ITPA Topical Group on Diagnostics
Report on Activities in the period July 2009 – June 2010

The coordinated activities of the Topical Group on Diagnostics were continued over the period of July 2009 to June 2010, with an emphasis being placed on designated high priority topics. There were two meetings of the ITPA Topical Group (TG) on Diagnostics during that period.

1. Meetings of the Topical Group on Diagnostics

The Seventeenth Meeting was organized by Postech University, Pohang Korea, from October 12 thru 15, 2009. The meeting was combined with a Progress Meeting on ITER relevant diagnostic developments in Korea, which took place on 12 October. The meeting was opened by Prof. S.G.Baik, President of Postech, and was attended by 44 participants drawn from Korea (10), China (6), EU (12), India (2), Japan (6), Russia (3), USA (2), and the ITER IO (3).

The Eighteenth Meeting was organized by the Oak Ridge National Laboratory, Oak Ridge, TN, USA from May 11 thru 14, 2010. The meeting was combined with a Progress Meeting on ITER relevant diagnostic developments in the US, which took place on May 11th. The meeting was opened by Dr. D. Hillis, and was attended by 45 participants drawn from USA (21), China (1), EU (12), Japan (8), and the ITER IO (3). There was no participant from India, Korea or Russia. Additional experts attended remotely during the meeting. The meeting was scheduled just prior the High Temperature Plasma Diagnostics conference.

A special attention was given to the High Priority Items. In addition to the special sessions topics, the key topics reviewed and discussed at the TG meeting were:

- Progress and plans in meeting the goals of the Physics Voluntary R&D tasks in Diagnostics and especially the high priority topics;
- Developments in the ITER measurement requirements and justifications of these measurements;
- Review of critical areas of ITER diagnostic design and integration;
- Recent progress in ITER relevant diagnostic development and application in the Parties;
- Review the status of key elements of ITER diagnostic design and integration;
- Review the responses to the action items from the previous meetings of the ITPA Diagnostic TG and plan future actions;
- Review progress by the Specialist Working Groups in Diagnostics;
- Discussion on the date of the 19th meeting and location of the 20th meeting of the TG;
- Future activities.

2. High Priority Topics

Good progress has been made in the tasks designated as high priority:

2.1. Development of methods of measuring the energy and density distribution of escaping α-particles

2.1.1. Escaping α-particles

One key task that was identified over the last year corresponded to the need to identify proper alpha particle orbits that can reach a potential detector. These orbits were calculated in 2 scenarios, and show that a smooth/flat outer wall would prevent a direct detection of particles. Options including wall

modifications are being evaluated. Orbit calculations will be continued which would include a quantification of alpha particle populations in the relevant orbits.

Discussions were also held at a satellite meeting in Chita, Japan, in October 2009 (see section 2.2. for details).

In order to fully assess the feasibility of a standard (e.g. pitch-angle, energy resolved) lost alpha detector, the following items have to be completed and forms the required work plan.

- Develop full orbit detection efficiency (status: nearly complete)
- Develop full MCNP neutron and gamma calculation including angular dependence (status: partial completion)
- Obtain full proposed detector response to ions, gammas, neutrons and secondary electrons (status: partial completion)
- Obtain full detailed 3D description of First Wall (status: partial completion, still evolving)
- Include full description (e.g. dimensions) of probe head in orbit description and detection efficiency (status: not started)
- Evaluate full heat flux calculation on probe head (status: partial completion)
- Incorporate full description of image/signal path (e.g. light collection efficiency) (status: partial completion)

An evaluation of activation techniques is continuing but is likely to lack time resolution. This would require the introduction and removal of samples from the vacuum vessel after a certain number of discharges. A joint experiment is being proposed to further develop this concept. This high priority activity will continue.

2.1.2. Confined α-particles

The status of the ITER fast ion Collective Thomson scattering system has been changed to enabled system, which covers only the LFS front-end interface at this time. As part of the changes arising from the design review process, the in-port components of this system are included in the revised ITER diagnostic system. In view of this change, the work on confined α-particles has been moved to intermediate priority. The work will focus in further developing the CTS concept and continue proposing alternate techniques.

2.2. Assessment of the calibration strategy and calibration source strength needed

The Neutron Working Group has reported much progress regarding the neutron calibration strategy, and has presented their current findings and conclusions over the last 2 meeting. In particular, a special meeting was held October 18-20, 2009 at Chita, Japan, following the Fall 2009 ITPA meeting. Over 40 participants drawn from Japan, the IO, USA, Russia, Sweden, Denmark, Germany, England, China, Korea, and India, attended the meeting. During the meeting, the neutron calibration strategy was a major topic of the discussions, the other being discussions on lost-alpha approaches. These discussions were followed by electronic domain exchanges.

To achieve the required 10% accuracy in total fusion yields (e.g. neutron), a functional combination of neutron flux monitors, neutron profile monitors, and the activation system are needed, together with their in-situ calibrations, cross calibration, and establishment of reliable neutron transport calculation. In

addition, since the needed dynamic range in neutron detection is rather large, and since limited strength calibration sources are available, cross-calibrations between detectors will be necessary, as it is normally performed in existing devices. This can be done with dedicated plasma discharges, and supported by appropriate MCNP calculations. The suitable calibration source is a either a DT or DD neutron generator of source strength of 10^{10} n/s for DT and 10^{8} n/s for DD or better. While taking into account these generator yields, it is estimated that 2 neutron calibrations will be required, of 2 and 8 weeks duration respectively, which does not presently include the usually significant set-up time. Efforts are continuing in devising ways to optimize the number of calibration steps and to reduce the time necessary to complete it, while meeting the required accuracy. Options are being developed which may include additional or more sensitive detectors, additional calibration sources or slight changes to detector configuration. Finally, additional efforts will be required to minimize the self-shadow effects of the source/generator on the actual calibration results.

In view of these results, this HP item will be closed by the next meeting (Fall 2010), with a final report expected during the summer of 2010. It is though expected that discussions will be ongoing for the foreseeable future, as this will impact many aspects of ITER construction and commissioning.

2.3. Determination of life-time of plasma facing mirrors used in optical system

The report of the Specialist Working Group on First Mirrors gave an overview of all activities in the field of first mirrors. Much ITER-diagnostic specific research is in progress at many laboratories worldwide, but in general more solution-oriented research is needed and should be supported. More refined geometries are continuously being introduced for predictive modelling, although gas/plasma background conditions need considerable refinements. The effort in this field should be intensified and accelerated to serve the rising needs. Further progress was reported in the field of deposition mitigation (e.g. by flowing gas in front of the mirror) and mirror cleaning, coated mirrors, mirror manufacturing and irradiation testing of mirrors. With the progress accomplished so far, it was agreed that the development of mitigation methods for metallic (beryllium, tungsten) deposition is fast becoming urgent.

A roadmap to direct the international R&D in the field of first mirrors has been prepared and has been further detailed and evolved in special breakout sessions during both TG meetings. The road map is now actively used to direct the international research in the field of first mirrors and the priority of these activities has been established and agreed upon. One step proposed is to cluster the various diagnostic mirrors in groups with approximately the same functional requirements and operational environment in order to recommend baseline solutions for each group on the basis of present knowledge. Furthermore, it was agreed that candidate mitigation methods against deposition need to be reviewed to identify the most promising ones for further development.

Recent developments and research plans in the area of diagnostic mirrors were reviewed in the regular report of the FM SWG. The report outlined the progress in fulfilment of the Work Plan (WP) - the coordinated and prioritized plan of R&D on first mirrors.

The WP contains of 6 main areas (tasks):

- Performance under erosion-and deposition-conditions: material choice
- Predictive modelling of mirror performance in ITER
- Mitigation of deposition
- Cleaning of deposited layers on the mirror - surface recovery
- Tests under neutron, gamma and X-ray environment

- Engineering and manufacturing of ITER first mirrors.

The current research is already largely aligned with main areas of the work plan. In particular, promising results were presented on active control over carbon deposition in diagnostic ducts and remote areas – the complete suppression of carbon deposition was attained in the prototype of diagnostic duct by the deuterium gas feeding in the duct interior. Encouraging results were achieved on the cleaning of mirrors exposed in tokamaks: softer carbon films formed on the surfaces of the mirrors exposed in the divertor of DIII-D were cleaned completely and the reflectivity was restored, whereas harder films originating from TEXTOR were largely removed leading to the significant increase of the mirror reflectivity. Promising results from laser cleaning were reported from many laboratories was used to remove deposits. Important results were recently obtained in mirror cleaning techniques using laser irradiation. Significant improvement of optical reflectivity of treated mirrors was reported. However, in some cases the laser cleaning resulted in additional damage to the mirror surface. Applicability of these techniques for ITER conditions should be fully assessed.

Set of new molybdenum- and rhodium- coated mirrors were produced by evaporation and magnetron sputtering techniques at the University of Basel was exposed under erosion-dominated conditions in TEXTOR tokamak. Surface and optical characterizations revealed acceptable performance of all exposed mirrors: the reflectivity decreased insignificantly. Recently, the new experiment was carried out at higher fluence of eroding particles. Molybdenum mirrors withstood the erosion, the moderate decrease of the reflectivity was noticed for the Mo-coated mirrors. On a contrast, the Rh-coated mirror was severely sputtered by the plasma. This activity is being performed in the frame of collaboration program between FZJ and the University of Basel.

Single crystal molybdenum mirrors demonstrate an excellent performance under erosion-dominated conditions in tokamak experiments. Mirrors withstood fluences of eroding particles corresponding to several hundreds of ITER discharges without noticeable degradation of their reflectivity. The availability of such mirrors has recently increased significantly following new developments with industrial partners.

Studies of the shielding structures for the protection of retroreflectors were continued at LHD. V-shaped protection was introduced to mitigate the deposition on the mirror guiding the light to the retroreflector. The baffling of the optical channel was used to mitigate the impurity transport towards the retroreflector. Mitigation techniques were able to completely suppress the deposition on the retroreflector routinely observed under these conditions before.

A new topic is being added to the Work Plan. Investigations of diagnostic mirrors and in particular the assessment of the impact of conditioning discharges on the mirror performance is of significant importance. Therefore, it was decided to expand this area of the WP by introducing tests of ITER-relevant mirror under relevant conditioning techniques. The investigations of an impact caused by O-bake treatment of the tokamak were started as a collaboration effort between DIII-D and TEXTOR teams. Molybdenum and copper mirrors were placed in the main chamber and in the divertor where they were exposed for several hours in oxygen and helium mixture. Investigations are in progress.

Additional details can be found in Appendix 2, which covers the tasks made under the Joint Experiment umbrella.

2.4. Development of measurement requirements for measurements of hot dust, and assessment of techniques for measurement of hot dust.

Recall that last year's studies and discussions within the ITER Organization reached the conclusion that the inventories for dust and tritium are expected to reach their maximum limits on a timescale comparable to the target erosion lifetime. Based on this, a control strategy for dust and tritium had been

formulated. Dust would be removed during the scheduled divertor replacements (approximately every 4 years). Additionally the dust will be monitored during and before shutdowns. Local measurements will be benchmarked versus the tritium and dust recovered during the replacement of the divertor cassettes. The first benchmarking will be done in the hydrogen phase. Following these findings, the HP item was refocused on the remaining issue of hot dust, e.g. dust can be found on hot surfaces, that if exposed to steam could lead to an explosive situation.

At the last meeting, a presentation was made on the evaluation of the requirements on the presence of dust on hot surfaces (i.e. hot dust). It was found that a maximum of ~18kg of hot dust can be tolerated within the vacuum vessel. Separately, if one accounts for the total amount of dust that could be found within the vacuum vessel, it is estimated that up to ~40kg of dust could be uniformly distributed on hot surfaces, which would represent a factor of 2 above the safe limit shown above. With these estimations and constraints we are now ready to derive the relevant measurement requirements, and these will be reviewed at the next meeting (Fall 2010). They will be the basis for the TG recommendations to the IO for inclusion in the full measurement requirements table.

Initial concepts for the development of a technique for measuring hot dust were also briefly discussed. The main proposal consists in measuring the chemical reactivity inside the tokamak with a controlled injection of water (steam) during a bake. This technique presents the advantage of being a global measurement, consistent with the expected measurement requirement. This technique can be complemented by qualitative study of IR emissivity of key surfaces.

While the topic of measurement requirements of cold dust appears resolved, the testing of the proposed technique (capacitance micro-balance) is still outstanding. This testing has been proposed as a Joint Experiment and a few devices have volunteered to help in this matter. However, the micro-balances are not presently available for testing. If resources are made available, it is expected that such micro-balances could be provided to various devices for testing within a year or so.

In view of the progress this HP item is expected to be closed by the next meeting (Fall 2010), although discussions and results of the testing(s) will be ongoing.

2.5. Assessment of impacts of in-vessel wall reflections on diagnostics

Many of the optical diagnostics will have to work against the background of stray light coming from the plasma and, because the ITER plasma is much larger than existing tokamak plasmas, this problem will be more severe than that experienced thus far. The problem needs to be evaluated through a process of modeling and measurements on existing machines, and measurements of the reflectivity of relevant materials. Codes are being developed at UKAEA that can now include arbitrary sources of light (vs edge/divertor only) such as neutral beam emission. This work has also been extended to spectroscopic measurements where reflections can actually perturb the measured spectrum, and not just its apparent intensity.

In parallel, commercial packages have been evaluated within the IO, and many appear suitable for the task. These commercial packages may greatly reduce the development needed for in-house codes. In order to be fully integrated, they will require a full 3D rendition of the internal components of ITER, with the proper reflections coefficients. As a test, and using a much simplified optical model, this approach has been used to model the effects of reflected DNB emission on the active spectroscopic measurements.

Depending on details of the blanket surface, the reflected edge CXRS signals from the beam could significantly pollute the core signals for upper port viewing systems. The situation appears less severe for the equatorial systems. The software is readily available and permits the quick importation of 3D CATIA models as well as scans of Bidirectional Reflectance Distribution Function (BRDF) effects. Such packages would be a powerful tool for simulating and qualifying diagnostic performance on many existing devices. They are also being used successfully to simulate plasma radiation loads on in-vessel components.

Extensive R&D efforts are ongoing at W7-X to quantify and study the effects of stray microwave radiations onto diagnostics and other in-vessel components. The research plans were presented alongside with initial results, indicating the importance of understanding these effects in W7-X, and likely in ITER as well. Therefore, it is proposed to enlarge the scope of this item to include effects of stray microwave radiation on (all) diagnostics.

This HP item will remain.

2.6. Assessment of the measurement requirements for plasma initiation and identification of potential gaps in planned measurement techniques

The early phase of plasma formation and control may require additional or special measurements different than during the flat top phase. A special session was held during the Fall 2009 meeting to review the experience from existing devices and to project potential additions or changes to the ITER measurement requirements. The periods in question include in-between discharges, breakdown, ramp-up and ramp-down periods. Calibration needs are also very important, especially in terms of magnetic structure measurements. Results from KSTAR, EAST, JET, ASDEX, DIII-D, C-Mod, TCV, and others were presented and discussed.

Areas of interest include measurements between discharges (e.g. wall conditioning, gas composition, erosion, etc), at breakdown (e.g. null structure, impurity levels, etc), at the ramp-up phase (density, current profile, etc), and ultimately at the ramp-down phase (e.g. density, radiation levels, etc). The needs for ITER have been tabulated and will be reviewed at a future meeting in conjunction with a discussion of the potential gaps in planned techniques corresponding to the measurement needs.

This HP item will remain.

3. Party Reports

During the Progress Meetings on ITER relevant diagnostic developments in Korea (combined with the 17th meeting) and in the US (combined with the 18th meeting) Korean and American scientists, respectively, presented their work on a large variety of diagnostic systems in preparation for ITER. Many of these presentations were directly related to the high priority research topics of the TG.

Representatives of the ITPA Party Teams (PTs) reported steady progress for many diagnostic techniques that are ITER relevant. It is clearly evident that many scientists working on diagnostics in the various PTs are becoming more aware of the problems and challenges of implementing diagnostics on ITER. This is again demonstrated by the large attendance to both meetings. Emphasis in the presentations is now shifting from detailed integration and implementation as needed in fulfilling procurement arrangements to more generic issues, including impacts of the selected design on scientific capability.

4. Specialist Working Groups

The eight Specialist Working Groups (SWGs) continue to work in a focussed manner in their specific fields (active spectroscopy, passive spectroscopy, neutrons, first mirrors, first wall, laser-aided, and radiation effects). Good progress was reported by the SWGs for many of the current action items. Most of the work described above under the high priority issues has been the result of the coordinated effort within the various SWGs. The work on many action items has been completed and a number of new action items were formulated at the meetings.

The update of the SWGs has been finalized early this year. The working groups had been realigned and new leadership has been selected in many groups in 2009, while retaining sufficient "institutional" memory to carry through important tasks. The membership has been revised and updated, and was completed in August 2009. The SWGs include now a total of 201 participants distributed amongst all parties and the IO. Altogether, the realignment was needed in order to better fulfil the needs for ITER, while remaining more attuned to generic burning plasma diagnostic issues. The renewed groups have reported much progress in key areas, demonstrating the dynamism of these groups.

Table 1 summarizes the current list of chairs, and co-chairs (June 2010).

SWG	Chair	Co-Chair	IO Co-Chair
Active Spectroscopy	N. Hawkes (EU)	S. Tugarinov (RF)	D. Thomas[2]
First Mirrors	A. Litnovsky (EU)	V. Voitsenya (RF)	D. Thomas[2]
First Wall	C. Skinner (US)	D. Rudakov (US)	R. Reichle
Laser Aided	M. Beurskens[1] (EU)	Y. Kawano (JA)	G. Vayakis
Microwave	G. Conway (EU)	M. Austin (US)	V. Udintsev
Neutrons	M. Sasao[2] (JA)	S. Popovichev (EU)	L. Bertalot
Passive Spectroscopy	B. Stratton (US)	W. Biel (EU)	R. Barnsley
Radiation Effects	B. Brichard (EU)	T. Nishitani[2] (JA)	C. Walker

Table 1. Chair and co-chairs for the Specialist Working Groups (July 2009). [1] Replacing M. Walsh, [2] Expected to be replaced over the next year

5. Progress in other fields

5.1. Alternate techniques for current and rotation profile measurements

Work is proceeding on DIII-D and MST to study the application of sigma/pi ratios for MSE measurements - seeking to avoid the deleterious consequences of first mirror contamination affecting the polarisation transmission characteristics. Encouraging results were reported from DIII-D where a good match to MSE results can be obtained if the relative S and P transmission of the optics is adjusted by 4% from the calibrated values. The ADAS group has been working on the modelling of angle resolved collision cross sections and the effect of field ionisation from high n-levels on the population. Both these effects may lead to a distortion of the populations of the lower n-levels.

First results of the coherence imaging technique on TEXTOR and DIII-D have been obtained. This technique allows the extraction of ion temperature and rotation velocity across a 2-D field using charge exchange emission. The technique is also being applied the analysis of the polarisation characteristic of MSE emission, again in two dimensions. As well as the extra physics information available from 2-D measurements, this technique offers the possibility of excluding parts of the image, which can be polluted by reflected light.

5.2 Fuel ion ratio measurements

Much progress has been reported in the last few years regarding the needed measurements of the ion fuel ration during D-T discharges. In the past these measurements appeared to be very difficult to perform. The proposed techniques for measuring the fuel ion ratio were reviewed at the Fall meeting. These techniques include neutron spectrometry, collective Thomson scattering, and CXRS. Each technique exhibits limitations, although perpendicular CTS probing may be possible through ion Bernstein excitation. First CTS measurements in TEXTOR are showing clear spectral signatures of the IBW's in H, D and He^3 plasmas, a technique that could be extrapolated to ITER in the right geometry and sensitivity.

5.3 Microwave systems calibration

A report (ITER_D_33ZRFR / MWG-55F-0902) was prepared on the generic calibration and test requirements of the ECE/Reflectometer microwave transmission system. The report highlights the importance for all ITER diagnostics to have established test and calibration procedures. For the generic antenna/waveguide transmission line systems of the microwave-based diagnostics the report identified some 18 specific sets of procedures and tests to be performed before, during and after the diagnostic system installation. These include testing and documenting individual component performance (to allow subsequent monitoring of component degradation) as well as the antennae and overall system performances. The diagnostic safety features (such as stray radiation protection) and the specific in-situ calibration hardware will also require periodic testing for correct functionality.

5.4 Data Analysis and Validation

Efforts are continuing in developing techniques for the data analysis of data sets encountered in present and future fusion experiments, including ITER. It is expected that the amount of data generated in each ITER discharge can exceed present-day approaches of data analysis and/or handling. A variety of issues are envisioned, such as fault conditions, pattern recognition, large data set handling, etc. These issues lend naturally to the necessary data validation and processing for advanced control, as expected to be developed and required in ITER.

5.5 International Diagnostic Database

The activity in the International Diagnostic Database has been relatively low. Only a few diagnostics have been added. The IN PT has started an analysis of the data in the IDD for a number of different diagnostics. First results of the analysis were shown at the 15th meeting, and further analysis of the International Diagnostic Database is scheduled for upcoming meeting(s).

5.6 Joint ITPA/IEA Experiments

The Joint ITPA/IEA experiments in the field of diagnostics were discussed in both meetings.

Multiple experiments on first mirrors are in progress and are reported in Sec 2.3 and full details are shown in Appendix 2.

A joint experiment to resolve the discrepancy between measurements made by ECE and Thomson scattering that occurs at high temperature under some conditions was launched by the end of 2007. First results of this activity were reported last year.

A new joint experiment has been approved on the design, fielding and testing of capacitance micro-balance in existing devices. This diagnostic aims at measuring cold dust contents and is presently scheduled to be installed in ITER, but presently lacks testing in fusion devices. The proposal has been conditionally approved, provided that the IO can provide the basic unit for testing. Presently, it is not expected that such units would be available before late 2011.

6. Publications

Two papers co-ordinated by either the TG or by the SWGs have been accepted for poster presentation at the IAEA Conference on the following topics: progress in HP issues, and first mirrors. Also a paper from the IO on the implementation of diagnostics systems on ITER has been accepted.

An overview of the publications by the ITPA TG on Diagnostics is included as Appendix 1.

7. Plans for Future Meetings

The 19th meeting of the Diagnostics TG has been approved and will be organized by JAEA, Japan from 18 - 21 October 2010. A special session will be held on the assessment of the measurement requirements for plasma initiation (HP#6). The meeting will be combined with a Progress Meeting on ITER Relevant Diagnostic Developments on-going in Japan. The 20th Meeting is tentatively scheduled to be organized by the FOM Institute, The Netherlands in Spring 2011.

R.L. Boivin
H. Park
G. Vayakis

30 June 2010

Appendix 1
Publications by the ITPA TG on Diagnostics 2009-2010

Publications in peer-reviewed journalswww

- Litnovsky, V. Voitsenya, T. Sugie, G. De Temmerman, A.E. Costley, A.J.H. Donné, K.Yu. Vukolov, I. Orlovskiy, J.N. Brooks, J.P. Allain, V. Kotov, A. Semerok, P.-Y. Thro, T. Akiyama, N. Yoshida, T. Tokunaga and K. Kawahata, *Progress in research and development of mirrors for ITER diagnostics*, Nucl. Fusion **49** (2009) 075014
- V.S. Voitsenya and A. Litnovsky, *Investigations of mirrors for ITER diagnostics in modern fusion devices*, Plasma Devices and Operations, Vol. 17, No. 4 (2009) 309

Presentations at the 2010 IAEA Fusion Energy Conference, Korea

- R.L. Boivin, H. K. Park, G. Vayakis, for the ITPA Topical Group on Diagnostics*, R&D ITPA Activities in Support of Optimizing ITER Diagnostic Performance,* Paper ITR-P1-2

- Litnovsky, V. Voitsenya, D. Thomas, M. Rubel, G. De Temmerman, L. Marot, K. Yu. Vukolov, I. Orlovskiy, W. Vliegenthart, Ch. Skinner, D. Johnson, V. Kotov, J.P.Coad, A. Widdowson, G. Vayakis, R. Boivin, M. Joanny, J-M. Travere, and the members of the ITPA Specialists Working Group on First Mirrors, *Mirrors for ITER diagnostics: new R&D developments, assessment of the mirror lifetime and impact of the mirror failure on ITER performance*, Paper IT

- M. Walsh, P. Andrew, R. Barnsley, L. Bertalot, R. Boivin, D. Bora, R. Bouhamou, S. Ciattaglia, G. Counsell, M. F. Direz, J. M. Drevon, A. Encheva, T. Fang, G. Janeschitz, D. Johnson, K. Junghee, Y. Kusama, H. G. Lee, F. Le Guern, B. Levesy, A. Martin, R. Reichle, K. Patel, C. S. Pitcher, A. Prakash, N. Taylor, D. Thomas, V. Udintsev, P. Vasu, G. Vayakis, E. Veschev, C. Walker, A. Zvonkov*, Overview of high priority ITER Diagnostic systems status,* Paper IT

This list does not include individual papers published by members on specific ITER diagnostics or generic R&D. Many additional publications and presentations were made at the IAEA meeting, HTPD conference and Varenna meeting on diagnostics, and other various diagnostic workshops held during that period. That list is too long to describe in details here and are summarized in the working groups' reports.

Appendix 2
PROGRESS REPORT on the ITPA Joint Experiment Proposal

Task: DIAG 2 **Environmental tests on diagnostic first mirrors**

Topic Group: Diagnostics

Spokes person: **A. Litnovsky**
Key persons: **I. Orlovskiy (T-10), A. Litnovsky (TEXTOR), Th. Loarer (Tore-Supra), M. Rubel (JET), D. Rudakov (DIII-D), J. Chen (EAST, HT-7), A. Herrmann (AUG), N. Ashikawa (LHD), C.Skinner (NSTX), V. Voitsenya, Y. Zhou (HL-2A), V.Kumar (Aditya), G. Maddaluno (FTU), G. De Temmerman (MAGNUM PSI).**

Devices: **T-10, TEXTOR, Tore-Supra, JET, LHD, AUG, FTU, NSTX, HL-2A, Aditya, EAST, MAGNUM PSI**

Purpose and goals:

Mirrors will be used in all optical and laser diagnostics in ITER to observe the plasma radiation. The performance of respective diagnostics will rely on the characteristics of mirrors outlining the need in high-performance robust mirror solutions for ITER. Recently, the prioritized work plan (WP) of the R&D on diagnostic mirrors was developed. The aim of the WP is to provide the set of measures to be fulfilled to ensure the maximum lifetime of the high-performance mirrors in ITER – to enable the so-called baseline mirror solution. The WP consists from six main directions – tasks:

- **Performance under erosion- and deposition- dominated conditions: material choice;**
- **Modeling of the impact of plasma, neutral and neutron environment on optical properties of diagnostic mirrors;**
- **Mitigation of deposition;**
- **Cleaning of deposited layers;**
- **Tests under neutron, gamma and X-Ray environment;**
- **Engineering and manufacturing of ITER first mirrors.**

Activities in 2009 were concentrated on addressing these tasks of the work plan.

Key Results:

Performance under erosion- and deposition- dominated conditions: material choice.

- Surface analyses were made on the single-crystal molybdenum and rhodium-coated mirrors retrieved from the midplane port of DIII-D tokamak after a long-term exposure. Despite for an absence of visible deposition, the reflectivity of the exposed mirrors were significantly lower than that of non-exposed samples. Surface analyses revealed the presence of the thin (~ 10 nm thick) carbonaceous film on the surface of the mirrors. The further surface analyses are underway. This activity is a subject of joint investigations of DIII-D and TEXTOR (Forschungszentrum Jülich, FZJ) teams with participation of the University of Basel;
- Set of new molybdenum- and rhodium- coated mirrors were produced by evaporation and magnetron sputtering techniques at the University of Basel was exposed under erosion-dominated conditions in TEXTOR tokamak. Surface and optical characterizations revealed acceptable performance of all exposed mirrors: the reflectivity decreased insignificantly. Recently, the new experiment was carried out at higher fluence of eroding particles. Molybdenum mirrors withstood the erosion, the moderate decrease of the reflectivity was noticed for the Mo-coated mirrors. On a contrast, the Rh-coated mirror was severely sputtered by the plasma. This activity is being performed in the frame of collaboration program between FZJ and the University of Basel.
- Polycrystalline molybdenum mirrors are being exposed in Additya tokamak for a long-term experiment to study erosion and deposition processes, their impact on the mirror performance and to compare this data with the results from the other tokamaks.
- Analyses were continued on the mirrors exposed at the outer wall and in several locations in the divertor of JET for several JET campaigns. The deposits formed on the mirrors contained mostly carbon with the minor

fraction of beryllium. Optical characterization revealed the significant decrease of the reflectivity of all exposed mirrors. Studies of the morphology of deposited layers are underway.

Mitigation of deposition

- New experiment with Periscope Upgrade system equipped with polycrystalline molybdenum mirrors was made in TEXTOR. A half of each mirror was pre-coated with an amorphous carbon film with known properties. Optical and surface characterizations were made on all mirrors before exposure. After exposure, all the deposits on the first mirror were disappeared and the reflectivity was restored. The capability of dynamic active control over deposition by the gas puff was explicitly demonstrated during this experiment. No change was observed on the second and third mirrors after the exposure.
- Studies of the shielding structures for the protection of retroreflectors were continued at LHD. V-shaped protection was introduced to mitigate the deposition on the mirror guiding the light to the retroreflector. The baffling of the optical channel was used to mitigate the impurity transport towards the retroreflector. Mitigation techniques were able to completely suppress the deposition on the retroreflector routinely observed under these conditions before.

Cleaning of deposited layers

- The successful cleaning of the ECE window of the HL 2A tokamak using YAG laser was reported: the transmission of the window was restored up to 90%. Ytterbium fiber laser was applied in the beryllium-handling facility at JET to clean the contaminated mirrors exposed in JET. The significant improvement of the reflectivity was detected, although the complete recovery of reflectivity was not achieved.
- Several mirrors exposed in TEXTOR and DIII-D tokamaks were cleaned from carbonaceous deposits at FZJ using electron-cyclotron resonance (ECR) generated plasmas in hydrogen and deuterium. The reflectivity of the mirror exposed in the divertor of DIII-D was completely restored, whereas for the recovery of the reflectivity of the mirrors exposed in TEXTOR required the use of an additional biasing increasing the energies of hydrogen and deuterium ions. This activity is a part of TEXTOR-DIII-D collaboration. The present cleaning exposures show non-ambiguously that in case of plasma cleaning application for ITER diagnostics, the sputtering of the sacrificial affected layer remain the only option for a successful mirror recovery.

Tests under neutron, gamma and X-Ray environment

- Metallic mirrors, secondary mirrors coated with protective dielectric layers were exposed under the strong X-ray source of the DAFNE Light facility. Surface investigations are started. This activity is a joint effort of ENEA, IPP Kharkov and Ioffe Institutes.

Engineering and manufacturing of ITER first mirrors

- Large single-crystal molybdenum mirror with a diameter of 10 cm was supplied by Kurchatov Inst. to FZJ. The preparations for the exposure of the mirror in TEXTOR are in progress. This activity is a part of TEXTOR-T-10 collaboration.
- New topic to be introduced to the WP

Investigations of diagnostic mirrors and in particular the assessment of the impact of conditioning discharges on the mirror performance is of significant importance. Therefore, it was decided to expand this area of the WP by introducing tests of ITER-relevant mirror under relevant conditioning techniques. The investigations of an impact caused by O-bake treatment of the tokamak were started as a collaboration effort between DIII-D and TEXTOR teams. Molybdenum and copper mirrors were placed in the main chamber and in the divertor where they were exposed for several hours in oxygen and helium mixture. Investigations are in progress.

Appendix 3
Members of the ITPA TG on Diagnostics 2009-2010

PARTY	FAMILY NAME, FIRST NAME	AFFILIATION
CN	Fan, Tieshuan	PKU
CN	Hu, Liqun	ASIPP
CN	Yang, Qinwei	SWIP
CN	Zhao, Junyu	ASIPP
CN	Zhong, Guangwu	SWIP
EU	Beurskens, Marc	UKAEA
EU	Donné, Tony	FOM
EU	Ingesson, Christian	F4E
EU	Koenig, Ralf	IPP
EU	Murari, Andrea	ENEA
EU	Serra, Fernando	IPFN
EU	Weisen, Henri	CRPP
EU	Zoletnik, Sandor	HAS
IN	Pathak, Surya K	IPR
IN	Rao, CVS	IPR
IN	Vasu, P	IPR
IO	Barnsley, Robin	IO
IO	Costley, Alan	IO
IO	Vayakis, George	IO
JA	Itami, Kiyoshi	JAEA
JA	Kawahata, Kazuo	NIFS
JA	Kawano, Yasunori	JAEA
JA	Kusama, Yoshinori	JAEA
JA	Mase, Atsushi	Kyushu Univ.
JA	Peterson, Byron	NIFS
JA	Sasao, Mamiko	Tohoku Univ.
KO	Lee, HG	NFRI
KO	Lee, JH	NFRI
KO	Lee, SG	NFRI
KO	Nam, YU	NFRI
KO	Park, H	Postech
RF	Kaschuk, Yu	TRINITI
RF	Krasilnikov, A	RF DA
RF	Ljublin, B	Efremov Institute
RF	Petrov , M	Ioffe Institute
RF	Vukolov, K	Kurchatov Institute
RF	Zaveriaev, V	Kurchatov Institute
US	Allen, Steve	LLNL

US	Boivin, Réjean	GA
US	Brower. David	UCLA
US	Hillis, Don	ORNL
US	Johnson, Dave	PPPL
US	Stratton, Brent	PPPL
US	Terry, Jim	MIT