI V	64x64	12 bit	300 frames at 250 kHz		S. Zweben - PPPL
	Photron (intensified)	>64x64	8 bit	<40 kHz		K. Shinohara - JAERI
	Photron	>64x64	8 bit	<40 kHz		N. Nishino – U. Hiroshima
	Phantom	>64x64	12 bit	120 kHz continuous		R. Maqueda - NOVA
	Canadian Photonics			<40kHz		R. Kaita - PPPL
	DICAM	1024x1080		2 frames at > 3nsec sep		L. Dorf, G. Wurden - LANL
First wall temperature	20-1200°C	30 Hz, 15° FOV	5°C abs <1°C rel	IR Cameras	2 FLIR Omega and 1 FLIR Alpha compact μbolometer cameras with views of lower divertor, CS, and beam armor	R. Maingi - PPPL
Vacuum Vessel Illumination				3 in-vessel tungsten filaments, ~ 25x5 mm helical	Provide lighting of the first-wall surfaces, Bays G and K near midplane, Bay K/L above midplane	H. Kugel - PPPL
Fast Lost Ions				FLIP	radial array of Faraday cups	D. Darrow - PPPL
		13-40 kHz with intensified Photron camera		SFLIP	scintillator probe with energy and pitch angle resolution	D. Darrow - PPPL K. Shinohara - JAERI
Fast ion distribution	1-100 keV	2 msec	rel 5% abs. x2	scanning NPA	horizontal and vertical spatial distribution	S. Medley - PPPL

	35 – 100 keV	1 msec counting window		solid state NPA	4 chords R_{TAN}= 60, 90, 100, 120 cm, Si-diodes with 0.15µ Al foils and apertures, pulse height analysis	D. Liu, W. Heidbrink – UC Irvine

Table III. Systems Capable of Supporting Active Diagnostics - July 2005

(black = routine operation, blue = under active development, ***red = EXAMPLES of potential future diagnostics***)

System	Purpose of system	Characteristics	Used in diagnostic:	Contact
Heating Neutral Beam	Provide neutral population to produce beam emission for various diagnostics	D, 90 - 100 keV, ~50cm V x 20cm H, ~ 150mA/cm^2 neutrals entering plasma	CHERS, MSE/CIF, MSE/LIF, ***BES (D), BES (impurity seeded)***	T. Stevenson - PPPL
Diagnostic Neutral Beam	Provide excited neutral atoms for intensity and polarimetry measurement	H, 40 keV, 1 - 2 cm dia., 30 mA neutrals entering plasma	MSE/LIF/DNB	F. Levinton, J. Foley NOVA
Impurity Pellet Injector	Provide impurity population to enhance signals	solid pellets or dust, .5 – 10 mg per sabot, < 200 m/s, ≤ 8/pulse	***pellet plume detector*** ***BES (impurity seeded)***	H. Kugel - PPPL
Supersonic Gas Injector	Provides low divergence, high pressure gas jet	Laval nozzle, on midplane probe	***thermal atomic beam spectroscopy***	V. Soukhanovskii - LLNL
Gas Puff Manifold	Provides neutral atoms to highlight edge density turbulence	linear manifold ⊥ to edge B field, multiple 1 mm dia holes, D, He or Ar.	gas puff imaging ***2-D Doppler imaging***	S. Zweben - PPPL