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FOURTEENTH MEETING OF THE ITER PHYSICS EXPERT GROUP ON DIAGNOSTICS

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

The Fourteenth Meeting of the ITER Physics Expert Group on Diagnostics was held at the Institute for Plasma Physics, Jülich, Germany, 21 - 23 March 2001. The meeting immediately followed a Progress Meeting on ITER Diagnostic Design and R&D and ITER relevant diagnostic development work in progress in Europe, which was held in the same location, 19 - 20 March 2001. A similar meeting concerning ongoing work in the Russian Federation took place in Moscow one week earlier, 12 - 13 March, 2001. This summary covers mainly the discussions at the Expert Group meeting but, where appropriate, developments reported at the progress meetings are included.

The main objectives of the Expert Group meeting were:

- to review and update the requirements for measurements on ITER-FEAT, in particular in the divertor region;
- to review the progress and plans in meeting the goals of the 'Voluntary R&D' tasks within the Parties approved by the ITER Physics Committee; and
- to review and plan ongoing supporting activities, including the work of the five Special Topical Working Groups.

Recent progress in relevant diagnostic developments in the Parties was also reviewed during the meeting.

The principal conclusions of the meetings mentioned above are as follows:

Good progress has been made in the tasks designated as high priority by the ITER Physics Committee.

(1) The requirements for plasma and target measurements in the divertor region have been reviewed in collaboration with the Scrape-off Layer and Divertor Physics Expert Group. Some of the target measurement requirements have been relaxed and in these cases there is a now a closer match between the target requirements and what can probably be achieved. However, difficulties are still foreseen in meeting some of the measurement requirements, in particular those for the measurement of surface plate temperature and electron temperature. Further work in collaboration with the divertor group is planned.

(2) The data on Radiation Induced EMF (RIEMF) in cables has been reviewed and it has been concluded that according to these data it should be possible to design magnetic coils for ITER which can operate satisfactorily even in the presence of this effect. The results obtained in the radiation tests with prototype magnetic coils apparently show a much higher RIEMF. However, a reanalysis of these results suggests that either a systematic error was present in the measurement of the drift (the integrator is the most likely cause of the difficulty), or another voltage source was present in the measurement. Further tests are required in which more detailed measurements are made, and these tests are in preparation.

(3) Progress has been made in the implementation of systems for the measurement of the safety factor, q(r). Solutions to the difficult installation of retroreflectors on the high field side for the Poloidal Field Polarimeter are being developed. For the Motional Stark Effect system, an improved optical design has been developed which gives good optical performance and at the same time as enables adequate neutron shielding to be obtained. Further design work is required on both systems and this is in progress.

(4) Progress has been made with the plasma-facing mirrors for optical systems. 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). Progress has also been made with mirrors made from metallic coatings such as Mo and Rh. However, deposition of 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.

- Steady progress continues in the investigation of radiation effects in candidate materials for diagnostic construction. The identification of some low loss quartz glass (KS-4 and KU-1) which has a very low radiation-induced loss means that refractive optics can be used inside the vacuum vessel in some situations, considerably simplifying the optical designs. Some specific component tests are also in progress. In particular, measurements on a JET-type bolometer irradiated in the JMTR reactor in Japan showed promising results before a problem with the electrical contacts to the bolometer occurred. More tests are planned.

- The International Database on the Reliability and Availability of Diagnostic Systems continues to be developed and will soon be accessible via the internet. A feedback to the contributors to update their 1.5-year-old information will soon be made available along with a report of a first analysis. Information on more diagnostics and more machines is being sought.

- Good progress has been made in the design of many of the diagnostic systems and with the integration of the systems into the machine. It is expected that it will be possible to accommodate most of the planned diagnostic systems.

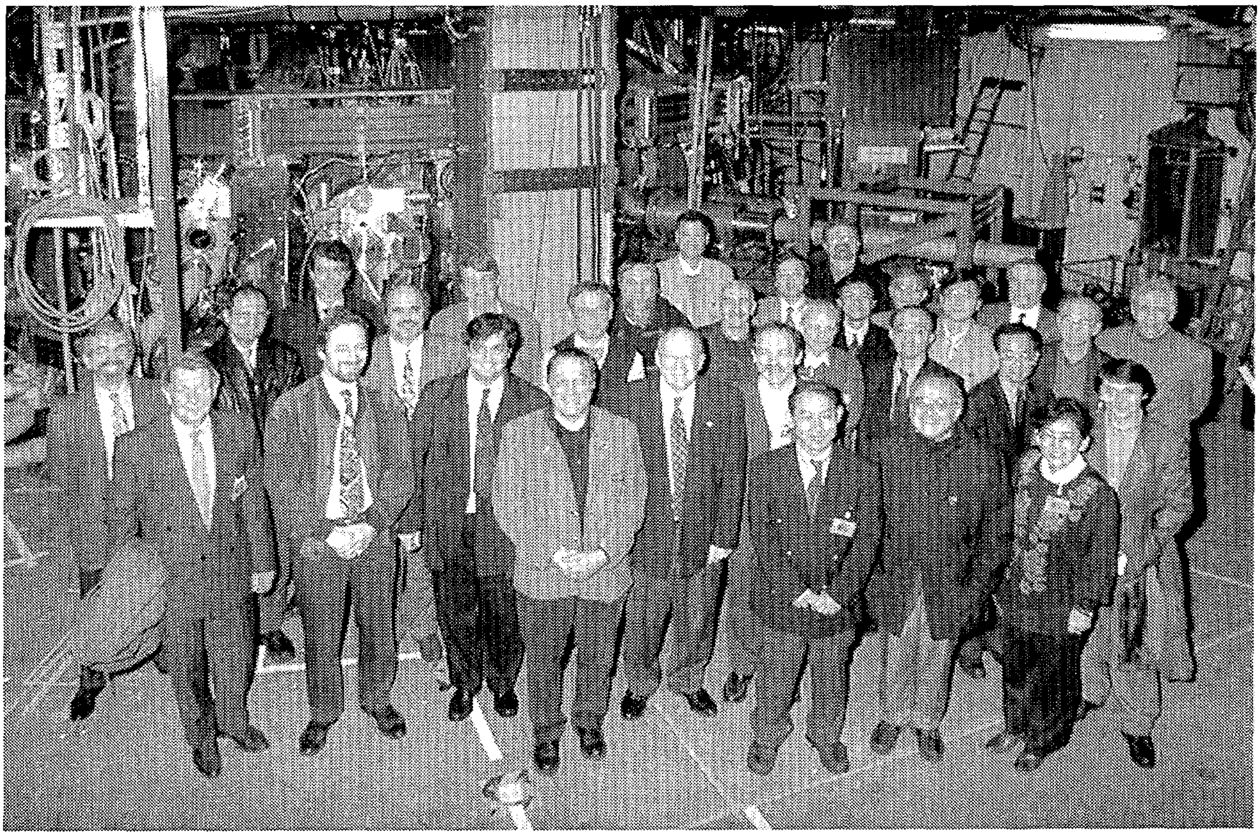
- Independent studies undertaken in Europe and in the Russian Federation have confirmed the expected performance of the Charge Exchange Recombination System with the Diagnostic Neutral Beam. By optimizing the geometry, the diagnostic beam and the measurement parameters, an improvement in the expected signal to noise of over a factor of four has been obtained.

- The Specialist Working Groups reported good progress in their specific fields since the previous meeting.

- Very productive progress meetings were held just before the EG Meeting in Moscow (RF) and Jülich (EU). Good progress has been made in many of the credited R&D and design activities and ITER relevant activities.

- It is provisionally proposed to hold the 15th Meeting of the ITER Physics Expert Group on Diagnostics jointly with the 1st Meeting of the ITPA from 10 - 14 September, that is in the week immediately after the international diagnostic meeting to be held in Varenna, Italy.

All the participants agreed that the meeting was highly productive and sound plans were drawn up for making progress with the key issues in ITER diagnostics. The Expert Group members wish to thank the Trilateral Euregio Cluster for its hospitality and for providing the facilities for the meeting. We are especially indebted to Mrs. S. Küper of the Plasma Physics Institute for her excellent assistance.



Participants in the Meeting

Attendees at the 14th ITER Physics Expert Group Meeting on Diagnostics

Members of the Expert Group

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Tony Donné (FOM, Netherlands, EU)
Anatolij Kislyakov (Ioffe, RF)
Anatolij Krasilnikov (TRINITI, RF)
Yoshinori Kusama (JAERI, JA)
Francesco Orsitto (EFDA JET-CSU, EU)
Vyacheslav Strelkov (Kurchatov, RF)
Tatsuo Sugie (JAERI, JA)

Guests and Attendees at the Expert Group Meeting

Claude Boucher (INRS, Canada)
David Campbell (EFDA-CSU, Garching, EU)
Katsuyuki Ebisawa (Naka JWS, ITER)
Ruggero Giannella (CEA, France, EU)
Manfred von Hellermann (FOM, EU)
Yoshihiko Hirooka (NIFS, JA)
Eric Hodgson (CIEMAT, EU)
Roger Jaspers (FOM, EU)
Satoshi Kasai (JAERI, JA)
Yuri Kaschuk (TRINITI, RF)
Rudi Koslowski (FZJ, EU)
Artur Malaquias (Garching JWS, ITER)
Per Nielsen (RFX, Italy, EU)
Takeo Nishitani (JAERI, JA)
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Sergei Tugarinov (TRINITI, RF)
George Vayakis (Naka JWS, ITER)
Chris Walker (Garching JWS, ITER)
Victor Zaveriaev (Kurchatov Inst., RF)

INTERNATIONAL WORKSHOP OF THE CONFINEMENT DATABASE AND MODELLING EXPERT GROUP IN COLLABORATION WITH THE EDGE AND PEDESTAL PHYSICS EXPERT GROUP

by Drs. J. Cordey, UKAEA, and O. Kardaun, IPP Garching

A Workshop of the Confinement Database and Modelling Expert Group (EG) was held on 2 - 6 April at the Plasma Physics Research Centre of Lausanne (CRPP), Switzerland. The first four days of this Workshop were devoted to general database issues and this part of the meeting was attended by delegates from the EU, Japan, and the Russian Federation, as well as from the USA. Some Members of the Edge and Pedestal Physics EG were invited, and a Combined Workshop of these two EGs was informally held during the first two days. Pedestal database physics issues were discussed. For the next two days, topics within the Confinement Database area were delineated. During the first day, presentations were held on the present status of the plasma pedestal (temperature and energy) scalings from an empirical and theoretical perspective. The next day was devoted to 1-D modelling presentations. During the four days, the afternoons were used for practical working sessions. On the third day, both 1-D modelling results and new experimental data on global H-mode confinement were discussed and the following morning was divided between presentations on L-H threshold power and global confinement. Detailed working sessions took place in separate groups, using the excellent computer facilities provided by CRPP.

The official scientific minutes of the meeting are available on the internet (http://www.ipp.mpg.de/netreports). We present here an outline of the material treated during four working sessions and from the special session on ITER, while omitting individual contributors' names, for which readers should refer to the minutes.

Pedestal Group Working Session (co-ordinated by J.G. Cordey, O. Kardaun)

Analysis of the scaling of the plasma pedestal parameters in relation to confinement is important for several reasons: First, for stiff profiles, which are empirically observed in a variety of situations, the central plasma temperature is proportional to the pedestal temperature, critical gradients of which are determined by stability aspects rather than by conductive heat transport in the plasma core. Hence, it is expected that the accuracy of simple power-law confinement scalings can be improved by two-term power-law (or other log non-linear) scalings for which one part is described by the pedestal energy and the other by the plasma core energy. Second, the ELMing behaviour of the plasma edge is not only interesting from a physics point of view, but is also an important consideration for the heat load protection of the divertor. In practice, high resolution, specialized diagnostics in the edge region are needed and a basic difficulty is to obtain consistent data across several machines (ASDEX Upgrade, C-Mod, DIII-D, JET, JT-60U) to allow extrapolation for ITER. Presentations at the workshop ranged from empirical analysis of the existing multi-machine dataset to semi-empirical integrated modelling and reviews of plasma physics theories predicting pedestal parameters. With respect to the latter we mention (1) pressure gradients limited by the condition of plasma stability against MHD ballooning modes, (2) turbulence damping caused by shear of the poloidal 'E_r x B' velocity, where the radial electric field E_r is produced by ion orbit losses, (3) the role of neutral particles, and (4) the role of magnetic shear in the pedestal region. Some of the specific theoretical models were claimed on the basis of the available data to be an incomplete description. However, for a more definite discrimination, an improvement of both the extent and the inter-machine consistency of the data was felt to be indispensable. Increased diagnostic requirements for separate determination of the pedestal gradient and the pedestal width of the plasma temperature and density, as well as the intricate involvement of the plasma equilibrium, were realized and identified. Whereas a spectacular breakthrough was not achieved during the meeting, the awareness of the participants from both expert groups of the need to co-operate further in this direction in the future was intensified. Advances in this area are apt to combine scientific insight with possible experimental tools to tune plasma performance in ITER-FEAT.

Global Confinement Group Working Session (co-ordinated by O. Kardaun, T. Takizuka)

New experimental results from various machines, obtained after the IAEA Conference in Sorrento, were presented from the ASDEX Upgrade, JET, T-10 and MAST tokamaks. These were generally well described by the empirical simple power-law scaling for the thermal energy confinement time in ELMy H-mode, ITERH-98P(y,2) or IPB(y,2), derived in the ITER Physics Basis Document (Nucl. Fusion, Dec. 1999). From JET it was reported that at high density, an appropriate form of gas puff fuelling is required to avoid substantial confinement degradation. Preliminary JET helium experiments were presented to disentangle the influence of isotope mass and isotope charge on confinement. Results from ASDEX Upgrade indicated that a higher plasma density at the separatrix is correlated with a lower normalized confinement time. ELM-free H-modes with confinement close to the prediction of IPB(y,2) were obtained in T-10 with pellet injection, and also in the tight aspect ratio MAST device. Reanalysis of the two-term (offset non-linear) confinement time scaling based on the updated standard H-mode dataset ITERH.DB3 led to higher predictions for ITER-FEAT than previously; these predictions are now within two standard deviations of the point prediction by IPB(y,2), (see the ITER prediction session). The joint work on the confinement database from the IAEA Conference, including a special section on ohmic/L-mode confinement, is intended to be submitted for publication soon. An improved pedestal energy database analysis is planned to be presented at the coming H-mode workshop in Japan.

Threshold Group Working Session (co-ordinated by F. Ryter)

In the last few years, several empirical scalings have been derived for the heating power across the separatrix needed to attain ELMy H-mode in ITER-FEAT. The most recent one, utilized in the ITER-FEAT Final Design Report, predicts a lower threshold power than the previous one from the ITER Physics Basis Document. This is Amongst other reasons, this is related to additional discharges from Alcator C-Mod and JT-60U. To keep a sufficient margin for operation, the foreseen heating power in ITER-FEAT (73 MW, upgradable to 110 MW) is some 30% above the point prediction (48 MW) of the latter scaling at the reference operating point. A remaining concern is the scatter of the data, all taken near the power threshold, around the empirical scaling law. This is expected to be partly due to hidden variables, which complicate the analysis as well as the accuracy of the prediction. At the meeting, the effect on the threshold power of the position of the X-point above the divertor was investigated, which is possibly related to the already well established favourable effect of the ions drifting in the direction towards, instead of away from, the X-point. Results from JFT-2M were presented indicating an increasing power threshold with a decreasing height of the X-point above the divertor. For JFT-2M the power threshold also increases with a decreasing distance between the separatrix and the outer plasma wall in the midplane, in concordance with earlier observations from ASDEX. Data from ASDEX Upgrade, DIII-D and JET exhibit at present an opposite trend with respect to the effect of the X-point location. Ohmic H-mode data from TCV were shown with the threshold power increasing with increasing distance between the separatrix and the inner plasma wall. Hence, additional factors may play a role and dedicated experiments are needed to distinguish between them. An action list to address this issue consistently across the various devices was determined. It has been decided that the threshold database work will be presented in a joint paper at the next H-Mode Workshop in Toki.

1-D Modelling Group Working Session (co-ordinated by J. Connor)

An integrated approach to modelling tokamaks, incorporating core transport, edge pedestal and the SOL, together with a model for ELMs was presented by the JCT, and it was stressed that the interaction between the different elements can modify the anticipated scalings that result from each element considered in isolation. A number of talks were given on the important issue of critical gradients and profile stiffness. At Lehigh University a model for the pedestal temperature scaling was formulated with the pedestal width $\Delta \propto (\rho_{p,i}\alpha)^{1/2}$ and the usual ballooning stability criterion for the pressure gradient, allowing for the effect of the bootstrap current on the equilibrium at the edge. It fitted data well at high collisionality, while for low collisionality an empirical fit to the pedestal database was presented. From PPPL it was reported that the standard IFS/PPPL model, while correctly predicting JT-60U and TFTR data, underpredicted the temperature gradients in the high collisionality Alcator C-mod tokamak, which were better predicted by the GS2 gyrokinetic stability code. Large machines with lower collisionality would not experience such a large upshift of the ion temperature gradient. A contribution from Tore Supra described how the electron heat fluxes for their predominantly electron heated plasmas were empirically well described by an ETG turbulence model. The magnetic and density fluctuations increased consistently with the diffusivity. The normalized critical temperature gradient, and hence the energy confinement, increased with increasing magnetic shear. Investigations on temperature profile stiffness and model comparisons based on JT-60U experiments were presented by PPPL/JAERI. Selected scans of ELMy H-modes indicated that the profiles were rather stiff, in the sense of varying approximately in a multiplicative way with heating power, heating location and pedestal temperature. Normalized at the pedestal, each of the models considered, (Rebut-Lallia-Watkins-Boucher (RLWB), IFS-PPPL and Multimode) predicted the electron temperature within some 15% outside the sawtoothing region, while the Multimode model overpredicted the ion temperatures by some 20%. IPP presented discharges with ECRH at

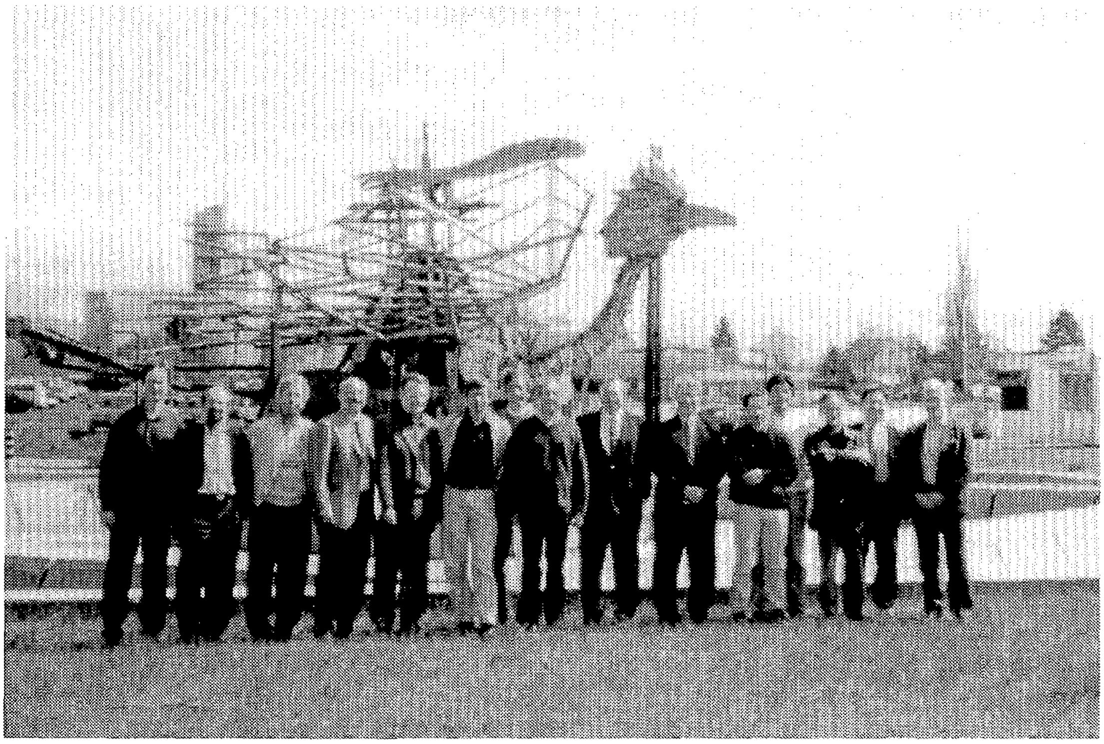
ASDEX Upgrade that yielded a consistent picture for both steady-state and modulated electron heating in terms of a gyro-Bohm-like critical gradient model. Also, the transport model developed by Weiland gave a good prediction of the modulation experiments. The JCT reported benchmarking of the transport model used in ASTRA for ITER-FEAT predictions against data from JET and DIII-D in the profile database. A special seminar on the US National Transport Code was delivered. A proposal to host and manage the International Profile Database at Culham was presented, during which the suggestion was made to incorporate MDS+ and SAS-based user interfaces. During the working sessions, the 1-D Modelling Group specified plans to extend the profile database and reactivate the 1-D modelling activity, with an emphasis on electron transport and internal transport barriers.

ITER Prediction Session

A presentation was given by the JCT on the charge to the expert groups and the foreseen structure of the international ITER Physics meetings for the coming years. Although the main size parameters of ITER-FEAT are not liable to change, adaptations of important details within the constraints of the overall budget are still feasible and institutions carrying out laboratory experiments were invited to assist with their contribution.

ITER-FEAT simulations based on a predictive transport code for drift wave transport with the H mode pedestal as the outer boundary condition were presented by Chalmers University. The H-mode pedestal was obtained by using the Sugihara model. First the steady state operation of ITER was simulated. The low current restricts the average density to about 7.5×10^{19}. This gave a fusion Q of 2.6. However, with Z_{eff} reduced from 1.85 to 1.63, a transport barrier with Q = 10 was obtained. Also, the particle pinch can yield Q in the range 5 to 10. ITER in inductive mode was simulated while treating the hot alpha particles as an auxiliary hot ion species. This gave better performance than the usual simulations where all the alpha power is given to the electrons. This was due to a slowing down of the alphas so that more energy was given to the main ions. The alpha particle η_i mode was stable owing to the hot ion regime.

The background of the recommended simple power-law confinement scaling ITERH-98P(y,2) and the interval estimate for the ('true') confinement time in ITER FEAT at the reference operating parameters (15 MA, 5.3 T, etc.) was outlined by IPP. The reasons for choosing ITERH-98P(y,2) as a standard from the various scalings in the ITER Physics Basis (Nuclear Fusion, December 1999) were explained. The statistical framework of interval prediction ('distributional inference') was indicated. While direct application of the usual statistical error propagation formula leads to unrealistically narrow intervals, the physically relevant sources of variation have to be assessed and quantified by a number of complementary methods, which are described and calculated for ITER FDR in IPB-99 and PPCF-99. A more detailed documentation for ITER-FEAT was expected to be feasible soon. Because of the considerable additional data from several tokamaks in DB3 and the more moderate extrapolation to ITER-FEAT compared with ITER FDR, as well as several subsequent analyses along the lines described in PPCF-99, a reduced interval width for ITER-FEAT is thought to be justified: 3.6 times $\exp(\pm 0.14)$ s at the reference operating point, where 0.14 corresponds to one 'technical' standard deviation. According to 0-D power balance calculations, the above confinement time interval H_{H98y2} = (0.87,1.15) translates into the interval ($7 < Q_{max} < 50$) under more or less realistic estimates for Z_{eff}, dilution by helium, and temperature profile shape. It was stressed that the confinement-time interval estimate is derived for ITER-FEAT operated under the usual ELMy H-mode, while applying 'gentle' gas puffing with adequate triangularity. In particular, no coverage is given by the interval of the problem of how to reach H-mode at densities close to the Greenwald limit for high current (or high magnetic field), or of the restricted existence region of type II ELMs which are at present considered to be most compatible with sustained divertor operation. Furthermore, it was recalled that a radiation correction for the confinement time is not being applied at present in the analysis of the DB3v9 database. To zeroth order this tends to give a somewhat conservative touch to the ITER prediction, but it is also an additional, systematic source of uncertainty. Further investigation of the role of the edge density and/or neutrals was mentioned to be scientifically interesting, as well as further analysis of non-linear models and pedestal relationships.



Participants in the Workshop

The present recommended scalings from IPP for the L to H power threshold and their interval prediction for ITER-FEAT were discussed, while progress was indicated in reducing the scatter through understanding of the influences of the separatrix and X-point locations in the vessel. An H-mode Workshop contribution is planned. The presently recommended expressions are essentially the ones in the International Threshold Database Group Paper presented by J. Snipes (PPCF, May 2000). The predictions for ITER-FEAT in deuterium at a line-averaged density of 5×10^{19} m^{-3} are 43 (25-74) MW and 38 (21-66) MW respectively, where the numbers in brackets correspond to 95% log-linear interval estimates.

Any recommendation for W_{ped} for ITER-FEAT was deferred pending evaluation by the pedestal group at their meeting in Garching, and thereafter at the combined Meeting in Japan. The preliminary IAEA-2000 pedestal energy scaling is suitable for interpolation only and is intended to stimulate further improvement and integration of the database. From an empirical perspective, the present status of the international database bears a certain similarity with Isaac Asimov's phrase (in The Last Question): 'no sufficient data yet to answer your question'.

It was agreed that the international ITERH.DB3v5 global confinement database be made publicly available on the internet site maintained at EFDA.

The next combined Expert Group Meeting was proposed to be held after the IAEA H-mode Workshop (5 - 7 September) at NIFS, Toki, Japan. The intended dates are 10 - 12 September, with an offered facility to hold any pre-meetings on 8 September.

The organizers of the present meeting in Lausanne were complimented for their professional arrangements.

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