Version 7 - August 20, 2007

NSTX Program Letter for Research Collaboration by Universities and Industry for FY 2008-2010

Introduction

This NSTX Program Letter provides updated information about NSTX topical research priorities and collaboration opportunities during the upcoming three years (FY 2008-2010). This information is useful for the preparation of proposals from universities and industry in response to the Office of Science Notice *Fusion Research on National Spherical Torus Experiment*, which will be issued in early August 2007. Researchers from universities and industry have typically carried out approximately one third of the collaborative research on NSTX. Major diagnostic development and implementation proposals are not the primary emphasis of this Program Letter, as such proposals will be emphasized in 2008. This Program Letter suggests specific collaboration opportunities, as well as broader areas of research, in order to encourage proposals that address the research areas on NSTX. These research areas were described in the NSTX Five-Year Plan[1] and the FESAC Facilities Report[2]. In the Appendix to this Letter, these areas are cross-referenced to the ten-year goals in the FESAC Priorities Report as background information.

The NSTX Program Advisory Committee reviewed this Program Letter on August 6, 2007. Its advice was incorporated in the final version.[3]

Mission of NSTX

The *programmatic* mission of NSTX is to evaluate the attractiveness of a compact Spherical Torus (ST) configuration—such as a Component Test Facility[4] (CTF)—in reducing cost, risk, and development time for practical fusion energy; to contribute to the physics basis for an ST-based DEMO device; and to use the special properties of NSTX in order to resolve key burning plasma physics issues anticipated in ITER. The NSTX programmatic mission thus addresses two of the long-term goals of the Office of Fusion Energy Sciences: viz., configuration optimization, and developing a predictive capability for burning plasmas. Both ITER participation and also CTF development are included in the DOE 20-year strategic plan for the Fusion Energy Sciences Program.[5]

In support of the above programmatic mission, the *scientific* mission of NSTX is to advance fusion plasma science by understanding the special physics principles of the Spherical Torus (ST). Due to its low aspect ratio, the ST is characterized by strong magnetic field curvature and by high β_T (the ratio of the average plasma pressure to the applied toroidal magnetic field

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[1] http://nstx.pppl.gov/Pages_folder/research_folder/5YrPlan.html.

[2] http://www.ofes.fusion.doe.gov/more_html/FESAC/FacilitiesVol1.doc and http://www.ofes.fusion.doe.gov/more_html/FESAC/FacilitiesVolume2_v3.pdf.

[3] http://nstx.pppl.gov/nstx/NSTX_Program_Letter (available August 20, 2007).

[4] Recent information on the concept of compact CTF is available in Peng et al., IEEJ Transaction **125** (2005) 1 and Peng et al, Plasma Phys. Control. Fusion **47** (2005) B263. CTF plasmas are expected to be similar in nature to ITER driven steady-state plasmas, for which $f_{BS} \sim 0.5$ and $\beta_N \sim 0.5\ \beta_{Nlimit}$.

[5] http://www.sc.doe.gov/bes/archives/plans/SCSP_12FEB04.pdf.

pressure). The ST, with its unique properties, thus extends and complements the normal aspect ratio, lower β_T tokamak in addressing the overarching scientific issues in magnetic fusion energy science.

NSTX Research Priorities and Key Collaboration Opportunities for FY 2008-2010

This section lists the research topics of high priority in the NSTX Program during FY 2008-2010 and then highlights key collaboration opportunities for which collaborative research proposals are solicited. The NSTX research priorities and key collaboration opportunities are organized according to the six categories used in the FESAC Priorities Plan. For each category a key person is listed who should be contacted for further information prior to submitting collaboration proposals.

The list of research priorities is guided by the NSTX programmatic and scientific missions and by its schedule of milestones, subject to anticipated funding during FY 2008-2010. The key collaboration opportunities highlighted below were determined on the basis of several factors: what the NSTX Program considers to be necessary; what the program thinks could be contributed through university and industry grants, what is currently being carried out through diagnostic grants, ongoing contributions from other national laboratories, and by the PPPL team. Proposals for innovative collaboration activities beyond the ones listed in this Program Letter are also welcomed; such proposals might be motivated by the list in Appendix A. All proposals will be considered by means of the normal DOE peer review process, according to the criteria described in the solicitation announcement.

I. ***Macroscopic Plasma Physics*** – the role of magnetic structure in plasma confinement and the limits to plasma pressure in sustained magnetic configurations.
For more information contact: Jon Menard (jmenard@pppl.gov)

Research Priorities:

I-1. *Optimize error field correction and resistive wall mode (RWM) control to produce stable, shaped, toroidally rotating plasmas above the "no-wall" pressure limit – relevant to CTF.*

Background:

Significant progress has been made in NSTX in the detection and active control of error fields (EF) and resistive wall modes (RWMs), understanding passive RWM stability, and in understanding and controlling toroidal flow damping from non-axisymmetric fields. More advanced control algorithms and enhanced predictive capability are sought to understand present RWM and EF results and allow extrapolation of performance to ITER and future STs. In particular, the high-β, near-Alfvenic toroidal flow velocities from NBI, the ability to control the toroidal flow velocity with magnetic braking, and the strong toroidicity of NSTX provide an excellent test-bed for validating models of RWM control and mode damping. Alternative non-magnetic mode detection techniques may ultimately be required for burning plasmas, and could also benefit existing experiments. Finally, the interplay between edge-resonant magnetic perturbations for ELM control and locked mode and RWM stability is an important related area of research.

I-2. *Identify, understand, and control modes that tear magnetic field surfaces and limit plasma pressure and energy confinement as the plasma pressure approaches and exceeds ideal stability limits.*

Background:

Recent research has revealed the importance of neoclassical tearing instabilities in limiting the plasma poloidal β and bootstrap fraction. Low-frequency (f=1-30kHz) MHD activity (including tearing activity) has also been observed to redistribute the fast ions from neutral beam injection, but the mechanism by which this occurs is not quantitatively understood. Such physics may be relevant to proposed "hybrid" operating scenarios for ITER. Strong rotation and rotational shear, enhanced stabilization effects from curvature, and enhanced mode coupling may all play a significant role in modifying tearing mode stability in NSTX.

I-3. *Understand the effects of significant loss of plasma thermal and magnetic energy caused by exceeding a global macroscopic stability threshold.*

Background:

NSTX has contributed plasma current quench rate data to the ITPA international database on disruptions with application to ITER. Low aspect ratio data has already improved the understanding of the quench rate scaling for all aspect ratios, and NSTX has begun extending these studies to measure halo currents and characteristics of the thermal quench. Additional data analysis and modeling of disruptions is desired to develop a predictive capability for disruptions applicable to the ST – in particular for low internal inductance, high elongation, high β, strongly wall-coupled plasmas of STs.

Key Collaboration Opportunities in Macroscopic Plasma Physics:

- *Model and test advanced methods for control of Resistive Wall Modes (RWM) and error fields, and assess the impact of possible off-midplane control coils on macroscopic stability. Understand dissipation mechanisms responsible for RWM stabilization via rotation. Assess the feasibility of non-magnetic sensors for diagnosis and control of the plasma boundary, the plasma-material interface, and low-frequency plasma instabilities.*

- *Develop tearing mode stability modeling tools, compare to experiment, and develop mode avoidance techniques for NSTX plasmas taking into account the unique ST physics features described above.*

- *Perform data analysis for and numerical simulations of disruptions in NSTX, focusing on halo current magnitude and peaking, and the thermal quench.*

II. ***Multi-Scale Plasma Physics*** – physical processes that govern the confinement of heat, momentum, and particles in plasmas.

For more information contact: Stan Kaye (skaye@pppl.gov)

Research Priorities:

II-1. *Determine relationship between local high-k turbulence and electron heat transport.*

Background:

NSTX results indicate that ion energy and particle transport levels are routinely at the neoclassical level, implying suppression of long-wavelength turbulence and associated anomalous transport. Such suppression is likely related to NBI-induced toroidal rotation leading to ExB shearing rates exceeding low-k turbulence growth rates. This plasma state with (controllable) suppression of long-wavelength turbulence provides an excellent environment to study short wavelength turbulence and its relationship to electron heat transport. For some plasma configurations, the recently implemented high-k scattering diagnostic is already revealing possible correlations between increased high-k fluctuation amplitude and increased electron thermal transport. Additional experiments, analysis, and simulation are desired to more fully assess the relationship between electron transport and high-k fluctuation measurements.

II-2. *Establish plasma rotation and momentum transport properties, including momentum pinch, in sustained high-β plasmas relevant to ITER and CTF.*

Background:

Recent NSTX results indicate that angular momentum diffusivity is routinely significantly smaller than ion energy diffusivity. These results are qualitatively different than those commonly obtained in higher aspect ratio tokamaks, and may be the result of increased ExB flow shearing rates achievable in rapidly spinning low aspect ratio, high β NSTX plasmas. Further, recent experiments using perturbative momentum transport techniques indicate the existence of an inward momentum pinch. Improved understanding of this pinch, how it influences the interpretation of the diffusivity inferred from steady-state momentum balance, and the relationship to neoclassical theory is desired.

II-3. *Assess particle fueling and transport, and compare to existing theories, with application to fueling and density control requirements for NSTX lithium program, ITER, and CTF.*

Background:

Recent results indicate that Lithium evaporated onto the lower divertor surfaces of NSTX can act as a pump of hydrogenic neutrals, can reduce the bulk plasma effective charge, and increase plasma energy confinement. At high evaporation rates, Lithium can act as a strong pump, lowering the plasma density by as much as a factor of three at fixed fueling rate. Additional support is desired for experimental analysis and simulation of the potentially stronger pumping conditions expected during liquid lithium divertor (LLD) module operation in NSTX.

Key Collaboration Opportunities in Multi-Scale Plasma Physics:

- *Perform simulations of plasma turbulence for NSTX plasmas from ion to electron gyro-scales focusing on improved understanding of electron thermal transport. Perform experiments designed to test various theories of anomalous electron transport, and perform data analysis to support comparison of theory to experiment.*

- *Perform simulations of plasma turbulence for NSTX plasmas focusing on improved understanding of momentum transport, and perform experiments to support comparison of data to theory. Compare new poloidal rotation data to neoclassical theory, and use this data to improve radial electric field shear calculations for use in simulating low-k turbulence suppression, transport barrier formation, and momentum transport modifications. Extend neoclassical framework to low aspect ratio, full (large) gyroradius and banana width, high rotation, and high rotation shear regimes as needed.*

- *Develop modular 2D neutral transport simulations for incorporation into comprehensive plasma evolution codes to improve predictive modeling of NSTX plasmas in general, and particle transport in particular, and compare to experiment.*

III. ***Plasma Boundary Interfaces*** – the interface between fusion plasma and its lower temperature plasma-facing material surroundings.

For more information contact: Bob Kaita (rkaita@pppl.gov)

Research Priorities:

III-1. *Assess the performance of novel wall and divertor plasma facing component materials with respect to particle control and power handling with ITER-level heat fluxes and relevance to CTF.*

Background:

Results from TFTR, FTU, T-11, and CDX-U have shown that lithiumized limiters can dramatically improve particle control and energy confinement in magnetically confined plasmas. For the first time, NSTX has demonstrated that evaporated lithium can improve particle control and energy confinement in diverted H-mode plasmas. To investigate the effects of liquid lithium in diverted H-mode plasmas, NSTX will be implementing a liquid lithium divertor (LLD) module. Substantial additional analysis and experimentation is desired to understand and optimize LLD preparation and operation.

III-2. *Characterize, optimize, and control H-mode pedestal stability limits to provide a high-confinement plasma while avoiding/minimizing the impact of transient heat pulses from ELMs on the divertor.*

Background:

NSTX has made significant progress in characterizing pedestal stability and developing small ELM regimes, and is beginning to compare measured ELM stability thresholds to theory. Additional experiments and analysis are desired to understand the impact of the unique ST features (high edge magnetic shear, high elongation and triangularity, high edge flow and flow shear, etc.) on ELM stability. In addition, enhanced control of pedestal stability to completely suppress ELMs is important for future steady-state ST devices such as ST-CTF or ST-DEMO. An assessment of resonant magnetic perturbations and other techniques is also desired to understand the potential impact of unique ST features on ELM control. If NSTX were to adopt RMP coils, it would be the only ST capable of investigating the interplay between edge ergodization and operation above the no-wall stability limit. For example, edge flow damping from RMP could destabilize the RWM and therefore require active RWM control in ELM-mitigated high-β scenarios.

III-3. *Understand and control heat transport in the scrape-off-layer and at the divertor, with application to divertor operation at very high heat flux - compatible with high plasma performance and good particle control in next-step devices such as ITER and CTF.*

Background:

NSTX has made significant progress in developing a partially detached divertor regime for reducing peak heat flux at the divertor consistent with good H-mode confinement and acceptable density control. However, it is unclear if such techniques extrapolate to CTF, demonstration power plants, and reactors. Additional research is desired to understand the role of SOL transport and turbulence in determining the peak divertor heat flux, and to understand and project the applicability of various heat-flux mitigation techniques to CTF conditions.

Key Collaboration Opportunities in Plasma Boundary Interfaces:

- *Characterize the effects of lithium wall coatings and the liquid lithium divertor (LLD) module on recycling and particle control – including the requirements for core fueling. Perform modeling, laboratory experiments, and diagnostic feasibility studies focusing on understanding particle retention, heat flux mitigation, and ELM and disruption effects on the LLD.*

- *Perform experiments and modeling aimed at understanding and improving H-mode access and pedestal pressure limits in NSTX plasmas. Assess via experiment and/or simulation ELM reduction and elimination techniques. For example: development of small ELM regimes compatible with low pedestal collisionality, resonant magnetic perturbations (RMP), paced pellets, or other fueling/pumping modifications.*

- *Perform experiments, analysis, and simulation of scrape-off-layer density, temperature, and heat-flux profile scale-lengths, to develop a predictive capability for projecting divertor performance in next-step devices. Perform two-and three-dimensional plasma boundary physics modeling, including turbulent transport and intermittency for NSTX plasma conditions.*

IV. *Waves and Energetic Particles* – the use of waves and energetic particles to sustain and control high-temperature plasmas.

For more information contact: Gary Taylor (gtaylor@pppl.gov)

Research Priorities:

IV-1. *Characterize and simulate the transport of supra-Alfvénic fast ions due to fast-ion driven oscillations relevant to ITER and CTF.*

Background:

The capability to excite and diagnose a broad range of fast-ion driven instabilities makes NSTX a powerful tool for understanding energetic particle physics for ITER and future ST's. In 2007, NSTX researchers mapped and diagnosed the stability space of TAE modes - from mode onset to multi-mode avalanche threshold. In addition, coupling between Alfven Cascade modes and Geodesic Acoustic Modes was characterized, and the eigenstructure of high-β Beta-induced Alfven Acoustic Eigenmodes (BAAE) was measured and successfully compared to theory. Additional experiments, data analysis, and modeling are desired to determine the extent to which the Alfvenic MHD activity described above leads to transport of energetic particles with application to ITER and CTF.

IV-2. *Develop more efficient high-harmonic fast wave (HHFW) coupling, heating, and current drive with application to plasma ramp-up and sustainment in high-performance plasmas relevant to CTF.*

Background:

Extensive HHFW coupling and heating studies have identified surface wave excitation as a key parasitic absorption mechanism that can reduce the effective core heating efficiency. Surface wave excitation can occur for plasma conditions in which the fast wave can propagate close to the antenna and/or wall. Similar physics could play a role in the coupling of ICRF to ITER plasmas. Higher magnetic field, lower density at the antenna, and higher parallel wavenumber all reduce surface wave excitation. Further, for the first time, at high magnetic field (lower cyclotron harmonic number), HHFW has been shown to be capable of heating electrons in the presence of fast ions from NBI. These performance improvements motivate dedicated experiments and modeling aimed at incorporating HHFW into high performance NBI-heated H-mode discharges, and for heating during the current ramp to access scenarios with elevated safety factor.

IV-3. *Develop efficient Electron Bernstein Wave (EBW) coupling and ultimately heating and current drive for the over-dense plasma conditions of high-β STs with application to CTF.*

Background:

Recent experiments have demonstrated for the first time that significant Bernstein, X-mode, O-mode (B-X-O) mode conversion can be achieved in H-mode plasmas. High plasma elongation, boundary shape optimization, and evaporated Lithium can all apparently improve BXO conversion efficiency. To better understand the physical mechanisms by which these experimental parameters influence EBW mode conversion, additional experiments, simulation, and theory are desired. Moving beyond emission measurements, the first phase of a 28 GHz EBW heating system (coupling up to 250 kW of EBW power via OXB conversion) will be operational on NSTX by 2010. This new heating system will allow the study OXB conversion at power levels where parametric decay to lower hybrid waves or ponderomotive effects in the EBW mode conversion region could become important.

Key Collaboration Opportunities in Waves and Energetic Particles:

- *Simulation of, and participation in, experiments measuring the fast-ion distribution function and its evolution, focusing on the influence of MHD instability activity.*
- *Simulate and experimentally exploit the improved coupling efficiency of launched fast plasma waves, with emphasis on enhancing plasma performance in advanced operating scenarios with H-mode and NBI heating, and on heating during the plasma current ramp.*
- *Perform integrated experimental and theoretical studies of electron Bernstein wave excitation, propagation, heating, and current drive in NSTX. Extend present theory of EBW mode conversion - for example, investigate 2D equilibrium effects and/or improved edge wave damping models.*

V. *Plasma Start-up and Ramp-up without a Solenoid* – the physical processes of magnetic flux generation and sustainment.

For more information contact: Mike Bell (mbell@pppl.gov)

Research Priorities:

V-1. *Develop operating conditions that allow transition from Coaxial Helicity Injection (CHI) plasmas to standard inductively and non-inductively sustained toroidal plasmas.*

Background:

Coaxial helicity injection has created closed-poloidal-flux plasma current of up to 160kA on NSTX, and recently demonstrated transformer flux savings when CHI was added to an inductively-driven plasma current ramp. A key near-term research goal is to couple CHI to the standard (pre-charged solenoid) ohmic ramp-up scenario to extend the duration of high-performance NBI-heated H-mode discharges. Improving CHI plasma formation with increased ECH pre-ionization power, and coupling HHFW heating power to CHI plasmas are additional research objectives, with potential extrapolation to non-inductive current ramp-up to high current.

V-2. *Explore new plasma start-up techniques on NSTX, such as plasma-gun startup.*

Background:

Given the importance of solenoid-free plasma formation to the ST concept, all viable plasma start-up techniques (consistent with NSTX device constraints) will be considered for testing in NSTX. Plasma gun startup has produced plasma currents up to 30kA in the Pegasus experiment, and flux closure and core temperature increases have also been observed. Additional areas of research include an assessment of the impact of increased ECH pre-ionization power on gun startup, and possible synergies with vertical-field current ramp-up and possibly CHI.

V-3. *Develop scenarios for solenoid-free ramp-up to substantial plasma currents via heating and current drive by neutral beam injection and high harmonic fast wave.*

Background:

In addition to the goal of creating closed-flux plasma current without a solenoid, ramping the current to values compatible with sustained high-performance - without a solenoid - is also an important research objective for the ST. Current overdrive (from bootstrap and RF and NBI sources) is being pursued to provide current ramp-up to high performance. HHFW heating of low current H-mode discharges has achieved high poloidal beta and bootstrap current fractions up to 85%. Additional heating power, HHFW current drive, and sustained heating could all increase the non-inductive current drive, potentially allowing completely non-inductively-driven current ramp-up. With plasma currents sufficient for confinement of NBI fast ions, NBI current drive can also aid ramp-up.

Key Collaboration Opportunities for Start-up and Ramp-up:

- *Perform experiments and modeling aimed at improved control of, and increased current and closed poloidal flux production from, coaxial helicity injection plasmas. Explore synergies between CHI and vertical field ramp-up and increased ECH pre-ionization power.*

- *Implement plasma gun startup in NSTX, and explore synergies with vertical field ramp-up, CHI, and increased electron-cyclotron preionization power.*

- *Perform experiments,data analysis, and simulations to achieve non-inductive current-ramp-up from low current to currents relevant to high performance scenarios.*

VI. ***Physics Integration*** – the physics synergy of external control and self-organization of the plasma.

For more information contact: Dave Gates (dgates@pppl.gov)

Research Priorities:

VI-1. *Develop understanding of the evolution of high non-inductive current fraction plasmas with high-beta, high-bootstrap-fraction, and sustained conditions relevant to CTF and advanced operations in ITER, and how these plasmas could be achieved through a variety of tools, with integration of physics issues in categories I thru V above.*

Background:

Recent analysis of long-pulse high-non-inductive current fraction (up to 65%) discharges finds that in the absence of strong MHD activity, the current profile evolution of NSTX plasmas is well described by neoclassical theory combined with the beam current drive computed by TRANSP. While particular kinetic profiles have been identified which allow integrated high performance scenarios in NSTX, additional dedicated experiments and enhanced time-dependent modeling are desired to improve the prospects for achieving fully non-inductive high-β scenarios in NSTX.

VI-2. *Develop and simulate advanced plasma shape control techniques for plasma conditions relevant to CTF.*

Background:

(NOTE: Plasma control research on NSTX is typically covered by the Physics Integration group).

Real-time EFIT and iso-flux control algorithms have been successfully implemented on NSTX to provide robust control of several boundary parameters (outer gap, elongation, etc). With the upcoming implementation of the liquid lithium divertor (LLD) module, precise control of the strike point at the divertor surface is needed and will require more sophisticated feedback control. Dedicated experiments and new modeling tools to optimize the strike-point control are desired.

Key Collaboration Opportunities for Physics Integration:

- *Perform time-dependent modeling for, and participate in, the experimental development of advanced operating scenarios, focusing on verification and validation of models for plasma start-up, ramp-up, and sustainment - with particular emphasis on the sustainment phase.*

- *Simulate and implement advanced plasma boundary control techniques in the divertor with application to particle and power exhaust to a liquid lithium surface.*

Appendix: FESAC Priorities Panel 10-Year Goals (as additional background information)	**Relevant NSTX Research**
Macroscopic Plasma Physics	
1. Understand the coupled dependencies of plasma shape, edge topology, and size on confinement in a range of plasma confinement configurations.	1. I-1
2. Identify the mechanisms whereby internal magnetic structure controls plasma confinement.	2. I-2,3
3. Identify the effects and consequences on confinement of large self-generated plasma current.	3. V-3, VI-1
4. Learn how to control the long scale-length instabilities that limit plasma pressure.	4. I-1, 2
5. Understand and control intermediate to short wavelength modes responsible for limiting the plasma pressure, particularly at the edge, and extrapolate their effects to the burning plasma regime.	5. III-2,3
6. Understand the equilibrium pressure limits in a range of magnetic configurations, including the effects of islands, stochastic magnetic fields, and helical states.	6. I-2, III-2
7. Understand and demonstrate the use of self-generated currents and mass flows to achieve steady-state high-pressure confined plasmas and improve fusion energy performance.	7. VI-1
8. Understand how external control can lead to improved stability and confinement in sustained plasmas in a range of magnetic configurations.	8. I-1,2, III-2
9. Understand the pressure limits and confinement properties in configurations where magnetic turbulence controls the distribution of the equilibrium magnetic field and for similar configurations with reduced turbulence. Assess their prospects for study in more collisionless plasma regimes for possible extrapolation to practical sustained burning plasmas.	9. V-1,2
Multi-Scale Transport Physics	
1. Develop predictive capability for ion thermal transport using simulations validated by comparison with fluctuation measurements.	1. II-2
2. Identify the dominant particle transport mechanisms, including the conditions under which pinch/convective processes compete with diffusive processes.	2. II-3
3. Identify the dominant mechanisms for momentum transport and their relationship to thermal transport.	3. II-2
4. Understand generation of flow shear, regulation of turbulence, and self-consistent profile dynamics and local steepening, and to identify conditions and thresholds for edge and core barrier formation.	4. II-1, 2, 3
5. Identify the dominant electron thermal transport mechanisms, including the role of electromagnetic fluctuations, short-scale versus long-scale turbulence, and spectral anisotropy.	5. II-1
6. Identify the dominant driving and damping mechanisms for large-scale and zonal flows, including turbulent stresses and cascades.	6. II-1, 2
7. Identify the dominant mechanisms by which turbulence generates and sustains large-scale magnetic fields in high-temperature plasma.	7. V-1,2
8. Identify the mechanisms and structure of magnetic reconnection, including the role of turbulent and laminar processes, energy flow, and the production of energetic particles.	8. I-2, V-1,2,3
9. Identify the conditions for onset of island growth and the factors controlling saturation and coupling with transport.	9. I-2

Appendix: FESAC Priorities Panel 10-Year Goals (as additional background information)	**Relevant NSTX Research**
Plasma Boundary Interfaces	
1. Predict the expected magnetohydrodynamic stability and plasma parameters for the ITER H-mode edge pedestal with high confidence. This is a time-sensitive issue relevant to the success of ITER	1. III-2,3
2. Identify the underlying driving mechanisms for mass flow and cross-field transport in the scrape-off-layer plasma, in H-mode attached and detached plasmas.	2. III-2, 3
3. Resolve the key boundary-physics processes governing selection of plasma-facing components for ITER. This is a time-sensitive issue relevant to the success of ITER.	3. III-1,3
4. Complete the evaluation of candidate plasma-facing materials and technologies for high-power, long-pulse fusion experiments. This is a time-sensitive issue relevant to the success of ITER.	4. III-1,2,3
Waves and Energetic Particles	
1. Develop the capability to design high-power electromagnetic wave launching systems that couple efficiently and according to predictions for a wide range of edge conditions.	1. IV-2, 3
2. Produce, diagnose in detail, and model with nonlinear, closed-loop simulations the macroscopic plasma responses produced by wave-particle interactions, including localized current generation, plasma flows, and heating, in both axisymmetric and non-axisymmetric configurations.	2. IV-1,2,3
3. Develop long-pulse radio-frequency wave scenarios for optimizing plasma confinement and stability and to benchmark against models that integrate wave coupling, propagation, and absorption physics with transport codes (including microturbulence and barrier dynamics) and with magnetohydrodynamic stability models.	3. V-2,3, V-3, VI-1
4. Improve analysis and models to match the experimental measurements and scale the understanding to predict the dynamics of energetic particle-excited modes in advanced regimes of operation with high pressure, inverted magnetic shear, and strong flow.	4. IV-1
5. Identify the character of Alfvén turbulence and the evolution of the energetic particle distribution in a nonlinear system, which can be used to predict alpha-particle transport in a burning tokamak experiment; and to evaluate and extrapolate energetic particle behavior in present-day confinement systems to reactor parameters.	5. IV-1
Fusion Engineering Science	
1. Deliver to ITER the blanket test modules required to understand the behavior of materials and blankets in the integrated fusion environment.	1.
2. Determine the “phase space” of plasma, nuclear, material, and technological conditions in which tritium self-sufficiency and power extraction can be attained.	2. II-3, III-1,3
3. Develop the knowledge base to determine performance limits and identify innovative solutions for the plasma chamber system and materials.	3. III-1, 3
4. Develop the plasma technologies required to support U.S. contributions to ITER.	4. I-1, II-3
5. Develop the plasma technologies to support the research program.	5. I-1, III-1, IV-3, V-1,2, VI-2