EFDA

Vol 2004 / 4
August 12, 2004

newsletter

EUROPEAN FUSION DEVELOPEMENT AGREEMENT

Issued by the EFDA Close Support Unit Garching

Contents

- ITER: Divertor mock-ups testing page 2/3
- Associations: ÖAW / Tekes page 4
- Associations: Czech Republic page 5
- ITER: Test Blanket Working Group page 6
- JET: Real-time control at JET page 6/7
- EPS / Fusion CD-Rom page 8

http://www.efda.org

News

Association EURATOM-CIEMAT (Spain): Sanchez succeeds Alejaldre

Prof. Carlos Alejaldre, Head of the Association EURATOM-CIEMAT has been appointed by the Spanish Government as "Director General de Política Tecnológica". He will now have responsibility for the strategy of the Spanish Government towards the large scientific and technological projects and facilities: fusion (TJ-II, JET, ITER), high energy physics (CERN), structure of matter (ILL, ESRF), space science (Large Telescope at Canary Islands, ESA) and others. The whole Fusion Community wishes to congratulate Prof. Alejaldre for his prestigious nomination and wishes him all the best in his new function. He will remain within the Fusion Community as a member of the CCE-FU ("Consultative Committee for the EURATOM Specific Research and Training Programme in the Field of Nuclear Energy Fusion") but he has decided to step down from the leadership of the Association EURATOM-CIEMAT. Dr. Joaquin Sanchez (born in Madrid 1956), who has been working in fusion at CIEMAT since 1987, has been nominated as Head of the Research Unit. He started his career in the area of microwave diagnostics and collaborated in the TJ-I (Madrid, Spain), Wendelstein 7-AS (Garching, Germany) and ATF (Oak Ridge, USA) devices. In 1989 he became Head of the TJ-I experimental group and since 1993 Head of Diagnostics for TJ-II. Dr. Sanchez has also participated in the ITER diagnostics effort (as Chairman of the ITPA Specialists Working Group on Reflectometry) and has collaborated in the EFDA-JET experiments as Task Force Leader for Diagnostics (2000-2002).

Dr. Joaquin Sanchez (left) and Prof. Carlos Alejaldre

EESC backs fusion option

The European Economic and Social Committee (EESC) has voiced strong support for the development of fusion energy approving an opinion submitted to the EESC plenary session on 30th June. For more information please see our website:

http://www.efda.org >> "Debates and Policy Papers" and
http://www.esc.eu.int/documents/summaries_plenaries/2004/synt_410_07_04_en.pdf

The neutron irradiation was carried out in the fission High Flux Reactor fission reactor located at the Joint Research Centre of Petten, The Netherlands. It is a light water-cooled and moderated multipurpose research reactor, which operates at a nominal thermal power of 45 MW.

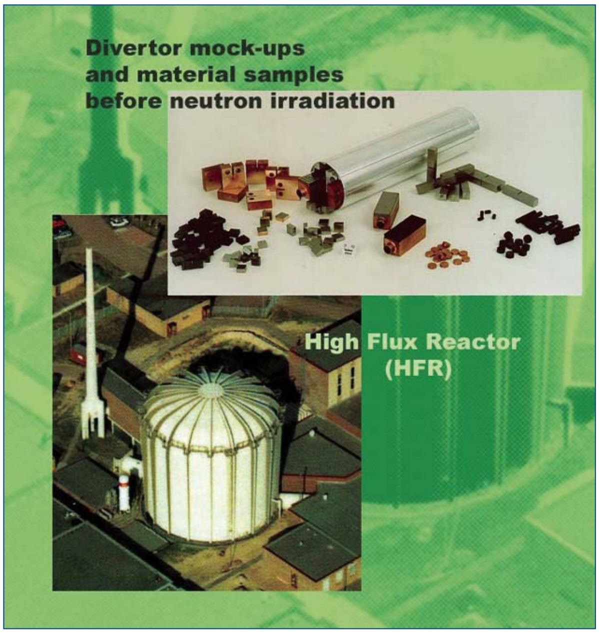
ITER

Completion of irradiated divertor mock-ups and material sample testing

The high heat flux testing of neutron-irradiated divertor mock-ups and the characterisation of neutron-irradiated material samples was recently completed at Forschungszentrum Jülich (FZJ), Germany. This worldwide unique R&D effort has provided essential information on the performance of the ITER divertor, which is now expected to meet the requirements of 1000 cycles of 10MW/m2 for 400s and 100 transient cycles of 20MW/m2 for 10s, even after a neutron irradiation corresponding to about 10 years of full performance plasma operation.

The effect of energetic neutrons on the performance of the divertor components is an important issue for ITER and future fusion devices as the material thermal conductivity can be reduced leading to a potential reduction of the power handling capabilities. In the divertor there are two critical components, the inner and outer divertor targets, where the plasma is allowed to touch the plasma facing material resulting in surface heat loads in the range of 10 to 20MW/m^2. Two plasma facing materials being proposed are, Carbon Fibre Composite (CFC) and tungsten (W). To study the effects of the neutron damage on these components, irradiation experiments PARIDE 1 and 2 were carried out in the mid Nineties in the High Flux Reactor (HFR) in Petten (The Netherlands) with a neutron damage of 0.35 displacements per atom (dpa) in carbon at irradiation temperatures of 350 and 700°C. Post irradiation testing was then performed at FZJ. Subsequently, a new irradiation programme was launched which consisted of two parts:

- PARIDE 3: temperature: ≈200°C; cumulative dpa: ≈0.2 in carbon; ≈0.15 in tungsten.
- PARIDE 4: temperature: ≈200°C; cumulative dpa: ≈1.0 in carbon; ≈0.6 in tungsten.



The 0.2 dpa (carbon) level corresponds to the integrated neutron damage of the divertor plasma facing components after about 10 years of full performance plasma operation, while the 1.0 dpa (carbon) level is that expected for basic machine components in the main reactor chamber of ITER.

The irradiation mock-ups are similar in design to the proposed ITER divertor targets and comprise either CFC or W plasma facing material or armour, joined onto an actively cooled CuCrZr heat sink. A soft pure copper interlayer between the armour and the CuCrZr is used to alleviate the joint stresses. Both monoblock and flat tile geometries were investigated in these experiments. The monoblock consists of armour tiles with a hole into which a cooling tube is inserted and joined to the tiles. The flat tile geometry consists of a hollow CuCrZr rectangular bar, the cooling channel, on to which the flat plasma facing tiles are joined. Testing of the mock-ups, before and after irradiation, under the relevant heat flux conditions, was performed in the electron beam facility, JUDITH, located in a hot cell at FZJ.

In the unirradiated condition both CFC flat tiles and monoblocks surpassed the ITER requirements. The flat tile survived 1000 cycles at both 11.5 and 20 MW/m^2 before failing at 23 MW/m^2. The CFC monoblock survived 1000 cycles at 19 MW/m^2, and 700 cycles at 23 MW/m^2. The testing was curtailed at this very high power (about twice higher than the ITER requirements) because of sublimation of the carbon at the high surface temperatures.

After irradiation to a level of 0.2 dpa, two CFC flat tile mock-ups failed at 19.5 MW/m^2. The 1 dpa irradiated sample testing was limited to 15 MW/m^2 due to surface temperatures of 2500°C causing excessive sublimation. These values are lower than pre-irradiation values but still surpass the ITER steady-state power handling requirements.

Thermal fatigue testing of a CFC monoblock irradiated to 0.2 dpa was carried out at 10 MW/m^2 for 1000 cycles and 12 MW/m^2 for 1000 cycles without failure. When the power was increased to 14 MW/m^2 excessive erosion occurred due to high surface temperatures which made thermal cycling experiments impossible.

W-armoured mock-ups in the flat tile unirradiated geometry were successfully tested for 1000 cycles at 8 MW/m^2 and 14 MW/m^2 (this is absorbed power density, the surface heat flux is approximately double this value). After irradiation however, a failure occurred at approximately 10 MW/m^2. Post-mortem metallography showed detachment of the armour tiles at the W/Cu joint caused by irradiation-induced embrittlement of the pure Cu.

In contrast to the flat tile geometry, the W monoblocks showed no degradation in thermal fatigue performance, even after irradiation, and all survived 1000 cycles at 18 MW/m^2.

Thermal conductivities were determined for the CFC material grade NB31 and the corresponding silicon-doped material NS31, produced by Snecma Propulsion Solide, France, before and after irradiation. As expected, the thermal conductivities were reduced significantly by the irradiation and the reduction increased with increasing neutron dose. For all three directions of the anisotropic CFC, the room temperature conductivity was reduced to 17% of the unirradiated value after 0.2 dpa (to 10% after 1 dpa). The effect of neutron irradiation on the thermal conductivity at high temperature was smaller (33% of the unirradiated thermal conductivity was measured at 700°C). Furthermore, a significant recovery of the CFC thermal conductivity (up to 80% of the unirradiated value) was observed during the post-irradiation high heat flux test. The thermal conductivities for the silicon-doped material NS31 and their neutron-induced degradation were comparable with those of NB31.

Pure tungsten and W-1%La_2O_3 were also tested in the unirradiated state and after irradiation in the PARIDE 3 and PARIDE 4 campaigns. Both materials showed a very small thermal conductivity degradation. At room temperature, it was reduced to 80% and 73% of the unirradiated value after 0.15 and 0.6 dpa, respectively. But at higher irradiation temperatures annealing became effective, and the conductivity degradation was negligible.

Important conclusions have been derived from the results of the testing of irradiated divertor mock-ups and material samples. The effect of the neutron damage on the performance of the mock-ups is greater in a flat tile than in a monoblock geometry, probably because the strain range in the pure Cu interlayer during operation is a factor of three higher in the flat tile configuration and this material rapidly becomes very brittle under irradiation. The thermal conductivity degradation in the CFC was determined and showed a significant recovery after the high heat flux testing. The data obtained in these experiments demonstrate that the effect of about 10 years full performance plasma operation in ITER will only cause an increase of the ITER CFC outer divertor target temperature by, at most, about 400°C under the reference normal operation power load of 10MW/m^2. In reality, as the neutron irradiation takes place in ITER the CFC target will be eroded contributing to a reduction in the surface temperature, which will be remain close to its reference value (about 1500 °C) throughout the ITER divertor target lifetime. It is also important to note that the measured degradation of the W thermal conductivity under irradiation should not represent a major issue for the operation of ITER with a W target.

JUDITH facility at FZJ

JUDITH is a 60 kW powerful high heat flux testing facility operated at the Forschungszentrum Jülich (FZJ), Germany. It is used to simulate the cyclic thermal loads, which act on the plasma-facing components of a fusion reactor. Being located in a hot cell, it can test irradiated mock-ups with or without beryllium armour. A new facility, named JUDITH-2, is under construction at FZJ with a larger vacuum chamber and a 200 kW electron beam gun.
Its completion is planned by the end of 2004.

For **more information** see:

http://www.fz-juelich.de/portal/

http://www.jrc.nl

Associations

For **more information** on the Association EURATOM-ÖAW please see:

http://www.oeaw.ac.at/euratom

ÖAW: 15th Association Day on Plasma Physics

On 16th June 2004 the Association EURATOM-ÖAW (Österreichische Akademie der Wissenschaften – Austrian Academy of Sciences) organised its annual Association Day on Plasma Physics at the University of Innsbruck (Austria). At this meeting the Austrian research groups active in this field presented their contributions to the physics programme and recent results. Guest lectures were given by Dr. David Coster (Association EURATOM-IPP Garching, Germany) on integrated tokamak modelling and Dr. Shakeib Arshad (EFDA-JET) on international collaboration at JET.

From left to right: Prof. Siegbert Kuhn (Univ. Innsbruck), Prof. Dumitru Luca (Al.I. Cuza Univ. Iasi, Romania), Prof. Ferdinand Cap (Univ. Innsbruck), Prof. Hannspeter Winter (HRU), Dr. Richard Kamendje (TU Graz), Prof. Roman Schrittwieser (Univ. Innsbruck), Prof. Klaus Schöpf (Univ. Innsbruck)

The meeting ended with a short celebration on the occasion of the 80th birthday of Prof. Ferdinand Cap. Prof. Cap founded the Department of Plasma Physics at the University of Innsbruck in the early 1960s and contributed to the inception of the Commission on the Coordination of Fusion Research in Austria (KKKÖ) at the Austrian Academy of Sciences in 1980s. The KKKÖ supports incentive projects in the field of fusion.

Prof. Cap is an Austrian pioneer in theoretical plasma physics and has always been a vigorous supporter of the Austrian fusion research.

10th Tekes Association Annual Seminar

The 10th Annual Seminar of the Association EURATOM-Tekes was held at the Tampere University of Technology on 1-2 June 2004. Over 50 fusion physicists and engineers representing Tekes, VTT, universities and industry participated in the seminar. The talks and posters presented a summary of the research activities of the Finnish Association during the past twelve months. The topics covered Tekes contributions to the EFDA JET work programme, EFDA technology programme and ITER-related industrial activities. The clear focus areas of the Tekes activities are scientific exploitation of JET in physics and the vessel/in-vessel field in technology. These cover over 70% of the Finnish fusion effort.

Physics presentations included the recent trace-tritium experiments at JET and predictive integrated transport modelling of JET plasmas, material transport studies in the ASDEX Upgrade (Germany) tokamak and molecular dynamic simulations of hydrocarbon sticking and tungsten blistering. Technology-related talks dealt with in-situ mechanical testing of materials under neutron irradiation, virtual reality techniques and water hydraulic manipulators in ITER divertor maintenance, welding robot system and beam welding studies. Contributions from industry concerned development of advanced superconducting wires by Outokumpu and 3D forming of thick stainless steel plates for ITER vacuum vessel manufacturing by Hollming Works.

The EFDA Leader, Prof. Minh Quang Tran gave an invited talk on European contributions to ITER covering the fusion technology aspects and heating systems. The main message of his presentation was that Europe has expertise in all key technologies needed for ITER. His presentation inspired a lively discussion on ITER and future EFDA activities.

The freshly published Annual Report 2003 of the Association EURATOM-Tekes was distributed to seminar participants.

Additional information on the activities of the Association EURATOM-Tekes can be found from the web-sites:

http://akseli.tekes.fi/Resource.phx/enyr/fusion/en/index.htx

and

http://www.vtt.fi/pro/research/fusion2003_06/indexe.htm

The Annual Report 2003:

http://www.vtt.fi/inf/pdf/publications/2004/P530.pdf

Associations

Association EURATOM-IPP.CR

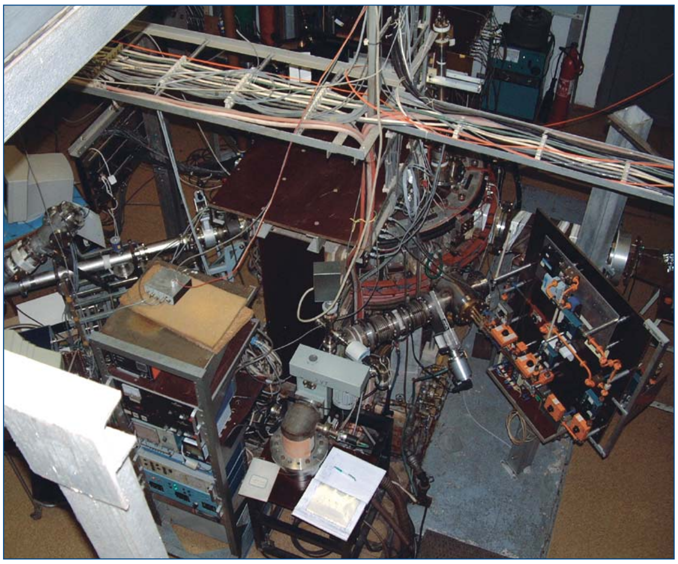
The fusion programme in the Czech Republic is coordinated by the Association EURATOM-IPP.CR, which was established in 1999. The Institute of Plasma Physics, Academy of Sciences of the Czech Republic (AS CR) performs the research together with six other national partners:

- J. Heyrovsky Institute of Physical Chemistry AS CR, Prague
- Nuclear Physics Institute AS CR, Prague
- Faculty of Mathematics and Physics, Charles University in Prague,
- Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague
- Nuclear Research Institute plc, Rez
- Institute of Applied Mechanics Ltd, Brno

The total staff resources amount to about 40 ppy. The experimental programme in physics is based on the small-size tokamak CASTOR (R = 40 cm, a = 8 cm, B = 1.3 T, I = 15 kA), which has been operational in IPP Prague since 1977. The experimental programme focuses on the study of processes in the edge plasma (in particular plasma turbulence), wave plasma interactions and the development of advanced diagnostic systems. Experiments on the CASTOR tokamak are accompanied by relevant theory and modelling. In addition, fusion-relevant atomic data are obtained (interaction of hydrocarbon ions with graphite targets).

The research is performed in a close **international collaboration**. Colleagues from the Associations EURATOM-CEA, Etat Belge, ÖAW and ENEA (RFX) frequently participate in CASTOR experiments. Czech physicists regularly work on TORE-SUPRA, TCV, MAST and TJ-II. So that the international collaboration is bi-directional. The expertise of Czech scientists is also exploited through **participation in the JET programme**. They are involved in the study of edge plasma (fluctuation and flow measurements using electric probes), and of the generation of fast particles in front of the Lower Hybrid grill.

Participation in the EFDA Technology programme is basically focused on the ITER project. A light water fission reactor is used for irradiation of first-wall materials and candidate Hall probes (for measurements of the tokamak magnetic field) and to study breeding blanket issues. Furthermore, the Association is involved in the simulation of the welding of the vacuum vessel, and mechanical testing of the first-wall panels attachments. A cyclotron is used to collect nuclear data relevant for the IFMIF project. The unique water-stabilised plasma torch is used for plasma spraying of tungsten.



The CASTOR tokamak

An essential part of our work is the **education** of the young generation of fusion scientists. A course on “Physics and Technology of Nuclear Fusion” is organised for three faculties in Prague and supervise diploma and PhD theses of students. Furthermore, together with Hungarian colleagues (Association EURATOM-HAS), an annual Summer Training Course for 10-12 graduate and PhD students, exploiting the unique features of the CASTOR tokamak for the practical training of domestic and foreign students is organised, with particular emphasis on those from newly associated countries (Hungary, Slovakia, Bulgaria, Estonia).

A regular scientific audit and invaluable help is provided by the **International Board of Advisors**, which consists of nine European fusion experts. The annual meeting of the Board is accompanied by the Association Day, where the results achieved and future plans are discussed in detail.

The Association also contributes to public information activities, such as a number of lectures, open days, and the recently published brochure “Fusion for everybody” (in Czech).

Additional information is available at:

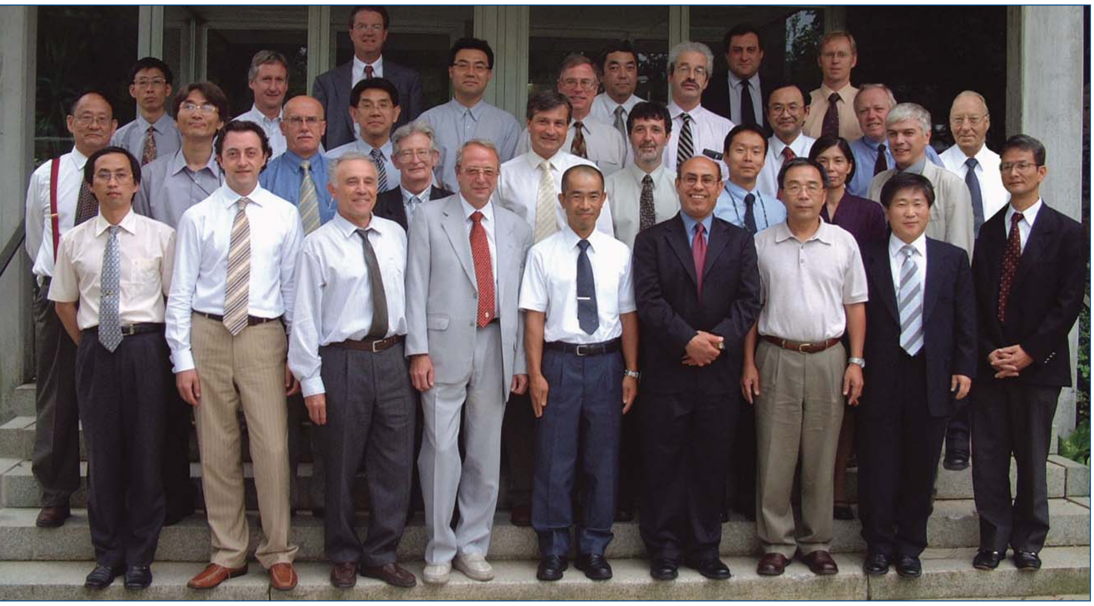
http://www.ipp.cas.cz
http://www.ujf.cas.cz/
http://www.mff.cuni.cz/
http://www.jh-inst.cas.cz/
http://www.fjfi.cvut.cz/
http://www.nri.cz/
http://www.uam.cz/

ITER

Test Blanket Working Group (TBWG)

The ITER Test Blanket Working Group (TBWG) was re-established in September 2003 and convened for the third time at EFDA Garching (Germany) from 7 to 9 July 2004. Four members of the ITER International Team and up to three members from each of the ITER Participants (China, EU, Japan, Russian Federation, South Korea, USA) contribute to the group. The main mission of the TBWG is to develop the Design Description Document for the Test Blanket Modules (TBMs) proposed by the participants, to promote collaborations in R&D and sharing of common TBM features and to define a coordinated TBM test schedule for the first 10 years of ITER operation.

Three horizontal ports of the ITER machine are reserved for the installation of DEMO-relevant TBMs capable of achieving sufficiently high tritium breeding ratios and thermal efficiencies for electricity production. The six ITER Participant Teams are proposing different types of breeding blanket concepts for the TBMs such as He-cooled or water-cooled ceramic/Be, He-cooled or dual cooled LiPb, self cooled Li concepts, etc. ITER will supply unique testing conditions for the TBMs under fusion-relevant conditions, although, due to the low neutron fluence, long-term irradiation damage in the materials cannot be addressed. It will be a big challenge to install the different types of TBMs in ITER in an integrated and harmonised way due to the limited available space in the ports and in the building. All the proposed TBMs have to pass stringent qualifications and acceptance tests before installation in order not to jeopardise the operation of ITER.



JET

Real-time control at JET

It is increasingly clear that real-time control is expected to play a crucial role in experiments based on magnetically confined plasma. From the early years of fusion research where the experimental scenario was 'hard-wired' and used elementary electronic control over a few key parameters, research has moved towards a completely different setup. The very fast response of today's computing and control systems gives the opportunity of extensive real-time control and data analyses. Real-time tools can not only precisely tailor key plasma parameters and keep them under control, but can also run several consecutive experiments within a single plasma discharge. This latter feature is very significant now that JET's plasma discharges may last tens of seconds - and will be in future superconducting facilities where plasmas could potentially extend over tens of minutes.

JET represents today the most spectacular experiment in terms of real-time control of a plasma. On JET, scientists leading the experimental sessions, are able to control a number of parameters in the same time, and space resolution, providing flexibility in experimental output between each plasma discharge.

Real-time measurements of neutrons, magnetic flux, plasma temperature, density, helicity, electromagnetic radiation (X-ray, UV, visible and IR) provide inputs for real-time analysis of magnetic fields, confinement, spectral lines, chemical composition, and profiles of temperature, density and current. There are over 500 signals involved, updating every few milliseconds and travelling over a high speed digital computer network (ATM), similar to those used by telephone companies in their backbone exchanges, designed to deliver sets of signals (datagrams) from different sources to the appropriate destinations.

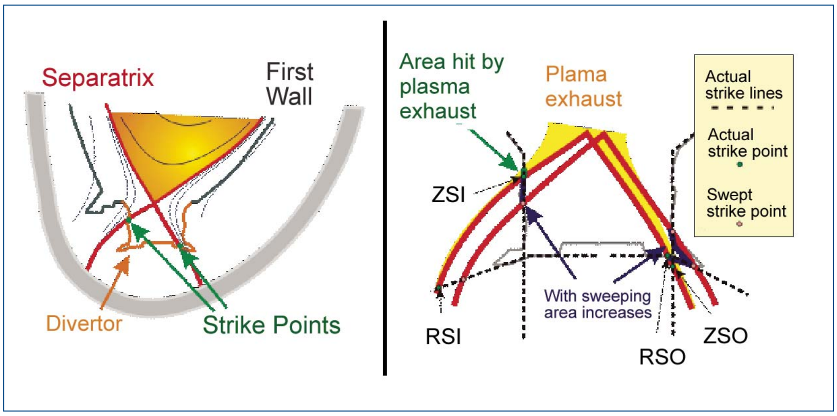


Figure 1: Strike point control and sweeping.
Left diagram shows the relative position of the divertor and the strike points with respect to the plasma and the first wall. Right diagram zooms into the details of the plasma exhaust lines interacting with the divertor.

Magnetic coils, gas valves, Neutral Beam Injectors (NBI), pellet injectors, Ion Cyclotron Resonance Heating (ICRH) and Lower Hybrid Current Drive (LHCD) systems can all act as actuators in JET. Two examples can give an idea of how challenging the task is: the control of the heat power load and the extreme plasma shape control.

The control of the power applies in particular to the X-point configuration. Here the particles escaping from the plasma and, following the field lines outside the separatrix, collide with the walls in two points called "strike points". This highly concentrated energy flow, delivering most of the energy output from the plasma, needs to be directed onto the divertor, where the thermalmechanical design and properties of the material can sustain the high thermal load (see fig. 1). Nevertheless, a prolonged and focused heat load could damage even the divertor and, to prevent such damage, the only possible solution is spreading the heat by sweeping the strike points over a wider area of the divertor. That means that it is the real-time control of the magnetic configuration which guarantees the integrity of the machine.

A further example is the implementation of the so-called Extreme Shape Control (XSC). In order to obtain reference scenarios with high quality H-mode plasmas at a plasma density close to the Greenwald density (for example through high triangularity and elongation) the control system at JET has been recently modified to maintain the plasma shape in the presence of large disturbances (e.g. giant edge localised mode [ELMs] and large variations of bp and/or li). The system has been successfully installed and commissioned during the last experimental campaign and proven during a set of high triangularity ITB discharges with bp up to 1.5 (fig. 2) and/or bli up to 0.5.

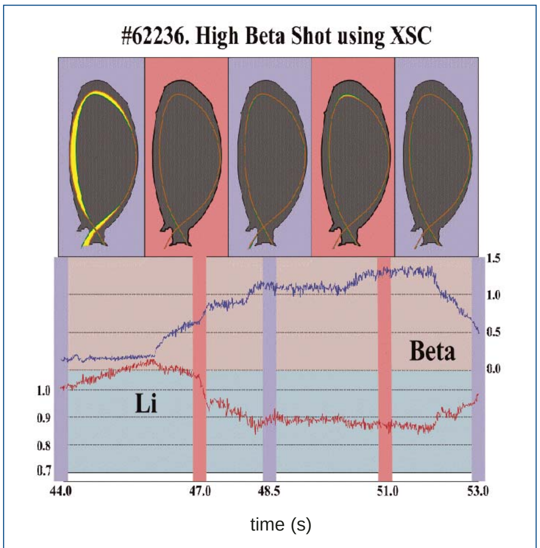


Figure 2: High beta experiment with XSC

In conclusion, as one of the recent tools developed in JET, the real-time equilibrium, together with real-time electron and ion temperature and current profiles measurements, has dramatically enhanced the experimental work on the integration of advanced tokamak scenarios and, in particular, the development of techniques to control in real-time the q and pressure profiles simulta-neously in real-time.

All these examples show the increasing role of real-time control at JET and demonstrate that this is an asset with an important role in exploring and preparing new scenarios for the first phase of the ITER operations.

ELM:
An instability that often occurs in short periodic bursts during the H-mode in divertor tokamaks.
It causes transient heat and particle loss into the divertor which can be damaging. Small ELMs are useful for impurity/density control.

Events

31st European Physical Society Conference on Controlled Fusion

London has always been an important centre of modern life, a point of intersection between science, arts and technology, trade and commerce. This year, from 28th June to 2nd July, Imperial College, which is located in London's South Kensington district, hosted the 31st European Physical Society (EPS) conference on plasma physics and fusion research with about 800 international participants. This time the science of laser-plasma interaction and inertial confinement fusion, as well as dusty and low temperature plasmas, had substantially greater prominence than previously. The conference was opened with a special address from Professor Sir David King FRS, Chief Scientific Advisor to the UK Government. Through its Plasma Physics Division, the EPS awards every year the Hannes Alfvén Prize for outstanding contributions in theory or experiment. This year's award-winners are Dr. J.W. Connor, Dr. R.J. Hastie and Dr. J.B. Taylor, from the UKAEA Culham Division (UK) "for their seminal contributions to a wide range of issues of fundamental importance to the success of magnetic confinement fusion, including the development of gyrokinetic theory, the prediction of the bootstrap current, relaxation theory, dimensionless scaling law, pressure-limiting instabilities, and micro-stability and transport theory." The 32nd EPS 2005 conference will be held at the Congress Palace of Tarragona, on the east coast of Spain, the so-called Costa Dorada (Golden Coast), from 28th June to 1st July.

For **more information** please see:
http://www.fusion.org.uk/eps2004/index.html

and

http://eps2005.ciemat.es/main.shtml

Promotion

New CD-Rom on Fusion available

"Fusion – an energy option for the future" is the title of the new CD-Rom issued by EFDA in June 2004. It aims at explaining the fundamental principles of fusion and the status of European research in this field. The information is based on the activities carried out by the European fusion community. The CD-Rom was produced by the Association EURATOM-FOM in cooperation with EFDA and with the financial support of the European Commission. It is available free of charge (for didactic purposes only) through EFDA (*Federico.Casci@efda.org*).

For more information see our EFDA website:
http://www.efda.org
and additionally
http://www.jet.efda.org
http://www.iter.org

EFDA Close Support Unit - Garching
Boltzmannstr. 2
D-85748 Garching / Munich - Germany

phone: +49-89-3299-4237
fax: +49-89-3299-4197
e-mail: federico.casci@efda.org
editors: Federico Casci, Doris Lutz-Lanzinger
graphic design: Karen Jens