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Journal of Nuclear Materials 290–293 (2001) 644–647

journal of nuclear materials

www.elsevier.nl/locate/jnucmat

ASDEX-Upgrade edge transport scalings from the two-dimensional interpretative code B2.5-I

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Abstract

An interpretative version of the edge plasma code B2-SOLPS5.0 has been developed in order to investigate transport in the tokamak edge. A multi-variable fit procedure is used to minimise the differences between code predictions of plasma quantities and the experimental measurements of these same quantities by varying input parameters to the code (e.g., the radial heat diffusivity, the radial particle diffusivity, the fractional amount of neutrals pumped). A number of ASDEX-Upgrade (AUG) shots have now been analysed, and a preliminary analysis of the resulting database performed. Regression analysis suggests a strong improvement of heat transport with increasing plasma current, and moderate degradation with increasing density and heating power. Separate regressions for hydrogen and deuterium discharges suggest differences in the scalings of the transport. Work has now started on fitting both a diffusivity and an inward pinch for the particle transport. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: B2/EIRENE; ASDEX-Upgrade; Anomalous transport

1. Introduction

The major difficulty in predicting divertor conditions for future tokamaks is the uncertainty in the magnitude of the anomalous radial transport of energy and particles.

One approach is to take experimentally measured gradient lengths of power, temperature and/or density from existing machines, and then to extrapolate these quantities to future machines. These numbers have then been compared to code predictions for these future machines and, if necessary, to adjust the transport coefficients in the codes to produce a better match [1].

The approach taken here is to try and find scalings directly of the transport coefficients. The two-dimensional edge plasma fluid code, B2-SOLPS5.0 [2–4], is used to determine the appropriate transport coefficients for various experimental discharges, and then scalings of these transport coefficients are sought.

This particular approach started on ASDEX-Upgrade (AUG) with the fitting of analytic or semi-analytic heat transport models to data gathered from the edge laser system [5]. In order to allow for convective effects, as well as to determine the particle diffusivity, development started of the interpretive version of the code [6].

Other similar work includes the fitting of multi-1d models such as the onion-skin model of Stangeby [7].

2. Fit procedure

The basic procedure is outlined in Fig. 1. A non-linear, multi-variable fit procedure is used to minimise the differences between the experimental and code results by varying the input to the plasma code. Every 'function' evaluation of the fit is a full run of the plasma code. The residual that is minimised is the weighted sum of the squares of the differences between the code results and the experimental measurements, and the quantities that are varied to find this minimum would include transport coefficients and boundary conditions.

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PII: S0022-3115(00)00599-7

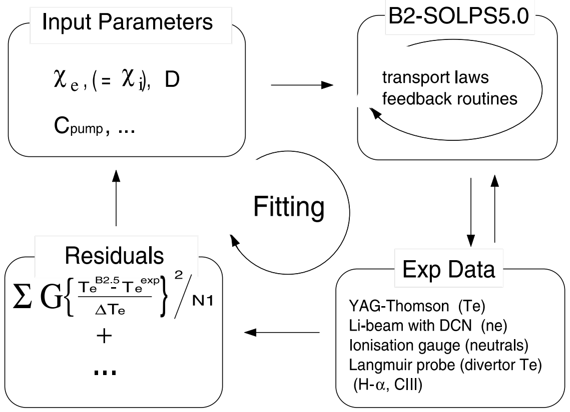

Fig. 1. Fit procedure used by the interpretive code.

The residual, R, is given by

$$R = \alpha_1 \frac{1}{M} \sum_M G_{T_e} \left(\frac{T_e^{\exp} - T_e^{\rm code}}{\Delta T_e^{\exp}} \right)^2 + \alpha_2 \frac{1}{N} \sum_N G_{n_e} \left(\frac{n_e^{\exp} - n_e^{\rm code}}{\Delta n_e^{\exp}} \right)^2 + \alpha_3 \frac{1}{N} \sum_N G_{\nabla n_e} \left(\frac{\nabla n_e^{\exp} - \nabla n_e^{\rm code}}{\Delta \nabla n_e^{\exp}} \right)^2 + \alpha_4 \left(\frac{\Gamma_{\rm pump}^{\exp} - \Gamma_{\rm pump}^{\rm code}}{\Delta \Gamma_{\rm pump}^{\exp}} \right)^2 + \alpha_5 \left(\frac{\Gamma_{\rm wall}^{\exp} - \Gamma_{\rm wall}^{\rm code}}{\Delta \Gamma_{\rm wall}^{\exp}} \right)^2, \quad (1)$$

where $T_e^{\exp}$ and $n_e^{\exp}$ are the mid-plane profiles of the electron temperature and density measured, $\nabla n_e^{\exp}$ the derived quantity from $n_e^{\exp}$, α the weighting factors, M and N the number of experimental T_e and n_e measurements, G the Gaussian weighting functions, $\Gamma_{\rm pump}$ the total neutral flux which is pumped, and $\Gamma_{\rm wall}$ is the mid-plane neutral flux density near the wall. The fitted quantities are radially and poloidally constant particle (D) and thermal ($\chi = \chi_e = \chi_i$) diffusivity, the electron density on the inner boundary ($n_{\rm e,core}$) and a quantity determining the amount of pumping from the private flux region ($C_{\rm pump}$). In addition the separatrix position (experimental error: ± 0.5 cm) is taken as a fit parameter.

The plasma code includes the ion-neutral recycling shown in Fig. 2 (see [6]) and the bypass neutral recycling [8] as an additional gas puff.

As the core edge boundary condition, a fixed density ($n_{\rm e,core}$) which is varied as a fit quantity is given to the plasma code. A fixed flux boundary condition was found to lead to bifurcations.

3. First database on ASDEX-Upgrade

The construction of a database of the radial transport coefficients has started on AUG. Only the limited

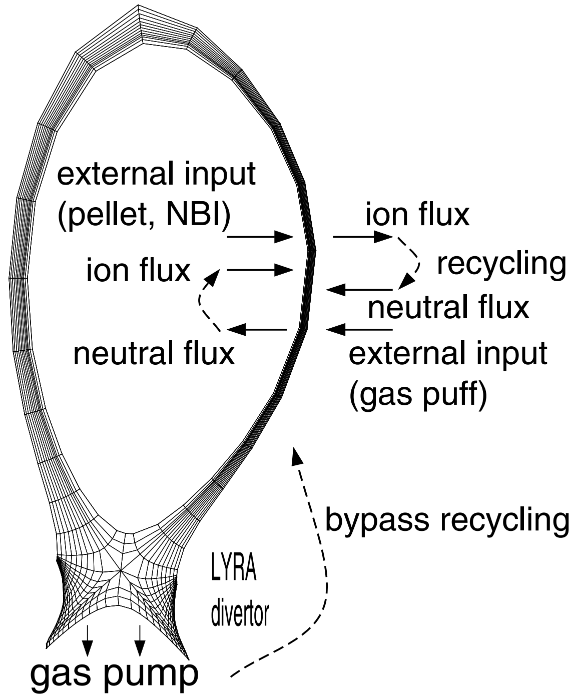

Fig. 2. Calculation region of the plasma code and boundary conditions.

number of discharges for which the YAG Thomson laser was at the edge and a slow radial scan of the plasma was performed [5] have been analysed. We have 44 shots with a range of plasma parameters as shown in Table 1.

The results of a fit are shown in Fig. 6(a).

The range of fitted transport coefficients, χ and D, is shown in Fig. 3. Obviously the transport coefficients and their ratio vary substantially over this data set, which contains shots with rather different parameters and confinement regimes. In order to identify first scaling trends, we plotted the transport coefficients against various parameters of interest. For instance, Fig. 4 shows a clear tendency of χ with respect to $\bar{n}_e/n_{\rm GW}$. It

Table 1
Range of experimental conditions (plasma current (I_p), power flux across the separatrix ($P_{\rm sol}$), safety factor near plasma edge (q_{95}), toroidal magnetic field (B_t), averaged electron density ($\bar{n}_e$), and the fraction of $\bar{n}_e$ to the Greenwald density limit ($n_{\rm GW}$)) in the edge transport database

Gas	D_2, H_2
Type	*H*-mode (ELM I and III), *L*-mode
I_p	0.4–1.2 MA
$P_{\rm sol}$	1.7–11 MW
q_{95}	3.2–11
B_t	1.5–2.6 T
$\bar{n}_e$	2.8×10^{19}–9.9×10^{19} m^{-3}
$\bar{n}_e/n_{\rm GW}$	0.34–0.81

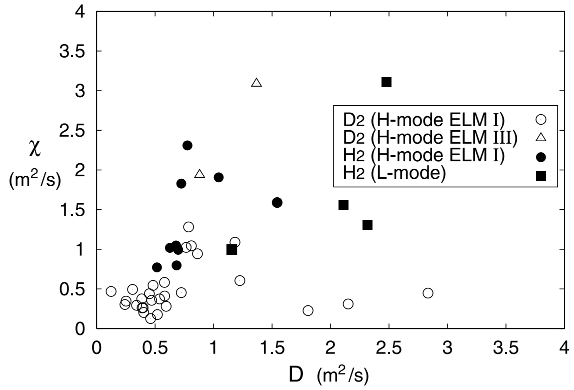

Fig. 3. Fitted radial transport coefficients.

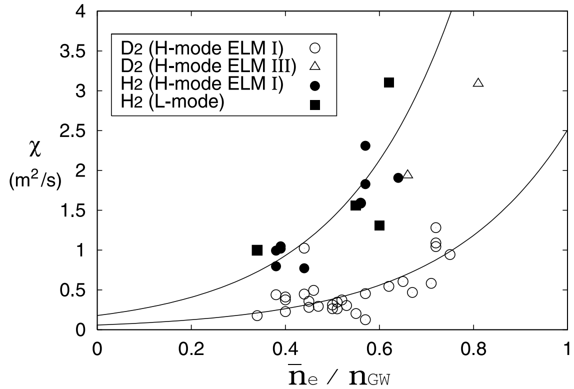

Fig. 4. Dependency of χ on $\bar{n}_e/n_{GW}$.

seems that the χ of hydrogen plasmas depends on $\bar{n}_e/n_{GW}$ more strongly than that of deuterium. (An earlier work [6] showed that χ is not as dependent on boundary conditions, so we concentrate on the heat diffusivity in the analysis.)

4. Preliminary multiple regression fit to χ

We have performed a multiple regression fit to the data fitting a power law (using a multiple linear regression to the logarithms of the quantities). Fitting to I_p, P_{sol} and $\bar{n}_e$ we get as a fit for the deuterium *H*-mode discharges

$$\chi \propto I_p^{-2.11\pm0.46} P_{sol}^{0.64\pm0.19} \bar{n}_e^{0.65\pm0.44} \tag{2}$$

and

$$\chi \propto I_p^{-1.69\pm0.45} P_{sol}^{0.00\pm0.52} \bar{n}_e^{0.68\pm0.68} \tag{3}$$

for the hydrogen *H*-mode discharges. This fit is shown in Fig. 5.

We see a strong decrease of transport with increasing plasma current (as might be expected by assuming some sort of ballooning *ansatz*), an increase of transport with increasing separatrix density, and for the deuterium, an increase of transport with increasing power across the separatrix.

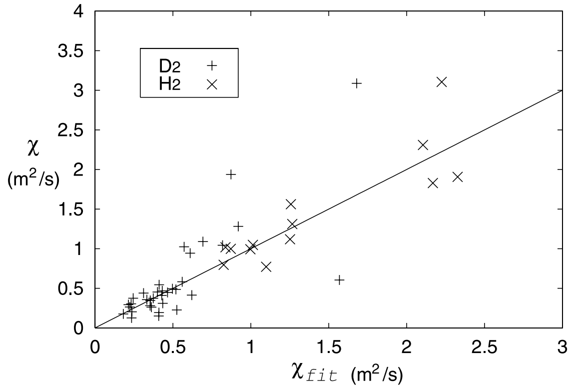

Fig. 5. Multiple regression fit to χ.

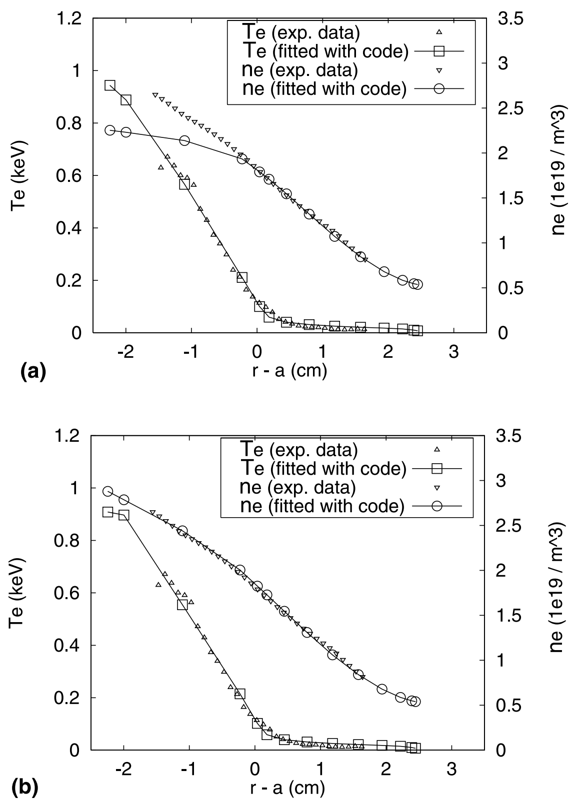

Fig. 6. Fitted T_e and n_e profiles of the shot #10814 (a) without and (b) with an inward pinch.

The fit is improved somewhat if the ELM frequency is included as a fit parameter, though this then obscures the dependence on the remaining parameters because of the dependence of the ELM frequency on these parameters.

5. Including an inward pinch

In some case it was not possible to get a good fit to the entire density profile. By extending the fitted quantities to include an inward pinch ($v_{\rm in}$) and a main chamber gas puff ($\Gamma_{\rm puff}$), and augmenting the residuals of Eq. (1) by

$$R = R_{\rm Eq.1} + \alpha_6\left(\frac{T^{\rm exp}_{\rm e,divin} - T^{\rm code}_{\rm e,divin}}{\Delta T^{\rm exp}_{\rm e,divin}}\right)^2 + \alpha_7\left(\frac{T^{\rm exp}_{\rm e,divout} - T^{\rm code}_{\rm e,divout}}{\Delta T^{\rm exp}_{\rm e,divout}}\right)^2 + \alpha_8\left(\frac{\Gamma^{\rm exp}_{\rm core} - \Gamma^{\rm code}_{\rm core}}{\Delta \Gamma^{\rm exp}_{\rm core}}\right)^2 \quad (4)$$

a better fit was possible, as can be seen in Fig. 6. Expanding the fitted quantities comes at the expense of added cpu time for the fit procedure, increasing this by about a factor of three.

6. Summary, conclusions and outlook

We have modified the fluid plasma code B2-SOLPS5.0 so that it can be used as an interpretive code, determining edge transport coefficients by minimising the differences between code 'predictions' and the experimental measurements.

44 AUG shots have now been analysed, and preliminary scalings of the edge transport deduced. The transport in the edge seems to decrease strongly with plasma current, and rise moderately with density and (for deuterium) with heating power.

The database needs to be expanded on AUG, covering a wider range of experimental conditions. It would also be of interest to extend the work to other tokamaks so that a size scaling could be deduced. In this context, JET would be of particular interest, though the lack of suitable edge diagnostics there might prevent this.

The work could also be extended to include fitting the pedestal region, different parameterisations of the transport and impurities.

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