# Summary Report

## International Workshop of the Confinement Database and Modelling Expert Group in Collaboration with the Edge and Pedestal Physics Expert Group April 2-6, 2001, Lausanne, Switzerland

### Introduction

A combined Workshop of the Confinement Database and Modelling Expert Group and the Edge and Pedestal Physics Expert Group was held April 2-6 at the Plasma Physics Reseach 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, the RF as well as from the USA. Pedestal database physics issues have been discussed during the first two days and then for the next two days topics within the Confinement Database area were delineated. On the last day, a special session was held on ITER FEAT prediction, during which also the results from the first four days were summarised. During the first day, presentations were held on the present status of the plasma pedestal (temperature and energy) scalings from 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 next day's 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.

### Summary of the Pedestal Group Working Session (J.Cordey, O. Kardaun)

The main activity of the joint meeting of the confinement database group and the pedestal group was the development of a programme to improve the condition of the pedestal database. Since the IAEA meeting in Sorrento additional data had been supplied by JET, ASDEX Upgrade and a method of incorporating a subset of the time-dependent pedestal data from DIII-D has been proposed. The target date for all tokamaks to improve the dataset for the present iteration round has been set to one month.

Papers were presented on the analysis of the JET pedestal data by L. Horton in which it was shown that the scaling of Wped increased with power as $P^{0.34}$ if one included both ECE and LIDAR data to increase the available power range or $P^{0.45}$ if only the ECE measurements of the pedestal data were used. The author recommended that one should exploit the new edge LIDAR diagnostic rather than use the core LIDAR to evaluate the stored energy in the pedestal.

M. Sugihara showed that although the pedestal pressure can be scaled as the width proportional to the poloidal larmor radius multiplied by an analytical formula for the critical pressure gradient in individual machines, to unify the intermachine data, a machine dependent parameter was required. It was proposed that the shear in the edge region, which can be largely modified by the bootstrap current, could be a possible machine dependent parameter.

O. Kardaun then first reviewed the pedestal scaling which has been derived in the Sorrento IAEA paper, and then showed how the condition of the database could be improved by the addition of further data and asked for cooperation in this direction.

A number of theoretical scalings for the pedestal width $\Delta$ were described by J.W. Connor, some of which could be put in the form $\Delta \propto \rho_i^{\mu} R^{1-\mu}$ and it was proposed that this type of expressions should be tested first. One should also expect the geometry in particular the triangularity to be an important element in the scaling.

A 1-D model of the transport in the edge and core was described by G. Janeschitz. The model assumed that the ion transport was ITG and the electrons were RLW with the particle diffusion being proportional to the thermal diffusivity. The model simulated the ELMying behaviour by using the ballooning stability criteria to trigger on ELMs, of particular interest was the energy loss to the divertor during an ELM.

An overview for ASDEX Upgrade was given by F. Ryter. Pedestal information at $\rho = 0.8$ has now been supplied for a substantial fraction of the data in the confinement database, and could also be made available at $\rho = 0.9$. The presented data showed a definite increase of the pedestal energy with triangularity.

Results on inboard gaspuffing and pedestal temperature measurements from COMPASS-D have been presented by M. Valovic.

**Summary of Global Confinement Group Working Session (O. Kardaun, T. Takizuka)**

The ELMy H-mode Confinement scaling ITERH-98P(y,2), abbreviated IPB98(y,2), was confirmed to be a good simple reference scaling for the prediction of next step tokamaks. The new database, called DB3v9, which includes new data from Alcator C-Mod, ASDEX Upgrade, DIII-D, JET, JT60-U, START, TdeV, agrees well with IPB98(y,2).

High density data of JET were highlighted (M. Valovic, J.G. Cordey). Density peaking can keep the high confinement $H_H \simeq 0.9$ for $n_e$ around $n_{GW}$. Gentle gas-puffing is the key. Further investigation of high $n_e$ at higher $I_p$ is required, as well as gentle gas-puff at higher power. It was found from the ASDEX Upgrade experiments that $\tau_{th}$ increases with the central density but decreases with the edge density (F. Ryter). High confinement for high density was also obtained in ECRH T-10 discharges with LFS pellet injection. The data agree very well with IPB98(y,2) (V. Leonov).

Re-examination of the offset-nonlinear scaling (so-called TT scaling) has been done by using the DB3v9 database. If only the data of type-I ELM are used, the core confinement part approaches GyroBohm-type confinement and the ITER prediction by the corrected scaling becomes similar to that by IPB98(y,2) (T. Takizuka). A method to express confinement scalings by semi-invariants was proposed as a complementary method for ITER prediction, with certain physics variables having the same values as ITER. This method is especially useful in the context of log non-linear scalings. (Dnestrovskij, presented by Leonov).

ELM-free data from the tight aspect ratio MAST machine were presented with confinement slightly above the IPB98(y,2) scaling, while new ELMy experiments are being planned to contribute to the database. The data extend $\rho^*$ and $\nu^*$ space (M. Valovic). From JET interesting confinement results were shown from a small number of helium discharges, which do not exclude a dependence on $(M/Z^2)$ (D. McDonald).

The new working version of the ohmic and L-mode database was analysed and a new dimensionally restricted scaling for saturated ohmic confinement was presented (G. Bracco).

**Summary of the Threshold Group Working Session (F. Ryter)**

Several presentations were made in this session. Y. Miura presented recent results from JFT2-M showing that the power threshold increases with decreasing height of the X-point above the divertor. He also presented a study of the scatter in the database for each device showing that further work on cleaning the database is required. F. Ryter showed that the effect of sawteeth crashes in ASDEX Upgrade has a clear effect in individual shots, as the well-known results of the related heat pulses, but has no overall influence on the scatter of the data in the database. The effect of the position of the X-point above the divertor is consistent with JET results when comparing divertor I and II. However no proof can be given that the X-point height is indeed the reason. Dedicated experiments will be required. Y. Martin presented results from the TCV Ohmic H-modes. The particular properties of these operational conditions with correlation of heating power with current and density add another difficulty in the interpretation of the data. A contribution to scatter arises from the determination of the Ohmic power under non stationary situations. The sawtooth crashes do not contribute to the scatter significantly but the distance to the wall does, as in other devices. First threshold data from MAST were presented by M. Valovic which will be compared to and included in the database.

In the discussion session the data scatter in the database was further discussed. The effect of the X-point height is clearly quite difficult to take into account across the database because the dependence is different from machine to machine and because this is a dimensional variable. The machine representatives are therefore asked to investigate their data on this effect and suggest a possible normalisation. The distances GAPBOT and XPLIM must be checked for consistency in the different devices. The effect of GAPOUT was also addressed and it was decided that all the devices should try to provide the limit value above which the power threshold clearly increases, as observed in JFT2-M and ASDEX. Data from Alcator C-MOD including new position scan will be given to the database as soon as possible. It has been decided that the work of the group on the threshold database will be presented in a dedicated paper at the next H-Mode Workshop. Co-ordinator is F. Ryter. The action list corresponding to the above items was determined.

**Summary of the 1-D Modelling Group Working Session (J. Connor)**

G. Janeschitz presented an integrated approach to modelling tokamaks, incorporating core transport, edge pedestal and SOL, together with a model for ELM's. He stressed the interactions between the different element which could modify the anticipated scalings that result from each element considered in isolation. The issue of the pedestal temperature scaling was addressed by A. Kritz who developed a model based on a pedestal width $\Delta \propto (\rho_{p,i} a)^{1/2}$ and the ballooning stability criterion (accounting for the effect of the bootstrap current on the equilibrium at the edge). It fitted data well at high collisionality. This was followed by a number of talks on the important issue of critical gradients and stiffness. D. Mikkelsen described how more accurate calculations of the critical ion temperature gradient were consistent with the higher values needed to describe the C-MOD data: he explained that larger machines with lower collisionality would not experience this large upshift and that inclusion of trapped electron dynamics could recover the value in the IFS-PPPL model. A paper by G.T. Hoang described how the confinement in the electron-heated tokamak Tore Supra could be explained in terms of a critical gradient model based on electromagnetic $T_e$ - gradient turbulence. D. Mikkelsen presented his work on stiffness and model comparisons on JT-60U. Controlled scans of ELMy H-modes showed that the models were somewhat stiff, more so in the core and for ions rather than electrons, but effects were not dramatic. Testing the RLWB, IFS-PPPL and Multimode models showed good predictions for $T_e$, although the multimode model rather overpredicted the temperatures. O. Kardaun suggested to improve on the discriminating statistical tests. F. Ryter then described ECRH experiments on 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. The Weiland model was also able to give a good description of the data. The plans to host and manage the International Profile Database at Culham were presented by C. Roach. This led to discussions with M. Greenwald on incorporating the MDS+ system and a plan to do this was agreed. O. Kardaun mentioned the SAS MDDB system for multi-dimensional tables. In a working session the 1-D Modelling Group made plans to reactivate the profile database and 1-D modelling activity, seeking new data and carrying out renewed modelling with an emphasis on electron transport and internal transport barriers. A. Kritz delivered a seminar on the US National Transport Code Collaboration (NTCC) and A. Polevoi reported benchmarking of the transport model used for ITER-FEAT predictions against data from JET and DIII-D in the profile database.

**Summary of the ITER prediction session on April 6 (A. Polevoi, O. Kardaun)**

M. Shimada discussed 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 all laboratory experiments are invited to assist with their contribution.

J. Weiland presented ITER-FEAT simulations based on a predictive transport code for drift wave transport with the H mode pedestal as outer boundary condition. The H-mode pedestal was obtained by using the Sugihara model. First the steady state ITER was simulated. The low current restricts the average density to about $7.5 \cdot 10^{19}$. This gave a fusion Q of 2.6. However with $Z_{\text{eff}}$ reduced from 1.85 to 1.63, a transport barrier with Q = 10 was obtained. Also the particle pinch can give Q in the range 5 to 10. Then 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 $\eta_i$ mode was stable due to the hot ion regime.

O. Kardaun discussed 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.). The reasons for choosing ITERH-98(y,2) as a standard from the various scalings in the ITER Physics Basis (NF. 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 DB3v9 and the more moderate extrapolation to ITER FEAT compared to ITER FDR, as well as several subsequent analyses along the lines described in PPCF, 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 $Z_{\text{eff}}$, dilution by helium, and temperature profile shape. It was stressed that the confinement-time interval estimate is derived for ITER FEAT operated under usual ELMy H-mode, while applying 'gentle' gaspuffing with adequate triangularity. In particular, no coverage is given by the interval for the problem how to reach H-mode at densities close to the Greenwald limit for high current (or high magnetic field), as well as for the restricted existence region of type II ELM's 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.

F. Ryter summarised the present recommended scalings for the L to H power threshold and their interval prediction for ITER FEAT. He also indicated progress in reducing the scatter by detecting influences from the separatrix and X-point locations to the vessel and said that an H-mode Workshop contribution is planned. The presently recommended expressions are:

$$P_{thres} = 1.51 B_T^{0.81} \overline{n}_{e,20}^{0.60} a^{0.83} R^{1.01} (\mathrm{rmse} : 26.8\%) \tag{1}$$

$$P_{thres} = 0.05 B_T^{0.85} \overline{n}_{e,20}^{0.50} S^{0.84} (\mathrm{rmse} : 27.9\%) \tag{2}$$

where $S$ is the plasma surface area and the units are $MW$, $T$, $10^{20} m^{-3}$ and $m$. The predictions for ITER FEAT in deuterium at line-averaged density of $5 \cdot 10^{19} m^{-3}$ are 43 (25-74) MW and 38 (21-66) MW respectively, where the number in brackets correspond to 95% log-linear interval estimates.

Any recommendation for $W_{ped}$ for ITER FEAT was deferred to subsequent evaluation by the pedestal group at their April Meeting in Garching, and thereafter at the combined Meeting in Japan. The IAEA-2000 scaling is intended for interpolation only and 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 to answer your question'.

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

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

The organisers of the present Meeting in Lausanne were complimented for their professional arrangements.