TRANSPORT IN BEAM-HEATED ASDEX DISCHARGES BELOW AND IN THE VICINITY OF THE BETA LIMIT

O. Gruber, W. Jilge, H.S. Bosch, H. Brocken, A. Eberhagen, G. Fussmann, O. Gehre, J. Gernhardt, G. v. Gierke, E. Glock, G. Haas, J. Hofmann, G. Janeschitz, A. Izvozchikov, F. Karger, M. Keilhacker, O. Klüber, M. Kornherr, K. Lackner, M. Lenoci, G. Lisitano, F. Mast, H. M. Mayer, K. McCormick, D. Meisel, V. Mertens, E. R. Müller, H. Murmann, H. Niedermeyer, W. Poschenrieder, H. Rapp, H. Riedler, H. Röhr, J. Roth, F. Ryter, F. Schneider, C. Setzensack, G. Siller, P. Smeulders, F. X. Söldner, E. Speth, K.-H. Steuer, O. Vollmer., F. Wagner,

Max-Planck-Institut für Plasmaphysik, EURATOM Association,
D-8046 Garching, Fed. Rep. Germany.

1. INTRODUCTION

Radial transport and confinement properties of ohmically and beam-heated ASDEX discharges are studied using the PPPL transport analysis code TRANSP[1] and measured radial plasma profiles and global parameters. Results are that the anomalous electron thermal transport is dominating in low-density ohmic as well as "L" beam-heated ASDEX plasmas. It leads, however, for these regimes to different scaling laws of the global energy confinement time [2]. At high-density ohmic and "H" mode beam-heated discharges the neoclassical ion heat conductivity and convective losses (H mode) are comparable to the electron losses and tend to dominate the energy balance.

The ion heat conduction χ_i is described by two times the neoclassical value calculated by C. Chang and F. Hinton in all discharge phases (OH, L, H, H^*). Thereby a χ_i of three times $\chi_{i,neocl}$ fits the central ion temperature measured by the energy spectrum of CX neutrals whereas a $\chi_i = \chi_{i,neocl}$ yields for the calculated T_i profiles the measured neutron fluxes.

Experiments show that the electron temperature profile shape in ohmically and beam-heated "L" discharges is only influenced by the safety factor $q^*(a)$[3]. According to this concept the elctron thermal diffusivity $\chi_e(r)$ depends directly on the electron thermal conductive loss $P_{cond,e}$ across the magnetic surface with radius r, which is a certain fraction of the input power. From the definition $\chi_e = -(P_{cond,e}/2\pi R)/(n_e T_e \frac{r}{T_e}\frac{\partial T_e}{\partial r})$ and from the "profile consistency" argument $\frac{r}{T_e}\frac{\partial T_e}{\partial r} \simeq -\alpha \frac{r^2}{r^{*2}}$ (where r^* may be the $q = 2$ radius, and α is a function of $q^*(a)$) one obtains $\chi_e(r) \sim P_{cond,e}(r)/(n_e(r)T_e(r)r^2)$. The definition of a local χ_e which depends on local plasma parameters does not seem to be appropriate. In this paper the χ_e values deduced from the transport analysis of OH, L and H mode discharges are used to show which description is applicable.

2. PROFILE CONSISTENCY IN OHMIC AND BEAM-HEATED "L MODE" PLASMAS

In nearly steady-state ohmic discharges χ_e can be described by a local parameter dependence $\chi_e(OH) = \chi_{CMG} \sim (B_t a/R)/(n_e^{0.8} T_e q)$ [2]. But in ohmically heated pellet discharges only the χ_e values averaged over one pellet cycle agree with χ_{CMG}, whereas a description in agreement with "profile consistency" depicts also the time-resolved χ_e measurements and yields an explanation for the scaling given by χ_{CMG} [4].

L-mode discharges at $q^*(a) \approx 2.6$ have been studied using $H^o \rightarrow D^+, D^o \rightarrow H^+, D^o \rightarrow D^+$ injection with 14.5–40 keV maximum energy/nucleon yielding about the same normalized T_e profiles (Fig. 1a), despite quite different heat deposition profiles (see Fig. 1b), total heating powers ($P_h = P_{bi} + P_{be} + P_{OH} = 1.5 \div 4.1 MW$) and densities ($\bar{n}_e = 4.10^{19} \div 11.3 \cdot 10^{19}\,\mathrm{m}^{-3}$). The electron heating ($P_{be} + P_{OH}$) exceeds slightly the ion heating (P_{bi}) and $T_i \gtrsim T_e$ is obtained. Accordingly the central confinement times $\tau_E^* = W_{pl}/(P_h - \dot{W}_{pl})$ are increasing with off-axis heating deposition, whereas the global confinement times are about the same. The deduced $\chi_e(r)$ values given in Fig. 1d can well be described by $\chi_e \sim P_{cond,e}/(n_e T_e r^2)$ for $r_{q=1} < r < 0.8a$ for individual discharges, and at a fixed radius of $r = 2a/3$ the relation $(\chi_e n_e T_e)\ |_{2a/3} \sim P_{cond,e}(2a/3)$ holds for different discharges too. At that radius $P_{cond,e} \approx (0.5 \div 0.65) P_h$ holds, showing the dominance of electron thermal transport in the L mode over the entire density range.

Despite this good agreement a fit of χ_e depending on the local plasma parameters I_p, n_e and T_e has been tried with the limited data base at present available (not only the discharges described here). Good agreement is obtained with a scaling $\chi_e(L) \sim r^2/(I^{1.5}(r) n_e^{0.3}(r) T_e(r) A_i)$, where A_i is the ion mass. This parameter dependence will be tested using a simulation code to reproduce the measured temperatures. We are aware of the "explosive" nature of the $1/T_e$ dependence and that the limited parameter set may give a misleading tendency with inherent correlations of the chosen local parameters.

3. H-MODE CONFINEMENT BELOW AND AT THE BETA LIMIT

Beam-heated ASDEX discharges with $D^o \rightarrow D^+$ show an H mode confinement of $\tau_E^*(a) = 0.2I$[MA, s] independent of the heating power for plasmas with $\beta < 0.9\beta_c$ and $\beta_c = 0.028 I/aB_t$[MA, m, T]. Reaching the β_c limit the energy confinement times decrease with increasing heating power. This confinement factor of 0.2 s/MA is more than a factor of 2 better than reported from D III and PDX discharges. At higher plasma currents ($I_p >$ 400kA) or lower q^* values (< 3) the confinement factor is decreased ($\tau_E^*(a) \lesssim 60ms \lesssim 0.15 I_p$) [5]. Together with $H^o \rightarrow D^+$ and $H^o \rightarrow H^+$ injection results, a scaling $\tau_E^*(H) = 0.1 I A_i$ is deduced.

At these high confinement times and therefore high plasma energies (see Fig. 2a) the convection losses ($P_{conv}/P_h \approx \frac{5}{2}\Gamma k(T_e + T_i)/\Gamma\langle E\rangle$, with the particle flux Γ and the medium energy $\langle E\rangle$ of the injected neutrals) and the ion conduction losses are comparable to the elctron conduction losses (see Fig. 2b). These are now only between $0.25((I_{pl} = 310kA, q^*(a) = 4)$ and $0.4(I_p = 410kA, q^*(a) = 2.7)$ of the total heating power over a large part of the plasma

cross-section. At the higher plasma current the neoclassical ion heat losses are reduced ($\chi_i \sim 1/I^2$). The ion heating by the beams exceeds the electron heating with $D^o \rightarrow D^+$ injection ($P_{bi} \lesssim 3P_{be}$) and the contribution of the beams to the total β value is about 25%. This fact results in the difference of the τ_E^* values with and without the beam contribution given in Fig. 2c. The confinement time τ_E includes only the conductive and convective losses and shows the influence of the radiation and CX losses on τ_E^*.

For these H-mode discharges no description compatible with "profile consistency" is available at present. But the local parameter dependence of $\chi_e(L)$ given above fits also the $\chi_e(H)$ values covering now a parameter range of $0.6 \lesssim \chi_e(L,H) \lesssim 3.7m^2/s, 200 \lesssim I \lesssim 350\,\mathrm{kA}, 2.8 \cdot 10^{19} \lesssim n_e \lesssim 11 \cdot 10^{19}\,\mathrm{m}^{-3}, 300 \lesssim T_e \lesssim 1100\,\mathrm{eV}, 1.3 \lesssim A_i \lesssim 2$. The χ_e for the discharge near the β limit described in Fig. 2 is above this scaling derived from discharges below the β limit.

4. CONCLUSIONS

In OH and L mode discharges the concept of "profile consistency" is supported by pellet injection and strongly varied deposition profiles, respectively. In H-mode discharges no consistent picture has evolved up to now. But also a dependence of χ_e on local parameters seems possible in both L and H mode. $D^0 \rightarrow D^+$ injection provides high confinement times with a scaling $\tau_E^* = 0.1IA_i[\mathrm{s, MA}]$ for $q^*(a) > 3$ and with strong ion heating. At the β limit confinement degrades with increasing χ_e compared with χ_e below the β limit.

REFERENCES

[1] R. Hawryluk, in *Physics of Plasmas Close to Thermonuclear Conditions*, Vol. 1, Varenna (1979) (EUR-FU-BRU/XII/476/80).

[2] O. Gruber, Proc. Invited Papers, Int. Conf. on Plasma Physics, Lausanne (1984) Vol. 1, p. 67.

[3] F. Wagner, O. Gruber, K. Lackner et al, submitted to Phys.Rev.Letters.

[4] O. Gruber et al, this conference.

[5] M. Keilhacker et al, Plasma Phys. Contr. Fusion **28** (1986), 29

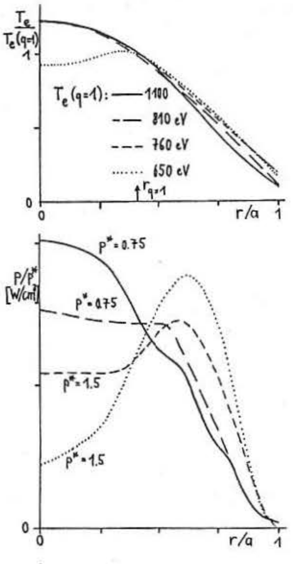

Fig. 1 Normalized T_e , heating power density p, energy confinement time τ_E^* and χ_e radial profiles of L-mode discharges with $q^*(a) = 2.6$.

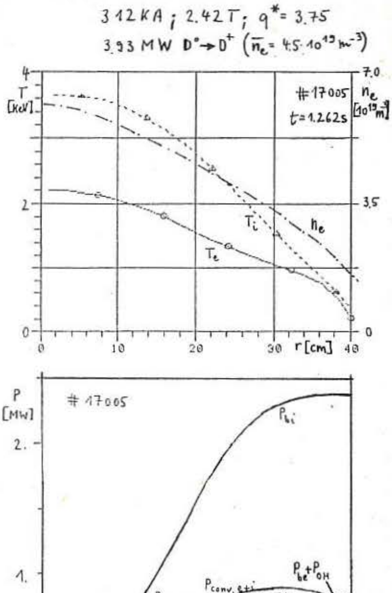

Fig. 2 Radial profiles of T_e, T_i and n_e, volume-integrated power balance, τ_E^* with and without beam contribution, $\tau_E = W_{pl}/(P_{cond}+P_{conv})$, χ_e and χ_i of H-mode discharge at the β limit $(\beta/\beta_c = 0.95)$.