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ABSTRACT.
The assumption that the magnetic entropy is stationary (SME) in the tokamak consistently with the Grad-Shafranov-Schlüter equation (GSS) restricts the toroidal current density and pressure profiles to special forms characterised by few global parameters [1]. The procedure provides a method for analysing and classifying the data from the point of view of general principles, independent of the details of the underlying dynamics. This method of analysis has been applied to the plasma profiles on different tokamaks (JET, FTU[2]) so as to verify its reliability under different conditions of geometry and auxiliary heating. This paper is focused on the implications on energy transport in both L (I_p = 1.6MA, B_t = 3.2T, 2-9MW NBI + 3.7MW ICRH in mode conversion scheme)[3] and H (I_p = 2.8MA, B_t = 2.8T, 14MW of ICRH+NBI)[4] mode JET plasmas in which electron and ion heating have been carefully tailored in order to investigate the electron stiffness.

1. DESCRIPTION OF THE PLASMA PROFILES

It has been found that in the shots considered, the SME model provides a satisfactory description of the profiles of electron temperature, pressure, diffusivity and toroidal current density in a region comprised roughly from 0.1 to 0.85 of the normalised minor radius. The theoretical predictions fit usually within 5% the whole safety factor (compared, when possible, with Motional Stark Effect measurements) and pressure profiles.

The SME assumption leads to an equation for the toroidal current density in the large aspect ratio approximation:

$$(\vec{E}/\mu^2) \cdot \nabla^2 \vec{j} + \vec{E} \cdot \vec{j} + p_A - p_L = 0 \tag{1}$$

Here E is the toroidal electric field, p_A and p_L are the additional and the non diffusive loss power density respectively. The present analysis is limited to plasmas in which the q = 1 surface is present. The equation is numerically solved in the confinement region defined by the radial position r_1 of the q = 1 surface and by the inner limit r_2 of the scrape-off region. The total current flowing inside r_2 and the value of the safety factor q_0 in the center are part of the input. All the physical quantities needed are taken directly from the database of the experiments (power densities, loop voltage, inversion radius of sawteeth or safety factor profile from MSE data) or deduced from interpretative transport analysis performed with JETTO code (external border of the diffusive transport region). A theoretical relationship of the parameter μ with the loop voltage is provided by the SME theory [1] The value of m can be checked *a posteriori* against the total plasma current and the total Ohmic power.

The equation (1) is written for circular plasmas. A corrective function factor depending on magnetic surface elongation has been formulated and included in the SME code. This geometrical correction plays an important role on the current density and on the temperature profiles as pointed out comparing FTU (circular plasma) and JET (elongated) results.

Figures 1 to 3 show the comparison of the current density profile (or safety factor) calculated from SME with the experimental profiles obtained from EFIT code (through JETTO), constrained with MSE data when they are available (Pulse No's: 55809 and 55802). A considerable effort has been put to reduce to a minimum the arbitrariness in the choice of the values of the input parameters. Due to the uncertainty in the determination of some of the physical quantities as q0 or r2 this arbitrariness cannot be completely removed at this stage of the analysis, yet the set of values of the parameters that allow to fit the experimental profile can be rather unambiguously determined.

2. ASSUMPTION ON THE DENSITY PROFILE.

Once the poloidal magnetic configuration is fixed, also the normalized pressure profile can be calculated in the frame of the SME theory provided that its zero order moment is known from the experiments or from some other physical observation. The simplest assumption for closing the theory when q(r) is monotonic and the Ohmic relaxation holds ($T \propto j^{2/3}$) is to put $n(\psi)/\bar{n} = (1/q(\psi))^{\eta}$ (Turbulent Equipartition, TEP)[5], where $\bar{n}$ (taken from experiments) is the density on the q = 1 surface. The exponent η can be fixed by the requirement that the normalized pressure profile $p_N = T(1/q)^{\eta}/\bar{T}$ and the corresponding expression derived from SME (consistent with GSS equation) have the same zero order moment $<p_N>$. Figure 4 shows the comparison for two JET shots between the experimental density profile and the TEP assumption. Although the TEP assumption fails to describe carefully the density profile, the normalized pressure profile can be satisfactorily matched (Fig.5) by the SME expression as it is not very sensitive to the details of the density profile. The h values which fit the pressure profile of the presented Pulse No's are: 0.85 for 50628, 0.80 for 50630 (JET, H-mode); 0.55 for 55802, 0.30 for 55805, 0.35 for 55809 (JET, L-mode); 0.30 for 18281 and 18290 (FTU, L-mode). According to SME the pressure profile should be always concave in the case $q_0<1$ [1].

3. TEMPERATURE AND OHMIC RELAXATION ASSUMPTION

In the theory the temperature profile is completely fixed by the current density profile when the Ohmic relaxation holds and the Spitzer law for the resistivity is assumed. It is still a matter of discussion whether either the total current density or its inductive component should be used for the temperature profile calculated through Ohmic relaxation. The present results indicate that the total current combined with the measured value of the loop voltage gives a better fit with the experiments. An alternative calculation of the normalised temperature profile uses the GSS pressure divided by the TEP assumption for the density. The temperature profile obtained in this way is still rather close to the $j^{2/3}$ dependence.

The electron temperature predictions are quite accurate along the whole profile (<3% for Pulse No: 55809) as far as complete Ohmic relaxation can be assumed. The time traces of Pulse No: 55802 show that plasma profiles are still evolving at the time of the analysis.

4. TRANSPORT AND CRITICAL GRADIENT

The SME theory leads to an expression for the effective thermal diffusivity [1] that can be compared with the experimental results. The profile of the heat flux involves primarily a critical dependence on the toroidal current density gradient, which translates into the electron temperature gradient when Ohmic relaxation holds. Implicit is the assumption that thermal transport is dominated by electrons in the confinement zone. In figure 7 and 8 the theoretical profiles of thermal diffusivity calculated with different procedures are compared with the experiment. The temperature profile and its gradient are obtained respectively by Ohmic relaxation (SME label) and by pressure divided by density as mentioned in the previous section (TEP label). For comparison also a curve calculated using experimental density is given (TEPnex label). Figure 9 shows the comparison between the experimental and calculated heat flux for Pulse No: 55809 versus the normalized temperature gradient length. The curve with Q_SME label is obtained using the theoretical heat flux directly derived from the poloidal magnetic configuration implied by eq. 1, which is independent of Ohmic relaxation [1]. The curve with Q_SME_nXdt label is obtained by the calculated effective diffusivity (assuming ohmic relaxation). Both the curves reproduce the main features of the experimental flux, showing in this case a critical transport behavior. The green line, also reported in figure 10, marks the R/Lte value (5.5) at which the theoretical heat flux has a sudden increase. This value is quite close to the experimental one (5.4) [3]. Figure 10 shows that in the plasma core ($\rho<0.6$) the actual R/Lte along the minor radius is everywhere close to the critical value.

CONCLUSIONS.

The SME method provides a satisfactory description of the current density profile and, if Ohmic relaxation holds, of the electron temperature profile. The theory introduces strong restrictions on the pressure profile consistent with the experiment. The diffusivity profiles are well reproduced and the threshold value of critical transport evaluated from SME is in good agreement with the value measured in L-mode plasmas.

ACKNOWLEGEMENTS

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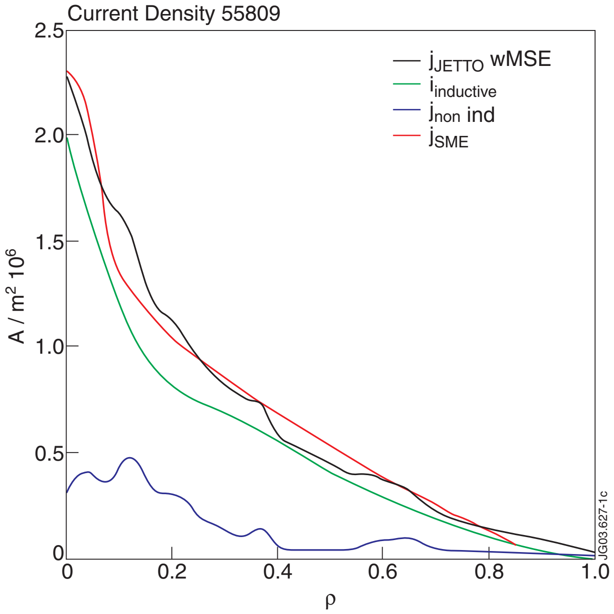

Figure 1: Current density profiles. L-mode plasma with off axis ICRH mode conversion electron heating.

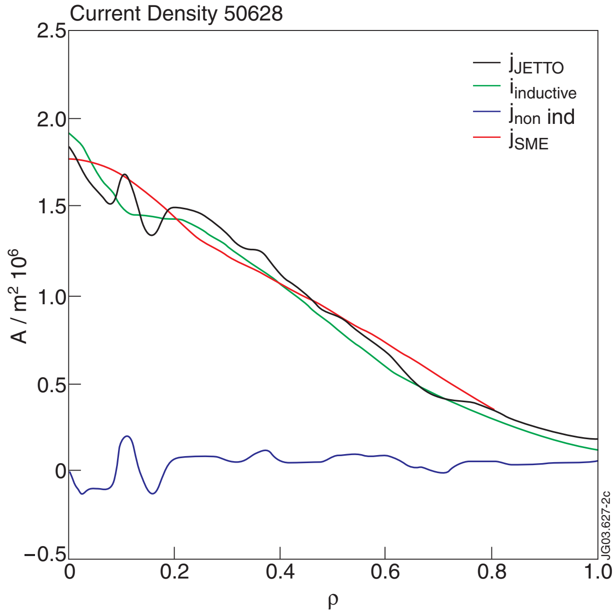

Figure 2: Current density profiles. ELMy H-mode with off axis ICRH heating.

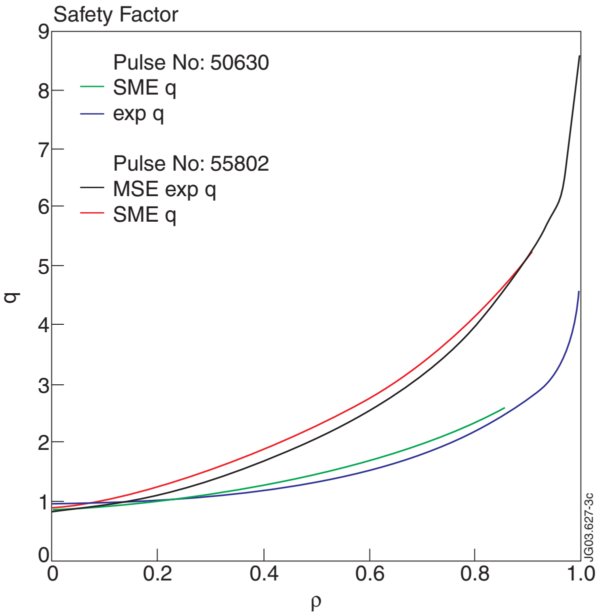

Figure 3: Safety factor profiles for H-mode Pulse No: 50630 and L-mode Pulse No:55802

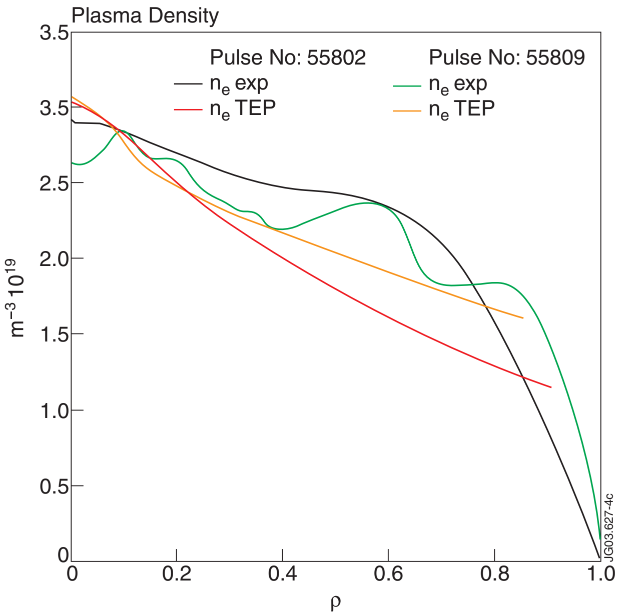

Figure 4: Plasma density for L-mode plasmas. Black lines: LIDAR data. Red lines: TEP

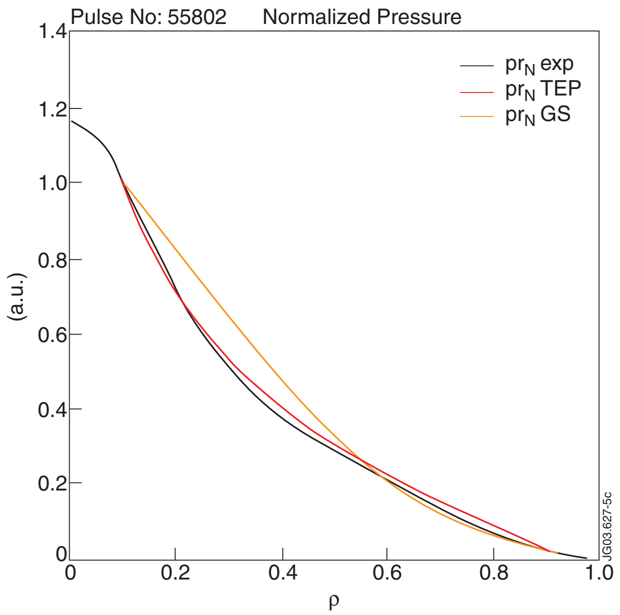

Figure 5: Pressure profile normalized on the q=1 surface. Black: experiments. Red: calculations

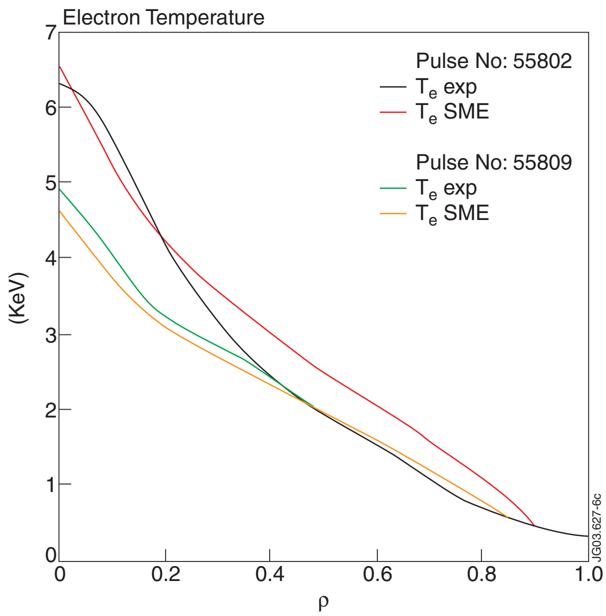

Figure 6: Electron temperature profiles for L-mode plasmas. Black: ECE interferometer. Red: SME.

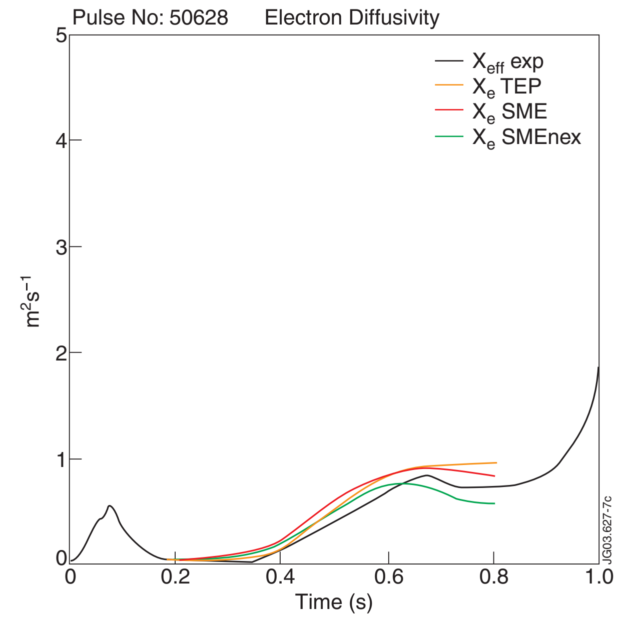

Figure 7: Electron thermal diffusivity for H-mode. Black: JETTO interpretive. Colors: theory (see text)

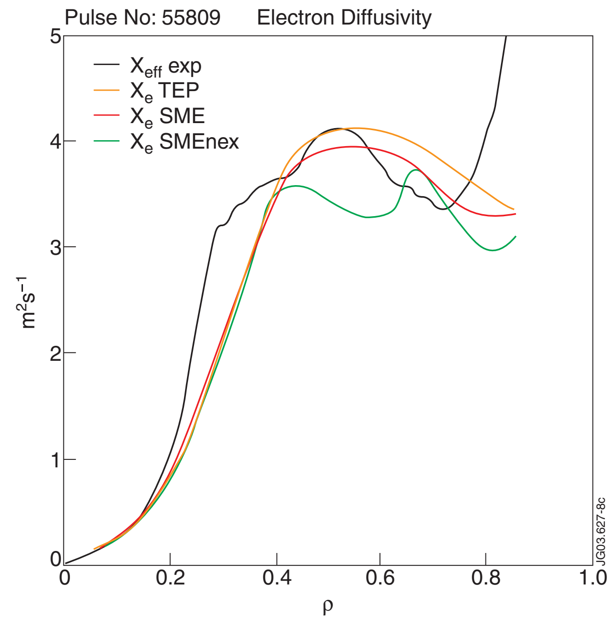

Figure 8: Electron thermal diffusivity for L-mode. Black: JETTO interpretive. Colors: theory (see text)

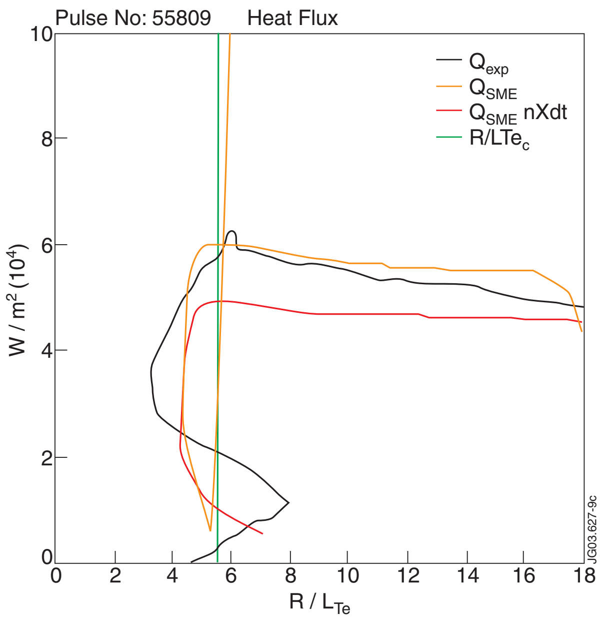

Figure 9: L-mode plasma. Black : experiment. Colors: theory (see text)

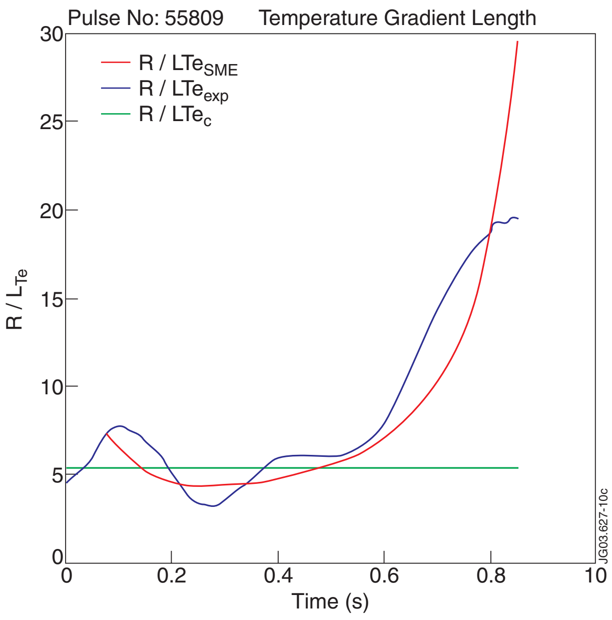

Figure 10: Normalized electron temperature gradient length. Blue: experiment. Red: theory.