EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT
JET

(EFDA-JET Bulletin Autumn 2000)

Message from the EFDA Associate Leader for JET

The first bulletin was announcing the start of the first Experimental Campaign conducted on the JET facilities under the new EFDA framework. After nearly four months of experiments, we are pleased to present, in this second Bulletin, an overview of the first results. These are quite promising and one can already say that significant progress has been achieved on at least two fronts. First of all, several results are consolidating the ITER reference scenario, the ELMy H-mode. Besides encouraging results obtained in MHD, several high density high confinement plasmas have been obtained which fulfil simultaneously several of the ITER requirements for the ELMy H-mode. Secondly significant progress in the coupling of the LHCD has led to routinely reversed shear plasmas being produced which develop unusually strong and broad Internal Transport Barriers (ITB) at reduced power thresholds. Very promising results have been obtained in terms of performance and of steady-state capability, although one should keep in mind that research in ITBs is still in its infancy and there is a long learning process in front of us.

These results would have never been obtained without the strong dedication of all the Operations team, whose efforts have been always successful in providing a high availability of the facility. It should also be stressed that these results could be obtained thanks to the vigorous involvement of all EU laboratories (about 200 physicists involved). The logistics which have been prepared for many months allow 70 to 80 visitors at a time to be accommodated. The soft organisation put in place has been instrumental in the success of the first campaigns and the UKAEA and CSU staff involved in these logistics have played a key role which should be acknowledged.

Besides this encouraging start, an important event occurred on 11 July 2000, when a positive recommendation was made by the Euratom-Fusion Consultative Committee (CCE-FU) on the JET-EP project. This project aims at increasing the heating power capability of JET to a level of 50 MW. The physics programme will put emphasis on the consolidation of the ITER-relevant operating scenarios and in support of timely design choices in key areas of subsystems of ITER (heating, diagnostics, control tools, etc).

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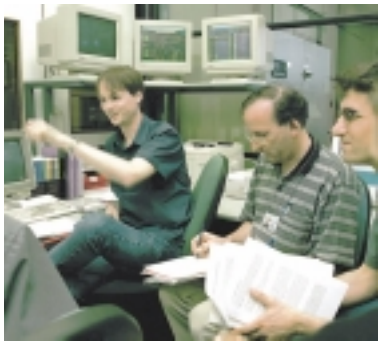

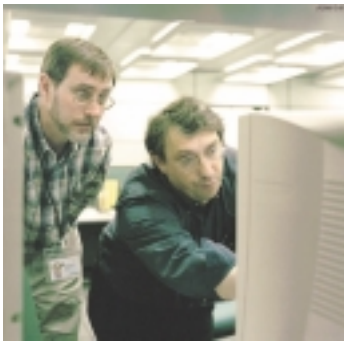

Fig 1–4. Scenes in the J2 control room as the task forces and operator team begin the first experimental campaigns on JET

TASK FORCE S1

Task force S1 has been concentrating mainly on reaching high density high confinement plasmas. Among the different techniques which have been tried are impurity seeding, high gas puff with strong heating and varying the plasma shape. All methods have shown to be beneficial. An example of a discharge obtained with strong gas puffing and high heating levels is shown in the Fig. 5. The remarkable point about this discharge is that despite the high gas puff (which is normally degrading confinement to a significant extent) now only little change in confinement is observed. The net result is a discharge at rather high densities, with high confinement, and low Z_{eff} values of about 1.4, illustrated in Fig.5.

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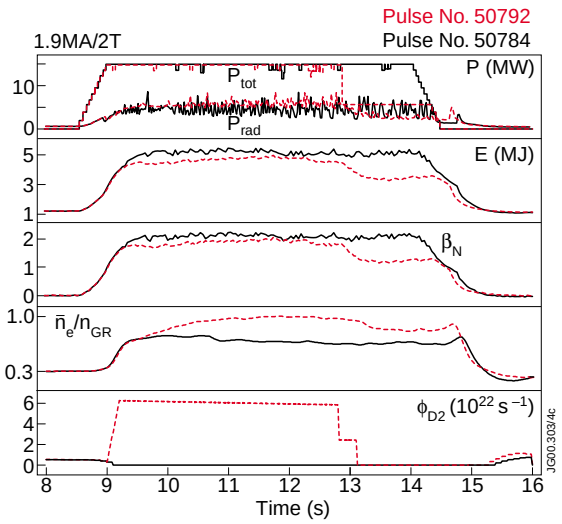

Fig. 5. Time evolution of Pulse No: 50792 and Pulse No: 50784

TASK FORCE S2, D AND H

Task Force S2 has now performed most of its experiments planned in campaign C2. During this campaign a systematic study was undertaken of “preheating” of the discharge, i.e. the application of heating before the main heating phase. Different methods have been applied in order to obtain a hollow current profile, with the aim of obtaining discharges with an Internal Transport Barrier (ITB), also called “reversed magnetic shear” discharges. Both off-axis Ion Cyclotron Resonance (ICRH) and Lower Hybrid Current Drive (LHCD) have been used during the preheating phase, after which usually a combination of ICRH and Neutral Beam Heating (NBI) is applied. An illustration of the plasma profiles obtained in one of the best performing ITB discharges is given in Fig.6. The strong internal barriers are clearly visible in the profile of the ion temperature, with a maximum around 25 keV, and the plasma density, which reaches a value of more than 5 10^{19}m^{-3} over more than half the plasma radius. This work was done in close collaboration with Task Force H, which focussed on optimising the coupling of the LH power into ITB discharges. Improved coupling of LH waves to the plasma has been obtained using CD_4 in order to increase the plasma density in front of the launcher. The hollow current profile obtained gives rise to a profile of the safety factor with a mild maximum in the centre of the discharge as illustrated in Fig. 7. This profile has been measured with the Motional Stark Effect (MSE) diagnostic, which is based on the transformation of a magnetic field into an electric field for a fast moving plasma particle. Here, the particles injected into the plasma by the neutral injectors are used as fast particles. Difficulties are encountered in analysing the signals when more than one injector is used at the same time (which is nearly always the case) due to the cross talk of the signals from the particles from the different neutral injectors with nearly identical acceleration voltages. To remedy the situation possible upgrades of this diagnostic are under discussion.

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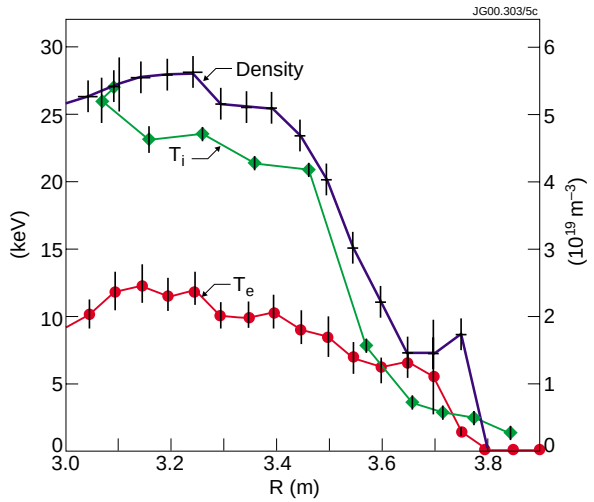

Fig. 6. Ti, Te and ne ITBs forming during the high power phase of Pulse No: 51726. This discharge was performed with LHCD power during the plasma current ramp-up phase and NB + ICRH power at a late phase

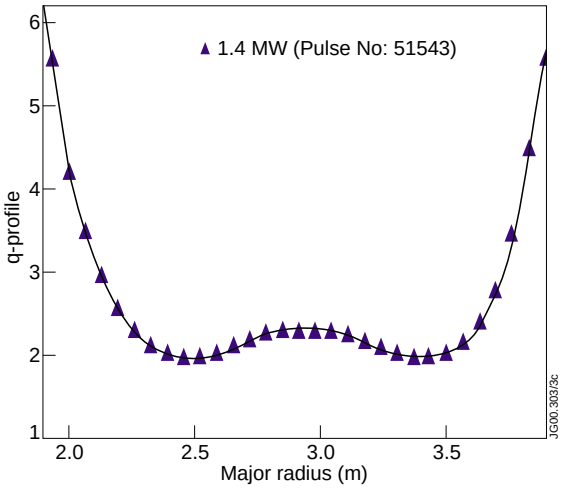

Fig. 7. q-profile reconstructed with MSE data on Pulse no: 51543

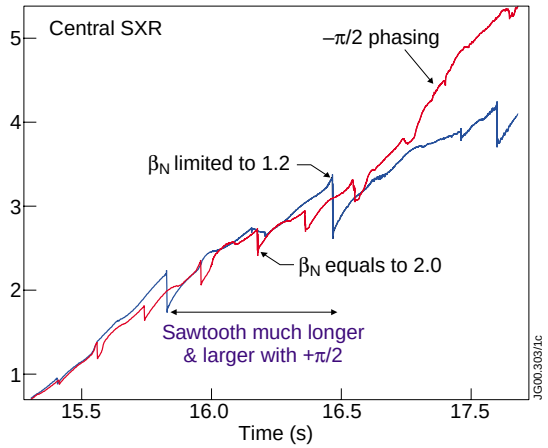

Fig. 8. Central SXR signal showing the increase in the sawtooth period when ICRH with +90° phasing is applied. Under these conditions the NTM is destabilised at lower β_N value of 1.2, consistant with a larger seed island produced by the sawtooth.

TASK FORCE M

Task Force M used the well-known stabilization of sawteeth by ICRH to improve the Neoclassical Tearing Mode (NTM) onset. Large sawteeth can trigger the development of a seed island which is large enough to destabilize a NTM. One could demonstrate that by reducing the sawtooth period and the amplitude of the sawtooth crash, the NTM is not unstable, and the limiting beta value could be much increased in this way. The reduction of the sawteeth could be induced by changing the phase of the antennae and in a careful positioning of the resonance. This results in a modification of the local magnetic shear and of the fast particle content in the plasma centre. The effect of this method on the sawteeth is illustrated in Fig. 8. It has now become possible to couple a maximum amount of power (5MW of ICRH and 21MW of NBI) in a sawtoothing ELMy H-Mode plasma, without suffering from the appearance of NTMs. This shows the essential role for sawtooth control in JET, and more importantly also for ITER.

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TASK FORCE E

The first objective of recent experiments of Task Force E has been to optimise the edge diagnostic data as input to the international divertor and scrape-off layer profile database which is to be the focus of edge modelling efforts. The ultimate aim is a more accurate prediction of divertor conditions in ITER. New techniques have been employed such as the use of slow strike point sweeps across thermocouples which, after analysis with a finite element thermal analysis code (ABAQUS), provides power profiles, as shown in Fig. 9. The main objective of the Task Force E has been to improve the database on the SOL parameters and power exhaust for low and high triangularity Elmy H-mode conditions. New techniques such as slow strike point sweeps in combination with finite element thermal analysis of thermocouple data and improved edge and target diagnostics have been used. About $^3/_4$ of the divertor total energy is deposited on the outer divertor independent on the plasma conditions. Under lower density H-mode conditions the profile on the outer target consists of a narrow peak corresponding to a midplane decay lengths of only 2-3 mm which carries about 70% of the ELM-averaged power and a wider deposition profile (5-7 mm midplane). The contribution of the narrow deposition on the inner target is negligible and decreases on the outer target with increasing density whereas the wider part remains unchanged. The most likely cause of the narrow power peak is ion orbit loss of hot ions within the separatrix region. Careful analysis of the separatrix density in JET ELMY H-mode shots reveal a comparable small separatrix density in JET when related to the density on top of the pedestal, with a typical value of n_s/n_p of only about 0.2, which is significantly smaller compared with ASDEX-U .

Other main activities of the Task Force concentrated on the analysis of hydrocarbon chemistry in the divertor region using methane and higher hydrocarbon puffs and fluctuation driven transport measurements in the SOL.

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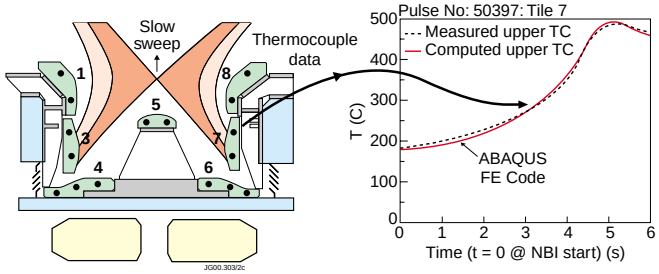

Fig. 9. Slow sweeps of the plasma across thermocouples embedded in the divertor tiles have been used to reconstruct power profiles. These are found to have a very narrow peak at the outer strike point.

REMOTE ACCESS DEMONSTRATED SUCCESSFULLY AT SOFT

Delegates at this years SOFT conference in Madrid were able to log into the JET control room via a two-way computer link using the Ten 155 network. Volker Schmit of ENEA Padova, Jon How CEA Cadarache and Martin Wheatley UKAEA, Culham demonstrated the link as part of the EFDA-JET exhibition stand at SOFT.

See EFDA-JET Bulletin No. 1 “Towards a Collaboratory”.

Fig. 10 (a). Left to right In the **JET control room:** Federico Milani (Experiments Plasma Configuration) and Xavier Litaudon (Task Force S2), communicating with (b) **in Madrid** Dr Karl Lackner (EFDA Leader), Michael Pick (EFDA Team Garching), Volker Schmit, Martin Wheatley and Pierre Paris (EPFL).

The JET-Enhanced Performance (EP) project received a positive recommendation by the CCE-FU on 11 July 2000.

The main objectives of the proposed enhancements are :

– to consolidate the preparation of ITER operating scenarios by increasing the present operating domain of ELMy H-modes (the reference mode of operation of ITER) and further expanding the range of operating scenarios.

– to support design choices in key areas of subsystems of ITER which could be finalised even after the start of construction of ITER.

Fig. 11: Photograph of EP Leader Carlo Damiani

It is planned to install a third Neutral Beam Injection box (7.5 MW, upgradeable to 15 MW), an ECRH system (injecting 5 MW into the plasma, upgradeable to 10 MW) and an ICRH ITER-like antenna. The increased heating power and the features of the ITER relevant plasmas requires an upgrade of the divertor. Upgrades of the diagnostic systems at JET are also under consideration, including in particular the diagnostics for the new divertor. Installation of a Be first wall (limiters), in order to guide the decision on ITER plasma facing components, is another possible option, but is not yet part of the project.

The JET-EP is organised in five projects (NB, ECRH, ICRH, Divertor and limiters, diagnostics), under the overall responsibility of the EFDA Associate leader, and conducted in the Associations, under Project Leaders (PL's). The co-ordination of the project, in terms of planning, budget, QA, documentation, follow-up of the procurement and installation of the systems, design integration, interfaces, will be performed by the JET EP Project Manager (C Damiani) assisted by a team in the Close Support Unit. Essential contributions are expected from the PL's and the JET operator (UKAEA) who is responsible for the safety, the installation and the commissioning of the enhancements. This co-ordination is essential in order to ensure that the various participants, i.e. EFDA CSU, the PL's and Associations, the Operator, the industrial suppliers, will link with each other successfully, and that the technical issues are harmonised and integrated properly. The present time-table is as follows: start of a 9 month shutdown in July 2003, re-start of the machine in April 2004, experiments in July 2004. The new NBI and ICRH systems should be commissioned during the second half of 2004. Staged installation of the gyrotrons should allow to deliver 2 MW of ECRH in September 2004 and 5 MW by March 2005.

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PUBLICATIONS

At the time this bulletin nr. 2 has been produced, the first experimental campaign C1 under EFDA had been successfully concluded and the second one, C2, was in full swing. Already 18 papers were submitted to the Americal Physical Society meeting in Quebec, Canada.

Meanwhile the SOFT conference in Madrid and the IAEA in Sorrento have taken place and a few first EFDA papers appeared there, amongst a range of papers reporting results obtained under the JET Joint Undertaking.

The paper clearance procedure under EFDA has been set-up and has undergone the first life testing, in particular during the phases preceeding the conferences mentioned. This seems to be the appropriate place and time to emphasize once again that all publications, lectures and other documents for external distribution reporting on data obtained on JET are subject to clearance by the EFDA Associate Leader for JET. The relevant rules and procedures are indicated on the clearance forms and can also be found on the EFDA JET web site at the address http://users.jet.efda.org/.

The list of publications is given on a separate sheet of paper allowing separate filing.

VISITORS BOOK

Over 350 people visited the JET facilities over the summer. These included three MEPs, E Seppanen (Finland), K Alyddandraskis (Geeece) and Peter Skinner (UK), journalist Dinah Greek (Professional Engineering) and a large number of schools and universities from all over Europe.

Many thanks to the members of JOC, CSU and Task forces who made these visits possiblle.

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The following is a first list of papers cleared for publication by the EFDA-JET Associate Leader. Note that the papers have not necessarily been published yet, nor been presented at the relevant conference.

Joint Varenna-Lausanne Workshop, Varenna, Italy, 28-31 August 2000

- MHD limiting JET optimised shear performance, T.C. Hender

7th EU-US Transport Task Force Workshop, Varenna, Italy, 4-7 September 2000

- On the relationship between q-profile, heating and ITBs in JET optimised shear plasmas, Yu.F. Baranov
- On the link between ExB sheared flows and rational surfaces in fusion plasmas, C. Hidalgo

21st Symposium on Fusion Technology, 11 - 15 September 2000, Madrid – Spain

Oral presentations:

- JET under EFDA: Organisation and recent results, J. Pamela
- Experience and lessons from the JET 4.0T assessment, (invited), M. Gasparotto, E. Bertolini,, M. Buzio, A.Kaye, J. Last, P. Noll, P. Miele, S. Papastergiou, V. Riccardo, M. Sjöholm, R. Walton, F. Hofmann, D.C. Robinson, E. Salpietro
- Modelling ion source non-uniformity, D. J. Godden and D. Ciric
- The audio and visual communications systems for suited engineering activities on JET, R JH Pearce, J Bruce, R Middleton, J Tait.

Posters:

- Tritium off-gassing trials on dust and flakes from the JET MKIIA divertor, S J Knipe, A C Bell, P D Brennan, C J Manning and A Perevezentsev
- Vacuum pumping developments on the JET tokamak, R JH Pearce, S Bryan, R Cerruti, N Green
- The error field correction coils on the JET machine, I. Barlow, M. Bigi, J. Bird, G. Bonizzoni, R. Buttery, R. Clay, M. De Benedetti, T. Dobbing, G. Gervasini, G. Gittini, T. Hender, S. Hotchin, E. Lazzaro, M. Lennholm, V. Riccardo, L. Rossi, A. Santagiustina, D. Starkey, A. Stevens, M. Tabellini, A. Tanga, P. Watkins, M. Way
- CODAS object monitoring service, M.R. Wheatley, M. Rainford
- Operational experience with a variety of plasma facing tile assemblies at JET, P.Edwards, H.Altmann, L.Pedrick, J.Tait, M.Way
- Comparisons of accrued and expected radiation doses to personnel during manual access to the JET vessel, B Patel, P Edwards,D Campling, P Schofield
- Remote participation at JET from DRFC Cadarache, J.How, J-M Theis, Y.Buravand, X.Litaudon, A.Maas
- Remote participation technical infrastructure for the JET facilities under EFDA, John A How, Volker Schmidt
- Classical and fracture mechanics analysis of the tails of the JET TF coils, V. Riccardo, J.R. Last, A.S. Kaye
- Neutron Activation Studies on JET, M.J. Loughlin, R.A. Forrest, J.E.G. Edwards

9th International Workshop on Carbon Materials, Hohenkammer Castle, Munich, 18-19 Sept. 2000

- Spectroscopy of hydrocarbon fluxes in the JET divertor, M.F. Stamp

18th IAEA Fusion Energy Conference, Sorrento, 4-10 Oct. 2000

Oral presentations:

- ITER shaping and elongation experiments in JET, D.C. McDonald
- Pellet Fuelling and ELMy H-mode Physics at JET, L.D. Horton
- Core and Edge Confinement Studies with Different Heating Methods in JET, F.G. Rimini
- Internal Barrier Discharges in JET and their sensitivity to Edge Conditions, A.C.C. Sips
- Radiating Edge Plasma Experiments on JET, G.P. Maddison

Poster

- Dynamics of Runaways in JET, R.D. Gill
- Energetic Particle Physics and MHD Stability in JET and START, K.G. McClements
- Neoclassical Tearing Mode Studies in JET, T.C. Hender
- Role of Magnetic Configuration and Heating Power in ITB Formation in JET, V.V. Parail
- Direct measurements of damping rates and stability limits for low frequency MHD modes and Alfvén eigenmodes in the JET tokamak, A. Fasoli,

D. Testa, A. Jaun, S. Sharapov, C. Gomezano

- Drift-/kinetic Alfvén eigenmodes in high performance tokamak plasmas, A. Jaun, A. Fasoli, D. Testa, J. Vaclavik, L. Villard
- Dynamics of runaways in JET, R.D. Gill, B. Alper, A.W. Edwards

Post Deadline Paper

- Overview of recent JET results, J. Pamela

ITER Energetic Particles, H and CD exp. group, Frascati, 11-13 Oct. 2000

- Preliminary results of TF-H (C1-C2), A.A. Tucillo

Joint meeting of the 42nd Annual Meeting of the Division of Plasma Physics (DPP) of the American Physical Society and the 10th International Congress on Plasma Physics (ICPP), Québec City, Canada, October 23-27, 2000.

Oral presentations:

- Neoclassical tearing modes in JET, R.J. Buttery, T. C. Hender, D. Howell, S. D. Pinches, O. Sauter
- First results from JET under EFDA, M.L. Watkins
- Testing critical H-mode edge parameters in JET-Asdex Upgrade similarity plasmas, W. Süttrop , F. Ryter, J. Stober, W. Treutterer, M. Beurskens, J.-M. Chareau, M. Charlet, J.G. Cordey, N. Hawkes, D. McDonald, A. Meigs, F. Milani, K.-D. Zastrow, E. Righi, G. Saibene
- Optimisation of divertor and edge diagnostic data in JET, G.F. Matthews, Arne Kallenbach
- Comparison of RF-heated and NBI heated ELMy H-Mode plasmas in JET, R.V. Budny, D.R. Ernst, J.D. Strachan, R. White, M. de Baar, C. Gowers, K. Gunther, A. Gondhalekar, D. McDonald, G. Maddison, M. Stamp, K.-D. Zastrow, P. Lamalle, J. Ongena, E. Righi, G. Saibene, R. Sartori, W. Süttrop
- ELMy H-mode near the Greenwald limit on JET with impurity seeding, Dumortier, S. Jachmich, A. Messiaen, J. Ongena, P. Monier-Garbet, M.E. Puiatti, G. Telesca, K. Lawson, S. Sharapov, K.D. Zastrov, M. Nave, J.D. Strachan, H. Nordman, H.R. Koslowski
- A comparison of high recycling H-mode regimes on ALCATOR C-Mod and JET, J. Snipes, A Loarte, E Righi, G Saibene, R Sartori, R D Monk, P J Lomas, G Maddison, G Matthews, M Greenwald, I H Hutchinson, C S Pitcher.
- JET-EP: The JET Enhancement Project, J. Pamela, E. Solano
- Comparison of tritium retention in TFTR and JET, C.H.Skinner, C.A. Gentile, J.P. Coad, J.T. Hogan
- Tokamak integrated scenarios based on internal transport barriers, A. Bécoulet

Posters:

- Dependence of Helium compression on power geometry and confinement mode in JET, C Grisolia, D Hillis, J Hogan, Ph. Morgan, G. Matthews, V Philipps
- Real-time measurements of damping rates of MHD modes on the JET tokamak, D Testa, A Fasoli, A Jaun, S Sharapov
- Measurement and analysis of radial redestribution of MeV energy ions due to MHD modes in JET plasmas, A. Gondhalekar, N.Gorelenko, A.Korotkov, S.Sharapov, D. Testa
- Influence of Ne and Ar recycling on RI-mode confinement in JET, D. L. Hillis, J. T. Hogan
- Use of impurity injection for improved performance in the DIII-D and JET tokamaks, G.L. Jackson, T.E. Evans, C.M. Greenfield, A.W. Hyatt, G.R. McKee, M. Murakami, C.L. Rettig, G.M. Staebler, R.V. Budny, G. Maddison, J. Rapp, M. Tokar, B. Unterberg
- Motional Stark effect measurements of q-profiles in JET optimised shear plasmas, B. C. Stratton, N. C. Hawkes, C. D. Challis, V. Drozdov, P. Lomas, E. Joffrin, X. Litaudon, P. Lotte, D. Mazon, R. DeAngelis, E. Rachlew, S. Reyes-Cortes
- Power deposition measurements in the JET MKIIGB divertor by IR-thermography, T. Eich, A. Chankin, E. Gauthier, G.F. Matthews, V. Philipps, V. Riccardo, W. Fundamenski
- Influence of triangularity and gas fuelling on energy losses in ELMs on JET, M Becoulet, M Zabiego, G.F. Matthews, A Kallenbach, J Ongena, O Sauter

Papers submitted to scientific journals

- A possible explanation for doubly peaked profiles at the divertor target in JET, A.V. Chankin, Plasma Physics and Controlled Fusion
- ITB formation in terms of ω_{ExB} flow shear and magnetic shears on JET, T.J.J. Tala, Plasma Physics and Controlled Fusion
- Ionisation balance in EBIT and tokamak plasmas, N.J. Peacock, Rev. Sci. Instr.