# Opportunities for US Diagnostic Participation in ITER
# A Draft White Paper to the Department of Energy

**DRAFT**

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With contributions from the US fusion community
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## Executive Summary

The recent decision by the US administration to rejoin the ITER negotiations enables the US fusion community to participate in this important scientific project. This draft White Paper is intended to stimulate discussions among potential US contributors in the development and implementation of the diagnostic set (measurement capability). This White Paper is thought to be a way to bring the various US groups (universities, national labs and industries), to participate in discussions into producing a coherent plan and integrate all contributions and partners for a more effective proposal. It is recommended that participation opportunity forums be organized for the whole US fusion community. The first opportunity for discussions will be arranged within the framework of the UFA-hosted US ITER Forum at the University of Maryland on May 8-9 2003. The US fusion is in a very strong position to contribute to the ITER diagnostic set.

# ITER diagnostic systems and US expertise

The ITER mission is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. This mission will require a comprehensive set of diagnostics to assess the plasma and technological performance, in addition to providing many of the control tools necessary for that purpose.

The exploration and study of the science of burning plasmas will require an extensive set of measurements (diagnostics), arguably the best ever to be implemented on a fusion research device. The physics studies will require reliable operation of diagnostics in an extremely hostile radiation environment during long pulses, with the type of precision expected of the best present-day diagnostics. This set of diagnostics will necessitate a comprehensive R&D program in order to meet the scientific requirements as set by the research goals.

The diagnostics are the primary tools for accessing the science that is to be obtained on ITER. They possess a high leverage impact on our participation in the planning and execution of the scientific program, and hence on our scientific productivity and relevance to the international fusion community. In addition, the focus of these diagnostics will shift dramatically from the traditional scientific evaluation instruments to the full discharge control tools as required in a fusion reactor. These elements will directly apply to the next step such as DEMO.

The US program has historically been at the forefront of the development and implementation of diagnostics for fusion research. Prime examples of such development include current profile measurement (Motional Stark Effect-MSE), ion temperature and velocity (Charge Exchange Recombination Spectroscopy – CHERS), density fluctuations (Beam Emission Spectroscopy – BES, and reflectometry) amongst many others.

An important aspect of the US diagnostic program has been the very successful integration of many institutional contributions into facilities such as DIII-D, TFTR and more recently, into Alcator C-Mod and NSTX. Contributions originating from university groups have proven to be an essential part of the undertaking, ranging from the building and implementation of the diagnostic to its full scientific utilization. This relationship also incorporates the important facet of training the next generation of scientists, while maintaining a dynamic exchange with other branches of physics.

This White Paper summarizes the diagnostic needs of ITER, some of its basic constituents, and the diagnostic expertise of the US fusion community.

# ITER diagnostic systems

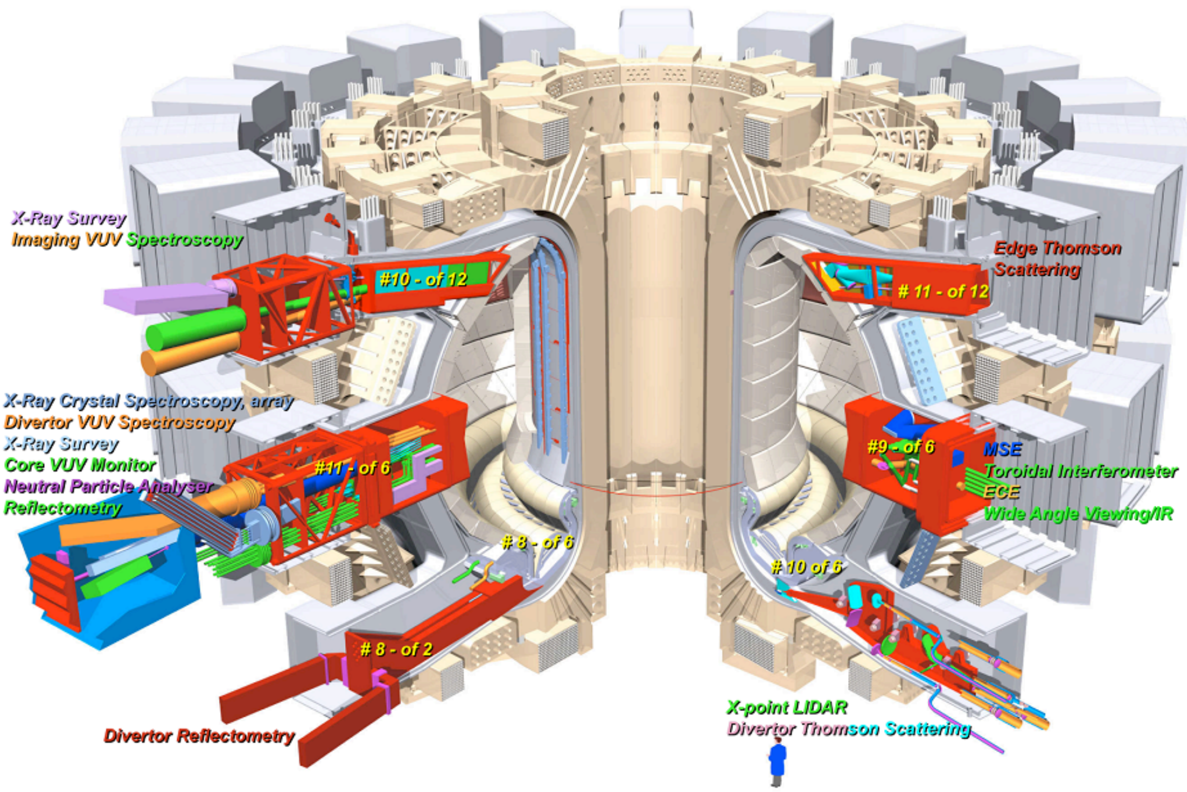


Figure 1. Example of diagnostic port implementation for ITER at the three elevations.

ITER diagnostics will serve 3 roles, which have been categorized: 1) machine protection and basic control, 2) advanced plasma control and 3) physics evaluation. A number of ports are dedicated for diagnostic use, and details can be found in Figure 2. The complete list of planned systems can be found in Table I (some diagnostics still remain to be assigned to a give port). A first attempt at characterizing the level of interest and possible US institutional contributors are also shown. In setting this list, it was assumed that the budgetary envelope would limit the US participation to approximately one quarter of the ITER diagnostic effort.

| | | Categ. | Level of Interest | Scale of Involvement | Potential US Contributor |
|---|---|---|---|---|---|
| | | | H,M,L,F | A to G | (not complete) |
| | | | | | |
| **5.5.A** | **Magnetic Diagnostics** | 1a | M | D | GA, PPPL, Columbia |
| | | | | | |
| **5.5.B** | **Neutron Diagnostics** | | | | |
| 5.5.B.01 | Radial Neutron Camera | 1b | M | D | PPPL,LANL |
| 5.5B.02 | Vertical Neutron Camera | 1b | M | E | PPPL,LANL |
| 5.5B.03 | Microfission Chambers (in-vessel) | 1a | L | G | |
| 5.5B.04 | Flux Monitor (ex-vessel) | 1a | M | D | |
| *5.5B.07* | *Gamma-Ray Spectrometers** | *2* | L | G | CSM, MIT |
| 5.5B.08 | Neutron Activation System | 1b | H | B | |
| *5.5B.09* | *Lost Alpha Detectors** | *1b* | H | B | PPPL, CSM |
| *5.5B.10* | *Knock-on Tail Neutron Spect.** | *2* | M | D | GA |
| | | | | | |
| **5.5.C** | **Optical Diagnostics** | | | | |
| 5.5.C.01 | Thomson Scattering (Core) LIDAR | 1b | M | E | GA, PPPL |
| 5.5.C.02 | Thomson Scattering (Edge) | 2 | H | B | GA, PPPL |
| 5.5.C.03 | Thomson Scattering (X-point) | 2 | M | D | GA, PPPL |
| *5.5.C.04* | *Thomson Scattering (Divertor)** | *1b* | L | G | GA, PPPL |

| | | | | | |
|---|---|---|---|---|---|
| 5.5.C.05 | Toroidal Interf./Polarim. System | 1a | M | D | Washington |
| 5.5.C.06 | Polarim. Sys. (Pol. Mag. Field Meas.) | 1b | M | C | UCLA |
| *5.5.C.07* | *Collective Thomson Scattering** | *2* | F | F | MIT |
| | | | | | |
| **5.5.D** | **Bolometric System** | | | | |
| 5.5.D.01 | Bolom. Array for Main Plasma | 1a | L | F | LANL, PPPL |
| 5.5.D.02 | Bolom. Array for Divertor | 1a | L | F | LANL, PPPL |
| | | | | | |
| | | | | | |
| **5.5.E** | **Spectroscopy** | | | | |
| 5.5.E.01 | CXRS Active Spect. (based on DNB) | 1b | H | B | ORNL, GA, Wisc.,PPPL, UT |
| 5.5.E.02 | H Alpha Spectroscopy | 1a | H | C | Md, JHs |
| 5.5.E.03 | VUV Impurity Monitor (Main Plasma) | 1a | H | C | Md, JHs, LLNL |
| 5.5.E.04 | Vis. And UV Impurity Monitor (Divertor) | 1a | M | E | Md, JHs, ORNL |
| 5.5.E.05 | X-Ray Crystal Spectrometers | 1b | M | C | PPPL, LLNL |
| 5.5.E.06 | Visible Continuum Array | 1a | M | D | UT |
| *5.5.E.07* | *Soft X-ray Array** | *1b* | L | G | Wisc. |
| 5.5.E.08 | Neutral Particle Analyzers | 1a | L | F | ORNL |
| *5.5.E.10* | *Laser Induced Fluorescence** | *2* | L | G | Wisc. NovaPhot., WVU |

| | | | | | |
|---|---|---|---|---|---|
| 5.5.E.11 | MSE based on Heating Beam | 1b | H | C | Wisc.,LLNL ,PPPL, NovaPhot, LANL, ORNL |
| | | | | | |
| **5.5.F** | **Microwave Diagnostics** | | | | |
| 5.5.F.01 | ECE Diagnostics for Main Plasma | 1b | H | B | Idaho, UT, NM Tech, Auburn, |
| 5.5.F.02 | Reflectometers for Main Plasma | 1b | H | B | UCLA,UCD, PPPL |
| 5.5.F.03 | Reflectometers for Plasma Position | 1b | M | D | UCLA,UCD, PPPL |
| 5.5.F.04 | Reflectometers for Divertor Plasma | 1b | L | G | UCLA,UCD, PPPL |
| 5.5.F.05 | ECA for Divertor Plasma | 1b | L | G | |
| *5.5.F.06* | *Microwave Scatt. (Main Plasma)** | *2* | M | C | UCLA,UCD, PPPL |
| *5.5.F.07* | *Fast Wave Reflectometry** | *1a* | M | C | GA,UCI, MIT |
| | | | | | |
| **5.5.G** | **Plasma-Facing Components and Operational Diagnostics** | | | | |
| 5.5.G.01 | IR Cameras _ Visible / IR TV | 1a | M | E | LLNL,LAN L |
| 5.5.G.02 | Thermocouples | 1a | L | G | SNL,GA |
| 5.5.G.03 | Pressure gauges | 1a | M | E | Washington, MIT |
| 5.5.G.04 | Residual Gas Analysers | 1a | M | E | |
| *5.5.G.06* | *IR Thermography Divertor** | *1b* | L | G | LLNL,LAN L |
| 5.5.G.07 | Langmuir probes (G.07) | 1a | H | B | SNL,GA,UC SD |
| | | | | | |
| **5.5.N** | **Standard Diagnostics** | | | | |

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|---|---|---|---|---|---|
| | **Interface** | | | | |
| 5.5.N.01 | Diag, In-Vessel Services | | L | G | PPPL,GA, ORNL |
| 5.5.N.03 | Diag. Port Plugs & First Closures | | F | F | PPPL,GA, ORNL |
| 5.5.N.04 | Diag. Interspace & Second Closures | | F | F | PPPL,GA, ORNL |
| 5.5.N.05 | Diag. Divertor Components | | F | F | PPPL,GA, ORNL |
| 5.5.N.06 | Ex-Bioshield Electrical Equipment | | L | G | PPPL,GA, ORNL |
| 5.5.N.07 | Diag. Window Assemblies | | F | F | PPPL,GA, ORNL |
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* *Asterisked diagnostics are not included in the ITER Diagnostics Budget*
Assumes that the Langmuir probes include a package of first wall measurements.
Column 4/level: High (~1/4), Medium, Low and Fractional (~1/4, e.g. windows, port-plugs).

Evaluation done in style of Japanese (scale): A ~100%, B ~75%, C ~67%, D ~50%, E ~ 33%, F ~25%, G ~0%.

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|---|---|---|---|---|---|
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| **5.5.X** | **Other Diagnostics not presently included in ITER list** | | | | |
| 5.5.X.01 | BES (density fluct.) | | N/c | | Wisc. UT |
| 5.5.X.03 | Heavy Ion beam Probe (HIBP) | | N/c | | RPI |
| 5.5.X.04 | MHD spectroscopy | | N/c | | MIT |

| | | | | | |
|---|---|---|---|---|---|

**Table I. ITER diagnostic list, including present party and potential US interests.**

Six of the large equatorial ports have been assigned fully or partially to diagnostics and eleven upper ports are allocated for diagnostics. To insure shielding integrity for the facility, these ports must contain a large amount of shielding material, "plugs", with labyrinths or small holes for diagnostics access. In addition, the interfacing with the cryostat must be carefully engineered. Hence the engineering tasks which would integrate these large components with the wiring, component mountings, window and mirrors, are also significant elements of the full ITER Diagnostic requirements. In addition to assuming responsibility for individual systems, the US could take responsibility for some port plug modules. The US has the capability, expertise and experience for integrating these systems as needed in ITER. These activities will require coordination with many partners, and compatibility with a nuclear environment and its associated remote handling requirements. The diagnostics projected for one port plug could come from many Parties, and the provision of any one diagnostic could be shared between a few institutions worldwide. In this context, it is important that all interested parties (universities, labs and industries) be involved in an open process at the national level where participation can be discussed and evaluated. We recommend that we should aim to start a discussion between interested participants in diagnostic preparation at the US ITER Forum in early May 2003, with the ultimate goal of establishing a way forward for the US specialist diagnosticians to take part in the ITER process.

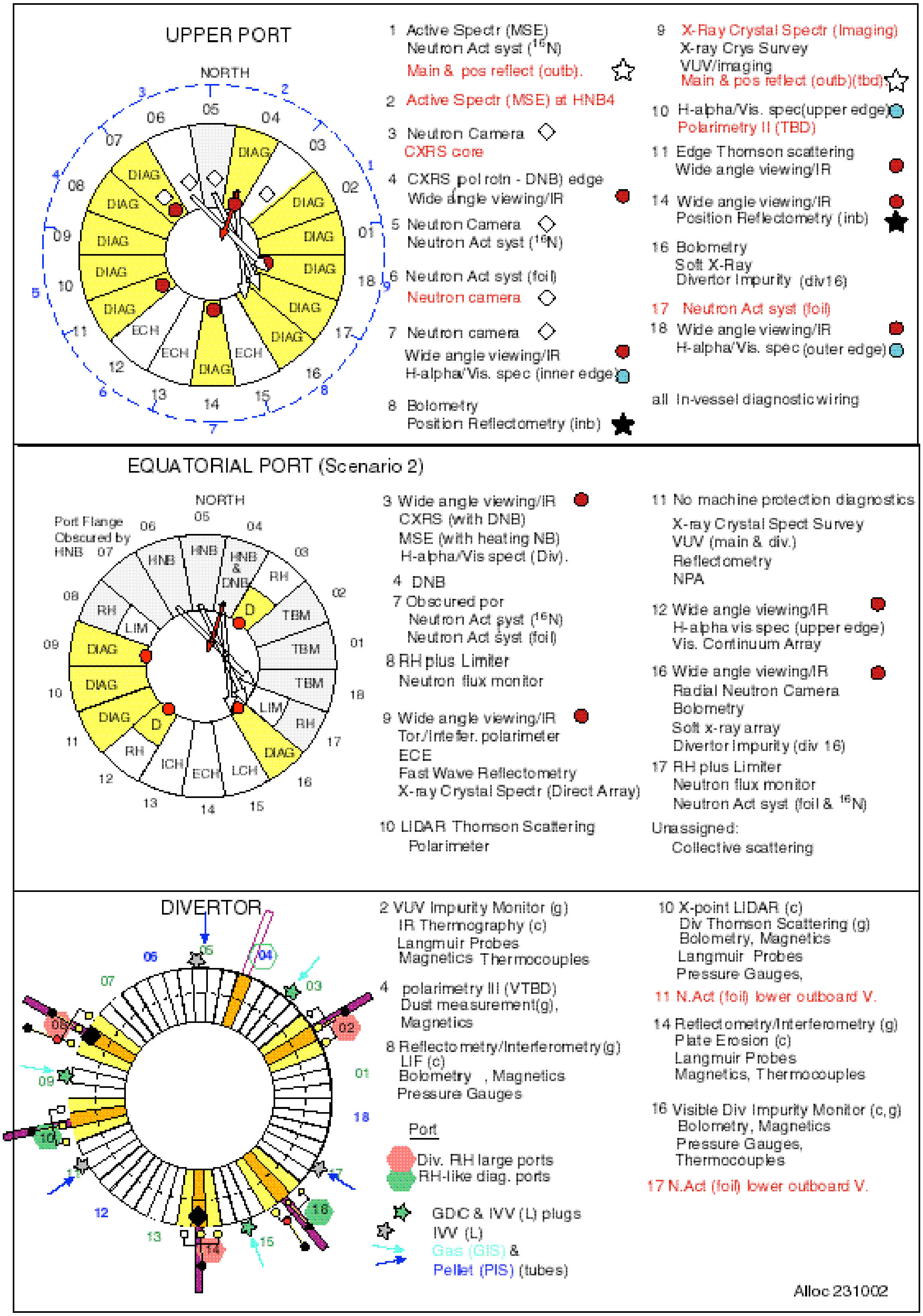


**Figure 2 Physical distribution of diagnostic systems, at the 3 elevations as a function of port number. List is current as of Oct 23rd 2002.**

# Required ITER diagnostics R&D

Although most of the diagnostic techniques planned for ITER are relatively well understood and developed, a significant number of issues remain to be addressed. These issues include factors such as radiation effects (induced EMF, induced conductivity, nuclear heating, photoluminescence), long pulse (stability, drifts), optics degradation (erosion, redeposition). Others include the development and testing of a new technique, either to replace a conventional one, which is not expected to be available on ITER, or to measure a previously undiagnosed parameter such as tile erosion. These issues must be addressed as soon as possible, following a strong R&D program and by taking advantage of existing facilities. These activities should be coordinated with the fusion technology community whose expertise can be very beneficial. This expertise can be found in many US groups, and should be utilized and strengthened. Dedicated resources should be allocated for these studies where appropriate.

Shown in table II is a partial listing of R&D areas in which the US fusion community could contribute directly, either by design activities, or by testing in existing facilities. These activities are also directly connected with high-priority items found on the ITPA-diagnostics topical group list of activities.

| Measurement | R&D required | priority | Current party interest | US strength/interest |
|---|---|---|---|---|
| Confined alpha particles | New techniques | High | All | Strong |
| Lost alpha particles | New techniques | High | All | Strong |
| Magnetics | Radiation effects | High | All | Moderate |
| Current Profile | Improved techniques | High | EU | Strong |
| Optical Diagnostics | Erosion/redeposition | High | All | Moderate |
| Measurement of fuel composition | Fast wave reflectometry | Intermediate | None | Very Strong |
| Tile Erosion | New techniques | Intermediate | None | Strong |
| Impurity measurements | New techniques | Intermediate | None? | Moderate |
| Core fluctuations | New techniques? | Long-term | None | Strong |
| Dust | New technique | Long-term | RF | Moderate |
| | | | | |

**Table II. US fusion community R&D potential direct contributions**

# US expertise

The development, implementation and operation of diagnostics have long been a strength of many US universities and fusion research institutions. As shown in Table III, we can see that the expertise is vast, and that a great potential exists, which can be tapped for developing the best systems for ITER. This list is at present incomplete; nevertheless it shows the richness of the existing program and the resources available. In developing this document we wish to engage the potential contributors to promote their expertise, and capability and to stimulate a discussion on their possible involvement in ITER diagnostics.

| Institution | Expertise |
|---|---|
| | |
| Auburn University | ECE |
| Columbia University | Magnetics |
| Colorado School of Mines | Alphas, fast ions, gamma, neutrons |
| General Atomics | Magnetics*, CHERS*, Thomson, Alphas, Neutrons*, Interferometer/Polarimeter*, Fast Wave Reflectometer*, Generic Packages* |
| Johns Hopkins University | Spectroscopy |
| Lawrence Livermore National Laboratory | MSE, IR cameras, imaging |
| Los Alamos National Laboratory | Imaging, Intense Diagnostic Neutral Beam*, Bolometry*, Neutrons*, CHERS |
| Massachusetts Institute of Technology | Collective Thomson Scattering, Phase Contrast Imaging, Spectroscopy, Gamma, MHD spectroscopy |
| Nova Photonics | MSE, LiF |
| Oak Ridge National Laboratory | Neutrals, Spectroscopy, Pellets, Collective Thomson Scattering*, Generic Packages* |
| Princeton Plasma Physics Laboratory | Thomson, MSE, Spectroscopy*, Fast ions*, Neutrons*, CHERS, ECE, Reflectometry*, Generic Packages* |
| Rensselaer Polytechnic Institute | Heavy Ion Beam Probes[1] |
| Sandia National Laboratory | Probes, First wall diagnostics |
| University of Maryland | Spectroscopy, ECE |
| University of California, Davis | ECE, reflectometry |
| University of California, Irvine | Fast ions |
| University of California, Los Angeles | Reflectometry*, Scattering, ECE, Polarimetry |
| University of California, San Diego | Probes, Bolometry |

| | |
|---|---|
| University of Idaho | ECE |
| University of Texas, Austin | ECE, fluctuation diagnostics, CHERS, BES, Visible Bremmstrahlung, Spectroscopy |
| University of Washington | Interferometry, neutrals |
| University of Wisconsin, Madison | CHERS, BES, Polarimetry, First wall diagnostics |
| West Virginia University | Neutrals, LiF |
| | |
| | |
| | |

* Dedicated/credited ITER-EDA (prior to 1999) US diagnostic activity

[1] No heavy ion beam probe is presently planned for ITER

**Table III. Examples of US institutions' expertise**

# Benefits to US program

Development of, and research using, plasma diagnostics is a key area for training and educating the next generation of researchers. The challenge of developing new measurement techniques and the excitement of new scientific discoveries give unique opportunities for students and young scientists to participate in and contribute to the exciting field of burning plasma science. It strengthens the vital link between university facilities, and research laboratories, while connecting with the strong theory and modeling program. It is directly tied to the next step in fusion development and thus benefits the Nation. Research and development in plasma science also creates many spin-offs across the whole technological base, stimulates innovation, while supporting businesses and universities alike. It is also a domain that naturally bridges the gap between the various fields of physics and engineering, and builds strong ties across the scientific community.

# Summary

The participation of the US fusion community in the ITER project should include a strong diagnostic component. This participation should include the development, construction, implementation and operation of the system allowing a direct connection with the scientific and technological benefits of the undertaking.

A large constituency, from universities, national labs and industries, should be called upon to create teams in order to develop the best diagnostic systems for ITER. We recommend that we should aim to start discussions between interested participants on how to participate in diagnostic preparation at the US ITER Forum in early May 2003. The benefits to the nation are important and follow naturally our long tradition of expertise in this domain. The US has considerable experience and expertise in both individual diagnostic implementation and utilization as well as in the integration of diagnostics into subsystems.