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TWELFTH MEETING OF THE ITER PHYSICS EXPERT GROUP ON DIAGNOSTICS

by Dr. A.E. Costley, ITER JCT and Dr. A.J.H. Donné, FOM Institute for Plasma Physics 'Rijnhuizen"

The Twelfth Meeting of the ITER Physics Expert Group on Diagnostics was held at the Kurchatov Institute and the TRINITY Institute, Moscow, on March 30 - April 1,2000. The meeting immediately followed a Progress Meeting on ITER-relevant diagnostic developments on-going in the Russian Federation.

At the end of the previous Expert Group meeting, Dr. P. Stott resigned as European Task Area Leader for Diagnostics and as Expert Group member. The chairman, the co-chairman and the members of the Expert Group and the ITER JCT working on diagnostics extend their warm thanks and appreciation to Dr. Stott for all his efforts on behalf of ITER diagnostics and the Expert Group since the beginning of the EDA. It is expected that Europe will appoint a replacement for Dr Stott in the near future.

The main technical objectives of the meeting were (i) to review the present status of ITER and to determine any required changes in the specifications for plasma measurements; (ii) to review the progress and develop plans for meeting the goals of the Voluntary R&D tasks approved by the ITER Physics Committee within the Parties; (iii) to review and plan the work of the five specialists electronic working groups, and (iv) to hear reports of ITER relevant diagnostic developments in the Party Laboratories and assess their possible application to ITER. The principal conclusions of the meeting are as follows:

- It is recommended that the measurement requirements for a few parameters should be revised. The accuracy in the q(r)-measurement should be 10% for $q < 5$ and ± 0.5 for $q > 5$; and the spatial resolution in the measurement of rotation velocity should be relaxed from a/50 to a/30. No specific requirements should be included for fast ions (no recommendations were received from other Expert Groups for this measurement). The plasma measurement requirements for the divertor should be critically re-assessed in the light of the reduced access for diagnostics in the new divertor design. This should be done in conjunction with other Expert Groups.

- It is believed that measurements on dust can be made but the key questions on the specific measurement requirements - where, when, what resolution, etc., remain unanswered. An electronic Task Force to address the entire issue of dust in ITER-FEAT has been proposed. A promising new measurement technique for measuring dust on hot surfaces by laser ablation was proposed during the RF progress meeting.

- Investigations have confirmed that noise, due to MHD activity, on magnetic measurements of the plasma vertical speed will most probably be insignificant. On the other hand, the effect of Radiation Induced Electromotive Force (RIEMF) in mineral insulated cables is still a cause for concern. Studies of this effect underway in the supporting irradiation effects programme should be continued until it is understood. The Expert Group supports the consideration underway in the JCT to mounting an additional set of magnetic sensors on the outside of the vacuum vessel. These sensors would give some protection against RIEMF and, if they could measure static fields, would also give a measurement capability for steady state operation.

- Good progress was reported on many of the action items and voluntary physics tasks. Many new action items and follow-up activities have been defined.

- The Specialist Working Groups have reported on progress made in their respective fields. Good progress has been made on several topics since the last Expert Group meeting. A new Specialist Working Group on First Mirrors has been launched. Its chairman, Dr. V. Voitsenya of the Kharkov Physics and Technical Institute and associate of the RF Home Team, presented a detailed working plan.

- Responses have been received for the diagnostic reliability survey from many machines. Many data came in just before the Expert Group meeting and still need to be analysed. An in-depth analysis of all the data is now required. Information from additional machines would be helpful and is being pursued.

- Good progress has been made on a variety of ITER-relevant diagnostic developments in Japan and Europe, and especially (because this was highlighted in the two day Progress Meeting) in the Russian Federation. This is very stimulating.

- The latest developments in the irradiation effects programme were reported. Good progress has been made characterising optical fibers and materials for optical windows.

- Good progress was reported for many of the credited tasks undertaken by Japan and the Russian Federation. It is expected that the EU Home Team will soon commence a number of credited design tasks.

- A paper on the measurement requirements and system designs for ITER-FEAT will be submitted to the IAEA conference. The paper will be co-ordinated by the Expert Group. A paper on the design of the ITER-FEAT diagnostic system will be prepared by the JCT for presentation at the High Temperature Plasma Diagnostics Conference.

- The 13th Meeting of the ITER Physics Expert Group on Diagnostics will be held in combination with an International Workshop on 'Diagnostics for Burning Plasmas' from 18 - 22 Sept. in Naka, Japan. The International Workshop is being organized in the framework of the International Energy Agency Large Tokamak Agreement.

Participants in the Meeting

In conclusion, all the participants agreed that the meeting was highly productive, and sound plans were made for making progress with the key issues in ITER diagnostics. The organization of the meeting was excellent and the Expert Group members wish to thank both the Kurchatov and the TRINITY Institutes for their hospitality and care and attention to many details which assured a smooth running meeting.

LIST OF PARTICIPANTS
Members of Expert Group

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Tony Donné (FOM, Netherlands, EU)
Anatolij Kislyakov (Ioffe, RF)
Anatolij Krasilnikov (TRINITI, RF)
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Vyacheslav Strelkov (Kurchatov, RF)
Tatsuo Sugie (JAERI, JA)
Shin Yamamoto (Garching JWS, ITER)
Hideki Zushi (Kyushu University, JA)

Guests and Attendees at the Expert Group Meeting

Andrey Alekseev (TRINITI, RF)
Vladimir Bryzgunov (Kurchatov, RF)
Michail Dremin (Kurchatov, RF)
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Vladimir Voitsenya (KPTI, Ukraine)
Konstantin Vukolov (Kurchatov, RF)
Chris Walker (Garching JWS, ITER)
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14TH INTERNATIONAL CONFERENCE ON PLASMA-SURFACE INTERACTIONS IN CONTROLLED FUSION DEVICES

by Dr. G. Federici, ITER JCT Garching

The 14th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices (PSI-14) was held from 22 to 26 May 2000 in Rosenheim, Germany. The PSI conference is the largest in the field covering research in fundamental and applied surface physics and plasma science. Representatives from major fusion research laboratories throughout the world attended. More than 200 poster papers were presented, together with 46 oral contributed papers, 27 invited papers and 2 review papers. The general organization of the meeting was excellent.

The subject matter of this meeting is a very interesting blend of laboratory studies of basic processes, simulation of specific plasma-surface interactions and measurements on existing confinement devices and their extrapolation to future reactors. As in previous meetings of this series, much attention was devoted to discussion of plasma-surface interaction studies relevant to ITER, and many contributions focussed on ITER-relevant research and development (R&D) topics (see Table II).

It is well recognised in this research field that the ITER design activities, and its supporting R&D programme, have highlighted the need to deepen our understanding of plasma-surface interactions in tokamaks, since plasma-wall interactions through proper material selection, machine design and plasma operating conditions will be strongly influenced by the ability to control the operational availability of ITER. The increase in pulse duration and cumulative run time, together with the increase of the plasma energy content, will represent the largest changes in operation conditions in ITER, compared to todayís experiments. These will have profound consequences, giving rise to important plasma-physics effects and plasma-material interactions which open new design, operation and safety issues. The challenge of addressing these issues in ITER has stimulated much work in this field.

Important results were presented at this conference from operation of major fusion facilities and other experiments in laboratories around the world. These results, together with advances in modelling, have greatly expanded our knowledge on plasma-wall interaction processes in a fusion environment, for conditions of direct relevance to the design and operation of ITER. Nevertheless, there are still numerous areas of uncertainty and a variety of challenging issues that remain to be urgently resolved prior to building ITER (see Table II). This requires a continuing co-ordinated R&D effort, involving extensive participation by all parts of the fusion community. ITER also in this conference succeeded in providing a focal point to numerous activities ongoing world-wide by providing a direct link between new data and research on plasma-surface interactions and decisions in the ITER design.

The recent progress with the physics basis and the design of the reduced cost 'ITER-FEATî' was presented by G. Janeschitz. This design aims at a fusion performance of Q = 10 in inductive ELMy H-mode discharges (fusion power ~ 500 MW) with a pulse length of about 400 s and should be able to achieve effectively steady state operation at Q = 5 with non-inductive current drive. Higher values of Q may be accessible in low or reversed shear regimes. The neutron wall load is set to be about 0.5 MW/m^2 or above. The design of ITER-FEAT is to be completed in 2001. There are still several issues on the operation and safety constraints (e.g., divertor erosion lifetime, tritium inventory and control, dust, etc.) resulting from anticipated plasma-wall interaction effects for the current material choice (i.e., beryllium on the first-wall, carbon near the strike points and tungsten elsewhere in the divertor). These concerns were picked up during the conference in many presentations, in particular, discussing the implications of using carbon in a D-T fuelled next-step, because of chemical erosion and the potential to trap tritium in regions far away from the plasma where it is difficult to remove.

It is beyond the scope of this short summary to review all the topics presented at the conference. Below, only some topics of primary interest for the ITER design are highlighted.

TABLE I: **ITER PAPERS PRESENTED AT THE 14TH PSI**

ITER plenary talk:
- Plasma wall interaction issues in ITER FEAT, *G. Janeschitz*

ITER oral presentations:
- Assessment of erosion and tritium codeposition in ITER-FEAT, *G. Federici, et al.*
- Critical issues in divertor optimisation for ITER-FEAT, *A. Kukushkin, et al.*

ITER poster presentation:
- Efficiency of secondary electron emission from divertor plates and sheath potential drop in
  the presence of impurities. *Y. Igitkhanov and G. Janeschitz*

Table II: **TOPICS OF PRIMARY INTERESTS FOR ITER**

- Carbon chemical erosion at high fluxes - Codeposition patterns in present-day tokamaks - Use of high-Z materials - Mixed-materials - Power deposition during ELMs - Modelling plasma edge and plasma-surface interactions - Plasma material interactions diagnostics - Mitigation/avoidance of plasma disruptions in tokamaks - Disruption erosion in plasma simulators and modelling

Carbon chemical erosion at high fluxes

The issue of the chemical erosion of carbon has been debated for some time within the fusion community, and there are still inconsistencies on some of the observations (Whyte), in particular with respect to the influence of the flux dependence, which need to be reconciled. The results of recent investigations to study chemical erosion yields at high fluxes (i.e., 10^{22} -10^{23} m^{-2} s^{-1}) in plasma simulators such as PISCES (Doerner) or in-situ tokamak measurements (Stamp, Monk) were reported showing almost no flux dependence, in clear contrast to past studies. Further work in this area is needed to determine the extent to which parameters other than flux (e.g., energy, redeposition, photon efficiency and viewing geometry in spectroscopic measurements, etc.) affect the observed erosion rates. There is also experimental evidence of an energy threshold for chemical sputtering (Wenzel), and results from recent experiments in DIII-D (Wampler), with very cold detached plasmas, showed that the net erosion is suppressed everywhere in the divertor.

Codeposition patterns and films in present-day tokamaks

Intense codeposition of carbon and deuterium is found in many tokamaks in regions which are shaded from ion flux but are near carbon surfaces receiving high ion flux (Coad, Mayer, Rohde, Rubel, Skinner, Wienhold). Since ions cannot reach these shaded surfaces, this carbon deposition must be due to neutral carbon atoms or molecules/radicals resulting from dissociation of hydrocarbons released from carbon surfaces. This has prompted a novel area of research in laboratories (von Keudell, Hopf, Arkhipov, Gorodetsky) and in tokamaks (Rohde) to characterize and measure formation and properties of these films and recommend mitigating measures for the design of the private region of the ITER divertor.

A marked asymmetry in deposition between inner and outer divertor channels has been observed in several tokamaks (Coad, Monk), with the inner divertor plate being an area of net deposition and the outer divertor plate an area of net erosion. ∇B drifts offer potential explanations for these asymmetries (Chankin). A complete implementation of the drifts in the plasma edge codes and a comparison of the predictions with the data have just started (Kirschner).

Use of high-Z materials

There is a renewed emphasis on the use of high-Z materials compared to previous meetings, stimulated by the success of the molybdenum wall in Alcator C-Mod (Lipschultz) and Triam-1M (Yoshida), tungsten limiter in TEXTOR-94 (Pospieszczyk, Tanabe), the recent use of tungsten tile on the central column of ASDEX Upgrade (Neu) and the proposal to use W in parts of the ITER divertor (Janeschitz). New measurements, both of fundamental physical processes in W and of their use in plasma experiments (Alimov, Causey, Doerner, Haasz, Makhankov), were presented. In particular, the results of ASDEX-Upgrade presented at this conference looked promising with the tungsten concentration in the main plasma generally below the detection limit ~1×10^{-5}, and no deleterious effect on confinement and plasma stability.

Mixed materials

The present design of ITER employs a variety of plasma-facing materials selected for their suitability to regions of the vessel with different power and particle flux characteristics. Erosion, and the subsequent transport of impurities, will inevitably lead to a certain amount of material mixing between these components. The physical and chemical properties of mixed materials may be significantly different from those of the substrate (Linsmeier, Goldstrass, Luthin, Tanabe), e.g., thermal conductivity, adhesion and sputtering yields, reflection coefficient, D/C ratio, etc., and yet little is known about these properties for the materials of interest to a next-step device. Research in these areas has just started.

Power deposition during ELMs

ELMs are of concern to ITER-FEAT because of the transient heat and particle flux they deposit on the divertor target (Janeschitz). For frequent ELMs, surface melting and strong evaporation must be avoided. Several papers on the characteristics of different types of ELMs and the criteria for determining what would be tolerable for ITER were given (Gauthier, Leonard). Research in existing machines has to focus on reducing the ELM size without reducing confinement and / or substantiating existing back-up regimes such as Type II ELMy H-mode or RI-mode as well as density profile peaking by pellet injection.

Modelling plasma edge and plasma-surface interactions

Modelling of plasma-edge and plasma-surface interactions is recognised to be a vital tool in designing next-step tokamaks. Although some models are available (Brooks, Kirschner) and are applied to interpret some of the observations in tokamaks (Coster, Fundamensky, Stangeby, West) or to make predictions for ITER (Kukushkin, Federici), there are clearly processes occurring in the plasma edge that are not understood and need further investigation. Validation is still limited and only some of these codes have been benchmarked with some success against results from dedicated plasma-material interaction experiments in current tokamaks. Predictions for ITER showed a tritium codeposition rate of about 5 g-T/1000 s pulse for ITER-FEAT (Federici). This requires efficient methods of control and retrieval in-situ. Peak erosion of a Be-clad first-wall is estimated to be about 0.1 nm/s due primarily to the flux of energetic charge-exchange neutrals and impurity ions, together with low redeposition rates. While this erosion rate is acceptable for a low-duty-factor operation device, such as ITER, it may be too high for a reactor.

Plasma-material interaction diagnostics

The complex and varied discharge history in tokamaks makes ‘archaeological’ comparisons of post-campaign in-vessel components with erosion/deposition and retention models of limited utility. In-situ time-dependent diagnostics are necessary for understanding plasma-material interactions and must be developed and implemented with dedicated machine time (Counsell). Such measurements are a valuable input to the codes, providing increased constraints to the models. Novel in-situ diagnostic techniques have been reported at this conference (Summers, Rohde, Reichle) that provide measurements at locations where erosion/deposition occurs and where tritium and dust/debris are expected to accumulate.

Mitigation/avoidance of plasma disruptions in tokamaks

Disruption avoidance and the development of techniques to terminate the discharge safely and mitigate the destructive effects of disruptions are critical to the future of tokamaks as fusion reactors. Encouraging results on experience on disruption mitigation in ASDEX Upgrade were presented (Pautasso) involving a neural network developed on the basis of understanding pre-disruption mechanisms and trained with the ASDEX Upgrade disruption database to predict these events. Also experiments with neon pellets confirmed that these pellets sufficiently ablate, reduce thermal and mechanical loads on the machine and do not generate runaways.

Disruption erosion in plasma simulators and modelling

Divertor heat loading caused by high energy density disruptions (1-50 MJ/m^2 in 1-10 ms) and Type-I ELMs (=1 MJ/m^2 in 0.1-1 ms) plays a major role in defining the design of the ITER device (Janeschitz). Since disruption conditions cannot be achieved in existing tokamaks, laboratory experiments (e.g., laser and electron beams, open plasma traps and plasma guns) are used to study and simulate disruption effects. A review on simulator experimental results was presented (Safronov). Understanding the physics of material response during off-normal heating has improved, and now complex modelling tools are available (Hassanein, Wuerz). However, extrapolation to reactor conditions remains somewhat uncertain, and the modelling of the effect of vapour shielding and the stability of the melt layer must be further developed and tested against experimental results to better understand the complex interactions at work.

In conclusion, the wealth of data from existing tokamaks and simulators has facilitated great strides in our understanding of the processes involved in plasma-surface interactions. However, there are many unresolved issues relating to ITER, and further work remains to be done in this area. Nevertheless, much more relevant information can be learnt from existing facilities, particularly in areas such as mixed material effects, alternatives to the use of carbon on the wall and in the divertor (including disruption avoidance), transport effects in the plasma edge, and longer-term retention and release of hydrogen isotopes. Planning of experimental objectives is important, and much more operational time dedicated to plasma-material interaction issues is required than heretofore. Continued and increased communication/collaboration among plasma experimentalists, modellers and the materials community is necessary.

The proceedings of the conference will be published in the Journal of Nuclear Materials early in 2001. The next meeting will be held in Gifu near Nagoya in Japan, in May 2002.

Items to be considered for inclusion in the ITER Newsletter should be submitted to B. Kuvshinnikov, ITER Office, IAEA, Wagramer .Strasse 5, P.O. Box 100, A-1400 Vienna, Austria, or Facsimile: +43 1 2633832, or e-mail: c.basaldella@iaea.org (phone +43 1 260026392).

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