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Transport Analysis of High Performance JET Discharges in D, D-T and T Plasmas

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The transport analysis code TRANSP has been used extensively to simulate the recent high performance JET discharges in deuterium, deuterium-tritium and tritium plasmas. High fusion performance is obtained in two types of regime: the hot ion ELM-free H-mode and the optimised shear L-mode. The time evolution of the main plasma parameters is shown in Fig. 1 for the best deuterium discharges obtained in the two regimes. The hot ion ELM-free H-mode, # 40305 (3.8MA / 3.4T plasma, P_{NBI} = 19MW, P_{RF} = 3MW) achieved a neutron yield of 5.2 x 10^{16} neutrons/s. The performance is limited by a giant ELM which occurs when the edge pressure gradient is close to the ballooning limit [1]. The optimised shear L-mode, # 40554 (3.4MA / 3.4T plasma, P_{NBI} = 19MW, P_{RF} = 2MW), achieved a neutron yield of 5.6 x 10^{16} neutrons/s. A fast current ramp (0.4MA/s), low power lower hybrid current drive (1-2MW) and ICRF pre-heating are used to control the current profile evolution [2]. This regime operates close to the beta limit for most of the heating phase [3]. Fig. 2 compares the T_e and T_i profiles for both regimes at the time of maximum neutron yield: the central values of T_e and T_i reach similar values . For the optimised shear pulse, the profiles of T_e and T_i show steep gradients for a normalised radius ρ = 0.4 - 0.6 ; this feature is also seen in the electron density and the toroidal velocity profiles. For the hot ion H-mode pulse, all profiles have high edge values typical of the H-mode regime and the electron density profile is very flat. The toroidal angular velocity is higher for the hot ion H-mode pulse.

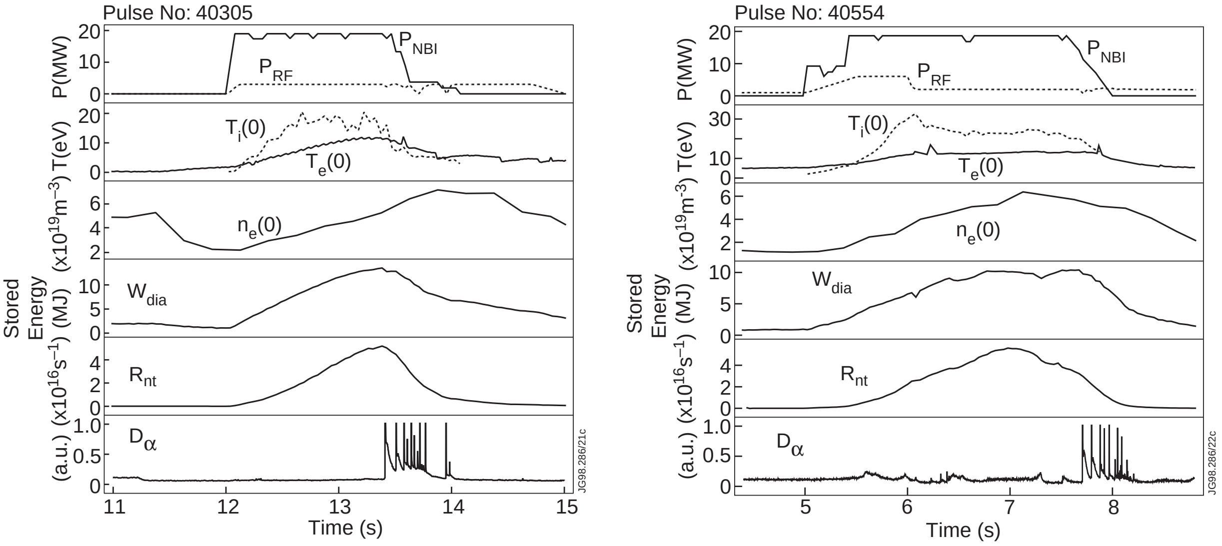

Fig. 1: Time traces of the 3.8MA/3.4T hot ion H-mode #40305 and of the 3.4MA/3.4T optimised shear L-mode #40554.

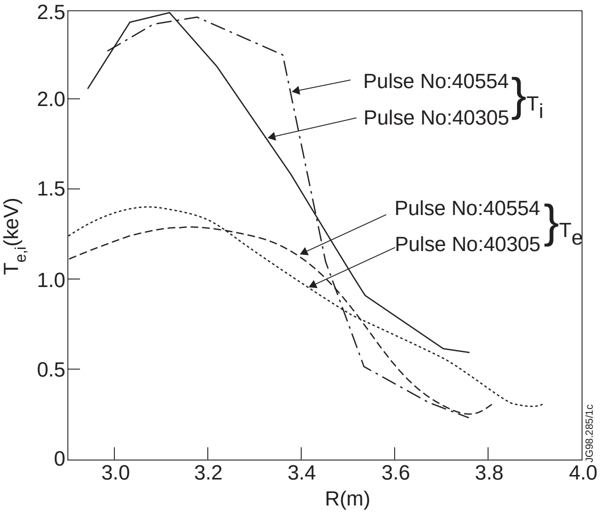

Fig. 2: T_e, T_i profiles for both pulses.

ION POWER BALANCE

The ion channel is the main loss channel in both cases with nearly 90% of the absorbed fast ion heating going to the ions. For the hot ion H-mode, the conduction loss is dominant through the whole plasma column. The NBI ion heating profile is rather broad as only 27% of it is absorbed within $\rho < 1/3$. By contrast, the RF ion heating is more peaked with 65% being absorbed within $\rho < 1/3$. For the optimised shear pulse, the convection and equipartition terms are the dominant losses in the centre ($\rho < 0.3$). The conduction loss is the main loss for $\rho > 0.4$. By contrast with the hot ion H-mode case, the ion heating profiles are much more peaked with 59% of NBI and 73% of the RF heating being absorbed within $\rho < 1/3$ (see Table 1).

Table I	PULSE # 40305		PULSE # 40554	
P (MW) to	$\rho = 1/3$	$\rho = 1.0$	$\rho = 1/3$	$\rho = 1.0$
P_{NBI}	3.5	13.1	7.5	12.8
P_{RF}	1.3	2.0	0.8	1.1

ELECTRON POWER BALANCE

For the hot ion H-mode, the conduction and the electron gain dWe/dt are the main losses. The equipartition term contributes ~2MW to the electron heating. The NBI electron heating profile is even broader than the ion one; only 12% is absorbed within $\rho < 1/3$. The RF electron heating is more peaked with 51% being absorbed within $\rho < 1/3$. For the optimised shear pulse, the conduction loss shows an amplitude similar to the losses by convection or electron gain dWe/dt for $\rho < 0.5$; it becomes dominant in the outer part of the plasma. As for the ions, the heating profiles are more peaked than in the hot ion H-mode case with 32% of NBI and 79% of the RF heating being absorbed within $\rho < 1/3$. The ohmic power is displaced to the plasma periphery (see Table 2).

Table 2	PULSE # 40305		PULSE # 40554	
P (MW) to	$\rho = 1/3$	$\rho = 1.0$	$\rho = 1/3$	$\rho = 1.0$
P_{NBI}	0.21	1.75	0.51	1.61
P_{RF}	0.7	1.36	0.85	1.07
P_{OH}	0.07	0.23	0.001	0.4

ION AND ELECTRON HEAT CONDUCTIVITIES

For both pulses, the central ion heat conductivities are small ($\chi_i < 1\ m^2/s$ for $\rho < 0.4$) at the time of maximum neutron yield. This values are very close to the neoclassical ones for the optimised shear case (less than a factor 3 higher) whereas χ_i/χ_i^{neo} varies between 5 and 15 for the hot ion H-mode case. In the outer part of the plasma, χ_i remains low for the hot ion H-mode whereas it reaches higher values, characteristic of L-mode behaviour, for the optimised shear case (see Fig. 3). The electron heat conductivities χ_e are less certain due to the low power flow through that channel and to losses of similar amplitude. However, χ_e profiles show the same trend as χ_i: low in the centre for both pulses, remaining low through the whole plasma for the hot ion H-mode but increasing near the edge for the optimised shear case. The time evolution of χ_i at different normalised radius ρ is shown for both pulses in Fig. 4. For the hot ion H-mode case, χ_i decreases through the whole plasma column at the formation of the H-mode and the loss of confinement seems to first occur in the centre. For the optimised shear case, a broadening of the good confinement region is observed after formation of the internal transport barrier (t ~ 5.6s); the transition to H-mode at t ~ 7.2s is marked by a drop in the edge χ_i.

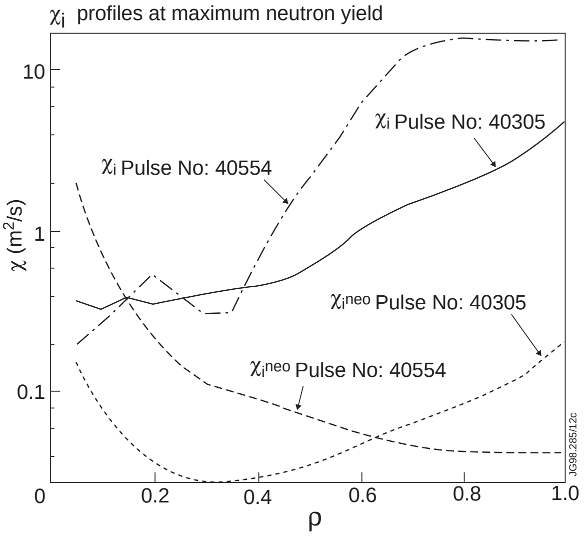

Fig. 3: χ_I, χ_i^{neo} profiles for both pulses.

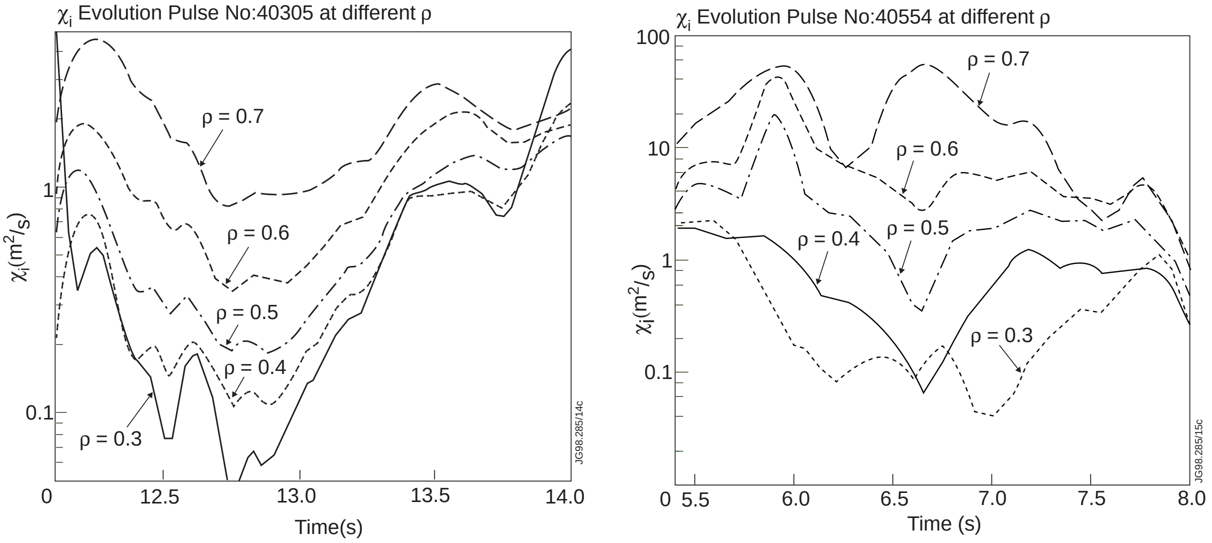

Fig. 4: Time evolution of χ_I at different normalised radius ρ for both pulses.

HEAT TRANSPORT IN DT PLASMAS

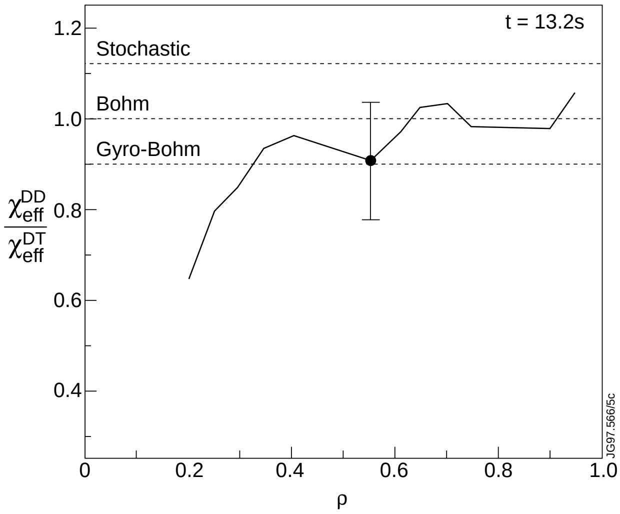

Fig. 5 $\chi_{eff}^{DD}/\chi_{eff}^{DT}$ *versus normalised radius* ρ *for the hot ion H-mode pulses*

For the hot ion ELM-free H-mode regime a full DT mixture scan from pure D to nearly pure T was completed at a fixed power level of P_{NBI} ~ 10 MW. The TRANSP analysis, which includes the effects of alpha particle heating, shows that the heat conductivities depend only very weakly on mass [4]. The analysis of the 50:50 DT pulse # 42676, similar to the DD pulse # 40305 discussed earlier, reinforces this result. Fig. 5 shows the ratio of the effective heat conductivities χ_{eff}^{DD} / χ_{eff}^{DT} for these pulses: the heat transport appears to be mainly Bohm-like, tending to Gyro-Bohm near the centre. For the optimised shear regime in DT plasmas, the scenario had to be modified compared to DD operation because of the lower H-mode threshold power and the different current profile in DT [5]. However, an internal transport barrier with an L-mode edge followed by an ELM-free H-mode has been obtained. The heat transport of such DT pulse is the same as in the DD case discussed above, in particular the central ion heat conductivity χ_i is close to its neoclassical value.

CONCLUSION

The two high performance regimes show similar low central ion heat conductivity close to their neoclassical values. For the hot ion H-mode case the conductivities remain low throughout the plasma column whereas they reach higher values characteristic of L-mode behaviour for the optimised shear case. These features still stand in DT plasmas where no strong isotope effects on heat transport are observed.

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