NSTX

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NSTX FY2012 Milestone Idea Discussion

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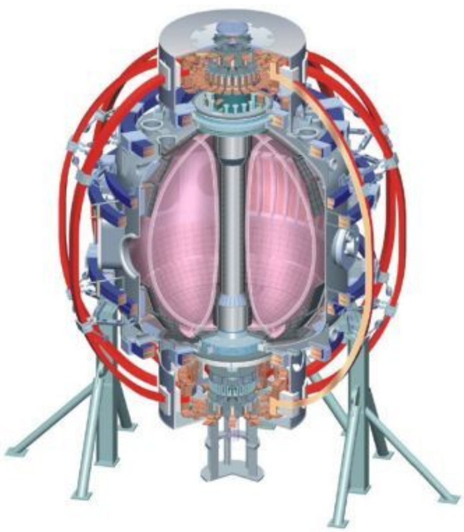

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NSTX FY2010-11 Research Milestones

(base and incremental)

	FY2010	FY2011	FY2012
Expt. Run Weeks:	15 w/ ARRA	14 (20)	14 (20)

1) Transport & Turbulence

- FY2011: Study turbulence regimes responsible for ion and electron energy transport

2) Macroscopic Stability

- FY2010: Assess sustainable beta and disruptivity near and above the ideal no-wall limit
- FY2011: Assess sustained operation above the no-wall limit at reduced collisionality

3) Boundary/Lithium Physics

- FY2010: Assess H-mode characteristics as a function of collisionality and lithium conditioning
- FY2011: Relationship between lithiated surface conditions and edge and core plasma conditions

4) Wave-Particle Interaction

- FY2010: Characterize HHFW heating, CD, and ramp-up in deuterium H-mode
  Joint milestone w/ solenoid-free TSG
- FY2011: Assess predictive capability of mode-induced fast-ion transport

5) Solenoid-free start-up, ramp-up

6) Advanced Scenarios & Control

- FY2011: Dependence of integrated plasma performance on collisionality

Joint Research Targets (3 US facilities):

- FY2010: Understanding of divertor heat flux, transport in scrape-off layer
- FY2011: Characterize H-mode pedestal structure

New tools to utilize for FY2011-12 campaign, milestones

- BES (first data FY2010, milestones FY2011-12)
- Routine Li density profiles (trying for early 2010)
- Tangential FIDA (TBD – maybe 2010 - 2011 for sure?)
- Enhanced edge MPTS resolution (2011)
- 2^{nd} SPA – independent control of 6 EFC/RWM coils (2011)
- Aiming for rt-rotation for FY2011 run, control by FY2012
- LLD enhancements (faster Li reloading + diagnostics) (2011)
- MSE-LIF for |B|, pitch-angle w/o heating NB (2011-12)
- **Metallic IBD (try for 2011 readiness, 2012 a safer bet)**

Very strongly considering metallic (Mo or W) inboard divertor for use in FY2012 run (maybe as early as FY11 run)

- Replace IBDH, and likely IBDV where ISP hits in high-δ shots
  - Options: use tiles, plates, or a combination
  - Can IBD(H) be heated – using bake-out system or other active heating?
- Motivations/potential benefits
  - Reduce C impurity influx from divertor
    - Carbon dominates Z_{eff} in long-pulse ELM-free Li-conditioned shots
  - Useful to CHI for C, O impurity reduction
  - Informs choice of C or metallic divertor NSTX Upgrade
    - Baseline CS upgrade design has all C PFCs – is this right choice?
    - Should NSTX-U (ultimately) have *all metal* PFCs? And be able to run hot?
  - Better test of LLD concept, since influence of C is reduced
- Risks/issues
  - High-Z accumulation/radiation possibly worse, especially if ELM-free
    - Need/use central RF heating, ELM pacing, PDD, snow-flake to remove?
  - May need to eliminate all C PFCs to eliminate C from plasma (AUG)
  - Have no systematic expts/data on impurity source characterization
  - Tile alignment critical (and we should do better job in present NSTX!)
- We need candidate designs (Kugel + others have been asked to start)

TSG milestone input presentation order

- **SFSU**
- **ASC**
- **MHD**
- **T&T**
- **BP**
- **LRTSG**
- **RF/WPI**

SFPS TSG Suggested FY-12 Milestones

- 1) Test the effect of a metallic divertor on Low-Z impurity reduction during CHI plasma start-up
  - Methods to reduce low-Z impurities in NSTX allowed substantial progress in coupling CHI started discharges to induction. The benefits of a partial metal electrode will have been tested during the 2010 campaign. In 2012, measure the benefits to CHI start-up through the use of a full metal electrode configuration by measuring the maximum electrode currents that can driven while maintaining the low-Z impurity levels below the 2009 levels.

- 2) Test the coupling of HHFW to a CHI started target.
  - TSC simulations by C. Kessel indicate that at the higher BT and higher RF power anticipated in NSTX-U, RF coupling should be considerably higher than in NSTX, and combined with NBI allows for the possibility of full non-inductive start-up, ramp-up and sustainment demonstration in NSTX-U. In preparation for this, measure the extent of electron heating and non-inductive current drive with HHFW on a high-current CHI initiated target to benchmark TSC simulations and to develop start-up and ramp-up scenarios in NSTX-U.

SFPS TSG #1: Test the effect of a metallic divertor on Low-Z impurity reduction during CHI plasma start-up.

1. **Provide a short, specific, actionable title describing the milestone:** (see title)
2. **Why is this issue important to fusion?**
   Elimination of the CS would reduce the cost and complexity of a ST or tokamak based reactor
3. **Why is this issue important to NSTX?**
   Solenoid-free plasma startup and ramp-up is an important goal of the NSTX program.
4. **What general research is proposed to address this issue?**
   FY08: Obtained data with unconditioned carbon tiles

   FY09: Electrode conditioning improved CHI performance

   FY10/11: Partial metal divertor may further reduce low-Z imp. (may need cathode metallic electrode)

   Spheromaks using full metal electrodes have reached 500eV electron temperatures.

   FY12: Full metal electrode will provide new results on the benefits of significantly reduced low-Z impurities on CHI capability in NSTX and this can be extrapolated to the capabilities that could be attained in NSTX-U (Re: upgrade to cap-bank, improvements to divertor design)
5. **What specific measurements and or experiments are needed to perform this research, and what diagnostics and theory/simulation capabilities are required?**
   Filter-scope data for low-Z measurements. Bolometer profiles for radiated power.

   Normal CHI start-up.
6. **What comparisons between experiment and theory will be carried out?**
   NIMROD simulations previously used for Spheromaks and for HIT-II will be used to benchmark the limits on low-Z impurity requirements for CHI in NSTX and NSTX-U
7. **What are the scientific implications of successful completion of the milestone?**
   High current (400-500kA) SFPS current generation has been a long-term goal of the NSTX program.

SFPS TSG #2: Test the coupling of HHFW to a CHI started target.

1. **Provide a short, specific, actionable title describing the milestone:**
   (see title)
2. **Why is this issue important to fusion?**
   Elimination of the CS would reduce the cost and complexity of a ST or tokamak based reactor. Full non-inductive start-up and ramp-up is an important goal for fusion research.
3. **Why is this issue important to NSTX?**
   Solenoid-free plasma startup and ramp-up is an important goal of the NSTX program.
4. **What general research is proposed to address this issue?**
   FY10: Will obtain data on heating a low-current (300-400kA) OH target with HHFW.
   FY11: Will obtain data on current coupling by HHFW to a low current OH target.
   FY12: Replace OH generated plasma with a high current (>300kA) CHI target and implement the methods developed during FY10 and 11 for the OH target.
5. **What specific measurements and or experiments are needed to perform this research, and what diagnostics and theory/simulation capabilities are required?**
   CHI start-up followed by HHFW application. MSE and Thomson Scattering measurements.
6. **What comparisons between experiment and theory will be carried out?**
   Simulations using TSC for extrapolation to NSTX-U
7. **What are the scientific implications of successful completion of the milestone?**
   Demonstration of full NI start-up, ramp-up and sustainment would be a major result from NSTX-U.

ASC Milestone idea overview

- There are three ideas here, we need to winnow them down.
- Titles:
  - *#1: Dependence of integrated plasma performance on controlled plasma rotation and β.*
  - *#2: Limits of shape control in a spherical torus and shape optimization at high-κ*
  - *#3: Compatibility of non-solenoidal ramp-up with advanced plasma scenarios.*
- If we are (independently) planning to implement rotation control, then it seems reasonable to utilize it in a milestone (#1).
  - Mario appears to be on path for this development. (?)
- How can the physics connection of #2 be improved. Does it need to be?
- Idea #3 is a bit of a long-shot.

ASC #1: *Dependence of integrated plasma performance on controlled plasma rotation and β.*

2. **Why is this issue important to fusion?**

   Plasma rotation and rotation shear are known to impact plasma transport, as well as the stability of the core and edge. The achievable bootstrap current is tied to transport and stability through their impact on β_P and the local profile shapes. Impurity accumulation and mode triggering are linked to pedestal stability.

3. **Why is this issue important to NSTX?** (See answer #2.)
4. **What general research is proposed to address this issue?**

   Scans of the controlled plasma rotation speed will be implemented in high-performance plasmas. If possible, this will be done with at least two different levels of plasma collisionality, since performance limiting mechanisms like RWMs may additionally be collisionality dependent.

5. **What specific measurements and or experiments are needed to perform this research, and what diagnostics and theory/simulation capabilities are required?**

   Simultaneous rotation and beta control must be implemented by FY12 for this to be possible. This implies that the realtime measurement must be implemented in FY11, imposing a tight schedule. Other aspects of the study are likely already in hand.

6. **What comparisons between experiment and theory will be carried out?**

   Possible MISK modeling. Lots of TRANSP runs and current profile analysis. Ideal stability calculations. Transport code predictions?

7. **What are the scientific implications of successful completion of the milestone?**

   The typical ST-CTF or ST-FNSF design point utilizes load of neutral beam injection to drive current, and also rotation. The ST- reactor scenarios, however, will likely have minimal external momentum input. This milestone will help determine what rotation states are required for optimal performance in an ST.

ASC #2: *Limits of shape control in a spherical torus and shape optimization at high-κ*

2. **Why is this issue important to fusion?**

   Future fusion devices, including ITER, the ORNL FNSF design, or FDF, will have strict rules on plasma shape control. Boundary-wall gaps must be strictly maintained, and SPs must not be allowed to wander. High flux expansion must be maintained. Shape parameters such as squareness must be optimized. These problems will be more severe in an ST, where inboard coils are forbidden and the control trade-offs are more severe.

3. **Why is this issue important to NSTX?**

   NSTX-Upgrade will have additional shaping coils, as well as bi-polar supplies on coils that are presently unipolar. The algorithm development in this milestone will enable us to use this new capability more efficiently.

4. **What general research is proposed to address this issue?**

   Development of shape controller with off-diagonal control elements (M-matrix). Implementation of improved divertor control with multiple X-points. Experiments to demonstrate the limits of these techniques. Development of high-κ shots with optimal boundary shape for stability and divertor performance.

5. **What specific measurements and or experiments are needed to perform this research, and what diagnostics and theory/simulation capabilities are required?**

   Experiments to demonstrate the control, and then to optimize the shape.

6. **What comparisons between experiment and theory will be carried out?**

   Comparison of plasma evolution to dynamic models (TSC, TRANSP +ISOLVER) could be carried out. Ideal stability calculations.

7. **What are the scientific implications of successful completion of the milestone?**

   Will have a more firm foundation for projecting boundary and divertor control in future ST plasmas. Will also know better the optimal squareness/triangularity at high-κ.

ASC #3: *Compatibility of non-solenoidal ramp-up with advanced plasma scenarios.*

2. **Why is this issue important to fusion?**

   Future STs will likely need to forsake a central solenoid; the current must be ramped up non-inductively. The final plasma equilibrium will then need to be maintained at high-β and f_{NI}. The compatibility of these two requirements must be addressed.

3. **Why is this issue important to NSTX?**

   Not really so critical for NSTX, but important for next step.

4. **What general research is proposed to address this issue?**

   non-inductive ramp-up techniques will be further developed, with the goal of coupling those plasmas to high-κ, high-β_P targets. Will need to navigate through the various constraints of HHFW coupling, locked-modes, β-limits,…

5. **What specific measurements and or experiments are needed to perform this research, and what diagnostics and theory/simulation capabilities are required?**

   A scenario with non-inductive ramp-up must be developed for this to go anywhere. Control of density will be helpful, and good HHFW coupling is likely required. TSC or TRANSP (+ ISOLVER) simulations with improved models for the HHFW coupling would be very helpful.

6. **What comparisons between experiment and theory will be carried out?**

   Likely comparison with TSC or TRANSP. Better model for transport during the early phase would clearly help.

7. **What are the scientific implications of successful completion of the milestone?**

   Better understanding of the process of achieving the high-β state in an ST. Should help constrain thinking about future devices like an ST-CTF or reactor. Benchmarking of ramp-up predictions in an ST.

Macrostability TSG Suggested FY-12 Milestones – Address key ReNeW issues for ST development

All of these address high-level ReNeW Thrust 16 Actions

- 1) Assess sustained operation above the no-wall limit at reduced collisionality
  - From incremental milestone IR(11-2) – critical for steady-stated ST operation
    - Promote to major milestone if not performed as incremental milestone in FY-11
    - Revise to add new capabilities of FY-12 (2nd SPA, initial rotation control, etc.); add EP effects on Macrostability; change name if desired
- 2) Assess sustained operation at reduced plasma internal inductance
  - Key for burning/driven burn ST development; start this investigation, which would gain full prominence in NSTX-U
  - Couple to milestone suggestion #1 above?
- 3) Assess physics of rotation control for sustained high beta ST operation
  - Couples strongly to ASC suggestion, which has many Macro TSG aspects
  - Suggest that milestone couple Macro, ASC, Transport TSG elements

Macro TSG #1: Assess sustained operation above the no-wall limit at reduced collisionality

1. **Provide a short, specific, actionable title describing the milestone:**
   (see title)
2. **Why is this issue important to fusion?**
   Key for ST development toward low collisionality burning/driven-burn applications. This is a ReNeW Thrust 16 Action.
3. **Why is this issue important to NSTX?**
   NSTX is moving to lower collisionality. Understanding the stability physics ramifications is key to support high beta, continuous operation of the device.
4. **What general research is proposed to address this issue?**
   Given in detail in IR(11-2). Suggestion is to promote this milestone to full milestone if 20 run weeks not granted in FY-11, and also add some topics recently uncovered as important. Topics include RWM stability dependence at low ν and due to effects of EPs, NTV scaling with ν, alteration of stability vs. density and collisionality, etc.
5. **What specific measurements and or experiments are needed to perform this research, and what diagnostics and theory/simulation capabilities are required?**
   Plasma rotation control a major plus, but not required. LLD operation needed. 2^{nd} SPA. Theory includes further development of the MISK code for stability, IPEC code for plasma response, VALEN code for multi-mode stability, continued NTV theory development.
6. **What comparisons between experiment and theory will be carried out?**
   Dedicated experiments to determine effects of collisionality, EPs, multi-mode RWM, etc. to codes mentioned in (5).
7. **What are the scientific implications of successful completion of the milestone?**
   Will provide required scientific understanding of stability at reduced collisionality critical for NSTX-U, future burning STs, ITER.

Macro TSG #2: Assess sustained operation at reduced plasma internal inductance

1. **Provide a short, specific, actionable title describing the milestone:**
   (see title)
2. **Why is this issue important to fusion?**
   Key for ST development toward burning/driven-burn applications, which operate at reduced plasma internal inductance. This is a ReNeW Thrust 16 Action.
3. **Why is this issue important to NSTX?**
   To support (2) above, NSTX is moving to lower l_i. Understanding the stability physics ramifications is key to support high beta, continuous operation of the device.
4. **What general research is proposed to address this issue?**
   Essentially, preparation for the main focus that will come with 2nd NBI in NSTX-U – plasma targets that operate as close to future ST target l_i as possible and assessment of instabilities in this regime – current-driven kink at all values of betaN, NTM, ELM, RWM stability (all functions of current profile).
5. **What specific measurements and or experiments are needed to perform this research, and what diagnostics and theory/simulation capabilities are required?**
   Plasma rotation control a major plus, but not required. LLD operation and 2nd SPA a plus. SXR and global mode diagnostic expansion. MISK code for stability, IPEC code for plasma response, multi-mode VALEN code, ELM stability tools, NTV theory development.
6. **What comparisons between experiment and theory will be carried out?**
   Dedicated experiments to determine effects of l_i, EPs, multi-mode RWM, etc. to codes mentioned in (5).
7. **What are the scientific implications of successful completion of the milestone?**
   Will provide required scientific understanding of stability at reduced l_i critical for NSTX-U, future burning STs, ITER.

Macro TSG #3: Assess physics of rotation control for sustained high beta ST operation

1. **Provide a short, specific, actionable title describing the milestone:**
   (see title)
2. **Why is this issue important to fusion?**
   Key for sustained ST operation in burning/driven-burn applications. This is a ReNeW Thrust 16 Action.
3. **Why is this issue important to NSTX?**
   NSTX is supporting (2) above. Demonstrating controlled rotation profiles is key to support high beta, continuous operation of the device.
4. **What general research is proposed to address this issue?**
   Physics governing plasma rotation control, including resonant and non-resonant magnetic braking over entire range of NSTX operations. Key aspects here are saturation (or not) of NTV at low collisionality, physics of observed NTV increase at low ω_E, accurate plasma response (including shielding) to applied 3D fields, etc.
5. **What specific measurements and or experiments are needed to perform this research, and what diagnostics and theory/simulation capabilities are required?**
   Real-time plasma rotation measurement and control required. LLD operation and 2nd SPA a plus. Further development of IPEC code for plasma response, continued NTV theory development. MISK development, calculations of rotation profiles for best stability.
6. **What comparisons between experiment and theory will be carried out?**
   Verify detailed resonant and non-resonant magnetic braking physics theory. Support development of simple, accurate models for rotation control. MISK stability vs. experiment.
7. **What are the scientific implications of successful completion of the milestone?**
   Will provide required scientific understanding of rotation control and associated plasma stability critical for NSTX-U, future burning STs, ITER.

Transport and Turbulence Ideas

- 2011 - Measure fluctuations responsible turbulent for ion and electron energy transport.
  - This mostly keeps the existing milestone, but strips out the simulation comparison and the MSE part (there is zero chance for MSE magnetic flucutations to measure turbulence, nor does it have ANY k-space resolution). The low-k portion of the turbulent density fluctuation spectrum will be measured with a Beam Emission Spectroscopy (BES) diagnostic. Experiments will be performed to vary plasma parameters such as collisionality, ExB shear, magnetic shear, plasma current, and magnetic field to span the instability drive space of candidate micro-instabilities (ITG, CTEM, micro-tearing, and ETG) thought to possibly be responsible for anomalous energy transport. The measured k spectrum of the turbulence will be measured as function of plasma parameters and correlated with energy diffusivities inferred from power balance analysis.

- 2012 - Gain physics understanding for turbulent transport mechanisms by benchmarking theory and simulation with measured fluctuations.
  - Fluctuation measurements will be compared with linear and non-linear instability calculations. Synthetic diagnostics built into modern high-performance simulation codes can serve to identify the micro-instabilities responsible for the observed transport by direct comparison to experimentally measurements of fluctuating quantities. Improved physics insight of how these micro-instabilities may affect electron and ion energy transport in future STs can is highly desirable to reduce the uncertainty of extrapolation to next-step STs.

Boundary – edge and SOL control with 3d fields

(*draft 1/11/10 – proposed by R. Maingi*)

1. **Provide a short, specific, actionable title describing the milestone:**
   Optimize control of pedestal and divertor plasma with applied 3d fields
2. **Why is this issue important to fusion?**
   3d fields are proposed in ITER to suppress ELMs and reduce time averaged heat flux. This research aims to understand underlying physics, and use this understanding to optimize boundary plasma control
3. **Why is this issue important to NSTX?**
   On NSTX, 3D fields are used to trigger ELMs in ELM-free discharges to reduce impurity and radiated power buildup, but we don't completely understand how.
4. **What general research is proposed to address this issue?**
   Focus is to conduct experiments aimed at code predictions (e.g. XGC-1, EMC3-EIRENE, IPEC, M3D, ELITE? or PEST?), to optimize edge control
5. **What specific measurements and or experiments are needed, and what diagnostics and theory/simulation capabilities are required?**
   The divertor heat and particle flux profiles, as well as midplane profiles and fluctuations, will be measured with a variety of applied 3d fields. Trends from the calculations should point to optimization of heat flux control, ELM control, etc.
6. **What comparisons between experiment and theory will be carried out?**
   These measurements will be compared to XGC-1, EMC3-EIRENE, IPEC, M3D.
7. **What are the scientific implications of successful completion of the milestone?**
   This research will provide the scientific understanding to optimize edge control with 3d fields for NSTX-U and ITER.

Boundary Physics TSG Milestone Idea (#2)

1. **Provide a short, specific, actionable title describing the milestone:**
   Assess properties of advanced high heat flux handling divertors (Snowflake, X-divertor)
2. **Why is this issue important to fusion?**
   Key for ST and tokamak concept development, ReNeW Thrust 16 Action
3. **Why is this issue important to NSTX?**
   Key for NSTX-U and possibly for lithium divertor research
4. **What general research is proposed to address this issue?**
   Advanced divertor concepts: magnetic control development and characterization will be performed. Divertor heat flux handling, pumping with LLD, impurity production, SOL turbulence and their trends with P_{NBI}, I_p, B_t, n_e, etc will be studied in prototype snowflake and X-divertors. Edge pedestal stability, ELM characterization and edge and core transport and confinement will also be studied
5. **What specific measurements and or experiments are needed to perform this research, and what diagnostics and theory/simulation capabilities are required?**
   Edge, divertor and SOL diagnostics will be used. Edge transport and turbulence codes (UEDGE, BOUT) will be used for divertor transport studies. Edge pedestal stability codes will be used for pedestal MHD stability calculations
6. **What comparisons between experiment and theory will be carried out?**
   Measurements will be compared to analytic and numerical code predictions
7. **What are the scientific implications of successful completion of the milestone?**
   This research will provide a significant impact on the present PMI concept development for both the ST and tokamak

RF/WPI input (from program director)

- **Text is from Incremental Research Milestone IR(11-1)**
- **Assess predictive capability of mode-induced fast-ion transport.**
- *Description:* Good confinement of fast-ions from neutral beam injection and thermonuclear fusion reactions is essential for the successful operation of ST-CTF, ITER, and future reactors. Significant progress has been made in identifying the Alfvénic eigenmodes (AEs) driven unstable by fast ions, and in measuring the impact of these modes on the transport of fast ions. However, the predicted transport of fast-ions caused by AEs often does not agree with the measured fast-ion transport even in conditions when the measured mode amplitude is utilized to constrain simulations. At present, it is unclear if the source of the discrepancies lies in the mode displacement measurements, in the theory/modeling, or both. To improve the predictive capability for mode-induced fast-ion transport, NSTX experiments will build on results of the FY2009 milestone (to measure the current profile dependence on AE modes) and make new measurements of the mode eigenfunction structure utilizing a Beam Emission Spectroscopy (BES) diagnostic and enhanced reflectometry resolution. NSTX will also make new measurements of the internal magnetic field structure of AEs using far-infrared polarimetry (if available) and improved measurements of the fast-ion distribution function utilizing a tangentially viewing Fast-Ion D-alpha (FIDA) diagnostic. Finally, to broaden the range of discharge conditions studied to those more relevant to future devices, eigenfunction measurements will be extended from L-mode to H-mode scenarios.

LR TSG input (from program director)

- **Assess a liquid lithium divertor utilizing a fully metallic substrate**

- *Description:* Utilize temperature-controlled metallic OBD and IBD and assess liquid lithium divertor particle pumping and power handling as a function of LLD temperature, strike-point, flux expansion, divertor configuration, and a range of SOL conditions

Proposed NSTX FY2010-12 Research Milestones
(base and incremental)

	FY2010	FY2011	FY2012
Expt. Run Weeks:	15 w/ ARRA	14 (20)	14 (20)
1) Transport & Turbulence		Measure fluctuations responsible turbulent for ion and electron energy transport	Assess relationship between observed fluctuations and observed transport utilizing advanced turbulence simulations (no high-k in 1st year of NSTX-U ops)
2) Macroscopic Stability	Assess sustainable beta and disruptivity near and above the ideal no-wall limit		Assess sustained operation above the no-wall limit at reduced collisionality
3) Boundary/Lithium Physics	Assess H-mode characteristics as a function of collisionality and lithium conditioning	Understand pedestal and divertor response to externally applied 3d fields Relationship between lithiated surface conditions and edge and core plasma conditions	Assess high flux expansion divertor operation and control with solid high-Z and liquid-lithium divertor PFCs (joint with LRTSG)
4) Wave-Particle Interaction	Characterize HHFW heating, CD, and ramp-up in deuterium H-mode *Joint milestone w/ solenoid-free TSG*	Assess predictive capability of mode-induced fast-ion transport	
5) Solenoid-free start-up, ramp-up			Assess achievability of fully non-inductive start-up using combined CHI and HHFW H&CD (joint with HHFW TSG)
6) Advanced Scenarios & Control		Dependence of integrated plasma performance on collisionality	Understand physics and control of rotation & rotation damping at low collisionality (joint with MS TSG)

Joint Research Targets (3 US facilities):

FY2010	FY2011	FY2012
Understanding of divertor heat flux, transport in scrape-off layer	Characterize H-mode pedestal structure	Characterize H-mode pedestal transport/control??? (TBD)