RESPONSE OF PLASMA PROFILES TO NEUTRAL BEAM POWER DEPOSITION IN ASDEX

E. Speth, O. Gruber, K. Lackner, H. Riedler[6], A. Stäbler, O. Vollmer,
G. Becker, H.S. Bosch, H. Brocken, A. Carlson, A. Eberhagen, G. Dodel[1],
H.-U. Fahrbach, G. Fußmann, O. Gehre, J. Gernhardt, G.v.Gierke, E. Glock.
G. Haas, W. Herrmann, J. Hofman, A. Izvozchikov[2], E. Holzhauser,
K. Hübner[3], G. Janeschitz, F. Karger, M. Kaufmann, O.Klüber,
M. Kornherr, M. Lenoci, G. Lisitano, F. Mast, H.M. Mayer, K.McCormick,
D. Meisel, V. Mertens, E.R. Müller, H. Murmann, J.Neuhauser,
H. Niedermeyer, A. Pietrzyk[4], W. Poschenrieder, H. Rapp, A. Rudyj,
F. Schneider, C. Setzensack, G. Siller, F. Söldner, K.Steinmetz,
K.-H. Steuer, S. Ugniewski[5], F. Wagner, D. Zasche

Max-Planck-Institut für Plasmaphysik
EURATOM Association, D-8046 Garching

[1] University of Stuttgart, [2] Ioffe Institute, [3] University of Heidelberg, [4] University of Washington, Seattle, USA, [5] Inst.for Nuclear Research, Swierk, Poland, [6] Schiedel-Stiftung, Austria

1. INTRODUCTION

Profile consistency has been the subject of an ongoing discussion. From the prevailing results of different experiments /1,2,3,4,5/ did not emerge a consistent pattern yet. Among the open questions we address two topics in this paper: namely (1) how the plasma profiles in the H-regime respond the variations of the deposition profile and (2) more generally, to what extent the observed resilience of the plasma profiles would be consistent with a local but nonlinear relation between temperature - or pressure gradients and the local heat flow.

2. H-MODE EXPERIMENTS

Heating profile experiments in the L-regime have previously been reported from ASDEX /1,2,3/, where the most extreme cases of hollow deposition could be realised by working at elevated densities ($\bar{n}_e$ = $1.1 \cdot 10^{14}$ cm^{-3}) /3/. Due to the upper density limit of $(7 \div 8) \cdot 10^{13}$ cm^{-3} observed for the H-regime on ASDEX in non-pellet-fuelled discharges, the deposition profile in the present H-mode experiments could be varied only over a more restricted range. In particular we have injected 40 keV H^0 and 45 keV D^0 respectively into D^+-plasmas with otherwise identical parameters (I_{pl} = 420 kA, $\bar{n}_e$ = $6.2 \cdot 10^{13}$ cm^{-3}, P_N = 1.7 MW). Figure 1 shows the deposition profiles of the total power to ions and electrons as computed with the FREYA-code including the ohmic power. The subsequent response of the pressure profiles is shown in Fig. 2: there is no significant difference. The beam-induced change on plasma composition and the known isotope effect on confinement should be small, since the profiles analysed are taken 150 msec after the beams are turned on.

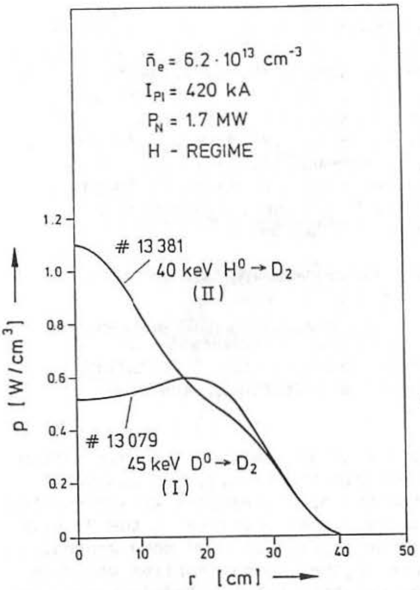

Fig. 1:
Deposition profiles of the total power to ions and electrons including ohmic power.

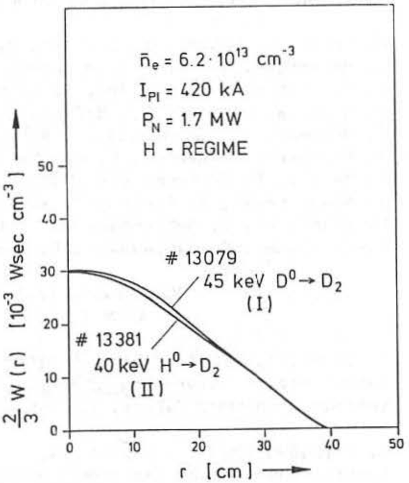

Fig. 2:
Resulting experimental pressure profiles for the power deposition cases of Fig. 1
$2/3\ W(r)=\int n_e(r)(T_e(r)+T_i(r))dV$
The T_i-profiles not being known precisely, electron pressure and ion pressure form factors were assumed to be identical and the integrated energy content was normalised to the diamagnetic signal (fast ions neglected).

Typical parameters of the two cases are compared in Table 1. Although the Te-profiles (not shown here) establish the well-known differences to those in the L-regime, (pedestal at the edge) their shape agrees within the error bars, and also the previous findings in the L-regime concerning deposition profile changes /1/ are valid: $\tau_{Ee}(0)$ shows a 60 % enhancement, τ_E (a) is about 15 % higher, $T_e(0)$ is marginally higher for hollow deposition. Thus the conclusions drawn previously /1,2/ for profile invariances in the L-regime appear to be applicable to the H-regime too at least within the range of presently accessible deposition profiles.

Table 1

	# 13 079 (45 keV $D^{\circ} \rightarrow D_2$)	# 13 381 (40 keV $H^{\circ} \rightarrow D_2$)
$T_e(0)$	(1.33 ± 0.15) keV	(1.25 ± 0.17) keV
τ_E (a)	58 msec	51 msec
$\tau_{Ee}(0)$	158 msec	96 msec

(Concerning the rather lowish global confinement times (for the H-mode) one should note that the burst frquency of the ELM's dramatically increases when approaching the upper density limit in the H-mode; consequently the confinement time is considerably reduced in comparison to the medium density cases or the quiescent H*-mode.)

3. NONLOCAL HEAT TRANSFER

Theoretical examinations by other groups have shown the incompatibility of predictions of standard first principle drift wave theories with the experimentally observed T_e-profiles. This resilience has led to the proposition /6/ that a globally acting principle has to be invoked to explain their very weak variation with any change of power deposition. As an alternative explanation, we compare the response predicted by empirical heat transport laws containing a nonlinear relation between temperature- or pressure-gradients and the local heat flow.
For the stated purpose of a rather qualitative illustration we make a number of simplifying assumption which otherwise would have to be viewed critically. So we do not distinguish between electron and ion transport (assuming $T_e = T_i$). We use in the following calculations two heat transport models, a linear one

$$q_{heat} = - f_1(r) \cdot \nabla p \qquad (1)$$

and a quadratic one

$$q_{heat} = f_2(r) \cdot (\nabla p)^2 \qquad (2)$$

with f_1 and f_2 chosen as $f_1(r) = f_2(r) = (1 + (r/a)^2)^3$. Only relative variations will be considered, so that no absolute coefficient values need to be specified (q_{heat} ... radial heat flux density).

As a realistic example we consider the two extreme deposition profiles reported in /2/, which are more or less identical to the ones in Fig. 1. The corresponding unnormalised profiles are shown in Figs. 3a and 3b. They show, in spite of the large apparent difference in the power deposition, a remarkable small difference already for the linear transport model case, which is further diminished when changing over to the quadratic transport law.
The above examples show that on the basis of presently available data it seems difficult to rule out a local, nonlinear transport law as an explanation of the observed profile resilience in tokamaks. A nonlinear transport law of the form (2) would automatically link profile resilience to confinement degradation with power as globally observed in

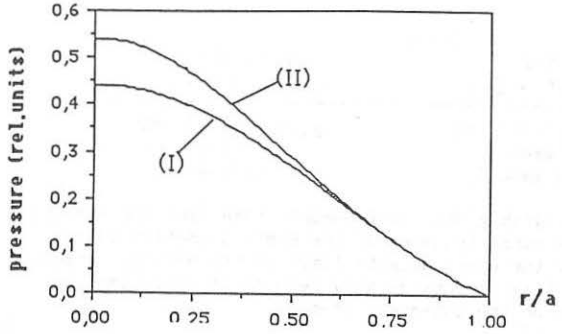

Fig. 3a:

unnormalized pressure profiles predicted by the linear transport law for the power deposition cases of Fig. 1.

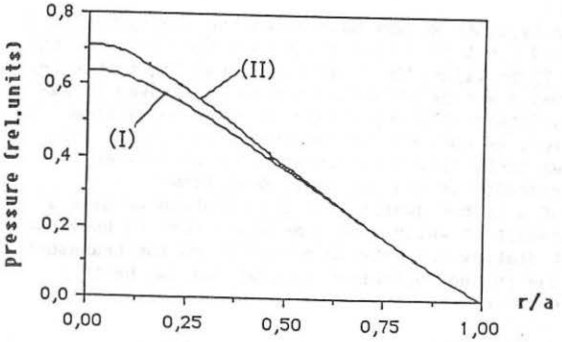

Fig. 3b:

unnormalized pressure profiles predicted by the quadratic transport law for the power deposition cases of Fig. 1.

L-discharges. Power independence of confinement times as observed in ASDEX H-mode discharges could however be made compatible with strong profile resilience e.g. by an ansatz $q_{heat} \sim (\nabla p/p) \cdot \nabla p$. The considerations can of course not rigorously disprove the explanation that plasma profile shapes are determined by some non-local principle. One so far unanswered argument in favour of such a more global explanation is the sharp transition between L- and H-mode behaviour, and the obvious nonexistence of mixed situations where part of the plasma volume is in the L- and the other in the H-regime.

REFERENCES

/1/ E. Speth et al., Proc. 12th EPS Conference, Budapest (1985), Vol. II, 284
/2/ F. Wagner et al., Phys. Rev. Lett. 56 (1986) 2187
/3/ E. Speth et al., Proc. 13th EPS Conference, Schliersee (1986), Vol. II, p. 281
/4/ R.J. Goldston et al., ibid. P. 41
/5/ J.G. Cordey et al., Proc. 11 Int. IAEA Conf., Kyoto (1986) paper A-II-3.
/6/ H.P. Furth, Plasma Physics and Contr. Fus. 28, 9A (1986) 1305

FUSION IGNITION EXPERIMENT WITH NO AUXILIARY HEATING

R. Carrera, E. Montalvo and M. N. Rosenbluth

University of Texas at Austin*

The crucial step to prove that fusion energy is accessible in a controlled manner is the realization of an experiment in which stable ignited plasmas are produced. An experiment (IGNITEX) to produce and control thermonuclear ignited plasmas is considered here. The original concept was proposed by M. N. Rosenbluth, W. F. Weldon and H. H. Woodson[1]. Some of B. Coppi's ideas[2] for a compact thermonuclear experiment are used in conjunction with recent advances in the technology of high current systems to envision a novel ignition tokamak system with 20 Tesla toroidal field on axis and plasma currents in excess of 12 Megamperes.

The IGNITEX device is a single-turn coil high-field compact tokamak capable of reaching and controlling fusion ignition with ohmic heating alone[3]. A copper-alloy single-turn coil operating at low voltages permits very high filling factors and then, a high-strength toroidal field magnet system. The mechanical stresses are reduced to tolerable levels by preloading the coil structure and by using a central compression bar. The electromagnetic pulse is lengthened by cryogenic precooling of the magnet system to liquid nitrogen temperature. Because of the low impedance of the nonconventional magnet system a special power supply is required that can provide a very large pulse of current at very low voltage. A set of twelve homopolar generators, each one rated to 12.5 MA, 10 volts and 1.GJ are used in parallel to feed the single-turn coil. An internal poloidal field magnet system formed by ten toroidal single-turn coils can induce the plasma currents required for fusion ignition and provide for plasma equilibrium and shaping. This system permits bucking of the single-turn coil, then increasing the strength of the toroidal field magnet, and provides a high coupling to the plasma, then minimizing the requirements for the poloidal field system power supply. Because of the thick single-turn coil surrounding the plasma, the magnetic flux requirements are lower than in a conventional tokamak. A set of five homopolar generators that swing the current in the coils from 22 MA to -15.7 MA along the discharge serve as the power supply for the internal poloidal field system.

In a deuterium-tritium plasma ignition is a state in which the fusion reaction rate is high enough for the plasma heating due to alpha particles to be greater than the plasma power losses due to conduction, convection and radiation. A self-sustained thermonuclear fusion reaction is then produced. The energy confinement in ignited plasmas is not yet known. In the calculations presented here the heating due to the alpha particles is assumed to degrade the plasma energy confinement as auxiliary heating does in present tokamak experiments. Bremsstrahlung and cyclotron radiation losses also contribute to the cooling of the plasma.

The plasma column has a major radius of 150 cm and the minor radius is 47cm. An elongation of the plasma cross section 1.6 with no triangularity has been considered. Theoretical calculations of the plasma power balance at the flat-top of the plasma discharge (using conventional energy confinement scalings) indicate that the IGNITEX experiment has an ample margin for ignition without auxiliary heating. The device is designed to approach ignition ohmically at very low plasma beta (< 1%) which makes the experiment simple and reliable.