Fusion News

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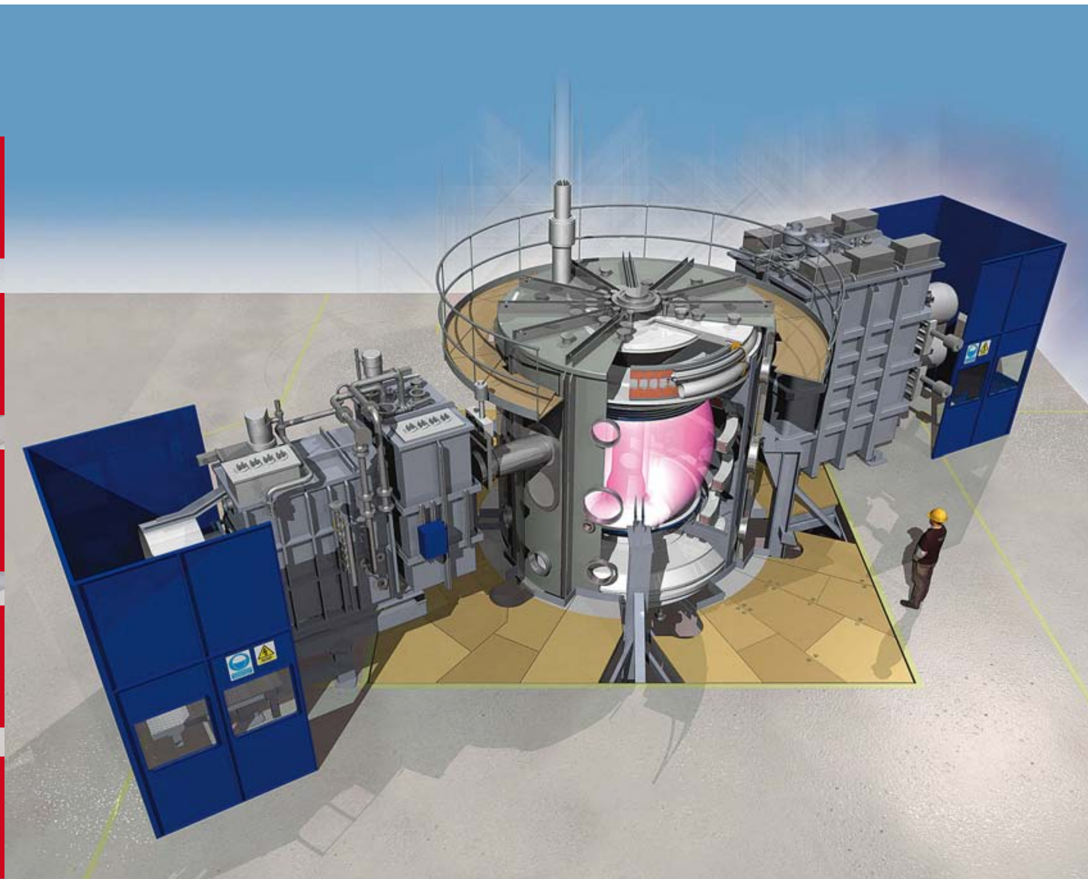


The Mega Amp Spherical Tokamak MAST at Culham Centre for Fusion Energy (CCFE) will undergo a £20M machine upgrade. Main features will be a new central solenoid and new divertor technology as well as significantly increased neutral beam power. The picture shows the double beam injector to the right and the off-axis beam injector to the left of the tokamak. See page 9 *(Picture: CCFE)*

EFDA during FP7 – Reinforced coordination of physics and technology in EU laboratories Part 7

Socio-economic studies

A successful fusion programme must result in an energy source which is both economically and socially acceptable. For this reason, back in 1997, Euratom established a programme on the subject of Socio-Economic Research on Fusion (SERF) which became the responsibility of EFDA after it was established in 1999. SERF gathers the expertise of researchers from economics as well as social and environmental sciences. Currently 11 Associations are actively involved in SERF: CIEMAT (Spain), SCK-CEN (Belgium), ENEA (Italy), CCFE (UK), OEAW (Austria), IPPLM (Poland), IPP (Germany), RISØ (Denmark), CEA (France), IST (Portugal), and HAS (Hungary).

Continued on page 5.

EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

Y. Capouet and G. Lelli cutting the anniversary cake *(Photo: ENEA)*

EURATOM-ENEA Association 50th anniversary celebrations

On 8th July, the EURATOM-ENEA Association in Frascati, Italy, celebrated its 50th anniversary. At the event, which was attended by more than 150 people, Giovanni Lelli (ENEA Chairman), Aldo Pizzuto (EURATOM-ENEA Association Director), Romano Toschi, (Italian Representative at CCFU), Francesco Romanelli (EFDA Leader), Maurizio Gasparotto (ITER Department Director, F4E), Maurizio Lontano (IFP-CNR Director) and Giorgio Rostagni (Consorzio RFX Leader), all recalled the Association's history and its main scientific and technological achievements. They particularly acknowledged the contribution of the first ENEA Director, Prof. Bruno Brunelli, and the first European Fusion Programme Director, Prof. Donato Palumbo. Octavi Quintana Trias (EURATOM Director) emphasised the Italian Association's contribution to fusion. Alessandro Giordani, Italian Advisor to the Foreign Department of the Council of Ministers, emphasised the importance of ITER and Italian participation in this project, as well as the realisation of the FAST project as part of the EURATOM programme. Among the guests were Carlos Varandas (Chairman of the F4E Government Board), Yvan Capouet (Head of Fusion Association Agreement, Euratom) and Ambrogio Fasoli (CRPP Executive Director).

Maria Polidoro, ENEA

14th International RFP workshop reviews significant progress

Dodging the erupting volcano Eyjafjallajökull, is more difficult than confining a fusion plasma? This was probably a common question among the reversed field pinch community in mid April this year when volcanic ashes disrupted European air traffic and put the 2010 IEA RFP workshop at risk.

But all went well and late spring saw the 80 participants of the 14th International Reversed Field Pinch (RFP) workshop in Padova, organised as part of the framework of the International Energy Agency (IEA) Implementing Agreement on RFP research. The workshop is held about every eighteen months and brings together scientists interested in RFP physics and its links with the tokamak and stellarator. Four RFP devices were represented: RELAX based at Kyoto Institute of Technology, MST at University of Wisconsin, Madison, EXTRAP T2-R at Royal Institute of Technology, Sweden and RFX-mod at Consorzio RFX, Padova. The event drew a good number of young colleagues, which reflects one of the strengths of the RFP community: With all of its four devices based and run in university environments, they take on a strong role in education and training.

Talks given at the meeting portray very significant progress. Recent results on helical states and regimes in which magnetic fluctuation is strongly suppressed by a poloidal current drive – with beta record values – have reinforced the perspectives of RFPs to support the advancement of fusion. European RFP devices are at the leading edge of research on active control of MHD plasma stability with well-established collaboration with tokamaks on this subject. Recently, a growing partnership with the stellarators on the subject of three-dimensional physics has started up. As a result, the workshop was, for the first time, enriched by talks given by stellarator colleagues.

The RFP family is growing and thus welcomed a delegation from the University of Science and Technology of China led by the Dean of the School of Physical Sciences Prof. Wandong Liu. USTC, one of the top Chinese universities, is planning to construct a new RFP device. It will be located on the USTC campus and will be designed and built in collaboration with the Chinese Academy of Science Institute of Plasma Physics, which also realised the EAST tokamak. The new RFP will contribute towards meeting the need for a strong research program on alternate concepts, which is considered essential for the success of the Chinese domestic fusion programme in the ITER era. As Prof. Wandong Liu reminded the audience during his lecture, an ancient Chinese philosophy (770 BC) states: "Let a hundred schools of thought contend"!

Piero Martin, Consorzio RFX

Workshop home page:
http://www.igi.cnr.it/rfpws2010/

The **International Energy Agency Implementing Agreement on RFP research** was signed in 1990 by the US Department of Energy, EURATOM and the Government of Japan. It is designed to improve the physics and technology base of the RFP concept and to enhance the effectiveness and productivity of research and development efforts related to the RFP concept by strengthening co-operation among the contracting parties.

Executive Committee: EURATOM: Piero Martin (Chair) and R. Giannella; Govt. of Japan: A. Komori, S. Masamune; US DOE: N. Podder, J. Sarff

Half a century of fusion research

At IPP's 50th anniversary, political representatives emphasised support for fusion research

On 26th July, Max Planck Institut für Plasmaphysik (IPP) celebrated its 50th anniversary in Garching. IPP Director Prof. Dr. Günther Hasinger welcomed several high standing representatives of German and European politics and fusion research and from German research among the 800 invited guests and staff. He was also pleased to greet the Friends of Fusion, a circle of fusion researchers and high-level industry representatives that supports and promotes fusion research in Germany.

"When Heisenberg and the Max Planck Society founded IPP in 1960, scientists were talking about milliwatts of fusion power over a period of just a few milliseconds. With ITER, we are now aiming for half a gigawatt for up to 5 minutes". In his welcome address, Hasinger summarised the long path to fusion power and the significant role that IPP has played in it. "Fusion research does not need to hide behind other technology developments. It will play a significant role towards the end of the century," he said.

"Bavaria is proud to be the home to IPP": Bavarian Prime Minister Horst Seehofer stressed the great importance of research and technology to the state, and emphasised his support for fusion research: "Fusion is one of the great opportunities afforded to the energy mix of the future". Dr. Helge Braun, Parliamentary State Secretary for the Federal Ministry of Education and Research (BMBF), repeatedly encouraged the scientists to pursue their research and to convey to the public how necessary and enormous an undertaking the quest for fusion energy is. He stressed that fusion power will surely be needed in 2050 due to the limitations and challenges associated with all currently available or feasible energy technologies. Braun also noted that a third of German public spending on energy research goes to fusion energy (120 million euros a year; note by the editor): "We are sure that this money is well-invested in you". Prof. Dr. Peter Gruss, President of Max Planck Society, congratulated the oldest and largest institute of the society and presented Hasinger with a bust of Minerva, the Roman goddess of wisdom and the emblem of the society. Norbert Holtkamp and Eugen Velikhov communicated their congratulations as well as the latest ITER news. Yvan Capouet, Head of Fusion Association Agreement, Euratom, was also included amongst the guests. The reception concluded with a lecture by Prof. Dr. Jochem Marotzke, Director of the Max Planck Institute for Meteorology, regarding the two-degree global warming limit which the EU is aiming for. Marotzke is one of the coordinating lead authors of the IPCC report 2012.

IPP director Günther Hasinger receives a bust of Minerva, the Max Planck Society's emblem, from the Society's president Peter Gruss *(Photo: IPP, Ulrich Schwenn)*

More information about 50 years of fusion research at IPP can be found on the Internet (in German):

http://www.ipp.mpg.de/ippcms/de/presse/pi/09_10_pi.html

Selected milestones at IPP

One of the significant milestones of fusion research was the discovery of a high-confinement tokamak regime at IPP in 1982. The confinement was further improved in the ASDEX Upgrade in 1998. Today, IPP investigates Advanced Scenarios, which enable long-pulse or even continuous operation. In 2010, the ASDEX UPGRADE achieved well insulated high-power plasmas with an all tungsten wall, which is a highly promising result for ITER. In 1992, IPP was also able to reach high confinement mode in the Wendelstein 7-AS stellarator. The development of Advanced Stellarators could offer a way to continuously operating fusion reactors and has led to the construction of Wendelstein 7-X in Greifswald.

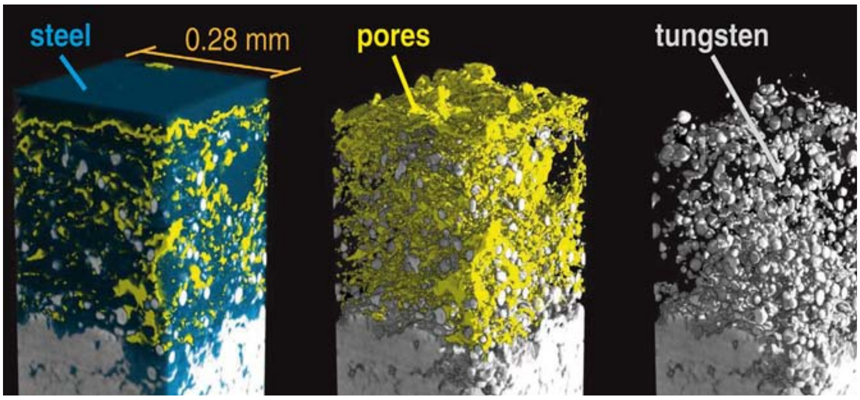
FUSION EXPO

Where is Fusion Expo?

Brussels, Belgium:

24. September and
25 October – 15. November 2010

Full Schedule: www.fusion-expo.si



Micro-mechanical modelling of the pore microstructure (yellow) at the interface between a plasma-sprayed tungsten layer (grey) and an Eurofer substrate (blue). *(Photo: IPP and ESRF)*

Connecting fusion material research to top-level labs

The development of materials that are capable of sustaining the harsh environment inside a fusion reactor is one of the most challenging tasks faced by fusion research (see, for instance, FN December 2008). Understanding the mechanisms which act on the materials and components in a fusion environment, requires considerable efforts in basic materials science, characterisation and modelling. The most sophisticated and advanced material characterisation methods must be applied to quantitatively elucidate the structure of materials (from the nano to the composite level) and the respective damages. In order to fully exploit the capabilities of these techniques, intense collaboration between fusion material research and highly specialised material science experts and their facilities must be established.

The FP7 coordination action "FEMaS – Fusion Energy Materials Science" addresses this issue. The project started in October in 2008 and will run for 36 months. It is designed to merge the knowledge about fusion material requirements and top-level material characterisation techniques. Collaborative activities are stimulated in various fields: benchmarking experiments for radiation damage modelling, the application of micro-mechanical characterization methods, synchrotron and neutron radiation-based technologies and advanced nanoscopic analysis based on transmission electron microscopy. Their focus lies in the development of materials for oxide-dispersion-strengthened steels, tungsten-based materials and fusion-relevant coatings.

A major concern of FEMaS is the integration of large-scale facilities into the fusion materials research program. Associated activities are performed at the synchrotron light sources HZB-BESSY II in Berlin, at the European Synchrotron Facility ESRF in Grenoble, at the neutron source FRM-II in Garching, and at the multi-ion beam accelerator facility JANNuS in Saclay. Several collaborations involve top-level electron microscopes in Europe. High heat flux facilities available at FEMaS partners are involved in material loading tests. Finally, highly-advanced micro-mechanical testing is developed and shared within the consortium.

The collaborative activities between the 27 FEMaS partners are mainly carried out during bilateral training events. During an initial workshop in January 2009, the project partners from the fusion materials community communicated their specific material needs, whereby the experts from the materials characterisation community demonstrated the capabilities of their respective techniques. More than 65 new collaborations emerged as a result of this workshop, and the results were reported during a second workshop which took place in January 2010. In May 2011, an international FEMaS conference will be jointly organised with the "Workshop on Plasma-Facing Materials and Components" in order to finalise the integration of the partners from large-scale facilities into the fusion materials science community. It is planned that the newly established collaborations will be sustained by integrating activities into the EFDA Materials Science topical group and Plasma-Wall Interaction task force after FEMaS comes to an end.

More information:

http://www.femas-ca.eu/main/main.php

Christian Linsmeier, FEMaS

Industry and fusion research successfully launch an innovation forum

The European fusion industry gathered in Brussels on 6^{th} July 2010 to launch the Fusion Industry Innovation Forum (FIIF). The Forum has three objectives: To promote industrial involvement in fusion technology development and power plant studies, to transfer knowledge from research centres to industry and to create a European Fusion Industry by developing skills in the industry. Over 90 participants, including industry representatives, as well as other representatives from the energy and power supply sectors, the Euratom Fusion Associations, Fusion for Energy and the European Commission met to discuss how best to establish the Forum. The workshop was opened by Deputy Director General for scientific advances, DG RTD Rudolf Strohmeier, who presented the main objectives of the Europe 2020 strategy and the place of fusion research within it. Octavi Quintana Trias, Director for RTD Euratom, followed by a general overview of the current fusion research situation and an introduction to the forum's objectives.

These topics were addressed in three different sessions with speakers representing a wide range of industry and research sectors. The participants emphasised the existing impressive examples of fusion technology applications in industry, for example, accelerators used for medical purposes. The real need for initiatives that address the shortage of well-qualified young engineers and researchers was also noted. Furthermore, as a first step to achieving the forum's objectives, the creation of a flagship project such as a power plant design and a detailed technology road map was proposed. Finally, the workshop turned to the practicalities of managing the forum activities via the FIIF Management Board. Potential candidates are now being nominated and will be selected at the end of September, with the first meeting of the board then taking place in October.

Based on the success of this launch event and the strong industry support, the future of the FIIF looks very promising.

Paula Cejalvo Cabral, EC

EFDA during FP7 – Reinforced coordination of physics and technology in EU laboratories Part 7

Socio-economic studies

Continued from front page

It explores public attitudes with regard to fusion and investigates suitable communication tools and methods designed to engage the public in a social dialogue about energy in the future, including fusion as a possible option. SERF also develops tools intended to support political decision-making. It also looks at the fusion community itself as a socio-technological system, collecting insights both on how fusion scientists, working in distributed heterogeneous teams, jointly represent and solve complex problems and create new knowledge, as well as about the organisational culture of fusion research. All in all, the SERF programme aims at creating a repository of relevant social science results and insights, which will be a useful resource when drawing up a sustainable energy policy, enhancing fusion energy awareness and for the governance of fusion research and development projects like ITER.

SERF also investigates energy systems and markets, analysing the dynamics of technological development and of energy policies and their implications regarding fusion. Among other things, SERF studies how fusion energy production costs will depend on plant engineering, on so called “technology learning” and on the evolution of energy demand. It also analyses future energy scenarios with respect to fusion's prospects to enter the market.

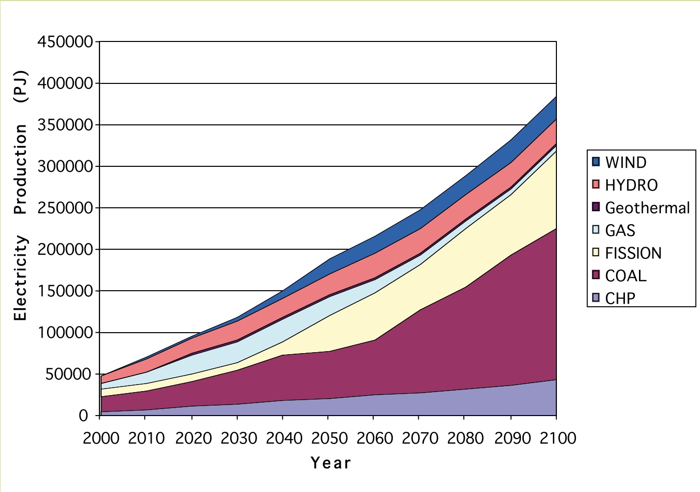
Social acceptability of fusion

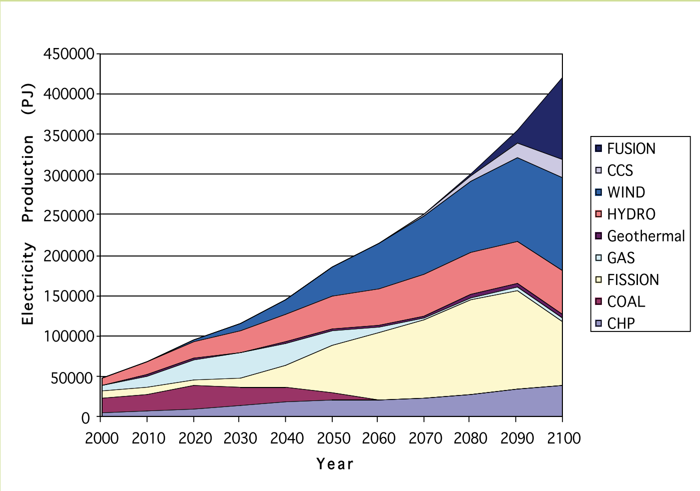
Because fusion power is still decades away from becoming reality, the public has not yet formed an opinion on it and often is not even aware of it. SERF studies have revealed that the European public frequently confuses fusion with fission and that this association impacts the acceptability of fusion in a negative way. People, who accept fusion energy usually do on the basis of two arguments, a perception of fusion as an energy source that guarantees an abundance of energy and is more environmentally friendly than other available sources with similar potential, or their positive association with “top” or pioneering scientific research. The latter is based on the fact that these people are happy to put their trust in high ranking scientists and research endeavours. Lay persons that reject fusion energy either show a high perception of risks or a strong preference for other energy options.

The research has revealed that public attitudes towards complex, new technologies like fusion are not only derived from scientific evidence. Many other resources contribute to their formation, including imagery created by mass media and individual social-context related experiences, such as accidents or good or bad practice examples regarding technology governance. Furthermore, public attitudes are enrooted in values and worldviews, in ways of thinking with regard to science and technology, in the perceived experts' dependability and in the generalised sensitivity to risk of any kind. As with any discourse about a new technology, the discourse about fusion involves the discussion of other technologies as well the individual understanding of progress and visions regarding a desirable future.

Economic acceptability of fusion

A team of researchers from seven Associations (IPP, CCFE, ENEA, IST, CIEMAT, OEAW and RISØ) are engaged in the development





Energy scenarios up until 2100 as derived from EFDA TIMES: If CO_2-emissions are not restricted (top), cheap energy sources like coal will dominate the energy mix. If CO_2-emissions are restricted (bottom), the energy market is opened up to renewable energy sources and fusion.

and exploitation of the EFDA TIMES model. It is based on the TIMES model generator supplied by IEA and yields scenarios up until the year 2100, showing the conditions under which fusion and other technologies will enter into the energy market. Since fusion will only be commercially available in the second half of the century making it too far removed for accurate scientific forecasts, these scenario studies act as important decision-supporting tools for energy policy on the global and regional level. SERF intends to get involved in the international scientific energy debate by contributing EFDA TIMES scenarios and by introducing the fusion option into other long-term energy models used by the community.

Experts agree that energy demand will increase significantly throughout the 21st century. Based on various assumptions, regarding, for instance, technology development or political regulations, there are different scenarios of the future energy systems. If a global threefold increase in primary energy demand and a sevenfold increase in electricity demand by 2100 is assumed, a number of scenarios have been developed based on EFDA TIMES. It appears that the greatest impacts on the role of fusion in the energy market are related to CO_2-emissions regulations, the overall energy demand, the availability of uranium resources and the cost of fusion. Important potential aspects include the development of renewable as well as CCS (carbon capture and storage) technologies and the evolution of fast breeder fission reactors.

If CO_2-emissions are not restricted, the energy mix of the year 2100 will be dominated by coal and gas since these are the cheapest energy sources. The situation is completely different if CO_2-emissions are to be considerably reduced. In this instance, climate-friendly technologies will dominate the energy mix and renewables and fusion will become highly competitive on the energy market.

SERF 2011 Work Programme (WP)

1) Studies in support of governance and public engagement

a. Integrated sustainability assessment of energy systems including fusion as an energy option – ISAF:

ISAF aims to build a platform for a deliberative energy policy discourse at European level that will bring both fusion energy and other energy technology experts together, as well as policy makers. The programme will examine the views of the invited stakeholders and it will also test the usability of decision-supporting methodologies, procedures, structures and tools, such as the energy scenarios developed by the EFDA TIMES model.

b. Analysis of the European public discourse with regard to fusion:

A critical analysis of public information documents produced by the fusion community, science centres and the media (the discourse "deconstruction") will clarify the various positions on fusion and the underlying assumptions, frames and values or focal points. The study kicked off in 2010 with an analysis of the public discourse regarding ITER and will expand to include fusion energy and nuclear energy in general in 2011.

c. Evaluation of public information actions:

One of the main public information activities carried out by EFDA is the 'Fusion Expo' travelling exhibition. Following the example of many museums and science centres, a study has been launched under the 2010 Work Programme. It evaluates Fusion Expo from the point of view of its success in fostering an understanding of fusion among lay publics in Europe, and employs both ethnographic and sociological research instruments. The work will collect data during exhibitions in Spain and in the UK which will enable inter-cultural comparisons. The results will support EFDA in the further development of the Fusion Expo exhibition and other public information activities.

2) Studies in support of fusion RTD socio-technical systems

Fusion Research and Technology Development (RTD) takes place within large, international scientific networks composed of people, ideas and artefacts. SERF will investigate how the scientific work is coordinated and synchronised, for example, how members of the research body join or contribute to projects or form alliances and how tools and resources are produced or employed to cope with the complexity of problems within these networks. It will also look into the various dimensions of the organisational culture of fusion RTD bodies, addressing e.g. the role of cultural differences on organisational practices and the shared definition of problems and role responsibilities within international, multicultural research teams. The studies are designed to identify organisational and situational factors which support or undermine the successful accomplishment of collaborative tasks in fusion RTD structures. Within WP 2010, the first tasks have already been launched, commencing with a review of the state of the art in social and cognitive studies of science relevant to fusion and with two pilot research projects to be carried out in selected fusion labs. Within WP 2011, a wider research project will follow with a special focus to ITER.

3) Economic research based on EFDA TIMES

In 2009, the affordable new master version of the EFDA TIMES model was delivered. The partners agreed on a common database and on the first set of scenarios, the analysis of which will be presented to the international scientific community at the IAEA conference in Korea in October 2010. The results achieved will be consolidated in 2010 by a more detailed sensitivity analysis, which tests the robustness of the model against parameter variations as well as by studies regarding individual energy technologies, the implementation into the model of which will thus be improved. The latter refers to the representation of, e.g. generation IV fission reactors and nuclear fuel cycle, intermittent energy sources such as solar or wind power, CCS as well as the impacts of possible energy saving strategies and technologies which can reduce the growth rate of the energy demand. The EFDA TIMES model will be further exploited by the Associations and improved to make its scenarios more comparable with other models' results, more robust and significant from a research point of view, and more relevant with respect to energy policy support.

A BIG thank you to Madgalena Gadomska, EFDA, for her input and support

Boosting inspiration – Polish teachers and students visit JET

On 18th June 2010, a group of thirty five Polish students and their teachers stormed enthusiastically into the START area of CCFE. Visiting JET, Europe's biggest fusion experiment, for the first time, they were literally bursting with questions and eager to see and learn as much as possible. After a warm welcome by Michael Watkins, the Head of the Programme Department and of International Relations at EFDA-JET, Chris Warrick, Head of CCFE Communications, gave a short introduction. The visitors were then shown around the MAST and JET facilities and the day was rounded off with a question and answer session with chief engineer Tom Todd. The visit was perfectly timed as JET was not under operation and the guests were able to enter the Torus Hall to see the world's largest tokamak at very close quarters. They were especially impressed by the remote handling facilities and the real scale model of the tokamak itself.

The group had come to Oxford on a one-week training course as part of a project for science teachers and students called 'Fusion at school and in society' which has been run by the Polish Euratom Association IPPLM for a total of three years now. It is designed to introduce fusion to young people aged 13 to 19 in secondary and high schools throughout Poland. Last year, IPPLM organised a similar visit to JET for teachers but this year's trip was aimed specifically at the most talented students. These were selected during the course of a two-stage competition. Firstly, teachers selected their best students by means of competitions within their schools and cities. Then, the local champions attended a training meeting and completed a central test on fusion and nuclear physics in April 2010. Only these national winners qualified for the educational trip during which they were accompanied by their teachers. Alongside visiting JET, the group also stopped by the Physics Department of Oxford University, where they attended a lecture given by Prof Nick Jelley on the subject of the energy crisis and had a tour of the undergraduate laboratories. The Rutherford Appleton Laboratory invited the pupils and teachers to visit the Space Physics Division and showed them the Solar, Terrestrial, Astronomy, and Cosmic Rays Physics labs along with the projects being carried out there.

In addition to the strictly professional activities, the group also found time for a sightseeing tour around the picturesque old quarter of Oxford, which gave them the opportunity to observe university students in full swing of their annual exams and listen to the Oxford Bach Choir concert at the Sheldonian Theatre. Exhausted but happy, the party completed their science adventure with a visit to the Greenwich Royal Observatory in London.

These visits proved to have an extremely motivating effect, on both teachers and pupils. The young people mostly appreciated the opportunity to talk to scientists and students in each of the renowned places. These informal encounters are a source of inspiration to the teachers and shows them how to appeal to young people whose interests are often far from pure academic knowledge, and to encourage them to investigate the sciences and how to induce curiosity. They are more credible to their students if they are able to give examples involving real scientists. All of the teachers emphasised the importance of meeting colleagues from other parts of the country, exchanging ideas or even making friends. Many of them have stayed in contact after returning home and have thus a form of support group for science teachers. As for the students, this statement gets to the heart of it: 'I always perceived physics at school as a very though, extremely complicated and maybe a little boring subject but now, to my surprise, I see that physics can be a hobby that gives a lot of satisfaction'.

Was it not worth the effort?

Helena Howianec, IPPLM

TEC to focus on plasma-wall interaction

The Trilateral Euregio Cluster TEC, a fusion research cooperation in of the Euregio of The Netherlands, Belgium and the German federal state of North Rhine-Westphalia, renewed its contract and defined future research priorities. Based on the unique competence of its partners – the Ecole Royal Militaire/Koninklijke Militaire School at Brussels, the FOM Institute for Plasma Physics at Nieuwegein and Forschungszentrum Jülich – TEC will concentrate on the investigation of plasma-wall interaction processes. During the signing ceremony on July 8th 2010 at Forschungszentrum Jülich, the consortium also welcomed a new partner, the Belgian Studiecentrum voor Kernenergie/Centre d'étude de l'énergie Nucléaire (SCK·CEN) at Mol. TEC was established in 1996 and has been a real success story. It also integrates the euroregional universities for fusion education and joint research.

Plasma-Wall Interaction (PWI) research is vital to the development of suitable first wall materials for ITER and future fusion reactors (see FN December 2009), a task, which has been identified by EFDA as one of "seven missions" required to ensure the rapid and efficient realisation of fusion energy (EFDA Facility Review of 2008). The review states that Europe still lacks experimental facilities for research into first wall materials, which are in contact with boundary plasmas and therefore contain tritium and are irradiated by neutrons. These facilities are an absolutely essential prerequisite for the success of ITER and subsequent fusion power plants.

The partners in the Trilateral Euregio Cluster share the necessary key knowledge and experience that will enable them to build new experimental installations in the Euregio or further enhance existing ones: JULE-PSI at Jülich, MAGNUM in The Netherlands and VISION-I at Mol in Belgium. These specialised linear plasma machines will soon form a centre of competence for the study of plasma-wall interaction in future fusion reactors that will be unique worldwide. TEC's new scope comprises the investigation of tritium retention and removal whilst taking account of safety aspects, the investigation of erosion and re-deposition of activated materials, the development of advanced boundary plasma and plasma-surface interaction diagnostics and control tools – and much more. The new experiments at Jülich and Mol will be conducted in hot cells in order to be able to handle wall materials which are radioactive and contain tritium. Together the envisaged devices deliver particle fluxes and ion energies which are ideal for studying the mechanisms that take place in the ITER divertor.

Ralph P. Schorn, Forschungszentrum Jülich

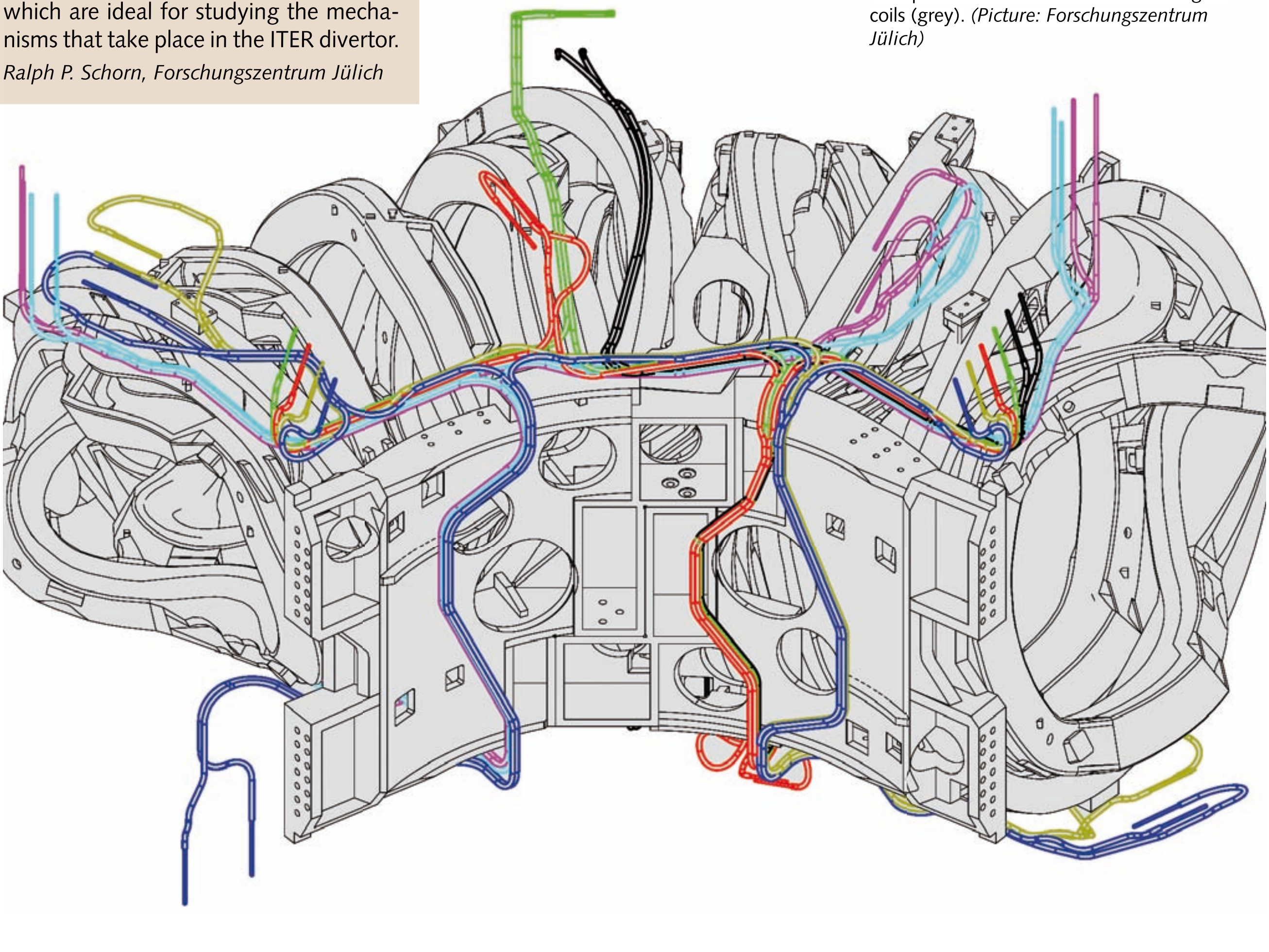
Superconducting connectors for Wendelstein 7-X delivered

Forschungszentrum Jülich (FZJ) with its great expertise in fusion technology took over the crucial engineering tasks for the construction of the Wendelstein 7-X stellarator at Greifswald. The project had a financial input of 30 million euros and came to an end successfully on 30th June 2010.

Jülich mastered the design, the manufacturing and also the qualification tests of the "busbars" – an important subsystem used to electrically interconnect the superconducting magnet coils of the stellarator. These connectors also need to be superconducting. The system consists of individual supports, clamps and joints for the electrical and hydraulic connection of the busbars and coil terminals. Major challenges arose not only from the complex geometry of the stellarator coils, but also from the mutual displacement of the components to be connected, the considerable electromagnetic loads and the limited space available for the accommodation of the busbar system. Moreover, the busbar insulation must withstand electrical fields corresponding to a test voltage of 13,000 Volts even after multiple mechanical and thermal load cycles down to a temperature of 77 K. In order to fulfil all these requirements, FZJ constructed a dedicated production and qualification hall full of computer-controlled machinery and tools.

In a ceremony at Jülich on June 30th 2010, project leader Dr.-Ing. Olaf Neubauer handed over the final busbar elements to Prof. Thomas Klinger, the representative of Max-Planck-Institut für Plasmaphysik in Greifswald. In total, Forschungszentrum Jülich had designed and manufactured about 400 supports, 700 clamps and 240 superconducting electrical joints for Wendelstein 7-X. The pre-assembly of these components had also been performed at Jülich before they were delivered to Greifswald.

Ralph P. Schorn, Forschungszentrum Jülich



The complex geometry of the superconducting busbar System for Wendelstein 7-X, which interconnects the stellarator's magnet coils. The picture shows how the busbars (in colour) "wrap" around vacuum vessel and magnet coils (grey). *(Picture: Forschungszentrum Jülich)*

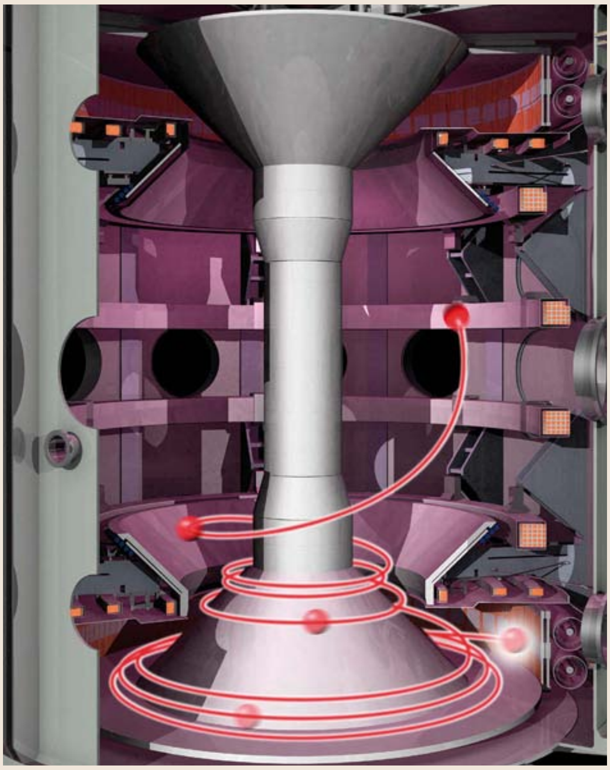
MAST Upgrade opens up new collaboration opportunities

A major machine upgrade, with around £20M of procurement contracts, has recently been approved for the Mega Amp Spherical Tokamak (MAST) at Culham Centre for Fusion Energy in the UK. This will enhance MAST's role in international research and offer EFDA Associations significant opportunities for collaboration.

MAST Upgrade (MAST-U) has three core objectives that are central to the drive towards commercial fusion power:

- Exploring the suitability of the spherical tokamak (ST) as a candidate for a Component Test Facility (CTF), as well as the viability of an ST as a compact design for fusion power plants.
- Adding to the knowledge base for ITER by simulating ITER scenarios in an ST configuration in order to assess how the alternative shape affects plasma parameters.
- Evaluating the Super-X divertor design (see below) that, if successful, could be adopted by future fusion devices, including DEMO. MAST-U will also test steady state tokamak operation with current driven by neutral beams.

Spherical tokamaks like MAST confine the plasma in a tighter magnetic configuration than the conventional JET or ITER-style design, resulting in a cored apple-shaped plasma rather than the usual ring doughnut shape. This offers the potential for more compact and economical fusion operation. Since being commissioned, in 2000, MAST has made significant contributions to fusion physics, particularly in understanding the instabilities that form at the edges of the plasma.



The Super-X divertor increases the distance that exhausted plasma travels before hitting the target by steering in a particular way along magnetic fields. *(Picture: CCFE)*

According to these objectives, MAST Upgrade will provide high performance plasmas with pulse lengths of five seconds (up to ten times longer than the present duration), allowing the study of stable operating regimes that could be used for the design of future fusion machines. Improved parameters approaching fusion conditions will enable highly accurate scaling of plasma confinement models to DEMO, ITER and a CTF. Target parameter deliverables – including temperature up to 50 million °C and density over twice that of the existing machine – will allow experiments at significantly higher plasma pressure. MAST-U will be the first machine to include the high power exhaust system Super-X divertor. This design steers the exhausted plasma along magnetic field lines in such a way that it travels an increased distance before interacting with the targets. The particles are thus radiatively cooled and spread over a larger area, which will significantly reduce the power loads on the targets. With this configuration, MAST-U will be able to study the reduction in power loadings that will be required to handle the plasma exhaust in a CTF and future reactors. MAST-U will also be equipped with a 'conventional' divertor to compare the two systems.

A **Component Test Facility (CTF)** would test complete components like blanket modules or first wall structures under fusion power plant conditions and thus complement the qualification of materials by IFMIF. The EFDA facilities review 2008 lists a **CTF** as desirable in order to reduce those risks for DEMO, which are associated with the qualification of nuclear technology components. CTFs would have to be driven in steady state mode for some days or weeks and produce enough neutron, particle and heat flux to resemble fusion reactor conditions. Spherical Tokamaks offer attractive features for such a facility, in that they are, for example, compact assemblies and, due to their relatively small plasma, can produce sufficient neutron flux while consuming low amounts of tritium.

MAST Upgrade plan

The upgrade to MAST will be implemented in two stages. The first stage will be ready for plasma operations in 2015, with the second phase following two to three years later (subject to funding).

Stage 1 will address scenarios and issues for plasmas that have reached steady conditions. It will enable normal-

ised plasma pressures to be reached in excess of those required for CTF and DEMO. Stage 1 will include the following machine improvements: A new central solenoid with improved insulation and cooling, allowing extended pulse lengths; Increased neutral beam power (from 5 MW to 7.5 MW), including on- and off-axis beams allowing heating in different configurations; An upgraded main toroidal field (from 0.55 T to 0.84 T); A complete set of new divertor coils to fully control the plasma in both a 'standard' and a 'Super-X' divertor configuration; Completely new carbon plasma-facing armour. New diagnostic systems, particularly divertor diagnostics, will also be installed.

In stage 1, MAST-U is expected to prove the physics concept of high heat load divertors, to achieve sustained stable operation at high plasma pressure with high fast particle pressure, and to prove the use of current profile control for enabling stable high performance operation (including definition of the neutral beam current drive efficiency).

Stage 2 upgrade, if funded, would include improved density profile and ELM control, further enhanced neutral beam heating power, a microwave system to test plasma current drive and enhanced diagnostics for fast particle studies. Once the Stage 2 programme is completed, in around 2020, it would be possible to install tungsten plasma-facing components and divertor targets to test aspects of tungsten operation in a CTF or DEMO.

The key parameters of the current MAST machine and how they will improve following the two stages outlined above can be found on the MAST-U website:

http://www.ccfe.ac.uk/MAST_upgrade.aspx

Opportunities for collaboration

MAST-U will offer many possibilities for researchers from other Associations to work with CCFE on areas of mutual interest, both in physics and in tokamak engineering. The MAST programme already involves 14 European Fusion Associations, five laboratories from the US and Russia, and nine UK and overseas Universities. With the upgrade, CCFE will be looking to expand these links and open the new MAST programme up to collaborators as a 'user facility'.

MAST has perhaps the best set of diagnostics of any tokamak now operating, for example its recently-upgraded Thomson scattering system (FN May 2010). Many of these have been implemented with collaborators (see May 2010 and this issue). CCFE will seek similar partnerships to design and build diagnostics and other components for MAST-U. Associations will be able to use MAST-U as a platform for developing new diagnostics and CCFE is inviting proposals on systems for the project.

When completed, MAST-U will enable increased input from collaborators on experimental campaigns. Scientists using MAST-U will benefit from the expertise of Culham's renowned plasma theory programme, which will be fully involved in the project. In addition, facilities for remote collaboration are now available at MAST – the University of York has already set up a 'virtual' control room at its campus, allowing researchers to run experiments and analyse data.

To discuss collaboration opportunities on MAST Upgrade, please contact

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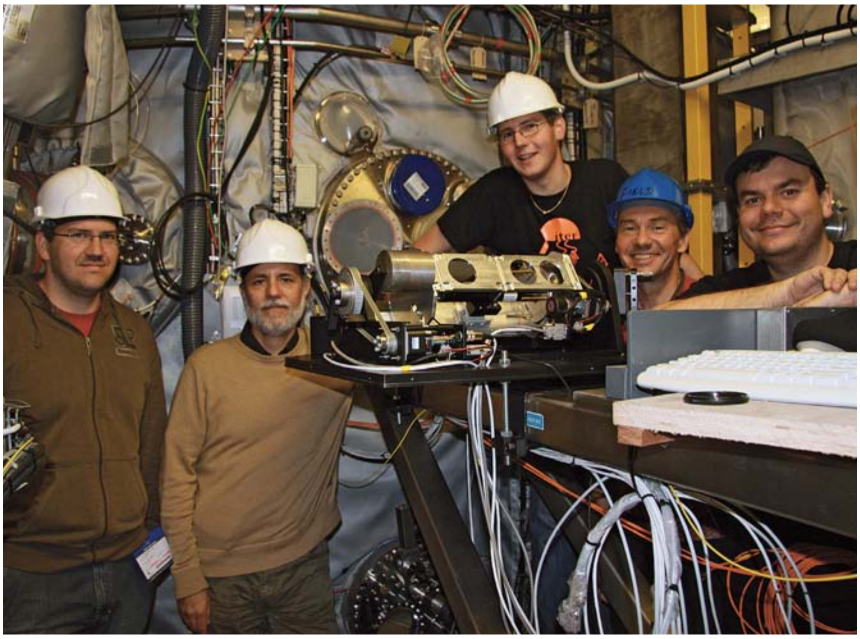
Nick Holloway, CCFE

BES diagnostics installed successfully on MAST

In July 2010, the Hungarian Association KFKI-RMKI and CCFE completed the installation of the Beam Emission Spectroscopy (BES) diagnostics in the MAST tokamak. The BES diagnostics system measures plasma turbulence by detecting light emitted by the neutral heating beams. Thanks to a new, highly sensitive detector as well as extensive optical systems both inside and outside the vessel, the system provides an extraordinary data quality. It is the first 2-dimensional turbulence BES diagnostics built in Europe. The project received preferential EFDA support as it is expected to provide important data which will enable the improved modelling of heat and particle loss during turbulence. The diagnostics will also enhance the understanding of the internal transport barrier and other turbulence phenomena in the spherical tokamak MAST.

Neutral beam heating systems inject fast atoms into the plasma, extending deep into its core. At MAST, these beams measure 10-20 centimetres in diameter. The atoms of the beam are excited – primarily by collisions with the plasma ions – and emit photons with a characteristic frequency. This light is registered by the BES diagnostics. The variations in intensity reflect the local plasma density fluctuations, thus enabling the plasma turbulence to be measured. The challenge lies in the very low light levels that require extremely sensitive detectors as well as relatively big optical elements. A trial BES diagnostics system was installed on MAST in 2006 by KFKI RMKI and CCFE. It has successfully demonstrated the detector technology, but its light level was not sufficient to resolve the small amplitude turbulences in the core plasma. The system has been in operation since 2006 and will, in future, be used alongside the new installation.

The new BES diagnostics is expected to collect around 100 times more light and thus dramatically enhance the data quality. It features a high efficiency detector unit, developed and built by Adimtech, a spin-off company of RMKI. The low noise, high-frequency camera is a standalone unit and incorporates all of the necessary features, including temperature stabilisation via an integrated cooler, internal calibration, signal digitising, high voltage generators and an optical Ethernet interface. The detector has also proved to be an attractive proposition for other applications that require high-frequency measurements at low light levels. The size of the optical elements, the first objective lens in the vacuum chamber measures 14 centimetres in diameter, posed a great challenge in terms of mechanical design, due to the limited space available inside the vessel. Another issue was choosing an observation point that permitted the monitoring of turbulent eddies. These are a couple of centimetres in diameter and form metre-long flute-like structures that follow the magnetic field lines. In order to be able to observe them, you need to look along field lines and the first optical elements should be both large in size and close to the beam. The optics were designed by CCFE and placed in the MAST vacuum chamber close to the plasma edge. They needed to be mounted, protected against the harsh environment, but at the same time they also needed to enable the rotation of the first mirror in order to take measurements along the beam in various radii. These requirements were solved by a complex but sound mechanical system which was designed, built and tested at the Hungarian Association in close collaboration with CCFE. An important element of the mechanism is a helmet formed rotatable shutter that protects the optics when not in use. Changing the observation direction – the 2D diagnostics measures in 4*8 spatial positions in the radial poloidal plane – requires the adjustment of various other optical elements, thus the four moving elements of the resulting system are controlled by computer. KFKI-RMKI has already installed a BES diagnostics in TEXTOR and JET and is currently constructing one for COMPASS. A similar detector unit will be installed at JET at the beginning of 2011.



Happy faces all round after the successful installation of the BES external optical hardware at MAST (in the background). From left to right: Tibor Krizsanóczi, Sándor Zoletnik, István Gábor Kiss, Anthony Field, Dániel Dunai, all from KFKI-RKMI, Anthony Field, from CCFE. *(Photo: KFKI-RKMI)*

Thanks to István Gábor Kiss at KFKI-RMKI for his input

JET shutdown reaches important milestone

As most of us sit back and enjoy the summer holidays, the JET shutdown continues in its rhythm of two-shifts-per-day, seven-days-per-week. The shutdown team is in the process of changing all of the machine's plasma-facing components to the combination of beryllium and tungsten foreseen for ITER (see FN December 2009). By August, nine months into the shutdown, a key milestone had been reached with virtually all of the carbon components removed and the 'naked' vessel having been surveyed in detail to confirm the geometry of the machine prior to proceeding with the installation of the beryllium and tungsten components.

Before starting to install the new tiles, the machine will be thoroughly cleaned using a specially designed vacuum cleaner that is remotely operated. This will remove residual carbon dust resulting from the previous operation to ensure that it will not influence the results obtained with the new metal wall. The installation of the wall will then commence with the re-installation of the beam which holds the diagnostics for measuring the plasma-generated magnetic field.

Another important component of the present enhancement of JET is the upgrade of the suite of diagnostics, with particular emphasis on systems that will help to study the interaction of the plasma with the new wall. Many of these new diagnostics, especially those based on spectroscopy, require calibration. A new remote handling-compatible calibrated light source has been developed and will be used to calibrate these systems 'end-to-end', including the in-vessel optical components, like lenses, windows and mirrors. In a similar manner, a strong neutron source has been hired and will be deployed on the remote handling boom to enable the calibration of the JET neutron diagnostics. As with many of the procedures and techniques being used in this JET shutdown, progress is being closely monitored by colleagues at ITER, who are hoping to develop similar techniques.

The target shutdown duration remains at 65 weeks. In early 2011, JET will be restarted with a new all-metal first wall, an increase of neutral beam power from 23 to 34 megawatts and a significantly enhanced set of diagnostics. The preparations for scientific exploitation of these new capabilities are already well underway and the high level of participation of scientists from around Europe attests to the excitement that these new capabilities have generated within the community.

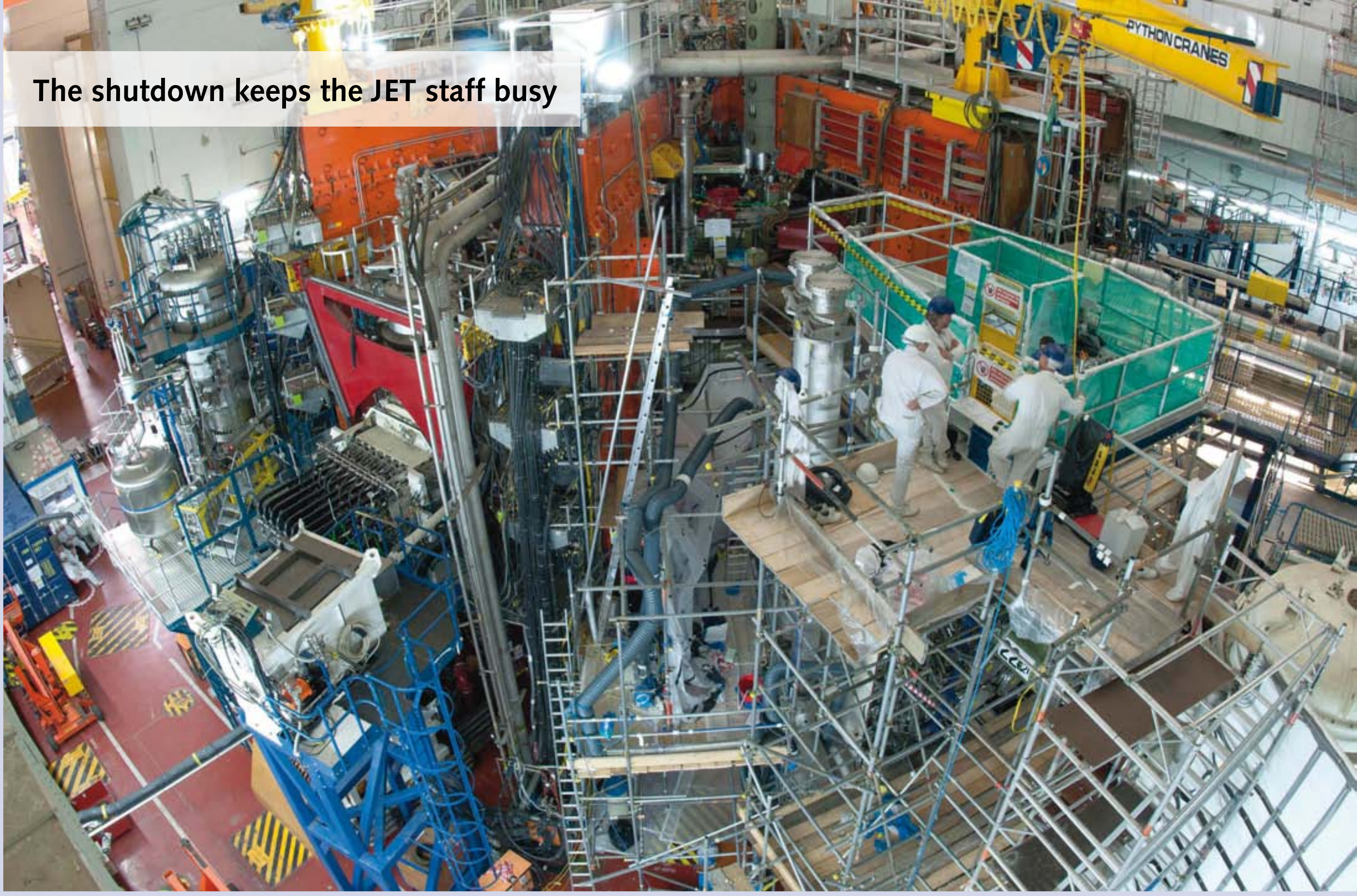
More information in JET's shutdown weekly:

http://www.jet.efda.org/jet/news/category/all-news/shutdown-weekly-all-news/

Lorne Horton, EFDA-JET

JET

The shutdown keeps the JET staff busy














By row: Removing conduits which carried wiring for some of the in-vessel magnetic pick-up coils; Installation of cooling pipework on High Voltage Power Supply equipment; Discussing the final configuration of the input fibres to the spectrometres;

Vacuum Technician prises the wels lips apart; One of the wide-angle camera systems being withdrawn for maintenance; Transfer of the updated Duct Scraper Cryo Panels to a Controlled Area;

Dismantling the waveguides for the microwave diagnostics; Testing the the reflectivity of the mirrors for the Far Infra-Red Interferometer inside the torus; Installing cables for photomultiplier in the neutron spectrometer;

Centralising the shaft of the flywheel rotor, prior to taking guide bearing clearance readings; In the Remote Handling control room; JET machine surrounded by scaffolding. *(All Photos: EFDA-JET)*

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For more information see the websites:
http://www.efda.org
http://www.jet.efda.org
http://www.iter.org

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