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?

- 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

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

- 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 α-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
    - α-physics

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1) Evaluate ITER Diagnostic Risks and Mitigation

- 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

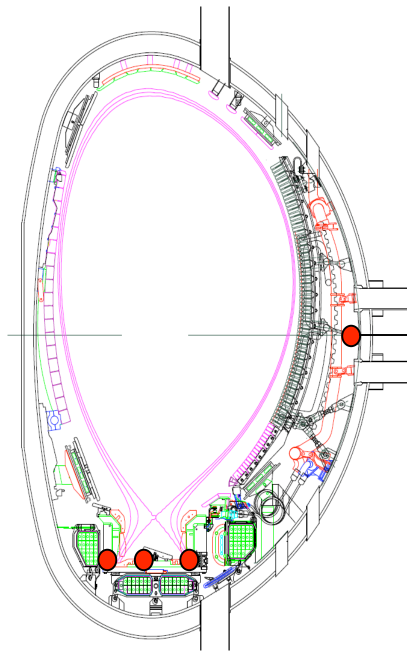
      some of which is being funded by ITER, but more support is needed.
  - Lifetime of in-vessel sensors, cables, connectors also a concern

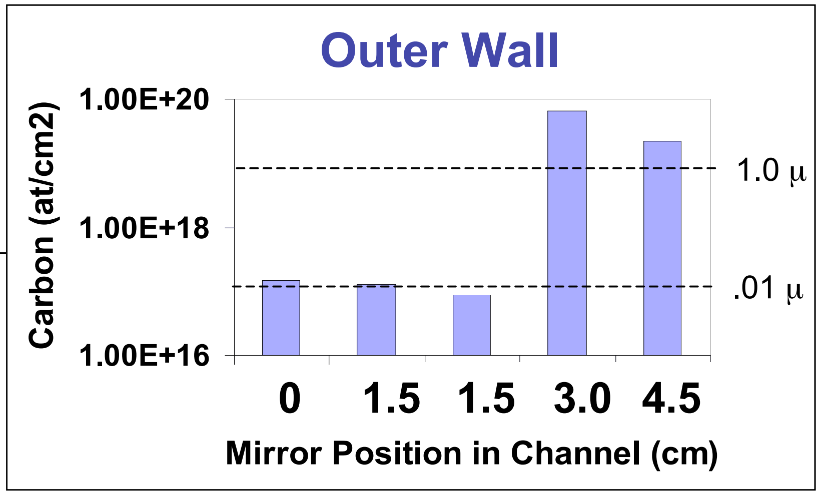
- Due to difficulty of remote maintenance on ITER, designs face more stringent reliability requirements than on present devices.
  - Failure rates of < $5x10^{-5}$ per measurement per year are required.
  - Calibration stability will be major challenge with front-end degradation and difficulty of accessing 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)

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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
Plasma shape and position, separatrix-wall gaps, gap between separatrixes	Neutron and α-source profile	Confined α-particles
Plasma current, q(a), q(95%)	Helium density profile (core)	TAE Modes, fishbones
Loop voltage	Plasma rotation (tor and pol)	T_e profile (edge)
Fusion power	Current density profile (q-profile)	n_e, T_e profiles (X-point)
$\beta_N = \beta_{tor}(aB/I)$	Electron temperature profile (core)	T_i in divertor
Line-averaged electron density (	Electron density profile (core and edge)	Plasma flow (divertor)
Impurity and D, T influx (divertor, & main plasma)	Ion temperature profile (core)	$n_T/n_D/n_H$ (edge)
Surface temp. (divertor & upper plates)	Radiation power profile (core, X-point & divertor)	$n_T/n_D/n_H$ (divertor)
Surface temperature (first wall)	Z_{eff} profile	T_e fluctuations
Runaway electrons	Helium density (divertor)	n_e fluctuations
Halo' currents	Heat deposition profile (divertor)	Radial electric field and field fluctuations
Radiated power (main pla, X-pt & div).	Ionization front position in divertor	Edge turbulence
Divertor detachment indicator (J_{sat}, n_e, T_e at divertor plate)	Impurity density profiles	MHD activity in plasma core
Disruption precursors (locked modes, m=2)	Neutral density between plasma and first wall	
H/L mode indicator	n_e of divertor plasma	
Z_{eff} (line-averaged)	T_e of divertor plasma	
n_T/n_D in plasma core	α-particle loss	
ELMs	Low m/n MHD activity	
Gas pressure (divertor & duct)	Sawteeth	
Gas composition (divertor & duct)	Net erosion (divertor plate)	
Dust	Neutron fluence	

All Primary Techniques at Risk, Some Primary at Risk, No Primary at Risk

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2) Prioritize Measurement Issues

- 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

- 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

- 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

- 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

- 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

- 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 α Physics
  - Evaluate measurements of α 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

- 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.