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## Thrust 1

# **“Develop Capable and Reliable Measurements for Understanding and Controlling Burning Plasmas”**

Shared Thrust from Themes 1 and 2

Measurements Panel

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# Why a Burning Plasma Measurement Thrust?

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- A broad variety of issues challenge ITER diagnostics in providing the measurements needed for the desired range of research topics.
  - Acknowledged measurement gaps
  - Emerging measurement needs
  - Very stringent reliability requirements
  - New environmental hazards
  - Opportunities for new measurement techniques
- Delivery of US 'in-kind' scope must be the highest diagnostic priority.
  - However, this effort is constrained to specific systems.
- No US program exists to consider full range of BP measurement issues.
  - Present diagnostic program supports developments for existing facilities.
  - Developments benefiting existing US devices may be BP relevant, but are not targeted at qualification for ITER.
- Broader mandate is needed for US diagnostics experts to consider full range of measurement issues, in coordination with efforts elsewhere.

# Measurement Thrust Elements

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A US panel with broad expertise could periodically:

- 1) Evaluate ITER measurement needs, capabilities, and risks.
- 2) Prioritize burning plasma measurement issues, including those for DEMO.

US diagnostics community could:

- 3) Carry out phased developments targeted to high-priority needs, including prototyping on present devices.
- 4) Evaluate the success of the developments, and for those applicable to ITER, work with the ITER Project to implement qualified techniques.

# 1) Evaluate ITER Diagnostic Requirements & Capability

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- Evaluation could be done by US panel with broad expertise
  - Diagnostic, operations, programmatic, ITER expertise
  - Could include international experts
- It is timely to plan for such an evaluation – good information exists and much more will soon be available
  - ITER Procurement Arrangements are being drafted, containing functional requirements for each diagnostic
  - Conceptual design reviews are planned prior to issuance of PAs, now scheduled for July, 2010
- There are acknowledged deficiencies in present diagnostic plan
  - Escaping  $\alpha$ -particles, tritium retention, dust accumulation, divertor flows, He profile in core, ... lack qualified techniques.
  - More requirements will emerge as planning matures for ITER experiments, including developments of, for example:
    - more detailed control scenarios
    - more off-normal avoidance strategies
    - $\alpha$ -physics

# 1) Evaluate ITER Diagnostic Risks and Mitigation

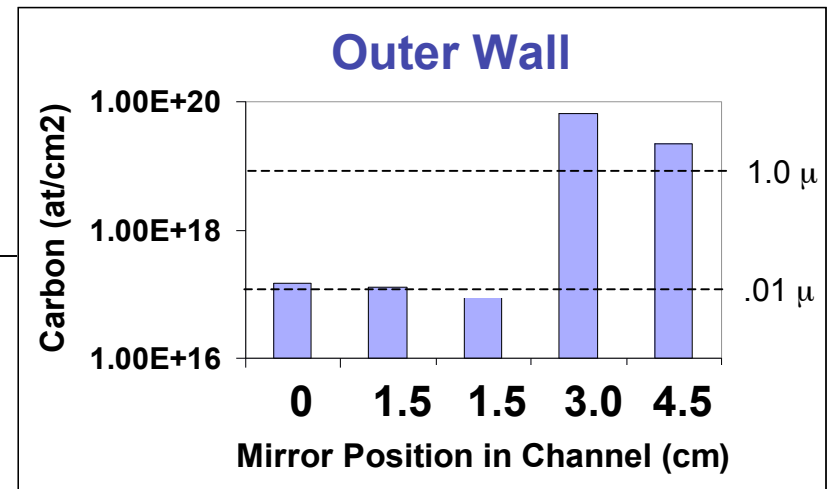
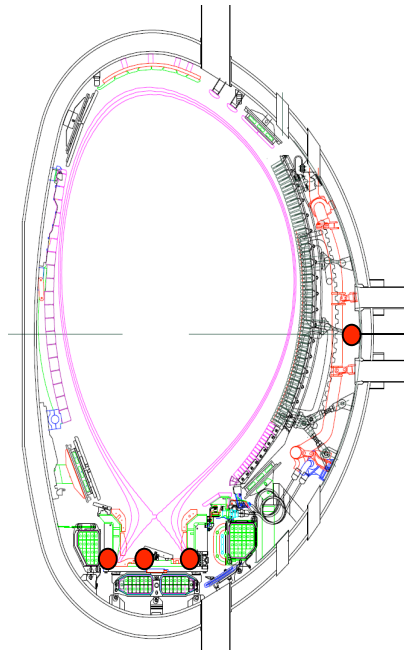
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- Large uncertainty in the impact of environmental hazards on ITER
  - Hazards: thermal excursions & gradients, irradiation-induced damage and noise, degradation due to erosion/deposition, disruption-induced vibrations
  - Understanding lacking in many areas, especially for combined hazards
  - Uncertainty in lifetime of first mirrors is a particular concern
    - Evidence from both modeling and experiment indicates that severe problem may exist for ITER - but uncertainty is large.
    - ITPA working group has outlined research plan, including US expertise
      - some of which is being funded by ITER, but more support is needed.
  - Lifetime of in-vessel sensors, cables, connectors also a concern
- Due to difficulty of remote maintenance on ITER, designs face more stringent reliability requirements than on present devices.
  - Failure rates of  $< 5 \times 10^{-5}$  per measurement per year are required.
  - Calibration stability will be major challenge with front-end degradation and difficulty of accessing vessel.

# Risk Example - First Mirror Failure

Mirror Degradation on JET (Rubel, PSI-2008)

ITER-relevant  
locations



**Scaling to ITER, JET exposure time equivalent to:**

- ~ 8 ITER pulses scaled by energy input
- ~ 2/3 pulse scaled by expected divertor fluxes

**“The most urgent issue is to develop methods for cleaning and/or mitigation of the plasma impact on mirror performance.” (Rubel)**

# First Mirror Failure Impact on ITER Measurements

GROUP 1a Measurements For Machine Protection and Basic Control	GROUP 1b Measurements for Advanced Control	GROUP 2 Measurements for Performance Evaluation and Physics
<p>Plasma shape and position, separatrix-wall gaps, gap between separatrices</p> <p>Plasma current, <math>q(a)</math>, <math>q(95\%)</math></p> <p>Loop voltage</p> <p>Fusion power</p> <p><math>\beta_N = \beta_{tor}(aB/I)</math></p> <p>Line-averaged electron density (Impurity and D, T influx (divertor, &amp; main plasma))</p> <p>Surface temp. (divertor &amp; upper plates)</p> <p>Surface temperature (first wall)</p> <p>Runaway electrons</p> <p>Halo' currents</p> <p>Radiated power (main pla, X-pt &amp; div).</p> <p>Divertor detachment indicator (<math>J_{sat}</math>, <math>n_e</math>, <math>T_e</math> at divertor plate)</p> <p>Disruption precursors (locked modes, <math>m=2</math>)</p> <p>H/L mode indicator</p> <p><math>Z_{eff}</math> (line-averaged)</p> <p><math>n_T/n_D</math> in plasma core</p> <p>ELMs</p> <p>Gas pressure (divertor &amp; duct)</p> <p>Gas composition (divertor &amp; duct)</p> <p>Dust</p>	<p>Neutron and <math>\alpha</math>-source profile</p> <p>Helium density profile (core)</p> <p>Plasma rotation (tor and pol)</p> <p>Current density profile (q-profile)</p> <p>Electron temperature profile (core)</p> <p>Electron density profile (core and edge)</p> <p>Ion temperature profile (core)</p> <p>Radiation power profile (core, X-point &amp; divertor)</p> <p><math>Z_{eff}</math> profile</p> <p>Helium density (divertor)</p> <p>Heat deposition profile (divertor)</p> <p>Ionization front position in divertor</p> <p>Impurity density profiles</p> <p>Neutral density between plasma and first wall</p> <p><math>n_e</math> of divertor plasma</p> <p><math>T_e</math> of divertor plasma</p> <p><math>\alpha</math>-particle loss</p> <p>Low <math>m/n</math> MHD activity</p> <p>Sawteeth</p> <p>Net erosion (divertor plate)</p> <p>Neutron fluence</p>	<p>Confined <math>\alpha</math>-particles</p> <p>TAE Modes, fishbones</p> <p><math>T_e</math> profile (edge)</p> <p><math>n_e</math>, <math>T_e</math> profiles (X-point)</p> <p><math>T_i</math> in divertor</p> <p>Plasma flow (divertor)</p> <p><math>n_T/n_D/n_H</math> (edge)</p> <p><math>n_T/n_D/n_H</math> (divertor)</p> <p><math>T_e</math> fluctuations</p> <p><math>n_e</math> fluctuations</p> <p>Radial electric field and field fluctuations</p> <p>Edge turbulence</p> <p>MHD activity in plasma core</p>
<p><b>All Primary Techniques at Risk, Some Primary at Risk, No Primary at Risk</b></p>		

## 2) Prioritize Measurement Issues

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- Panel performing evaluation should be asked to list and prioritize burning plasma measurement issues.
- Several issue categories could be imagined, some focused on ITER:
  - Discovering new techniques to fill “measurement gaps”
  - Improving the capability or reliability of presently planned diagnostics
  - Develop new, more robust techniques to supplement high-risk systems
- Better definition of measurements needed for devices beyond ITER, and an exploration for feasible concepts for such devices.
- Priorities could be given to topics that:
  - US experts can address
  - Benefit US research interests
  - Are not duplicated elsewhere
- Advantageous to repeat steps 1) and 2) periodically
  - Priorities will change as ITER research plan and US role evolve.
  - Measurement issues will come into sharper focus as designs for credited systems mature.

### 3) Phased Developments Targeted to Selected Issues

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- Major US experimental fusion programs have benefited greatly from OFES diagnostic development program.
  - Supports developments for existing devices only.
- A similar new program should be launched, dedicated to US developments addressing high priority BP measurement issues prioritized by panel.
- New program could be phased
  - Feasibility studies
  - R&D and design of prototype on existing facility
  - Implementation of prototype and qualification for ITER
- Similar diagnostic development programs, focused on ITER, now exist in other countries.
  - Europe - “EFDA Diagnostic Work Programme”
  - Japan - “Advanced Diagnostics for Burning Plasma Experiments”
  - Ambitious program proposed in Australia

## 4) Implement Qualified Techniques on ITER

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- After a new technique is successfully qualified, a handoff to ITER for full implementation is a critical step.
- The ITER Project has been receptive to incorporate qualified new ideas.
  - It is likely that ITER will install diagnostics in several phases, permitting flexibility to install yet-to-be-defined systems.
  - Most ITER diagnostics are housed in “port plugs”, which are replaceable periodically throughout ITER’s life.
  - Diagnostic “upgrades” are planned as part of the ITER operating phase
- Communication with ITER is key to successful implementation
  - Promising new developments will need to be promoted as early as possible.
  - Communication with other Domestic Agencies would be needed for modifications to credited systems not supplied by US.
- ITER could serve as an excellent test bed for robust diagnostics developed under this program for next-step devices.

# Scale of Effort and Readiness for Thrust

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- Recommend starting from a level of support comparable to the present US development program and ramping to several times this level, depending on response.
  - Initially ~ 10 - 15 feasibility studies
  - In steady state, this support would provide for mix of new feasibility studies along with fewer, more mature hardware design and prototyping efforts.
  - Will need access to US facilities and run time.
- In recent years, as US community began thinking more about ITER measurements, new ideas have been generated.
  - With a clear funding path, these could be developed into proposals.
- The timescale for development varies:
  - 5-10 years for brand new technique
  - Shorter for new maintenance or calibration technique
  - Shorter for modifications that expand capability of a credited system
- To get the best return on investment, and most positively impact ITER during design phase, effort should begin as soon as possible.

# Integration of Thrust 1 Elements

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- Thrust 1 elements comprise a coherent program
  - Evaluate ► Prioritize ► Develop ► Implement
- Coordination with other diagnostic groups concerned with burning plasmas will be essential
  - Most importantly with ITER Organization
    - Including other ITER Domestic Agencies developing ITER diagnostics
  - Diagnostic Topical Groups of USBPO and ITPA
  - Independent BP diagnostic development organizations in Europe, Japan, ...
- Coordination could be facilitated by inclusion of representatives from these groups in US evaluation/prioritization panels and in proposal selection panels.
- Coordination with other burning plasma Thrusts is also needed, particularly in identification and prioritization of issues for development.

# Relation to Other ReNeW Thrusts

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- Strong synergy exists with other burning plasma Thrusts
  - Measurement needs in other Thrusts could impact the identification of high priority issues for development.
  - Other Thrusts could benefit from successful implementation of new techniques.
- Thrust 2 - Control of Transient Events
  - Examine adequacy of ITER measurements of core and edge stability
- Thrust 3 - Understanding  $\alpha$  Physics
  - Evaluate measurements of  $\alpha$  distributions, instabilities, and losses
- Thrust 4 - Burning Plasma Scenarios
  - As scenarios are developed on existing devices, measurement capabilities outside those currently planned for ITER may be used.
- Thrust 5 - Plasma Control
  - Control solutions may involve sensor capabilities not yet in ITER's plan
- Thrust 6 - Predictive Modeling
  - Critical validating measurements may be developed on existing devices, with a desire to extend capability to ITER

# Summary

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- The US role in ITER will be strengthened by a targeted effort to develop supporting measurement capability not presently planned.
- US expertise provides opportunity to contribute to overcoming the significant measurement challenges to provide needed capabilities.
  - USIPO effort is presently narrowly constrained to US defined contributions.
- Proposed Burning Plasma Measurements Development would
  - Engage US experts to address those challenges that are highest priority in line with other thrusts.
  - Reduce the significant risks to ITER measurement capability.
  - Develop concepts for diagnostics for devices beyond ITER.