Minutes of the 1st Meeting of the ITPA Topical Group on Diagnostics held in St. Petersburg, Russia from 14 — 16 November 2001

1. Introduction

The First Meeting of the ITPA Topical Group on Diagnostics was held at the Ioffe Physical Technical Institute, St. Petersburg, Russia, 14 - 16 November 2001. The meeting immediately followed a Progress Meeting on ITER Diagnostic Design and R&D and BPX relevant diagnostic developments on-going in the Russian Federation, which was held in the same location, 12 - 13 November 2001. In total 38 participants attended the meeting and all four ITPA partners were represented. These minutes cover mainly the discussions at the Topical Group (TG) meeting. A brief summary of the RF progress meeting is also attached. The presentations given at both meetings have been collected on CD-ROM. **(Action item 01a083: Kislyakov to provide participants with CD-ROM containing presentation of TG and RF Progress meeting).**

The final agenda for the meeting and the list of participants are shown in Attachments 1 and 2, respectively. There were no comments on the minutes of the 14th Meeting of the ITER Physics Expert Group on Diagnostics.

An overview of the International Tokamak Physics Activity (ITPA) was presented by D. Campbell. The ITPA replaces the ITER Physics Expert Group activity. It aims at the cooperation in the development of the physics basis for burning tokamak plasmas. The organizational structure of the ITPA consists of a Co-ordinating Committee (CC) and several Topical Physics Groups (at present seven). Each Topical Group will coordinate tokamak physics research in its specific area, analyze experimental results and develop appropriate databases, carry out modelling and simulations, and develop materials for its report to the CC. The ITPA commenced on 1 July 2001, for an initial duration of two years. The charges to the Topical Groups for the year 2001 — 2002 were presented and discussed.

The draft mandate for the TG was further developed and it was agreed that it would be finalised by the end of November for submission to the ITPA Co-ordinating Committee (CC). The final draft that has been submitted to the CC is shown in Attachment 3. **(Action item 01a084: Donné to collate the comments on the mandate from the TG members, to develop the mandate accordingly, and to distribute the final version to the ITPA CC members before the end of 2001).**

Both the ITPA meeting and the RF Progress meeting were successful in all respects and the participants are grateful to the Ioffe Institute for its hospitality and express their gratitude to Dr Anatoli Kislyakov and his colleagues for their care and attention to all the meeting arrangements.

2. Review of the present status of ITER and FIRE and their diagnostics

The present status of ITER-FEAT and in particular its diagnostics were presented by A. Costley. Many of the diagnostic designs are based on those for ITER-98, but have been further developed. In terms of the access and overall provision for diagnostics, the situation is improved relative to ITER-98 primarily because diagnostics were considered effectively at an earlier stage in the design of the machine and on the basis of experience with some system designs. The documentation and costing are also more complete although they still lack depth in some areas. Many Design and R&D issues remain and must be the focus of the next phase of the work. The Coordinated Technical Activity (CTA) has commenced and will be the instrument to carry this work forward.

Costley emphasised a key point on resources and timing. If ITER keeps to the planned time schedule, the diagnostic designs will have to be completed in about 3 to 7 years, depending on the system. Some diagnostic components have interfaces with the early procurement items of ITER (e.g. the vacuum vessel) and the designs of these interfaces need to be completed on a one to two year timescale. This requires that the choice of the techniques and the outline design of the relevant components have to be finalised very soon. Further, for some techniques, there are still feasibility issues and new approaches are desired. Experience has shown that the development of new techniques typically takes several years. Hence, although it is several years before ITER goes to construction, the work to do on diagnostics is substantial and enhanced effort is now required. The support, contribution and drive of the ITPA group are essential.

In the presentation Costley included an assessment in broad terms for each measurement parameter of the likely measurement performance, assuming reasonable extrapolations of current design and R&D, relative to target requirements. The measurement requirements as they have been published in the ITER Final Design Report are listed in Attachment 4. In some cases it is probable that the target measurement capability will not be achieved. It may be useful to begin a dialog with other TG groups on specific cases to determine if the measurement requirements can be relaxed, and/or the consequences of the measurement shortfall be evaluated. This process is already underway for the measurements in the divertor region (see below) and could be extended to measurements in the other regions of the plasma. **(Action item 01a085: Costley to consider how best to develop this study and to communicate the results with other TG groups; Action item 01a086: Young to draft the justification for the specification (resolution, etc.) for each measurement requirement for review by the TG members).**

The developments of diagnostic integration and implementation on ITER were reviewed by C. Walker. Most of the selected diagnostics have been assigned to specific ports (upper, equatorial, divertor). Two diagnostics which are not yet assigned to a specific port, because the designs are not sufficiently advanced, but may ultimately be required, are fast ion collective Thomson scattering and laser-induced fluorescence. The designs of many of the systems that provide the category 1a measurements (machine protection and basic control) are quite far evolved with detailed CATIA models existing. Some of the systems that provide category 1b measurements (advanced control) also have detailed drawings in CATIA or have preliminary models in CATIA. In the near future a strong emphasis needs to be put on the Participant Teams to provide engineering effort for the detailed design and specification of the concepts that have been developed for diagnostic integration and also for the design of key diagnostic components.

An overview of FIRE and its diagnostics was presented by K. Young. A very comprehensive set of diagnostic is being considered. The small size, high field and high density of the FIRE plasma, however, give rise to some measurement difficulties relative to ITER-FEAT. For example, all the prompt radiation effects will be higher because of the higher first wall radiation levels. Proposals for the required qualifying R&D are under development. The determination of the spatial resolution achievable for some measurements has to await some conceptual design. The performance of even standard measurements such as n_e and T_e may not meet the requirements for some applications, for example measurements on internal transport barriers. A diagnostic neutral beam is essential for control and physics: profiles of q, ion temperature, rotation, He-ash, slowing α s, and possibly E_r require it. A short pulse beam is being considered but does not permit BES fluctuation measurements. Fast ion Thomson scattering in the microwave region has been adopted for the measurement of confined α s. The development of suitable techniques for diagnosing escaping α s is necessary and it is recommended that they should be tested on JET-EP.

3. Progress with the high priority tasks

The present high priority physics research areas were defined at the last meeting of the ITER Physics Committee (October 2000). Progress with the tasks will be reviewed at the ITPA CC Meeting in March 2002. The diagnostic tasks are listed in Attachment 5. There were several presentations on these tasks.

3.1. Update an RIEMF

G. Vayakis gave an update on the effect of Radiation Induced Electro-Motive Force (RIEMF) and its potential impact on the magnetic measurements for ITER. New measurements of RIEMF in coils have been made under γ-irradiation and, for the ITER application, the results indicate a manageable effect. However, the key test in a reactor (neutrons and γ's) remains outstanding. The Japanese participating party plans to carry out the test in 2002. Reactor tests on plain cable have also been performed and the results obtained suggest that RIEMF should not be a concern for large coils (e.g. saddle loops).

3.2. Measurement of q(r)

In general, the measurement of q(r) on a BPX is considered a very difficult but important task that is presently not well covered and so the development of new techniques that would demand less access and be more rugged in a reactor environment is being encouraged.

Progress has been made in the implementation of systems for the measurement of q(r) on ITER (A. Donné). Solutions to the difficult installation of retro-reflectors on the high field side for the Poloidal Field Polarimeter are being developed. A database containing a large number of different ITER equilibria has been generated and will be used to simulate signals for the polarimeter, the magnetics and if possible also for the MSE, to test the quality of the equilibrium reconstruction.

Issues which arise in the implementation of MSE on ITER were discussed by A. Malaquias. An improved optical design has been developed by P. Nielsen which gives good optical performance at the same time as enabling adequate neutron shielding to be obtained. However, several problems have been identified, in particular, the viewing beam will have to be reflected off several mirrors (about four) before detection and it is probable that the state of polarisation will be severely degraded. 'Polarization-free' mirrors with a dielectric coating exist and the possibility of using them on ITER will be examined.

3.3. Divertor measurement requirements and diagnostic capabilities

The requirements for plasma and target measurements in the ITER divertor region have been further developed in collaboration with the ITER Scrape Off Layer and Divertor Physics Expert Group. The latest developments were presented by G. Vayakis. R. Pitts has been selected by the Divertor group to act as liaison person for this task and the collaboration with him has proved very effective. Following the earlier presentations, the discussion is concentrating on six topics:

- (i) the spatial resolution in the measurement of the radiated power;
- (ii) the time resolution in the measurement of the plate temperature;
- (iii) the sensitivity in the measurement of target plate erosion;
- (iv) the requirement for the measurement of plasma parameters (ne and Te) at the target plates;
- (v) the requirement for the measurement of Te along the divertor leg;
- (vi) the requirement for spectroscopic measurements in the UV.

In the case of topics (ii), (iii), (v) and (iv) changes to the measurement requirements are proposed. In general the changes give a relaxation in the measurement requirements and should improve the chances of achieving agreement between the requirement and capability for measurements. The revised specifications are summarised in Attachment 6. Further development of the measurement requirements and investigation of possible approaches for divertor measurements are required and will be carried out in collaboration with the divertor TG.

A. Leonard also stressed the importance of a tight dialog with the boundary researchers in order to determine the priorities and specifications for measurements. He also emphasised the need to maintain flexibility for future diagnostic development. He pointed out that the recent evolution in boundary research will certainly affect the diagnostic priorities. Two key examples are the measurement and control of ELMs, and the understanding and reduction of Tritium retention. Both examples are the subject of active current research and it is likely that the requirements for measurements, and relevant diagnostic techniques, will develop in the next few years. Leonard also pointed out that the main chamber is effectively part of the boundary and so a comprehensive coverage of the main chamber fluxes and sources is likely to be needed in the optimisation of divertor performance.

3.4. First Mirrors

Progress with the plasma facing mirrors for optical systems was reported by V. Voitsenya. A source of single crystal and stainless steel mirrors has been located. These mirrors are very resistant to erosion caused by sputtering and can be made in large sizes (up to 12 cm). Good results have also been reported for mirrors made from metallic coatings such as Mo and Rh.

However, deposition of divertor and wall material on diagnostic mirrors remains a potential problem and dedicated experiments, especially with mirrors mounted in the divertor region of existing machines, are required in order to build a database and to test models of the process. It was suggested to carry out experiments on plasma simulators where the conditions, and in particular the ion fluxes, can be well controlled. Moreover it should be possible to carry out such experiments on a relatively short time scale.

K. Vukolov presented the detailed plans for the proposed First Mirror R&D in the RF Home Team. The programme includes the development of manufacturing technologies of mirrors of various materials including Be, experimental investigation of surface erosion and co-deposition, and irradiation tests of mirrors with dielectric coatings with a γ-source.

3.5. Recommendations on High Priority Physics Research Areas

It was agreed that the above four topics should be maintained as high priority topics in the proposal to the ITPA CC. Furthermore, it was proposed that the development of diagnostic techniques for the measurement of confined and escaping alpha particles should be added to the list of high priority issues. Measurements of the alpha particles are judged to be essential in the evaluation of the performance of a BPX plasma but as yet there are no developed techniques although some promising approaches exist. A proposal for this addition will be made to the ITPA CC. **(Action item 01a087: Donné/Costley to develop a proposal for High, Medium and Long Term Priority Research Tasks for the coming year and submit it to the ITPA CC before the end of 2001).**

4. Progress with on-going activities

4.1. Reliability survey

A. Donn gave a brief presentation of the status of the International Database on the Reliability and Availability of Diagnostic Systems (IDD). Since the summer of 2001 the IDD has been accessible via the internet (www.rijnh.nl/IDD). A username and password is given to each group contributing to the database. Details on the specific diagnostics can be submitted via a special form. A call was made just before the summer to add more diagnostics to the database but only four new diagnostics have been added. The database now contains information on 93 diagnostics from 12 magnetic confinement devices. It was decided to contact again all groups working on magnetic confinement devices with the specific request to update the already available information (if necessary) and/or to include information on more diagnostics.

4.2. Recent developments in radiation effects R&D

The progress in the determination of radiation effects in candidate materials for diagnostic construction was reviewed by E. Hodgson. Progress has been made in a number of areas. A low loss quartz glass (KS-4V and KU-1) has been identified. The radiation induced loss is so low that it is possible to envisage the use of refractive optics in the vacuum vessel in some situations, thus simplifying considerably the optical designs. Fluoride glass, which might have some specific advantages, is also presently under experimental investigation.

For fibre optics, H_2-hardening leads to a factor of 10 improvement in terms of radiation-induced absorption (RIA). Since it is possible to make sharp bends with optical fibres and embed them in neutron shielding only the first 10 or 20 centimeters will probably be affected by RIA. Hence, application of fibers from the back of the port plugs seems to be possible.

Tests on some specific components are also in progress. Measurements on a JET type bolometer irradiated in the JMTR reactor in Japan have resulted in a problem with the electrical contacts to the bolometer. The problem is thought to be due to transmutation of the material of the meanders (Au was transmuted into Hg). More tests are planned with bolometers with a Pt meander and possibly also with a different substrate material instead of the presently employed mica, which is vulnerable to swelling. A prototype j×B magnetic field sensor showed a 7% non-linearity with the radiation field and a 30% sensitivity decrease following irradiation up to 2×10^{23} n/m^2.

Recent post-irradiation examination of samples that have been exposed to the HFIR reactor for Radiation Induced Electrical Degradation (RIED) indicate electrical degradation in some sapphire and alumina samples to levels similar to those observed in early electron and proton experiments, and in agreement with JA in-reactor results. While RIED is considered a potential problem for ITER only near the first wall, in the case of other BPX devices such as FIRE the effects may be more serious due to the higher radiation levels, and should be assessed.

Data on laser damage of window materials have indicated that thin layers of deposits onto the window will significantly reduce the damage threshold. Some of the contaminations may be removed by means of sub-threshold laser pulses, however, this is not possible for layers of stainless steel sputtered onto the window.

4.3. Progress with the action items and recommendations

Progress on action items of the previous EG Meetings is described at the appropriate place in these minutes and partly in the summary of the RF Progress meeting (see Attachment 7). All action items are listed in Attachment 8, along with a short statement on progress since the previous meeting (blue font). The various action items have a number xxayyy, where xx refers to the number of the meeting and yyy is a sequential numbering of the action items. Recommendations have a similar numbering xxryyy. All action items written in italic will be taken from future lists, since they are either completed or they are not longer considered to be relevant.

All new action items arising from this meeting are also given in the list with a number starting with 01a083.

4.4. Reports of the Specialists Working Groups

It was agreed that the charter of the five Specialists Working Groups (SWG) on Diagnostics should be updated to be in agreement with the ITPA framework. At the same time the TG members of the US party are invited to nominate US members to the SWG s. As soon as concensus on the charter and membership is reached, the groups will be officially relaunched. **(Action item 01a088: Donn / Costley to draft the charges for the Specialists Working**

Groups and relaunch the groups; Action item 01a089: US TG members to nominate members to the Specialists Working Groups).

The completion of the ITER EDA has meant that the radiation effects work no longer has a formal arrangement for coordinating its activities. It was suggested that a possible way to achieve the required coordination would be through a SWG working under the wing of the diagnostic ITPA group. The formation of the SWG under the wing of the ITPA TG would also have the benefit of enhancing the connection between the radiation effects work and the development of the diagnostic designs and wider diagnostic R&D. **(Action item 01a090: Donné/Costley to consider the establishment of a new SWG on Radiation Effects).**

4.4.1. Reflectometry Working Group (reported by J. Sanchez)

The Reflectometry Working Group reported on progress in a number of issues. In ASDEX-UG it has been demonstrated that sharp peaks occur in the density fluctuation level when rational q-surfaces are crossed during density ramp down experiments. No clear peaks were observed during density ramp up. The measurements indicate that under some conditions the reflectometric measurements might be used to give a constraint on the q-profile.

Much progress has been achieved in the field of plasma rotation measurements by means of reflectometry. The plasma rotation can be either measured directly by Doppler reflectometry (ASDEX-UG, W-7AS, TUMAN-3N) or by correlation measurements using two independent reflectometer systems at different poloidal angles (T-10). It is accepted now that reflectometry can be used to measure the rotation of the microturbulence. In most cases the microturbulence has been found to have the same rotation as the E×B rotation measured by means of CXRS. However, during transient changes in the plasma this is not necessarily the case.

In the report of the work of the Reflectometry SWG given at the last Expert Group meeting it was demonstrated that reflectometry can be used to track the position of the density layer near the separatrix. A new finding is that this measurement is insensitive to vertical displacements of the plasma column. Similar measurements have been achieved with the UCLA reflectometer system at DIII-D (see section 5.2.3).

The group is considering using 2D simulations to determine the spatial resolution of core density measurements using the lower cutoff frequency from the high field side. Routine operation and analysis of reflectometer data for density profile determination was reported for ASDEX-UG, T-10 and Tore Supra at the previous meeting. It is now also established at TJ-II. Finally a new configuration of divertor antennas (dual antenna system) has been approved for JET-EP and should provide improved measurements in the divertor region. Corrugated waveguides with quasi-optical bends will be used for broadband (< 140 GHz) operation.

4.4.2. Spectroscopy and NPA Working Group (reported by R. Giannella)

A point that arose during the 14th meeting of the ITER EG on Diagnostics was whether the quadratic Stark effect has to be explicitly taken into account in the interpretation of MSE measurements due to the higher magnetic fields and the increase in beam velocity. An extensive study has been carried out by Ph. Lotte (CEA Cadarache) with the following conclusion: for the Lorentz electric fields expected for ITER, the second order Stark term is a few percent of the first order term. The consequence for the MSE diagnostic, using the measure of the direction of the polarisation of the σ or π line, is only a shift of the different lines towards the higher wavelengths. Since no modification in the transition quantum rules occur, and no mixing of π and σ lines are expected either, *the conventional method can still be applied.* A possible effect could be a small diminution of the signal due to a slight decrease in the populations of the energy levels resulting from the atom ionisation, and a decrease of the signal to noise ratio due to the use of wider interference filters. The ionisation of the high energy level populations by the strong Lorentz electric field might also lead to some increased attenuation of the neutral beam. These two effects are expected to have a minor influence on the MSE diagnostic, but their quantitative assessment should be made and further analysis is needed. If it is necessary to implement the MSE diagnostic using intensity measurements, the Lorentz field can still be deduced from the Stark splitting measurement.

Another point addressed was the usefulness of modelling for the interpretation of spectroscopic data. This was demonstrated by a detailed comparison of carbon erosion measurements made with the visible endoscope in Tore Supra, and calculations made with the so-called BBQ 3D Monte Carlo code. Good agreement was obtained between measurement and model predictions for the carbon impurity flow. However, the model calculations for the brightness differ significantly from the measurements. The difference is attributed to geometric effects and to variations of T_e and n_e inside the emission region.

The sensitivity and signal-to-noise ratio of the ITER crystal X-ray spectrometer array have been studied by R. Barnsley. The conclusions of this work are that the main noise source will be due to the plasma continuum and not from background gamma radiation. A good signal-to-noise ratio is compatible with a temporal resolution of 10 – 30 ms with acceptable concentrations of krypton puffed into the discharge. Finally, it was concluded that a direct viewing fan array would be an order of magnitude more sensitive than a system employing a graphite reflector. Pilot tests have been proposed to use the JET high-resolution x-ray spectrometer to measure ion temperatures by analysis of spectra from injected heavy trace elements.

4.4.3. Neutron Working Group (reported by M. Sasao)

The report of the Neutron Working Group was fully devoted to the potential usefulness of the Magnetic Proton Recoil (MPR) Spectrometer on ITER. The NWG recommends that a high resolution neutron spectrometer is included on one channel of the radial neutron camera to provide a reference on the measurement of the line width for the determination of T_i, but the question as to which neutron spectrometer to use is still open. The MPR has been successfully used on JET where it has a very close coupling with the plasma. This coupling gives a high signal count despite the intrinsic low efficiency of the instrument. Other possible measurements with the MPR, for example the n_D/n_T ratio and the plasma rotation, were thought unlikely to be feasible on ITER although a detailed determination of the performance in this application is not available.

Another type of neutron energy spectrometer, the Time-of-Fight spectrometer, is a possible candidate. It has a higher efficiency but will require very effective shielding and may have a count rate limitation which is significant in this application. Compact spectrometers with high efficiency and good resolution (e.g. silicon diodes, diamond detectors or scintillator detectors (NE213)) would be ideal, but are not yet fully established.

After discussion, the TG meeting concluded that the proposal of the possible application of the MPR on ITER is thus far based mainly on the results that have been achieved on JET and not on the evaluated measurement capabilities at ITER. For that reason it is recommended to ask the proponent of the MPR (J. K llne) to perform a feasibility study of the MPR for ITER which includes predictions of the measurement performance that would be obtained with an achievable coupling to the plasma. (The ITER IT can advise on this and would be happy to contribute to this study). The performance predictions should be compared with the detailed measurement requirements and on that basis an informed decision can be taken as to whether to include the MPR in the selected set of instruments for ITER. **(Action item 01a091: Donn to ask the proponents of the MPR (K llne et al) to show the feasibility of implementing the MPR for ITER by comparing the calculated performance predictions with the target measurement requirements).**

After the presentation by the Neutron Working Group a discussion was initiated on the different neutron diagnostics that have been proposed for ITER and the need to prioritize and to consider the integration of these diagnostics for ITER. The prioritization and integration should specifically take account of the detailed measurement requirements of the various plasma parameters that will be measured by the neutron diagnostics **(Action item 01a092: Neutron WG to advise on the priorities and the integration of the various candidate neutron diagnostics for ITER).**

4.4.4. Thomson scattering Working Group (report by G. Razdobarin)

The designs of the ITER TS diagnostics for the core and edge plasma regions are reasonably advanced and, since the last EG meeting, the designs of the divertor and X-point systems have been further developed. Two of the systems (core and X-point) are based on the time-of-flight LIDAR technique while the other two systems are conventional systems relying on the imaging of a laser beam to provide the required high spatial resolution. The engineering description and performance analysis for the systems have been summarized in the ITER final report documentation.

Each of the systems is designed to provide an instrument capable of measuring the profiles of electron temperatures and relative profiles of electron density in the respective locations in pulses of 400s (reference) to 1000s (extended) and up to 3000s (steady state). Each LIDAR and each conventional system is arranged on the same principles. However, the geometrical constraints and the different requirement for the different regions have led to significantly different implementations. These were assessed in two-way interactions between the members of the Thomson Working Group and specialists outside. The assessment has shown that the performances of the core, X-point and edge systems have a reasonable margin but the performance of the divertor system has relatively little margin. The next step in the design will be to develop the outline engineering designs of the main front-end components.

4.4.5. First Mirror Working Group (reported by V. Voitsenya)

Summarizing the results of simulation experiments, it seems that, for situations where the dominant potentially damaging mechanism is erosion due to bombardment by energetic particles, the problem for the first mirrors (FMs) has been solved. This is likely to be the case for many FMs viewing the core plasma. The mirrors can be fabricated from monocrystalline metal (Mo or W), or as a metal film on metal substrate mirror (Rh is probably the best candidate) with the film thickness depending on the mirror location relative to the core plasma. However for mirrors located in ducts, deposit growth can occur and requires the development of a model in order to predict mirror lifetime. Three different experiments are needed to benchmark the models that have to be developed and are proposed by the FM Working Group:

First, experimental data on diffusion of impurities along a diagnostic duct is required. This can be obtained by means of a set of collector probes distributed along a duct, which can be closed by a shutter and is opened only during the working discharges. One to two collectors should be placed directly on the flange near the window in a large to medium-scale fusion device (i.e., TEXTOR, Tore Supra, JT-60U, D-IIID). The collectors need to have a size of ~1 cm^2 and will probably not hinder the main plasma experiments. Modern methods of surface analysis (after finishing the experimental campaign) can provide the measurements of the composition of contaminants, even in the case that the total integrated open time of the shutter is much less than the time of ITER operation. The data can be used as a basis for the development of a model for “diffusion” of impurities along a diagnostic duct and the subsequent deposition on the plasma facing first mirrors. It was suggested in the meeting that it would make sense to also perform specific measurements with a test duct mounted on present-day plasma simulators, because the fluxes and ion compositions can be better controlled in these devices.

Second, it is proposed to install mirror samples of different materials (SS, Cu, Mo, W), without any protection against the impact of conditioning discharges, on the vessel walls for a long period of time (between two machine openings). The aim is to check the estimations on the mirror survivability made on the ground of the simulation experiments already undertaken. Such an experiment could be conducted at present large-fusion devices (e.g. Tore Supra, JT-60, ASDEX, D-IIID) that do not operate with tritium. Mirrors made of monocrystalline Mo and mirrors with a thick Rh film are good candidates for such an experiment.

In general, the ions in the divertor have a much lower energy than those in the edge region in the main plasma and usually the energy is below the threshold for sputtering. Hence, the divertor first mirrors (DFMs) require different treatment. At the moment there is neither any experiment nor model that could be a base for solving the DFM problem. The only factor that has been analyzed to some degree in connection with divertor operation is the appearance of dust. Using data obtained on tokamaks with a divertor, one can state that the rate of deposit growth will depend on the position of the DFMs behind the slits, on the angle of inclination of the mirror surface to the gravity vector, the mirror temperature, etc. It will also be different for DFMs which observe plasma in the outer and inner divertor legs. Therefore, a special programme on environmental effects on DFM operation should be developed and realized, including experiments on large-scale fusion devices under operation as well as modeling calculations. Among all fusion devices under operation, JET is the most suitable for incorporating the special experiment concerning the DFM survivability during a long exposure time. The construction of the divertor in JET is rather close to that planned for ITER. Second, the material of the divertor plates is in many aspects similar to the material planned for ITER. Finally, no other divertor tokamak will have, in the foreseeable future, pulses with such a long pulse duration under the above mentioned conditions.

5. ITER relevant diagnostic developments in the Home Teams

5.1. Report on RF Progress Meeting

A summary on the RF Progress Meeting on BPX Relevant Diagnostic Developments is attached (Attachment 7). An overview of diagnostic developments in the RF, including the status of each diagnostic system, was presented by V. Zaveriaev.

5.2. Reports of BPX Diagnostic Developments in the other Parties

5.2.1. Japanese Party Report

An overview of the BPX/ITER relevant diagnostic activities that have been undertaken in Japan in the last few years was presented by T. Sugie. A few key topics were highlighted.

Details of the real-time feedback systems employed in JT-60U were presented. Progress has been made with the development of a feedback control algorithm on ∇T_e to sustain internal transport barriers (ITB s). The ITB s could be sustained in this way for more than 4 s. Moreover, a control loop for the suppression of Neoclassical Tearing Modes (NTM s) based on the detection of the magnetic island with ECE systems has been developed. The center of the magnetic island could be successfully determined and the complete feedback loop (using ECRH as the actuator) will be demonstrated in the near future.

There have been developments in a number of relevant JT-60U diagnostics. The feasibility and merits of the combined tangential CO_2 interferometer/polarimeter have been demonstrated on JT-60U. The system is suitable for long pulse operation and a high accuracy of 0.05° on the measurement of the Faraday rotation has been achieved. In the near future the system will be used for real-time control of the electron density.

Detailed spectroscopic measurements in the divertor have been performed at JT-60U with the aim to lead to a better understanding of physical processes in the divertor, including impurity generation mechanisms, chemical/physical sputtering, impurity transport, atomic/molecular processes, etc. Radial electric field measurements are done with two counter-injected neutral heating beams. The sensitivity in E_r is ±9 kV/m at a field of 4.05 T. This value is about 20% of the typical value of E_r expected in a ITB.

Mo and W mirrors have been exposed to particle irradiation. The damage to the mirrors depends sensitivily on the mirror fabrication technique. Mirrors that were surface heated to eliminate holes in the manufacturing process showed a stronger deterioration than mirrors that were not heated.

The in-situ transmittivity of KU-1 quartz was studied under 14 MeV neutron irradiation. Almost no reduction in transmittivity was observed for wavelengths > 350 nm. Significant losses were observed in the wavelength range 200 –300 nm, which could be attributed to two absorption peaks.

An overview of the irradiation tests in Japan, prepared by T. Nishitani, was also presented. The tests included KU-1 window material and optical fibres as well as prototype diagnostic assemblies, including bolometers, j×B sensors, window seals, optical fiber feedthroughs and an optical current meter. Part of these tests have already been presented in Section 3.1 and 4.2. V-shaped window seals that were tested under ^{60}Co gamma irradiation up to ~ 100 MGy did not suffer from any vacuum leaks due to subcritical crack growth. A multi-core optical fibre feedthrough suffered from a vacuum leak at the solvent between fibres and metal flange at an irradiation dose below 1 MGy, which implies that a more radiation hard feedthrough still needs to be developed. Finally, an optical-fibre current transformer has been tested but showed a strong deterioration in its sensitivity at a gamma ray irradiation as low as 1-2 kGy. The plan of the future radiation test was also presented.

M. Sasao reported on the progress in the field of imaging diagnostics for LHD (ECE-Imaging and Imaging Bolometry) and illustrated the recently achieved long pulse operation in LHD and the related development of digital integrators for magnetic probes. She also briefly reported on progress in the development of a number of other key diagnostic topics, including artificial diamond detectors, microfission chambers, position sensitive proton recoil telescopes and bubble detectors.

5.2.2. European Party Report

D. Campbell presented an overview of the EU activities in ITER diagnostic design and R&D that have been undertaken during 2000 — 2001 under the ITER credited arrangements. The designs of a number of systems have been further developed particularly magnetics, core LIDAR, edge Thomson scattering, polarimetry, radial and vertical neutron cameras, bolometry, active CXRS and the related Diagnostic Neutral Beam. Reports of some of the work have been completed, others are in preparation and should be completed by the end of the year. Credited R&D activities on windows, ceramics and radiation-hard bolometers and pressure gauges were also continued in 2001 and are expected to continue until the end of 2002. The EFDA Technology Work programme 2002 including diagnostic design activities is presently in the definition phase and so the detailed programme has not been finalised. A survey has been undertaken to identify the interest of the EU Associations in the design, development and construction of ITER diagnostics for the ITER construction phase. Considerable interest has been expressed.

An overview of the JET-EP diagnostics and the possible implications for ITER diagnostics was presented by J. Sanchez. Approval has been received to increase the NBI power with an additional 7.5 MW, to install a new ITER-like ELM-resilient ICRH antenna and to upgrade some of the existing diagnostics and install some new systems. The approved programme also includes some diagnostic developments: specifically, an extension of the heterodyne ECE systems and the installation of a new Michelson ECE interferometer, installation of a Li-beam and a He-doped beam, extension of the fast data acquisition system, upgrade of the CXRS system to yield also the edge poloidal rotation, installation of a high-resolution Thomson scattering system, and a new bolometer system. Other proposed developments (magnetics upgrade, TAE antennas, MPR upgrade and Li beam polarimetry) are awaiting a decision.

A number of direct ITER-relevant developments are planned and others are under consideration. A divertor mirror test duct (as described in Section 4.4.5) is presently in the design phase. A project has been launched to study T retention, erosion and dust deposition. This system will consist of quartz microbalances, sticking boxes, etc. Divertor reflectometry is under study, albeit with the constraint that only small changes would be possible to the present in-vessel waveguide and antenna system. A fast wave reflectometer for the measurement of the isotope ratio is under consideration, but more detailed information on such a system that has been proposed by the DIII-D team some years ago is still lacking. The application of bubble chambers and lost alpha detectors has been proposed and a decision depends on the definition of a possible DT campaign. Collective scattering below the electron cyclotron frequency has been proposed and is considered important. However, the budget and manpower requirements are considerable and implementation can only be contemplated if the 67.5 GHz heating option is adopted by the ECRH team. The budget for the receiver is available and the prospects for the system to operate during the full DT campaign are good. Other systems that have been approved are new quasi-optical antennas with corrugated waveguides for reflectometry as well as an IR viewing system that is very similar to the system proposed for ITER. Various developments in the field of real-time control algorithms, which are of relevance to ITER, have also been approved.

This programme will provide useful information for ITER diagnostics but so far the developments of novel ITER relevant systems, such as fast wave reflectometry, CTS below the cyclotron frequency, high resolution neutron spectrometry by ToF techniques, are not secured. These systems could potentially satisfy some unresolved measurements issues on ITER and so it is recommended that these developments are adopted. **(Recommendation 01r012: It is recommended that the ITER relevant systems that are candidate for implementation on JET – especially Fast Wave Reflectometry, CTS below the cyclotron frequency, and High Resolution Neutron Spectrometry by ToF - are implemented).**

5.2.3. US Party Report

Recent BPX relevant diagnostic developments in the US were presented by D. Johnson.

DIII-D is installing internal poloidal field probes for more effective stabilization of resistive wall modes, which are currently limiting β. Closed loop stabilization has been clearly achieved with external sensor probes in combination with external drive coils. Modeling indicates feedback effectiveness with new internal probes will improve and should enable ideal wall limits to be approached.

A UCLA reflectometer has been used on DIII-D to obtain accurate position information on the edge/SOL density profile. The position density contours from reflectometry correlate well with those determined from magnetics and EFIT. Fast dynamics of the edge motion in the EHO mode on DIII-D have also been correlated with Mirnov signals.

The details of the edge current profile are critical to the understanding and stabilization of AT plasmas. A team at GA will attempt to measure edge current profile by doing combined spectroscopy/polarimetry of Zeeman split lithium resonance line components from an injected lithium beam. This measurement is insensitive to large local electric fields. The diagnostic is currently in the commissioning stage with initial results expected early 2002. Presently the work is concentrated on the characterization of etalons and reduction of high voltage ripple in the beam line.

A very narrow bandwidth (.075 nm), high throughput (~5° field half angle) birefringent filter was developed to successfully isolate H_α motional Stark components in the NSTX MSE system, operating at a toroidal field <0.45T. Currently a custom optical system is installed with a vertically elongated aperture to reduce Doppler broadening due to the spread in the viewing angle.

Using a compact, 40 keV, low ripple DNB and a coaxial ring dye laser with a rotating polarization, tuned to Doppler shifted H_α, it is planned to view laser induced fluorescence at many points in the plasma. LIF from H_α fine structure has been observed by injecting into a vacuum.

At C-Mod a ‘cigar detector’ is employed to measure the angle of the plume from a lithium pellet injected at ~ 1 km/sec is studied. A high speed CCD camera with 4 μsec/frame (12 frames) is used. It was possible to obtain a full 12-point radial pitch angle profile with a single pellet. The accuracy is estimated to be ~ 0.2 degrees. Improvements in the accuracy are expected with shorter integration time. A fast CCD camera, developed by Princeton Scientific Instruments (PSI), has 64x64 pixels and can operate at 2 MHz frame rate. A 300 frame version is currently being tested at PSI.

Progress on measurements of edge turbulence has been made at various confinement devices. Probe measurements of intermittent convective bursts on DIII-D featuring higher pressure than the surrounding plasma and which move radially outward at a high velocity (several km/sec) are responsible for ~50% of the radial transport. The bursts are present in both L and H-mode plasmas but appear to have reduced amplitude in L-mode.

A compact, re-entrant optical system was used to allow a high speed CCD camera to view a helium gas puff at the outer midplane in NSTX and C-Mod, on a sightline parallel to the local field direction. In both machines, “blobs” were observed in the resulting high speed frames. On C-Mod, these blobs had a correlation length of ~ 1 cm in radial and poloidal directions. Using the same PSI camera as the one described for the “CIGAR” detector above, high speed (250000 frames/sec) movies were made, which indicated blob poloidal and radial motion with velocities of ~ 1 km/sec.

The US Department of Energy has initiated a solicitation for “Diagnostic Systems for Magnetic Fusion Devices” and it is expected that this will generate ideas for novel systems and diagnostic developments. Web-based lists of “Measurement Needs” are available to proposers. These lists were compiled by major projects and other organizations (C-Mod, DIII-D, NSTX, MTF,TTF). Approximately 40 proposals were received by the end of August. The proposals are confidential, although basic ideas, in many cases, have been presented in public meetings (Varenna, APS). It is expected that 6-10 can be funded, with grants typically for up to 3 years with amounts up to $400,000/year. Currently the proposals are being peer-reviewed and awards are expected to be announced around March, 2002.

6. Forthcoming Meetings of the TG on Diagnostics

It is proposed to hold the 2nd Meeting of the ITPA TG on Diagnostics in San Diego from 4 - 8 March 2002, immediately after the ITPA Co-ordinating Committee Meeting, that takes place on 1 – 2 March 2002. The present plan is to start the week with a joint session (together with some key members of the Divertor Topical Group) on the specific divertor diagnostic issues. This will be followed by a two-day meeting on US work in the field of BPX diagnostics including some initial preparations for the Snowmass meeting. The TG Meeting will follow on 7 and 8 March. **(Action item 01a093: Boivin to make provisions for the 2nd ITPA and related meetings (4 - 8 March, San Diego)).**

The location and venue of the 3rd Meeting of the Group was also briefly discussed. It is provisionally proposed to follow the established schedule and hold the meeting in Japan, possibly in Toki, in the autumn. Holding it in Toki would give us the opportunity to have a close coupling with Japanese University diagnosticians. **(Action item 01a094: Sasao to discuss with the LHD management the possibility of having the 3rd ITPA meeting in the autumn of 2002 in Toki, Japan).**

7. Miscellaneous

It was agreed to establish an internet website for the TG on Diagnostics, containing information such as minutes of previous meetings, presentations at the recent meetings, charter, membership and contact co-ordinates as well as information on the Specialists Working Groups (charter, membership), action items, etc. **(Action item 01a095: Donné to establish a website with a password protected area for the ITPA TG on Diagnostics that should be available by the end of 2001).**

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A. E. Costley, A.J.H. Donn
15 January 2002

Attachment 1

1st Meeting of the ITPA Topical Group on Diagnostics
St. Petersburg, Russia, November 14 – 16, 2001

AGENDA

Wednesday 14 November

10.00-12.00 Visit to the Ioffe Institute

12.10-13.30 *Lunch*

Introduction

13.30	Welcome Introduction of new members and guests, Local Arrangements, Discussion of agenda, Comments on minutes of 14th ITER EG Meeting	A. Donn
13.50	ITPA Update	D. Campbell

Overview of Present Status of Diagnostics for ITER and FIRE

14.15	Review of Present status of ITER and its Diagnostics	A. Costley
14.45	Developments in Diagnostic Implementation (ITER)	C. Walker
15.15	*Tea Break*	
15.35	FIRE and its Diagnostics: A Status Report	K. Young

General Topics

16.15	Status of the International Diagnostic Database	A. Donn
16.45	Developments in Radiation Effects R&D	E. Hodgson
17.30	Discussion	
18.00	*Adjourn*	

Thursday 15 November

Reports on Progress with High Priority Issues (e.g. RIEMF, First Mirrors, Divertor and Current Density Diagn.)

09.00	Developments with RIEMF	G. Vayakis
09.30	Developments with work on First Mirrors	V. Voitsenya
10.10	RF Plan of First Mirror R&D	K. Vukolov
10.20	*Coffee Break*	
10.40	Requirements for divertor measurements on ITER	G. Vayakis
11.20	Divertor Diagnostics	T. Leonard
12.00	Developments with work on the poloidal polarimeter for ITER	A. Donn
12.15	Developments with the ITER MSE system?	A. Malaquias
12.30	*Photo*	
12.35	*Lunch break*	

Reports on BPX/ITER Relevant Diagnostic Developments

13.45	Developments in the US	D. Johnson
14.15	Developments in Japan	T. Sugie M. Sasao
14.55	Developments in Europe	D. Campbell
15.10	Diagnostics for JET-EP	J. Sanchez
15.40	*Tea Break*	
16.00	Developments in Russia (brief since just had progress mttg)	V. Zaveriaev *et al.*

Progress and Plans for the Specialist Working Groups
Reports from Chairmen and agree next activities

16.15	Reflectometry group	J. Sanchez
16.40	Spectroscopy group	R. Giannella
17.05	Thomson Scattering	G. Razdobarin

17.30	Neutron Diagnostics	M. Sasao
17.55	First Mirrors	V. Voitsenya
18.15	*Adjourn*	

Friday 16 November

Review of Action Items

09.00	Various contributions connected to list of action items	Various contr.
10.15	*Coffee Break*	
10.35	Various contributions connected to list of action items	" "
11.00	**Closing Activities**	
	Forthcoming BPX diagnostic relevant meetings Date and Location of Second ITPA Meeting Selection of High Priority Issues for Coming Year Preparation and Agreement of Meeting Summary	A. Donné

Attachment 2

Attendees for 1st ITPA Topical Group Meeting on Diagnostics (St. Petersburg, RF, 14 – 16 November 2001)

Members of Topical Group on Diagnostics

Rejean Boivin (GA, USA)
Alan Costley (ITER Int. Team, EU)
Tony Donné (FOM, Netherlands, EU)
David Johnson (PPPL, USA)
Anatolij Kislyakov (Ioffe, RF)
Anatolij Krasilnikov (TRINITI, RF)
Francesco Orsitto (EFDA JET-CSU, EU)
Tony Peebles (UCLA, USA)
Mamiko Sasao (NIFS, JA)
Vyacheslav Strelkov (Kurchatov, RF)
Tatsuo Sugie (ITER Int. Team, JA)
Konstantin Vukolov (Kurchatov, RF)
Victor Zaveriaev (Kurchatov, RF)

Members of Topical Group that could not attend

Yoshinori Kusama (JAERI, JA)
George McKee (GA, USA)
Francesco Orsitto (EFDA JET-CSU, EU)
Fernando Serra (IST, Portugal, EU)
Glen Wurden (LANL, USA)

Guests and Attendees at the Expert Group Meeting

Sergey Bender (Efremov, RF)
Victor Bulanin (Ioffe, RF)
Oleg Buzhinski (TRINITI, RF)
David Campbell (EFDA-CSU, Garching, EU)
Igor Chugunov (Ioffe, RF)
Ruggero Giannella (CEA, France, EU)
Manfred von Hellermann (FOM, EU)
Eric Hodgson (CIEMAT, EU)
Boris Kuteev (Ioffe, RF)
Tony Leonard (GA, USA)
Alberto Loarte (ITER Int. Team, EU)
Boris Lyublin (Efremov, RF)
Artur Malaquias (ITER Int. Team, EU)
Alexander Medvedev (Kurchatov, RF)
Per Nielsen (RFX, Italy, EU)
Alexei Petrov (TRINITI, RF)
Gennady Razdobarin (Ioffe, RF)
Joaquin Sánchez (CIEMAT, EU)
Alexander Shevelev (Ioffe, RF)
Leonid Shmaenok (Phystex, Netherlands, EU)
Sergei Tugarinov (TRINITI, RF)
George Vayakis (ITER Int. Team, EU)
Vladimir Voitsenya (KPTI, Ukraine via RF)
Chris Walker (ITER Int. Team, EU)
Ken Young (PPPL, USA)

Attachment 3

OBJECTIVES OF THE ITPA TOPICAL GROUP ON DIAGNOSTICS

Within the International Tokamak Physics Activity (ITPA) the Topical Group on Diagnostics will aim to identify and resolve the key diagnostic issues that might arise both in plasma control and in the analysis of burning plasma experiments (BPXs). The main tasks undertaken will be as follows:

1. Identify, in close contact with the other ITPA Topical Groups, specific measurement requirements for the control, evaluation and understanding of burning plasma experiments (BPXs).

2. Identify research and development needs in the area of BPX diagnostics and propose relevant research programmes.

3. Advise on the selection of diagnostic techniques for BPXs, on the design of the diagnostic systems, and on their implementation on BPXs, including integration with other components.

4. Develop and maintain the International Diagnostics Database (IDD) and stimulate diagnosticians in the participating countries to contribute to the IDD and evaluate its contents.

5. Facilitate good communication within the area of diagnostics and specifically on BPX diagnostic issues between diagnostic specialists in the participating countries; report on the BPX diagnostic development work on-going in the participating countries and encourage co-ordination and joint developments.

6. Anticipate future diagnostic programmes and innovations and advise what steps should be taken so that the designs of BPXs do not preclude these opportunities.

7. Propose testing of prototype diagnostic systems and components on present operating confinement devices and facilitate implementation.

8. To aid the progress in some specific diagnostics areas, the Topical Group can establish Specialists Working Groups consisting of up to 3-5 scientists per party nominated by each. The Specialists Working Groups will communicate by electronic means and will not require travel to any dedicated meetings (although opportunities should be taken to meet at conferences etc). The chair and co-chair of the Topical Group will appoint the chair and co-chair of the Specialists Working Group.

9. Report on all activities to the ITPA Co-ordinating Committee as required.

Attachment 4
Target Measurement Specification (ITER-FEAT)
(as published in the Final Design Report)

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	RESOLUTION Time or Freq.	RESOLUTION Spatial or Wave No.	ACCURACY
1. Plasma Current	I_p	Default	0 – 1 MA	1 ms	Integral	10 kA
			1 – 17.5 MA	1 ms	Integral	1 %
		I_p Quench	20 – 0 MA	0.1 ms	Integral	30 % + 10 kA
2. Plasma Position and Shape	Main plasma gaps, Δ_{sep}	I_p > 2 MA, full bore	-	10 ms	-	1 cm
		I_p Quench	-	10 ms	-	2 cm
	Divertor channel location (r dir.)	Default	-	10 ms	-	1 cm
		I_p Quench	-	10 ms	-	2 cm
	dZ/dt of current centroid	Default	0 – 5 m/s	1 ms	-	0.05 m/s (noise) + TBD % (absolute)
3. Loop Voltage	V_{loop}	Default	0 – 30 V	1 ms	4 locations	5 mV
		I_p Quench	0 – 500 V	1 ms	4 locations	10 % + 5 mV
4. Plasma Energy	β_p	Default	0.01 – 3	1 ms	Integral	5 % at β_p=1
		I_p Quench	0.01 – 3	1 ms	Integral	~ 30%
5. Radiated Power	Main Plasma P_{rad}	Default	TBD – 0.3 GW	10 ms	Integral	10 %
	X-point / MARFE region P_{rad}	Default	TBD – 0.3 GW	10 ms	Integral	10 %
	Divertor P_{rad}	Default	TBD – 0.3 GW	10 ms	Integral	10 %
	Total P_{rad}	Disruption	TBD – 50 GW	3 ms	Integral	20 %
6. Line-Averaged Electron Density	$\int n_e\,dl / \int dl$	Default	$1\cdot10^{18} - 4\cdot10^{20}$ /m³	1 ms	Integral	1 %
		After killer pellet	$8\cdot10^{20} - 2\cdot10^{22}$ /m³	1 ms	Integral	100 %
7. Neutron Flux and Emissivity	Total neutron flux		$1\cdot10^{14} - 5\cdot10^{20}$ n/s	1 ms	Integral	10 %
	Neutron / α source		$1\cdot10^{14} - 4\cdot10^{18}$ n/m³/s	1 ms	a/10	10 %
	Fusion power		TBD – 1 GW	1 ms	Integral	10 %
	Fusion power density		TBD – 10 MW/m³	1 ms	a/10	10 %
8. Locked Modes	Br(mode)/Bp		$10^{-4} - 10^{-2}$	1 ms	(m,n) = (2,1)	30 %
9. Low (m,n) MHD Modes, Sawteeth, Disruption Precursors	Mode complex amplitude at wall		TBD	DC – 3 kHz	(0,0) < (m,n) < (10,2)	10 %
	Mode – induced temperature fluctuation		TBD	DC – 3 kHz	(0,0) < (m,n) < (10,2) Δr = a /30	10 %
	Other mode parameters TBD					
10. Plasma Rotation	VTOR		1 – 200 km/s	10 ms	a/30	30 %
	VPOL		1 – 50 km/s	10 ms	a/30	30 %
11. Fuel Ratio in Plasma Core	nT/nD	r/a < 0.9	0.1 – 10	100 ms	a /10	20 %

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	RESOLUTION		ACCURACY
12. Impurity Species Monitoring	Be, C rel. conc.		$1 \cdot 10^{-4} – 5 \cdot 10^{-2}$	10 ms	Integral	10 % (rel.)
	Be, C influx		$4 \cdot 10^{16} – 2 \cdot 10^{19}$ /s	10 ms	Integral	10 % (rel.)
	Cu rel. conc.		$1 \cdot 10^{-5} – 5 \cdot 10^{-3}$	10 ms	Integral	10 % (rel.)
	Cu influx		$4 \cdot 10^{15} – 2 \cdot 10^{18}$ /s	10 ms	Integral	10 % (rel.)
	W rel. conc.		$1 \cdot 10^{-6} – 5 \cdot 10^{-4}$	10 ms	Integral	10 % (rel.)
	W influx		$4 \cdot 10^{14} – 2 \cdot 10^{17}$ /s	10 ms	Integral	10 % (rel.)
	Extrinsic(Ne,Ar, Kr) rel. conc.		$1 \cdot 10^{-4} – 2 \cdot 10^{-2}$	10 ms	Integral	10 % (rel.)
	Extrinsic (Ne, Ar, Kr) influx		$4 \cdot 10^{16} – 8 \cdot 10^{18}$ /s	10 ms	Integral	10 % (rel.)
13. Zeff(Line-averaged)	Zeff		1 – 5	10 ms	Integral	20 %
14. H-mode: ELMs and L-H Transition Indicator	ELM D_α bursts	Main Plasma	–	0.1 ms	One site	–
	ELM density transient	r/a > 0.9	TBD	TBD	TBD	TBD
	ELM temperature transient	r/a > 0.9	TBD	TBD	TBD	TBD
	L-H D_α step	Main Plasma		0.1 ms	One site	–
	L-H Pedestal formation (ne, Te)	r/a > 0.9	–	0.1 ms	–	TBD
15. Runaway Electrons	E_{max}		1 – 100 MeV	10 ms	–	20 %
	$I_{runaway}$	After Thermal quench	(0.05 – 0.7) $\cdot I_p$	10 ms		30 % rel
16. Divertor Operational Parameters	Max. surface temperature		200 – 2500°C	2 ms	–	10 %
	Real-time net erosion		0 – 3 mm	1 s	1 cm	10 %
	Gas pressure		$1 \cdot 10^{-4}$ – 20 Pa	50 ms	Several points	20 % during pulse
	Gas composition	A = 1-100 ΔA = 0.5	TBD	1 s	Several points	20 % during pulse
	Position of the ionisation front		0 – TBD m	1 ms	10 cm	–
17. First Wall (FW) Visible Image & Wall Temperature	FW image		TBD	100 ms	TBD	–
	FW surface temperature		200 – 1500°C	10 ms	TBD	20°C
18. Gas Pressure and Composition in Main Chamber	Gas pressure		$1 \cdot 10^{-4}$ – 20 Pa	1 s	Several points	20 % during pulse
	Gas composition	A = 1-100 ΔA = 0.5	TBD	10 s	Several points	50 % during pulse
19. Gas Pressure and Gas Composition in Ducts	Gas pressure		< 7 kPa	100 ms	Several points	20 % during pulse
	Gas composition	A = 1-100 ΔA = 0.5	TBD	1 s	Several points	20 % during pulse
20. In-Vessel Inspection	Wall image		100 % coverage of FW and divertor	–	1 mm	
21. Halo Currents	Poloidal current	In disruption	0 – 0.2 I_p	1 ms	9 sectors	20 %
22. Toroidal Magnetic Field	B_T		2 – 5.5 T	1 s	2 locations x 2 methods	0.1 %
23. Electron Temperature Profile	Core T_e	r/a < 0.9	0.5 – 30 keV	10 ms	a/30	10 %
	Edge T_e	r/a > 0.9	0.05 – 10 keV	10 ms	0.5 cm	10 %

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	RESOLUTION		ACCURACY
24. Electron Density Profile	Core N_e	r/a < 0.9	$3{\cdot}10^{19} – 3{\cdot}10^{20}$ /m^3	10 ms	a/30	5 %
	Edge N_e	r/a > 0.9	$5{\cdot}10^{18} – 3{\cdot}10^{20}$ /m^3	10 ms	0.5 cm	5 %
25. Current Profile	q(r)	Physics study	0.5 - 5	10 ms	a/20	10 %
			5 – TBD	10 ms	a/20	0.5
	r(q=1.5,2)/a	NTM feed-back	0.3 – 0.9	10 ms	–	5 cm / a
	r(q_{min})/a	Reverse shear control	0.3 – 0.7	1 s	–	5 cm / a
26. Zeff Profile	Z_{eff}	Default	1-5	100 ms	a/10	10 %
		Transients	1-5	10 ms	a/10	20 %
27. High Frequency Macro Instabilities (Fishbones, TAEs)	Fishbone–induced perturbations in B,T,n		TBD	0.1 –10 kHz	(m,n) =(1,1)	–
	TAE mode – induced pertur-bations in B,T,n		TBD	30 –300 kHz	n = 10 - 50	–
28. Ion Temperature Profile	Core T_i	r/a < 0.9	0.5 – 50 keV	100 ms	a/10	10 %
	Edge T_i	r/a > 0.9	0.05 – 10 keV	100 ms	TBD	10 %
29. Core He Density	n_{He}/n_e	r/a < 0.9	1 – 20 %	100 ms	a/10	10 %
30. Confined Alphas	Energy spectrum	Energy resolu-tion TBD	(0.1 – 3.5) MeV	100 ms	a/10	20 %
	Density Profile		(0.1 – 2) $10^{18}/m^3$	100 ms	a/10	20 %
31. Escaping Alphas	First wall flux	Default	TBD – 2 MW/m^3	100 ms	a/10 (along poloidal direction)	10 %
		Transients	TBD – 20 MW/m^3	10 ms	TBD	30 %
32. Impurity Density Profile	Fractional con-tent, Z<=10	r/a < 0.9	0.5 – 20 %	100 ms	a/10	20 %
		r/a > 0.9	0.5 – 20 %	100 ms	5 cm	20 %
	Fractional con-tent, Z>10	r/a < 0.9	0.01 – 0.3 %	100 ms	a/10	20 %
		r/a > 0.9	0.01 – 0.3 %	100 ms	5 cm	20 %
33. Fuel Ratio in the Edge	n_T/n_D	r/a > 0.9	0.1 – 10	100 ms	Radial inte-gral	20 %
	n_H/n_D	r/a > 0.9	0.01 – 0.1	100 ms	Radial inte-gral	20 %
34. Neutron Fluence	First wall fluence		0.1 – 1 MWy / m^2	10 s	TBD	10 %
35. Impurity and D,T Influx in Divertor	Γ_{Be}, Γ_C, Γ_W		$10^{17} – 10^{22}$ at/s	1 ms	5 cm	30 %
	Γ_D, Γ_T		$10^{19} – 10^{25}$ at/s	1 ms	5 cm	30 %
36. Plasma Parameters at the Divertor Targets	Ion flux		$10^{19} – 10^{25}$ ions/s	1 ms	0.3 cm	30 %
	n_e		$10^{18} – 10^{22}$ /m^3	1 ms	0.3 cm	30 %
	T_e		1 eV – 1 keV	1 ms	0.3 cm	30 %
37. Radiation Profile	Main plasma P_{rad}		0.01 – 1 MW/m^3	10 ms	a/15	20 %
	X-point/MARFE region P_{rad}		TBD – 300 MW/m^3	10 ms	a/15	20 %
	Divertor P_{rad}		TBD – 100 MW/m^3	10 ms	5 cm	30 %
38. Heat Loading Profile in Divertor	Surface tem-perature		200 – 2500°C	2 ms	3 mm	10 %
	Power load	Default	TBD – 25 MW/m^2	2 ms	3 mm	10 %
		Disruption	TBD – 5 GW/m^2	0.1 ms	TBD	20 %

MEASUREMENT	**PARAMETER**	**CONDITION**	**RANGE or COVERAGE**	**RESOLUTION**		**ACCURACY**
39. Divertor Helium Density	n_{He}		$10^{17} – 10^{21}$ /m^3	1 ms	–	20 %
40. Fuel Ratio in the Divertor	n_T/n_D		0.1 – 10	100 ms	integral	20 %
	n_H/n_D		0.01 – 0.1	100 ms	integral	20 %
41. Divertor Electron Parameters	n_e		$10^{19} – 10^{22}$ /m^3	1 ms	10 cm along leg, 3 mm across leg	20 %
	T_e		0.3 –200 eV	1 ms	10 cm along leg, 3 mm across leg	20 %
42. Ion Temperature in Divertor	T_i		0.3 –200 eV	1 ms	10 cm along leg, 3 mm across leg	20 %
43. Divertor Plasma Flow	V_p		TBD – 10^5 m/s	1 ms	10 cm along leg, 3 mm across leg	20 %
44. nH/nD Ratio in Plasma Core	n_H/n_D		0.01 – 0.1	100 ms	a/10	20 %
45. Neutral Density between Plasma and First Wall	D/T influx in main chamber		$10^{18} – 10^{20}$ at/m^2/s	100 ms	Several poloidal and toroidal locations	30 %

Attachment 5
High Priority Physics Research Areas 2000 - 2001

	Research Areas	Issues
*	Finite-β effects in H-mode	Tolerable ELMs (δW/W<2%) with good confinement alternate to type-I ELMs (e.g. type II, Type III+core confinement) Stabilisation of neoclassical islands at high β and recovery of β
*	Plasma termination and halo currents	Runaway electron currents: production and quenching, e.g. at low safety factor
*	Sol and divertor	Achievement of high n_{sep} and relation of $n_{sep}/\langle n_e \rangle$ in ELMy H-modes, especially at high n and δ Carbon Chemical sputtering, redeposition and deuterium retention/cleaning methods
*	Core confinement	Non dimensional scaling and identity experiments; effect of finite β and flow shear Determine dependence of τ_E upon shaping, density peaking etc.
*	H-mode power threshold	H-mode accessibility in ITER-FEAT , Data scatter
*	Good H-mode confinement at high n	Confinement degradation onset density; its dependence on aspect ratio, shape and neutral source
*	Pedestal physics	Scaling of pedestal properties and ELMs Effects of plasma shape on pedestal and ELMs MHD stability analysis of transport barrier
	Internal transport barrier properties	ITB power thresholds vs n, B, q, Te/Ti, Vrotation etc. for strong reversed shear (q_{min}>3), moderate reversed shear(q_{min}>2, and weak shear (q_{min}>1). Compatibility with impurity exhaust and divertor Accessiblity of ITBs in reactor scale devices at low toroidal rotation, Ti/Te ˜ 1, and flat density profile, etc.
	Resistive Wall Mode	RWM analysis and experimental verification
	Heating/CD, Steady State	Development of steady state scenarios :active current and pressure control Active control of LHCD coupling Assess fast particle effects (EPMs and ITBs)
	Diagnostics	**Continue assessment of possible methods for measurement of q(r) and search for new approaches** **Continue study of First Mirrors especially effects of deposition and possible mitigating methods** **Assess impact of RIEMF on magnetic measurements and perform improved measurements on prototype coils** **Complete determination of measurement requirements for divertor target and divertor plasma parameters (in collaboration with the Div Expert Group), and complete assessment of the probable performance of proposed diagnostic methods**
* : relevant to main scenario of ITER (ELMy H)		

Attachment 6

Proposed Revised Requirements for Divertor Measurements in ITER

Changes with respect to the FDR (see Attachment 4) are indicated in red.

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	RESOLUTION		ACCURACY
				Time or Freq.	Spatial or Wave No.	
16. Divertor Operational Parameters	Max. surface temperature		200 – 2500°C	2 ms	–	10 %
	Erosion rate		1 - 10 µm/s	2 s	1 cm	30 %
	Net erosion		0 – 3 mm	Per pulse	1 cm	12 µm
	Gas pressure		$1 \cdot 10^{-4}$ – 20 Pa	50 ms	Several points	20 % during pulse
	Gas composition	A = 1-100 ΔA = 0.5	TBD	1 s	Several points	20 % during pulse
	Position of the ionisation front		0 – TBD m	1 ms	10 cm	–
38. Heat Loading Profile in Divertor	Surface temperature		200 – 1000°C	2 ms	3 mm	10 %
			1000 – 2500°C	20 µs	3 mm	10%
	Power load	Default	TBD – 25 MW/m^2	2 ms	3 mm	10 %
		Disruption	TBD – 5 GW/m^2	0.1 ms	TBD	20 %
41. Divertor Electron Parameters	n_e		$10^{19} – 10^{22}$ $/m^3$	1 ms	5 cm along leg, 3 mm across leg	20 %
	T_e		0.3 –200 eV	1 ms	5 cm along leg, 3 mm across leg	20 %
42. Ion Temperature in Divertor	T_i		0.3 –200 eV	1 ms	5 cm along leg, 3 mm across leg	20 %

Attachment 7

Progress Meeting on BPX Relevant Diagnostic Work on-going in the Russian Federation Ioffe Institute, St. Petersburg, 12 - 13 November 2001

Prepared by A E Costley

1) The interfaces for Thomson scattering diagnostics in the divertor and SOL near the X-point plasmas of ITER-FEAT — *G.Razdobarin*

- Designs for the implementation of the divertor TS and LIDAR X-point systems have been developed including the design of the appropriate interfaces.
- For the divertor TS system, proposals to cope with the potential problem of dust have been developed. It is proposed to use a gas over pressure of about 10 Pa in the vicinity of the in-vessel optical components as a means to prevent dust accumulation. The gas over pressure would be provided with a dedicated line. Additional measures using baffles and/or thin transparent shields are also contemplated.
- Modifications to a divertor cassette (or to two adjacent cassettes) to provide the line of sight necessary for the LIDAR X-point system are proposed.
- The expected performance of both systems is close to meeting the requirements but the margins are not large especially for the divertor TS system.

2) Diagnostics of the reactive dust accumulation on PFC in burning devices — *G.Razdobarin*

- Laser-induced breakdown spectroscopy (LIBS) is proposed as a means to determine the composition and quantity of dust at specific locations. By scanning the laser beam and collection optics a limited survey can be made.
- Proof-of-principle experiments have been conducted.
- Although promising the technique represents only a first step towards the development of a methodology to determine the in-situ the quanity of dust on the PRC during operation
- The remaining areas of R&D have been identified and conceptual design guidelines have been developed which will meet the space, safety and inspection requirements.

3) Progress in CXRS diagnostics development and design for ITER-FEAT — *S.Tugarinov*

- The potential performance of the CXRS diagnostic based on the planned DNB has been calculated using a code that, it is believed, includes all relevant effects.
- Optical schemes for implementing the diagnostic on ITER have been developed. Using these schemes, it is predicted that He ash measurements will be possible into r/a = 0.3 for relevant plasma conditions.
- The possibility of using LIF techniques to improve the s/n has been investigated. No significant improvement is expected because of the low duty cycle (short laser pules, long time between pulses) of available lasers.

4) State of work on H Alpha spectroscopy for main plasma *A.Medvedev*

- The design and integration of the H-alpha spectroscopic system has been further developed including the design of the first mirror assembly.
- The proposed arrangement consists of four independent conceptually identically optical systems installed in the upper and equatorial ports. The poloidal viewing angle of each system is significantly more than the toroidal viewing angle.
- The four systems cover the entire first wall in one poloidal cross section with the exception of the divertor region.
- The divertor region will be covered with the Divertor Impurity Monitor system.

5) Gamma Ray spectrometry system design for ITER plasma diagnostics *A.Shevelev*

- The prospects for gamma ray spectrometry on ITER have been further developed. It is shown that, in principle, the technique can provide information on several important plasma parameters including the effective temperature of fast ion components, the fuel mix ratio and the confined alpha particles.
- It is proposed to install dedicated detectors in the Radial and Vertical Neutron Cameras.
- Gamma cells have been developed and tested in conditions of high neutron and gamma background rates. Passive (LiH) and active filters are incorporated in the cells to reduce the signals arising from neutrons.
- There are gaps in the neutron reaction database which need to be filled for full exploitation of this technique.

6) Progress in NDD based compact DT neutron and fast atom spectrometers and flux monitors development application and design for BPX *A.Krasilnikov*

- It is proposed to use NDDs as neutron flux monitors and spectrometers on ITER. Due to their small size they can be installed inside the collimators of the radial and vertical neutron cameras. An enlargement in the aperture of the collimators is requested.
- The predicted performance meets many of the ITER measurement requirements.
- As a neutron flux monitor the lifetime would be ~6000 full power plasma pulses and as a spectrometer it would be 300 — 500 pulses.
- The performance can be recovered using annealing techniques and these are under development.
- It is also proposed to use NDDs to measure fast neutrals escaping along a tangential line of sight which have charge exchanged on fast ions in the plasma and thereby obtain information on fast ion distributions. A stripping foil and analysing electrostatic mirror would be used to prevent direct view of the NDD of the plasma in order to reduce the signal due to neutron and gamma rays. Studies of toroidal Alfv n eigen mode activity and MHD instabilities would, in principle, be possible.
- The ultra-fast electronics necessary to operate the NDDs is under development.

7) Progress in development and design of the neutron flux monitoring systems for BPX *A.Krasilnikov*

- It is proposed to use the commercially available Russian fission chamber, KNU-3, as the ex-vessel neutron flux monitor. The detector has three independent sensors, with different sensitivities to thermal neutrons. Radiation tests have been performed and show that the detector has a linear response over a wide neutron flux range. To extend the dynamic range it is proposed to surround the detector with a hydrogen moderator.
- The design of the ^{238}U threshold microfission chamber has been advanced. To increase the sensitivity it is proposed to increase the amount of fissile material (up to about 2 gm). It is

proposed to use a blank sensor to compensate for stray signals due to electromagnetic and/or radiation noise.

- Work on a compact neutron generator for calibration purposes continues.
- A 1D model has been developed to analyse the performance of the proposed gas jet activation system. The sensitivity and temporal resolution have been determined.
- Development of the organic scintillator stilbene neutron detector/spectrometer continues. Successful results have been obtained on Tore Supra. In application on ITER it is predicted that the stilbene detector would provide neutron flux measurements with a time resolution of 10ms and measurements of T_i in DD plasmas for $T_i > 4$ keV and time resolution of 100 ms.

8) The nowaday view on the problem of the first mirrors for burning plasma *V.Voitsenya*

- The results obtained in experimental investigations of various first mirror candidates including polycrystalline metal mirrors, single crystal metal mirrors and thin film metal coatings on metal substrates, are reviewed. Guidelines have been established for their application.
- The prospects of using Be as a first mirror material are considered.
- It is pointed out that deposition remains the primary remaining unresolved problem for diagnostic first mirrors. A model which treats comprehensively the three processes of erosion, transportation and re-deposition is required.
- Mitigating methods including the use of baffles, discharge cleaning and laser ablation cleaning are under consideration.

9) Laser damage of First Mirror prototypes *A.Gorshkov*

- The possible effect on the lifetime of diagnostic mirrors due to multiple pulses of high power laser radiation is investigated. The laser power density was typically about 50% of the single pulse damage threshold.
- For stainless steel mirrors (SS316) a significant reduction in the reflectivity was found to occur after about 1000 pulses. On the other hand, Mo/SS and Rh/SS did not degrade even after being exposed to 4000 laser pulses.
- A programme for further investigations including examining the effects of laser rep rate, spatial gradients of laser power, and mirror fabrication method is proposed.

10) Status of irradiation tests on window materials and future plans *K.Vukolov*

- The results obtained in irradiation tests of the candidate window materials, quartz glass KS-4V and KU-1, were reviewed. The results show that high transmission is maintained for $\lambda >$ 320 nm (KS-4V) and > 350 nm (KU-1) after irradiation up to a neutron fluence of 10^{16} n/cm^2. The absorption is less at elevated temperatures. In the visible an absorption band is observed which may reduce the transparency of a typical window by 5%.
- Initial results on the effects of radiation on the optical properties of fluoride glasses were presented. Unirradiated these glasses have a very wide transparency range (typically 0.2 — 6 μm). The transmission in the visible region is reduced by irradiation but at $\lambda > 1.5$ μm there is almost no effect.
- A programme for further investigations has been developed.

<u>11) Photoluminescence Induced in Pre-Irradiated Optical Materials under UV Radiation</u> *I.Moskalenko*

- The photoluminescence in the visible region of pre-irradiate sample candidate window materials (KS-4V and KU-1) have been measured. A tunable laser operating in the range 245 — 800 nm was used to supply the exciting radiation.
- Significant levels of photoluminescence were measured. However, the pre-irradiated levels were rather high especially the neutron radiation levels, typically corresponding to an order of magnitude higher than the levels that a window would receive after one full year of DT operation. Also, in practice, most diagnostic windows will not be exposed to UV radiation because this radiation will not be transmitted along the diagnostic labyrinths.
- A programme of further work is planned and will address some of these issues.

<u>12) Results of the Russian part of the round robin in-situ reactor test of the optical fiber radiation resistance</u> *S.Tugarinov*

- In-situ measurement of the radiation induced absorption and luminescence of candidate optical fibres have been made in the Russian Federation test reactor IR8. These tests form part of the EU/A/RF round robin tests on optical fibres.
- Detailed results are obtained and show that the optimum fibre to be used in any particular application will depend on the environmental conditions and the wavelength range of the interest. The results contribute to the established data base of fibre performance which can be used by diagnostic designers.
- The results obtained so far have been obtained with fibres protected by a polymer jacket and at temperatures in the range 26 - 50ßC. Future investigations should also examine fibres mounted in metal jackets and be carried out at higher temperatures (150 — 200ßC). These conditions could be more relevant for some fibre applications in ITER.

<u>13) Modeling experiments on ion temperatures using LIF technique in ITER divertor on PNX-U machine</u> *I.Moskalenko*

- LIF is a technique under consideration for providing measurements of the He density, the density of extrinsic impurities (eg Ne, Ar, Kr), and the ion temperature in the divertor.
- An experimental demonstration of the technique has been undertaken on the linear laboratory device PNX-U at the Kurchatov Institute. Measurements of the mean ion energy of Ar^{1+} in the range 4 — 25eV were made.
- On the basis of the results predictions of the possible performance of the technique on ITER are made.
- Further experimental tests are planned.

<u>14) Development of Vacuum Photo Detectors for SXR measurements in BPX</u> *M.Stepanenko*

- VPDs can potentially provide measurements of the soft X-ray emission in ITER. By making measurement along multiple lines of sight the internal structure of the plasma can be determined by tomographic analysis.
- A potential problem with VPDs is the signal due to the gamma background.
- It is shown that by using multiple plate detectors a ratio of bremsstrahlung/background of 15/1 can be obtained for measurements in the central core region, and 1/1 for the periphery.
- However, the multiple plate detectors are probably too large to be accommodated in the gaps between the blanket modules and so probably it will only be possible to install these detectors in the port plugs.

15) Progress in NPA development *S.Kozlovskij*

- The design of the high energy NPA (0.1 — 3.6) MeV has been further developed using a new code which models in 3D the electric and magnetic fields.
- The new code allows optimisation of key instrument parameters such as the shape and magnitude of the magnetic field.
- Improvements relative to the earlier GEMMA NPA are reduced overall dimensions, increased energy range, increased He^o detection efficiency and reduced n-γ sensitivity.

16) Determination of hydrogen neutral density profile in ITER-FEAT from radial distribution of He+ ions *A.Kislyakov*

- The profile of the hydrogen neutral density can be important in the interpretation of CX measurements and in the ionization balance of impurity ions and related problems.
- A method for determining the profile of the neutral hydrogen density from the measured profile of He^+ ions is proposed. The method requires a knowledge of the profiles of T_i, T_e and n_e.
- The method can be tested on existing machines.
- Further development of the method taking into account inward transport of He ions is needed.

17) Spectroscopic measurement of He+ radial distribution in ITER-FEAT *L.Shmaenok*

- A new spectroscopic method to measure the radial distribution of H+ ions is proposed.
- The method involves the reconstruction of the He II, λ = 30.4 nm emissivity distribution and requires high resolution measurements in the line wing.
- Potentially complicating effects such as plasma rotation and variations in the bremsstrahlung background need to be taken into account.

18) Development of Pellet Charge Exchange (PCX) -diagnostics for BPX. *B.Kuteev*

- The merits of pellet charge exchange diagnostics (PCX) are reviewed and the possible application on ITER considered.
- The flux of CX neutrals would be higher than in the case of passive measurements leading to higher s/n and the measurement would be performed in a short time interval.
- The interpretation of the measurement requires a detailed knowledge of the pellet cloud.
- Complications can arise from the presence of fast ions due to ICRH and NBI and these have been considered. Potentially, complications can also arise from non-Maxwellian electrons produced by ECRH. These have not yet been considered.

19) The prospects of Doppler reflectometry diagnostics in plasma burning devices *V.Bulanin*

- Doppler reflectometry is considered as a technique for measuring the rotation of density fluctuations. The technique selects fluctuations with a specific k value determined by the angle between the launch and receive beams.
- A 2D code for simulating the measurement has been developed.
- Measurements on Tuman-3M have been made and successful results obtained.
- Preliminary predictions for the possible performance of a Doppler reflectometer on ITER have been made.
- The steps for further development of the technique are outlined.

20) Time-of-flight refractometry for robust line integral electron density measurements and control in BPX *A.Petrov*

- The main principles of Time-of-Flight Refractometry (TFR) are presented. In this technique theplasma is probed at a fequency just above the plasma frequency and the round trip delay time measured. It is shown that the delay time is proprotional to the line integrated electron density and inversely proportional to the square of the frequency.
- Successful demonstration measurements have been made on T11.
- For application on ITER a probing frequency in the range 100 — 120 GHz would be appropriate.
- By using multiple frequencies the dynamic range of the measurement can be increased.
- By using multiple lines of sight it may be possible to obtain information that could be used for the control of the plasma vertical position.

21) Divertor and first wall erosion diagnostic based on copper vapour laser. *O.Buzhinskij*

- Light from a copper vapour laser is used to illuminate the target and appropriate filtering on the receiving side in frequency and time permits a detailed image to be formed.
- The possible application of the technique to ITER is under investigation. Observation through upper, equatorial and divertor ports are considered.
- Preliminary performance analysis has shown that measurements with a resolution ~ 1 mm even during a plasma pulse are feasible. It is claimed that the technique can be used to measure erosion but the latter requires measurement of depth and it is not clear how that would be achieved.
- The precise role of the technique on ITER is not clear.

22) The optimization of ITER reflectometry waveguide and antenna systems on the base of modeling of electromagnetic waves propagation with full-wave «Rt Stream Grid 2D» code *S.Soldatov*

- A 2D numerical code has been developed to predict the performance of the components of the reflectometry system.
- It has been applied to the waveguide coupler in the band 20 — 60 GHz and determined the optimum length as 900 — 1200 mm.
- Application to the HFS antennas has demonstrated that they will operate satisfactorily even though they are mounted on the side of a Blanket Shield Module and there are many secondary reflcetions.
- It is pointed out that turbulence may decrease the resonance properties of the plasma-wall system. Calculations including turbulence will be carried out in the near future

23) X-ray high resolution spectrometer for measuring ion temperature in BPX *M.Stepanenko*

- It is proposed to introduce small quantities of argon and krypton into the plasma to provide sources of X-ray radiation.
- Spectral measurement of the X-ray radiation will provide T_i and plasma rotation.
- A method for unfolding the Ti spatial profile is proposed. The method requires a measurement of $T_e(r)$ and $n_e(r)$.

24) Possibility of using Kumakhov Optics in X-Ray spectra thermonuclear reactor plasma measurements *V.Trukhin*

- Bent capillary tubes are used to defect the X-ray radiation through a small angle to separate it from the direct neutron flux and thereby protect the X-ray spectrometer and detector from potentially damaging neutron radiation.
- Calculations and measurements of the X-ray transmission on candidate capillaries embedded in a neutron shielding block have been made as a function of energy and angle. With capillaries of 10 µm diameter the attenuation of the neutron flux is measured as more than 10^{-3} for a 5 degree bend. The transmission of the capillaries to X-rays is about 30% for the energy range 15 — 17keV. This would permit measurements of the central temperature up to about 5 keV
- For measurements at higher temperatures it is proposed to use capillaries with a smaller diameter (1 µm)
- Tests on T10 are planned.

25) Flow liquid bubble detector for neutron tails measurements *S.Trusillo*

- Development of the Flowing Liquid Bubble Chamber has continued.
- A working prototype has been constructed. Preliminary operation has shown intensive bubble growth in the nozzle. This confirms the formation of negative pressure. The presence of negative pressure was also confirmed with the measurements with the laser interferometer.
- A series of tests and measurements are planned to characterise the performance of the device.
- Plans for further development of the detector are being developed.

Attachment 8

Action Items and Recommendations

<u>Action items of previous meetings.</u>
Remarks in blue have been made during the 1st TG meeting. *Action items written in italic will be removed from future lists because they are either completed or because the reason for having the item on the list no longer exists.*

11a003: Spectroscopy WG to look for alternative techniques to active CXRS for measuring light in-core impurities. No progress in finding alternative techniques; continued activity.

11a006: TG members and Task Area Leaders (TALs) to comment on relevant drawings of the revised concepts for implementing diagnostics on ITER. Comments to be sent to Alan Costley and Chris Walker. The ITER-FEAT Final Design Report was issued in the summer and included drawings of diagnostic systems. Others are available from Chris Walker and Alan Costley. However some diagnosticians in the Participant Teams do not seem to have had access to them. This should be investigated. Task carried forward.

11a009: Neutron WG to make a full and detailed assessment of the distributed vertical neutron camera. The interface with the machine is still under development so this cannot be completed. Continued activity

11a022: Neutron WG to critically review the work and calculations of Källne for ITER and to make a recommendation. This can't be completed because there are no calculations from Källne. Hence the new action on Källne. This task awaits these calculations.

11a024: Sasao to continue the work on the Faraday-cup analyzer in LHD and the evaluation of scintillators. Special emphasis should be given to the design issues as well as to testing the detector with a Co^{60}-source. Continued activity.

11a026: Reflectometry WG to assess the possibility of reflectometry to track resonant flux surfaces. During magnetic field ramps the rational surfaces in ASDEX-UG show up as sharp peaks in the turbulence level measured with reflectometry.

11a029: Spectroscopy WG to look into the modeling of the divertor plasma. Carried forward.

11a031: Reflectometry WG to assess merits of divertor reflectometry. Carried forward.

11a032: Thomson WG to review the designs of the X-point and divertor TS systems for ITER. Task completed.

12a041: Reflectometry WG to investigate the possible relation between micro-turbulence rotation and plasma rotation. It has been clearly demonstrated on a number of devices that reflectometry can be used to measure the rotation of plasma turbulence, and sometimes the rotation of the plasma turbulence has been found to be close to the rotation of the bulk plasma. Task completed.

12a042: Reflectometry WG to look into the possibility of measuring the plasma rotation and/or density fluctuations by means of a dedicated scattering diagnostic. One type of scattering (reflectometric) has been successfully used to measure the rotation of plasma turbulence. The measurement of bulk plasma rotation would be best done by measuring the frequency shift in the central ion feature by CTS. This is outside the scope of the RWG. Task completed

12a043: Reflectometry WG to make an assessment of the plasma position reflectometer. It was demonstrated that the separatrix position can be measured by means of reflectometry in ASDEX-UG and DIII-D and that reflectometry could be a candidate control diagnostic.

12a045: Costley to contact the system designers to update the table with first mirror specifications and extend if possible. The table has been updated with the available FM details. Further details will be available as the system designs develop.

12a046: First Mirror WG to initiate and co-ordinate the activity to develop a model for deposition, to be checked with experiments. Continued activity.

13a055: Donn /Costley to connect the measurement needs to the various operating sc enarios of ITER. Carried forward.

13a057: Donn to improve the definitions on the survey questionnaire and feed it back to the contributors with the request to update the information where possible and to include data on more diagnostics. Task completed but the response is still low.

13a058: TG members to encourage the key staff at the magnetic confinement devices that do not yet take part in the international diagnostics database to join the survey. A few new diagnostics have been added to the database. Continued activity.

13a059: *Radiation experts to carefully look at the recent RIEMF data with the aim to understand the variable behaviour of RIEMF in the prototype coils of MI cables and to design improved measurements for the next set of coil tests. Task completed. A careful examination of the previous results has been carried out and recommendations made for the next set of reactor coil tests.*

13a062: TG members to encourage CTS experts to advise on the optimum wavelength of CTS on ITER taking account of recent results at JT-60U and TEXTOR. Carried forward.

13a063: TG members to encourage CTS experts (or the CTS group at JAERI) to perform a detailed feasibility calculation to assess the merits of impurity measurements (in particular the D/T ratio and the He-ash distribution) by means of tangential CO_2 collective Thomson scattering. Carried forward.

13a064: Spectroscopy WG to comment on the spherical crystal development and more specifically on the question whether or not fan-like observation is compatible with graphite reflectors. It should be also assessed whether we need this specific diagnostic because CXRS can potentially meet the need. Carried forward.

13a067: ITER-IT (IT) to examine the integration of a synchrotron radiation measurement based on the feasibility study by Jaspers. Continued activity. Looks integratable. Could need redesign because of longer wavelength < 5 µm. A key question is whether there should there be a dedicated single viewing system? This should be investigated.

14a073: IT to set up a communication mechanism to improve the interaction with the EG members and TALs so that comments can be feedback to the IT on diagnostic designs. Drawings in the DDD should be circulated to persons involved in the design work. This action is basic for further progress with action item 11a006. This is a specific old ITER task which will be taken from the list.

14a074: Donn to contact Ken Young with the question whether or not the US diagnostics community will join the diagnostic database. Task completed.

14a075: TG members to encourage diagnosticians working in the field of MSE to answer the open questions and to assist in the assessment of the feasibility of MSE on ITER. In progress, continued activity.

14a076: Costley to give feedback on the divertor measurement requirements and diagnostic potential to the Divertor TG. Task completed but further iteration with Divertor TG needed. This will be part of the new action item 01a085.

14a077: Spectroscopy WG to make an assessment of the spectroscopic systems for the ITER divertor. Carried forward.

14a078: Orsitto to provide Voitsenya with drawings of the JET divertor. Voitsenya to make a conceptual design. Campbell to discuss the implementation of such a device on one of the European fusion devices. The system is now in the package that is considered for JET-EP.

14a079: First Mirror WG to consider the plasma exposure conditions in burning plasma experiments and to check the relevance of the conditions in the model used by Hirooka. Carried forward.

14a080: Neutron WG to review the work on the threshold fission chambers and make a recommendation on the feasibility of implementation on ITER. Continued activity.

14a081: Neutron WG to make an assessment of the gas-flow activation system for possible application on ITER-FEAT. Continued activity.

14a082: Donn /Costley to make provisional plans for the next meeting by proposing the venue and date and appointing a local organizer. Task completed.

New action items

01a083: Kislyakov to provide participants with CD-ROM containing presentation of TG and RF Progress meeting.

01a084: Donné to collate the comments on the mandate from the TG members, to develop the mandate accordingly, and to distribute the final version to the ITPA CC members before the end of 2001.

01a085: Costley to consider how best to develop the assessment of the measurement capability relative to target requirements this study and to communicate the results with other TG groups.

01a086: Young to draft the justification for the specification (resolution, etc.) for each measurement requirement for review by the TG members.

01a087: Donné/Costley to develop a proposal for High, Medium and Long Term Priority Research Tasks for the coming year and submit it to the ITPA CC before the end of 2001.

01a088: Donn /Costley to draft the charges for the Specialists Working Groups and relaunch the groups.

01a089: US TG members to nominate members to the Specialists Working Groups.

01a090: Donné/Costley to consider the establishment of a new SWG on Radiation Effects.

01a091: Donn to ask the proponents of the MPR (K llne et al) to show the feasibility of implementing the MPR for ITER by comparing the calculated performance predictions with the target measurement requirements.

01a092: Neutron WG to advise on the priorities and the integration of the various candidate neutron diagnostics for ITER.

01a093: Boivin to make provisions for the 2nd ITPA and related meetings (4 - 8 March, San Diego).

01a094: Sasao to discuss with the LHD management the possibility of having the 3rd ITPA meeting in the autumn of 2002 in Toki, Japan.

01a095: Donné to set up a website for the Topical Group on Diagnostics with a password protected area (Incl. minutes, presentations of most recent meeting, info on members of TG and SWG's).

Recommendations of previous meetings

12r001: EU Party should develop divertor reflectometer systems for testing in existing divertor plasmas (preferably on JET) and to be assessed by Reflectometry WG.

12r002: Party that is responsible for the divertor spectroscopy (Japan) should develop and utilize modeling tools for spectroscopy in the divertor plasma.

12r003: Parties should make modeling calculations of the CX flux on first mirrors. This is very important for a better understanding of the mirror experiments and support for mirror modelling work.

12r005: EU Party to give a demonstration of the synchrotron emission measurements at JET. Can probably be done with the new JET-EP endoscope, maybe with some limitations.

13r006: The Parties are encouraged to develop real-time algorithms for simultaneous feedback control of the profiles of multiple plasma parameters.

13r007: The Parties are recommended to give successful proof-of-principle demonstrations of the proposed divertor diagnostics in present day devices. Specific examples of the measurement needs and possible diagnostics are in the presentation by G Vayakis given at the 1st TG meeting.

14r010: Reflectometer specialists in the Home Teams to demonstrate real-time feedback of the plasma position by means of reflectometry.

14r011: Spectroscopists in the Home Teams to develop strategies to ensure that measurements of Z_{eff} will be not perturbed by molecular bands.

New Recommendations:

01r012: It is recommended that the ITER relevant systems that are candidate for implementation on JET — especially Fast Wave Reflectometry, CTS below the cyclotron frequency, and High Resolution Neutron Spectrometry by ToF - are implemented.

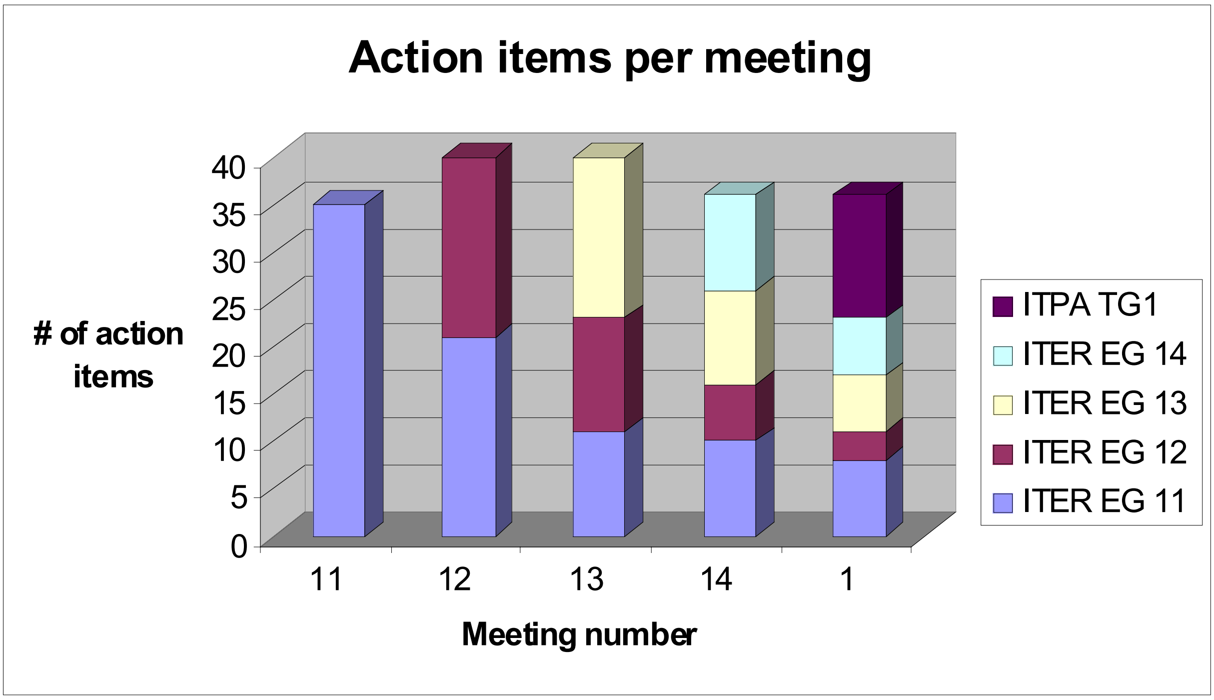

Figure: Progress with the action items from meeting to meeting. Numbers 11 — 14 refer to ITER Expert Group Meetings while 1 refers to this meeting..