Fusion News

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Jérôme Pamela takes up new assignment

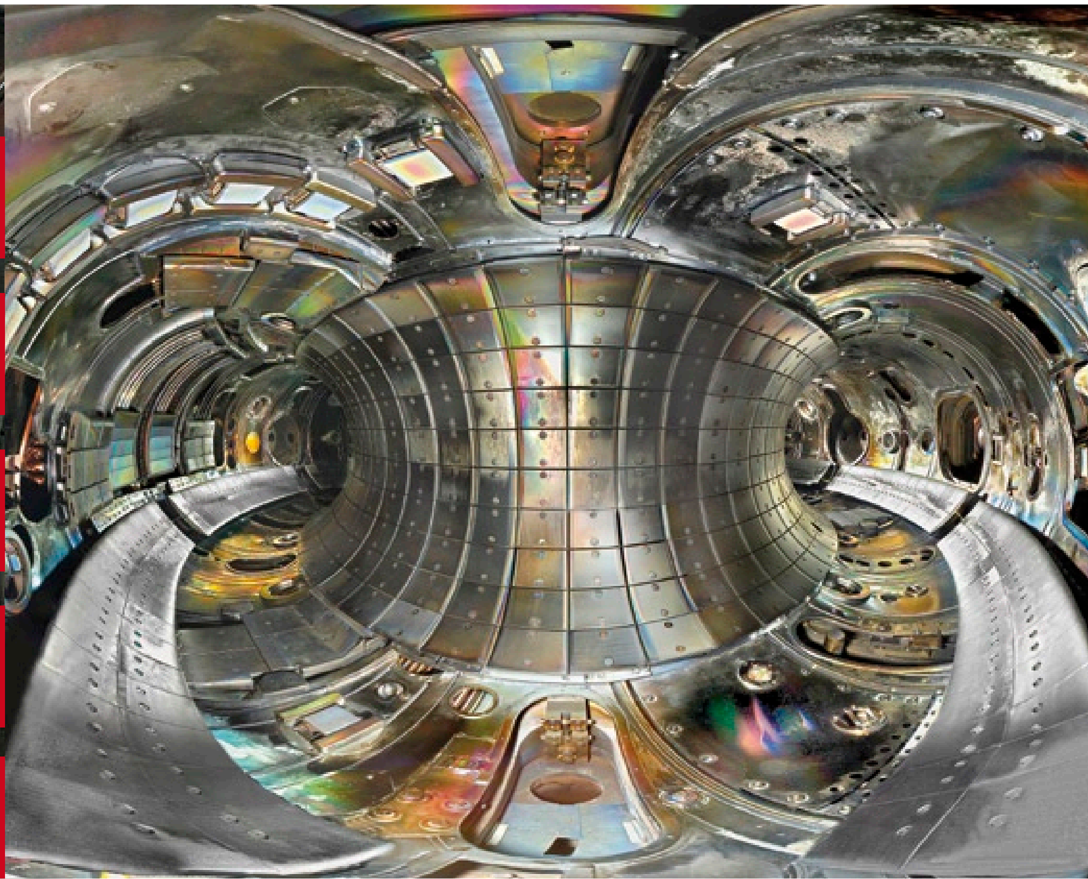
JET develops improved ICRH for ITER

Tore Supra starts up with new LHCD antenna

EFDA Plasma-Wall Interaction Task Force

What happens to JET during the 2009/10 shutdown?

Fusion Expo tours Poland



Panoramic view into the burn chamber of the TEXTOR tokamak at Forschungszentrum Jülich. The machine is specialised for material and Plasma Wall Interaction research (see the PWI article in this issue). To investigate how particle and energy transport in the plasma edge can be influenced by resonant magnetic perturbations, TEXTOR is equipped with the unique Dynamic Ergodic Divertor.
(Photo: Harry Reimer, Forschungszentrum Jülich, April 2009)

EFDA DEMO Meeting: Where does fusion research stand?

Scientists and engineers took a good look at the current status and future challenges of fusion research during a "*technical meeting on the status of DEMO achievements under EFDA*". Nearly one hundred participants, representing 17 European laboratories, EFDA, ITER and F4E as well as some industrial enterprises, met in Garching on September 29th and 30th to prepare the ground for a DEMO conceptual study. They had a lot of material to work through: Between 2000 and 2008 EFDA has supported 70 tasks directly aimed at DEMO. In addition, a number of other EFDA-tasks included DEMO-related research. In excess of 124 scientists from nearly all European Associations were directly responsible for DEMO-related EFDA tasks, with many more researchers involved as co-workers. It was now time to take stock of the results and derive guidelines for further work on DEMO. The meeting has indeed resulted in a useful set of information for a European DEMO advisory group which has the task to make proposals on future DEMO activities in Europe to the CCE-FU (Euratom consultative committee on Fusion) and F4E.

Continued on page 5.

EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

Jérôme Paméla takes up new assignment

After almost four years as EFDA leader, Jérôme Paméla will take on the role of director at Agence ITER France as of January 1st, 2010. Fusion News talks to him about the time he has spent at EFDA, fusion research in general and his new assignment.

Jérôme, your name has been associated with EFDA for a very long time. So before we start to talk about your future assignment, let us take a look back on your time at EFDA. How long have you been involved with EFDA?

In actual fact, I was with EFDA even before EFDA existed. At the end of the 90's we needed to create a replacement for the JET Joint Undertaking Agreement. The Joint Undertaking Agreement was set to come to an end at the end of 1999, but we wanted to continue using JET and had to find a new statute for that. A number of us also considered it very important to change the orientation of the fusion programme in a way that brings the laboratories closer together. Even though they had already been collaborating on various projects, they were not really working together as a united force. Two working groups were formed under CCE-FU to prepare this. I was involved in the group which prepared the first EFDA agreement. This agreement was not only intended to be a new agreement for JET, but was to implement a change of culture as well. The agreement also took over from the former NET agreement under which the fusion technology R&D was conducted, including the European contribution towards ITER.

In February 1999, in a corridor in Brussels, Umberto Finzi, the Director of the Fusion Programme, proposed that I should lead JET and implement the new organisation under EFDA which was to start as of 1 January 2000. I was very surprised and, I must admit, a bit apprehensive regarding the challenge, but eventually, in September 1999, I moved to JET with a small team which I had gathered within the space of just two months. The agreement was not even signed when we moved! That was the start of my involvement in EFDA.

If you look back at your time at EFDA and compare the European collaboration at the beginning with the way it is now, what progress have you observed?

The progress has been quite significant. During the first year, in 2000, a sense of ownership of JET developed rapidly among the European laboratories because they were very closely involved by us in the definition of the programme and its execution. I think this close involvement, including scientific and technical responsibilities assigned to key people in the laboratories, was essential in the development of this sense of ownership. Some people may find that it is less effective than a more classical hierarchical structure, but for me, this joint sense of ownership of the programme has been essential to both secure a future for JET and to prepare a joint approach to ITER. And the system works well when it comes to the joint scientific utilisation of a research facility.

What are your EFDA highlights from the last 10 years?

At JET, we managed - thanks also to the excellent collaboration with and work put in by our UKAEA colleagues who were led efficiently by Frank Briscoe - to set up a new system in just a few months and this system worked from day one. This was a most exiting period.

Also, back in 1999, JET had a very short term future in the minds of many people in Europe. By jointly taking ownership of JET, the Heads of Associations and the key physicists in Europe recognised the value of the device as the key facility to prepare for ITER and we managed to launch two enhancement programmes in 2001 and 2005, which are culminating now with the installation of the ITER-like wall in the JET system.

Another important achievement was the technical contributions made to the ITER project. When the project almost went on stand-by between 2001 and 2005 while waiting for a decision on the site, European contribution under the coordination of EFDA, together with that of Japan and Russia, the other partners involved in ITER at the time, was extremely important in keeping up the technical momentum on the project.

An important step was a new change in the EFDA Agreement which was made at the beginning of 2008, when Fusion for Energy (F4E) was set-up to cover all the European contributions to ITER. The mission of EFDA changed, with the aim of reinforcing the coordination of research activities in laboratories.

How do you see the different roles played by F4E and EFDA?

F4E is the entity in charge of the European contribution to the ITER construction. It is a very important task which implies a number of industrial contracts but also actively supporting R&D. The role of EFDA is directed more towards the research side, and in particular towards physics. F4E and EFDA must work together very closely – and with ITER of course – to ensure that our research programme supports ITER in its scientific questions and allows us to prepare efficiently for the utilisation of ITER. For the latter we will need a very strong scientific programme for both European devices as well as in terms of theory and modelling. The European Fusion Programme must also attract new young scientists that are well trained and capable of utilising ITER. I expect EFDA to coordinate these efforts, which means that the roles played by F4E and EFDA complement each other.

We have heard that the EFDA Steering Committee will revise the role of EFDA. Can you comment on that?

For the reasons I just mentioned, the EFDA Steering Committee is certainly interested in seeing how the role of EFDA could be expanded to develop and coordinate fusion research in Europe. So it is probable that we have positive evolution to look forward to. After two years with the new EFDA, I think it is also time to asses the way we have implemented the new activities, in view of consolidating, improving and simplifying.

What is your opinion on a European satellite tokamak designed to support and complement ITER?

On this, I will give you my very personal views. Preparing for ITER, we had two big tokamaks, JET and JT 60-U in Japan, which operated in the 3-5 MA range, and some smaller devices operating at around 1 – 2 MA. It was important to have this variety of machines because a number of physics phenomena need to be explored under a wide range of conditions and parameters. To prepare for DEMO, we will have one big machine, ITER, and we will also need intermediate sized machines. Currently an upgrade of the Japanese machine, called JT 60-SA, is under construction within the framework of a collaboration between Europe and Japan.

JT 60-SA will be quite strong in a number of fields, but it cannot cover all subjects. However, combined with ITER and JT 60-SA, a European satellite, also operating in the 5 MA range, would and should ensure that we have no gaps in our experimental capability to address all issues needed to prepare for DEMO. So we are now working to define what the programmatic objectives of such a machine should be in order to optimise its value for supporting ITER and preparing for DEMO. Having such a device in Europe would also help ensure that we maintain a strong community of physicists well trained to use ITER. A key question is: When can we afford to put in the financial and human resources necessary to build this new device?

Can you comment on the new DEMO group that was set up earlier this year by CCE-FU and F4E?

This advisory group needs to make some proposals regarding the activities which are to be conducted over the coming few years as well as preparing for a longer term vision to take us towards DEMO. Ideally, we would need to enter into a conceptual design and significant R&D phase for DEMO relatively quickly, but this will have to wait as ITER will drain most of the financial resources of the European Programme for several years. Therefore the question is: What shall we do in the meantime in order to ensure an efficient – but lean – programme preparing for the conceptual phase in form of pre-conceptual studies and R&D on long lead items, i.e. items that we cannot afford to neglect at this time. The best example is the materials programme which started more than a decade ago, because we know that we will need several decades in order to fully develop materials which can sustain the conditions we expect in DEMO.

What was the reason for connecting this DEMO advisory group to F4E?

DEMO is certainly one of the long term objectives of F4E. It is clear to everybody that when the conceptual study of DEMO is launched as a project, with a strong team and significant R&D programme, this should be set up under F4E which has the instruments to implement the project. One thing the European committees will now have to decide is, how the R&D, which I mentioned earlier, is to be conducted until such time as we have the means to enter into the conceptual study project phase, and how DEMO activities are coordinated within Europe. It may be that, for a few more years, the vast majority of the activities would need to be conducted by the Associations.

If we look at fusion in general - what do you say to the frequent comment "Fusion is always 30 years away"?

I reply that there will soon be a time where we won't be told that anymore and that will be when we carry out the Q=10 experiment on ITER. The people who started working on fusion in the 1950s and the 1960s were probably overly optimistic with regard to what was technically required to achieve fusion. Fusion is extremely demanding, it is probably as difficult as sending a man to Mars. We now have a clear idea of what needs to be done and I am convinced that when we have the results from ITER, the road towards the utilisation of fusion for generating energy will become real.

You already mentioned that ITER will need a new generation of scientists. Do you think that fusion research can attract the attention of enough young scientists and students?

Today there is a general difficulty in attracting people to science and engineering disciplines. In spite of that, we have a number of brilliant young people entering into the programme. But generally speaking, we will need more people than we can find today. And we are also limited by our budgets. Therefore the short-term situation could prove a bit difficult, but I am convinced that once the construction of ITER is well advanced and the prospect of its scientific utilisation nearing, a number of young people will hurry to get involved.

Let's talk about your future position: What exactly will you be doing at Agence ITER France?

The Agence ITER France, which was set up within CEA three years ago, is in charge of what CEA as the host organisation must supply to help the project. It provides interfaces between the ITER project and the French authorities, a welcome port of call for ITER staff and their families and other supporting activities. The agency also manages the French financial contributions to ITER. CEA and the ITER Organisation signed the Site Support Agreement on 18th November. This agreement defines all the supplies and services provided by the host organisation.

Until now a major achievement has been the preparation of the ITER site: All the work has been delivered on time and within costs, thanks to the excellent work of my predecessor François Gauché. Now we need to complete this by providing further on-site services (such as 400 kV electricity or cooling water); we also need to build the ITER offices and annex buildings, while other construction work will be conducted by F4E. For a while the agency will also remain responsible for the site.

So you will be less involved in scientific aspects and more in organisational tasks?

Yes, but I will continue to follow up all the scientific and technical aspects of the ITER project. I think it is a key aspect of the interfacing between ITER and the host organisation.

One last question: You will start your new job on January 1st. Will a new EFDA leader have been appointed by then and will you have an overlap period with your successor?

I cannot tell you the starting date for my successor, but I will certainly do my very best to help with the transition period.

News

ASDEX-Upgrade Annual Meeting

IPP scientists and their collaborators met at the Ringberg Castle, a conference site of the Max-Planck-Society, between 26th–30th October 2009. This traditional annual gathering is organised primarily to discuss the scientific and technical aspects of the ASDEX Upgrade research programme, but it is also characterised by very rich and comprehensive discussions on the main topics surrounding fusion research. In total, in excess of 100 scientists attended the meeting, 27 of them from collaborating institutions of IPP. Among the invited guests and speakers were representatives of General Atomics' DIII-D in San Diego, the ALCATOR C-MOD tokamak group at MIT, as well as JET and ITER. This year the meeting focussed on the ASDEX Upgrade enhancements and the extension of operation to low collisionality plasmas, as well as on topics related to real time diagnostics, pedestal physics, physics of rotation and MHD (magnetohydrodynamics) issues. The conclusions drawn by of the meeting will have an impact on the hardware changes planned for the 2010 shutdown of ASDEX Upgrade. During this shutdown (Jan – Aug 2010) the first set of internal coils will be installed which will enable the study of the effects of resonant magnetic perturbations on ELMs. In addition, measures to improve the compatibility of ICRF heating with a full tungsten wall are envisaged.

Thanks to Duarte Borba, EFDA, and Josef Schweinzer, IPP, for their input

A new 'identity' for UKAEA Culham

Culham Centre for Fusion Energy (or "CCFE" for short) is the new name for UKAEA Culham. An organisational change at the end of October, which comes as a result of selling the decommissioning sector of UKAEA to Babcock International, was a wonderful opportunity to rebrand fusion work at Culham. The resulting logo and style has been chosen to reflect a new identity that represents the aspirations of the senior management team at Culham to be at the forefront of the realisation of fusion as a new energy source. The new logo was designed by the in-house Culham Publications Services team and represents stylised fusion plasma. At the same time, the Culham Communications Group launched a new and much more dynamic website that should attract many more fusion fans. You will also find that email addresses which had previously used the suffixes '@ukaea.org.uk' and '@jet.uk' now end with '@ccfe.ac.uk'. Check the new website out at

www.ccfe.ac.uk.

Jenifer Hay, CCFE

New media prize for the film "Fusion 2100"

The most recent film produced by the European fusion community by the help of IPP, entitled "Energy of the future – Fusion 2100" (see FN July 2008), won the 2009 EuroPAWS MIDAS Prize for New Media (PAWS stands for Public Awareness of Science and Engineering Project). The prize recognises the best European new media production (web, promotional video etc.) involving science and engineering/technology. The award was presented at the "Environment in TV and New Media Awards Evening" at the Institution of Engineering and Technology in London on 23 November 2009. This is the second prize awarded for the film, it also took the Future Award 2008 at Photokina, the leading international fair of the imaging branch (see FN December 2008).

Örs Benedekfi

Fusion Expo tours Poland

In spring 2009, Fusion Expo went on tour in Poland. The tour started at University of Technology in Koszalin between 27th of May and 9th June, and moved on to University of Szczecin between 16th June and 15th July. After the summer holidays, two other cities welcomed the exhibition at their Universities: Łódź between 10th–25th October and Katowice between 3rd – 21st November. Each stop on the tour was visited by, on average, around 3000 people.

The tour is part of an educational project for science teachers from all over Poland organised by the Polish Association IPPLM. The teachers participate in lecture sessions about fusion, visit fusion laboratories and subsequently introduce the topic to young people at school. For the Fusion Expo tour, the teachers motivated their local universities to play host to the show in order to help make high school students more familiar with fusion.

Special questionnaires had been prepared for visitors in Łódź and Katowice to find out how much young people know about fusion and what they have learned from Fusion Expo. The answers will help to improve the exhibition in future. We are waiting impatiently on the results.

Helena Howaniec, IPPLM

Günther Hasinger new Chairman of EFDA-SC

On 6th October, 2009, Günther Hasinger was appointed Chairman of the EFDA Steering Committee (EFDA-SC).

Professor Dr. Hasinger was appointed scientific director of Max Planck Institute of Plasma Physics at Garching and Greifswald in 2008. Prior to this, as of 2001, he held the role of director of the X-ray and Gamma Group of MPE at Garching. Hasinger ranks among the world's leading capacities in the fields of cosmology and x-ray astronomy. In 2005, he was awarded the Leibniz Prize of the Germany Research Foundation for his research on cosmic background x-ray radiation.

More information about Günther Hasinger can be found under:

http://www.efda.org/about_efda/organisation-hasinger.htm

EFDA DEMO Meeting: Where does fusion research stand?

Continued from front page.

DEMO poses manifold challenges for fusion research. Stable scenarios for such powerful plasmas are not yet available. Suitable heating and current drive systems as well as control tools need to be developed beyond their present capabilities. DEMO will also need blankets that breed tritium at a rate which ensures self sufficiency. The very large flux of fast neutrons, which will be produced by the plasma, calls for wall materials with very low activation rates in order to keep the production of nuclear waste as low as possible. ITER is expected to deliver a number of key answers for many of the issues mentioned above, but not all. Therefore ITER needs to be complemented by an accompanying programme towards DEMO, a programme that needs to be very thoroughly defined.

A number of urgent issues to be assessed were pointed out at the meeting:

- The options for the DEMO plasma scenario will strongly depend on the solutions available for handling steady and transient power loads, mainly on the divertor. The most urgent open questions are with regard to the mitigation and / or avoidance of disruptions and ELMs, the power fluxes on the divertor plates and the behaviour of impurities eroded from the plasma facing materials. To limit power fluxes to the divertor plates, the plasma has to radiate higher levels of heat, therefore spreading the heat load in a larger area. This could be the main challenge for plasma scenario development.
- Many current diagnostic techniques are not suitable for DEMO's harsh environment and thus new methods must be developed. Rather than the sophisticated scientific instruments they are today, diagnostics on DEMO must be designed as simple and reliable tools, providing the plant operator with all necessary information in a practical and straightforward way,.
- To meet DEMO requirements, technological R&D can be undertaken independently from most physics and plasma operational issues. The development and design of fundamental subsystems such as breeding blankets, heating and current drives for profile control, high temperature (>500 °C) cooling as well as remote handling and maintenance systems should be pursued vigorously, since they require challenging long-lead developments.

The participants of the meeting concluded that keeping the 'European fast track' requires greater research efforts than today. They consider it vital to keep the design of DEMO flexible enough to incorporate new results as they come. Many insights may come at a later date, as DEMO construction is foreseen to start around the end of ITER's first experimental phase, i.e. about 10 years after ITER's first plasma. To prepare for DEMO, it is essential for Europe to get all key tools operational: ITER, a materials irradiation facility – the IFMIF project –, as well as an accompanying (or satellite) tokamak programme.

Participants therefore felt that it is time for the previously mentioned DEMO advisory group to define more precisely the objectives and mission of DEMO in order to design an integrated, complete, relevant and consistent programme for physics and technology R&D. When resources will become available, the DEMO conceptual design activity – encompassing design and R&D- should start with ambitious but realistic targets. The preparatory steps that start now are essential for the success of DEMO, the step after ITER that will mark the entry of fusion into the energy production era.

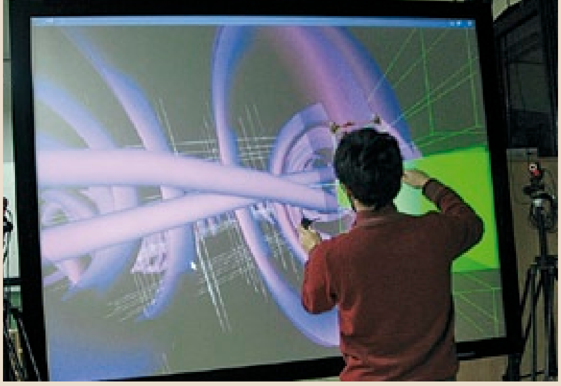
Thanks to Vincenzo Pericoli, EFDA, for his input

All presentations given at the meeting can be found on the EFDA website:

http://www.efda.org/efda_meetings/demo_2009.htm

DEMO

DEMO is part of the *European fast track to fusion* which started with the construction of ITER and will precede the construction of a commercial fusion power plant. DEMO will be built to demonstrate and optimise the operation of a fusion reactor capable of producing electricity. It will provide an integrated demonstration of all the required technologies in reactor operating conditions. DEMO is intended to supply several hundred MW of electricity in a more or less continuous operation. It will operate on deuterium-tritium fusion reactions. Tritium will be bred from lithium in dedicated breeding blankets surrounding the plasma.



Exploring TJ-II: A user wearing position sensors is detected by a camera and projected into the 3D model of the stellarator TJ-II. *(Photo: CIEMAT)*

Immerse yourself inside the plasma

Scientists from the Spanish Association CIEMAT, along with colleagues from the computational institute BIFI (Institute for Biocomputation and Physics of Complex Systems), have created a tool, which allows them to step inside their research results and have a look around. In their so-called 3D lounge, they can enter a fusion reactor, observe how the plasma behaves in various magnetic fields, launch ions and watch their trajectories and explore all corners of the vessel. Their software visualises anything that is available in a 3D data format. The image is projected onto a screen with polarised light and users wearing polarised glasses seem immersed inside it. They wear position sensors, which are tracked by a camera and this allows them to move around inside the 3D structure. The CIEMAT-BIFI group took the lounge to ITER, where they invited people to explore their future reactor.

CIEMAT scientist Francisco Castejon explains how the project started: "We are working on TJ-II, a stellarator with a very complex geometry. The results of our calculations – for instance the trajectories of millions of plasma particles or of the magnetic field – were so difficult to imagine that we developed a 3D visualisation software". In close collaboration with BIFI, the scientists created a system that projects users inside the 3D image. This turned out to be a fantastic tool for public information purposes: "At demonstration sessions in Zaragoza and Madrid, people were delighted to be able to enter fusion devices, getting a "real" impression of what stellarators or tokamaks are and how they work. The sessions helped fusion research to gain increased support in Spain," Francisco says. The 3D lounge is mobile and can travel to other Associations by van. Currently the group is planning to further enhance their equipment.

Thanks to Francisco Castejón, CIEMAT, for his input

The 3D lounge was developed by José Luis Velasco, José Miguel Reynolds, Luca Rossi, and Alfonso Tarancón from BIFI, and by Francisco Castejón, Daniel López Bruna and Antonio Gómez from CIEMAT. Contact: francisco.castejon@ciemat.es; tarancon@unizar.es

Videos of users exploring fusion structures:

http://www.youtube.com/user/BifiUnizar

BIFI:

http://bifi.unizar.es/

Wendelstein 7-X: Coil tests completed

Ten years after the contracts for seventy superconducting coils for the stellarator Wendelstein 7-X were signed, the last coil completed the functionality test at CEA Saclay. Professor Thomas Klinger, the scientific director of the project Wendelstein 7-X at IPP Greifswald, recalls the countless technical problems that needed to be overcome during these years of hard work. Now he is pleased that, for the last two years, IPP was able to keep to the mid-2014 target date for the end of construction. More than 15 years ago the 50 coils that form the confining magnetic field were assigned their special shapes as a result of calculations performed to optimise the stellarator design. Doubts had been expressed as to whether these coil shapes could be manufactured at all, but the test results show that optimised stellarators can indeed be built, points out Thomas Klinger.

The hardest test the coils had to pass was the so-called quenching, a process by which a material looses its superconductivity and all its magnetic energy is released at once. For this purpose, the test temperature of 5.7K was raised to 6.2K, forcing a quench. The tests show that the coils regained their superconductivity when they had cooled back down again, thus reaching the specified (electric) current levels. High voltages which may occur during the unlikely event of a fast shutdown are another critical issue. After reworking the insulation of some coils, all of them are now able to withstand the required voltage levels of up to 9k V.

At the inner edge of the stellarator vessel, the coils touch each other as a result of the limited space. This leads to the occurrence of so-called stick-slip events in which the tension that builds up between two coils is suddenly released and the coils slip, setting vibration energy free. It was not clear, however, whether this would cause a quench in the superconducting cables that make up the coils. But mechanical testing showed that, even at crash energies which correspond to several simultaneous stick slip events, quenching could not be triggered. Now that all coils have arrived in Greifswald the assembly process is well underway.

Thanks to Thomas Klinger, IPP, for his input

More general information about Wendelstein 7-X and its superconducting coils can be found here:

http://www.ipp.mpg.de/ippcms/eng/presse/pi/10_09_pi.html

Karlsruhe International School on Fusion Technologies

Worldwide plans to develop nuclear fusion into a future energy source will depend heavily on a new generation of highly trained and motivated engineers and physicists. The Karlsruhe Institute of Technology (formerly the FZK) therefore organises an annual summer school in co-operation with European research organisations and industrial companies. The workshops introduce the key fusion technologies to young scientists and engineers, giving them an insight into the challenges of fusion research. This year, 46 participants from all over Europe and India heard 35 lecturers present topics in their specific fields of competence. Visits to laboratories in the Karlsruhe Institute of Technology (KIT) completed the school programme. The presentations can be downloaded from:

www.kit.edu/summerschool-fusion.

The 4th Karlsruhe International School on Fusion Technologies 2010 will be held between 6th – 17th September 2010.

Dirk Radloff, KIT

EFDA Fusion News

Tore Supra starts up with new LHCD antenna

On October 28, the new ITER prototype Lower Hybrid Current Drive (LHCD) antenna (Passive Active Multi-junction (PAM) antenna, see FN October 2009) started its commissioning phase on the Tore Supra tokamak. The entire system operated successfully as soon as the second day, coupling 450 kW into the plasma for 4.5 seconds, which is an outstanding result after such a short commissioning period. Besides the need for long pulses, ITER poses a second challenge for the Radio Frequency (RF) power systems. This challenge takes the form of a large gap between plasma and antenna which causes higher reflections (see the JET ICRH article in this issue about the effect of reflections). Besides the active waveguides that transmit the power, the PAM antenna design incorporates passive waveguides which receive part of the reflected power, preventing it from affecting the RF generator. The first experimental results clearly meet the main design specifications: Even with a large plasma-antenna gap, less than two percent of the supplied power was reflected towards the transmission line and RF generator, compared to up to ten percent for conventional antennas. Thus the new system may enable a more continuous and reliable power injection into the plasma.

Thanks to Annika Ekedahl, CEA, for her input

Karlsruhe Institute of Technology founded

On 1st October, the Forschungszentrum Karlsruhe and Universität Karlsruhe merged to form the new Karlsruhe Institute of Technology (KIT). KIT combines the missions of a university with teaching and research tasks and that of a large-scale research institution within the Helmholtz Association, namely conducting program-oriented research. With approximately 8000 employees and an annual budget of around EUR 700 million, KIT is one of the largest research and teaching institutions worldwide. Suffixes in email addresses will change from '@fzk.de' and '@fusion.fzk.de' to '@kit.edu'.

www.kit.edu

Dirk Radloff, KIT

Fusion on a trapeze

A new science show on BBC1 entitled *"Bang Goes the Theory"* went to the circus to demonstrate how vital kinetic energy is for fusion reactions to occur. Presenter Dallas Campbell, dressed up as "superman hydrogen nucleus", together with a professional trapeze artist, tried to overcome their "repulsion" by moving higher and higher up on their trapezes until eventually they were able to grab each other and "fused". Culham scientist Melanie Windridge bravely climbed up to the trapeze platform to explain the theory to Dallas, making sure both "Fusion Boys" build up enough kinetic energy. Dallas also explored the JET facility accompanied by Maximos Tsalas of the EFDA-JET Close Support Unit, and concluded that the day fusion electricity powers our homes "is a day worth waiting for". "Bang Goes the Theory" was broadcast in the early evening, giving fusion research primetime exposure to around two million viewers.

Jennifer Hay, CCFE

Tore Supra research programme 2010–2011

On November 18th CEA presented the Tore Supra experimental programme for 2010 – 2011 at a meeting held in Cadarache. The programme is based on the significant upgrade of the Lower Hybrid (LH) radiofrequency system for heating and current drive that has been implemented within the framework of the CIMES project for long pulse operation (see FN October 2009). With the new systems, Tore Supra is able to produce plasma discharges lasting up to 1000 seconds. Starting in 2010, the programme will initially experiment with a large fraction of LH current drive, delivering 2 MW for 60 seconds. Later in 2010 or in early 2011, experiments can be conducted at full current drive, supplying 4 MW for 1000 seconds and 2 MW for 60 seconds. Ion Cyclotron Radiofrequency Heating (ICRH), which comprises three antennas, can deliver an additional total power of 9 MW for 30 seconds and 3 MW for 1000 seconds. Furthermore, some of the diagnostics have been improved ahead of this experimental campaign. The experimental programme will concentrate on plasma core physics (current profiles of the new scenario, transport, MHD, etc.), plasma edge physics (start up, antenna characterisation, erosion/mitigation/redeposition processes, etc.) as well as control and diagnostics developments.

Thanks to Danilo Pacella, EFDA, for his input

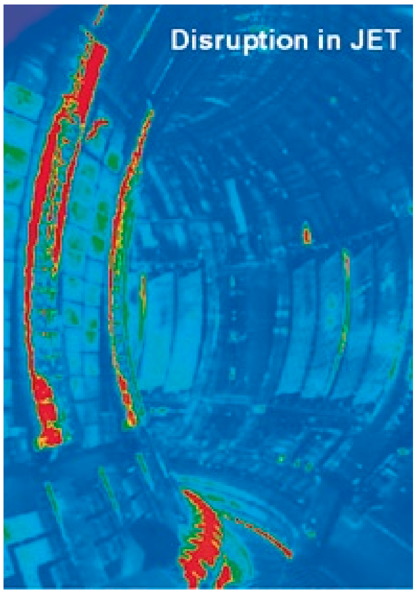
Fusion! "Fusion Boy" Dallas (bottom) and the artist built up enough kinetic energy to "fuse". *(Photo: CCFE)*

EFDA during FP7 – Reinforced coordination of physics and technology in EU laboratories Part 5

Plasma Wall Interaction Task Force

"The boundary edge is where the stellar world of hot plasmas meets the earthly world of cold solids. Understanding the complex interaction of these two worlds is essential for operating a fusion reactor successfully". This is how Wojtek Fundamenski, leader of the Task Force dealing with plasma edge issues for JET, describes Plasma Wall Interaction.

In a fusion reactor, fusion takes place in the extremely hot (above 100 million °C) centre plasma, while the edge plasma continuously exhausts large heat and particle fluxes (in future reactors it will also exhaust helium produced by deuterium-tritium reactions). To control the impact on the wall, two types of magnetic configurations have been developed: Limiters and divertors, which limit the plasma interaction with material surfaces to dedicated strike areas. These components are able to handle significant power loads of up to 20 MW/m^2 and are equipped with pumping systems that remove the particles. Despite the magnetic field confining the plasma, moderate heat and particle fluxes also impinge the vessel walls outside these dedicated strike areas. On top of these steady state loads, additional transient heat fluxes arise from Edge Localised Modes (ELMs), which occur in the improved confinement regime, the so-called H–mode (at which most modern tokamaks operate), and from anomalous events such as disruptions (see FN May 2009). ELMs generate periodic bursts of high heat and particle flux whereas during disruptions all the energy stored in the plasma is lost on very short time scales.



Heat flux patterns on the vessel walls during a disruption in JET. The red areas correspond to the plasma facing components heated by the disruption. The divertor is at the bottom of the vessel. *(Photo: EFDA JET)*

Where the four states of matter meet: Plasma, gas, solid and liquid are all present in a fusion reactor. The left side of this internal view of the Tore Supra tokamak shows a superimposed view of the machine in operation. The bright zones correspond to areas of strong plasma wall interaction. The plasma facing components are cooled by water flowing only a few millimetres below their surfaces. *(Photo: CEA)*

THE BASIC PROCESSES

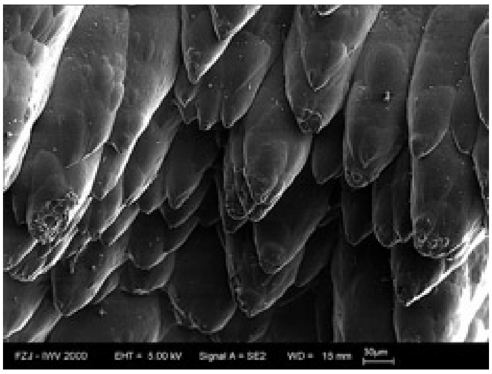
Erosion

Particle and heat fluxes lead to the erosion of PFCs by means of a number of processes:

- Physical sputtering: Incident particles eject atoms from the wall when their energy is above a given threshold.
- Chemical erosion: Wall materials react with plasma particles to form chemical compounds. For carbon based materials, this occurs even at low energy (no threshold), leading to the formation of hydrocarbons. There is no chemical erosion from tungsten PFCs.
- Melting: Metals melt and carbons sublimate when the heat flux exceeds the limits of the materials, for example, during transients such as ELMs and disruptions.

All these erosion processes determine the lifetime of the PFCs. But the PFCs take their revenge: Eroded impurities can travel into the plasma and degrade the fusion performance by diluting the fuel and cooling down the plasma core via radiative energy losses. These radiative losses are linked to different atomic physics processes, such as the excitation of the electrons of the impurities which take thermal energy away from the plasma. The excitation process continues until the impurities are fully stripped from their electrons. Light elements with few electrons – like carbon - are completely ionised in the plasma edge, and therefore do not radiate in the plasma core. For heavy elements like tungsten, however, this process continues in the plasma core. As a result some carbon may be tolerated in the plasma (in ITER up to a few percent), while tungsten levels must be kept drastically low (the levels of purity required for ITER are around 10^{-5}, and have been achieved on ASDEX-Upgrade, a European tokamak which is fully equipped with tungsten PFCs).

Microscopic view of a deposited carbon layer in TEXTOR. Thick layers (several hundreds of microns) are observed after several years of operation in present day tokamaks. They show distinctive features (like this tip structure) which allows us to gain an insight into the mechanisms of redeposition and the associated fuel retention. *(Photo: FZ Jülich)*



Material migration

After entering the plasma, the eroded impurities are eventually redeposited on the vessel walls, both close to and far away from their starting point, sometimes even in remote areas like gaps between tiles or pumping ducts. If they are still contained in an area of strong plasma wall interaction, they may be re-eroded and start another erosion – transport – redeposition cycle. If they are shadowed from the plasma, layers of redeposited materials may build up. If the vessel walls are made of various materials, mixed materials can form which may become a problem if these have degraded properties when compared to the original materials. Beryllium-tungsten alloys, for instance, have a lower melting temperature than pure tungsten.

Fuel retention

The build up of deposited layers also leads to fuel retention in the vessel walls as the deuterium or tritium fuel may be co-deposited along with the eroded materials. This is in particular true for carbon, which has a chemical affinity for hydrogen isotopes such as deuterium or tritium. While fuel retention is not a problem in present day tokamaks that are using deuterium plasmas, it would become an issue for next step devices, where the allowable in vessel tritium inventory is limited, in particular if carbon were used as the dominant PFC. This is the main driver for developing the use of tungsten PFCs in view of the deuterium-tritium phase of ITER.

Dust production

When the deposited layers reach a significant thickness they may flake and form dust. The impact of strong transient events like ELMs and disruptions on PFCs may also produce dust. This may lead to bursts of impurities penetrating the plasma and can become an operational difficulty. In next step devices, where dust may contain activated materials or tritium, the allowable in vessel dust inventory is limited.

THE CHALLENGES FOR ITER

In terms of plasma wall interactions, ITER is a significant scale up from today's devices. A full power nominal shot of 400 s in ITER is roughly equivalent to one JET operational year in terms of energy input, and more like 3–4 years in terms of particle fluence in the divertor. Handling power flux to walls is a very challenging task. Specific plasma scenarios – based on impurity injection intended to spread the power by radiation from the plasma edge – have been developed to maintain the heat loads in an acceptable range for the PFCs (10–20 MW/m^2 instead of 40 MW/m^2 without radiation). The main challenges for ITER are:

- PFC lifetime: While handling the steady state loads should not constitute a major challenge, transient events like ELMs and disruptions are an issue if they remain unmitigated. Promising techniques to mitigate ELMs have been developed, for instance by perturbing the magnetic fields at the plasma edge, as on the US device DI-II-D, and are contemplated for ITER. Several techniques are also developed to ensure that disruptions can be efficiently mitigated. Electron Cyclotron Resonant Heating (ECRH) is used to avoid disruptions by keeping the instability at stake under control. Massive Gas Injection (MGI) can mitigate the impact of disruptions on PFCs by spreading the power and preventing the formation of runaway electrons i.e. extremely highly energetic and potentially damaging electron beams. PWI research evaluates these measures by investigating their impact on the PFCs.

- Fuel retention: To keep within the ITER regulatory limit, the tritium inventory build up in ITER must be controlled. The build-up is extrapolated from present day machines and no serious inventory issues are foreseen if tungsten PFCs are used. Techniques for tritium removal and tritium inventory measurements are under active development since they could be needed in the case carbon PFCs are used during deuterium-tritium experiments.

- Dust production: Just as for fuel retention, research is being conducted to predict accurately dust build up. Dust removal techniques and dust inventory measurements are developed and tested as well.

After completing a Master in engineering at Cornell University (USA), **Emmanuelle Tsitrone** received her PhD in fusion plasma physics in 1995 at the Institute of Research on Magnetic Fusion (IRFM) of CEA. She then worked on experiments and modelling of a new concept for particle exhaust in tokamaks. After completing her PhD, she joined the Plasma Facing Components group of CEA as an officer responsible for designing and manufacturing the new pump system during the last upgrade of the Tore Supra tokamak. Once the device was installed in Tore Supra, she returned from technology to physics, taking part in the edge modelling project at JET, while specialising in the field of fuel retention, and became the deputy leader of the Plasma Edge Physics group in CEA. She is now coordinating research programmes in her field, in close collaboration with the ITER International Organisation, as the leader of the EFDA Task Force on Plasma Wall Interactions and the co-chair of the International Tokamak Physics Activities (ITPA) group which is investigating divertors and scrape-off-layers.

WORK PROGRAMME OF THE PWI TASK FORCE

The Plasma Wall Interaction Task Force (PWI TF) was implemented in 2002 making it the oldest of the EFDA Task Forces and Topical Groups. It gathers together the efforts of 23 European Associations in the field in order to tackle the most urgent PWI-related issues for ITER. The PWI TF is organized into seven Special Expert Working Groups (SEWGs).

While four of these groups directly address ITER priorities (SEWG transient heat loads, SEWG fuel retention, SEWG fuel removal, SEWG dust), the other three groups deal with material related issues (SEWG material migration, SEWG High Z materials and liquid metals, SEWG mixed materials). The main activities of the SEWGs are described on the PWI TF website (see link below). The various groups meet once a year to discuss their results and plan collaborative work. Their leaders report scientific highlights at the annual PWI TF meeting where the main orientations of the future work programme are debated.

The Task Force's present work programme reflects the priorities set by the ITER project and includes:

- The characterisation of the transient heat loads in present day tokamaks for extrapolation to ITER, as well as their mitigation. In particular, the use of massive gas injection to mitigate the impact of disruptions on the vessel walls is being examined in several European tokamaks.
- A strong PWI programme with tungsten PFCs. Besides experiments on ASDEX Upgrade with its full tungsten configuration, laboratory studies in dedicated PWI simulators are being carried out to study the fundamental processes such as erosion and fuel retention in a well controlled environment.
- An effort to establish multi machine scaling for fuel retention and dust production from the results of present day tokamaks in order to refine the predictions for ITER. Moreover, the basic processes involved in fuel retention and dust production are investigated.
- The development of different methods for fuel and dust removal from PFCs, including laboratory studies, as well as tests in the harsh environments of tokamaks.
- The investigation of the formation of mixed materials. In this field, a fruitful bilateral collaboration has been established with the PISCES B linear device (USA), a unique facility able to operate with beryllium. In this framework, EU scientists are regularly sent abroad on a one year contract.
- Understanding material migration. Tracer experiments, for instance, are performed in several European tokamaks in which a trace impurity is injected during plasma operation and located on the PFCs thereafter.

Interior view of ASDEX Upgrade in its final full tungsten configuration. The progressive year-by-year transition from a carbon configuration into a tungsten one has enabled insights to be gathered into tokamak operation with this plasma facing material. The ITER-like wall project at JET (see the article in this issue) will also be a major step allowing PWI studies to investigate a tungsten-beryllium mix similar to ITER.
(Photo: IPP)

Rudolf Neu did his PhD degree in nuclear physics at University of Tübingen in 1992. After his habilitation in experimental physics in 2004, he became a private lecturer at the University of Tübingen. Between 1992 and 1994 he was a post doctorate at IPP Garching in the ASDEX Upgrade spectroscopy group. Since 1995 he has held a permanent position at IPP, working on spectroscopy and plasma-wall interaction. In 2006, he was appointed head of the group dealing with scrape-off-layers, divertors and wall at ASDEX Upgrade. Since 1994, he has been Session Leader and, since 1996, he has coordinated the Tungsten Programme at ASDEX Ugrade. Between 2003 and 2008 he led the special expert working group High-Z/liquid metal PFCs and in 2008 he was appointed deputy leader of EFDA PWI Task Force. He has recently been appointed leader of the JET taskforce which will conduct the first JET experiments with the new ITER-like wall.

Wall materials

In order to cope with all the constraints in a tokamak environment, a plasma facing material must have outstanding thermo-mechanical properties, a low erosion yield and a low fuel retention capability. It should have a minimum impact on fusion performance (no core plasma radiation losses, low fuel dilution) and should be easy to machine into complex shapes. Schematically, there are two families of materials, each with pros and cons. Light elements (called low-Z, due to their low atomic number), such as carbon or beryllium, are generally good candidates for a low impact on core plasma performance. Carbon also has excellent thermo-mechanical properties and, unlike the metals, it does not melt, instead it sublimates. However, low-Z elements have a significant erosion yield, impacting their lifetime and leading to fuel retention. On the other hand, the heavy (or high Z) elements such as tungsten, have a low erosion yield, negligible tritium retention but can degrade the plasma performance. The article about the ITER-like wall project in this issue describes the material scenarios for ITER.

In addition, the PWI TF collaborates with other EFDA groups, like Fusion Materials TG, the MHD TG (on ELMs and disruptions) and the EFDA Emerging Technologies group (on dust and tritium).

Thanks to Emmanuelle Tsitrone, CEA, Rudolf Neu, IPP and Roman Zagôrski, EFDA for their input and support

More information about the Plasma Wall Interaction Task Force can be found on the web site:

http://www.efda.org/pwi_tf

JET develops improved ICRH for ITER

Ion cyclotron resonance heating (ICRH) is one of several methods of heating the plasma in a fusion reactor by injecting powerful radio frequency (RF) waves. An ICRH system consists of amplifiers, transmission lines and antennas that transmit the waves to the plasma. The antenna/plasma system can be regarded as single joint system. Transmitting the RF waves works well only if the impedances – the resistance to electromagnetic waves – of the amplifier and the antenna/plasma system match. The impedance of the antenna/plasma system, however, depends on the density at the plasma edge. In H-mode plasmas, which are intended for ITER, events like ELMs cause rapid changes in the plasma edge conditions and thus in the impedance. As a result, the waves are reflected back to the RF amplifier, which switches off ('trips') briefly as a result thus preventing overloading. The heating does not function steadily and power is lost in the reflections. It was essential to develop a "load resilient" antenna for ITER which can compensate impedance variations and supply continuous power.

A typical ICRH antenna consists of one or more "straps" (metallic blades) that radiate the waves into the plasma. Each strap is connected individually to an amplifier. In recent years, the problem of varying impedances has been combated by combining the reflections generated in two straps. So-called 3dB hybrid couplers at ASDEX Upgrade direct the reflected power to a so-called dummy load, preventing the RF amplifier from tripping. At Tore Supra and TEXTOR, conjugate T-junctions confine the reflected power within the two straps and these compensate each other at the T-junction because the impedances of the two branches are carefully adjusted using variable capacitors.

Both techniques have been used with JET's four "old" A2 antennas to demonstrate their viability. The straps of two antennas were combined with 3dB hybrid couplers, the straps of the other two antennas were combined using conjugate T-junctions.

Another challenge at ITER is the limited amount of space: Large amounts of power must pass through a small aperture, thus calling for high power densities at high operating voltages. The problem lies in the possible arcs caused by the high voltages needed. Their occurrence depends on the geometry of the antenna. The new ITER-like antenna, ILA, was designed in a collaborative effort between LPP/ERM-KMS Brussels, CCFE (formerly UKAEA-Fusion, Culham), Oak Ridge National Laboratory and CEA Cadarache. It is made up of eight straps combined in conjugate T-junctions to form four pairs. The ILA is very compact with a total surface of 0.9 m^2 and is designed to deliver a maximum of 7.2 MW which corresponds to a power density of 8 MW/m^2.

The ILA and the four modified A2 antennas have been commissioned and extensively tested at JET in the 2008/09 experimental campaigns. A total of 8.3 MW ICRH power could be delivered into ELMy H-Mode plasmas and the load resiliency of the systems could be demonstrated. Due to the continuous supply of power, the modified A2 antennas delivered 2.9 MW and 3.6 MW in case of the d3b and the conjugate T coupling, respectively. The A2 antennas can now inject a maximum of 3 – 4 MW power per pair into the plasma, depending on the plasma conditions. The maximum power density reached at the ILA, 6.2 MW/m^2 is a vast improvement over the limit of 1.8 MW/m^2 of the "old" A2 JET antennas. With 42 kV, the maximum voltage on the straps of ILA was close to the ITER design value and exceeded, by far, the previously achievable 30 kV. These results greatly increase the confidence in the ICRH antenna design for ITER.

The ITER-like Antenna ILA (installed in 2007, 7.2MW, 0.9m²) between two A2 antennas (1996, up to 4MW, 2.2m²) inside JET. The copper coloured areas behind the bars of the Faraday Screen are the straps of the ILA. *(Photo: EFDA JET)*

Thanks to Jef Ongena, JET, for his input.

For more information about the JET ICRH improvements, please contact Jef Ongena or Marie-Line Mayoral at JET:
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Marie-Line.Mayoral@ccfe.ac.uk

More about ICRH and other heating methods can be found in JET's Focus on:
http://www.jet.efda.org/pages/focus/heating/index.html

What happens to JET during the 2009/10 shutdown?

On Friday, October 23rd, JET's C27 Experimental Campaign came to a successful conclusion. As soon as the experimental team had finished, work began on the shutdown required to install the major components of the second JET Enhancement Programme in Support of ITER (EP2).

For EP2, JET's plasma facing components, which currently consist of carbon materials, will be removed, replacing the first wall and the divertor by a combination of beryllium and tungsten components, respectively (see article on the ITER-like wall (ILW) in this Fusion News). In parallel, JET's diagnostic and control capabilities will be enhanced and the neutral beam heating power increased from 23 to 34 megawatts.

The refurbishment, which will last 65 weeks, is a huge undertaking, exchanging a total of 4500 plasma facing components. Most of the tasks are carried out remotely, for which the equipment has been largely enhanced (see FN May 2009). The remote handling staff have been practicing manoeuvres for the past months to make sure they are operating the booms in the most efficient way. Nevertheless, the tight work plan requires remote handling to be run in two shifts, seven days a week, during the entire shutdown period. The ambitious schedule however does include contingency for the historically required allowances for equipment failures and maintenance periods for the remote handling equipment. In early 2011, JET will restart.

The critical path of the shutdown is determined by the in-vessel activities that must be carried out. As JET was not designed to be maintained entirely remotely, work will switch between remote and manual handling phases.

It will take several weeks alone to prepare JET for the work to come by attaching and commissioning access chambers for work personnel and access facilities for the remote handling booms. The divertor tile carriers are the first components to come off, so that they can be refitted with tungsten-coated tiles. This task is estimated to last about nine weeks. Next, the beams containing diagnostics to measure the magnetic field inside the vessel are dismounted from the vacuum vessel wall and the upper Inner Wall Guard Limiter tiles will be removed. Some components inside the vessel will be welded remotely and a photogrammetry survey will be carried out to measure the exact position of the ports and other important points inside the vessel, providing data for the subsequent remote handling procedures. Thereafter, all remaining tiles will be removed and stored. The empty vessel is then cleaned and surveyed, the diagnostic beam is put back in and the infrastructure for some of the new or enhanced diagnostics is installed. Beginning about 42 weeks into shutdown, the new wall tiles will be fitted, followed by the limiters and finally the divertor. After removing all previously installed access-facilities and remote handling equipment, JET can be pumped down.

Besides installing the new wall, the neutral beam duct scrapers will be replaced during the shutdown. The duct scrapers are located in the neutral beam ports of the vessel, protecting the ports from neutral particles in the edge of the beams that would not pass through the ports and from particles that are re-ionised as they pass through the port. Since the enhanced neutral beams will supply much higher power, the new scraper needs to be actively cooled.

During the entire shutdown period, significant attention will be devoted to the calibration and adjustment of JET diagnostics for the operation of the machine with the ILW. The main in-vessel activities on diagnostics will be the calibration of the neutron measurements and the calibration of the spectroscopic systems.

Thanks to Lorne Horton, JET, for his input

EFDA-JET's newsletter "Shutdown Weekly" will highlight the most exciting aspects of this shutdown week by week:

http://www.jet.efda.org

MEdC chosen to provide tungsten coatings for JET

When JET starts up at the end of 2010, after the 15-months shut down which started on 26 October 2009, it will be equipped with a new all-metal wall – the ITER-like Wall (ILW) – to conduct tests for the deuterium-tritium phase of ITER. A total of 2000 wall and divertor carbon-fibre reinforced carbon (CFC) tiles with a tungsten coating need to be produced for the project. Such tungsten coated CFC tiles will be used both for parts of the divertor and for certain recessed areas of the main chamber which do not have direct plasma contact, but are nevertheless subject to high heat loads.

Applying the required 10 – 25 µm thin tungsten coating is not an easy task, as its anisotropic thermal expansion does not match that of CFC. Indeed most of the layer types that have been tested have shown buckling (bending or forming bulges) or delamination (splitting off in layers). The "Combined Magnetron Sputtering and Ion Implantation" technology (CMSII) of the Romanian Fusion Association (Euratom/MEdC) has yielded the best quality coatings without buckling defects at high heat loads. EFDA therefore chose to use this technique for the JET ITER-like wall and funded the development of the process to an industrial scale. The production is set up in the laboratory of the Romanian National Institute for Laser, Plasma and Radiation Physics (NILPRP) where CMSII was developed. Today, about 90% of the divertor tiles (the most challenging area due to the high temperatures and the resulting thermal expansion issues) and 25% of the main chamber tiles have been successfully coated.

Material scenarios for ITER

ITER is intended to operate in two phases: It will start in a non-activated regime, using hydrogen and deuterium as fuel. For this phase, the high heat flux areas of the divertor are foreseen to be lined with CFC tiles due to their good thermal properties. The second phase will use a mix of tritium and deuterium as fuel. Since carbon has an affinity for hydrogen and its isotopes, CFC tiles would retain tritium. Therefore, in the second phase, all divertor tiles will be made of tungsten. It is planned to use beryllium as the main chamber wall material for both phases.

G6 and G7 divertor tiles for JET coated with tungsten by CMSII technology *(Picture: C. Ruset, MEdC)*

Magnetron sputtering is a standard technique used to produce a large variety of coatings (metallic or non-metallic). In principle, the atoms, which are to be deposited on the surface, are ejected from a target sample. For this purpose, a low pressure discharge is generated in front of the target using a special configuration of electric and magnetic fields. The CMSII process superposes a high voltage pulse discharge over the magnetron deposition which generates high energy ions that periodically bombard the growing coating. Consequently, an extremely dense, pore free, nano-crystalline structure is produced. At the same time, the stress in the coating relaxes and it is possible to generate relatively thick layers between 10 and 30 µm. For the tungsten coating of CFC, the adhesion was improved by applying a molybdenum interlayer of 2 – 3 µm with the aim of adjusting the thermal expansion mismatch between CFC and tungsten.

Thanks to Cristian Ruset, NILPRP, and Guy Matthews, JET, for their input

More information:

C. Ruset et al, *Industrial scale 10µmW coating of CFC tiles for ITER-like Wall Project at JET,* Fusion Engineering and Design 84 (2009) 1662–1665

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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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