Overview of ITPA R&D Activities for Improvement of ITER Diagnostic Performance

Y. Kawano¹, D. Brower², G. Vayakis³ for the ITPA Topical Group on Diagnostics

¹National Institutes for Quantum and Radiological Science and Technology, 801-1 Mukoyama, Naka, Ibaraki, 311-0193, Japan
²University of California, Los Angeles, Los Angeles, CA 90095-1547, USA
³ITER Organization, Route de Vinon sur Verdon, CS 90 046 - 13067 Saint Paul Lez Durance Cedex, France

E-mail contact of main author: kawano.yasunori@qst.go.jp

Abstract. The International Tokamak Physics Activity Topical Group on Diagnostics has been conducting R&D activities to support improved ITER diagnostic performance. Highlights of the Topical Group activity focus on: (1) mitigating degradation of first mirrors in optical systems and development of techniques for removing impurity deposition on mirrors; (2) characterization of in-vessel stray light to reduce impact on diagnostics; (3) diagnostics of escaping α particles and feasibility tests of the activation probe method; (4) studies of real time diagnostics and measurement of surface temperature of in-vessel components using infrared thermography; and (5) implementation of multi machine joint experiments for diagnostics.

1. Introduction

The ITER diagnostic system is essential for safe machine protection, reliable machine operation and comprehensive understanding of burning plasma behavior in ITER [1]. To achieve these goals, more than fifty sub-systems are being developed for measurement of parameters of plasma and plasma-facing components in the harsh ITER environment, characterized by higher neutron/γ-ray fluence coupled with lower maintainability compared to those in any existing fusion devices. The International Tokamak Physics Activity (ITPA) Topical Group (TG) on Diagnostics has addressed common physics issues towards improvement of diagnostics development [2]. The outline of the TG and recent highlighted progress which were presented and discussed in the TG are reported in this paper.

2. Outline of the ITPA TG on Diagnostics

Activities of the TG have been conducted under the following charter; "The Diagnostics Topical Group aims to identify and resolve the key diagnostic issues that might arise both in plasma control and in the analysis of ITER plasmas and in the reactor grade (high fusion gain) plasmas that will follow ITER (e.g. DEMO)." Currently 44 members are assigned to the TG from all ITER participating parties and ITER Organization.

The TG has organized 9 Specialist Working Groups. A total of ~300 experts are participating in these Specialist Working Groups. Areas for these Specialist Working Groups are shown below.
• Fusion product diagnostics: neutrons, α-particles, γ-rays, etc.
• Microwave diagnostics: electron cyclotron emission, reflectometry, etc.
• Laser aided diagnostics: Thomson scattering, Interferometry, Polarimetry, etc.
• Passive spectroscopy: Hα, X-rays profile, spectroscopies in X-rays / ultra-violet / visible / infrared ranges, etc.
• Active spectroscopy: charge exchange recombination spectroscopy, motional Stark effect spectroscopy, beam emission spectroscopy, neutral particles, etc.
• First wall diagnostics: visible / infrared viewing systems, bolometry, dust / erosion / tritium / deposition, etc.
• First mirrors: characterization of optical mirrors, mitigation of impurity deposition on mirrors, mirror cleaning technology, mirror technology, etc.
• Radiation effects: effects of neutrons and γ-rays radiation on diagnostic components, etc.
• Real-time diagnostics: diagnostics for plasma control and machine protection

The TG activity is mainly directed to High Priority research areas (HP);

• HP-1: Determination of the life-time of plasma facing mirrors used in optical systems,
• HP-2: Assessment of impact of in-vessel wall reflections on diagnostics,
• HP-3: Develop methods of measuring the energy and density distribution of escaping α particles,
• HP-4: Plasma control system measurement requirements,

and multi machine joint experiments for diagnostics (JEX-DIAG) under a framework between ITPA and the Implementing Agreement on Co-operation of Tokamak Programs of the International Energy Agency (IEA);

• JEX-DIAG-2: Environmental tests on first mirrors,
• JEX-DIAG-3: Resolving the discrepancy between ECE and Thomson Scattering at high \( T_e \),
• JEX-DIAG-5: Field test of an activation probe,
• JEX-DIAG-6: Cross comparisons of Charge Exchange Recombination Spectroscopy and X-Ray Imaging Crystal Spectroscopy,
• JEX-DIAG-7: Distributed monitoring of microwave power density,
• JEX-DIAG-8: Benchmark of Wall reflections,
• JEX-DIAG-9: Spectral MSE (MSE-LS) experiments as design driver for ITER MSE.

Progress and plans in every HPs and JEX-DIAGs are reported and discussed at the TG meetings which are held twice each year. Action Items including assessments of specific subjects are also launched and updated at each meeting.

3. Highlights

3.1. Mitigation of Degradation of Plasma Facing First Mirrors (HP-1, JEX-DIAG-2)

The reflectivity of optical diagnostic plasma-facing first mirrors degrades due to deposition of incident impurity particles such as beryllium and tungsten. Models suggest that fins (baffles) in an optical duct will reduce the impurity deposition rate on the mirror. For the validation of the model predictions, the so-called Mirror Station was installed at TEXTOR for exposure to plasmas under JEX-DIAG-2. The Mirror Station consisted of mirrors located in cylindrical ducts of various length where some the ducts had fins. Mirrors with conical ducts were also equipped. Contrary to model predictions, no drastic suppression of carbon deposition was
reported in experiments using cylindrical ducts with fins. Intensive analyses were carried out using the kinetic Monte-Carlo transport code EIRENE. Code simulation indicated that the total fluence of charge exchange carbon atoms from plasma to the aperture of the mirror station would be $1.3 \times 10^{15}$ cm$^{-2}$. This value was smaller than the amount of deposited carbon measured at mirrors which was of order $10^{16}$ cm$^{-2}$. Since ion fluence received by the front surfaces of the mirror station during wall conditioning glow discharge was inferred as $6.3 \times 10^{18}$ cm$^{-2}$, which was much higher than that of the above charge exchange atoms, the deposition was mainly attributed to wall conditioning discharges and not to plasma operation [3]. In case of the conical ducts, no visible deposition was observed on the mirrors. A possible mechanism for this is the deposition to large area behind the small aperture, indicating promising geometry for deposition mitigation. Recently, new data were obtained and analyzed under JEX-DIAG-2 at AUG, JET and LHD. It is expected to have better understanding for various operational parameters in future publications.

The results reported in the previous section suggest that protection of the mirror, e.g. by a shutter during wall conditionings, seems necessary. Such an integrated design of the duct with fins and shutter was made for the ITER core charge exchange recombination spectroscopy [4]. The shutter has two long arms (~2 m) with shutter blades and a gas actuator (~5 bars). The gas actuator drives the shutter arms to close or open the optical aperture. A dynamic behavior of the shutter was well understood by 3D finite element analysis. A prototype is under fabrication to validate the design.

If due to deposition, mirror degradation reaches a measurement-impeding level significantly prior to a scheduled maintenance, in-situ mirror cleaning is needed. Based on progress of cleaning techniques using radio frequency (RF) discharges [5,6], where mirrors themselves are utilized as electrodes, implementation schemes for ITER were proposed. This study also suggested that the effect of multiple cleaning cycles, which may lead to increased mirror surface roughness, is important [7]. Recently, an experiment evaluating multiple cleaning (5 cycles) was carried out for a single crystal molybdenum mirror. This test provided important data necessary to understand the change in total and diffusive reflectivity due to the multiple cleaning [8].

3.2. Assessment of Influence of Stray Light (HP-2, JEX-DIAG-7, JEX-DIAG-8)

In ITER, in-vessel wall reflections produce stray light which seriously distorts the signal of many optical diagnostics. Assessment of the effect of stray light on the divertor spectroscopy system in ITER was carried out with ray tracing simulations [9]. A method of synthetic Balmer alpha diagnostics by the use of high resolution spectroscopy was proposed for ITER [10]. Further comprehensive report for these topics and JEX-DIAG-8 in the visible and infrared diagnostics can be found in Ref. [11].

Stray radiation by electron and ion cyclotron waves used for heating (ECW and ICW) is also an issue. Loads due to ECW (20 MW, 170 GHz) and also probing microwaves of the Collective Thomson Scattering (CTS) diagnostics (1 MW, 60 GHz) were investigated [12]. It was shown that a high power refracted beam of ECW due to a mismatch in polarization is a risk due to the extreme power density of the focused beam. It was also shown that the thermal loads due to stray radiation levels by ECW and CTS can be handled by the first wall. In any case, however, microwave power may reach areas behind the blanket modules and inside the port plugs where diagnostics and other components are installed. This causes a risk that such components may be damaged by the radiation. In order to mitigate this risk, bolometers for
in-vessel monitoring of the stray radiation were newly developed [12] and recently installed in DIII-D for feasibility testing under JEX-DIAG-7. It is expected to obtain experimental data shortly.

3.3. Development of Escaping $\alpha$ Diagnostics (HP-3, JEX-DIAG-5)

An attractive candidate for an escaping $\alpha$ diagnostic in the harsh ITER environment is the activation probe characterized by its robustness although it lacks temporal information. Test samples activated by $\alpha$ particles are analyzed after their exposure to plasmas. This method was tested in AUG and JET under JEX-DIAG-5 indicating its feasibility [13]. In 2015, an experiment in KSTAR was started [14]. In KSTAR, an activation probe was installed on the multi-purpose mid-plane manipulator and was exposed to plasmas. Preliminary analysis on site showed that the fast ions were detected by the probe. A magnetically-driven manipulator was proposed for ITER to reduce heat load onto the probes. With this, it is expected that the use of the time-resolved sensors, e.g. scintillators, is possible [15] and further design study is ongoing.

Since it seems hard to cover the parameter range of the measurement with one diagnostic, implementing a combined approach using various methods seems important, e.g. probing technics, infrared camera systems (viewing heat load onto wall), fast ion charge exchange recombination spectroscopy, etc.

3.4. Studies of Real Time Diagnostics for Plasma Control (HP-4)

Monitoring the surface temperature of in-vessel components is one of the essential parameters for safe machine protection and reliable plasma control. In AUG, a new infrared thermography system was developed, in which the signal integration time is adapted in real time to keep appropriate signal level for good accuracy [16, 17]. Effects of parasitic radiation, e.g. emitted by hot spot, in the measurement were investigated together with possible mitigation techniques [18].

In order to support the development of ITER plasma control system which needs real-time data from diagnostics, Action Items were launched to gather experience from existing devices on how the density, heat load, MHD instability activity (e.g. locked modes, NTM, etc.), NBI shine-through, and High-Z impurity content measurements are validated and treated for plasma control in real time including processes to handle measurement failures, switchover process and other criteria. Such efforts will be continued in the TG activity.

3.5. Implementation of JEX-DIAGs

In addition to the highlights reported in the previous sections, steady and remarkable progress was also made in other JEX-DIAGs.

It is well demonstrated in existing devices that the Charge Exchange Recombination Spectroscopy (CXRS) is a suitable method for measurement of ion temperature and plasma rotation. Accordingly, CXRS will be employed to measure these parameters in ITER. It is also known, however, that penetration of probing beam for CXRS becomes weaker in the plasma core region and some concerns may arise for the optical (visible) diagnostics. X-Ray Imaging Crystal Spectroscopy (XICS) is expected to measure above parameters employing a different physical principle, but its capability needs to be precisely validated since it is a
relatively new method. Accordingly, JEX-DIAG-6 has been launched for cross comparisons between CXRS and XICS. In KSTAR, the cross comparison was successfully conducted by simultaneous measurement of CXRS and XICS for core ion temperature and toroidal rotation of different impurity species, like carbon and argon. As a result, reasonable agreement between the two measurements was shown for various plasma discharge conditions [19]. This is a promising result for establishing reliable measurement of ion temperature and plasma rotation in ITER.

Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Acknowledgements

The authors would like to thank all members of the ITPA Topical Group on Diagnostics and all members of the Specialist Working Groups for their participation in the Topical Group Activities. The authors are grateful to Drs. A. Litnovsky, P. Mertens, L. Moser, A. Razdobarin, L. Marot, S. Kajita, A.B. Kukushkin, M.F.M. De Bock, J.W. Oosterbeek, A. Fenyesvi, S. Zoletnik, S. Son, M. Kocan, B. Sieglin, A. Herrmann, S.G. Lee, S. Hong, H. Meister, V. Voitsenya, S. Tugarinov, J. Ko, M. Bassan, D. Mazon, M. Walsh, K. Itami and G. Conway for their fruitful discussions and contributions to this paper.

References