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1. INTRODUCTION

Assuming that energy confinement is dominated by the physics of fully ionised plasmas, it has been shown, theoretically, that the energy confinement time (τ_E) can be expressed in terms of the three dimensionless parameters $\rho^*(\propto m^{0.5}_i T^{0.5}/aB_T)$, $\nu^*(\propto Z_{eff}naq/T^2)$ and $\beta(\propto nT/B^2_T)$ [1, 2] where m_i is the ion mass, T is the plasma temperature, n is the plasma density, R is the major radius and a the minor radius. B_T and B_P are the toroidal and poloidal magnetic fields. This would imply that tokamaks of different physical size will have the same normalised energy confinement ($B\tau_E$) when these parameters are matched along with the plasma geometry and safety factor ($q \propto aB_T/RB_P$). Such experiments have been performed between JET and DIII-D [3, 4], JET and ASDEX-Upgrade [5], and JET and Alcator-CMOD [6], and all indicate that this is indeed the case. However, it has been suggested that the Greenwald fraction $F_{gr}(\equiv n/n_{gr})$ could play an important role in the scaling of confinement and that ρ^*, β and F_{gr} may be the more appropriate parameters to use in confinement scaling [7]. In order to test this, identity experiments must be performed on different sized tokamaks for a ρ^*, β and F_{gr} match and compared with a ρ^*, β, ν^* match on the same machines.

F_{gr} is clearly important in determining density limits for radiative collapse in tokamak plasmas [8]. However, its importance as a dimensionless scaling parameter is not well understood. Experiments performed on JET [9] have shown that confinement normalised to the IPB98(y,2) scaling (H98) decreases as n_{gr} is approached, suggesting that edge atomic physics or other unconsidered effects affect global energy confinement and that F_{gr} could be more relevant than ν^* in confinement scalings.

To test this hypothesis identity discharges matching ρ^*, β, F_{gr} were performed on DIII-D and JET [7]. $B\tau_E$ on the two machines was found to differ by about 20%. Previous similarity experiments matching ρ^*, β, ν^* [4, 3] show agreement in global and local confinement to within 5%, suggesting that ν^* is the more appropriate parameter. However the small difference in $B\tau_E$ for the F_{gr} match, which is a consequence of the small change in size ratio ($a_{JET}/a_{DIII-D} \approx 1.5$), is not outside the errors in the measurements and hence the result was not conclusive. Hence it was decided that a better result could be obtained by comparing matched pulses on CMOD and JET where the size ratio is ≈ 4. It is also possible to achieve matched geometries between JET and Alcator-CMOD, so experiments matching first F_{gr} and also ν^* were performed on the two machines.

2. EXPERIMENTAL SET-UP

Shots were first run on Alcator CMOD and shot 1001018013 at time 1.26s was chosen as the most suitable match. A collisionality scan was then performed on JET with the MarkIIGBSRP divertor at fixed ρ^*, β, q and plasma geometry, all matching the chosen CMOD pulse. The dimensionless parameters were matched by tuning ICRH power and gas puffing and using the relations $\beta \propto W_{th}/aI^2$, $\rho^* \propto (W_{th}/na^3)^{1/2}I^{-1}$ and $\nu^* \propto n^3a^7/W^{2th}$. ICRH heating was used in all shots. All discharges were single null, steady state ELMy H-modes without significant NTM or MARFE activity.

Electron density on JET was measured with an 8 channel interferometry system and a LIDAR Thomson scattering system, from which T_e measurements were also taken. $T_i = T_e$ was assumed as charge exchange spectroscopy was not available. Z_{eff} was calculated using the visible bremsstrahlung radiation. Equilibria and q-profiles were reconstructed using the EFIT code [10] based on data from magnetic coils.

3. EXPERIMENTAL RESULTS

The global results for the three discharges are given in table 1 (percentage random errors in brackets, systematic errors are not included). The Greenwald match (Pulse No: 62657) was acheived with F_{gr} matched to within 2% and the ν^* match (Pulse No: 62663) agrees to within 1%. Type III ELMs are observed with periodic transitions into ELM-free H-mode and occasionally Lmode. The two JET shots are matched to the CMOD shot within the quoted errors in all the relevant dimensionless parameters. The normalised global confinement is the same to within 1 standard deviation for the JET ν^* matched shot and the CMOD shot. For the JET Greenwald fraction matched shot the normalised global confinement differs from the CMOD value by 5 standard deviations and confirms that ν^* is the more relevant dimensionless parameter [7]. Figure 1 shows the dimensionless confinement time $B\tau_E$ against ν^* and $B\tau_E$ against the Greenwald fraction. Least squares log-linear regression was used to calculate the scaling of $B\tau_E$ with ν^* as $\omega_c\tau_E \propto \nu^{*\,-0.50\pm0.06}$. This contradicts the IPB98(y,2) scaling, $\omega_c\tau_E \propto \nu^{*\,-0.01\pm0.06}$, which is virtually independent of collisionality, however it is similar to the dependence seen in high collisionality scans on DIII-D. Previous scans on JET at lower collisionality have shown $\omega_c\tau_E \propto \nu^{*\,-0.35\pm0.04}$, this fact and data from other machines (Fig.2) indicates that the dependence of energy confinement on collisionality is not a simple power law.

The local values of the dimensionless parameters give a more detailed view of the differences in confinement in the JET CMOD comparison shots. Transport analysis was performed using the TRANSP code [11, 12]. Electron density and temperature profiles were smoothed over a 1s time window. There is a close match for ρ^* and β for all three shots for $0.4 < x < 0.8$ (where $x = \sqrt{\psi_T}$ and ψ_T is normalised toroidal flux). For the relevant shots the ν^* and F_{gr} matches are also close within this region. Outside of this region the matches are poor. The corresponding local transport coefficients χ_{eff} normalised to Ba^2 are shown in Fig.3. Outside $0.4 < x < 0.8$, χ_{eff} values are not used due to the presence of sawteeth and transient effects at the pedestal. The results of the local transport analysis support the conclusion of the global analysis that ν^* is the more relevant dimensionless parameter for confinement scaling.

CONCLUSIONS

These results demonstrate conclusively that ρ^*, β, ν^* is the correct set of dimensionless parameters for use in confinement scaling. Factors such as edge atomic physics do not play an important role in energy confinement. The result is supported both globally and by the local values of χ_{eff}. The increased scaling with ν^* shows that the dependence of $w_c\tau_E$ on ν^* is not a simple power law, although the precise form of the scaling remains to be found. The reduction in the H98 factor as the Greenwald limit is approached can be understood as being due to the incorrect dependance of the IPB98(y,2) scaling on ν^*. In order for accurate predictions to be made for ITER the dependence on collisionality needs to be more fully understood.

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REFERENCES

[1]. B.B. Kadomtsev, Soviet Journal of Plasma Physics **1**, 295 (1975)
[2]. J.W. Connor and J.B. Taylor, Nuclear Fusion **17**, 1047 (1977)
[3]. C.C. Petty *et al.*, Physics of Plasmas **5**, 1695 (1998)
[4]. T.C. Luce *et al.*, Nuclear Fusion **42**, 1193 (2002)
[5]. K. Thomsen *et al.*, In Proc. 25th EPS Conf. Contr. Fusion and Plasma Phys. **22C**, 468 (1998)
[6]. J.P. Christiansen and J.G. Cordey, Nuclear Fusion **38**, 1757 (1998)
[7]. C.C. Petty *et al.*, Plasma Physics and Controlled Fusion **46**, A207 (2004)
[8]. M. Greenwald, Plasma Physics and Controlled Fusion **44**, R27 (2002)
[9]. G. Saibene *et al.*, Nuclear Fusion **39**, 1133 (1999)
[10]. D.P. O'Brien *et al.*, Nuclear fusion **32**, 1351 (1992)
[11]. R.V. Budny *et al.*, Nuclear Fusion **35**, 1497 (1995)
[12]. R.V. Budny *et al.*, Physics of Plasmas **7**, 5038 (2000)

Shot	*62663 (JET)*	*62657 (JET)*	*1001018013 (CMOD)*
Times (s)	*31.38*	*34.68*	*1.26*
F_{gr} $(=n\pi a^2/I)$	*0.82 (–4.4%)*	*0.58 (–4.4%)*	*0.55 (–5.9%)*
W_{th}/aI^2 $(\propto \beta)$	*0.91 (–5.7%)*	*0.81 (–5.7%)*	*0.83 (–10.7%)*
$(W_{th}/na^3)^{1/2} I^{-1} (\propto \rho^*)$	*0.72 (–2.7%)*	*0.66 (–2.7%)*	*0.69 (–2.7%)*
n^3a^7/W_{th}^2 $(\propto \nu^*)$	*36.0 (–10.4%)*	*10.0 (–10.4%)*	*35.9 (–11.2%)*
$\beta\tau_E$	*0.28 (–11.4%)*	*0.69 (–11.4%)*	*0.26 (–14.6%)*

Table 1: Global parameters in the ν^* *and Greenwald JET-CMOD matches.*

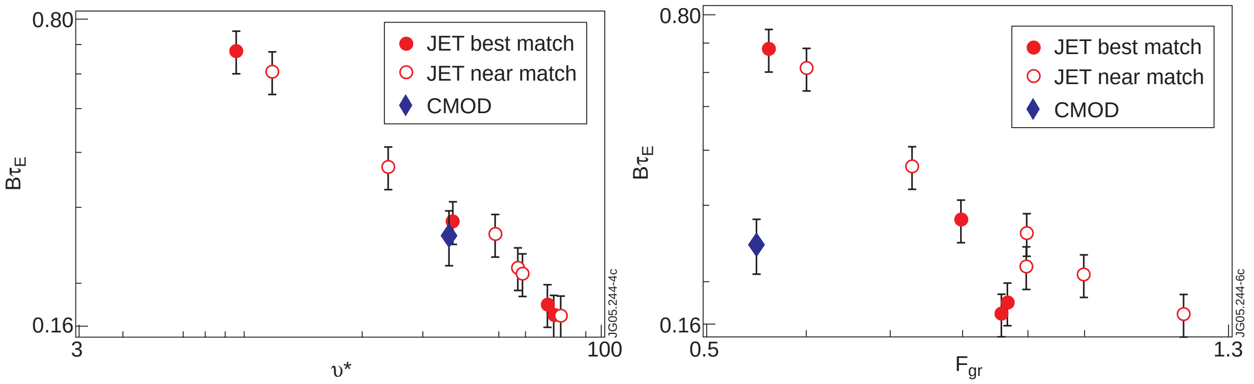


Figure 1: $B\tau_E$ v. ν^* (left) and $B\tau_E$ v. F_{gr} (right) for the JET ν^* scan. The solid blue diamond is the CMOD data, solid red circles are the best JET ρ^*, β matches and open circles are JET ρ^*, β near matches.

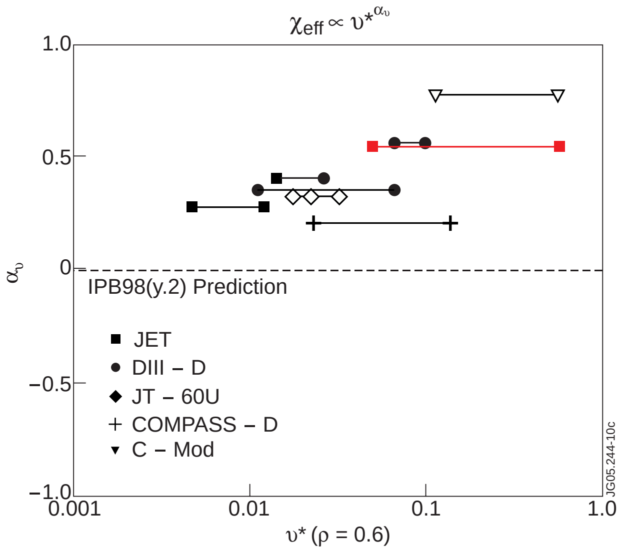
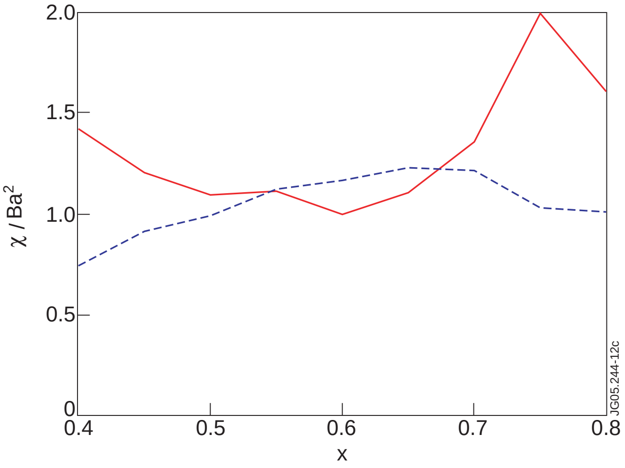


Figure 2: ν^* scalings from dedicated scans on different machines.



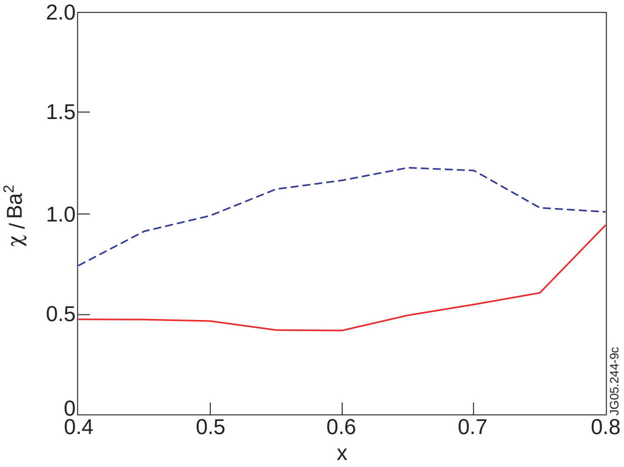


Figure 3: Profiles of the local transport coefficient χ_{eff} *for the JET (red/solid)* ν^* *match (left) and Greenwald match (right) compared to the CMOD discharge (blue/dashed).*