Research Thrust to Address Major Measurement Gaps

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Overview

A Research Thrust is proposed to address critical gaps in the area of control monitors and diagnostic physics measurements for the upcoming burning plasma era. The fusion community is unprepared for the reduced diagnostic measurement capability that will likely accompany the advent of burning plasmas. Currently there is no U.S. program focused on development of suitable diagnostics and monitors for the burning plasma environment. The challenges include heat and neutron loads on in-vessel components, such as mirrors, as well as fundamental limitations of existing diagnostic techniques related to new parameter regimes. The thrust proposes solutions through (1) new DoE initiatives focused on the development and demonstration of burning plasma diagnostic systems and components and (2) increased commitment from existing fusion plasma facilities to integrate (where practical) and test relevant burning plasma diagnostic components and emerging techniques.

Issues and Gaps in the Measurement Area

The measurement capabilities on existing U.S. fusion devices are exceptional, and have allowed significant advances in physics understanding and operational control. At DIII-D (for example) a whole array of profile measurements are available between discharges including q-profile (MSE EFIT), ion and electron temperature, electron density, etc. In addition, a broad range of turbulence and MHD diagnostics exist covering spatial scales from tens of centimeters down to millimeters. However, it is clear that if existing diagnostic techniques were simply transferred to ITER measurement capability would be significantly compromised and availability potentially reduced.

For example, relativistic effects (assuming T_{e0} ~25keV) will degrade the spatial resolution of electron temperature measurement using electron cyclotron emission (ECE) technique. Analysis by a scientific group led by the University of Texas (see :

http://www.pppl.gov/usiter-diagnostics/Instrumentation-Packages/Electron-Cyclotron-Emission/S006937F%20ITER%20ECE%20Report%20(U.%20Texas).pdf)

indicated a spatial resolution of ~10cm in the core of expected ITER plasmas – almost an order of magnitude worse than currently available. Even accounting for the larger scale ITER plasma this is clearly a significant dilution of measurement capability. In addition the Texas-led group has indicated further limitations as quoted below

> *"The simulations showed, in agreement with previous studies, that because of the ECE harmonic overlap and the extreme frequency downshifting of the electron cyclotron absorption, the only useful ECE measurements are from the outer half of the plasma major radius."*

The above is an example where the measurement technique itself degrades the measurement capability – the deterioration is not due to hardware limitations but is fundamental to the measurement technique itself.

In contrast, there is also significant concern regarding a broad array of existing optical diagnostic techniques such as Thomson scattering, charge exchange recombination spectroscopy, motional Stark effect, etc. Maintenance of the optical quality of mirrors, polarizers, windows, etc. located close to a burning plasma environment represents a significant and perhaps overwhelming challenge to overcome. In addition, the bremsstrahlung background emission will be far greater than observed in current devices and will potentially limit signal to noise. It seems likely that availability/accuracy of such visible diagnostics will be compromised in the ITER environment, especially during long pulse (~1000s) exposure to high heat and neutron loads. Projections to DEMO are even more pessimistic and would lead to further deterioration in reliability, availability and measurement accuracy.

The challenges posed by a burning plasma environment to measurement capabilities must be urgently addressed. Without a focused effort to resolve the numerous concerns, the fusion community is in danger of returning towards an era when plasma measurements were far more limited! A primary goal for ITER is to understand the physics of burning plasmas. This will require a wide range of detailed measurements – ideally *superior* even to the current capabilities. DEMO represents an even greater challenge. It is critical that we immediately work to both identify and resolve the “gaps” in measurement capability so that ITER can prepare us for future burning plasma devices such as CTF, FDF and DEMO.

Focus of Research Thrust

The fusion community needs to immediately initiate an effort to comprehensively determine measurement uncertainties for ITER and future burning plasma devices – we need to clearly identify (a) where measurement gaps exist, (b) how large they are and their impact and (c) how to resolve them. The first two steps are relatively straightforward. However, the third is not and requires an immediate DoE-funded initiative. Currently, existing programs at DoE (including the US IPO) only weakly support research and development in this area and are not focused on the long-term.

The initiative should solicit proposals to

(1) Identify and develop creative *new* diagnostic techniques compatible with the burning plasma environments expected in ITER, CTF and DEMO. The techniques would be focused to fill identified “measurement gaps”. Viable techniques would (where possible) initially be demonstrated on existing fusion devices and subsequently on ITER.

Currently there tends to be a belief that transferring existing measurement techniques will perhaps be sufficient to satisfy ITER needs. This is not the case and, unless action is taken, measurement capability will further deteriorate in devices such as FDF, CTF and DEMO. Even the routine determination of plasma position will likely be severely compromised in such devices.

There needs to be an emphasis on techniques where the diagnostic-plasma interface is amenable to *reliable* solutions and where the technique is able to be fully extrapolated to post-ITER devices. This requires a combination of new and existing techniques, and improved in-vessel components.

(2) Identify and develop creative solutions to in-vessel component problems e.g. plasma facing optical components such as mirrors, optical fiber damage, electrical signal/control cables, etc. Solutions will likely be both multifaceted and multi-institutional and will need to be tested using long pulse, high radiation and heat load environments that exist primarily outside of the fusion community. Of course, where practical, tests in-situ on existing fusion devices would also be employed to establish effectiveness.