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The Challenge of ITER Diagnostics.

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1. Introduction

The implementation of diagnostics on ITER, as the world's first burning plasma fusion device, will be a major challenge. The measurement parameters, parameter ranges, accuracies and resolutions, will be the same or more demanding than on present machines but the environment will be much harsher. For example, the levels of neutral particle flux, neutron flux and fluence will be respectively about 5, 10 and 10,000 times higher than the harshest experienced in today's machines and the pulse length will be about 100 times longer. In consequence, the selection and design of diagnostic systems has to take into account a range of effects and phenomena not previously encountered (see figure 1). The value of some key plasma parameters will be significantly different from current machines (higher temperatures, longer pulse length (possibly steady state), larger physical size etc) which can significantly influence diagnostic performance.

Since early in the ITER Engineering Design Activity, dedicated design and R and D on ITER diagnostics has been in progress. The radiation effects on candidate materials for diagnostic construction, and on some prototype diagnostic components, have been investigated and a substantial database of results has been established. The specifications of the required measurements have been detailed and specific diagnostic systems have been selected and are being designed. This work has shown the need for the development of specific diagnostic components and, for some measurement requirements, new diagnostic techniques. R and D on some of these topics is in progress, others are yet to be addressed.

In this paper, we consider the measurement of a few key representative parameters. We identify the main issues associated with implementing the relevant diagnostics on ITER,

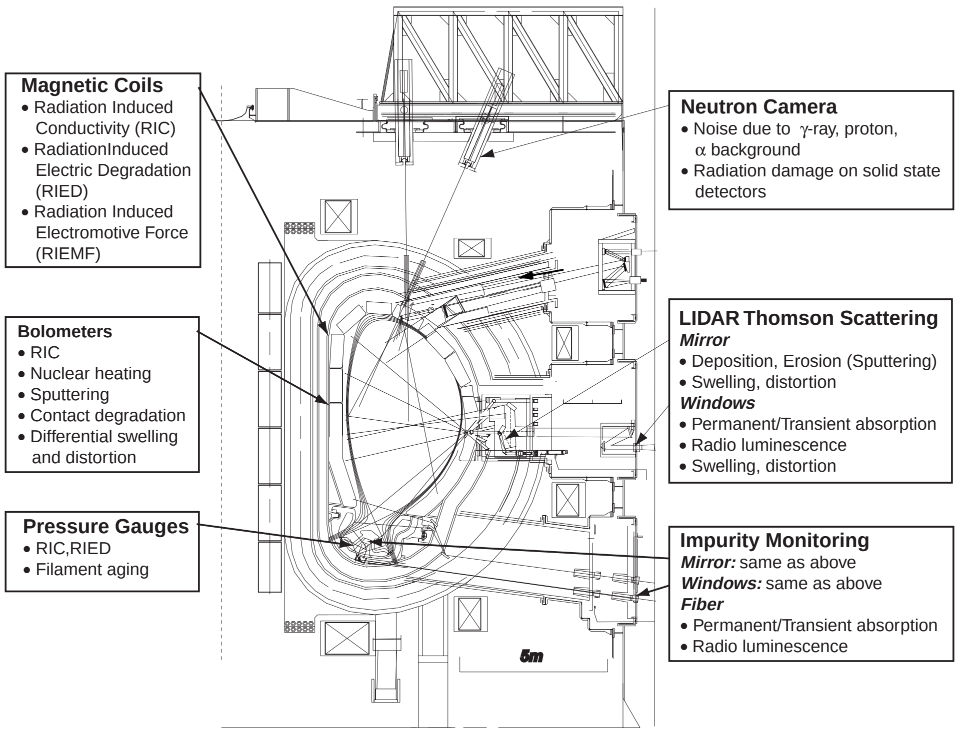

Figure 1. Location of some representative diagnostic components and the principal, radiation induced physical effects of interest.

and show how a successful implementation can be achieved by a careful interplay between design and R&D. Key issues which are presently unresolved and where further work is required are highlighted. Finally, a brief overall assessment of the anticipated performance of the ITER diagnostic system, as currently envisaged, is presented. More details will be published in the ITER-FEAT Final Design Report later this year [1].

2. Measurement of Some Representative Plasma Parameters.

To control and evaluate plasmas on ITER it will be necessary to measure the **plasma current** in the range 1 - 20 MA with an accuracy of 1%; the **plasma shape and position** to a few cms; the **loop voltage** to within a few mV, the **plasma energy** to < 10%, and the **amplitude**

of MHD modes to typically 10%. The measurements are required with a time resolution of $\leq$ 10 ms and for pulse lengths of up to 3,600 s. The measurements will be made primarily with the magnetic diagnostics. Magnetic diagnostics are, of course, well established on existing machines but the step to ITER involves several effects and difficulties which have not been previously encountered. The phenomenon of Radiation Induced Conductivity (RIC) can load magnetic pick-up coils while Radiation Induced EMF (RIEMF) can lead to spurious signals. The presence of in-vessel structures such as blanket modules affects the coupling between the sensors and the plasma. The intense plasma radiation and neutron emission leads to significant heating of the in-vessel sensors.

The system designed for ITER includes a set of pick-up coils, saddle loops and voltage loops mounted on the inner wall of the vacuum vessel and in some of the divertor cassettes for equilibrium and high frequency measurements. Extensive simulations have been carried out and have confirmed that the chosen configuration will provide the principal parameters with the required accuracy. The coils and loops are made from cables chosen for low radiation induced effects (for example Mineral Insulated cable). Further, they are mounted behind the blanket shield modules where they receive an attenuated neutron and gamma flux. It is also proposed to include a set of pick-up coils mounted inside the skins of the vacuum vessel. This set will be in a much lower radiation field and although slower, simulations suggest that it could be used for equilibrium control if necessary. Some of the sensors in this set will have the capability to measure static magnetic fields giving the required long pulse capability.

Naturally an important parameter to be measured on ITER will be the **fusion power** and related parameters such as the **neutron flux and emissivity, neutron fluence and ion temperature**. For the control and evaluation of ITER performance these are required to an accuracy of 10% with good temporal and spatial resolution. The main measurement difficulty arises from the expected very wide range (seven orders of magnitude) in neutron flux. Measurement of the spatial profile of the neutron emission is also a demanding requirement. The system proposed for ITER comprises neutron flux monitors mounted inside and outside the vessel, neutron activation systems and radial and vertical neutron cameras. In the vessel the flux monitors (microfission chambers) are deployed in poloidal arrays. Wide dynamic range is obtained by using several detectors with overlapping sensitivities. Two kinds of activation system will be employed: a conventional system employing encapsulated foils and a system developed for ITER in which the gamma-rays from the decay of ^{16}N produced in a continuously flowing fluid are measured. Radial and vertical viewing neutron cameras are planned. Access difficulties restrict the views that can be obtained and it is not yet clear whether the requirements for spatial resolution can be met. Some of the lines of the radial neutron camera will be equipped with neutron spectrometers for measuring the ion temperature from the Doppler width of the 14.1 MeV neutron emission. Compact, efficient, spectrometers with high energy resolution are required for this application and, while candidate spectrometers exist, some development is required.

Measurement of the **electron density, electron temperature and impurity influx and concentration** are required over wide parameter ranges in the core, edge and divertor regions with good spatial and temporal resolutions. In order to fulfill all the measurement requirements, several different diagnostic systems are planned including interferometry/polarimetry, Thomson scattering, ECE, reflectometry, passive and active spectroscopy. In order to maintain a high degree of neutron shielding simultaneously with a high optical throughput, labyrinthine transmission lines embedded in shielding blocks in the ports are employed. The element closest to the plasma will be a mirror and this is the most critical component. The mirror will be subjected to the intense plasma radiation including bombardment by high energy particles arising from the charge exchange process. An extensive R&D programme has demonstrated that mirrors made from single crystal W, Mo or stainless steel can maintain their optical performance even when eroded to a depth of several microns. For mirrors in the divertor region, deposition is likely to be the dominant potentially damaging mechanism. Possible mitigating methods are baffles, shutters and cleaning. The extent of this problem is not yet clear and further work is required.

3. Concluding Remarks - Overall Assessment

Although there is a very extensive experience and knowledge base for implementing diagnostic systems on tokamaks, the step to ITER conditions is substantial. Considerable progress has been made but several key issues remain outstanding. Further measurements are required in some areas on the irradiation effects on candidate materials for diagnostic construction, and development is required on some radiation hard diagnostic sensors. For a few of the required measurements, for example measurement of confined and escaping alphas, new or improved techniques are required. Many of the systems have been designed at the conceptual level but the detailed design remains to be done.

Reference

[1] 'Technical Basis for ITER Final Design Report', to be published by the IAEA in the ITER EDA Documentation Series, IAEA, Vienna (2001).

Acknowledgment

This report is an account of work undertaken within the framework of the ITER EDA Agreement. The views and opinions expressed herein do not necessarily reflect those of the Parties to the ITER Agreement, the IAEA or any agency thereof. Dissemination of the information in this paper is governed by the applicable terms of the ITER EDA Agreement.