EUROPEAN FUSION DEVELOPMENT AGREEMENT

MELTING TUNGSTEN ON BEHALF OF ITER
JET EXPERIMENTS HELP ITER MAKE SUBSTANTIAL COST SAVINGS

GETTING THE ROADMAP ROLLING
SOLID TUNGSTEN FOR ASDEX UPGRADE

HIGH PERFORMANCE COMPUTER FOR FUSION GOES OFFLINE

EUROPEAN FUSION DEVELOPMENT AGREEMENT

3 | 2013
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Dear reader,

A year ago I was proud to announce the completion of the Fusion Roadmap, an effort that has marked a change in the way our community commits itself to deliver fusion electricity. The year that is drawing to a close has been devoted fully to preparing the implementation of the Fusion Roadmap.

Within just a few months, a detailed Work Plan has been defined. This is a significant step forward in the implementation of fusion activities within a project-oriented structure. In addition, the activities regarding education, training and enabling research which complement and support the mission-oriented work, have been defined with the aim of pursuing excellence in our research field and training the “ITER generation”.

Project Leaders have been selected from amongst the best scientists in fusion and appointed by the Heads of Research Units in October. I am convinced that we have put together a very good team, ready to take on the responsibility for the delivery of the Roadmap objectives, and I am looking forward to working together.

The EUROfusion Consortium governance is about to be finalised. This has required considerable effort from all the Institutions involved and I would like to take the opportunity of this end of year message to thank everyone involved for their support regarding the success of the task. Fusion activities are an example of joint programming and the new Consortium will reinforce this aspect. The approval of the EU fusion budget in November has marked a crucial milestone and we can now build our activities in Horizon 2020 on solid ground.

The ITER-Like Wall exploitation on JET has delivered its most significant result. The experimental JET findings over the last two years – and the specific experiment in which operation has been successfully demonstrated after producing a shallow layer of molten tungsten – have together paved the way towards achieving a positive recommendation of the ITER STAC to begin with a full tungsten divertor in ITER. This decision was approved by the ITER Council at the end of November and it will allow an optimal preparation of early ITER operations with a substantial reduction of the investment costs.

The seventh EU Framework Programme is coming to an end. It has seen the commencement of ITER construction, the completion of the largest JET enhancement since the installation of the pumped divertor and the formulation of the Fusion Roadmap. The eighth Framework Programme, Horizon 2020, will be starting in 2014 with a number of ambitious objectives to be achieved.

I wish you a successful 2014.

FRANCESCO ROMANELLI
GETTING THE ROADMAP ROLLING

By forming the EUROfusion consortium, Europe’s fusion research community fills the Roadmap with life and strengthens its leading position in the field.
“We have come a very long way but we are nearly there now,” concluded EFDA Leader Dr. Francesco Romanelli at a meeting in October this year. And indeed, the European fusion community has come a long way. In 2012, the 30 EFDA Associations analysed their programmes, identified the most efficient path to realise fusion electricity and broke that down into necessary research missions. In early 2013 this Roadmap to the Realisation of Fusion Energy was published. The EUROfusion consortium is now being formed to implement the Roadmap into the fusion research activities under the Horizon 2020 Framework Programme. The members of EUROfusion will be all current EFDA Associates. Both EFDA and the bilateral agreements between the European Commission and the national fusion laboratories – Contracts of Associations, which used to provide annual baseline support – have come to an end. Activities within Horizon 2020 will be implemented by the new Consortium in accordance with the Fusion Roadmap.

**Pooling resources to make ITER a success.** EUROfusion enables a strong, joint programme towards fusion electricity by effectively pooling national resources. This will allow the European fusion programme to take on increasingly complex and large scale projects, which are required to prepare for ITER and to design and construct DEMO. EUROfusion will, for instance, not only define and implement the scientific programme of JET, but will also be allocated experimental time at other small- and mid-sized tokamaks.

**Industrial involvement** is another strategic priority in the Roadmap, especially with respect to DEMO design and construction. Specific opportunities for partnerships with industry have been defined in the five-year Work Plan for Power Plant Physics and Technology. During Horizon 2020, these partnerships between research laboratories and industries should be facilitated by EUROfusion by means of provision of support to joint programmes.

**Education and training** are called for in the Roadmap in order to create the next generation of fusion experts. During the 7th Framework Programme, the Fusion Education Network FuseNet has coordinated education activities at both Master and PhD-level. EFDA offers Post-Doctoral Fellowships and a Goal Oriented programme designed to train specific competences. For Horizon 2020, EUROfusion will additionally aim at supporting PhD and university student programmes, building on the FuseNet experience.

**The formation of EUROfusion** is currently underway and will be completed in 2014. Francesco Romanelli has been appointed as interim Programme Manager and IPP Garching as coordinator. The eight research missions identified in the Roadmap have been broken down into nearly 30 Work Packages outlined in the Consortium Work Plan 2014 – 2018. Project leaders for these Work Packages have been appointed. At an information meeting held in Garching in October, they presented their plans to the wider fusion community and proposed opportunities for collaboration. Work on these projects will start in January 2014. “The success of EUROfusion,” emphasised Francesco Romanelli at the meeting, “will rely on the strong collaboration between the EUROfusion Programme Unit, the Project Leaders and all Associated Laboratories”.

**More information:**
http://www.efda.org/efda/horizon2020/

Internal documentation on EUROfusion is continuously updated on the EFDA users’ website:

http://users.jet.efda.org/eurofusion-consortium/
http://users.jet.efda.org/upcoming-events/
HIGH PERFORMANCE COMPUTER FOR FUSION GOES OFFLINE

“...The HPC-FF platform and team – along with the High Level Support Team – have been invaluable to the European fusion theory community. They have facilitated many important scientific discoveries, including an explanation of the observed reduction of ion profile stiffness at the JET tokamak. This effect has striking consequences, in particular, for burning plasma experiments and is likely to enhance ITER's predicted fusion performance.

DR. FRANK JENKO, IPP

The microtearing instability shown in this image is one of the most challenging types of turbulence to simulate.
(Image: H. Doerk, IPP)
After having served European fusion research for four years, the High Performance Computer for Fusion (HPC-FF) completed operation in June 2013. HPC-FF provided scientists with a significant increase in computing power (100 teraFLOPS), allowing advances in plasma and materials modelling and fusion technology simulations. The European Commission (EURATOM) funded HPC-FF together with EFDA and the Forschungszentrum Jülich whose Supercomputing Centre operated the facility. Now fusion modelling work has moved to the significantly more powerful Helios computer which has a peak performance of around 1500 teraFLOPS. Helios is a Japanese-European facility under the Broader Approach agreement and is located in Rokkasho, Japan.

Turbulence simulations: a key application
Altogether, more than 200 projects were run on the HPC-FF. One of the major activities were simulations of plasma turbulence for a range of fusion devices. Turbulence is the key process governing energy confinement in tokamak plasmas. Simulating turbulence in fluids is already a demanding task, but simulating in plasmas brings the additional complexity of charged particles in an electro-magnetic field. The processes also take place on a broad range of time and length scales, and detailed simulations therefore require the use of High Performance Computers. Another important field of investigation, for which HPC-FF was used, was for studies of plasma instabilities. These phenomena can cause rapid energy losses in the plasma, which in large machines like ITER could result in damage to the reactor wall. A third focus of activity was the simulation of the behaviour of potential reactor wall materials under high-energy neutron flux. These conditions are characteristic for the deuterium-tritium plasmas that will be used in the second phase of the ITER experiment and in future fusion demonstration and power plants.

High Level Support Team continues to provide assistance
HPC-FF is the first shared High Performance Computer facility for the European fusion community. To ensure maximum benefit from the facility, a High Level Support Team was put in place. Its role is to help scientists optimise their codes for the massively parallel computer architecture of HPC-FF. The team consists of a core group based at IPP Garching and other support staff provided by the Associates. All members are HPC experts with a background in developing large scientific applications, including particular expertise in numerical algorithms and in graphical support and visualisation. The High Level Support Team will continue to provide invaluable assistance to the European fusion scientists using the Helios system and thus ensure a smooth transition to the new facility.

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The “Broader Approach” agreement for complementary research and development was signed in February 2007 between EURATOM and the Japanese government. It provides a framework enabling Japan to conduct research and development over a period of ten years to support ITER.
www.tinyurl.com/broaderapproach
The tungsten-coated tiles of the ASDEX Upgrade outer divertor have been replaced with tiles made of solid tungsten. This change brings various benefits including the possibility of new types of material studies with regard to ITER. Operation will start in January 2014.

Tungsten is the material intended for the first reactor wall in ITER. With the exception of JET, which features an ITER-Like Wall made from tungsten and beryllium, ASDEX Upgrade is currently the only other divertor machine in Europe which is equipped with tiles of solid tungsten. And will remain so until the French WEST experiment starts operation in 2016. Besides investigating the behaviour of solid tungsten when compared to tungsten-coated tiles, the change opens up options for long-term studies. Material erodes under heat and particle fluxes from the plasma. This effect is at its worst at the divertor, where the plasma touches the vessel wall. The ten micrometre tungsten-coating of the previously used graphite tiles would vanish in part after a longer period of operation, so tiles needed to be reworked regularly. The 15 millimetre thick tungsten tiles, on the other hand, may be exposed to the plasma over longer operational periods. During plasma pulses in ASDEX Upgrade, which may last up to ten seconds long, the tiles will experience a temperature excursion from room temperature up to melting temperature (around 3400 °C). This simulates the conditions during ITER overloads which will occur, for instance, during plasma edge instabilities which thrust very high...
heat and particle loads at the vessel wall. After some time of operation, the surface of the tiles will show signs of erosion and cracks. ASDEX Upgrade will help us to gain experience about operation with tiles degraded in this way.

Engineering challenges

In 2007, ASDEX Upgrade was the first tokamak to have an inner vessel wall coated with tungsten. Now it takes a big step and implements solid tungsten on a large scale. The tungsten tiles are a lot heavier than the previous tungsten-coated graphite tiles. And, for this reason, the divertor and the cooling system had to be reconstructed. Manufacturing the tungsten tiles is also not a standard industrial process, so IPP used its test stand GLADIS to first test the prototype tiles and then test the samples from the serial production under conditions which simulate two to three years of ASDEX Upgrade operation.

Changing tiles between experimental days

Within these reconstructions, a divertor manipulator was designed and installed, which allows the replacement of two tiles without breaking the vacuum. This enables dedicated experiments with special targets. While many material and divertor concept tests can be conducted in test stands such as GLADIS or in linear plasma machines, some conditions can only be realised in tokamaks. These include, for instance, special magnetic field configurations, grazing plasma incidence, or the effect that gyrating ions have on the tiles. The new divertor manipulator has a water inlet and thus also enables the testing of actively cooled targets, as planned for ITER. The IPP task force for plasma edge processes is currently discussing with ITER what possibilities ASDEX Upgrade offers to address specific ITER questions, for example, testing of various tile geometries or tesselations.

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How can tiny specks of metal, a fraction of the width of a human hair, help designers of future nuclear power stations? The answer lies in these images, which may look cavernous but in fact are only about 3/100th of a millimetre across. They have been generated in CCFE’s new materials laboratory, which allows scientists to look at processes which, although they take place at a microscopic level, could nevertheless damage the structure of large reactors weighing thousands of tonnes. The subject of investigation are fast-moving neutrons unleashed during both fusion and fission energy processes. Their effect on the structures of the reactors is of particular concern for tokamaks – in which neutrons hit surfaces at around 50,000 km per second – but is also a problem in fission devices, despite the slower speeds involved. CCFE’s materials laboratory, which opened in summer, is therefore available for use both in fusion and fission. It is part of the first phase of the UK’s National Nuclear User Facility (NNUF), a £15 million government-funded partnership designed to improve Britain’s experimental equipment for nuclear research.

Realistic conditions

The materials that future reactors are to be made from will come under intense and sustained bombardment from these sub-atomic bullets. Neutrons dislodge atoms within the metal and create new, unwanted elements, such as helium. The overall effect makes reactor components weaker and more brittle. But problems will not initially be obvious in the form of large cracks; they can only be spotted at the boundaries between tiny grains of the material and can only be seen using powerful microscopes.

The lab at CCFE cuts samples into small, but easy to handle, millimetre-sized shapes before examining them on a micron scale with a Scanning Electron Microscope that is capable of zooming in to view what is happening at the grain boundaries within the metal. In addition, a Focused Ion Beam cuts out miniscule fragments for even closer inspection, and a ‘nanoindenter’ presses down on them to test their hardness and elasticity. Researchers can use this information to benchmark simulation models and predict how materials will per-
form inside full-scale reactors, thus aiding the development of more robust alloys for power plant designs. CCFE’s Chris Hardie explained: “It is not the cutting-edge equipment, which is now found in several materials research laboratories, that provides value here at CCFE; it is the ability to look at real materials, subject to real reactor environments, which is difficult or impossible to investigate elsewhere, due to restrictions in working with radioactive samples.”

**Solving engineering issues**

And the new facilities have already been employed to solve a materials problem for CCFE’s project to upgrade the MAST tokamak. Attempts to braze stainless steel and copper chromium zirconium for a joint on MAST’s new centre column were proving unsuccessful. Using the Scanning Electron Microscope’s high magnification, the joint’s chemical composition was revealed, showing higher concentrations of zirconium than expected. This explained why the braze was not as effective as predicted and has helped the CCFE engineers to find a solution.

Chris Hardie added: “These results show how the facilities can be used independently to investigate real engineering problems faced at Culham – a really good early demonstration of its huge potential.” The project’s main phase will start when CCFE moves the lab to a specially-constructed facility at the Culham site in 2015. This building will have space for a greater range of equipment, with separate areas for examining fission and fusion materials, and hot cells for the processing and analysis of small amounts of neutron-irradiated material. It will cater for users from both academia and industry, forming a key element of the improved suite of UK nuclear research facilities being established by the NNUF partnership.

**Investigating JET wall materials**

EFDA’s materials programme is able to benefit from this facility which will complement those in other European fusion laboratories. More specifically, the new building at CCFE may well directly assist JET. In the run-up to ITER’s commissioning, scientists intend to carry out a ‘dress rehearsal’ on JET using the deuterium and tritium fuel mix required for full fusion power performance. Having a materials laboratory on-site will enable the quick inspection of components removed from the JET vessel. The lab’s Thermal Desorption Spectroscopy equipment will be used to detect how much fuel from the fusion plasma has been absorbed by tiles in the beryllium and tungsten ITER-Like Wall of the machine during these tests, and thus answer important materials questions for ITER.

Nick Holloway, CCFE

The CCFE materials laboratory is ‘open for business’ and requests for access can be sent to info@mrl.ccfe.ac.uk.

More Information:
http://www.ccfe.ac.uk/mrl.aspx.
A UNIQUE COMBINATION OF RESEARCH FOR FUSION MATERIALS

With the TEXTOR tokamak being shut down at the end of 2013, the plasma physics division at Forschungszentrum Jülich enhances its research on Plasma-Wall Interactions with materials science. A dedicated linear plasma device, JULE-PSI, is under construction and will start operation in 2015.
“We are currently the only group in Europe – if not in the world – that combines expertise in linear facilities for Plasma-Wall Interaction studies and materials research,” says material scientist Prof. Christian Linsmeier. In March 2013, Linsmeier was appointed director of the plasma physics division of FZ Jülich’s Institute for Energy and Climate research (IEK). He leads it in conjunction with director Prof. Ulrich Samm. Before that, Linsmeier headed the research group for plasma-facing materials and components at IPP Garching. He sees new opportunities for fusion material science at FZ Jülich, pointing out synergies with the IEK’s divisions for Microstructure and Properties of Materials and for Materials Synthesis and Processing.

As the global fusion community begins conceptual work on demonstration power plants, it has become important, not only to investigate the physical processes that take place between the hot plasma and the reactor wall, but also to develop new materials capable of withstanding the conditions in those plants. FZ Jülich’s new linear plasma device JULE-PSI is designed to deliver plasma conditions which are relevant for future fusion power stations (see Fusion Europe 1/2011). It will be located inside a hot cell, allowing investigations to be carried out with neutron activated materials or materials containing beryllium. Construction of the hot cell will commence in 2014.

Three main concepts
Fusion materials research at FZ Jülich addresses three main concepts. Firstly, tungsten composites which might help solve the problem that tungsten, the preferred wall material for fusion reactors walls, turns brittle under the anticipated operational conditions. The development of these materials started at IPP Garching and will be continued in collaboration. Secondly, self-passivating alloys which is an additional project that will be conducted in conjunction with IPP. These alloys provide an additional level of safety. For instance, if the cooling system fails, a self-heating alloy would develop a protecting oxide layer and thus prevent radioactive isotopes from escaping from the hot wall. Thirdly, barrier layers for tritium which prevent the element from diffusing through the first wall into the structural steels. The fusion fuel tritium is elaborately produced in the reactor wall and any loss has to be prevented. Moreover, tritium would activate the wall structure and possibly contaminate the cooling fluid.

A unique centre of competence
JULE-PSI is one of four linear devices for Plasma-Wall Interaction studies in Europe. VISION I at SCKCEN, Belgium, operates with tritium plasmas at moderate power. MAGNUM PSI at DIFFER in The Netherlands, features high enough particle and heat fluxes and densities to study divertor materials under realistic conditions. JULE-PSI is able to investigate hazardous or activated materials in a high-power tritium plasma. Finally, PSI2 – a similar experiment to JULE-PSI, but outside the hot cell – is already operational at FZ Jülich. Together these institutes form the Trilateral Euregio Cluster (TEC), a unique centre of competence for Plasma-Wall Interaction studies addressing the needs of the fusion device after ITER.

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A NEW ANTENNA FOR ASDEX UPGRADE

The all-tungsten wall of ASDEX Upgrade has raised the need for a differently designed antenna for its ICRF heating system. The current antenna design generates unwanted electric fields that sputter tungsten atoms from the wall. These impurities increase the radiation from the plasma and thus harm the plasma’s performance.

New antennas were designed to minimise these unwanted electrical fields. The first of two antennas, built by the Chinese partner, arrived this summer. “I am extremely happy with the way the antenna behaved in the test stand,” says Prof. Jean-Marie Noterdaeme of IPP. The Chinese team is lead by Dr. Song Yuntao of ASIPP and even though his team was able to draw on their experience from building the ICRF antennas for the institute’s tokamak EAST, the project is still quite challenging, he says. “The design and the manufacturing processes are very complex. We had to use special welding procedures, for instance, to meet the extreme precision requirements.”

Both project leaders agree that the collaboration went really well. “We had to work out the procedures first,” recalls Noterdaeme, “it was not sufficient to just exchange drawings, for instance. There are different standards in both countries and technical terms sometimes have different definitions.” “The good thing,” explains Song, was that “we all knew what we were talking about because both groups had built this type of antenna before”.

His institute hopes to see further collaborations after this successful project, he adds. The collaboration agreement also envisages that ASIPP scientists will participate in the experiments on ASDEX Upgrade with the new antennas.

The second antenna will arrive in Garching in early 2014. Both antennas will be installed into ASDEX Upgrade during the next shutdown in 2014. ENEA will supply additional components like the Faraday shield, cooling structures and a microwave reflectometry diagnostic, which is a powerful system for measuring the plasma density at several locations in front of the antenna. The Portuguese Association IST will contribute the electronics for this system.

“Even though the antenna has been optimised for low impurity levels, it has some flexibility to operate around this optimum and thus could thus allow a solid confirmation of the optimisation procedure,” explains Noterdaeme. IPP is also building a test stand, ISHTAR, which will complement the experiments on ASDEX Upgrade and allow dedicated experiments designed to provide us with a deeper understanding of the physical mechanisms. Jean-Marie Noterdaeme is looking forward to see the two antennas in action: “If we can prove our hypothesis that the antenna design solves the impurity problem, then we will have made a big step forwards,” he says.

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EFDA provides the work platform to exploit JET in an efficient and focused way. More than 40 European fusion laboratories collectively contribute to the JET scientific programme and develop the hardware of the machine further. The tokamak is located at the Culham Science Centre near Oxford in the UK. It is funded by EURATOM, by the European Associates, and by UK’s fusion Associate, the Culham Centre for Fusion Energy (CCFE) as host. CCFE operates the JET facilities including carrying out the maintenance and refurbishment work required to realise the given scientific goals.
There were a few frayed nerves in the JET control room in August, as experiments to deliberately melt tungsten tiles in the divertor got underway. These apparent acts of scientific vandalism were actually courageous experiments which have helped ITER make a decision that substantially reduces investment costs.
The tests were requested by ITER to support its assessment of what material should be used for its plasma-facing wall. Although tungsten is a front-runner, there is a concern about the effect that the melting of a tungsten tile might have on the plasma. Therefore, the original ITER design plan foresaw a more forgiving carbon wall for the run-in phase of the machine with a change to tungsten at a later stage.

“In earlier melt experiments in ASDEX Upgrade, molten metal was sprayed around, and it became hard to operate because the plasma disrupted a lot,” said Guy Matthews, who leads the JET ITER-Like Wall project. “But here nothing catastrophic happened, it’s quite well-behaved!” Gilles Arnoux, one of the scientific coordinators of the experiment agreed. “It was a smooth melt; the plasma didn’t seem to notice. I was surprised at how little impact it had.”

**Melting under ITER conditions**

The difference between these JET experiments and previous ones at ASDEX Upgrade is that the melting was achieved by the transient bursts of turbulence rather than by bulk melting. Transient bursts are caused by certain plasma instabilities called Edge Localised Modes or ELMs. They raise the temperature above the melting point for milliseconds only, and so the melting behaviour is harder to predict. JET is the only tokamak in the world which has enough energy in its plasma to melt tungsten with ELMs, thereby modelling conditions in ITER, in which ELMs could potentially carry a fearsome amount of energy.

The tests at JET involved subjecting a small area of a deliberately misaligned tungsten wall tile to regulated bursts of turbulent events. The peak temperature of the tile during the transient bursts was slowly increased until it exceeded tungsten’s melting point, 3422 degrees Celsius. The aim was to assess what effect molten tungsten might have on the operation of the plasma. In particular, it was feared that a melt event might contaminate the hydrogen-based plasma with tungsten and lead to a disruption – an uncontrolled energy dump from the plasma – which could cause further surface melting in a fusion experiment as large as ITER.

Instead, as shown in the picture, the molten tungsten moved smoothly to one end of the tile and formed a droplet that grew with each additional plasma pulse. Curiously the molten metal did not run downwards – a result of the magnetic forces inside the tokamak – and, to the scientists’ relief, moved away from the hottest part of the plasma rather than being swept back into the exposed area. Subsequent experiments were performed without any interruption in the proceedings.

Joining the JET team in the control room was the leader of ITER’s Divertor and Plasma Wall Interactions section, Dr Richard Pitts, who has been involved throughout the planning of the experiment. He said: “It has been a great success and has achieved what it set out to do: to demonstrate that repetitive, fast transient heat pulses pushing tungsten over the melt threshold for just one or two milliseconds each time.” He continued: “they do not drive melt splashing nor do they appear to have any observable effect on the core plasma. It seems that we can broadly understand what we have seen on the basis of complex computer simulations describing the melt dynamics and thus our confidence is increased in the extrapolations we make for the behaviour to expect on ITER, which use the same computer codes.”

Two months after these first experiments on JET, the ITER Council Science and Technology Advisory Committee proposed to the ITER Council, the highest committee in the ITER Organization, to equip the ITER divertor with tungsten targets from the very start of operations. In November, this proposal was approved and the ITER Council decided to commence ITER operation a full tungsten divertor.
Some of the about 1700 visitors who came to JET from July through November 2013:

- 518 school students, along with 61 teachers, learned about fusion and JET
- 256 university students attended tours and summer schools
- 260 professionals in science and industry came for workshops, tours and discussions
- Several journalists and film crews came to report about JET, MAST and fusion
Horizon 2020, our new framework programme, will provide unprecedented levels of support for European research and innovation. It will do so to achieve the goals of the Europe 2020 strategy for smart, sustainable and inclusive growth, and to address key societal challenges such as combating climate change and securing the supply of energy. Fusion energy research is part of this endeavour. Its importance has been underlined in the Strategic Energy Technology Plan and the next seven-year EU budget foresees significant funding for the completion of ITER and for the Euratom part of Horizon 2020. Fusion has enormous potential as an energy source for the future and the EU remains committed to this vision.

Europe has always played a leading role in this field. JET and ITER are hosted on European soil. JET is currently the world’s largest, and arguably most successful, operating fusion device. ITER is the world’s biggest and most ambitious energy research project, the success of which is paramount if the potential of fusion energy is to be realised. In the past, EFDA and the Contracts of Association have provided a solid basis in Europe for the scientific developments in fusion. However, the way we carry out research must now be reorganised and restructured so that Europe can effectively contribute to and benefit from the success of ITER. The recently agreed EFDA roadmap shows the path that should now be followed and is a testament to the high level of coordination and unity in the fusion community.

After consulting all stakeholders, the European Commission believes that to reach the roadmap’s objectives this new structure must be based on joint programming between the key research actors. The joint programme will bring together national and European resources to focus on the research needs of ITER, on its eventual exploitation and the goal of achieving fusion electricity within a reasonable timeframe. It will empower national laboratories and Member States to ‘take ownership’ of the process, but will also place more responsibility on them to redirect resources to the roadmap goals.

The European Commission remains committed to the fusion roadmap and to providing significant co-funding for the joint programme 2014-2018. The Commission expects that all member laboratories of EFDA will participate in the joint programme and thus benefit from European support. This participation will allow them to further develop their competencies to be fully aligned with the roadmap.

Fusion research is an excellent example of a collaborative European effort that has been built up over many years as a result of successive Euratom programmes. The time has come to take the next step in line with the new roadmap, exploiting results of basic research in applied science and technology and increasingly involving industry. The new joint programme is the first crucial stage in this process. The Commission counts on the continued effective collaboration of all stakeholders in order to ensure that the vision of commercial fusion energy becomes reality.
BEFORE THE SCIENCE COMES THE CONSTRUCTION

What do CERN’s Large Hadron Collider, Wendelstein 7-X and the X-ray laser XFEL have in common? They are big science projects that rely on a team of experts from the Scientific Infrastructure Section at the Institute of Nuclear Physics PAN in Krakow, Poland.

“To make big science, you have to build the device first,” says Dr Zenon Sulek from the Institute of Nuclear Physics PAN. The physicist knows what he is talking about. He spent nine years installing and assessing the quality of vital components at CERN and at Wendelstein 7-X. Sulek could also say “to make any experimental science, you have to build it first,” because building his own physics experiments has led him to acquire the special expertise that turned out to be so useful for big science experiments.
Science and technology partnership

The Institute of Nuclear Physics has a long history of elementary and particle physics. Its scientists have been working at CERN from the experiment’s very beginning and in the 1990s the institute became an official CERN partner. The involvement in the construction of experiments started when Zenon Sulek joined CERN’s Large Hadron Collider (LHC) project in 2003. The group he led was involved in the construction of the magnets’ interconnections – for vacuum, power supply or electrical signals. Together with another Polish CERN scientist, Dr Blazej Skoczen, he set off formulating quality standards for these connections.

Recognising the need for this kind of expertise, the institute in Krakow formed two expert groups – the InterConnection Inspection Team headed by Zenon Sulek, and the Electrical Quality Assurance team led by his colleague Dr Andrzej Kotarba. They wrote inspection procedures, outlined the technology needed for the task and submitted a proposal to CERN. From 2005 until 2008, their job was the quality assurance for the interconnections which had been installed by a commercial partner. Each group comprised between six and 15 people, depending on the project phase.

As they were starting to pack up in Geneva, another big science project had heard of their expertise and offered up another really challenging task, that of connecting the strangely shaped superconducting magnetic coils in the Wendelstein 7-X stellarator. For the next six years, some 50 engineers, physicists and technicians from Krakow were involved first in preparation and training and then in the assembly and first level quality assurance of these superconducting connectors known as bus-bars. The effort amounted to more than 160 full time equivalent years. One year ago, the project was successfully completed and – after having lived four years in Switzerland and five in Greifswald – Zenon Sulek is now back in Krakow. “I am officially retired,” he says, “but I still work in the institute”. His counterpart Andrzej Kotarba, is back in Germany again – assembling cryomodules and superconductors at the European X-ray Laser XFEL. Construction is scheduled to finish in 2015. Some other colleagues are back at CERN, carrying out additional work at LHC during the current shutdown.

The fun of making big science work

All in all, about 50 members of the institute’s expert groups are working abroad, and a smaller number is active in Krakow. The Institute of Nuclear Physics has an interest in such collaborations as an ‘in-kind’ contribution to big science facilities, and so the base of technicians and their expertise have continuously grown. Even though working abroad sometimes is hard, especially for young families, the groups are proud to be part of these big science projects. To ease the travelling, the institute has a rotating staff of technicians who are abroad for several months and then work at home for the same length of time. Management, however, needs to be on site most of the time, which is the reason why Zenon Sulek spent so many years living abroad – often taking his family with him. Does he miss travelling now? Not really, he says: “I am engaged in many interesting projects, so I’m not getting bored”. And then there is FAIR – the Facility for Antiproton and Ion Research –, which is under construction in Darmstadt, Germany. Another big science project that Zenon Sulek and his colleagues from Krakow are helping become reality.
How did you come to fusion research?

I came to fusion because I enjoyed plasma physics. I happened to pick plasma sources as a project for my third year at university in Manchester. It was great fun and I did another one the following year. Eventually I approached my supervisor about a PhD. He said I should get involved in the UK fusion programme and suggested I apply to the University of York to do a PhD at CCFE. So I joined the University of York and did my PhD, based at CCFE, on disruption mitigation. Had I stayed in Manchester, where I did my undergraduate studies, I would have still done a PhD in plasma physics, but not in fusion.

What challenges do you think need to be solved for fusion to be a potential energy source?

Well, I think that in order to get there, you need to deal with transient events such as the instabilities that I investigate. If we can solve these, then we are on the way to achieving power generation and energy from fusion for mankind. I think it is just a matter of making progress along the road until we get there and that is exactly what my work is about.

Andrew Thornton is a staff scientist at CCFE. He works on MAST and studies the mitigation of plasma edge instabilities (ELMs) by investigating how magnetic perturbations affect the heat loads and fluxes that these instabilities deliver to the surfaces inside the tokamak.

What are your next aims in your work?

Well, we are upgrading MAST at the moment, installing a new divertor we’ve made, the Super-X divertor. I am looking forward to see what happens in a few years time and to see how that develops over the next ten years.

Was does it mean for you to work in an international environment?

It makes CCFE an interesting place to work. We have a lot of people from abroad who come to MAST or to JET, which we collaborate with as well. It’s interesting to see how other people do their work. I think during the shutdown of MAST I will have more opportunity to look at other machines.

What do you like most about your job?

It’s always nice when you have a good day, when you were expecting something or you wanted to try to find something in an experiment and you succeed. Or when you’ve worked for a long time for a piece of equipment, installed it, its up and running and you get the first bit of data from it. The first glimpse of something you had not seen before, that’s really exciting.
How did you come to choose this topic for your thesis in the first place?

As part of my Bachelor's course I attended the course “structure of matter” held by Dr. Hans-Stephan Bosch from IPP. I liked his lecture and approached him about doing my Bachelor's thesis. We needed to find a topic, which I – not being a physicist – could handle and which was related to current scientific activities. We looked into a few options, among them the comparison of ³He-D and D-T fusion. After some reading, I found it really exciting. With the exception of an excursion to Wendelstein 7-X and some chapters in Bosch’s lecture, I had not dealt with fusion before.

Assuming that D-T fusion is successful. Is there a realistic possibility for ³He-D fusion plants in the far future?

Well, I don’t think so. The main issue is availability. Only traces of ³He are available on Earth – not sufficient to enable any usage. As long as the moon’s ³He resources cannot be exploited in an economical way, ³He-D fusion is not an option in my view. Furthermore, lunar regolith contains little ³He, so that one would have to mine immense amounts of it. I can’t say if that will ever be possible, but surely not in the foreseeable future.

Why is ³He-D fusion under discussion at all? Would it be a better alternative to D-T fusion?

It is often said that ³He-D fusion has the advantage of neutron free fusion reactions, because it produces alpha particles (⁴He) and protons. In contrast to neutrons, the movement of these charged particles can be controlled by magnetic fields. But, if one looks into the details, it turns out that ³He-D fusion is not completely free of neutrons. This is what I quantified in my thesis. The alpha particles, protons and the deuteron undergo further reactions which do produce parasite neutrons. The reaction yields less neutrons, with a lower energy, but they cannot be neglected.

Will you stay in energy research or even in fusion science?

I have now applied for a master’s course and I really enjoy physics, for instance. I can well imagine to continue in the areas of renewable energies or fusion, maybe with a master’s thesis. But just as I came across ³He-D fusion and found it a surprisingly fascinating topic, it is also likely that a completely different, but evenly fascinating topic will cross my path next.

The English edition of “Limit”, a science fiction novel set in a world in which fusion power is about to overtake traditional gas and oil business, was published in November. The main story unfolds around a conflict between China and the US over the Moon’s Helium-3 (³He) resources which they need as fuel for their fusion power plants. Limit, which was originally published in German in 2009, is very optimistic about the development of fusion power: It is set in the year 2025. In the real world of today, fusion research focuses on tritium and deuterium (D-T) fusion. ³He-D fusion has been considered on a theoretical level.
On 18 October 2013, the Association EURATOM-ÖAW organised its 28th Association Day – the annual gathering of the Associations’ scientists to discuss their work – in Salzburg. The Austrian Association forms a stable framework for the fusion-relevant research performed by eleven research groups from five institutions across the country (Universität Innsbruck, TU Wien, Erich Schmid Institut for Material Science, Research Studios Austria and TU Graz). In this context, there are two important tasks to be accomplished by the Association: to motivate young people to become part of the “Generation ITER” and to keep a repository of fresh knowledge generated in the framework of PhD theses. To underline this, the Association invited its young members to present their PhD theses. The invited guest speaker this year was Prof. Sibylle Günter, Scientific Director of IPP Garching, who introduced the future EUROfusion consortium – which also considers “forming the generation ITER” to be one of its objectives.

Elisabeth Wieninger and Monika Fischer from EURATOM-ÖAW asked some of the students why they chose a fusion-relevant topic for their PhD:

“I was fascinated by plasmas, and then I found a position for my thesis dealing with plasma turbulence.”

“I originally wanted to study quantum physics, but I could not find a suitable opportunity, so I turned to plasma physics, another promising subject of great diversity.”

“I want to work in an experimental field with visible results – and I like my colleagues at the University of Innsbruck!”

“One of my colleagues works with Plasma-Wall Interactions. I thought ‘this is pretty interesting’ and found a thesis position on a similar project – and somehow everything fell into place.”

More information:
http://www.oead.ac.at/euratom
“I want to create a better world – and physics gives me the tools for a change on the energy sector.”

“I started to study astrophysics, but after a while I had the urge for an approach with a sound theoretical basis and turned to plasma physics and this is definitely not the end of my journey.”

“Plasmas are dynamic phenomena .... the longer I worked with molecular dynamic simulations, the more involved I got.”
It was a plasma physics summer school that got Prof. Hartmut Zohm, director at IPP Garching, hooked on the subject he built his career on. Plasma physics is not a subject taught regularly at many universities, so summer schools are a vital method enabling the European fusion community to win students and young scientists for this field of research. These schools also provide a sense of the international character of fusion science: Students come from all over the world and courses are taught in English by lecturers from various European laboratories. This summer more than 280 students from over 20 countries took up the opportunity to get first hand information about fusion.
Half a century of Culham Plasma Physics Summer School
Culham
62 participants

Plasmasurf – Surfing ocean waves like electrons surf plasma waves
Oeiras near Lisbon
20 participants

Carolus Magnus Summer School – The physics behind fusion energy
Bad Honnef, 68 participants
The new Portuguese PhD programme APPLAuSE is very different from standard PhD courses: Addressing physics and engineering students worldwide, it grants up to ten students a four-year doctoral scholarship. The programme also includes a one-year secondment to one of the international institutions IPFN collaborates with. And students are assigned a personal mentor who will help him or her to maximise their potential. The overall objective of APPLAuSE is to provide each student with a broad knowledge in the field of plasma science and engineering. This will enable them to build a career in areas such as fusion science, astrophysics, space science or high-energy-density physics. The programme is designed to bring students into contact with renowned specialists and to motivate them to develop in-depth expertise in their chosen area of specialisation. The curriculum sets off with basic plasma science and continues with controlled nuclear fusion, high-energy-density physics, space and astrophysical plasmas and low temperature plasma science and engineering.

40 students – eight of them female – applied for the first year. Most of them are from Europe, but some come from Asia, Africa and Latin America. The applicants’ backgrounds range from plasma physics, astrophysics and quantum mechanics to instrumentation, electronics and lasers. The students were mostly attracted by the novelty and the curriculum of the doctoral programme, the prestige of Lisbon Technical University, and, of course, by the included PhD grant.

The selection process is now underway and the course will start in January 2014.

More information
http://tinyurl.com/ist-applause
Ready for the giants

The ITER Itinerary test convoy, featuring an 800-metric-ton trailer replicating the weight and dimensions of ITER’s most exceptional loads, successfully completed its journey on 20 September.

It is one of the specialities of the ITER project: Ninety percent of the seven Members’ contributions will be delivered “in-kind”, meaning that the Members fabricate components for ITER at home and deliver them to the ITER Organization. That implies the transport of exceptionally large and heavy goods – the nine segments of the 19 metre wide and 11 metre high vacuum vessel are just one example – from Marseille harbour to the ITER site.

The convoys will have to cross more than 30 bridges, bypass 16 villages and negotiate 16 roundabouts. France as the host state has widened roads, reinforced bridges and modified intersections to accommodate the transport. Between September 16 and 20, this Itinerary underwent a reality check: Pulling people out of their beds to watch, a 46 metres long and 10 metres high trailer travelled for four consecutive nights the 104 kilometre long Itinerary from the village of Berre near Marseille harbour to the ITER site. Bridges along the way were equipped with sensors and further measurements were taken at roundabouts and in villages to monitor the behaviour of the roads under these exceptional loads.

With the successful completion of the test transport, ITER is now ready for the giants to arrive: The first large components, among them large drain tanks and transformers, will be delivered in 2014. Between 2015 and 2017, the largest components will be shipped: the sectors of the vacuum vessel and the toroidal field coils.

More information:
http://www.iter.org/transport
The beauty of tungsten

This blue sphere measures about a twentieth of a millimetre and consists of pure tungsten. It was produced at Forschungszentrum Jülich in the electron beam test facility JUDITH, where Jülich researchers expose materials to high thermal loads. Inside JUDITH, even tungsten – the metal with the highest melting point of all the elements – can melt and then solidify again within a fraction of a millisecond, forming bizarre shapes. What appear to be ‘continents’ under a scanning electron microscope clearly show that the crystal lattice created in this process is not uniform. Tungsten is currently the material of choice for the inner wall of fusion reactors.

Forschungszentrum Jülich
28 European countries signed an agreement to work on an energy source for the future: EFDA provides the framework, JET, the Joint European Torus, is the shared experiment, fusion energy is the goal.