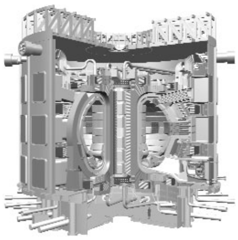

ITER ITA NEWSLETTER

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COMMON MESSAGE FROM FOURTH PREPARATORY MEETING FOR ITER DECISION MAKING

(IAEA, Vienna, 9 November 2004)

Delegations from China, the European Union, Japan, the Republic of Korea, the Russian Federation and the United States of America met at the IAEA headquarters in Vienna on 9 November 2004 to advance the ITER negotiations.

The two potential Host Parties, the European Union and Japan, presented the results of recent intensive bilateral discussions on the balance of roles and responsibilities of Host and non-Host in the joint realization of ITER in the frame of a six-Party international cooperation. These discussions will continue in the near future with the aim of aligning the two Parties' views.

All Parties were greatly encouraged by the positive atmosphere and expressed their optimism that the process was now proceeding effectively towards a fruitful conclusion among the six Parties in the near future.

TWENTIETH IAEA FUSION ENERGY CONFERENCE

1–6 November 2004, Vilamoura, Portugal

Opening Speech by Werner Burkart, Deputy Director General, IAEA

Excellencies,
Ladies and Gentlemen,
Dear Participants of the Twentieth IAEA Fusion Energy Conference:

On behalf of the Director General, Dr. ElBaradei, of the International Atomic Energy Agency, and on my own behalf, I welcome all participants to this 20th IAEA Fusion Energy Conference.

Since the beginning of its support of controlled nuclear fusion in the late 1950s, the IAEA has enhanced worldwide commitment to fusion by creating awareness of the benefits of magnetic and inertial confinement. Since 1970 leading experts from both developed and developing Member States, coming together in the IAEA International Fusion Research Council, have given guidance for the plasma physics and nuclear fusion activities of the Agency, including this conference.

I would like to thank the Government of Portugal for inviting the IAEA to hold the Fusion Energy Conference at this lovely place on the Algarve coast. This region was already once the starting point to new frontiers for seagoing Portuguese and Spanish explorers. Vasco da Gama sailed in 1499 on his discovery voyage and Prince Henry the Navigator started from Lagos, not far away from our conference site. This spirit of exploring new frontiers is driving our modern thinking and may help us to discover new treasures.

Programmes to harness the potential of nuclear fusion for electrical power production are being pursued by about fifty countries. We can welcome participants from 37 of these to this conference, which indicates their strong interest in fusion research. Fusion attracts many young scientists and I would especially like welcome the young researchers in this auditorium. The conference will serve as an open forum for young people as well as experienced scientists in the field.

Many of the papers presented here are important for the future development of fusion and will be reviewed for publishing in the Agency's journal *Nuclear Fusion*. The Programme Committee has done the first evaluation of these contributions and I would like to thank the Committee members, who invested a week of intense discussions in Vienna and many additional hours to ensure that this conference will be a scientific success.

The physics basis of controlled thermonuclear fusion has been established. The remaining scientific, technological and economic issues are now being addressed to make fusion power a viable energy option.

Within this scenario the ITER project is expected to become the most visible realization of progress in magnetic confinement. The IAEA is proud to be the facilitator, to provide the auspices for ITER activities and to offer common ground for high level ITER meetings. One major breakthrough of these meetings last year was the agreement on the financial plan for construction, operation and decommissioning. The negotiations on choosing a site for ITER have progressed but they have not yet reached a conclusion. The two candidate sites, in Rokkasho in Japan and Cadarache in France, offer excellent locations, and the ongoing discussions reflect the high scientific and economic interest in controlled nuclear fusion as a future energy option. During this conference we should focus on new perspectives and support new ideas that will be made available to all of us after a final agreement has been found. There is still hope for a final settlement before the end of this year.

- Large tokamaks are already demonstrating conditions close to the operation configuration of ITER. For example:
  - JT-60U has achieved high normalized beta and high bootstrap current fraction, and they are extending their discharge length to 65 s.
  - JET has demonstrated new diagnostics for high energy particle physics and studied particle transport in ITER-like regimes.
  - DIII-D has achieved high beta, high confinement, high bootstrap current fraction, and electron cyclotron heating control of the plasma current density profile.
- The Large Helical Device is reaching new levels of density, temperature and beta, and exploring long pulse operation.
- Alternative concepts may lead to more economical fusion power plants. For example, spherical tori are demonstrating high beta values and non-ohmic current drive. Spheromaks and field reversed configurations are exploring plasmas that tend to have natural stability in compact shapes. Magnetized target fusion may bridge the gap between magnetic confinement and inertial confinement.
- The US National Ignition Facility has produced a 10.4 kJ ultraviolet laser light in one single beam. France is building a powerful laser facility too, the Laser Mégajoule facility, and in Japan a Laser for Fast Ignition Experiment is under construction.
- Heavy ion beams, gas lasers, and diode-pumped solid state lasers are being developed to provide high average power drivers for inertial confinement fusion.
- Plasma theory and simulation are making good progress. For example, compact stellarators are being studied in simulations that specify plasma shapes, compute the required coil configurations, and predict the attainable beta and alpha particle confinement.
- On a more technical level, construction of an International Fusion Materials Irradiation Facility could provide an urgently needed source of neutrons for fusion reactor materials testing.

The Agency's aim to foster the exchange of scientific and technical information on peaceful uses of atomic energy worldwide is exemplified by this biennial conference. The first conference of this series was convened by the IAEA in Salzburg in September 1961. The number of papers submitted to the biennial IAEA Fusion Energy Conferences is escalating (1980s: 150–250, 2004: some 430). This strains the time available for oral presentations, but demonstrates the growing wealth of results that are being harvested.

The Agency recognizes the increasing need to exchange scientific knowledge by organizing many Technical Meetings on key issues of plasma physics and fusion research. Specifically the IAEA organizes coordinated research projects on major fusion topics, and encourages the training of scientists in Technical Cooperation projects.

A vital role within the approach of the IAEA to support management of scientific and nuclear knowledge is played by the Abdus Salam International Centre for Theoretical Physics (ICTP), which operates under the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the IAEA. Next year the IAEA and the ICTP will jointly organize two workshops related to plasma physics and fusion, supporting young scientists, mainly from developing countries. These workshops give young students the opportunity to expand their knowledge, to experience the excitement of analysing the physics of burning plasmas and to contribute to the worldwide work on controlled nuclear fusion.

The IAEA is proud to be a part of the worldwide fusion research effort, along with other international organizations, including the ICTP, the International Energy Agency of the Organization for Economic Cooperation and Development, the European Fusion Development Association and ITER.

We share with you a vision of a future world

– With power plants with inherently safe technology features;
– With fuel cycles that do not generate high level radioactive wastes, and do not lead to weapons proliferation;
– With abundant, inexpensive fuel readily available to all nations;
– With clean energy production and transmission;
– Where wars over fuel supplies are history;
– Where energy costs are low enough to promote a decent standard of living in all countries.

The IAEA will be pleased to continue supporting the worldwide fusion research efforts. We look forward to learning about the latest results in magnetic confinement, inertial confinement, plasma theory and simulation, fusion technology, safety and economy at this conference.

I wish you a successful and enjoyable conference, and a pleasant stay in Vilamoura and the Algarve coast.
Thank you.

FUSION ENERGY CONFERENCE 2004

by Dr. A. Louzeiro Malaquias, Physics Section, IAEA

The 20th IAEA Fusion Energy Conference was held in Vilamoura, Portugal, on 1–6 November 2005, and was hosted by the Portuguese Government through the Instituto Superior Técnico, Centro de Fusão Nuclear.

Dr. Werner Bukart, Deputy Director General of the IAEA, in his welcoming speech, remarked that nuclear fusion research was making great progress on many fronts — experiments, theory, simulation, technology and power plant studies — and emphasized the commitment of the IAEA to continuing its support to the worldwide fusion research effort.

Dr. Pedro Sampaio Nunes, Secretary of State of Science and Innovation, Portugal Host Government Representative, expressed his support for fusion research activities and for the initiative of the IAEA in organizing this international conference.

The Fusion Pioneers Memorial Session started with a homage to the pioneers of fusion research who have passed away in the past two years. Professor Kaw, the Chairman of the session, recalled the contributions of the following pioneers: Anders Bondeson (Sweden), Kaes Braams (Netherlands), R.S. Pease (UK), René Pellat (France), Derek Robinson (UK), Marshall Rosenbluth (USA), Kazuo Takayama (Japan) and Masahiro Wakatani (Japan).

Prof. Matos Ferreira (President of the Instituto Superior Tecnico, Portugal) emphasized the need for alternative sources of energy, in particular fusion, to respond to the energy demand of future generations and to the need for lowering the levels of CO_2 in the atmosphere.

Prof. Sir Chris Llewellyn Smith (Director of Culham Laboratory, UKAEA, UK) emphasized the importance of looking to a fast track option for the construction of the first commercial fusion power station. He defended the view that ITER and IFMIF should be built together to best use the synergy between burning plasma science and technology research and fusion power plant materials research. In parallel, research on alternative concepts such as the stellarator and spherical tokamaks should be pursued and serve to support physics on the larger projects.

To round out the session, Dr Shimomura gave an update on ITER. The ITER Transitional Arrangements were being implemented at the project technical level to facilitate progress once the negotiations are successfully completed. He emphasized that, for a successful project, further careful consideration and preparation were required, especially with respect to the project organization, staffing and procurement system, and the relationship between the ITER International Organization, Domestic Agencies and suppliers, and considered that the agreement should leave enough flexibility for the future Director General. He foresaw that, although negotiations on siting ITER were currently deadlocked, with the recognition that hosting the complementary activities of the Broader Approach were as essential as hosting the ITER facility, consensus could be achieved by the end of 2004, leading in his view to a delay of only 1 year in achieving first plasma (which would become 2015).

The Fusion Pioneers Memorial Session was followed by topical sessions of theory and experimental presentations, along with poster sessions also dealing with more detailed aspects. The topics covered were:

- Magnetic Confinement Experiments
- Magnetic Confinement Theory and Modelling
- ITER Activities
- Inertial Fusion Experiments and Theory
- Innovative Confinement Concepts
- Fusion Technology and Power Plant Design
- Safety, Environmental and Economic Aspects of Fusion.

Five summaries were presented on the various topics, and the main conclusions are given below.

Experiments in Confinement and Plasma-Wall Interaction, and Innovative Confinement Concepts (H. Ninomiya)

Significant progress has been made since the 19th IAEA Fusion Energy Conference in the following areas:

- Long pulse operation with high beta and high bootstrap fraction much longer than the current diffusion time;
- Extension of parameter regimes for the ITER baseline scenario and for steady state/hybrid scenarios and their sustainability;
- Understanding of global confinement and transport physics, especially non-dimensional scaling, zonal flow and particle transport;
- Material and retention/migration studies.

Discharge scenario optimization and its extrapolation towards ITER have progressed remarkably, by which the feasibility of ITER reaching the baseline target performance has been confirmed. Results of β scan and particle transport could lead to higher fusion power in ITER.

Efforts to reach a common understanding of the physics of toroidal plasmas across the magnetic configurations have been made and many interesting results have been obtained. These results will greatly contribute to ITER and the ultimate goal of fusion power.

Stability, Energetic Particles, Waves and Current Drive (R.D. Stambaugh)

In resistive wall mode physics, there was much progress in fundamental understanding and with direct feedback with low rotation. For neoclassical tearing modes, ECCD suppression by replacing the missing bootstrap current in the island is becoming a common application.

The technique of massive gas injection has been shown to mitigate all important consequences of disruptions, but work remains to be done to understand how the gas jets may penetrate into larger, higher magnetic field plasmas. For edge localized modes (ELMs) the peeling–ballooning model is converging and many avenues of approach to tolerable edge localized modes (including no ELMs) in ITER are being pursued. Studies of beta limits in stellarators are beginning. In Alfvén mode physics, internal plasma diagnostics show these modes are more pervasive than was thought.

In wave–plasma interactions, synergy between waves can increase current drive efficiency.

Finally, we are beginning to see challenges for the future in long pulse, transformerless operation.

Magnetic Confinement Theory (J.W. Connor)

The key questions addressed were:

– **Confinement**: confinement time scalings with plasma parameters and the conditions for improved confinement, e.g. transport barriers;
– **Stability**: the constraints on plasma current, density and pressure arising from macroscopic stability; the effects associated with fast particle populations such as alpha particles; and the consequences of loss of control of these instabilities;
– **Plasma exhaust**: acceptable heat loads associated with the steady flow of plasma to divertor target plates; seeking regimes with tolerable edge localized modes (ELMs), i.e. mitigating the transient heat loads without confinement degradation;
– **Steady operation**: integrating solutions to the above questions as well as developing efficient means of non-inductive current drive.

A number of themes, or trends, are springing from the growing use of numerical approaches to plasma theory. These are: (i) the use of direct numerical simulations to calculate and provide insights into turbulent transport (indeed there were some 30 papers with contributions on this topic), although analytic modelling plays a role in interpreting these 'numerical experiments'; (ii) increasing realism in modelling of geometry and physics in areas such as macroscopic MHD phenomena and radiofrequency heating and current drive, both of which involve modelling of fast-particle distributions; and (iii) a growing emphasis on integrated modelling, bringing together modules that describe interacting aspects of plasma behaviour.

Considerable progress has been made since the previous Fusion Energy Conference in 2002. Increases in computing power, allied to a growing basic understanding of the underlying physics, are paving the way for the realistic and soundly based calculations of confinement, stability, exhaust and current drive needed for ITER and the successful optimization and development of fusion power plants.

Inertial Confinement Fusion (M.M. Basko)

The laser fusion programme, based on the conventional ignition mode, advances steadily towards demonstration of ignition and high gain experiments (NIF and LMJ facilities). Remarkable progress in the confidence level and performance margin has been achieved recently. The concept of fast ignition is being explored both theoretically and experimentally. Wire array Z pinch is becoming a competitive option for achieving ignition in ICF and as a driver option for IFE.

Highlights presented at the conference included:

– New fuel capsule design based on a Be shell doped with Cu.

– Polar direct drive expected to contribute to gains G = 10.
– Fast ignition based on cone guided cold gas preimplosion followed by a fast ignition pulse. Fast ignition of precompressed cold DT could also be initiated by a high velocity impact of a separated DT shell.
– Transverse beam compression using plasma neutralization of space charge to reduce beam focal spot size by a factor of ~10.
– Numerical simulations indicating that with a longitudinal beam, compression factors of >100 might be possible.
– Direct drive using a cylindrical target expected to have energy gains G = 100. Some experimental evidence is required on achieving the different phases of ignition and burn front propagation in the fuel cylinder.

Progress was reported on multiwire Z pinches: up to 1.8 MJ and 230 TW in thermal X rays. Progress had also been made on mechanisms for recycling of the target (RTL line) at a relatively low repetition rate of 1 shot of ~3 GJ yield per 10 seconds and on increasing the efficiency of the compression (double shell targets).

Fusion Technology and Power Plant Design, ITER, and Safety, Environment and Economics (Y. Wan)

With respect to socioeconomic, safety and environmental aspects, fusion looks capable of offering attractive advantages. The cost of fusion electricity is likely to be comparable with that from other environmentally responsible sources of electricity generation. Through ITER, an economically acceptable first generation fusion power plant can be better accessed. Fusion could capture 20% of the electricity market by the end of this century, or earlier, if fast track development is adopted.

With respect to the ITER physics basis, progress was reported in that H mode confinement can now be obtained at densities exceeding the Greenwald density by increasing the triangularity and by using pellet injection or impurity gas puffing. A number of plasma parameters achieved in experimental advanced tokamak regimes (not simultaneously) are similar to, or above, the minimum values required for ITER steady state Q > 5 operation through stabilization of the resistive wall mode by feedback control, assisted by plasma rotation with reduced error field. Tailoring the current profile can improve confinement over the standard ELMy H mode and allow an increase in beta up to the no-wall limit at safety factors of ~4. Consequently, hybrid operation could provide an attractive scheme for high Q (>10), long pulse (>1000 s) operation with benign ELMs. Neoclassical tearing mode suppression by localized EC current drive has been successfully demonstrated in experiments which extrapolate to ITER. Analysis of disruption scenarios has confirmed the robustness of the ITER design against disruption forces with plasma currents of up to 15 MA. Disruption prediction and mitigation techniques have been proposed.

With respect to the technology developments that can support ITER construction and operation, most R&D activities have been completed, the design of the superconducting magnet system has been improved and optimized, and the detailed engineering design of the vessel and in-vessel components is almost completed and ready for fabrication.

The ITER safety case has been under development in collaboration with an international team of safety experts for over a decade. For the past five years, discussions have been taking place with the actual regulators who would be in charge of licensing ITER for their country. These initial steps towards licensing ITER have allowed refinement of the safety case and provide confidence that the design and safety approach will be licensable.

Regarding fusion technology, progress was reported in areas such as superconducting coils, heating and current drive, RF launchers and negative ion beams, divertor and blanket materials, and the construction of large national fusion devices: SST-1 in India, EAST in China, KSTAR in the Republic of Korea and Wendelstein 7-X in Germany.

Statistical Overview of the Conference

There were 604 participants, from 33 countries and three international organizations. There were 437 contributed papers, 134 of which were given orally. These papers are made available by the IAEA on its Internet site, and more than 230 of the papers were also submitted for publication in the IAEA's journal *Nuclear Fusion.* In addition to the conference itself, there were 28 satellite meetings and various exhibitions (Fusion Expo, ITER, EFDA-Cadarache, Consortio RFX, IST, CRPP, FZK, EPFL, IAEA).

The 21st IAEA Fusion Energy Conference will be held in Chengdu, People's Republic of China, on 16 – 22 October 2006.

Preprints are available from
http://www-pub.iaea.org/MTCD/Meetings/Announcements.asp?ConfID=116
Presentations are available from http://www.cfn.ist.utl.pt/20IAEAConf/Announcement.htm
Proceedings are in preparation and will be made available on a CD that can be accessed from the Internet.

R.S. "BAS" PEASE †

R.S. "Bas" Pease, who until his retirement had been Director of UKAEA Culham for 20 years, died aged 81 on 17 October 2004 after a short illness. After obtaining a wartime Honours Degree in Physics at Trinity College, Cambridge, he joined AERE Harwell in 1947, specializing in solid state physics and producing some of the classic work on radiation damage and neutron diffraction.

In 1955 he began his long career in fusion research and became leader of the ZETA Team, coming into the public eye in 1958 when worldwide coverage was given to the results obtained on this machine.

In 1964 he moved to the newly built Culham Laboratory and became its Director in 1968. He played a leading role in worldwide collaboration in fusion research, playing a key role in both bringing JET to Culham and in the early planning of the next international device, INTOR — later to become ITER.

Following his retirement in 1987 he took on an active role in Pugwash, an international organization of influential scholars and public figures concerned to bring scientific insight and reason to bear on threats to human security arising from science and technology in general.

Among his many awards and honours, he was President of the Institute of Physics from 1978 to 1980 and was elected a Fellow of the Royal Society in 1977 for "his distinguished contributions to the experimental study of behaviour of dense plasmas in strong magnetic fields with particular reference to nuclear fusion".

Items to be considered for inclusion in the ITER ITA Newsletter should be submitted to C. Basaldella, ITER Office, IAEA, Wagramer Strasse 5, P.O. Box 100, A-1400 Vienna, Austria, or Facsimile: +43 1 2633832, or e-mail: c.basaldella@iaea.org (phone +43 1 260026392).

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