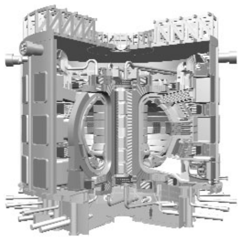

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THE WORK OF THE DIAGNOSTICS WORKING GROUP SUCCESSFULLY COMPLETED

Dr. A. E. Costley, ITER International Team

The ITER diagnostic system comprises about 45 individual measurement systems involving a very wide range of technologies (magnetics, neutron systems, optical systems, microwave systems etc). It is a distributed system with components installed in the vacuum vessel, the divertor, the ports (23 at all three levels in total), the port cells, the tokamak building and in the diagnostics building. It will play an important role in the operation of ITER and the scientific programme. It is expected that all ITER Parties will contribute to the supply of the diagnostics, but a new method for the procurement of the systems is being considered.

Because of the large number of systems and the relatively small number of ports, there are benefits in procurement to grouping the diagnostics into packages based on complete ports. This contrasts with the 'conventional way' of procuring diagnostics on a per system basis, where the institute or collaborator provides the individual diagnostic system and the institute that owns the tokamak integrates the system into the machine and buildings. This latter approach has the advantage of flexibility but to apply it to ITER would require a sizeable central technical team developing a large number of individual procurement packages and handling many interfaces both between diagnostic systems and with the basic tokamak. The nature of the work would be highly specialized and technical, and would draw expertise away from its experimental base in the Participant Teams (PTs).

Port-based procurement of diagnostics should lead to fewer interfaces and less specialized technical work to be dealt with by the Central Team. For each port a lead diagnostic would be defined. The Party that provides the lead diagnostic becomes the lead Party for the port and provides its structure, other diagnostics and diagnostic components in the port as far as possible, and thereby carries out the integration within that port and takes care of the interface with the tokamak.

In July 2003, the Participant Team Leaders and the International Team Leader approved a task to develop this approach to diagnostic procurement. A small group of two members per Party plus four of the IT staff working on diagnostics were appointed to carry out this task. For the period of this task, this group was known as the Diagnostics Working Group. The main aims of the task were:

i) To develop technically feasible, costed, port-based procurement packages based on the ITER reference distribution of diagnostics in the allocated ports;
ii) to identify the interfaces between these packages and, where possible, minimize them;
iii) to develop a cost-sharing proposal amongst the Parties which is consistent with the constraints laid down by the ITER Negotiators for diagnostic cost sharing;
iv) to identify and consider any key related matters;
v) to make a preliminary estimate of the level and nature of the staff required in the ITER Organization ('Organization') to manage the procurement of diagnostics through port-based packages.

The execution of the task commenced by updating the allocation of the individual diagnostics to the available ports. This is a complex process since many of the diagnostic systems are installed at different levels and have to operate together. It involves the allocation of a valuable commodity – space in the diagnostic ports. Very careful attention has to be paid to the importance of the measurements being provided by the individual diagnostic systems when they are allocated space to ensure that the limited space is used in the best possible way. The developed allocation of diagnostics to ports is shown in Figure 1.

A methodology for creating the port-based packages was developed. As far as possible it was based on objective considerations and minimized the need for judgement. Working from the information determined as part of the ITER costing in 2000, the fractional cost of the diagnostic components installed in each diagnostic port was determined. A lead diagnostic was chosen for each port according to specific guidelines. With port-based procurement, the ITER Party that commits to supply the lead diagnostic becomes the *lead Party* for that port and also takes on

a) the integration of the port and, in particular, the integration of other diagnostics within the port which may or may not be supplied by the lead Party;
b) the design and supply of other elements of the lead diagnostic that are located in other ports.

The supply of the lead diagnostic, plus the work under (a) and (b), plus the supply of the other diagnostic systems assigned to the same port as the lead diagnostic, constitutes a *port-based procurement package*.

Some diagnostics (about 15) are not located in ports – for example magnetics and neutron flux monitors. These are known as distributed systems and were treated as individual systems in the procurement.

The members of the DWG reviewed the draft port-based packages in consultation with their domestic experts and determined their level of interest in each package. As mentioned above, some of the systems have components in more than one port and these can be assigned to different port-based packages. A few systems have parts that function separately and these parts can be assigned to different port-based packages. This gave some flexibility and enabled adjustment of the package content and value. Through a close interaction between the members of the DWG, their experts in the Parties, and the IT, the content of the packages was adjusted to improve the fit of Party interest and package content. Obviously, because the Party interests and competences arise from many years of independent development, a perfect fit is impossible. However, for the sake of achieving the overall goal – that is, the full distribution of all packages to Parties with only one lead Party per package and with the fractional cost for each Party conforming with that determined by the ITER Negotiators – the Parties worked together to achieve a compromise distribution. The proposal has the merits of a high fraction of the distribution being consistent with individual Party preferences and Party competence thereby giving the best possible chance for a high performance of the ITER diagnostic system. It is also consistent with the cost-sharing for diagnostics set down by the ITER Negotiators.

Several related topics were identified and discussed. Since the costing of ITER diagnostics was carried out in 2000, the measurement requirements have changed and some diagnostics have matured, and it is desirable to include additional systems in the diagnostic set. This has led to some desirable systems being not currently included in the plan. For the current integration technical work, these systems are included to maintain the option for their later inclusion. It was recommended that a means to include these systems in the plan should be made as soon as possible.

Many of the diagnostic designs and some of the interfacing systems are at an early stage in design. As the designs mature it is probable that changes will be required. These may affect the procurement packaging and diagnostic supply. Moreover, diagnostics is a rapidly developing field and obviously the most up-to-date systems will be wanted on ITER. It is expected that during the detailed design phase the ‘Organization’ will organize reviews of the design and construction progress. To make the best use of the available expertise that exists in the laboratories of the ITER Parties, it was recommended that these *design reviews* should involve relevant diagnostic experts from the non-supplying Parties. Finally, a preliminary estimate of the IT resources, including the type of staff (specializations etc), necessary to support the port-based procurement was made.

The task of the group has now been executed and has laid the foundations for the procurement for diagnostics. By establishing a unique distribution at this stage it has become possible for the Parties to begin working on the details of their packages, thereby ensuring a good use of the time between now and the start of ITER construction. Specific recommendations have been made for the future stages in the preparation of the ITER diagnostic system and the ITER IT and PTs will carry these forward. The progress achieved has been a direct result of the cooperation and good will in this activity, and the willingness to compromise for the sake of achieving the overall goal, demonstrated by all those involved in this process. All the DWG members feel privileged to have been involved in such an important task.

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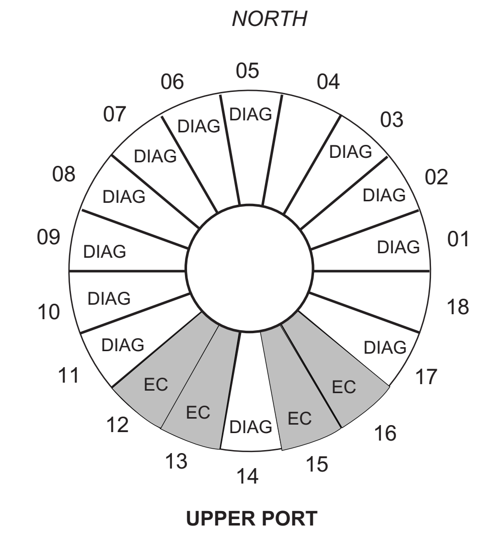


01 Position Reflectometry (1 of 2)
Divertor Impurity Monitor
Activation System (16N, 1 of 2)

02 Vis. / IR TV (1 of 6)
Ha spectroscopy (divertor outer)
Ha spectroscopy (outer edge)

03 CXRS (on the DNB, core)
Vertical Neutron Camera (1 of 3)

05 Vis. / IR TV (2 of 6)
Activation System (16N, 2 of 2)
Vertical Neutron Camera (2 of 3)

06 VUV grazing image (x 2)
Activation System (foil, 1 of 2)

07 Ha spectroscopy (inner edge)
Ha spectroscopy (upper edge)
Vertical Neutron Camera (3 of 3)

08 Vis. / IR TV (3 of 6)
Main Reflectometry (1 of 3)
Bolometry

09 X-ray Crystal Spectrometry (imaging),
Main Reflectometry (2 of 3)

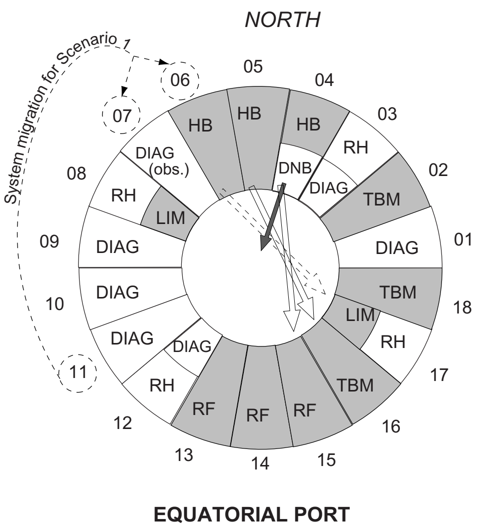
10 Polarimeter

11 Vis. / IR TV (4 of 6)
Edge Thomson Scattering
Activation System (foil, 2 of 2)

12 (EC), *CTS*

14 Vis. / IR TV (5 of 6)
X-ray Crystal Spectrometry (survey)
Position Reflectometry (2 of 2)

17 Vis. / IR TV (6 of 6)
Main Reflectometry (3 of 3)
X-ray Crystal Spectrometry (graphite)
Bolometry,
Soft X-ray Array



01 Vis. / IR TV (1 of 4)
Radial Neutron Camera
Bolometry, MSE (core, HB4)
Divertor Impurity Monitor
Gamma Ray Spectroscopy
High Resolution Neutron Spectrometer

03 Vis. / IR TV (2 of 4)
CXRS (on the DNB)
MSE (edge, HB5)
Ha Spectroscopy (divertor inner)

07 Activation System (16N, 1 of 2)
Activation System (foil, 1 of 2)
Neutron Flux Monitor (DD)

08 Neutron Flux Monitor (DT)

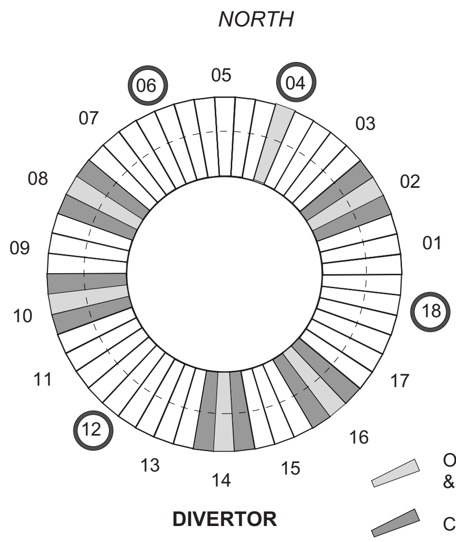
09 Vis. / IR TV (3 of 4)
Toroidal Interferometer/Polarimeter
ECE, X-ray Crystal Spectrometry (imaging)
Fast Wave Reflectometry
Soft X-ray Array

10 Thomson Scattering (main plasma)
Polarimeter
Thomson Scattering (inner divertor)

11 X-ray Crystal Spectrometry (survey)
VUV (main and divertor)
Reflectometry for the main plasma
NPA

12 Vis. / IR TV (4 of 4)
Ha Spectroscopy (upper edge)
Visible Continuum Array
CTS

17 Neutron Flux Monitor (DT)
Activation System (16N, 1 of 2)
Activation System (foil, 2 of 2)



Optical access (c: centre, g: gap) & Cassette Instrumentation (i)

Cassette Instrumentation(i)

Pumping Duct Instrumentation(d)

02 Divertor Impurity Monitor (Visible, gcg)
Langmuir Probes (i)
Magnetics (i)
Thermocouples (i)

04 *Dust measurement (c)*
Magnetics (i)
Pressure Gauges (i)
Pressure Gauge(d), RGA (d)

06 Activation System (foil, 1/3)
Pressure Gauge (d), RGA (d)

08 Reflectometry/Interferometry (gg)
LIF (c)
Magnetics(i)
Bolometry(i), Pressure Gauges(i)

10 X-point Thomson Scattering (c)
Divertor Thomson Scattering (outer leg,g)
Ha Spectroscopy (g)
Langmuir Probes (i)
Magnetics (i)
Bolometry (i), Pressure Gauges (i)

12 Activation System (foil, 2/3)
Pressure Gauge (d), RGA (d)

14 Reflectometry/Interferometry (gg)
Plate Erosion (c)
Langmuir Probes (i)
Magnetics (i)
Thermocouples (i)

16 Divertor Impurity Monitor (VUV, gg)
IR thermography (c)
Magnetics (i)
Bolometry (i), Pressure Gauges (i)

18 Activation System (foil, 3/3)
Pressure Gauge (d), RGA (d)

Figure 1. Distribution of diagnostics in ports at Upper, Equatorial and Divertor levels

Members of the Diagnostic Working Group

CN:
Dr J. Zhao (ASIPP)
Dr Q. Yang (SWIP)

EU:
Dr. D. Campbell (EFDA)
Dr. F. Romanelli (ENEA)

JA:
Dr. Y. Miura (Naka Research Establishment, JAERI)
Dr. Y. Kusama (Naka Research Establishment, JAERI)

KO:
Dr M Kwon (Korea Basic Science Institute)
Dr. S. J. Yoo (Korea Basic Science Institute)

RF:
Dr. V. Zaveriaev (Kurchatov Institute)
Dr. A. Krasilnikov (TRINITI, Troitsk)

US:
Dr. D. Johnson (PPPL)
Dr. R. Boivin (General Atomics)

IT
Dr. A. Costley
Dr. G. Vayakis
Mr. C. Walker
Dr. A Malaquias (until 31/12/03)

Members of the Diagnostic Working Group meeting at the ITER JWS, Naka, Japan.

SIXTH MEETING OF THE ITPA TOPICAL GROUP ON DIAGNOSTICS

by Drs. A.J.H. Donné, FOM Institute for Plasma Physics Rijnhuizen, and
A.E. Costley, ITER International Team

The Sixth Meeting of the International Tokamak Physics Activities (ITPA) Topical Group (TG) on Diagnostics was held at JAERI, Naka from 19 – 21 February 2004. This meeting was combined with a Progress Meeting on ITER/BPX (burning plasma experiment) relevant diagnostic developments on-going in Japan. For the first time, ITPA members from China, as well as observers from South Korea, attended. In addition, an associated sub-meeting was held at General Atomics, San Diego, 23 – 24 April, immediately after the 15th Topical Conference on High Temperature Plasma Diagnostics. At the sub-meeting a special one-day session was devoted to issues related to beam-aided spectroscopy. In total more than 50 participants attended the meetings and all ITER partners were represented.

The key topics reviewed and discussed at the TG meeting were: (i) the overall status of diagnostics developments for ITER, (ii) the progress in the research on the designated high priority topics, (iii) the progress with some key ITER/BPX-relevant diagnostic developments ongoing in the ITPA participant laboratories, (iv) the progress and plans for the work of the specialist working groups, (v) the status and plans for the International Diagnostic Database.

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

1. One of the outstanding questions connected to the measurement of the alpha/neutron source profile is whether the neutron emission profile can be expected to be a constant on a magnetic flux surface. If so, the need for the Vertical Neutron Camera (VNC) on ITER is much reduced because it would be possible to obtain the profile of the neutron emission from measurements with the radial camera (RNC) and magnetics. At the meeting, good arguments were made that under some ITER-relevant conditions in JET, for example under conditions where non-isotropic fast ions are present (ICRH), the neutron source profile is not a constant on a flux contour. Under these conditions both cameras are needed to reliably measure the neutron source profile in JET.

   A proposed new design of a VNC for ITER with ten viewing chords looking upwards adjacent to a divertor port through a gap between blanket modules was presented. The design appears to be feasible but further study of the concept is needed.

2. Progress was reported on the need and methods of making measurements of steady state magnetic fields. In a study by CRPP, Lausanne, it was suggested that it should be possible to compensate for drifts in magnetics during long plasma discharges by imposing a small modulation on the plasma position. This needs to be demonstrated.

   The understanding of Radiation-Induced Electro-Motive Force (RIEMF) and Radiation-Induced Thermo-Electric Sensitivity (RITES) is gradually increasing. New irradiation tests in the JMTR reactor were reported and confirm the earlier result that probably RITES is the dominant effect. Although there are still aspects of the results not fully understood, on the basis of the work carried out, it is probable that coils can be developed for ITER in which the combined action of RIEMF, RITES and other related effects is tolerable, and it may be possible to use the coils for measurements on long (> 1000 s) pulses. The development of steady state sensors also shows progress and it is likely that Hall sensors can be developed for applications outside the ITER vacuum vessel.

3. All the optical and infrared diagnostic systems will view the plasma via a mirror. The ‘plasma facing’ mirrors will be subject to erosion and deposition possibly leading to degradation in their reflectivity. Test mirrors made from candidate materials have been installed in some of today’s tokamaks and the extent of the erosion and/or deposition has been measured. The results are highly variable and depend on several factors such as the location of the mirror relative to the plasma, the material of the mirror, and the quality of the discharge. For example, some recent tests on the T-10 tokamak have shown deposition rates of 0.2 nm/s in normal, clean discharges, and 2 nm/s in highly polluted discharges. A periscope system on TEXTOR has shown that the plasma-facing mirror had a deposit of ~0.7 μm while the second mirror located deeper in the tube was clean.

An important recent finding is that the vulnerability of mirrors to sputtering strongly depends on the manufacturing process. For example, the reflectivity of Cu mirrors with a large grain size exhibits a much smaller decrease than that of Cu mirrors with small grain size for the same amount of erosion.

Possible cleaning techniques are also under investigation. One method is cleaning by laser ablation. It has been demonstrated that the mirrors can be completely cleaned by 30–50 laser pulses with >0.12 J/cm^2.

One method of measuring the confined alpha particles is by collective Thomson scattering. A study has been completed in Europe on the various collective Thomson scattering options to measure alphas and fast ions in ITER. It appears that the option that uses radiation at a frequency 60 GHz is the most attractive, because it combines a good signal/noise ratio with minimum required technological developments. The system is rather robust against density variations and mechanical disturbances, but it does have a magnetic field limitation (B > 3T). (In nominal ITER operation this is not a limitation since B > 4T throughout the plasma.) A collective Thomson scattering system for measuring confined fast alpha particles on ITER based on the 60 GHz option has been designed. Implementation of the system appears feasible although some key interface details need to be worked through.

A new concept for measurements of fast ions based on the observation of re-neutralized beam ions through Charge Exchange Recombination Spectroscopy (CXRS) has been proposed. The concept will be tested at DIII-D. A new approach for the measurement of the alpha knock-on tail neutrons, based on the measurement of proton tracks in nuclear emulsion foils, was also proposed.

New results have been reported with activation foils in JET. Six foils are mounted on a manipulator and can be removed from the plasma at regular intervals. By simultaneously using different foils it is possible to discriminate between different fast ions.

5. The results of many irradiation tests on candidate materials for diagnostic construction performed in the EU during 1989 – 2002 have been gathered in a detailed electronic table. The database now needs to be extended with the work done in the other ITPA Partners.

During the one-day special session on beam-aided spectroscopy, the present status and open issues in the field of CXRS, Beam Emission Spectroscopy (BES), and Motional Stark Effect (MSE), and particularly their planned application on ITER, were reviewed. Considerable progress has been made in the design of CXRS diagnostics for ITER and the analysis of expected performance. The studies have shown that, in principle, most of the ITER measurement requirements (ion temperature, ion densities, rotation velocities, He-ash distribution, etc.) can be met with the planned implementation. However, there still remain a number of important aspects to be studied.

Similarly, it is expected that the proposed implementation of the MSE system will also largely meet the ITER measurement requirements. The recent change in the port allocation, specifically for this diagnostic, has substantially improved the potential performance, in particular, the spatial resolution is now < 10 cm over most of the minor radius. Also here there are several aspects requiring further study.

There are also issues to be studied in relation to the Diagnostic Neutral Beam (DNB). Thus far it has been planned that the DNB would be a negative ion beam. However, there are some advantages (and disadvantages) in using a positive ion source. It is recommended that the choice of the ion type should be reviewed again. Since the DNB will be used to make important measurements, and possibly measurements used in the real time control of the plasma, a very high reliability of the DNB is required.

The ITPA Partners reported steady progress for many diagnostic techniques that are relevant to a BPX. A productive progress meeting on ITER/BPX-relevant diagnostic developments in JA was held, with many excellent contributions. Some examples of recent work are: development of radiation-resistant imaging bolometers for tangentially viewing the ITER plasma (JA), high-resolution charge exchange recombination spectroscopy to measure rotation and radial electric field profiles (US), conceptual design of a MSE diagnostic for ITER with optimised views (EU), an alternative design of a LIDAR Thomson scattering system to monitor the inner divertor leg (RF). The Chinese members as well as the observers from the Republic of Korea gave an overview of the diagnostic programme in their respective countries.

The International Diagnostic Database (IDD) presently contains information on 265 diagnostics operating on experiments worldwide. In particular, since the last meeting the NSTX team has been very active in adding new diagnostics. The ISTTOK and EXTRAP T2R teams have joined the IDD. Addition of information on new diagnostics and information updates of diagnostics that are already in the database continues to be actively stimulated.

The Seventh Meeting of the ITPA TG on Diagnostics will be held in Hefei, China from 11–15 October 2004. During this meeting it is planned to organize a one-day session with extended overview/review talks on ITER/BPX diagnostic developments on-going in Europe, Japan, the Russian Federation and the US, and diagnostic activities within the ITER IT. The meeting will be further combined with a one-day meeting on relevant diagnostic developments on-going in China.

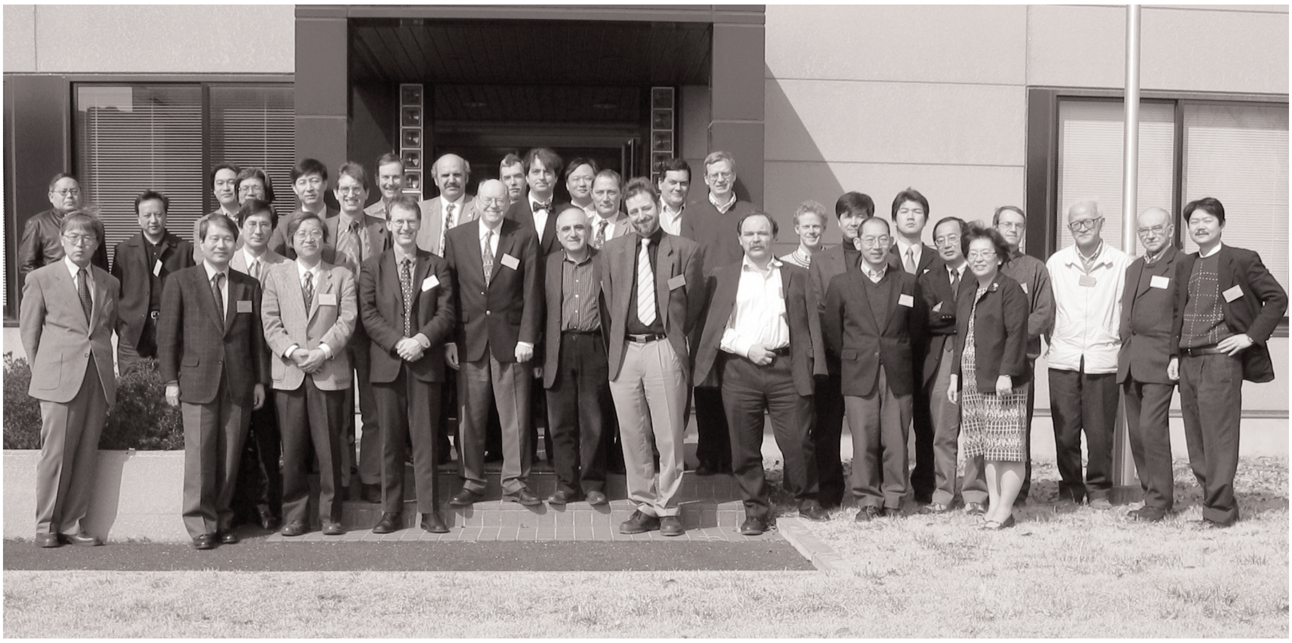
Participants at the Sixth Meeting of the ITPA Topical Group on Diagnostics, Naka, Japan, 18–21 February 2004 (Main Meeting)

Members of Topical Group on Diagnostics

Rejéan Boivin (GA, USA)
Alan Costley (ITER Int. Team, Naka, JA)
Tony Donné (FOM, Netherlands, EU)
David Johnson (PPPL, USA)
Kazuo Kawahata (NIFS, JA)
Yasunori Kawano (JAERI, JA)
Anatolij Krasilnikov (TRINITI, RF)
Yoshinori Kusama (JAERI, JA)
Atsushi Mase (Kyushu Univ., Japan)
Francesco Orsitto (ENEA, Italy, EU)
Mamiko Sasao (Tohoku Univ., JA)
Fernando Serra (IST, Portugal, EU)
Tatsuo Sugie (ITER Int. Team, Naka, JA))
Konstantin Vukolov (Kurchatov, RF)
Qinwei Yang (Southwestern Inst., CN)
Victor Zaveriaev (Kurchatov, RF)

Guests and Attendees at the Topical Group Meeting

Leonid Bruskin (Kyushu Univ., JA)
Ruggero Giannella (CEA, France, EU)
Yasuji Hamada (NIFS, JA)
Takaki Hatae (JAERI, JA)
Nick Hawkes (UKAEA, UK, EU)
Takao Hayashi (JAERI, JA)
Christian Ingesson (EFDA-CSU, EU)
Masao Ishikawa (JAERI, JA)
Kiyoshi Itami (ITER Int. Team, Naka, JA))
Takahi Kondoh (ITER Int. Team, Naka, JA))
Shigeru Konoshima (JAERI, JA)
Hirotaka Kubo (JAERI, JA)
Myeun Kwon (KBSI, Korea)
Masayuki Nagami (JAERI, JA)
Takeo Nishitani (JAERI, JA)
Byron Peterson (NIFS, JA)
Gennadiy Razdobarin (Ioffe, RF)
Tatsuo Shikama (Tohoku Univ., JA)
Kentaro Toh (Tohoku Univ., JA)
Yury Verzilov (JAERI, JA)
Chris Walker (ITER Int. Team, Garching, EU)
Jingwei Yang (Southwestern Inst., CN)
Suk Jae Yoo (KBSI, Korea)
Junyu Zhao (IPP-CAS, CN)



Participants in the Main Meeting

Participants at the Sixth Meeting of the ITPA Topical Group on Diagnostics, San Diego, USA, 23 – 24 April 2004 (Sub-meeting)

Members of Topical Group on Diagnostics

Rejéan Boivin (GA, USA)
Alan Costley (ITER Int. Team, Naka, JA)
Tony Donné (FOM, Netherlands, EU)
David Johnson (PPPL, USA)
Kazuo Kawahata (NIFS, JA)
George McKee (Univ. Wisconsin, USA)
Tony Peebles (UCLA, USA)
Glen Wurden (LANL, USA)

Participants in the Sub-Meeting

Guests and Attendees at the Topical Group Meeting

Leonid Askinazi (Ioffe, RF)
Ronald Bell (PPPL, USA)
Henrik Bindslev (Risø, Denmark, EU)
Manfred Bitter (PPPL, USA)
Maarten De Bock (FOM, Netherlands, EU)
Patrick Carolan (UKAEA, UK, EU)
Luis Cupido (IST, Portugal, EU)
Ivan Duran (IPP-CSA, Czech Rep., EU)
Rainer Fischer (IPP-Garching, Germany, EU)
Ray Fisher (GA, USA)
Jill (Elizabeth) Foley (PPPL, USA)
Ruggero Giannella (CEA, France, EU)
Punit Gohil (GA, USA)
Sami Hahto (LBL, USA)
Nick Hawkes (UKAEA, UK, EU)
Bill Heidbrink (UC Irvine, USA)
Manfred von Hellermann (FOM, EU)
Don Hillis (ORNL, USA)
Christian Ingesson (EFDA-CSU, EU)
Maso Ishikawa (JAERI, JA)
Kiyoshi Itami (ITER Int. Team, Naka, JA)
Katarzyna Jakubowska (FOM, Netherlands, EU)
Jay Jayakumar (GA, USA)
Ralf Koenig (IPP-Greifswald, Germany, EU)
Takahi Kondoh (ITER Int. Team, Naka, JA)
Joe Kwan (LBL, USA)
Fred Levinton (PPPL, USA)
Yadong Luo (UC Irvine, USA)
Michael Makowski (GA, USA)
Darlene Markevich (DOE , USA)
Mark May (LLNL, USA)
Fernando Meo (Risø, Denmark, EU)
Susanne Michelsen (Risø, Denmark, EU)
Roberto Pasqualotto (ENEA-RFX, Italy, EU)
Roger Reichle (CEA, France, EU)
Lane Roquemore (PPPL, USA)
Joaquin Sanchez (CIEMAT, Spain, EU)
Wayne Solomon (GA, USA)
Vlad Soukhanovskii (LLNL, USA)
Brent Stratton (PPPL, USA)
Dan Stutman (J. Hopkins Univ., USA)
Dan Thomas (GA, USA)
George Vayakis (ITER Int. Team, Naka, JA)
Chris Walker (ITER Int. Team, Garching, EU)
Michael Walsh (UKAEA, UK, EU)
Andreas Werner (IPP-Greifswald, Germany, EU)
Paul Woskov (MIT, USA)
Kenneth Young (PPPL, USA)
Klaus-Dieter Zastrow (UKAEA, UK, EU)

Items to be considered for inclusion in the ITER ITA Newsletter should be submitted to C. Basaldella, 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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