

Fusion News

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How can plasma be created in a microwave oven? And how can you get people interested in fusion? Fusion researchers demonstrated both at the European City of Science event in Paris where the European Fusion Community participated with great success. See page 3.

Reviewing status of fusion – FEC in Geneva

JET on track for a promising future

The International Atomic Energy Agency this year held its biennial Fusion Energy Conference (FEC), often cited as the “main” conference on fusion, in the Palais des Nations in Geneva, Switzerland. The FEC always provides a good opportunity to review the status of fusion research in the world. 50 years ago the same building hosted the historical 2nd International Conference on the Peaceful Uses of Atomic Energy, where leading countries in fusion research revealed their program and opened the way to fruitful international collaboration.

Another striking feature of the conference was that ITER, the embodiment of international cooperation on fusion, has started providing a powerful drive for physics and technology R&D all over the world. The vast majority of tokamak results presented at the conference aim at supporting ITER design choices, developing modes of plasma operation applicable on ITER or addressing ITER relevant physics issues. *(Continued on next page)*

And indeed, 50 years later, the most striking feature of the 22nd FEC was the success of this international collaboration, which resulted in tremendous scientific and technical progress. This is clearly shown by statistics: the 22nd FEC was attended by 761 participants from 42 countries; the contributions included 116 oral presentations and 507 posters. In a special evening session the conference organizers celebrated the anniversary by looking back on the history of 50 years of magnetic confinement fusion research.

Reviewing status of fusion - FEC in Geneva

The status of ITER was presented in various talks. An update on the project's progress including the ongoing site preparation, the outcome of the Design Review and the impacts the technical updates will have on the ITER baseline design were introduced.

Key tests in the preparation of ITER construction were reported on, including: the Nb-Ti and Nb₃-Sn conductors required for the large superconducting coils have been qualified with adequate margins; a world record was obtained with a Japanese gyrotron operating at 170 GHz, 1MW, 800s, reaching ITER specifications except for the pulse duration (3600s); ITER-like antenna concepts are being successfully tested on Tore Supra (France) and JET (EU). Important progress was also reported on prototyping in preparation for the construction of the Divertor, First-Wall, Shielding Blanket, Vacuum Vessel and Cryopump.

Several tokamaks were reported as demonstrating plasmas that meet ITER requirements, although more work is required towards a full set of ITER-like operating conditions. In particular performance with metal walls to reduce erosion and fuel retention looks promising (the first full tungsten wall was recently experienced on ASDEX-Upgrade, Germany), but more work needs to be done. The ITER-like wall experiment in preparation at JET is expected to play a crucial role in the next few years.

Steady-state operation has seen significant advances, with fully non-inductive operation of tokamaks, but issues remain for long pulse operation, in particular with localized heat/particle handling and heating systems technologies. New superconducting tokamaks have started operation recently, EAST in China (first plasma in September 2006) and KSTAR in Korea (first plasma in June 2008). This latest is the first tokamak using Nb₃Sn superconducting coils as planned for ITER.

Transport of particles, heat or momentum, remains a key topic related to the performance of magnetic confinement devices. Theory-based models for particle transport have seen progress and experimental validation. Clear evidence of critical temperature gradient was demonstrated; the evidence of zonal flows (phenomena in fusion plasmas reducing turbulent transport, thus improving thermal insulation) is growing. Worldwide work on heat and particle transport was reported to confirm former predictions of ITER performance. Significant efforts are now targeting the description of momentum transport in the plasma.

Progress has been achieved to avoid or mitigate transient events, with, in particular, an increased level of confidence in controlling and mitigating such events on ITER, supported by experiments (e.g. DIII-D, US and JET, EU), theoretical analysis and modelling. Real time control of magnetohydrodynamics (MHD) instabilities has seen further advances, which should increase opera-

Report of the Fusion Facilities Review Panel presented

The Fusion Facilities Review Panel finalised and delivered its report to the European Commission. It was presented by the chairman of the panel, Pr. T. Hartkopf, at the CCE-FU on 30 October. This independent panel of experts appointed in December 2007 at the beginning of the Seventh European Research Framework Programme (2007 - 2013) by the EU Commission was set up to develop a vision of the R&D required to make fusion energy production ready for commercial exploitation, and to review all significant facilities, existing or under construction. It comprised five European members outside the fusion research community and four non-European fusion experts.

The report can be found on http://ec.europa.eu/research/energy_under_Fusion/Publications.

tional margins and allow normalized plasma pressure operation above ITER requirements.

The stellarators research line is also progressing steadily, with the superconducting helical device LHD, Japan, operating in nearly 1/4 hour pulses and exploring ways towards high plasma pressure operation. The superconducting stellarator W7-X (Germany) construction is on good track, with first plasma foreseen in 2014.

Inertial fusion results were also presented at the conference. In the US the National Ignition Facility (NIF) is almost completed with 4.2 MJ laser obtained in September 2008. The first deuterium-tritium experiments are foreseen in 2010, and high gain $G \sim 10-20$ ($G = \text{fusion energy/laser energy to target}$) experiments foreseen a few years later.

The Fast Ignition Scheme is progressing steadily with several experimental and theoretical projects reported; compared to the direct drive technique, this approach drastically reduces the requirements in terms of laser energy required to bring the target to ignite. "Sub-ignition" experiments will start soon on the facilities in the US (OMEGA-EP) and Japan (LFEX). The fast ignition concept will be tested with 10-30 kJ lasers for compression and ~5kJ lasers for heating. Future high-gain experiments are projected in Japan (FIREX II) and Europe (HIPER).



New image film on fusion honoured

The film, "Energy of the Future. Fusion 2100", produced by IPP on behalf of EFDA, was presented with the Future Award 2008 at Photokina, the leading international fair of the imaging branch. The prize was conferred by the German section of the Integrated TV & Video Association (ITVA) to mark its 25th anniversary. At a gala evening the President of the Association for Audiovisual Communication, Dr. Gerhard Dotzler, presented the award to film producer Klaus Naumann and IPP's Julia Sieber.

Isabella Milch



SOFT conference in Rostock

The 25th Symposium on Fusion Technology (SOFT 2008) in September 2008 presented a survey of the most recent progress in fusion research. It was held in the hanseatic town of Rostock, situated on the Baltic coast in north-eastern Germany. More than 680 scientists and engineers from all over the world – from 28 countries – attended this important forum of fusion technology and presented a total of 535 contributions. The traditional conference takes place every second year, hosted by a different country each time. This year's organizer of the conference, the 25th event in this series, was the Max Planck Institute for Plasma Physics at Greifswald.

The objective of the SOFT is to exchange information on design, construction and operation of fusion experiments and on the technology for present and future fusion machines and power plants. With the start of the ITER project, fusion research is now making a big step forward. Accordingly, ITER with its demanding requirements was a major topic – more than 50 percent of the oral presentations were referring to the test reactor.

A Fusion Technology Forum with 38 exhibitors supplemented the scientific sessions bringing together industry, research laboratories and institutions active in fusion technology. Promoting

exchange between industry and research was also the objective of a panel discussion entitled "ITER and Industrial Development". Chaired by Harri Tuomisto from the Finnish power and heat company Fortum, Didier Gambier and Maurizio Gasparotto, Director resp. Chief Engineer of F4E, Hans-Dieter Harig, former EoN

C.E.O., Dr. Claude Jablon from the Comité Industriel ITER, Kurt Ebbinghaus from Deutsches ITER-Industrie-Forum, and Philippe Garderet, the Scientific Vice President of AREVA, discussed industrial involvement in fusion technologies and in the implementation of ITER.

Isabella Milch

Fusion in the heart of Paris

This November European science moved to Paris for three days. To celebrate its presidency of the European Union, the French government organised a huge fair for European scientific organisations to introduce themselves to the public. Held in the heart of Paris in the grandiose Grand Palais, just a minute's walk from the Champs Élysées, the event was very successful attracting more than 42 000 visitors.

The European Fusion Research Community was represented at the event by an enthusiastic and really international team. Based on the itinerant EFDA exhibition Fusion Expo, now managed by the Slovenian Association, the stand was supported by the Danish Fusion and Plasma Road Show developed by Risø DTU. French and Italian colleagues also manned the stand.

Having acquired stand number 1 which was right at the main entrance of the building, the fusion area was continuously full during the event. By listening to the presentation and spectacular experiments performed by Danish colleagues, or by talking to the fusion experts, the visitors were able to get a memorable impression of the European efforts in fusion.

The international team consisted of Jean-Marc Ané, Gloria Falchetto (CEA), Fernando Meo, Søren Korsholm, Martin Jessen (Risø DTU) and Örs Benedekfi (EFDA).

EFDA during FP7 – Reinforced coordination of physics and technology in EU laboratories Part 2

Diagnostics Topical Group

It is widely recognized that improvements in diagnostic capabilities are very important for further understanding of the plasma processes and their control. This is the reason why research in diagnostics has to be a continuous process, both by the refinement and improvement of existing techniques and by the development of new concepts.

Diagnostics can be grouped into three major families, depending on their role: measurements required for machine protection; measurements required to infer physical processes and parameters; and measurements for plasma control.

One intrinsic difficulty in the development of a diagnostic research program is the extremely wide range of parameters which need to be measured. Among the most important ones are the plasma current, density and temperature as well as neutron flux. There are almost one hundred physical parameters that are routinely diagnosed in fusion experiments. These parameters can be deduced by detecting fields, particles and radiation coming from the plasma. The plasma emits particles and radiation with a huge variability: for radiation we have microwaves, infrared, visible and ultraviolet light, soft-X rays, hard-X rays and gamma rays; for particles we have D, T, He neutrals, alphas, impurities and neutrons escaping from the core with energies ranging from keV to MeV or low energy electrons or ions at the plasma edge. In addition the

Tony Donné

Tony Donné obtained his PhD degree in 1985 in the field of nuclear physics at the Free University of Amsterdam. He then moved to the FOM Institute for Plasma Physics, where he started as post-doc on the Rutherford scattering diagnostic for TEXTOR. In 1986 he became leader of the TORTUR tokamak group and from 1988 till 1998 he headed the diagnostics division of the Rijnhuizen Tokamak Project. In 1997 he moved to TEXTOR in Germany, first as head of the diagnostics group of FOM at TEXTOR and from 2004 as 'Chef de Mission' of the FOM-team at TEXTOR. In 2006 he became deputy head of the fusion research department of FOM Rijnhuizen. Tony Donné has been involved in diagnostics for ITER for a long time. During the ITER EDA phase he coordinated the work in Europe in the field of microwave and far infrared diagnostics. In 1999 he became chair of the ITER Experts Working Group on Diagnostics and later from 2001 till July 2008 was chair of the ITPA Topical Group on Diagnostics. Additionally he chaired the JET Diagnostics Expert Group for EP2. Since 2001 he has been a member of the Science and Technology Advisory Committee (STAC). He has published about 140 papers in refereed journals and approximately 250 conference proceedings.



plasma is characterized by strong electromagnetic fields. All these can be detected using a wide range of different techniques.

In some cases the same measurement can be exploited for different purposes such as physics studies, machine protection, control. Therefore the diagnostics are operated with different time resolution, spatial resolution, dynamic range, sensitivity, accuracy etc. optimized for different functions. Nowadays we have hundreds of diagnostics at our disposal. The ambitious goal of controlling the fusion plasma therefore benefits from these continuous diagnostic developments.

For future burning plasma experiments, like ITER, the demands on diagnostic performance become much more stringent. The difficulties of implement-

ing diagnostics on ITER arise mainly from the conditions under which it has to operate, especially the relatively high levels of neutron flux and fluence. New phenomena which are expected to occur in future experiments (radiation induced conductivity, radiation induced absorption and luminescence in optical materials, activation, transmutations...) can change the physical properties of the component/sensor. Other effects, like tritium retention in the materials, can be a safety issue. Burning plasma experiments are extremely demanding also in terms of engineering of the diagnostic systems: integration on the machine, accessibility and maintenance. For example, due to the high neutron fluences some components are difficult to access either for maintenance or repair.

There are many areas in the field of diagnostics that require further R&D: fast detection of MHD instabilities, fusion product measurements, real time diagnostics for plasma control and radiation resistant detectors are only a few examples among the most crucial ones.

Developments consistent with the requirements for DEMO (the first electricity producing fusion power plant which will be built after ITER) represent an excellent opportunity to launch an ambitious program on diagnostic research, stimulating a relevant step forward, in terms of new concepts, extremely advanced performances and highly integrated sets of diagnostics. In order to face all the challenges ahead, a great effort will be required to coordinate the research on diagnostics.

Marc Beurskens

Marc Beurskens got his PhD at FOM, the Netherlands. He worked from 1999 to 2003 at JET as a long term FOM secondee and as a UKAEA contractor. After spending 2 years again at FOM, Dr Beurskens returned to JET in 2005 and now works for UKAEA. He has experience on JET in a wide variety of roles such as diagnostician and scientific coordinator. Dr Beurskens was closely involved in the development of the new JET high resolution Thomson scattering system and is now also involved in the design of the ITER LIDAR system. He manages to be active in both the areas of diagnostic development (on JET, the EFDA DTG and the ITPA Topical Group on Diagnostics) and in the study of edge pedestal physics on JET and within the ITPA Topical Group on pedestal and edge physics. He is the author of over 90 scientific publications.



EFDA Fusion News

To integrate the research activities of the different laboratories and help EFDA in the definition of research guidelines and future work programs, EFDA has created the Diagnostics Topical Group. The Topical Group is led by Tony Donné (chairman), helped by Andrea Murari and Marc Beurskens (deputies).

The topical group activities include both diagnostics developments for further and more detailed physics studies, in order to improve the knowledge basis; and specific developments aiming at performing the required measurements in the difficult environments posed by future fusion devices such as ITER. In particular, as an example of the activities to be carried out in the framework of this Topical Group, the creation of three expert groups on relevant subjects, common to most of the techniques, is foreseen: Methodologies for

Heating and Current Drive Topical Group

Magnetically confined plasma devices for fusion research rely more and more on flexible heating systems able not only to heat the plasma and to increase plasma current but also to condition the plasma parameters with the view of achieving safe, high performance and plasma pulses of long if not continuous duration.

Indeed, passing electric current through the plasma generated by induction as in a tokamak alone is not sufficient to achieve the temperatures required for positive energy balance (an ion temperature of ~ 100 million degrees is needed while the ion temperature reached by inductive current is in the range 10 to 20 million degrees). Different methods have been developed to overcome this difficulty. One of these methods, the injection of neutral particles (NBI

field lines, but it could be a match with another frequency like the lower hybrid resonance frequency or the Alfvén resonance frequency.

Even if today the performances of the H&CD (Heating and Current Drive) systems suffice to reach high plasma performance, several issues have still to be considered. For example, in contrast to present experimental devices, all the plasma facing equipments, like the antennas, have to be protected from the neutron flux resulting from fusion reactions. The neutron flux will reach values much higher than in the present JET tokamak (UK) while the power flux, which is today less than 15 MW/m², will reach 24 MW/m² in ITER and possibly more in the demonstration reactor DEMO.

Also, due to the greater plasma volume in a reactor, the need for power capabilities will also strongly increase. For instance, ITER is designed in its first phase with 20 MW electron cyclotron, 20 MW ion cyclotron and 33 MW negative ion based neutral beam. This has triggered significant R&D on the three heating systems. A main goal in terms of electron wave heating has recently been achieved thanks to the successful new 170 GHz gyrotron. Major difficulties for the ion cyclotron wave heating system and the lower hybrid system for ITER still have to be solved. One is the coupling of the waves with the plasma in the large gap between the antenna and the plasma; another is the stability of the coupling during large magnetohydrodynamic

edge events like the Edge Localized Modes which transport large amount of particles and energy. Such problems are well identified and handled with great attention in the EU and elsewhere. In particular, ITER-like antennas are undergoing tests at Tore Supra, France, and JET.

In 2007 EFDA set up physics activities together with the Heating and Current Drive Topical Group (H&CD-TG) to foster the collaborative activities amongst the Associations with the view of solving the most urgent and important tasks required to insure the success of ITER and to prepare the ground for an efficient and cost effective fusion power plant.

Andrea Murari

Dr Andrea Murari received his B.A. degree in applied electronics and M.S. degree in plasma engineering in 1989 and 1991, respectively, from the University of Padua, where he obtained his PhD degree in nuclear power plants from the Faculty of Electrical Engineering in 1993. After experience in private companies (in the fields of laser diodes and vacuum technology), he has mainly worked on measurement techniques and technologies for nuclear fusion experiments. He has installed various diagnostic systems on several European experiments and, between 1998 and 2002, he was responsible for the support to all the diagnostics of the RFX experiment in Padua. Dr Murari is presently the Leader of the Group on JET Diagnostic and CODAS (Control and Data Acquisition Systems) in the JET Close Support Unit. He is the Scientific Coordinator of all JET diagnostic upgrades for the next framework programme and in January 2008 he was nominated co-chair of the EFDA Topical Group on Diagnostics. He has been a member of the Euroforum thematic working group on measurements since 2003. In August 2008 he was appointed the coordinator of the European delegation to the ITPA Topical Group on Diagnostics.



feedback control, Calibration techniques, Data and error analysis. The first one is to promote the development of integrated control systems, incorporating sensors, hardware, software and actuators, with a particular emphasis on the algorithm, related to more powerful and complex modelisation of the plasma. The second one arises from the necessity to develop accurate and reliable calibrations for many diagnostics, in particular for future burning plasma experiments, and to standardise these techniques. The third group will face the important issue of improving data analysis capability. Different statistical methods will be considered, after a proper evaluation of the error bars and uncertainties related to the measurements.

heating) allowed the Princeton tokamak PLT (USA) to reach an ion temperature of the order of 70-80 million degrees as early as at the beginning of the eighties. Plasma-wave interaction is another way to transfer energy, leading to an increase in temperature and momentum (causing faster rotation) of the plasma. The principle is to launch electromagnetic waves via antennas or wave guides in such a way as to fulfil inside the plasma some plasma wave interaction conditions. The condition could be the matching of the wave frequency with one of the naturally existing frequencies in the plasma, such as the ion cyclotron frequency or the electron cyclotron frequency, which are both related to the particle gyration around the magnetic



The duties of the H&CD-TG are multiple, ranging from advising the EFDA leader, to assisting in the resolution of physics and technology issues, in particular in terms of performance and reliability of the H&CD systems. The TG, in close collaboration with Fusion for Energy (F4E), prepares the EU Fusion Community to support ITER and DEMO H&CD physics in the short term but also in the long term as in the case of the lower hybrid current drive system. The TG also works in close collaboration with the EFDA Integrated Tokamak Modelling Task Force in promoting experiments and modelling activities.

The annual activities of the H&CD-TG are proposed by the TG-Chairman, assisted by the Scientific and Technical Board, including representatives of F4E. The Chairman of the group is Alain Bécoulet.

The main activities of the Heating and Current Drive Topical Group for the years 2008 and 2009 can be summarized as follows:

Burning plasmas, that is plasmas in which fusion reactions are taking place, will be simulated experimentally using heating and current drive tools, eventually including helium injection. The objective of this research is to prepare the path for high

Alain Bécoulet

Alain Bécoulet is a former student of the Ecole Normale Supérieure in Paris. "Professeur Agrégé" in Physics since 1986 he finished his PhD work in CEA Cadarache in 1990 on the Hamiltonian approach of the wave-particle interaction in tokamak plasmas and its application to ion cyclotron resonant heating. He then took responsibility for the Ion Cyclotron Physics studies in CEA. His next interest was linked to advanced tokamak studies, when he took the leadership of the JET task force on Advanced Scenarios in 2000-2001. He then became leader of the new European Task Force on Integrated Tokamak Modelling between 2003 and 2006, setting up the overall activity in Europe and the necessary connections with the other ITER partners. He took over the Chairmanship of the European Topical Group on Heating and Current Drive in October 2007. He has been leading the Plasma Heating and Confinement division in the "Institut de Recherche sur la Fusion par confinement Magnétique" at CEA Cadarache since 2004.



pulse operation. Coordinated studies will be performed to determine the best combination of H&CD to be used during the early evolution of the plasma.

Wall conditioning, in particular using the ion cyclotron heating scheme, is needed in order to control and eventually modify the composition of the gas trapped in the plasma facing materials. This is particularly important for avoid-

Technology related activities are needed for making the H&CD systems ready for safe operation of the tokamak. In particular, improvement, qualification, and compatibility of arc detection systems, which will be studied, are important for protecting the heating systems against failure. Other safety operation issues will be considered, for example those related to the overheating of the machine structures.

The mission of the H&CD-TG also extends to ITER upgrades and to DEMO, in particular the possibility of using the lower hybrid current drive system in large reactors.

This structure of the H&CD-TG activities coincides with the proposed organization of future EFDA activities in terms of 7 R&D missions that have to be accomplished for a successful approach to a fusion energy source based on magnetic confinement. These missions include, among others, physics activities related to burning plasmas or long pulse and steady operation but also engineering type of activities necessary to achieve reliable tokamak operation.

As can be concluded from the list of activities, the H&CD systems take an important share in the EFDA work-programme. Indeed, plasma operation always requires one or more H&CD systems: assisted plasma initiation to save magnetic flux, heating or/and current generation all along the plasma pulse in order to help sustain high performance or assisted termination to avoid loss of control.



Tore Supra's ITER like ICRF antenna

power steady state plasmas in reactor relevant conditions. Controlling plasma termination is also important in order to avoid electromagnetic forces which are too strong acting on the device structures. Experiments on plasma termination will be performed using radio-frequency waves.

The way the plasma is generated in a tokamak constrains its later evolution. One reason is that the magnetic field flux consumed during plasma start-up cannot be quickly replaced and must therefore be saved to allow for long

impurity flow from the walls to the plasma or for avoiding uncontrolled changes in, for example, hydrogen and helium composition of the plasma during its evolution. Experimental work on this subject is in progress.

Specific studies will also be performed to test different techniques such as gas puffing allowing the radio frequency waves propagating from the antennas to be coupled to the plasma when the distance between the antennas and the plasma is as large as will be the case in ITER.

50 years of tokamaks

From the historical point of view, the year 2008 seems more than symbolic to start the construction of ITER. The whole fusion community celebrated 50 years of the first open fusion conference (the 2nd International Conference on the Peaceful Uses of Atomic Energy in Geneva, 1958). It is also 40 years ago that the IAEA Novosibirsk conference marked a turning point of fusion research with the reported success of tokamaks, see e.g. <http://www.jet.efda.org/pages/multimedia/yop/nov05.html>.

Indeed, many tokamaks have been built since then all around the world to culminate in the present ITER design. In this article we would like to recall the first ten years of tokamak studies during which the team of the Kurchatov Institute in Moscow fostered tokamak R&D from the first device T-1 to the success of its bigger, more advanced version T-3.

In the evening talk of the IAEA Fusion Energy Conference in Geneva (see other article in this issue) this year, given by the current director of fusion research at the Kurchatov Institute Prof. V.P. Smirnov, the year 1958 was mentioned as the year when the tokamak programme started. "I would definitely agree that 1958 is the year of birth of tokamaks, because T-1 started operation then" says Prof V.S. Strelkov from the Kurchatov Institute, who personally participated in the tokamak T-1 work. "One can even find this facility mentioned in the proceedings of the 1958 Geneva conference as 'Experimental arrangement 5', however without mentioning any results, because the facility was only about to start operation."

T-1 was the first toroidal facility with a steel vacuum vessel that satisfied the Kruskal-Shafranov stability condition. The condition requires that the safety factor q is bigger than one, i.e. the pitch angle of the magnetic field helicity needs to be very low – in practice it means that the toroidal field must be strong, which distinguishes tokamaks from the then popular toroidal pinches like ZETA in Harwell. The tokamak T-1 major and minor radius were 62.5 cm and 24 cm, respectively, with the main toroidal field approximately one tesla. Interestingly, the word 'tokamak' – a Russian abbreviation of Toroidal Chamber with Magnetic Coils - was coined probably the same year by I. N. Golovin, head of a neighbouring laboratory.

Fusion research was launched in the U.S.S.R in the 1950s under the expert supervision of I. V. Kurchatov. In the LIPAN Institute in Moscow (nowadays the Kurchatov Institute) the fusion sector was headed by the young and charismatic L. A. Artsimovich. Like in the other institutes, also in LIPAN priority was originally given to pinch experiments. Future tokamaks were developed in a rather small laboratory under the enthusiastic leadership of N. A. Yavlinskij. Quite naturally, a few other facilities preceded T-1 in order to validate the basic ideas of toroidal magnetic confinement set in the work of I. E. Tamm and A. D. Sakharov, who introduced the field helicity in plasma in order to close the particle drift trajectories. Among these facilities, the machine TMP with ceramic vessel and strong toroidal field is often mentioned as the direct predecessor of tokamaks. When N. A. Yavlinskij tragically dies in an airplane accident in 1962, the results of tokamaks are already so prominent that L. A. Artsimovich himself assumes leadership of the laboratory, including the brand new T-3 machine which later allows for the tokamak breakthrough.

Still, it is the tokamak T-1 that can be considered the first experiment proving

atures in T-2 plasmas. In the early 1960s, two smaller tokamaks TM-1 and TM-2 were built, both with major radius 40 cm, to provide more detailed insight into specific problems of experimental research. TM-1 is probably the oldest tokamak still in service, as its main components form the basis of the Golem facility at the Technical University in Prague, currently under construction to become a new plasma hands-on experiment for students.

In the following machine T-3 (commissioned in 1962), the major radius was increased to one meter in order to allow for full ionisation of major impurities in ohmically heated plasmas. The choice was right, full ionisation minimised radiation losses and T-3 achieved macroscopically stable plasmas with the then record temperatures of 1 keV (10 million degrees). This result was confirmed by the Thomson scattering system imported and operated by a team of British scientists in 1969. This led to a real worldwide "tokamania".

What determined the success of the Kurchatov team? And did it surprise its members? "For sure I would not say that it came as a surprise. Our determi-



Past and present: the first tokamak T1 (left) and tokamak Golem (right) based on TM-1 from the early 60s

the Kruskal-Shafranov stability condition. Results also indicated that the main power losses were due to the radiation of impurities and not anomalous diffusion. As the level of impurities was high, the next step T-2 (of the same size, commissioned in 1959) had for the first time a system for vacuum vessel baking. The system heated the vessel in between experiments in order to release residual impurity gases attached to the vessel surface. This procedure – standard in all tokamaks today - clearly led to less impurities and increased temper-

nation was based on the results of our experiments. We could see that unlike in pinches, our discharges were stable. We worked, analysed results and progressed without really paying attention to the claims that the Bohm diffusion, predicting extremely high losses of heat of plasmas, may be universal," pointed out Prof. V. S. Strelkov from the Kurchatov institute.

Scientific team of tokamak T-1: G.G. Dolgov-Saveljev, V.S. Muchovatov, V.S. Strelkov, M.H. Shepelev and N.A. Yavlinskij. Jan Mlynár and Milan Ripa

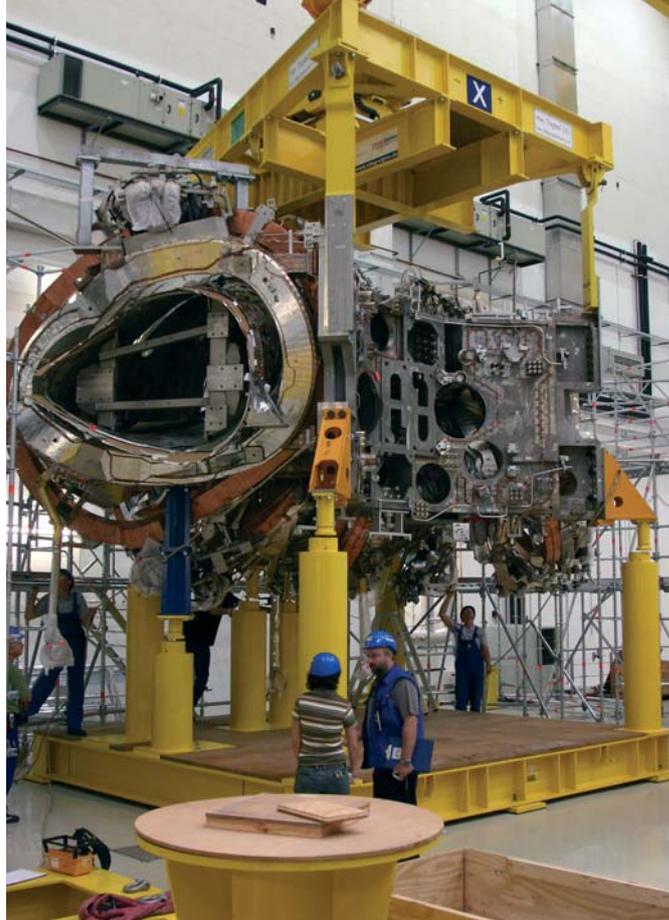
Wendelstein 7-X taking shape

The first milestones in the assembly of the Wendelstein 7-X fusion device at the Greifswald branch of Max Planck Institute of Plasma Physics (IPP), Germany, have been reached with the completion of the first of five modules of the large-scale experiment: one-fifth of the inner core of the device is now ready. Construction of the complex device will take about another six years. Wendelstein 7-X will then be – next to the Large Helical Device in Japan – the world's largest fusion device of the stellarator type. With discharges lasting up to 30 minutes it is to demonstrate the stellarator's essential property – continuous operation at reactor relevant plasma parameters.

The components

Industrial production of the essential components for Wendelstein 7-X is almost complete. Manufacturing of the core of the device – 50 complex shaped, helium-cooled superconducting magnet coils about 3.5 metres high – has been finished. They were produced by a German-Italian consortium headed by Babcock Noell GmbH in Würzburg and ASG Superconductors S.p.A. in Genoa. In order to vary the magnetic field, a second set of 20 planar, likewise superconducting coils, are superposed on the stellarator coils. The manufacturer, Tesla in the UK, has delivered all 20 planar coils. More than half of the 70 coils have been successfully tested under cryogenic and high voltage conditions, demonstrating superconductivity at full current and the ability to withstand the voltage required in case of quench. A massive ring-shaped support structure, already half completed by the Spanish company ENSA, will hold the coils in their exact positions.

The entire coil configuration will be enclosed by a cryostat 16 metres in diameter. Two of its five sections have already been finished by MAN DWE in Deggendorf, Germany. A refrigeration plant will later provide cold helium to cool the magnets and supports to the temperature of a few Kelvin needed to achieve superconductivity. Inside the coils the plasma vessel has a peculiar shape matched to the twisting of the plasma contour, designed to provide optimised confinement and stability. Its 20 sections were likewise produced by MAN DWE. More than 250 openings are engineered in the vessel to allow the plasma to be observed and heated and for cooling tubes to penetrate for cooling the plasma facing compo-



nents. An equal number of ports produced and supplied by the Romabau Gerinox company in Switzerland connect these openings with the outer wall of the cryostat.

The assembly

The assembly of Wendelstein 7-X is organized in six stages making use of the five-fold symmetry of the magnetic field structure. Five almost identical modules are pre-assembled before being joined into a torus in the experiment hall. In the first stage the coils are threaded onto the vacuum vessel and joined to the central support ring, while installing the mechanical support elements between the coils. This work is done separately for each half module. For this stage two assembly rigs Ia and Ib are used, allowing parallel assembly of two half modules simultaneously. The half modules are then joined together to form a full magnet module in assembly rig II. On this rig the preparations for the installation of the superconducting bus and of the cryo-pipes for the liquid helium supply also take place.

In September 2008, the first of five modules moved on from assembly rig II to rig IIIa inside the torus hall (see picture), where the superconducting bus and cryo-pipes are being installed. From now on work can progress on three magnet modules in parallel. Subsequent assembly stages are the completion of the five single magnet modules, the fi-

nal alignment of these modules on the machine base, the successive connection of the modules and the set-up of the periphery, including electrical connections and cooling system.

A major task concerning the first magnet module during recent months was the manufacturing and installation of the support brackets and clamps of the superconducting bus, which is provided by Forschungszentrum Jülich, and the design and manufacturing of the cryo-pipes. Because of limited space inside the cryostat and the calculated movement of the coils and structures for the different magnetic field load cases, a very complex collision analysis has been required. Assembly trials for the holders of the superconducting bus have turned out to be very time consuming. Countermeasures, to avoid delays during these working steps, require an increase in design, manufacturing and assembly capacities.

Parallel to the advancing assembly in Greifswald, the first half shells of the cryostat vessel have been delivered. In a first step to prepare the cryostat for the final assembly, experts from MAN DWE are applying the thermal insulation to the cryostat which is required to reduce thermal radiation to the cold structures. After enclosing the magnet modules with the lower and upper half shells of the cryostat vessel the port installation can start.

Isabella Milch

Prof. Friedrich Wagner retires

Professor Dr. Friedrich Wagner from the Max Planck Institute of Plasma Physics (IPP), Greifswald Branch, retired at the end of November. Professor Wagner (born 1943) discovered in 1982 on the ASDEX tokamak (IPP-Garching) the High-Confinement Regime, later called H-Mode, a plasma state with confinement properties about twice as effective as in former modes of operation. He was able to show that under certain conditions self-organised transport barriers form at the plasma edge. The thermally insulating layer ensures good plasma confinement, a very important discovery in the development of fusion research. This achievement gave new momentum to the research which was facing serious difficulties at the end of the 70s due to the fact that thermal insulation inevitably diminished as the temperature approached ignition conditions.

Friedrich Wagner was appointed project head of the ASDEX experiment in 1986, and two years later Scientific Fellow and Director at IPP. This was followed by his appointment as project head of the Garching stellarator Wendelstein 7-AS. In 1992 Wagner and his team also succeeded in developing the H-mode on this stellarator, proving this regime to be a universal plasma state.

From 2003 till 2005 Friedrich Wagner was in charge of the construction of the follow-up experiment, Wendelstein 7-X, at the Greifswald branch of IPP, whose spokesman he was from 1999 till 2007. In 1999 he was appointed Professor of Physics at the Ernst Moritz Arndt University in Greifswald and in 2007 became President of the European Physical Society.

Professor Wagner has been awarded the Stern-Gerlach Medal 2009 by the German Physical Society (DPG) for his work in high-temperature physics and fusion research.

Youth festival in Hungary – communicating fusion to young people

Is it possible to talk about fusion and science in the middle of a youth music festival? Young Hungarian fusion scientists think that the answer is definitely yes. That is why for the last 4 years they have been attending the “Sziget” (Island in Hungarian) Festival which celebrated its 15th Anniversary last year. Evolved from a local event into one of the major international musical and cultural festivals in Europe, Sziget has today a reserved place in the Summer calendar of many young European people.

It is hard to define what makes the Sziget extraordinary among the many music festivals around Europe, but its atmosphere is surely unique. It might come partly from the locale itself, since it is organised on an island of the Danube in the heart of Budapest. Or partly from the programme since besides concerts in all music styles there are movies, performances, talks, dances, etc., all together more than a 1000 events. But the ambience is made mostly by the people attending the festival who come from all over Europe; this year 371000 visitors per day attended a week-long fiesta.

One unique feature of this festival is the Civilian Island, a separated place in the area where non-profit organisations

can introduce themselves and their activities. Since 1999 the FINE (Youth for Nuclear Energetics), the youth section of the Hungarian Nuclear Society has been pitching a tent and providing information about nuclear energy. In 2005 PhD students from the Hungarian Euratom Association HAS joined the work to show a possible future of nuclear technology.

“In the young generation there is a well observable demand for information about the latest results of research including fusion” – explains Dániel Dunai, a young fusion scientist of HAS who attended the event. “This year about 1000 young people participated in the program. Our visitors filled out a test with the help of a fusion brochure, which then was corrected and explained by an expert. The questions were designed to give a short introduction on matters from fusion reaction to the future reactor, and pointed to the importance of ITER and its European site. Many young teachers also visited our tent and received information materials. The informal discussion we had with our visitors proved to be a very effective tool in disseminating information on fusion” - he adds.

So what is fusion? Filling out test on nuclear energy by not typically science oriented young people at Sziget Festival. Photo by Dávid Légrády



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New Director and spokesperson at Max Planck Institute of Plasma Physics

On 1 November 2008 Professor Dr. Günther Hasinger took up his appointment as Scientific Director of the Max Planck Institute of Plasma Physics (IPP) at Garching and Greifswald. He succeeds Professor Dr. Alexander M. Bradshaw, who has headed IPP since 1999. At the same time Prof Sibylle Günter was appointed as IPP's spokesperson in the group of the Heads of the Research Unit.

After studying physics Günther Hasinger, born in 1954 at Oberammergau, did his PhD at Ludwig Maximilian's University (LMU), Munich, and Max Planck



Dr. Hasinger and Dr. Zohm playing the guitar at the IPP meeting.

Institute of Extraterrestrial Physics (MPE), Garching. He then joined MPE, where he was concerned with the EXOSAT, GINGA and ROSAT X-ray satellites. In 1995 Günther Hasinger took his lecturership qualification at LMU, Munich. After research spells in the USA he was given a chair at the University of Potsdam in 1994. At the same time he was appointed as a Director at the Astrophysical Institute Potsdam (AIP); from 1998 he was spokesman for the Board. In 2001 he was finally made a Scientific Fellow and Director of the X-ray and Gamma Group of MPE at Garching.

Günther Hasinger ranks among the world's leading capacities in the fields of cosmology and X-ray astronomy – the investigation of outer space in X-ray light. With ROSAT he was able to show that cosmic background X-radiation, a very old and puzzling phenomenon, is emitted by massive Black Holes in the centres of distant galaxies. Thanks to his decisive contribution to this research, it is now known that these Black Holes constitute the seedlings of galaxies and motors for their development – results for which Günther Hasinger was award-

ed the Leibniz Prize of the German Research Foundation in 2005.

Since then he has played a key role in the development of future X-ray observatories such as eROSITA, Simbol-X and XEUS/IXO. These will serve to clarify the early development of Black Holes and galaxies as well as the nature of Dark Energy and Dark Matter. At IPP he will contribute not only his experience in heading major international projects, but also concrete research methods: for example, plasma physics will benefit from his application of X-ray diagnostics, so important to his previous work, in conjunction with astrophysics groups.

When Dr. Hasinger gave his speech of introduction to members of the IPP on

10 December, one of his lesser known skills was exposed. He and his colleague Hartmut Zohm performed a live rendition of a rock song by guitar, theme: plasma! Indeed, he has been playing instruments like bass guitar and flute for a long time. As part of an established Oberammergau family he made it onto the stage (albeit in crowd scenes) in the world-renowned Passion play in 1970 which takes place there every ten years. More time on stage followed, particularly in the 70s, with performances in "Saffran", a German rock band playing progressive rock. Instead of following a career in music however, Günther Hasinger took up studies in physics...

Sibylle Günter studied physics at the University of Rostock, where she did her PhD in 1990. After working in the US at the University of Maryland and National Institute of Science and Technology (NIST) in 1994, she defended her habilitation thesis on optical properties in dense plasmas in 1996. In the same year she moved to IPP Garching, and changed her research field from the study of quantum statistics of cold dense plasmas to the investigation of

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magnetohydrodynamic stability of high temperature fusion plasmas. In 2000 she was appointed Scientific Member of the Max-Planck Society and Director at the IPP, currently heading the tokamak theory division. Since 2001 she has been teaching as adjunct professor at Rostock University and in 2006 was made honorary professor at the Technical University Munich. She has been a member of the IPP directorate since 2007. Prof. Günter is now chairing the Topical Group on Energetic Particle Physics in the International Tokamak Physics Activities (ITPA) and has recently been elected to chair the European High Performance Computer for Fusion board. Since 1 November she has been representing the IPP in the EFDA Steering Committee as Head of Research Unit.

Loss of Prof Skalný

On 17 October 2008 the scientific community lost a great friend and colleague with the sudden and unexpected death of the Head of the Slovakian Association, Professor Jan Dušan Skalný.

The professional career of Jan Dušan Skalný was entwined with the Comenius University in Bratislava. Jan Dušan started his career as a researcher and scientist in 1966 at the Department of Experimental Physics. Initially focused on high pressure discharges, he later extended his interest to electron and ion processes related to electric discharges and plasma. His career, which had been restricted during the Communist era in former Czechoslovakia, developed rapidly after the fall of the iron curtain in 1989. In 1991 he obtained the position of associated professor and in 1998 full professorship in Plasma Physics at the Comenius University. During the period 1996 - 1999 he was head of the Department of Plasma Physics at the same university.

Jan Dušan was an open, friendly person. He was ready to help and collaborate with colleagues from home and abroad. He actively contributed to several European and international projects and played a key role in the formation of the Slovak-Euratom Association.

Jan Dušan's personality, joy of living and enthusiasm for science made his friendship a rewarding and memorable experience. He will be sorely missed.

New HoA in Romania, new HRU in Belgium and France

Dr. Florin Spineanu was appointed Head of the Fusion Research Unit of the Association EURATOM-MEDC at the Steering Committee Meeting in 8 October 2008. Florin Spineanu has graduated from the Faculty of Physics (1977) and the Faculty of Mathematics (1986) of the University of Bucharest, Romania and obtained his PhD in 1992. He has done basic research on the statistical physics of anomalous transport, instabilities and transport in thermonuclear plasma, including numerical simulations. In recent years he has focused on coherent structures and organized flows, using particularly powerful methods of field theory formalism and integrability theory. He is currently working on the theory of L to H transition, Edge Localized Modes and density pinch in various regimes of tokamak. F. Spineanu has published 65 papers in international refereed journals, many in collaboration with groups from France, Belgium, Italy, Japan, USA.

In November 2008 Prof. Dr. Ir. Michael Van Schoor was appointed Director of the Belgian research unit LPP ERM/KMS. Prof. Van Schoor is a poly-technical engineer by training and is a former Air Force Officer. In 1990 he was appointed at the Physics Department of the Royal Military Academy in Brussels and became involved in fusion research, where he did research work on topics like edge turbulence, plasma rotation, biasing and confinement. He became professor in 2003 and is now also head of the Physics Department.

Dr Gabriel Marbach was appointed Head of the Research Unit at CEA on 1 November 2008. Dr Marbach graduated from Ecole Centrale de Paris as a mechanical engineer in 1972 and he also got a degree in solid and material physics. He received his PhD in material behaviour in Orsay in 1976. After starting work for CEA, Dr Marbach headed a group in charge of development and operation of fuel for fast breeder reactors between 1978 and 1988. Then he was the leader of the instrumentation and design laboratory for fast breeder reactors until 1995. From 1996 to 2000 he was involved in the coordination of technical and safety activities for fusion at the nuclear reactor division at CEA and contributed to the ITER project as a European expert for nuclear integration and safety. Dr Marbach was Deputy Head of the Department of Controlled Fusion Research from 2001 to November 2008.

Fusion in Dutch secondary schools

The Dutch association EURATOM-FOM has produced a teaching module to bring fusion research into the classroom. The module was recently certified by the Dutch Ministry of Education and is now an official (elective) part of the new subject "Nature, Life and Technology" (NLT) in the Dutch curriculum. NLT aims to increase the interest in science and technical subjects in secondary schools by involving pupils in research, showing the cross links between different disciplines and stressing the applications of science in society.

The module challenges students in the last years of secondary school to design their own fusion reactor, capable of producing enough energy to power the city of New York. They are guided through seven design steps to accomplish this. After a brief overview of the field of alternative energy, the module features diverse subjects such the physics of magnetic confinement, plasma heating and choices of wall material. Students are encouraged to make their own design choices such as the fuel to use or the choice between a divertor or a limiter, and defend them on the basis of physical arguments.

Included are ample exercises and hands-on activities. A strong link with

current research in the field is established by using data and examples from international fusion experiments such as TEXTOR, MAST and JET to perform calculations and make predictions. In one (optional) activity, students come to the FOM-Institute for Plasma Physics Rijnhuizen, the Dutch fusion lab, and perform measurements on the plasma wall interaction experiment Pilot-PSI with their home-made spectrometer.

The module was developed by Erik Min (chief editor) and Amy Shumack from FOM-Rijnhuizen, in close collaboration with secondary school teachers Lieke Heimel and Peter van Soest. Before certification, the module was tested in several schools. Judging by the reactions, students are very keen on learning about this fascinating subject.

Plans exist to translate the module into English for use by EFDA.

For more information, please contact Erik Min, Public Information Officer at the FOM-Institute for Plasma Physics Rijnhuizen. E.Min@Rijnhuizen.nl, +31 30 6096 836.

JET on track for a promising future

With the year coming to an end JET has many reasons to be looking back in delight. To start with, 2008 marks an anniversary year for the JET Experiment. Indeed, on the 25 June 1983 the first plasma was achieved. The continuous success of the Experiment since then made it possible to gather together many of the key players from day one for a joyful celebration exactly 25 years later. The 25 June 2008 went down in history as a day when JET's present young scientists had the opportunity to meet and exchange with many of those who contributed to the milestones set by JET in international fusion research.

On the other hand, it was also an appropriate occasion to look into the future with a certain degree of confidence. In fact, at its meeting in Ljubljana back in March, the EFDA Steering Committee unanimously approved a resolution that recognised "the scientific need for full exploitation of the JET Enhancement Programme 2 and for tritium operation"

and requested the Commission "to investigate the possibility of making adequate resources available within the fusion programme budget". This will entail exploiting JET beyond the currently foreseen horizon of 2010, up to 2014/15. Moreover, later in the year, the Facilities Review Panel (see our other article in this issue) recognised JET as "the most relevant device for support to ITER until new devices with improved capabilities become available" and concluded that "JET needs to operate until 2014/15 at least and would benefit from an early installation of an Electron Cyclotron Resonance Heating System. Depending on the JT60SA schedule JET operation for a few further years should be foreseen."

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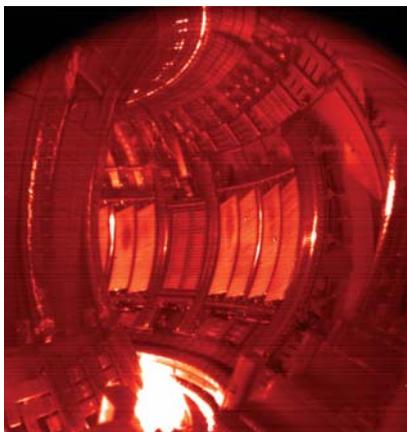
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The remarkable scientific capabilities of JET, recognised by these positive recommendations, have been extensively exploited during 2008 in a scientific programme devoted to the consolidation of ITER design choices and the qualification of ITER regimes of operation. These regimes of operation, referred to as plasma scenarios, are the sequence of operational events applied to prepare and then initiate the plasma, raise the plasma current to the required value, apply the auxiliary heating and current drive during the burning phase and finally extinguish the plasma discharge safely.

A tokamak, like JET and eventually ITER, uses a transformer such that the secondary current (the plasma current) is driven inductively by continuously increasing/decreasing the current in the primary circuit. This feature effectively limits the pulse length (it ends when the poloidal field coils have reached their maximum achievable currents). For this reason, in ITER, the baseline plasma scenario (referred to as ELMy H-mode) is envisaged to operate for a duration not exceeding 500s at a plasma current of 15 million Ampere.

During this year's experimental campaigns a substantial part of the ITER plasma scenarios development activities at JET has been dealing with the development of the tokamak concept towards steady-state operation, based on "advanced tokamak" (AT) plasma scenarios. The objective of the AT research is to provide a candidate plasma scenario applicable for continuous opera-



A view into the JET vacuum vessel using a wide-angle infrared camera system. The system allows the observation and measuring of the temperature increase of plasma facing components following transient power loads induced, for instance, by Edge Localised Modes such as in this picture.



EFDA Associate Leader for JET, Francesco Romanelli, welcomes the guests at the celebration of the 25th Anniversary of JET's first plasma.

tion in fusion power plants. In ITER, fully non-inductive operation (i.e. without transformer flux consumption) is envisaged for up to 3000s at a reduced plasma current of 9 million Ampere (compared to the 15 million Ampere current capability). To compensate for the reduction in energy confinement associated with reducing the plasma current, the ITER steady-state scenario must achieve improved energy confinement by a factor of 1.5 compared to the standard confinement projection for the baseline scenario. Crucially, JET results have demonstrated that substantially improved confinement is achievable on a large tokamak (so far up to a factor 1.4), thereby increasing confidence of the successful operation of this scenario on ITER.

However, resolving the issues associated with the performance of plasma scenarios is not the entire story. In reality, due to the expected large amount of energy stored in ITER plasmas and future fusion power plants, plasma scenarios must be compatible with power load limits imposed by first wall materials. This is currently a very active field of research in which JET has been at the forefront of integrating ITER scenarios with relevant first wall materials. Transient power loads are, for instance, induced on plasma facing components by a phenomenon which occurs at the edge of the plasma: Edge Localized Modes (ELM). In 2008 JET experiments have investigated different active techniques for reducing ELM induced power loads on plasma facing components. These techniques are based on applying a perturbation to the plasma, which results in a frequency increase of the ELM events

and a decrease of the induced power loads on the plasma facing components.

These are just a few examples of the many achievements made by JET in 2008. Work is still ongoing to complete the comprehensive set of experiments planned before and in preparation for the future ITER-like wall which will build the very core of the JET programme in support of ITER and whose installation will start during the Summer of 2009.

Richard Kamendje & Petra Nieckchen

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For more information see the websites:

<http://www.efda.org>
<http://www.jet.efda.org>
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