2005 - UNESCO World Year of Physics

Thanks to an initiative by the World Congress of Physical Societies in Berlin four years ago, 2005 is declared a World Year of Physics. In November 2003, the General Conference of UNESCO adopted a resolution supporting this initiative.

The main theme of the World Year of Physics is the celebration of the 100th Anniversary of Albert Einstein’s “Annus Mirabilis” in which he published four remarkable papers on three different topics: the photoelectric effect (Nobel Prize 1921), Brownian motion and the Special Theory of Relativity (including, in a separate letter, the E=mc² formula).

2005 also marks two other important anniversaries for fusion researchers: 50 years ago, British scientist John D. Lawson formulated his criteria for a power-producing fusion reactor and 20 years ago, the initiative for an international fusion project (today's ITER) was launched at the Reagan-Gorbachev summit in Geneva.

Many national and international events and activities are planned by Physical Societies (see the official webpage of the World Year of Physics, http://www.wyp2005.org). These activities aim to enhance the public perception of physics and provide numerous opportunities for increasing public understanding of fusion as well. Individual participation will be encouraged, for example, in the proposed “Stories in Physics” world-wide competition.

To mark the World Year of Physics, EFDA JET has issued a special desk-top calendar with images from European Fusion Research, including relevant historical and current dates. If you need further information, wish to suggest an idea or have any comments and/or news concerning the role of the fusion community in the World Year of Physics please contact public-relations@jet.efda.org. Happy New Year!

Progress in understanding transport at JET

by P.Mantica, X.Garbet and EFDA-JET TF-T

The understanding of the physics of turbulent transport has made significant progress in recent years [1]. Regarding confinement in a next step device, however, our theoretical capabilities are not yet mature enough to corroborate or improve (with physics based modelling) the performance extrapolations obtained using global scaling laws. Several transport issues deserve careful attention in present-day machines, in order to optimize the way of operating a next step device. Amongst these, issues such as temperature profile stiffness in ELMy H-mode, mechanisms for formation of Internal Transport Barriers (ITBs) in Advanced Tokamak scenarios, and density peaking and impurity accumulation clearly have a significant impact on the expected plasma performance.
An intense activity based on focussed experiments, theory development and modelling effort (using 1D empirical or physics based transport models, 3D fluid turbulence simulations or gyrokinetic stability analysis) has been carried out at JET with the aim of advancing transport understanding and consequently our capability to predict ITER performance. This activity took advantage of a project to integrate the various transport, stability and equilibrium codes under the same platform, which provided a user-friendly access of users to several modelling tools available at JET and enabling an integrated edge-core modelling effort. In general the theoretical framework of transport driven by electrostatic turbulence such as Ion Temperature Gradient driven (ITG) or Trapped Electron Modes (TEM) seems substantially capable of explaining most observations on JET, consistent with the recent removal of the beta (normalised pressure) dependence from the global scaling law of energy confinement. Some peculiar observations however still escape a convincing explanation and may require a more complex picture involving electromagnetic effects and interaction of turbulence with Magneto-Hydro-Dynamic (MHD) modes.

A clearer picture of particle transport has emerged [1,2], based on diffusive and convective transport both significantly exceeding neoclassical values. Convective terms driven by magnetic field curvature and temperature gradient are both present, and lead to a significant dependence of density peaking on collisionality (Fig.1), as found also on ASDEX-Upgrade. This suggests that in ITER low collisionality plasmas, density profiles may be peaked rather than flat as commonly assumed, leading to a significant enhancement of fusion power. One caveat comes from the understanding that significant electron heating (as from $\alpha$-particles in ITER) may lead to inversion of the thermodiffusive pinch and consequent density flattening. However this situation has never been reached in JET with the available electron heating power, and should not be too harmful for ITER where conditions of $T_e$-$T_i$ and coupled ITG/TEM are expected, rather than dominant TEM.

![Fig.1: Experimental dependence of density peaking on collisionality in JET H-mode plasmas [2].](image)

Profile stiffness: tendency of plasma to counteract an increase in temperature gradient $\nabla T$ due to a large increase of turbulence and transport above a critical $\nabla T/T$ value, thus making temperature profile (i.e. $T$ as a function of plasma radius) “stiff”, not responding to increase in heating power.

Temperature gradient length: $L_T = (\nabla T/T)^{-1}$, distance that would separate $T$ from zero temperature, given temperature gradient is fixed to $\nabla T$.

Thermodiffusive pinch: A convective component of particle flux driven by the temperature gradient.

Mode Conversion: In this article, conversion of fast waves into short wavelength Ion Bernstein Waves at the ion-ion hybrid layer, subsequently damped directly on electrons.

The understanding of impurity transport is far less clear and still awaits a systematic phenomenological investigation [2]. Anomalous diffusion and convection are measured in most L- and H-mode plasmas, while in ITBs and in high collisionality plasmas a reduction to neoclassical values is observed. The turbulence driven impurity transport is observed to exhibit the same threshold in temperature gradient length as electron heat and density. Impurity accumulation does not appear to be an issue for low Z impurities, although it remains a potential problem for high Z impurities. Central radio-frequency power appears beneficial to reduce impurity accumulation, although it is not yet clear if this acts through an increase of diffusion or a reduction of neo-classical or anomalous inward convection, or even through effects on MHD instabilities like sawteeth.
Regarding heat transport [3], electron temperature modulation experiments using Ion Cyclotron Heating (ICH) in Mode Conversion are consistent with the concept of a critical inverse temperature gradient length above which transport is enhanced by the onset of turbulence. Threshold values are found in the range predicted by theories of electrostatic turbulence. Normalized stiffness levels are found to be moderate and consistent with values in other machines and with global scaling laws. Due to temperature dependence, the actual stiffness is stronger in JET’s hotter plasmas than in machines like ASDEX Upgrade or Tore Supra. Coupling between electron and ion channels is an important factor that requires further consideration. A systematic test of available transport models on these data has shown that the Weiland model [4] gives the closest correlation with experimental observations. However, highly stiff models are not compatible with the data. On the whole, the physics mechanisms behind temperature profile stiffness seem fairly clarified, but precise quantitative conclusions regarding profile stiffness in ITER deserve further work.

The plasma current profile is found to play a major role in ITB formation. The effect of negative magnetic shear on electron and ion stabilization is demonstrated both experimentally and theoretically using turbulence codes (Fig.2). The role of rational magnetic surfaces in ITB triggering is well assessed experimentally, but still lacks a convincing theoretical explanation. First results of perturbative transport in ITBs show that the ITB is a narrow layer with low heat diffusivity, characterized by sub-critical transport and loss of stiffness. However no 1st principle model is found yet capable of reproducing satisfactorily the JET ITB experimental evidence. Further work in this direction is on-going and planned for the next work-programme.

Fig.2: Contour lines of electric potential $\phi$ in a turbulence simulation using the fluid, electrostatic, 3D code TRB [5], for two configurations with monotonic and reverse q profile (shown below). Turbulence suppression in the region of negative magnetic shear leads to the formation of an ITB.

In the framework of EFDA, the JET Fusion Technology Task Force (FT-TF) aims at contributing to the R&D programme of both JET and ITER by making use of the facilities and the relevant operating experience at JET. In the last four years, tasks - which involve several European laboratories - have been launched focussing on tritium, plasma facing components, waste management and engineering and safety issues.

**Tritium in the Tokamak and Plasma facing components**

A small part of the tritium used during JET operations is still retained inside the JET torus. In order to investigate where the tritium and deuterium are trapped and what are the characteristics of erosion and/or deposition of the plasma-facing component, tiles removed during the shutdowns are analysed at UKAEA, TEKES, FZK, IPP and VR. The results of these studies are also used in the modelling of impurity transport inside the torus.

In the frame of FT-TF, detritiation methods based on laser (CEA) or flash lamp (UKAEA) are being investigated for the plasma-facing components. The aim is to demonstrate the technical feasibility of in-situ detritiation of tiles by ablating a thin surface layer that contains the largest part of the tritium. Laboratory tests showed that with a laser, it is possible to remove (at about 1 m²/h) approximately 20 µm of the deuteriated layer. Using the flash lamp, simulated layers of about 50 µm have been removed at more than 3 m²/h. The flash lamp method has also been experimentally tested in JET during 2004 shutdown using remote handling tools.

**Tritium Processes and Waste Management**

Deuterium and tritium from the torus are processed in the JET Active Gas Handling System (AGHS). A new cryopanel prototype developed at FZK has been installed at AGHS and tested during TTE (Trace Tritium Experiments) at the end of 2003 to pump gas from the torus and neutral beam injectors. It performed well, showing high pumping speed and efficiency. Dedicated tests with other gas mixtures are currently being performed and, afterwards, the prototype will be dismantled for post-experiment characterisation in FZK and CEA. In addition, a new ITER relevant purification system for the collected gases (PERMCAT) developed by FZK has been installed in AGHS. Following purification of impurities like He, CO₂, H₂O, CH₄, the different hydrogen isotopes (H, D and T) are isolated and D and T stored for JET fuelling.

In fusion devices operating with tritium, several kind of tritium contaminated wastes are produced. Decreasing the tritium content inside these materials can reduce the constraints on their storage and final disposal. Therefore, dedicated procedures are being developed by SCK-CEN, FZK, CEA and UKAEA to decrease the tritium levels in tritiated stainless steel, carbon-based materials (graphite and carbon fibre composite), organic liquids (pump oils, liquid scintillation cocktails) together with process and housekeeping wastes. JET also provides samples to test and optimise various methods (needed in ITER) to increase the detritiation efficiency while reducing the production of secondary waste (tritiated water).
With 20 years of experience in the use of tritium, beryllium and Remote Handling for maintenance, the JET experience provides a lot of useful information for ITER licensing and guidelines for ITER design. Data has been collected by ENEA on the component failure rate in different sub-systems (AGHS, vacuum system, heating systems, power supply) and on the occupational radiation exposure (dose to the workers depending on the worker categories and operation conditions). Despite the fact that the ITER design calls for a machine that is significantly larger than JET and different operational procedures are expected, the raw data and the analysis resulting from this study are relevant and offer significant insight and perspective for ITER.

JET is also used as test bed for studying the behaviour of ITER bypass switches (power supply), carbon-based tiles under high ion loads (Neutral Beam test bed) and optical fibres under fusion spectra neutron irradiation. The doses measured in different locations of the machine are used to benchmark codes developed by FZK and ENEA to predict the doses corresponding to various operating scenarios. Also, data related to tritium inventory and AGHS performances are collected by UKAEA to provide useful information to ITER.

The use of the JET facility is of crucial importance in the testing of technological solutions for ITER. Within the JET Fusion Technology Task Force, several ITER relevant issues have been addressed. Future activities will continue to support ITER designing and licensing activities.

Safety and Engineering Testbeds

The tritiated water produced at AGHS is presently collected and re-processed off-site. The components of an integrated system for on-site tritium recovery from tritiated water are being developed with contributions from UKAEA, SCK-CEN, FZK and MEC. If such system is built in JET, it will allow checking - in plant conditions (size, operating mode, and integration of the different sub-systems tested in laboratories) - the technologies that are foreseen for ITER.

PERMCAT device for JET AGHS (M. Glugla, FZK)

Use of the flash lamp in JET for removing tritiated film (animation)
Remote Handling in 2004

by Stephen Sanders - Remote Handling Group

After several months of intensive in-vessel remote operations, all preparatory work in anticipation of installing the new diagnostic systems is now complete.

Most recently completed were the remote welding of component rails in many areas of the vessel and JET’s first remote structural welding (Mig) of supports in Octant 7 which will provide mounting points for the new Lost Alpha diagnostic. Development and use of remote structural welding will play an important part in future JET enhancements.

All welded components together with areas of the local vessel environment have been remotely surveyed using a Photogrammetry camera held by Mascot (the servo-manipulator) and pre-installed targets mounted to points of interest (see figure).

All surveys are first simulated using the Remote Handling Virtual Reality system to generate and test locations for Targets and Photogrammetry camera. Teach files and Mascot moves are then generated to reproduce the locations in-vessel.

Several such remote surveys have been successfully completed. The data was processed by the JET drawing office and is now being used for final machining of components by suppliers around Europe.

In August, Francis Sabathier from CEA joined the Department of Enhancements, Domenico Frigione from ENEA joined the Department of Programmes in September, and Marco de Baar from FOM joined the Department of Operations in October.
EFDA JET organised the Third IEA Large Tokamak Workshop (W58) on the “Implementation of the ITPA Co-ordinated Research Recommendations” at Eynsham Hall near Oxford on 8-10 December. Directors and senior scientists from fusion research centres in Europe, USA, Japan, Korea and the Russian Federation – in total 25 participants – drew up a list of proposals for co-ordinated tokamak experiments in order to implement programme recommendations made by ITPA (International Tokamak Physics Activity). This will be used in finalising the details of the JET 2005 Campaigns, and will reinforce our collaborations with other machines involved so far: ASDEX Upgrade, C-Mod, DIII-D, JT-60U, MAST, TEXTOR, NSTX, Tore-Supra, FTU and JFT-2M.

Dr R S (Bas) Pease, Director of UKAEA Culham for twenty years, died in October 2004 after a short illness.

Following a wartime Honours degree in Physics at Trinity College, Cambridge, he joined AERE Harwell in 1947, specialising in solid state physics and producing some of the classic work on radiation damage and neutron diffraction. In 1955 he began his long career in fusion research and became leader of the ZETA Team.

He moved to Culham when it opened in 1964 and became Director in 1968. He was very influential in the planning and eventual hosting of JET at Culham and played a leading role in worldwide collaboration, including the early planning stages for INTOR (which became ITER). Following his retirement in 1987 he took on an active role in Pugwash, an international organisation that brings together influential scholars and public figures concerned with reducing the danger of armed conflict and seeking co-operative solutions for global problems.

He was a frequent visitor to Culham right up the end of his life, and his enthusiasm for fusion and capacity to ask searching questions will be sorely missed.
On Sunday 26th September, 25 riders set out on the 50 mile JET Cycle Ride in the JET neighbourhood: from Abingdon, through Didcot, Wantage and Oxford back to Abingdon. The weather was fine and in spite of eight punctures the event was a great success. Special thanks go to Clive Elsmore who initiated and organised this social event.

On this occasion, the participants and sponsors of the JET ride raised more than £2500 in aid of Kingfisher school, Abingdon, to fund a special swing for disabled children in wheelchairs. “With the amount you have raised, I will be able to kit out the playground for the children. You have no idea what a wonderful thing you have all done for these children,” said Rosie Jackson from the school.

JET Events

Sept 18 JET participates in UKAEA 50th Anniversary
Sept 26 JET Cycle ride
Sept 28 Visit of “Cycle de Formation Supérieure” from CEA France
Sept 27 Visit of Prof. Martin C. E. Huber, President of EPS
Oct 1 BBC Horizon filming at JET
Oct 6 Public visit to JET during the first Culham Open Evening
Oct 27 Visit of Brazilian Ambassador José Mauricio Bustani
Nov 3 Richard Ashworth MEP visits the JET facilities
Nov 8 Visit of Prof S. Itoh and Prof E. Jotaki from Kyushu University
Nov 9 Remote participation in Au-revoir of Jean Jacquinot, CEA DRFC Director, former JET Director
Dec 8-10 IEA Large Tokamak Workshop organised by EFDA JET at Eynsham Hall, near Oxford

After the visit, Prof. M.C.E. Huber wrote to Dr. J. Paméla, EFDA Associate Leader for JET: “I noted with great pleasure the enthusiasm of your collaborators. The setup at Culham is really remarkable. What I found fascinating were the means to store energy (the gigantic flywheels) and the robot working inside JET, providing enormous flexibility to experiment.”