Global Energy Confinement Analysis

by

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Investigation of the scaling of the plasma confinement is, in combination with the analysis of existence regions (power threshold scaling), of importance both for predicting empirically the performance of future devices and for providing a benchmark for theoretical as well as experimental results.

The currently most adequate simple power-law scalings of the thermal confinement time, which is based on the ITERH.DB2 confinement dataset, are ITERH93-P (EPS-93, NF-94) for ELM-free and ITERH92-P (IAEA-92) for ELMy discharges. The use of 0.85 times the ELM-free scaling ITERH93-P for ELMy confinement is to be considered as a second choice since it gives for the ELMy standard dataset a root mean squared error which is significantly higher (17.3%) than does ITERH92-P(y) (14.3%), which is is for a large part due to a different parameter dependence (notably q_{95} or B_t/I_p) of the ELMy data with respect to the ELM-free scaling, which difference can be understood from relatively plausible physical reasons. The average ratio of observed versus predicted confinement time of a small set of high-quality ELMy ITER Demonstration Discharges, performed at DIII-D and JET in 1994-1995, was 0.98 ± 0.04 for ITERH92-P(y), and 1.12 ± 0.03 for 0.85 times ITERH93-P.

Further investigations have been made in the direction of non-linear scalings that are more flexible with respect to the size dependence than the log linear scalings.

First, to provide an alternative of the EPS-94 (ELM-free) offset-linear scaling, by inheriting the aspect ratio dependence from ITERH93-P and expressing the two-term scaling in current density $j = I_p/\pi a^2\kappa$ and input power per surface area $P_{L'}/S$ (instead of, as in EPS-94, in the unnormalised I_p and $P_{L'}$), the $M_{\rm eff}$ exponent of the linear term from an analysis of the D into D and H into H data only. (In order to fit all geometrical exponents of a two term scaling empirically, confinement data from two additional, differently shaped, tokamaks would be required.) This scaling of W_{th}, based on the standard dataset including the low q data (except for DIII-D) is

$$0.0212\ I_p^{0.95} B_T^{0.40} \overline{n}_{19}^{0.67} M^{0.0} R^{3.0} \kappa^0 \epsilon^{0.3}$$

for the linear and

$$0.0057\ I_p^{1.1} B_T^{0.40} \overline{n}_{19}^{-1.1} M^{1.0} R^{-0.75} \kappa^{4.45} \epsilon^{-0.9} P_{L'}$$

for the offset term of the thermal energy, with (on log. scale) a rmse of about 11% and based on 1011 observations. Engineering units have been used (MJ,MA,T,10^{19}/m^3,MW), and $P_{L'}$ stands for $P_{NBI}+P_{ohm}$ minus the losses from shine-through, charge exchange and unconfined orbits and minus $\dot{W}_{tot}$.

Secondly, Dorland and Kotschenreuther have found and presented at the NAKA Meeting an exponential interaction model, which multiplies a power law by $(2q_{cyl})^{c/a\sqrt{n_{19}}}$ where c is a (non-linear) regression parameter, estimated to be negative. Also this model has a rmse of about 11%, and leads, in contrast to the offset-linear scalings, to less favourable predictions for ITER than the standard prediction of 6 sec. Although this problem is, especially for the ELMy data, alleviated when W_{th} for DIII-D (which are some 5 to 20% above their predictions by the simple power scaling) would be based, as they are for JET, on W_{dia} instead of on W_{mhd}, this curvature should be taken seriously. It is noted that in ITERH.DB2, W_{th} has been based on W_{dia} for ASDEX and JET, and on W_{mhd} for DIII-D and PDX/PBX-M, whereas for JFT-2M the consistency between both measurements was sufficiently high to warrant the use of the relation $W_{th} = \frac{2}{3}W_{mhd} + \frac{1}{3}W_{dia} - W_{fp}$.

Together with the curvatures from quadratic interaction terms reported earlier (IAEA-92, EPS-93), which were mainly between normalised input power $P_{L'}/n_e V$ and M_{eff}, and between n_e and B_T/j, and led to some 15-20% higher prediction for ITER than the simple power law expression, we have now three types of non-linear models in the plasma parameters, none of which can empirically be excluded on the basis of the ITERH.DB2 dataset. Due to their flexibility, these non-linear models are presently felt to be more adequate for physical discussions and interpolation than for extrapolation to ITER.

A realistic interval estimate for the (average) confinement time of ITER has to take into account a number of considerations. A summary of these are presented in the scientific minutes of the ITER Confinement Database and Modelling Expert Meeting in NAKA. Based on this meeting, an approximate '95%' interval for $\tau_{th,E}$ (ITER) at $I_p = 21$ MA, $B_T = 5.68$ T, $n_e = 13 \cdot 10^{19} m^{-3}$, $P_{L'} = 192$ MW, $R = 8.14$ m, $\kappa = 1.73$, and $\epsilon = 0.344$, has been estimated to be $(3.5, 9)$ sec, provided (ELMy) H-mode is reached. To reduce the length of this interval and eliminate possible sources of bias, an extension of the database and improvement of its experimental accuracy is needed, along with increased (non-linear) regression modelling, in combination with analysis from plasma theory.

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Revision (text in this font): Garching, Dec. 1996. ($\overline{n}_{19}^{-1.1}$ instead of $\overline{n}_{19}^{-1.0}$)