Towards a Long-Range, Dedicated, Integrated US Diagnostic Development Program - A US Initiative

Presented by
R.L. Boivin

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A Strong Diagnostic Development Program is Required to Fulfill Mission

- **A strong fusion program requires the development and utilization of innovative physics measurements**
  - Key element in validation of theory and models -> science goal
  - Key element in advanced control -> energy goal
- **Goals:**
  - Aggressively pursue the development of new diagnostic capability in support of scientific and energy missions
    - New diagnostics in support of fusion science
    - New diagnostics in support of ITER (science and diagnostics)
    - Develop new techniques to support DEMO and other BPX

"The required progress in […] key areas will not be possible without a significant expansion of our plasma diagnostic capabilities. Quite simply, we cannot understand what we cannot measure."

NRC, *Plasma 2010* panel report

The US Program has lost its Competitive Edge in the Development of State-of-the-Art Diagnostics

- **Historically, significant progress in key areas followed the development and fielding of new, relevant diagnostics**
  - MSE (current profile) is a typical example
- **Presently, participation from smaller and/or new groups limited**
  - Traditionally strong university role
  - Excellent entry point, student involvement, training, etc
- **Cycle time (3 years) limits innovation**
  - Wait 3 years before you can re-apply, even when proposal receives high marks!!!
- **Existing program(s) do not favor transformational breakthroughs with higher risk ideas**
  - Favors conservative approach, protects existing programs
- **Technology program rarely supported diagnostic development in the past**
  - Will be needed for material, radiation testing

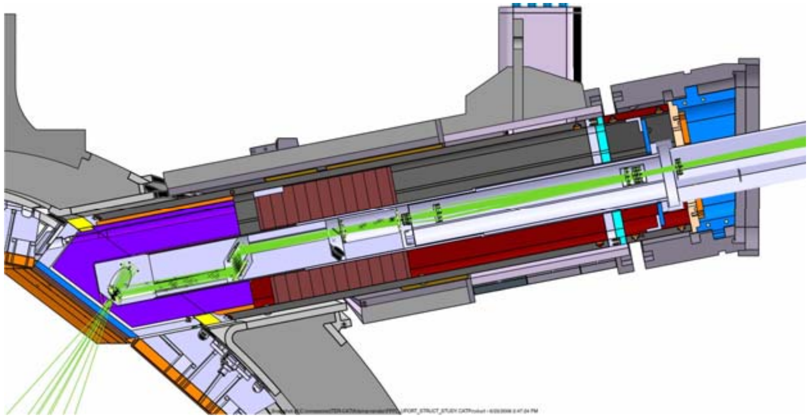
ITER and BPX Are Not Business as Usual for Diagnostics

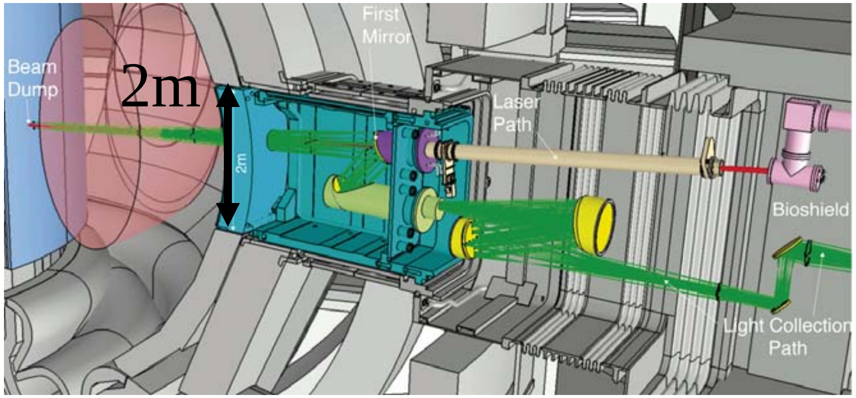
- **The future experiments bring new constraints, rarely encountered in existing projects**
  - Very demanding environment
    - Radiation, particle flux, access, pulse length, blankets, etc
  - Diagnostics called to be part of the control scheme very early
  - Reliability and availability must be extremely high
    - Repeat shots no longer acceptable practice
  - Retaining calibration, alignment present big challenges
- **The Greenwald Panel (2007) has identified many significant gaps in our capability to develop the needed diagnostics**

ITER Environment Leaves Little Room for Error

- **Many issues rarely encountered in present-day experiment**
  - Physical (e.g. relativistic effects, alphas, etc) and technological (radiation, pulse length, heating, blankets, etc)
- **Number of iterations (e.g. fixes) very small**
- **Redundancy very limited**

Upper Plug with Visible/IR Endoscope





Equatorial Plug with LIDAR Front End

In spite of Many Years of R&D, Many ITER Diagnostics are Expected to Perform Marginally

- **Many ITER systems are too close to margins in expected performance or reliability**
  - Very little testing done right now
  - Programs delayed in the US to the extreme
  - Alternatives NOT being developed or even considered
  - Large impact on control capability
- **Also, there will be very large pressure to delay diagnostic installation on ITER**
  - Very large impact on physics program
  - Could lead to bottle necks if key system not available or compatible with environment
  - Stronger test will come with radiation field, need to be fully prepared

Many ITER Key Measurements are Presently at Risk

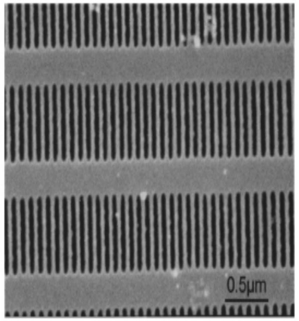
- **These are great examples where US program can make huge contributions to ITER success**

Measurement	Required R&D	Priority
Confined alpha particles	New or very greatly evolved techniques	High
Lost alpha particles	New or very greatly evolved techniques	High
Magnetics	Radiation effects	High
Optical diagnostics	Erosion/redeposition, cleaning/restoring mirrors	High
Dust	New techniques	High
Tritium inventory and retention	New techniques	High
Optical diagnostics	New self-calibration techniques	Intermediate
Instability features (core and edge plasma regions	Soft X-ray	Intermediate
Fuel composition	Fast wave reflectometry	Intermediate
Tile erosion	New techniques	Intermediate
Impurities	New techniques	Intermediate
Core fluctuations	New techniques	Longer term

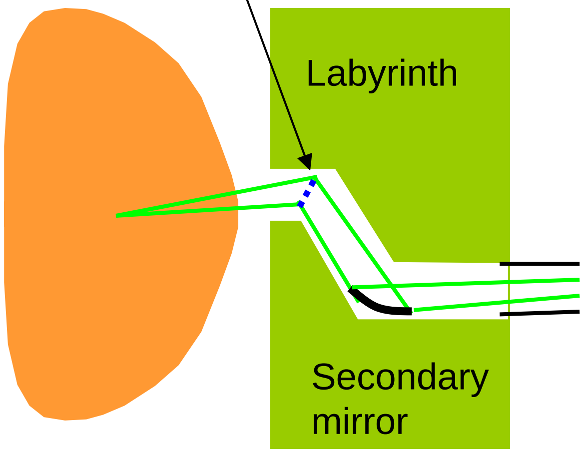
- **There is presently no program in the US to try to address those issues**

Development of Alternate Techniques is not Sufficiently Supported - *An Example*

- **First Mirrors are a weak point for all optical diagnostics**
- **Very few efforts are supported to find alternatives**
- **In general, higher risk, high payback ideas not supported**
- **Example: JHU's efforts to develop *free-standing diffractive optical elements***



Transmission grating (TG) or Zone plate (ZP)
spacing ≈ 0.1 - 50 μm (XUV-IR)



D. Stutman, et al, JHU

Longer Term Success is Jeopardized by a Serious Lack of R&D

- **Imagine a CTF, FDF, NHTX and/or DEMO without (for example) :**
  - CER/CXRS system
  - Thomson scattering
  - Reliable magnetics or reliable bolometers
  - *What would you use? Where would test or develop?*
- **Imagine having to make all necessary measurements within a total footprint of less than ~1.5 m^2 at the first wall!**
  - Maximum surface area needed for breeding
  - ARIES studies do not include diagnostic needs, impacts and required R&D
- **Imagine trying to develop solutions when existing development programs specifically prohibit them!!**

Very Few Facilities are Dedicating Resources to Develop and Test New techniques

- **ITER will not be a conceptual diagnostic test facility**
  - However, it should be part of the final stage for proof of performance for later mission (route to DEMO)
  - Can we reduce the necessary set?
- **New diagnostic technique can take 10+ years in development before it becomes "accepted"**
  - Starts in small labs, and moves to larger facilities
- **The development of BPX relevant diagnostics will require a strong technology support**
  - New materials, radiation testing and hardening, new detectors, optical elements, etc

ITPA- Diagnostics (ITER) High Priority Tasks (5) are Largely Ignored by US Program

- **Development of requirements for measurements of dust, and assessment of proposed techniques**
- **Assessment of the various options for the Vertical Neutron Camera to measure the 2D/alpha source profile (including asymmetries) and assessment of the calibration strategy including required calibration source strength**
- **Development of methods of measuring the energy and density distribution of confined and escaping alpha particles**
- **Determination of life-time of plasma facing mirrors used in optical systems and assessment of mitigation techniques**
- **Assessment of the integrated measurement capability of the diagnostic systems relative to the specified measurement requirements *(closed June 2008)***
- **US participation (including meetings) has been very weak**

In its 2007 White Paper the BPO is Proposing 3 Main Thrusts for the Diagnostic Development Program

- 1. Expansion of the present OFES diagnostic development program so as to provide support for short- and long-term development and implementation of new diagnostics needed for burning plasma research.

- 2. Integration of the capabilities of burning plasma diagnostics into existing analysis and simulation codes and, ultimately, into control systems

- 3. Provision of some modest funding with short time scales for the execution of specific tasks, such as modeling plasma/diagnostic interactions, reviewing designs of ITER diagnostic systems credited to other Parties, evaluating environmental issues for diagnostics, and coordinating this diagnostic initiative with the USBPO and the USIPO.

1. Diagnostic development for burning plasmas

- **A diagnostic program to provide support for short- and long-term development and implementation of new diagnostics needed for burning plasma research.**
  - Develop new techniques where serious gaps in the measurement capability exist.
  - Develop instrumentation for un-credited ITER systems to a level where they could pass a Proof-of-Principle/Performance test.
  - Seek alternate techniques to improve scientific output and productivity of a burning plasma experiment such as ITER and DEMO.
  - Stimulate needed diagnostic specific development and understanding in technological areas such as:
    - mirrors/relaying optics
    - detectors
    - sources and lasers
    - radiation effects

2. Prediction and verification of burning plasma diagnostic performance

- **Integration of the capabilities of burning plasma diagnostics into existing analysis and simulation codes and, ultimately, into control systems.**
  - Develop synthetic diagnostics.
  - Develop new post-processors and other relevant hardware.
  - Predict and verify expected performance of systems for ITER.
  - Identify deficiencies in diagnostic coverage or operation.
  - Prepare for full integration into a control system.

3. Diagnostic program integration

- **Execution of smaller, targeted tasks, such as:**
  - Modeling plasma/diagnostic interactions.
  - Provide opportunities through formal collaborations for US experts to participate in the design and construction of non-US ITER diagnostics assigned to other Parties.
  - Reviewing designs of ITER diagnostic systems credited to other Parties or the ITER organization.
  - Evaluating and addressing environmental issues for diagnostics.
  - Initiate coordinated efforts in developing diagnostics for DEMO with international partners.
  - Coordinating this diagnostic initiative with the USBPO and the US ITER Project Office.

Diagnostic Development Represents a Large Gap in Our Program

- The US is losing its competitive edge in diagnostic development
- The success of ITER requires an integrated effort from the US program on diagnostic issues
- No effort is presently undertaken for DEMO diagnostics
- The ReNeW process and workshops should include a serious and global discussion of where the US diagnostic program should be heading