INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR

ITER EDA NEWSLETTER

VOL. 8, NO. 11 NOVEMBER 1999

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, AUSTRIA

ISSN 1024–5642

SUMMARY OF THE ELEVENTH MEETING OF THE ITER DIAGNOSTIC EXPERT GROUP

by Dr. A. E. Costley, ITER Joint Central Team and Dr. A. J. H. Donné, FOM Institute for Plasma Physics 'Rijnhuizen'.

The Eleventh Meeting of the ITER Diagnostics Expert Group was held in Cadarache, France. The meeting immediately followed a Progress Meeting on ITER Diagnostic Design and R&D for work being performed in Europe. This Progress Meeting was very successful, with many excellent presentations on a wide range of topics.

Dr. Kenneth Young (US, PPPL) had to resign recently as Chairman of this group. The members of the group and the ITER JCT extend their warm thanks and appreciation to Dr Young for his all his efforts on behalf of the Expert Group and ITER diagnostics since the beginning of the ITER activities. Dr. Tony Donné (EU, FOM) has been appointed new Chairman of the Expert Group and chaired this meeting.

The parameters of the ITER-FEAT have now been determined and diagnostic design work will now concentrate on the new reference design.

It is proposed to develop specific requirements for control purposes on the measurement of q(r) concentrating on r(q=1.5), r(q=2), $r(q_{min})$, q_{min} and q_0. The more extensive requirements on the measurement of q(r) will be maintained as a design goal for physics studies.

Participants in the Meeting

The main technical objectives of the meeting were (i) to review and update the measurement capabilities to meet the anticipated needs of the ITER-FEAT; (ii) to review the progress and plans in meeting the goals of the Voluntary R&D tasks approved by the ITER Physics Committee within the Parties; and (iii) to hear reports of ITER relevant diagnostic developments in the Party Laboratories and assess their possible applications to ITER. The principal conclusions of the meeting are as follows:

- Active spectroscopy using the Diagnostic Neutral Beam (DNB) needs to be re-evaluated for the conditions of ITER-FEAT. It is also necessary to study whether alternative techniques (that do not rely on a DNB) can be used to measure the plasma parameters for which the DNB is required (principally T_i, plasma rotation and the density of light ion impurities). A discussion at the meeting did not give much hope that alternative techniques could be found for the light ion density.

- Because of reduced access, the measurement capability in the divertor may be significantly reduced with respect to ITER FDR. All divertor diagnostic systems should be critically re-assessed.

- A possible additional required measurement, is the measurement of fast ions (in addition to the measurement of the confined (a's). The other Expert Groups will be contacted to inquire about the need for general fast ion measurements.

- The upper ports on ITER-FEAT have considerable advantages with respect to the FDR top ports. A number of diagnostic systems should be re-evaluated to determine the optimum implementation in these ports.

- First results of a survey to determine the reliability and availability of key diagnostics on existing machines were presented. The survey included an investigation of the key factors that limit the reliability. The results showed a wide range in the reliability of different diagnostic techniques. These initial results have shown that much useful information can be expected from this study but the questions in the survey need to be further developed.

- A first study on the effect of noise on the magnetic measurements of vertical velocity has shown that it should not present serious problems for plasma control.

- The wide-angle viewing system has many potential applications. Important questions are; what is the minimum number of viewing systems required and what are their optimum locations? The possible use for other measurements, especially spectroscopic measurements, should be studied.

- The problem of dust within the ITER vessel was discussed extensively. The key question remains: what is the measurement requirement? It was agreed that the best way to answer this is to define the role the measurements will play in the overall strategy of dealing with the dust on ITER. This strategy has to be developed and agreed by the different groups involved with this topic.

- Significant progress has been made on R&D for the first mirrors (radiation effects, erosion and deposition). It is believed that solutions now exist for diagnostics that operate in the visible and infrared and that do not require a large solid angle of observation of the plasma.

- There have been promising diagnostic developments in several areas relating to the measurement problems included in the Voluntary Physics Task list. For example, measurement of the core ($r/a < 0.5$) fuel density ratio n_D/n_T by Neutral Particle Analysis now seems possible, and recent measurements by Neutron Emission Spectroscopy of the alpha knock-on effect have proved the principle of a new technique for diagnosing confined alpha particles. For most of the tasks, Expert Group members have taken the responsibility to take further action.

- The four Specialists Working Groups have been re-launched and re-motivated. The new charges proposed by the previous Chairman of the Expert Group have been accepted and new members have been nominated.

- In the Party Reports, the JA and RF Home Teams presented relevant work on a variety of machines and a range of topics. The JA and RF Task Area Leader's Reports showed that good progress has been made on a number of voluntary and credited tasks.

- It is proposed to hold the next meeting in the Russian Federation (probably in or near Moscow) around mid April 2000.

In conclusion, it can be stated that much progress has been made since the last meeting. The Working Groups are re-launched and most of the voluntary tasks have agreed actions. Actions have been agreed on most of the tasks that have to be carried out. The majority of the participants highly appreciated the motivational character of the meeting. The organisation was excellent and those attending were very grateful to the CEA, Cadarache, for hosting the meeting.

LIST OF ATTENDEES

Members of Expert Group

Alan Costley (Naka JWS, ITER) (Co-Chair)
Tony Donné (EURATOM-FOM, Neth., EU) (Chair)
Anatolij Kislyakov (Ioffe Inst., RF)
Anatolij Krasilnikov (TRINITI, RF)
Yoshinori Kusama (JAERI, JA)
Francesco Orsitto (EURATOM-EFDA, EU)
Peter Stott (EURATOM-CEA, France, EU)
Vyacheslav Strelkov (Kurch. Inst., RF)
Tatsuo Sugie (JAERI, JA)

Guests

Mario Bagatin (EURATOM-RFX, Italy, EU)
Katsuyuki Ebisawa (Naka JWS, ITER)
Akira Ejiri (Tokyo University, JA)
Rugero Giannella (EURATOM-CEA, France, EU)
Albrecht Herrmann (EURATOM-IPP, Germany, EU)
Jan Källne (EURATOM-Uppsala Univ., Sweden, EU)
Satoshi Kasai (JAERI, JA)
Artur Malaquias (EURATOM-IST, Portugal, EU)
Maria Manso (EURATOM-IST, Portugal, EU)
Osamu Mitarai (Kyushu Tokai U., JA)
Per Nielsen (EURATOM-RFX, Italy, EU)
Takeo Nishitani (JAERI, JA)
Roger Reichle(EURATOM-CEA,France, EU)
Joaquin Sanchez (EURATOM-CIEMAT, Spain, EU)
George Vayakis (Naka JWS, ITER)
Chris Walker (Garching JWS, ITER)
Shin Yamamoto (Garching JWS, ITER)
Victor Zaveriaev (Kurchatov Inst., RF)

ITER JCT PRESENTATION AT THE INTERNATIONAL CONFERENCE ON FUSION REACTOR MATERIALS (ICFRM-9)

by Drs. G.Kalinin, V.Barabash and K.Ioki, ITER Joint Central Team, Garching Joint Work Site

The Ninth International Conference on Fusion Reactor Materials (ICFRM9) was held in Colorado Springs, USA, on 10–15 October 1999.

The Conference was organized by the USA National Laboratories, Pacific (PNL), Argonne (ANL), Oak Ridge (ORNL), and by the University of California (Santa Barbara) under the support by the DOE Office of Fusion Energy Science. The Conference was guided by its Chair, Dr. Russell H. Jones.

The International Conference on Fusion Reactor Materials (ICFRM) is the major international forum for the exchange of information on materials to be used in fusion power systems. The scope of ICFRM-9 includes materials selection, engineering, and research related to both near- and long-term fusion applications.

The presentations concerned the following topics:

- blanket materials and technology, coatings and barriers,
- corrosion and compatibility,
- design materials interface,
- dielectrics, insulators, windows and optics, diagnostic materials,
- fundamentals of radiation effects,
- hydrogen and helium effects in materials,
- joining of structural materials,
- low activation and other structural materials,
- near-term fusion devices including ITER,
- magnetic and superconducting materials,
- materials issues for inertial fusion energy,
- materials processing and fabrication,
- plasma facing and high heat flux materials,
- radiation facilities and specialised test techniques.

ITER presented several papers at the previous ICFRM Conferences. This time, .four invited papers and one poster paper were presented on behalf of the ITER Joint Central Team with the review of latest achievements. The results of the comprehensive materials R&D program in support of the ITER design were extensively reported by representatives of the ITER Home Teams.

An invited paper, “Assessment and Selection of Materials for ITER In-vessel Components”, was presented at the plenary session by G. Kalinin, in which the database on the properties of all structural and plasma facing materials was assessed and briefly reviewed, together with the justification of the material selection (e.g. effect of neutron irradiation on the mechanical properties of materials, effect of manufacturing cycle, etc.). It was pointed out that:

- during the ITER EDA, significant progress had been made in the selection and justification of the materials;

- the progress was a result of world-wide collaboration of material scientists and industries;

- the effort was focused on optimisation of materials and component manufacturing and on the investigation of the most critical material properties;

- standard industrially available materials are preferred options for the design, and for this group of materials only limited R&D was nessesary to investigate the specific working conditions of ITER components;

- some modifications had been implemented for the group of materials (steel 316L(N)-IG, copper alloys CuCrZr-IG and CuCrZr-IG (Glidcop Al25), beryllium S-65C or DShG-200 grades and carbon fibre composite CfC) comprising with more extended R&D, including the study of the effect of component manufacturing cycle and irradiation;

- the database on the design relevant properties of these materials had been significantly improved during the EDA;

- consideration of real components for the ITER design has highlighted materials issues not identified without this focus.

The current ITER design status was presented by K.Ioki in the invited paper “Design and Fabrication Methods of FW/Blanket, Divertor and Vacuum Vessel for ITER”. The design had progressed on the vacuum vessel, FW/blanket and Divertor for ITER-FEAT. Design and fabrication methods of the components had been improved to achieve ~ 50 % reduction of the construction cost.

The applicability of alternative fabrication methods for parts of the VV had been investigated to save money. The use of forged structures would be cost-beneficial without causing additional issues. Other methods such as casting or powder HIP were being further investigated.

Design improvements for the blanket modules had been pursued using separable FW concepts (faceted geometry). The concepts resulted in considerable cost reductions compared to the 1998 ITER design. Further cost reductions proposed were (i) use of CuCrZr instead of DS Cu, (ii) Be joining to Cu-alloy by brazing instead of solid HIPing, (iii) powder HIPed FW panels, and (iv) casting instead of forging and drilling or powder HIPing for the shield block manufacturing.

The reduced coolant inlet temperature achieved a cost saving for the divertor purification and heat transfer system and increased the fatigue lifetime of the PFCs. Further improvements proposed for the divertor PFCs were (i) low temperature HIPing (~500°C) instead of brazing (~900°C) for CfC/CuCrZr joining, (ii) the annular flow concept with larger coolant tubes, and (iii) flat CfC tile designs (including cascade failure analysis).

The invited paper “Neutron Irradiation Influence on Plasma Facing Materials” was presented by V. Barabash. For ITER-FEAT, beryllium, tungsten and carbon-based materials had been proposed as plasma facing armour. For ITER-FEAT, DEMO and for more advanced reactors, neutron irradiation effects are an important factor that have to be taken into account during selection of the armour materials and during analysis of the performance of plasma facing components. This paper reviewed the effects of neutron irradiation on thermal and mechanical properties and bulk tritium retention of beryllium, tungsten and carbon based materials. In recent years, mainly in the frame of the ITER R&D program, the database on the influence of neutron irradiation on the properties of Be, W and CFC had been significantly improved and new qualification data on physical and mechanical properties for the improved Be, W and CFCs grades have been generated.

For each material, the main properties affected by neutron irradiation had been determined and were described. For each material the main problem was the mechanical integrity and keeping their function of the wall structure protecting. For beryllium and tungsten, the key issues were the loss of ductility and embrittlement at low irradiation temperature, which could lead to additional loss of material due to cracking and delamination. To avoid possible crack formation and delamination of the brittle Be and W in cold areas near the heat sink, it was recommended to use armour tiles without any stress concentrations and with the orientation of texture perpendicular to the surface of the armour/heat sink joint. For carbon-based materials, neutron irradiation at ITER conditions affects mainly the thermal conductivity. Finally, it was stated that an important point for the armour lifetime assessment was the behaviour of neutron irradiated armour materials at high heat fluxes during steady state operation and transient events. A study of the combined effects of neutron irradiation and high heat flux on the behaviour and performance of armour materials had been started recently and had to be continued for ITER-relevant conditions.

Chair Dr. R. Jones opening the Conference

G.Federici presented the invited paper “Critical plasma wall interaction issues for plasma-facing materials and components in near-term fusion devices such as ITER-FEAT”. This reviewed some of the most recent database together with the projections of state-of-the-art modelling tools for next-step conditions. Although significant progress had been made over the last few years, thanks, primarily, to the collaborative design and R&D efforts from the Home Teams supporting the ITER project, there were still several critical issues which needed to be urgently addressed.

The reference design for ITER FEAT retained CfCs in the region of the divertor near the strike points. That material was ‘forgiving’ frequent major off-normal events, e.g., disruptions and ELMs. However, the use of CfC meant that wall conditioning, and control of the tritium inventory and minimisation/removal of tritium in the codeposited layers, remained a formidable challenge that must be overcome. Because tungsten minimized erosion under normal conditions and minimized the retention of tritium (and of fire hazards), it was the leading candidate for a reactor. ITER was planning to use all-tungsten targets capable of intercepting the scrape-off-layer plasma. The primary shortcomings of tungsten to be addressed were the lack of operational experience and the dearth of experimental data regarding formation of melt layers (and their properties) during disruptions. An important point was the need to determine how effectively different impurity sources (from the main chamber and the divertor) were screened from the core. To permit the use of non-carbon materials in ITER, efforts to reduce transients and mitigate disruptions were the highest priority. In addition, under ‘normal’ or steady-state operating conditions, at lower densities may lead to further problems for tungsten that needed to be explored.

Finally, it had become clear that in order to understand the plasma material interaction effects observed in present-day tokamaks and to make reliable predictions for ITER, there was a need to enhance the modelling of plasma-surface interactions. However, measurements were needed to underpin those models, in particular through (1) dedicated operation time on current devices and/or a dedicated machines with appropriate properties and (2) development of PMI diagnostic techniques. Furthermore, there was a need to conduct tests in tokamaks with the proper wall materials to provide a realistic test-bed which would closely mirror whichever situation is proposed for the next step.

A. Cardella presented the paper “Effect of plasma disruption events on ITER first wall plasma facing materials”. In ITER, plasma disruption events may occur producing large fast thermal transients on plasma facing materials. Particularly important for the integrity of the primary first wall were relatively ‘long’ duration off-normal events such as plasma vertical displacement events (VDEs) and runaway electrons (RE). A new analytical methodology had been developed to assess the effect of these events on first wall plasma facing materials. The method allowed to calculate the amount of melted and evaporated material, taking into account the evolution of the evaporated and melted layer during the event. The method had been used to analyze the effects of VDE and RE events on ITER baffle and primary first wall, to study a recent disruption simulation experiment on a beryllium sample and to benchmark the experimental and analytical results. Since the method was appropriate to analyze problems in 2 and 3 dimensions and could handle peaked volumetric heating, it was planned to perform detailed analyses of RE events in ITER in the near future.

An overview of the irradiation tests on diagnostic components under the ITER technology R&D and the solutions for the present diagnostic design were presented by S. Yamamoto. Not only the work shared among the four Home Teams, but also several bilateral collaborations and round robin experiments were performed to enhance the R&D activities.

Radiation aspects of design solutions for selected diagnostic systems had been examined, based on the ITER maintenance scheme, the irradiation database for physical and mechanical properties and the required signal-to-noise ratio (SNR) of the system taking into account the ITER irradiation environment and radiation shielding capability for diagnostic components.

A comprehensive irradiation database of diagnostic components had been analysed and the application of these components in ITER was overviewed.

Further details of R&D carried out for ITER were presented also at the Conference by the ITER Home Teams.

The proceedings of the conference will be published in a special volume of the Journal of Nuclear Materials.

7TH INTERNATIONAL WORKSHOP ON PLASMA EDGE THEORY IN FUSION DEVICES

by Dr. A. S. Kukushkin, ITER Joint Central Team, Garching Joint Work Site

This workshop took place on 4–6 October 1999 in Tajimi, Japan. Over 60 scientists actively working in this field got together to discuss their approaches and results in theory and modelling of the edge plasma in different fusion devices, mostly tokamaks and stellarators. Physics of the edge plasma has been intensively studied in the last years, both theoretically and experimentally. This area is considered one of the critical issues for the ITER project: the plasma-wall interaction in ITER must be arranged in such a way that the power removal and helium exhaust from the reactor-grade plasma be accomplished under conditions acceptable for the plasma-facing components. While the present experiments cannot reproduce the parameters of the edge plasma expected in ITER, they provide the reference data for the development of the theoretical models which, implemented in the computer codes, are used for the ITER design studies. The state of the edge plasma theory is therefore continuously monitored by the ITER JCT members responsible for the physics basis of ITER the design. On their side, the experts from JCT also contribute to the development of the edge plasma theory maintaining thus the ITER integration in the world-wide fusion science. The two papers presented by the JCT members – on the physics of the so-called pedestal region which can be responsible for the good plasma confinement in H-mode and on a self-consistent profile approach in the edge plasma modelling which could eliminate the uncertainty related to the cross-field transport – were received with interest by the audience.

The present workshop has shown a very positive trend of increasing attention to the validation of the theoretical models against the experimental data. The results generally increase confidence in the models used for ITER and help to develop these models further in order to make these predictions more reliable and detailed. In particular, the development of the fluid description of the drift effects in the edge plasma of a tokamak reported by the groups from JET and Asdex-Upgrade seems to be interesting for ITER and should, after its finalization, be included in the computational model of the ITER edge plasma.

Participants in the Workshop

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Printed by the IAEA in Austria
January 2000

00-00268