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newsletter

EUROPEAN FUSION DEVELOPEMENT AGREEMENT

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News

Roadmap on ITER negotiations

The recent ITER Ministerial Meeting, which took place in Washington the 20th of December 2003 resulted in a Joint Communiqué which, amongst other matters, asks *"...the ITER Team in conjunction with the ITER Parties to conduct a rapid exploration of the advantages of a broader project approach to fusion power."* (see text below)

Consequently, to address this request in a timely fashion, the ITER team is organising meetings with the parties to come, at the end of January, with a proposal that will be then considered by the Parties, possibly mid February.

Contents

JOINT COMMUNIQUE
From the Ministerial Meeting for ITER

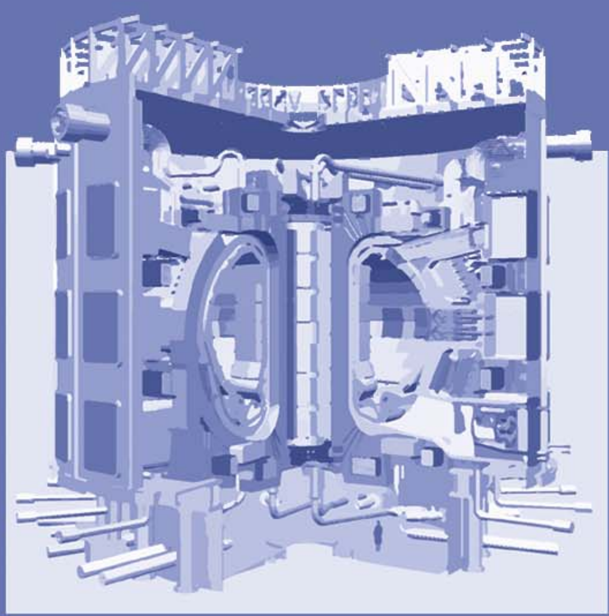
The Six Parties have reached a strong consensus on a number of points.

We have two excellent sites for ITER, so excellent in fact that we need further evaluation before making our decisions based on consensus.

We have agreed to provide the remaining questions to the candidate host parties by the end of December for their answers by the end of January.

We will ask the ITER Team in conjunction with the ITER Parties to conduct a rapid exploration of the advantages of a broader project approach to fusion power. This work will be done on the same schedule.

With all this information, we plan to hold a follow-up Ministerial meeting to reach consensus as quickly as possible, likely to be in February.



Timetable to ITER implementation

1) The ITER Parties must first reach a consensus on the preferred site for ITER
2) The draft agreement must then be completed, and submitted to the Parties authorities
3) In Europe, the Council of Ministers must approve conclusion of the agreement followed with the Commission signing the agreement.
4) When all the ITER Parties have concluded their constitutional requirements, the ITER agreement comes into force.

http://www.efda.org

Interview

Persuading other governments to take fusion more seriously

EFDA Newsletter (EN): *Prof. Llewellyn Smith, you were awarded a knighthood in 2001- can we expect you now to be something like a "white knight" for nuclear fusion after being successful in particle physics?*

Chris Llewellyn Smith (CLS): I'm new to fusion, of course, but I bring with me from particle physics knowledge of very similar technologies and of some of the political problems that fusion is facing in trying to make a co-ordinated programme on the European and world scale. I hope to harness the support of the British Government, which is convinced of the importance of fusion as a potential source of environmentally friendly energy. I'm hoping, with Sir David King, the UK's chief scientific advisor, to play a role in persuading other governments to take fusion and the need for fusion more seriously.

UK guest at EFDA CSU Garching (Germany):
Prof. Sir Chris Llewellyn Smith (right) welcomed by Prof. Minh Quang Tran (EFDA leader).

EN: *You served 5 years as Director General at CERN, which has an excellent reputation for public education and technology transfer, two items which are almost missing in the fusion programme. How do you think that this aspect of fusion research can be improved?*

CLS: CERN has certainly invented some wonderful technologies, such as the World Wide Web, but that was not the result of a deliberate technology transfer effort. CERN has had a big indirect effect on European industry by often asking industry to build things that are at or beyond the limit of their capability. When companies have got into difficulties, CERN engineers have gone in and helped them, and they have reaped future benefits from what they have learned. I think that similar things happen in fusion. There is a need to interest industry more in the long term prospect of a fusion industry, and the Euratom is taking steps to do so.
Turning to public education, one important step - in the UK at least - is for the fusion scientists to develop better relations with the university-based scientists. Fusion research in the UK has been rather isolated at Culham. If you ask most university professors - 'What do you think of fusion?', you may get a negative reaction based on information which is 20 years out of date. We will have problems convincing the general public of the potential of fusion if we have not convinced other scientists.

Prof. Sir Christopher Llewellyn Smith FRS is Director of the UKAEA Culham Division, which is responsible for the UK's thermonuclear fusion programme. He succeeds the late Derek Robinson FRS.

Find a short CV of Chris Llewellyn Smith on our website:

http://www.efda.org
> Additional information
> Interviews

EN: *Do you see any particular feature missing from the fusion programme – at the Culham level or in the European programme?*

CLS: The European programme is very strong: I think we lead the world. At Culham the UK programme is relatively small, but of very high quality, and of course we host JET which is currently the world's most advanced fusion device. However, world-wide there is currently not enough work on the materials that will be needed to build a reliable fusion reactor. We must intensify the work in this area – on the plasma facing components, the structural components, and the divertor for a fusion power plant, as well as just simply for ITER.

EN: *The US participates at CERN in the Large Hadron Collider (LHC) project. What important conclusions would you derive from your experience of collaboration with the US for their participation in the ITER project - as ITER tops the DoE list of their facility priorities?*

CLS: My main regret is that their contribution to the funding of ITER is not larger, although it is of course pleasing that ITER heads the DoE's priority list. The US has the largest economy in the world and it's a great pity that they are not prepared to contribute more than 10%, which is not commensurate with their scientific strength, and even less with their economic strength. Another point is that the Americans have a different way of working, and tend to reach decisions by "shoot-out", rather than by consensus. In international collaborations, reaching consensus, in a way that leaves everybody happy and feeling that they have gained, is essential in order to keep political support. It took time for the Americans who work at CERN to get used to working in this way.

EN: *Replacing Derek Robinson, what spirit do you take over from him into your new position?*

CLS: I think that Derek did a fantastic job. In a very difficult period when the budget had been cut very strongly in the 1980s and the early 1990s in the UK, and during a time when the British Government was rather negative about fusion, he and his colleagues took some very clever decisions, such as building START, followed by MAST. So he is a very difficult act to follow, especially for somebody who comes from a completely different background.

Interview and Photo: D. Lutz-Lanzinger

For **more information** on UKAEA Culham, JET and MAST, please see:

http://www.ukaea.org.uk/culham
http://www.fusion.org.uk/
http://www.jet.efda.org/

CERN is represented on :
http://public.web.cern.ch/pub

Associations

ÖAW: 14th Association Day on Fusion Technology

On 28th November 2003 the Association Euratom-ÖAW (Österreichische Akademie der Wissenschaften – Austrian Academy of Sciences) organised its annual Association Day on Fusion Technology, which was hosted by the Austrian Research Center Seibersdorf. At this meeting current contributions to the EFDA Technology Work Programme and Underlying Technology Programme were presented and discussed by junior and senior scientists currently active in this field.

Dr. Rainer Lässer (EFDA Garching, Germany) gave a lecture on recent and future developments in the field "Tritium breeding and materials". Dr. Ettore Salpietro (EFDA Garching) presented developments and results within the field "Magnetic structure and integration".

The presentations focussed on materials research (investigation of tungsten alloys, neutron-radiographic examination of SiC_f / SiC ceramic composites, impurity transport in beryllium) and testing of insulation materials for the ITER magnet system. Guests were also welcomed from the EFDA Close Support Unit Culham (UK) and the IAEA Department of Nuclear Science and Applications and from Austrian companies.

For **more information** on ÖAW see:
http://www.oeaw.ac.at/

TCV:
"**T**okamak à **C**onfiguration **V**ariable" is the main experimental facility on the Lausanne (Switzerland) site of the Association Euratom CRPP ("Centre de Recherches en Physique des Plasmas").

For **more information** please see:
http://crppwww.epfl.ch/crpp_tcv.htm
and
http://crppwww.epfl.ch/

NTM:
The magnetic island produced by a tearing mode perturbs the bootstrap current, which further amplifies the island and degrades confinement or leads to a disruption. This instability is the neo-classical tearing mode.

Gyrotron:
Device used for generating high power microwaves in the electron cyclotron range of frequencies (≈ 50 – 200 GHz).

Associations

ECRH on TCV tokamak – an ITER relevant system

Electron cyclotron (EC) heating in a magnetised plasma is performed by launching a radio-frequency (RF) wave which is resonant with the plasma electrons having a cyclotron frequency, f_{cycl}, (or integer multiple of f_{cycl}) equal to the RF. The cyclotron frequency is proportional to the local magnetic field amplitude (f_{cycl} = 28 [GHz]/[Tesla]). The resonant nature of the interaction, together with the space dependent magnetic field in a fusion device, creates a situation in which extremely localised power deposition can be achieved. This property can be used either for localised electron heating (ECH) or for generating non-inductive current drive (ECCD). Compared to other RF auxiliary heating systems EC waves have the additional advantage that the radiation propagates in free-space, which significantly simplifies the launching system.

Multi-megawatt ECH and ECCD system exists on several of today's toroidal magnetic fusion devices. In ITER, ECH and ECCD is foreseen not only as a principal auxiliary system for plasma heating and for plasma start-up, but is considered essential in meeting the key requirement of neoclassical tearing mode **(NTM)** stabilisation by localised current drive. The EC system is therefore distributed between a main horizontal port, through which 20 MW of EC power at 170 GHz can be launched, and three upper ports, also operating at 170 GHz, which are to be used principally for the stabilisation of NTMs.

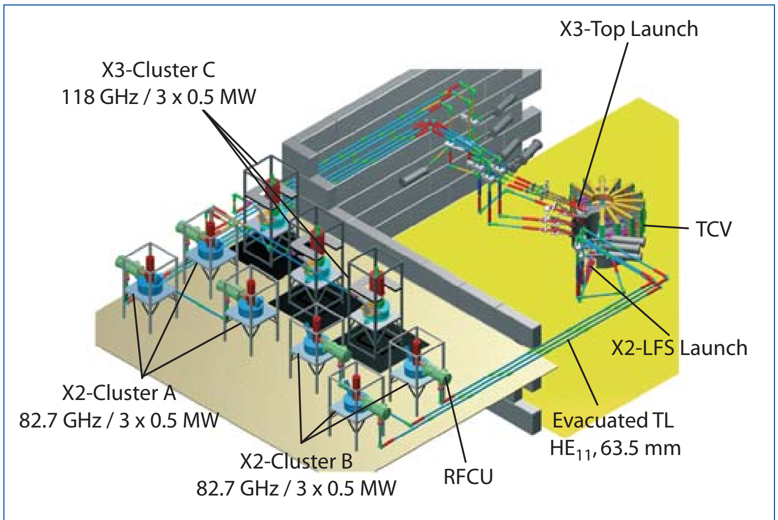
The recently completed ECH system installed on the TCV tokamak, with a total of 4.1 MW of injected power, and with a highly flexible launching mirror system allowing real-time control of the toroidal and poloidal mirror angles, is, at present, the most relevant ECH systems for ITER. It is made up of 9 **gyrotrons** grouped in three "clusters" of three gyrotrons. Two of the clusters operate at 82.7 GHz (0.5 MW/gyrotron, 2s) and are used for heating and/or current-drive, coupling to the X-mode plasma wave from the outboard (low field side) of the machine and being absorbed at the 2nd harmonic resonance (X2). The third cluster operates at 118 GHz (0.5 MW/gyrotron, 2s), couples to the X-mode from the top of the machine and provides the ECH power which is absorbed at the 3rd harmonic resonance (X3).

Each gyrotron RF output is connected to an RF conditioning unit (RFCU) whose optics is designed both for adapting the RF beam to the evacuated waveguide and for controlling the wave polarisation. The required polariser angles are calculated for the target plasma equilibrium and desired heating/current-drive scenario and then remotely set to these values using a motorised system. Each RFCU is connected to ~30 m of a 63.5 mm diameter evacuated waveguide, the reference transmission system for ITER. For the X2 gyrotrons each wave guide is connected to a low-field side launcher, which has two angular degrees of freedom. One degree of freedom has real-time steering capability with a maximum angular mirror sweep rate of 48 °/sec.

The mirror orientation can be such as to sweep either the poloidal or the toroidal injection angles during the plasma shot. The 3 wave guides from the X3 gyrotrons converge to a single top-launch mirror which has radial-position and poloidal-angle degrees of freedom. The X3 mirror angle has real-time steering capability of 20 °/sec. With the very flexible position and shape

TCV Parameters:

Plasma height:
Plasma width:
Plasma major radius:
Plasma current:
Plasma elongation:
Aspect ratio:
Toroidal magnetic field on the magnetic axis:
Additional heating (ECRH):
Transformer flux:
Loop voltage:
Plasma duration:
Vessel width:
Vessel height:
Vessel ohmic resistance:
Time constant of the vessel:



Electron Cyclotron Resonance Heating System layout control capability of the TCV poloidal field coil system, the real-time steering capabilities of the launching angles both for the X2 and X3 have proven to be essential. During a plasma discharge, the real-time steering of the RF beams primarily permits experiments to be performed that would be significantly more difficult to analyse and interpret if performed on a shot to shot basis. It also opens the door to the implementation of a feedback system for real-time control of the power deposition location and/or driven current, which are essential for ITER.

A variety of plasma heating and current drive experiments have been carried out in recent years. With the X2 gyrotrons, fully sustained non-inductive discharges are routinely achieved by replacing the inductively driven current with CO-ECCD. These discharges have been extended to the study of advanced tokamak regimes, specifically to the formation of a steady state electron internal transport barrier (e-ITB) in conjunction with a large bootstrap fraction (up to 80% of the total plasma current). The stabilisation of local MHD instabilities, such as the sawtooth instability by ECCD at the q=1 surface has also been extensively studied. The developed tools may be used to prevent long sawtooth periods, which have been shown to trigger the onset of NTMs in low beta discharges on JET, which are similar to the operating regimes planned for ITER.

max. 1.44m
max. 0.48m
0.875m
1.2 MA
max. 3
3.6
max.1.43T
max.4.5MW
3.4Vs
max.10V
max. 2 s
0.56m
1.54m
55µ Ω
6.7ms

The X3 system broadens the operational space of TCV with the possibility of heating plasmas at high density, well above the cutoff density of the X2 system ($n_e = 4.2 \times 10^{19}$ m^{-3}). In recent experiments with a target plasma density of $n_e = 4.5 \times 10^{19}$ m^{-3} and 1.35 MW of X3 injected from the top launcher, full single-pass absorption has been achieved, with the total plasma energy increasing by a factor of 2.5.

In parallel to the physics studies with the ECH system installed on TCV, within the frame of EFDA, the Association Euratom-CRPP is strongly involved in the European gyrotron development programme, which is, from its inception, focused on the development of sources having high unit power. Within this programme, the technical development by industry (gyrotrons for TCV, Tore-Supra and W7-X) aims at gaining all the necessary knowledge to build a high power Continous Wave (CW) tube. The European community is now engaged in the joint development by Associations and industry of a 2 MW, CW, coaxial cavity gyrotron at 170 GHz, its test stand (including the power supplies, series switch, transmission line, RF load) and a prototype upper launcher for the ITER EC system. Contributions to the gyrotron development come from the Euratom Associations CRPP, FZK and TEKES, with the participation of CEA, and from the industrial partner THALES Electron Device. The test stand involves a collaboration between the Euratom Associations CNR, CRPP, ENEA, and FOM while CEA, CNR, CRPP, FOM, FZK, IPP, IPF and UKAEA are collaborating on the development of the upper launcher and the modeling. These activities are preparing for high power tests to be carried out at CRPP once a suitable gyrotron is available.

General view of the gyrotron platform

More information:

FZK, Karlsruhe (Germany)
http://www.fzk.de/

TEKES, Helsinki (Finland)
http://www.tekes.fi/

CEA (France)
http://www-fusion-magnetique.cea.fr/

THALES Electron Device
http://www.thalesgroup.com/home/home/index.html

CNR, Milano (Italy)
http://www.ifp.it/

ENEA (Italy)
http://www.frascati.enea.it/

FOM, Utrecht (The Netherlands)
http://www.rijnh.nl/n0/f1234.htm

IPF, Stuttgart (Germany)
http://www.uni-stuttgart.de/ipf/index_e.html

IPP, Garching (Germany)
http://www.ipp.mpg.de

UKAEA, Culham (UK)
http://www.ukaea.org.uk

Associations

Successful test of the ITER lower hybrid launcher prototype on FTU

The Frascati Tokamak Upgrade (FTU) at the Association Euratom - ENEA in Frascati (Italy) has successfully tested a prototype of the Lower Hybrid wave launcher presently considered for ITER: the Passive-Active Multijunction (PAM). The PAM is a slow-wave structure in which the active waveguides (which transmit the RF power) are separated by passive waveguides (which transmit no power, but contribute to the launched wave spectrum) that allow enough space for the cooling system (see photo) and neutron shielding. Lower Hybrid waves could contribute significantly to the production of externally driven current in steady-state ("advanced") scenarios in ITER, so that the PAM test is crucial to test the viability of Lower Hybrid waves for such operational regimes. The FTU prototype, developed within a collaboration between ENEA and CEA, is aimed at testing the concept.

The power density achieved on the FTU experiment in almost steady state conditions has been 75 MW/m^2, close to the design value of 80 MW/m^2, and approximately 50% greater than the value required for ITER when allowance is made for the difference in RF frequencies between FTU (8 GHz) and ITER (5 GHz).

An important feature of the PAM is the good coupling capability at low density (below the cut-off value at the waveguide mouth), as will be the case in ITER. This feature has been successfully tested on FTU by coupling LH power with the PAM located close to (even

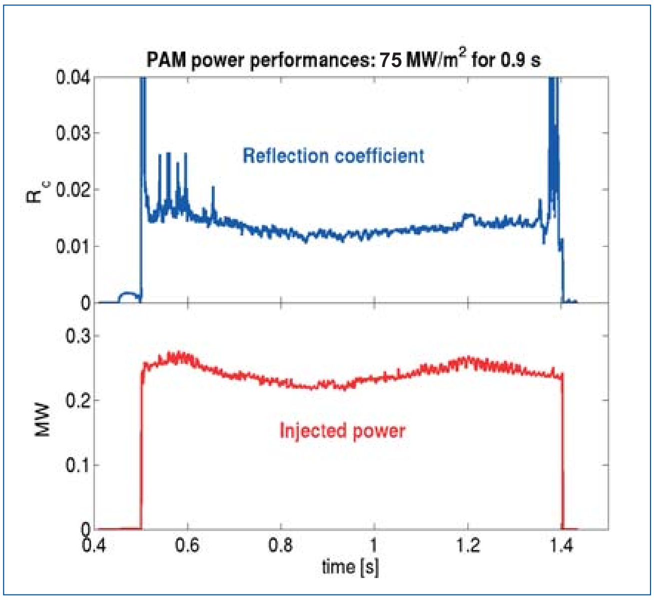


Fig.1 – Reflection coefficient and injected power in quasi steady state conditions.

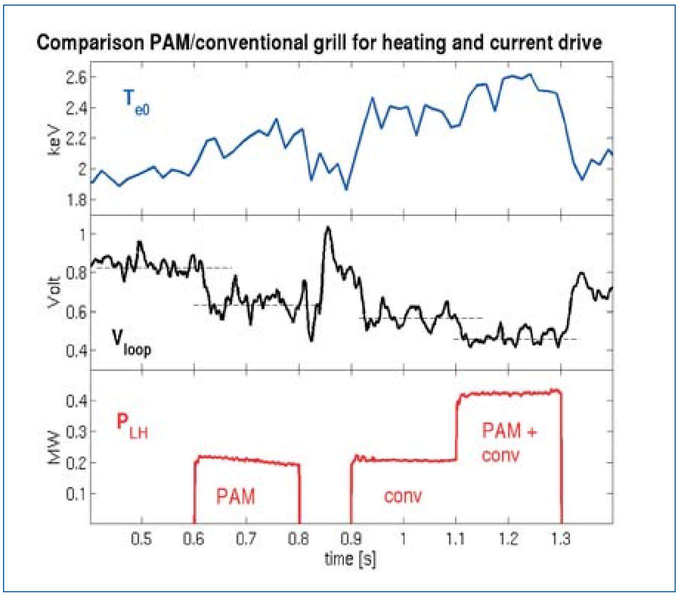


Fig.2 – Effects of the PAM power on the plasma (I_p=0.35MA, n=5 x $10^{19}m^{-3}$) compared with a conventional grill launching a similar $N_{||}$ spectrum

2 mm behind) the vacuum chamber inner surface: the reflected power in these conditions is below 1.6%, as shown in Fig. 1 for a discharge where the PAM grill was flush to the vacuum chamber wall, well behind the limiter.

Current drive effects are evidenced in Fig. 2, where a clear decrease in the loop voltage can be seen. A comparison is made between the PAM powered on its own, a conventional grill excited to launch about the same power with a quite similar spectrum of modes propagating in the plasma (as defined by their parallel refractive index, "$N_{||}$"), and with a combined PAM and conventional grill. From the dash-dotted horizontal lines indicating the average value of V_{loop} during the different phases of the discharge, it can be seen that the current drive efficiency, characterised by the decrease in loop voltage, is comparable for the PAM and a conventional launcher. A more detailed analysis using a camera which measures Bremsstrahlung radiation from fast electrons is underway.

For **more information** on FTU see:

http://www.frascati.enea.it/FTU

Energy

Workshop: What role can fusion energy play in developing countries?

The development of nuclear fusion is expected to reach new dimensions with the construction of the ITER experiment, which will be able to demonstrate the proof of principle for nuclear fusion. The question then arises as to what benefits and what kind of problems would be connected to the widespread use of nuclear fusion. Numerous studies predict that the increase in energy demand will occur mainly in countries as Asia, South America and Africa. Only technologies which can be applied in these recently emerging markets will be able to have an impact on the overall global development.

The joint IPP-EFDA-JIEE Workshop organised by **Dr. T. Hamacher** took place at the Association Euratom-IPP in Garching (Germany) on December 10th – 12th 2003 and addressed this question with particular reference to developing countries, such as India and China. On the first day invited experts from China, Korea, the US, Germany, as well as from IIASA and IEA discussed the global and regional energy scenarios and the perspective for R & D for nuclear fusion. **Prof. N. Nakićenović** presented the energy development dilemma of China and India between economically and environmentally driven scenarios. Regarding the future environmental commitments of transition countries, the presentation prepared by **Prof. R.P. Shukla** pointed out that only in the case of carbon restrictions fusion will make it into the scenarios. **Prof. Y. Huo** also referred to the massive use of coal in China. However, to avoid future environmental damage, nuclear energy – fission and fusion – is and will become a very important component in the rapidly evolving chinese energy system. **Dr. J. F. Clarke** presented nuclear pathways to a carbon-free future.

On the second day resource availability and technological capabilities were discussed. **Dr. J.-H. Han** presented the Korean fission programme and **Dr. H. Kato** showed recently elaborated scenarios on the availability of gas and oil in the world. **Dr. J. Sheffield** also focussed on world oil use as a central theme, presenting the analysis made by Greene et al. (ORNL/TM-2003/259). Other topics addressed included energy and geopolitics in Asia in the 21st century, presented by **Dr. F. Müller**, and the problem of proliferation, presented by **Dr. B. Richter.**

It was concluded that the future world energy demand, driven mainly by the need to raise standards of living across the world and constrained by climate change considerations, will require the introduction of new energy technologies on a massive scale, so that a global development effort in deploying new technologies is required. All energy sources will be required to meet the varying needs of the different countries and to enhance the security of each one against the kind of energy crisis that has occurred in the past. In fact, fusion energy is viewed as an important potential option in the latter half of this century for transitional and developing countries, including China, India and Korea – countries which are home to more than a third of the world's population.

Invited experts:

Prof. N. Nakićenović,
International Institute for Applied Systems Analysis (IIASA), Technical University, Vienna (Austria)

Prof. R.P. Shukla,
Indian Institute of Management (IIM), Ahmedabad (India) (not participating)

Prof. Y. Huo,
Zheng Zhou University, Zheng Zhou (China)

Dr. J.-H. Han,
Korea Basic Science Institute, Daejeon (Korea)

Dr. J. Sheffield,
Joint Institute for Energy and Environment (JIEE), University of Tennessee, Knoxville (USA)

Dr. H. Kato,
Energy Analyst, International Energy Agency (IEA), Paris (France)

Dr. J. F. Clarke,
Pacific Northwest National Laboratory, Richland (USA)

Dr. F. Müller,
Stiftung für Wissenschaft und Politik, Berlin (Germany)

Dr. B. Richter,
Forschungszentrum Jülich, Jülich (Germany)

The presentations and a summary of the workshop will be available by the end of February on:

http://www.efda.org

JET

Artificial diamonds for neutrons

A successful test on JET of artificial diamonds as a neutron diagnostic for ITER

The high neutron fluxes of burning plasmas will be an essential source of information to assess the performance and properties of ITER discharges. Therefore, neutron diagnostics are expected to play a key role in ITER and the possibility of testing them in advance is one of the reasons for the great emphasis placed on them during the recent JET Campaign which used trace levels of tritium in deuterium discharges. In the area of neutron counters, a significant effort is being devoted to the search for good detectors which can survive the harsh environment of a fusion device. This involves an international co-operation between EFDA parties and Russian Federation Institutes.

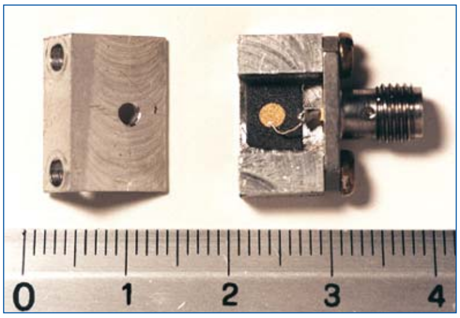


Fig. 1: Picture of the CVD diamond detector installed at JET during the Trace Tritium Experiments of 2003. Dimensions are in centimetres.

Silicon detectors provide accurate information on neutron fluxes but show severe limitations in their operational life when operating in the harsh environment present in a tokamak. This is a matter of concern for their use as 14 MeV neutron monitors in ITER, due to the expected high neutron fluences.

There are several approaches which could be alternatives to the more standard silicon technology. The large band gap energy (5.5 eV) and the high breakdown voltage (≈ 10^7 Vcm^{-1}) make diamond the most promising among the different proposed alternatives to silicon for fast and low-noise sensors. In the past, and also in the Trace Tritium Experiments (TTE) of 2003, Natural Diamond Detectors (NDD) have been used as 14 MeV neutron detectors. During these experiments Chemical Vapour Deposited (CVD) diamond detectors were also tested successfully (Figure 1 shows the diode installed on JET). A particular advantage of the CVD diamonds with respect to natural diamonds is their low cost and the possibility of producing large surfaces of variable thickness ranging from a few microns up to more than 1 mm.

For several years high quality polycrystalline CVD diamond films have been produced at the Faculty of Engineering, Rome "Tor Vergata" University. Since 1998 collaboration with Association Euratom-ENEA Frascati (Italy) has been established to study the use of CVD diamond films as fast neutron detectors. The comparison between CVD diamond and standard silicon detectors shows an excellent correlation (Figure 2).

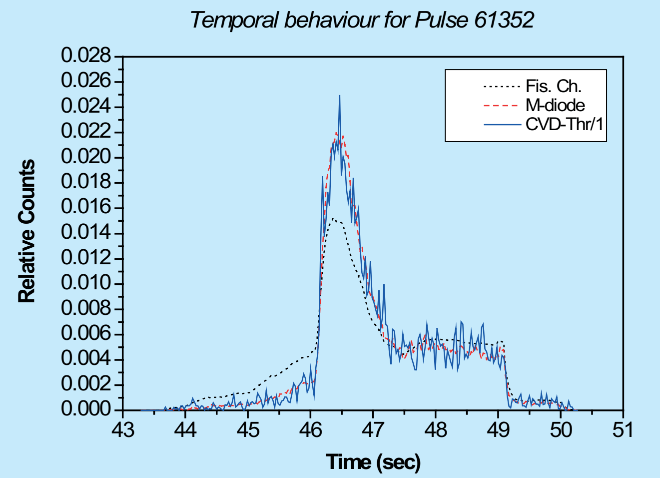


Fig. 2: Example of CVD diamond detector temporal response (blue line) compared to Fission Chamber (dashed line) and silicon detector M-diode (red line)

In the future, it is proposed to install new and more sensitive detectors to be used during the JET Experimental Campaigns of 2005 for the measurement of the total neutron flux and to provide additional information for the design of a neutron camera for ITER.

This work shows yet again that the tritium capability of JET is a key asset for progressing reactor relevant issues on the route to ITER.

For more information see our EFDA website:

http://www.efda.org
and additionally
http://www.jet.efda.org
http://www.iter.org

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

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