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# Dimensionless Pedestal Identity Plasmas on Alcator C-Mod and JET

G.P. Maddison<sup>1</sup>, A.E. Hubbard<sup>2</sup>, J.W. Hughes<sup>2</sup>, J.A. Snipes<sup>2</sup>, B. LaBombard<sup>2</sup>,  
I.M. Nunes<sup>3</sup>, M.N.A. Beurskens<sup>1</sup>, S.K. Erements<sup>1</sup>, M.A.H. Kempenaars<sup>1</sup>, B. Alper<sup>1</sup>,  
S.D. Pinches<sup>1</sup>, M. Valovic<sup>1</sup>, R. Pasqualotto<sup>4</sup>, A. Alfier<sup>4</sup>, E. Giovannozzi<sup>5</sup>  
and JET EFDA contributors\*

*JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK*

<sup>1</sup>*EURATOM-UKAEA Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK*

<sup>2</sup>*Plasma Science and Fusion Centre, MIT, 175 Albany Street, Cambridge, MA 02139, USA*

<sup>3</sup>*IPFN, Associação EURATOM-IST, 1096 Lisbon, Portugal*

<sup>4</sup>*Associazione EURATOM-ENEA sulla Fusione, Consorzio RFX Padova, Italy*

<sup>5</sup>*Associazione EURATOM-ENEA, ENEA Centro Ricerche Frascati, Italy*

\* See annex of M.L. Watkins et al, "Overview of JET Results",  
(Proc. 21<sup>st</sup> IAEA Fusion Energy Conference, Chengdu, China (2006)).

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## 1. INTRODUCTION AND GLOBAL REGIMES

Properties of the H-mode pedestal are crucial for standard ( $Q = 10$ ) operating regimes envisaged for ITER, but their scalings remain uncertain. Conflicting evidence exists for the variation of density pedestal width  $D_{ne}$ , which can be governed by particle sources on DIII-D [1] and MAST [2], but is more strongly affected by plasma transport on Alcator C-Mod [3, 4] and ASDEX Upgrade [5]. Further insight has been sought by producing plasmas on C-Mod and JET in a common single-null divertor equilibrium and with identical values of dimensionless variables  $v_{*e}^{ped}$ ,  $\rho_*^{ped}$ ,  $\beta^{ped}$ ,  $q_{95}$  at the pedestal top; this ensures local plasma transport is the same [6, 7] while stringently testing other susceptibilities through a ratio  $a_{JET}/a_{C-Mod} > 4$  in absolute size plus markedly different recycling regimes. Accurate realisation of the chosen magnetic configuration on both machines is illustrated by the overlay of scaled separatrices in Fig.1. Edge dimensionless identity then requires (as well as equal  $m_i/m_e$ ,  $Z_{eff}$ ) discharge parameters to be scaled as indicated in Table 1. Time intervals on each device can similarly be related according to  $(t_B - t_A)_{C-Mod} \approx (t_B - t_A)_{JET} (a_{C-Mod}/a_{JET})^{5/4}$ .

Global behaviour in most closely matching shot pairs is summarised in Fig.2, where JET signals are scaled onto the C-Mod time axis as just described. At the high field adopted in C-Mod, classic ELM-free H-mode phases, with monotonically rising density and radiation, were obtained. For JET, however, states were very steady despite occurrence of only small, irregular ELMs. This was probably attributable in part to a large radiated-power fraction within the confined volume, allowing a significant difference in scaled core properties between counterpart plasmas even for equivalent pedestal heights. Hence  $\beta_t$  and scaled sawtooth frequencies remained distinct. Nevertheless scaled efflux power through the edge ( $P_{SOL}$ ) was well reproduced and JET cases in fact reverted to ELM-free H-regime for only very small changes in conditions. Respective pedestal profiles could therefore be informatively compared.

## 2. COMPARISON OF PEDESTAL PARAMETERS

Edge profiles were detected on C-Mod with a millimetre-resolution, 60Hz Thomson scattering diagnostic and on JET with a new highresolution (HRTS) system providing 3 1.5cm detail at 20Hz. To suppress random fluctuations and increase statistical significance, three consecutive time-slices were averaged in C-Mod phases with smallest  $|\delta W/\delta t|$ , while JET signals were averaged over their 0.5 s measurement window. Data were interpolated using an established modified tanh form [3, 4], yielding consistent values of pedestal height, width and position. For JET, the instrument resolution of  $\approx 1.5$ cm was also taken into account, but was found to have little effect on derived parameters. Resulting electron temperature and density heights are shown in Fig.3(a), where again JET quantities have been scaled onto C-Mod ranges as indicated in Table 1. Note C-Mod plasmas comprised a scan to higher pedestal pressure at almost constant temperature and were matched by JET partners at highest densities spanned. These conditions corresponded to moderately collisional ( $v_{*e}^{ped}/Z_{eff} \approx 2$ ), low-pressure ( $\beta^{ped} \approx 0.002$ ) edges (NB  $Z_{eff}$  was not spatially resolved). Accompanying widths are plotted in Fig.3(b), now scaling JET figures with the size ratio, ie  $\Delta' = \Delta_{JET} (a_{C-Mod}/a_{JET})$ . Thus

matching profiles over the whole pedestal would imply coincidence with C-Mod points, but density widths were clearly systematically broader on JET. Its temperature widths were less reliably determined owing to only a single HRTS datapoint generally falling in the steep  $\nabla T_e$  zone, so formally they were bounded between zero and interpolated shapes somewhat broader than the scaled C-Mod level. Departure from linear scaling suggests  $\Delta n_e$  was subject to influences other than plasma transport. Particle sources have been estimated for best-matching shot pairs using the 1-D kinetic KN1D code [9]. This includes ionising and dissociative reactions, as well as multiple generations of charge-exchange events and elastic collisions on both ions and neutral particles. Influx onto a set plasma background is specified from measured gas pressure at the vessel wall. Typical values were  $> 100\times$  higher on C-Mod ( $\sim 0.3$  mtorr) than on JET ( $\sim 0.002$  mtorr), reflecting higher plasma densities on the former. Calculated ionisation rates differed proportionally by a factor  $\sim 100$ , though decay-lengths  $\ell_s$  within the respective density pedestals were themselves closely in proportion to their widths  $\Delta n_e$ .

Further support to such results was obtained from separate computation of one JET case with the 2-D EDGE2D-NIMBUS fluidplasma / kinetic-gas code suite [10], which replicated very similar source decay-length both poloidally averaged and at the outboard mid-plane. Equivalence of scaled neutral-particle penetration into the pedestal is illustrated for a pedestal-top identity shot pair in Fig.4, where sources normalised by their maxima are superimposed versus a coordinate with origin at each density pedestal foot (defined as the central position  $+ \frac{1}{2} \Delta n_e$ ) and in turn normalised by  $\Delta n_e$ . Hence the shaded region denotes the steep  $\nabla n_e$  zone of each profile. Evident correspondence of source fall-off behaviour against this abscissa strongly suggests  $\Delta n_e$  and  $\ell_s$  are related for the plasma conditions addressed. It is likely  $\approx 16 \times$  lower  $n_e^{\text{ped}}$  in the JET case allowed for a deeper source distribution, and so a wider density pedestal of  $\Delta n_e^{\text{JET}} / \Delta n_e^{\text{C-Mod}} \approx 7-9$ , relative to simple identity scaling as  $a_{\text{JET}} / a_{\text{C-Mod}} \approx 4$ .

## CONCLUSION

Single-null diverted plasmas with equal values of dimensionless plasma variables at the pedestal top have been achieved on C-Mod and JET, encompassing a factor  $> 4$  in absolute size as well as substantially different recycling regimes. For the moderately collisional, lowpressure edges investigated, electron temperature pedestal widths on JET were estimated to lie within a somewhat broader interval about scaled C-Mod extents. Density pedestal widths, however, were systematically broader in proportion to machine size on JET than on C-Mod, indicating an influence apart from plasma transport in their formation on at least one of the two devices. Calculations of edge particle sources for pedestal-top identity shot pairs with the 1-D KN1D code [9] revealed similar neutral-particle penetration for both machines compared with the respective density profile thickness, strongly suggesting they are related for the conditions tested. Such susceptibility to ionisation sources implies scaling of density pedestal width in the present experiments is not Kadomtsev-like [6], ie cannot be specified completely in terms of  $v_{*e}^{\text{ped}}$ ,  $\rho_*^{\text{ped}}$ ,  $\beta^{\text{ped}}$ ,  $q_{95}$ . In this case, unambiguous scans

could not be performed with respect to these arguments, since any changes seen could not be identified as due to the increment(s) in dimensionless variable(s) or to consequential alterations of particle sources.

## ACKNOWLEDGEMENTS

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Quantity	C-Mod	JET	Size scaling
$B_0$ (T)	7.9	1.4	$a^{-5/4}$
$I_p$ (MA)	1.3	0.91	$a^{-1/4}$
$n_e^{\text{ped}}$ ( $10^{19} \text{ m}^{-3}$ )	20	1.2	$a^{-2}$
$T_e^{\text{ped}}$ (eV)	550	270	$a^{-1/2}$

Table 1: C-Mod / JET pedestal identity parameters

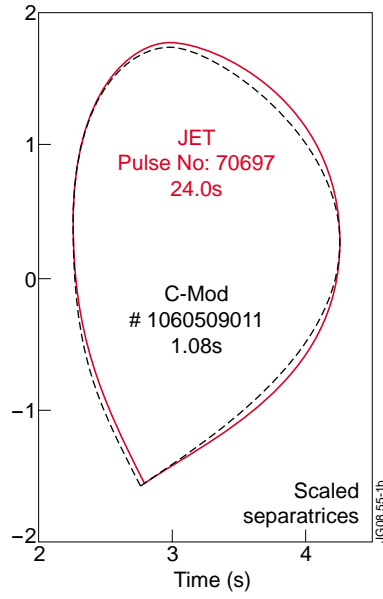


Figure 1: Scaled separatrices for identity pulses in C-Mod / JET.

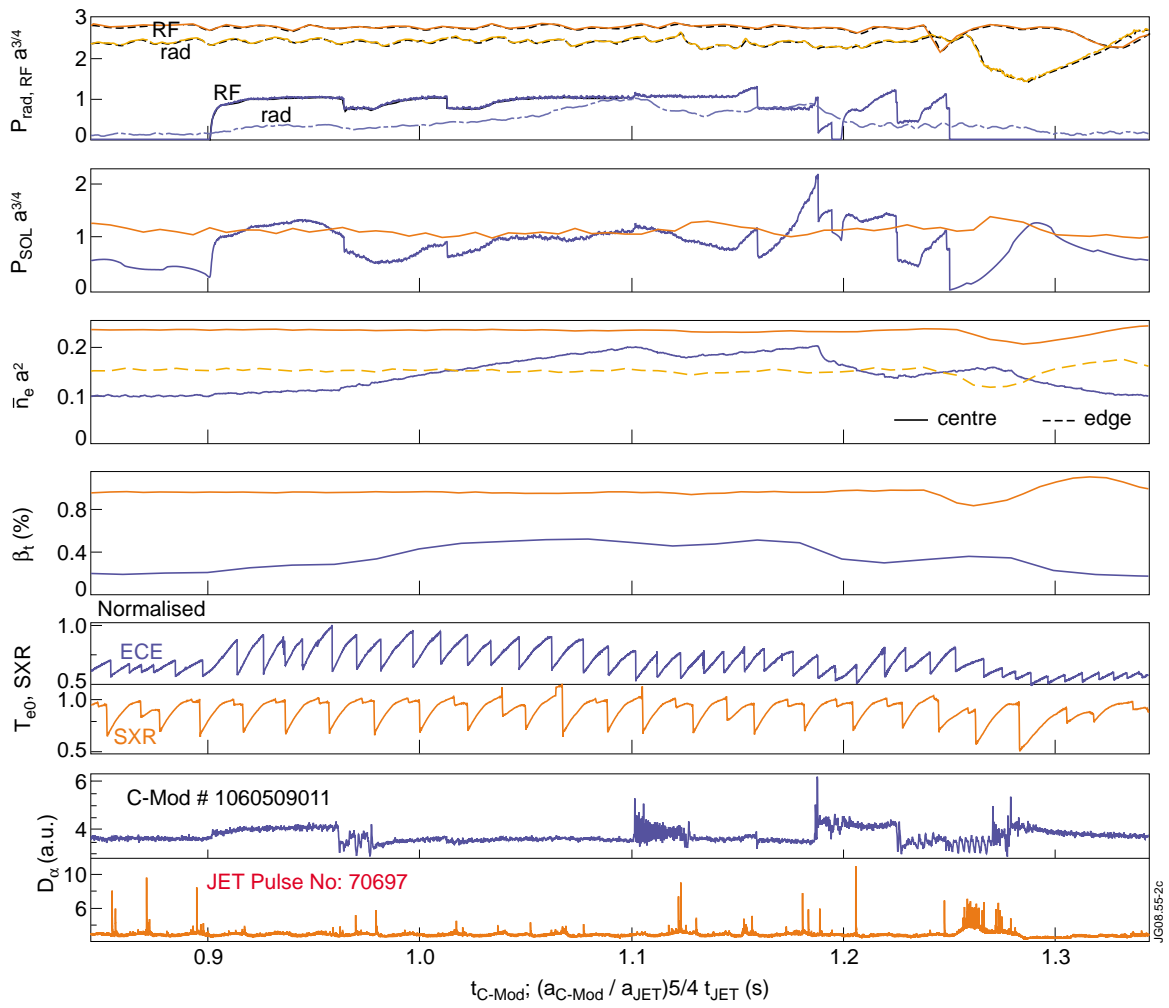


Figure 2: Global quantities (scaled powers and densities,  $\beta_t$ , sawtooth oscillations,  $D_\alpha$  emission) for C-Mod / JET shot pair with close dimensionless identity at the pedestal top. JET signals scaled onto time axis of C-Mod (see text).



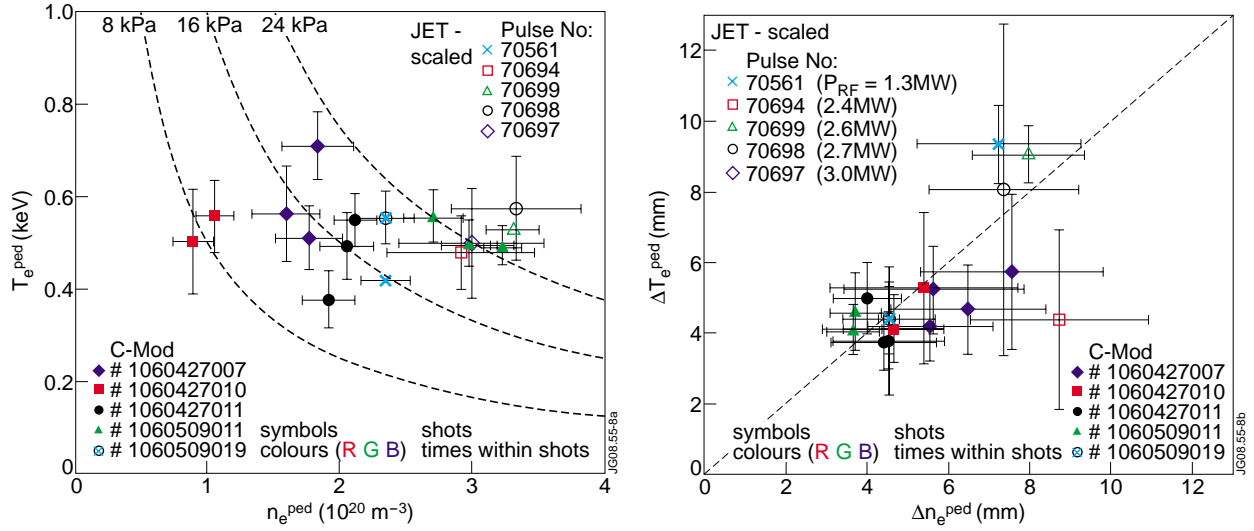


Figure 3: (a) Pedestal heights interpolated for C-Mod / JET power scans, JET data scaled onto C-Mod ranges (cf Table 1). Best matches implying edge dimensionless identity obtained for higher densities. (b) Accompanying pedestal widths, JET data scaled with size ratio.

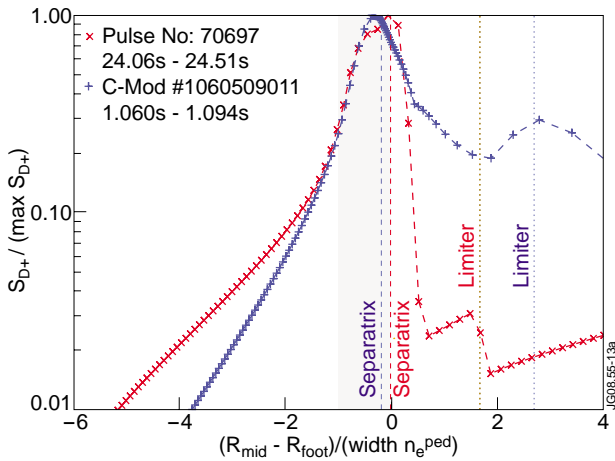


Figure 4: Normalised ionisation source rates from KNID for pedestal-top identity shot pair. The abscissa is centred on the density pedestal foot in each case and normalised by its width, i.e. the shaded region denotes the main gradient zone. Separatrices and boundary surfaces (“limiter”) of respective KNID grids indicated by dashed lines.