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GLOBAL CONFINEMENT ANALYSIS

Final Report

for Period May 1, 1992 - April 31, 1994

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**Final Report for
ITER Grant DE-FG02-92ER54157**

Task Area: Confinement

Task Name: Global Confinement Analysis

Principal Investigator and Institution:

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A brief description of the task: 1) Analyze confinement databases to develop confinement predictions for ITER, and identify and quantify major sources of confinement uncertainty. 2) Determine the parametric dependencies of the temperature and density profiles for reactor relevant plasmas.

Description of the Progress and Results Achieved:

Confinement Scaling:

Our statistical analysis of the ITER H-mode energy confinement database has been published in *Nuclear Fusion* (Ref. [1]), and has gained considerable acceptance.

The random coefficient two-stage regression algorithm with the collisional Maxwell-Vlasov constraint was applied to the ITER H-mode confinement database [2]. We predict an ITER confinement time of 4.4 - 4.65 secs $\pm$ 32%. The dimensionally constrained scaling is $\tau_E = .07192 M^{1/2} (R/a)^{-.221} R^{1.568} \kappa^{.300} I_p^{.904} B_t^{.201} \bar{n}^{.106} P^{-.493}$. Thus the H-mode scaling is well approximated by ITER89P with a multiplier of 2.2 to 2.3. In contrast to L-mode confinement, the exponent of the size scaling is a major source of uncertainty.

The pathological confinement scalings of the ITER H-mode database group occur because ordinary least squares is very ill-conditioned when applied to the elmy and elm-free datasets separately. The data violate the collisional Maxwell-Vlasov constraint at the 10% to 30% significance level, probably due to radiation losses. Thus the standard physics constraint of no Debye radius dependence is of marginal validity.

After publication of the *Nuclear Fusion* article, we have continued to examine the data [3]. Our major new findings are 1) PDX is especially influential in determining

the size scaling; 2) the corrected Akaike information criteria [4] was used to estimate the importance of elms to the total energy balance. We found the confinement differences between elmy and elm-free discharges can be best modeled by letting only the intercept depend on the degree of elmyness. Thus, the parametric dependencies on $I_p, B_t \dots$ are assumed to be independent of elmyness.

At JET, we examined the second release of ITER H-mode database in collaboration with Knute Thomsen. The SAS procedure PROC MIXED was used to examine tokamak to tokamak variation. Our preliminary results are that while PROC MIXED is more efficient than our present algorithm, it is also more ill-conditioned. Thus we continue to advocate the two step procedure used in Ref. 1. Unfortunately, we received the second release of the H-mode database after the expiration of this grant. Thus, we were unable to apply our methodology to the new data.

We advised DOE on the merits of single machine scans on the effect of triangularity and elongation on confinement and on the variation of the H-mode enhancement factor. We have advised the confinement community of potential experiments which will reduce the uncertainty in confinement predictions for ITER.

Temperature and Density Shape Analysis:

Our other primary focus will be in the statistical analysis of temperature and pressure profile shape scalings for reactor relevant plasmas [5-9]. Our goal is to predict profile peaking factors as a function of the plasma parameters, including tritium concentration. The fitted profiles can then be input into ITER design codes and compared with theoretical models. In particular, the predictive accuracy of our empirical regression of profile shapes can be used to test the merits of Rebut's critical temperature gradient model.

The statistical analysis of profile shapes is based on an additive model of the profile shape dependence. Let $y(r, q, B_t, P, \bar{n}, M)$ be the logarithm of the temperature or pressure profile. The additive model is

$$y(r, q, B_t, P, \bar{n}, M) = y_0(r) + y_q(r) \ln q + y_B(r) \ln B_T \dots$$

The one dimensional functions, $y_0(r), y_q(r) \dots$, are parameterized by cubic B splines and estimated using penalized likelihood. See Refs. [5-8].

An analysis code has been developed in collaboration with Kaya Imre of City University at Staten Island. The code not only fits the profiles, but also determines which covariates are most important in fitting the data.

We have applied our code to data from TFTR and JET and are able to fit the data with a relative error of 10-12%. For the JET Ohmic temperature data, we found that changing q_{95} by raising B_t peaks the temperature profile more than lowering I_p . Changing the geometric variables, a, R, κ , only weakly changes the temperature profile. Two important observations for ITER are 1) the JET Ohmic density shape depends only on a Murakami-like parameter $\bar{n}/B_t$; 2) ICRH heating peaks the JET temperature profile appreciably more than NBI heating.

References [6]-[9] document these findings.

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