EUROPEAN FUSION DEVELOPMENT AGREEMENT

An Analysis of the Multi-machine Pedestal and Core Databases

by J.G. Cordey, O. Kardaun, D.C. McDonald and members of the ITPA Pedestal and Global database groups

Contents

•Fitting Pedestal data to a) Thermal Conduction Model. b) MHD Limit Model.

•Determining scaling of Core.

•Predictions of the pedestal temperature and τ_ε in ITER.

DATABASES

Joint Pedestal-Core database

Consists of 239 pulses from Asdex Upgrade(63), CMOD(19), DIII-D(11), JET(74), JT-60U(62). Similar selection to paper by K. Thomsen at H-mode workshop. Type I ELMs + CMOD.

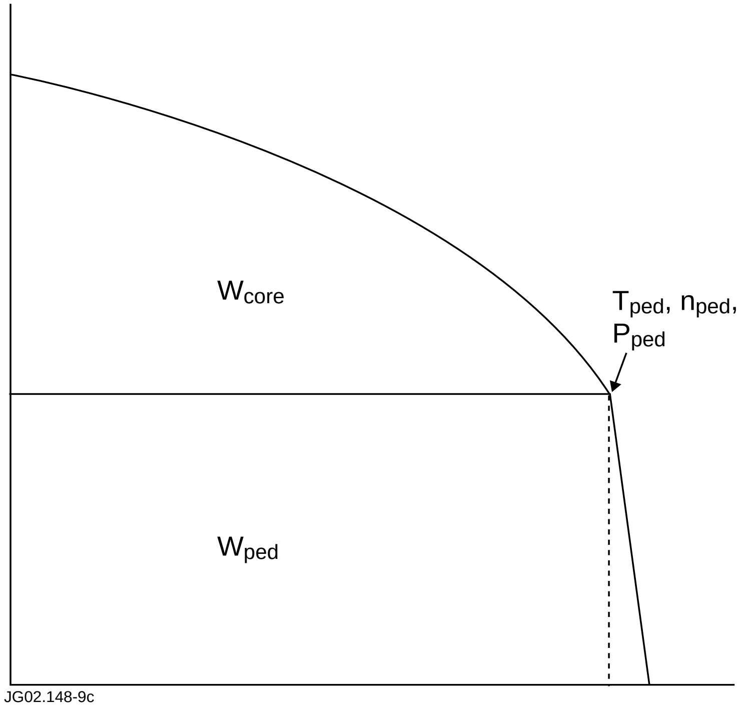
Expect database to be roughly doubled in size in the very near future, 180 pulses from DIII-D, 60 from JET, CMOD? So the analysis is on going.

Global Confinement ELMy H-mode Database DB3v10

Consists of 2677 pulses from 14 devices, the selection is the same as used in the IAEA Sorrento paper by O.Kardaun

Background

T_{ped}, n_{ped} etc. averaged over several ELM cycles.



Pedestal Models

a) Thermal Conduction model

$$\dot{W} = P - \frac{W_{ped}}{\tau_{\varepsilon cond}} - g(\beta, \nu^*)P$$

Thermal conduction through pedestal

ELM loss term

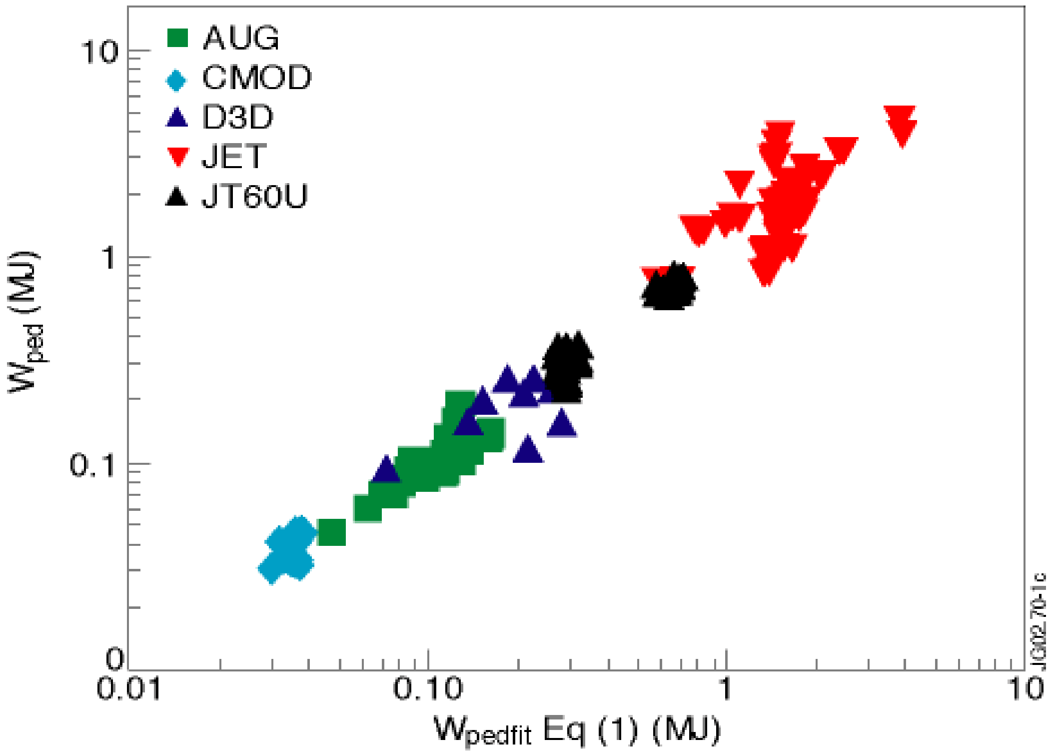
b) MHD limit model

$$\frac{\partial \beta_c}{\partial r} = \frac{\alpha_c}{Rq^2} \Rightarrow \beta_c \sim \frac{\Delta \alpha_c}{Rq^2} \quad \text{where} \quad \Delta \sim \rho_i^{\alpha} R^{1-\alpha}$$

•Main difference between models is the dependence on P in model (a).

Pedestal Scaling - Thermal Conduction Model

$$W_{ped} = e^{-3.76\pm0.1}\, I^{1.76\pm0.05}\, R^{1.17\pm0.06}\, P^{0.31\pm0.06}\, M^{0.28\pm0.12} q_{sh}^{1.33\pm0.19}$$



$$q_{sh} \equiv q_{95} / q_{cyl}$$

No dependence on B or n_{ped}

Dependence on ε, κ_a is indeterminate.

Satisfies Kadomtsev, Connor-Taylor constraint.

Expressed in Dimensionless Variables

$$B\tau_{ped} \sim \rho_{ped}^{*-3.4}\ \beta_{ped}^{-1.7}$$

Close to gyro-Bohm but with a large degradation with respect to β.

For small power loss by ELMs can be re-expressed approximately as

$$P \sim \frac{BW_{ped}}{\rho_{*ped}^{-3}\beta_o^{-1.7}} + 1.7\left(\frac{\beta_{ped}}{\beta_o} - 1\right)P$$

Pure gyro-Bohm heat loss

Elm loss term

β_o Type III/Type I transition β.

MHD Limit model

If a ballooning mode formalism was to apply then

$$p_{ped} \propto \frac{I^2}{R^2} \rho *^{\alpha} \propto \frac{I^2}{R^2} \left[\frac{\left(mT_{ped}\right)^{1/2}}{I} \right]^{\alpha}$$

Fitting this type of expression to the data is statistically quite difficult since there are strong correlations in the database between nped and R and between Tped and I. Two techniques have been used an Errors in Variables technique and the simpler technique of changing the variables to a set that are not correlated.

Both techniques give the same result.

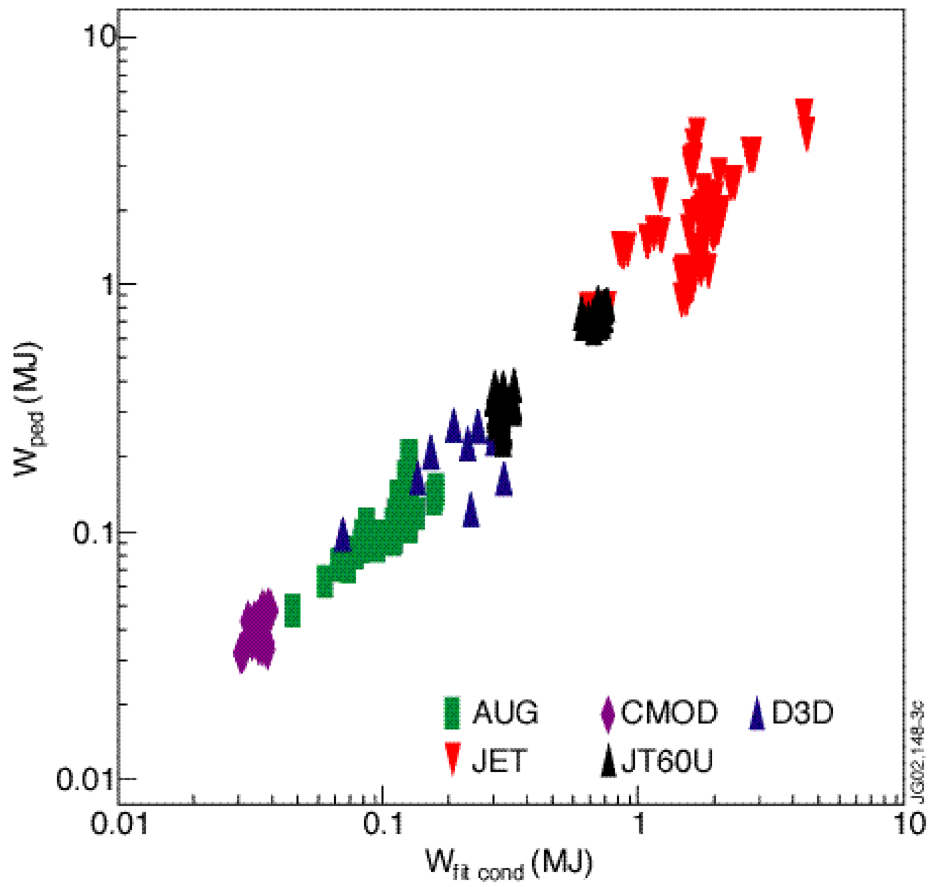
The resulting regression is

$$W_{ped} = \exp(-2.65 \pm 0.10)\, I^2 R\, \rho_*^{0.17\pm0.05} \nu_*^{-0.14\pm0.01}\, q_{sh}^{1.40\pm0.18}\, m^{0.24\pm0.12}$$

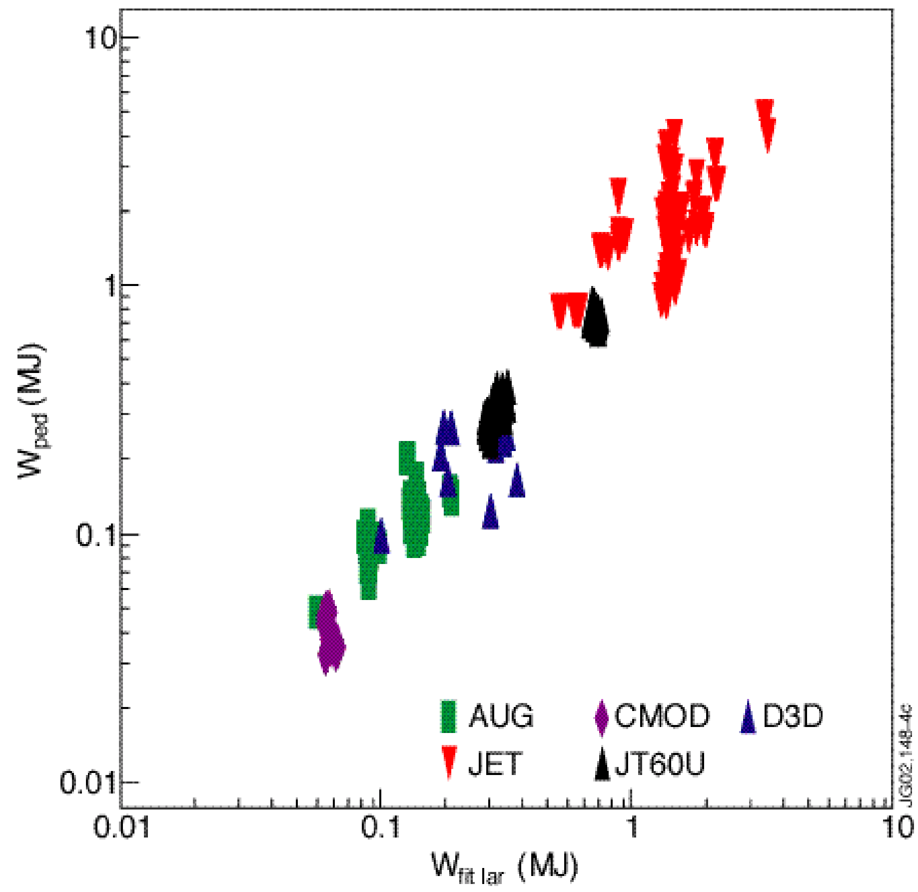
•Note both ρ* and ν* dependence is very weak.

Equivalent to $n_{ped} \sim T_{ped}^{-0.56}$ almost identical to result from “Errors in variables” technique.

Comparison of fits of pedestal data to models



Thermal Conduction Model
RMSE = 21%



MHD Limit Model
RMSE = 32%

Scaling of the Plasma Core

•Use expressions derived for W_{ped} to obtain $W_{core} = W_{th} - W_{ped}$ and then obtain fit to full ELMy H-mode database.

•For the Thermal Conduction Pedestal Model

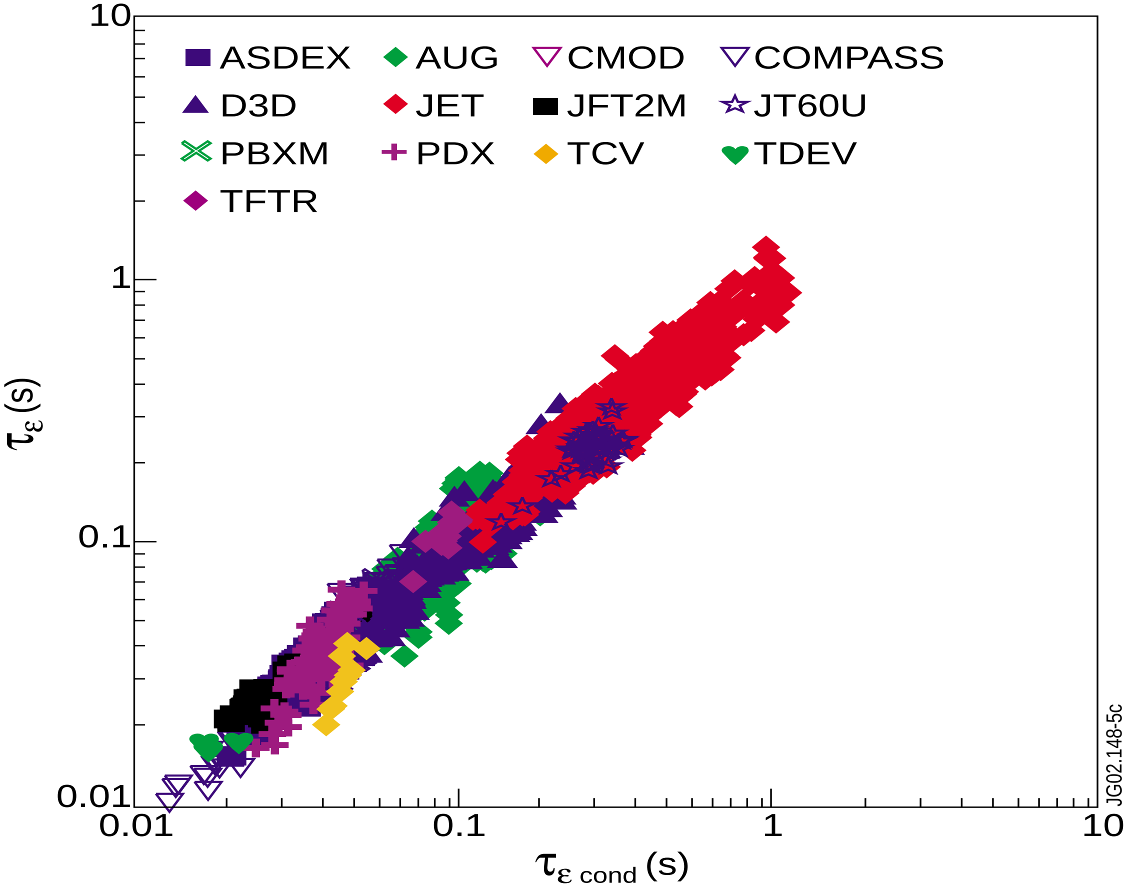
$$W_{core} = \exp(-3.35) I^{0.6} B^{0.17} n^{0.57} R^{2.24} \varepsilon^{0.88} \kappa_a^{0.8} m^{0.18} P^{0.34}$$

•The combined two term model $W_{th} = W_{ped} + W_{core}$ fits the ELMy H-mode database with an RMSE = 15.5% compared with 15.9% for the IPB98(y,2) one term scaling.

•The two term model with W_{ped} from the MHD limit ρ^* model has a somewhat worse fit 16.5%.

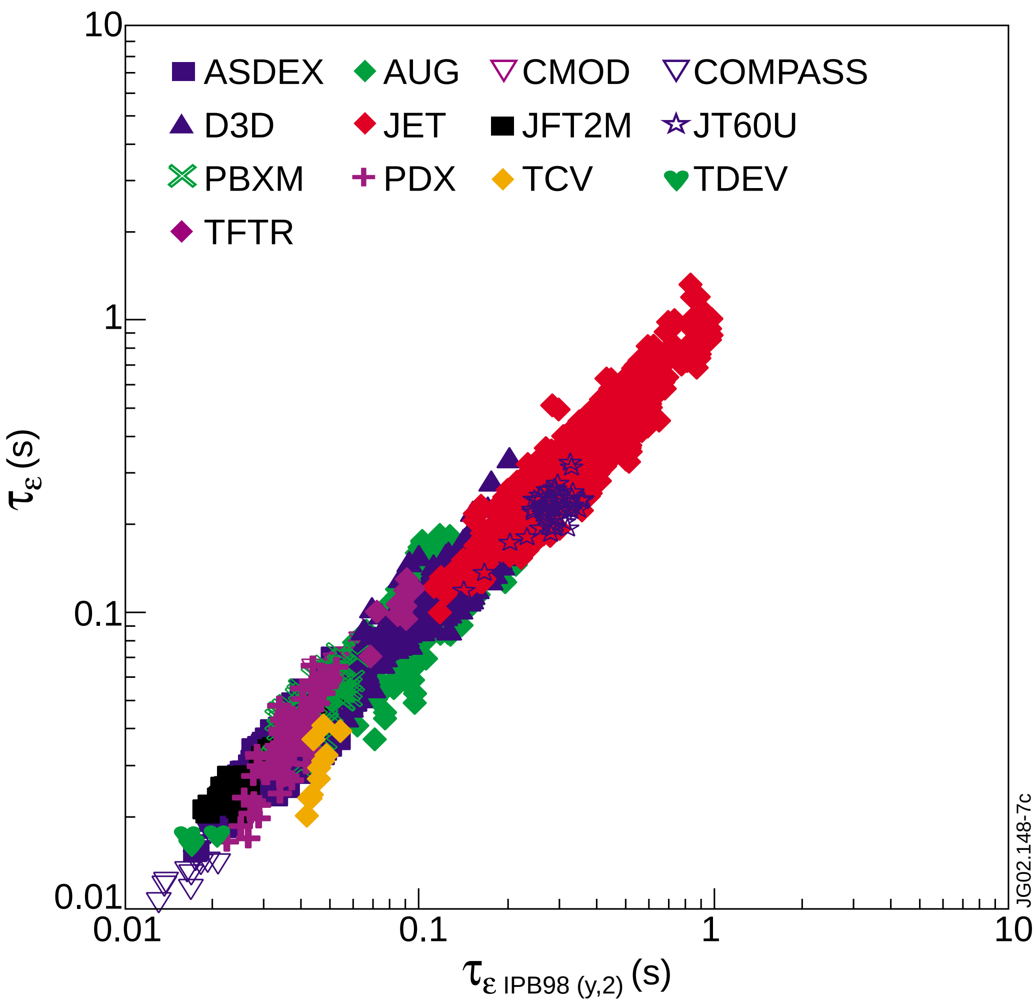
Fits to full ELMy H-mode DB

Two Term Thermal Conduction Model



RMSE = 15.5%

ITER reference one term model IPB98(y,2)



RMSE = 15.9%

Profile Stiffness?

Although scaling of W_{ped} and W_{core} with P and B is similar, their scaling with I, R and n is very different.

$$W_{ped} \propto I^{1.8} R^{1.2}; \quad W_{core} \propto I^{0.8} n^{0.56} R^{2.1}$$

Recent calculations by X.Garbet however suggest that this core model is partially stiff.

ITER Predictions	T_{ped}(KeV)	τ_{ε}(s)
ITER reference scaling IPB 98(y,2)	-	3.6
Thermal Conduction model	5.7	4.1
MHD Limit model	2.7	3.5

Both two-term model predictions are within the 95% confidence interval of the IPB98 scaling

The **FIRE** Tped predictions are 3.5 and 1.6 KeV

SUMMARY

•For the present pedestal DB, the thermal conduction model gives a better fit to the data than the MHD limit model.

•The origin of the degradation in τ_ε with β seen in the one term models, eg. IPB98(y,2) $\Rightarrow B\tau_\varepsilon \sim \rho^{*-2.7}/\beta$, is mainly from the pedestal and is probably a consequence of the ELMs.

•A two term model of the pedestal and core has been developed which is as good a fit to the full ELMy H-mode database as the one term models.

•The prediction of the pedestal temperature in ITER have been given for the two models, the global confinement times from both two term models are within the confidence interval of the IPB98(y,2) scaling.