IEA Implementing Agreement on Cooperation on Large Tokamak Facilities

End-of-Term Report for a period of 2001-2005 to be presented at 34th FPCC Meeting on 1-2 February 2005

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Introduction

The current 5-year term of the IEA Implementing Agreement on "Co-operation on the Large Tokamak Facilities" began on Jan 15, 2001 as an extension of the IEA Implementing Agreement on Cooperation among the three Large Tokamak Facilities (JET, JT-60U and TFTR)" initiated on February 19, 1986. The current IA reflects the major changes in the programs of the three Parties, which include the shutdown of TFTR in the U.S. in 1997, and the transfer of legal representation of JET from the JET Joint Undertaking to the European Fusion Energy Development Agreement (EFDA) on January 1, 2000.

The management of the JET scientific program by EFDA (European Fusion Development Agreement) in the EU has provided opportunities for all EURATOM Associations participating in EFDA to contribute to the scientific activities of this IA.

The management of the JT-60 scientific program by JAERI has provided opportunities for contracting researchers in Japanese Universities, NIFS and fusion related research institutes to contribute to the scientific activities of this IA.

The management of the large tokamak fusion science program by the USDOE has provided opportunities for all US institutes and universities funded by the Office of Fusion Energy Sciences of the USDOE. The US large tokamak fusion science, of course, consists of participation in JET and JT-60 research activities, contributions from US national devices such as DIII-D, C-Mod, and NSTX, and theory and modeling activities.

Furthermore, this IA has led the international tokamak community in implementing the High Priority Research Tasks identified by the International Tokamak Physics Activity (ITPA). Thus, the scientific content of the activities of this IA has been enriched by the broader participation of tokamak programs in the activities of this IA while still serving the original goal of cooperation among the large tokamaks and making major contributions to the ITER Physics needs.

1. Objectives, Scope and Strategy of Large Tokamak Agreement

The world fusion research is preparing to enter a new phase in the development of fusion devices: the construction of ITER, planned to last for 10 years, which will be followed by an operation phase where a controlled DT burn with Q=10 or more, and feasibility of steady state operation will be investigated. During the ITER construction phase, the confirmation and extension of ITER operating scenarios and their implementation in the ITER program become key research elements of existing tokamaks such as JET and JT-60. The importance of such supporting program has also been stressed during ITER negotiation process. This IA could be one of main vehicles for such cooperation, and could also contribute to the development of the tokamak line for the generation of devices following ITER through tokamak concept improvement.

Objectives:

The objective of this Agreement is to enhance the effectiveness and productivity of the research and development effort related to the development of the tokamak fusion concept by strengthening cooperation on the Large Tokamak Facilities, and thus to provide a scientific and technological basis for the further development of the tokamak concept.

Scope:

The collaborations include personnel exchanges for participation in experiments, data analysis, and program planning; joint workshops; and hardware exchanges such as diagnostics and heating systems. The topical areas cover all the major fusion science issues such as transport, stability, edge physics, Tritium, etc. Some of these collaborations involve technology matters such as Tritium handling, developments of Negative Neutral Beam Injection (N-NBI) and Radiofrequency (RF) heating system, and plasma facing components that are coordinated with other IEA fusion technology IAs.

Value:

Both JET and JT-60 provide the opportunity to conduct experiments in large sized plasmas with long pulses and high powers while US large tokamak fusion science concentrates on providing integrated research and knowledge basis with flexible experimental tools, extensive diagnostics systems and theory and modeling tools.

Strategy:

This cooperation is a long standing IA for demonstrating and improving tokamak confinement configuration through large tokamak experiments since 1986. The period of this cooperation could be categorized into three phases, as follows,

Phase I : 1986 - 1995 : Cooperation to achieve mission of Large Tokamaks

In this phase, cooperation was focused on achieving the mission of large tokamaks such as equivalent break-even or significant fusion power. The areas of cooperation were equilibrium control, confinement improvement, transport, stability, plasma heating, and wall conditioning in physics area, and tokamak device studies, diagnostics, heating systems, and power and control systems in technology area.

Phase II: 1994–2005: Cooperation to provide database for ITER construction and concept development of AT

The areas of cooperation in this phase were DT operation, energetic particle driven instability (Alfven Eigen mode), Helium ash exhaust, edge and internal transport barriers, characterization and mitigation of disruptions and tritium plant operation, waste management in fusion devices, performance extension of plasma heating system, etc.

Phase III: 2005~ : Cooperation to extend ITER operation scenarios and further development of AT

Before the start of ITER operation, large tokamaks will continue to be a key driving force to advance tokamak physics and tokamak concept with strong cooperation of other IAs. During this term, confirmation and extension of ITER operation scenarios and also further development of AT will be pursued through this cooperation.

During Phase II, we understood the importance of multi-machine joint experiments not only between JT-60 and JET, but also with other tokamaks for the contribution to ITER. Therefore, we started coordination with other IAs for planning and implementation of joint experiments for ITER from 2002. Next term, we will optimize our contribution to ITER by strengthening such coordination with other bodies. Also we will jointly plan and implement various tools to large tokamak facilities to maximize productivity of large tokamaks.

The strategy is to enhance close cooperation and coordination of research among these different programs, including experiments, theory, and advanced computing, in order to provide valuable insights on the complex and non-linear coupling among the different scientific issues, integration to achieve high beta and high performance plasmas in steady-state conditions, and to extrapolate them to burning plasmas in ITER. The Parties in this IA value such collaboration not only within the large tokamaks, but also with the broader international tokamak community and ITPA to accelerate the progress in tokamak research.

2. Participants of Large Tokamak Agreement

The participants of this agreement are EUROPEAN ATOMIC ENERGY COMMUNITY (EURATOM), JAPAN ATOMIC ENERGY RESEARCH INSTITUTE (JAERI) and UNITED STATES DEPARTMENT OF ENERGY (USDOE). The member countries of EURATOM have expanded from 15 countries (Germany, France, United Kingdom, Italy, Spain, Portugal, Belgian, Netherlands, Luxembourg, Ireland, Denmark, Greece, Austria, Finland, Sweden) to 25 countries (Poland, Hungary, Czech, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Cyprus, Malta are included).

Participating institutes to this cooperation are all EURATOM Associations under EFDA, JAERI and its contractors for JAERI, and all US institutes and universities funded by the Office of Fusion Energy Sciences of the USDOE. The EURATOM associations participating in the EFDA are EURATOM-Belgian State (Belgiun), EURATON-CEA (France), EURATOM-CIEMAT (Spain), EURATOM-Conf. Suisse (Switzerland), EURATOM-DCU (Ireland), EURATOM-ENEA (Italy), EURATOM-FOM (Netherlands), EURATOM-FZJ (Germany), EURATOM-FZK (Germany), EURATOM-Greece (Greece), EURATOM-VR (Sweden), EURATOM-UKAEA (United Kingdom), EURATOM-TEKES (Finland), EURATOM-RISO(Denmark), EURATOM-OAW (Austria), EURATOM-MEC (Romania), EURATOM-Latvia (Latvia), EURATOM-IST (Portugal), EURATOM-IPP.CR (Czech), EURATOM-IPP (Germany), EURATOM-HAS (Hungary) as shown in Fig.1.

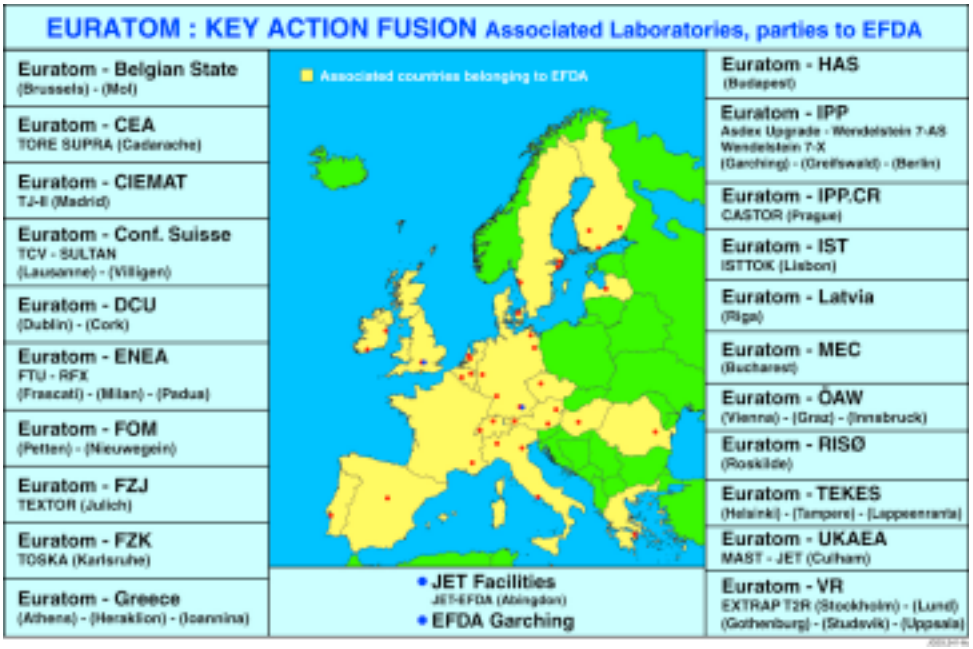

Fig. 1 European institutes participating European Fusion Development Agreement

Participation of researchers in Japanese University, NIFS and fusion related research institutes to JT-60 research becomes possible under the Facility Utilization Program of JAERI since 1999. Number of collaborators increased significantly, year by year as shown in Fig.2.

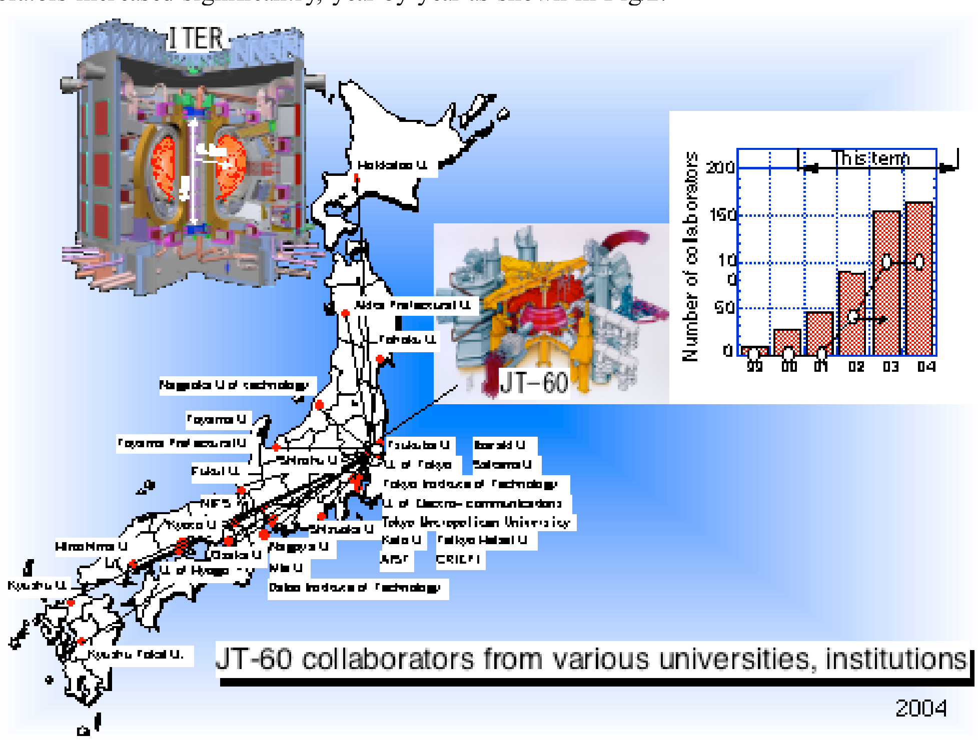

Fig. 2 JT-60 collaborators from various universities, NIFS and institutions.

The US fusion energy science program led by USDOE covers broad range of fusion research activities including tokamak research. The following US laboratories, industry and universities are the primary collaborators in this collaboration: PPPL, GA, MIT, ORNL, LLNL, Columbia University, Lehigh University, University of Wisconsin. Most of these collaborate through the DIII-D, Alcator C-MOD, and NSTX programs.

Fig. 3 All the Office of Fusion Energy Science Program participants in the United States

3. Work Program and Nature of Work

Contracting parties, EURATOM, JAERI and USDOE, have carried out the following items under this Large Tokamak Agreement since January of 2001, following the previous "Implementing agreement on co-operation among the three large tokamak facilities" and its greatly valued activities.

The first item to be carried out was the exchange of information between the Contracting Parties in the areas of:

(*i*) Experimental program plans for the Large Tokamak Facilities;

(*ii*) Design and planning of experiments on the Large Tokamaks to contribute to the data base for the next-generation Tokamak devices;

(*iii*) Experimental, theoretical and technical studies in: (*a*) Plasma equilibrium and stability; (*b*) Energy and particle transport; (*c*) Plasma heating; (*d*) Plasma-wall interaction; (*e*) Deuterium-tritium burning; *(f)* Plasma current drive; *(g)* Plasma fueling; *(h)* Plasma diagnostics; *(i)* Other areas as mutually agreed;

(iv) Management and operation of facilities related to:*(a)* Operating procedures; *(b)* Maintenance procedures; *(c)* Safety rules; *(d)* Inventory control; *(e)* Documentation procedures; *(f)* Control and management of operating records; *(g)* Computer control systems; *(h)* Other areas as mutually agreed;

The second item carried out was the assignment of scientists, engineers and other technical experts to work at the facilities of the other Contracting Parties in the areas of tokamak physics, systems engineering and project management, in accordance with agreements between the assigning Contracting Party and the Contracting Party which is responsible for the hosting facility;

The third item was the organization of selected workshops in the areas referred to in the first item above.

To carry out these items efficiently, the activities under this agreement have been performed under the good communication with International Tokamak Physics Activity, ITPA, Topical Groups since May 2002.

4. Coordination with other Bodies

Coordination with other bodies has increased significantly during the past three years of this IA, which includes other tokamak related IEA IA's (Poloidal Divertor and TEXTOR), technology related IAs (Environment & Safety), International Tokamak Physics Activity (ITPA) and other international tokamak programs in Russia and China through several appropriate bilateral agreements.

Coordination with ITPA involves mainly the planning and implementation of joint experiments on multiple machines with prescribed parameter ranges and conditions in order to investigate a specific physics issue that would benefit from comparative results. Where possible, several participants from different tokamaks conduct these experiments on different facilities and analyze them together to develop a coherent investigation of issues. These joint experiments are recommended by different Topical Physics Groups of the ITPA and they address High priority research for ITER. Thus, this activity adds much value to the collective results from different programs and advances the physics basis of ITER. The results from these joint experiments are discussed at the ITPA Topical Group meetings and presented at various international meetings and conferences.

This coordination with ITPA was initiated by the IEA Large Tokamak Executive Committee at its annual meeting in June 2002. The first planning meeting for this ITPA/IEA Coordination was held at MIT in November 2002, the second at Naka in November 2003 and the third meeting took place near Oxford in December 2004. While the first planning meeting was conducted by the IEA LT IA, the subsequent meetings were organized jointly by the three IEA Tokamak IAs, and included participants also from China and Russia collaborating in the framework of several bilateral agreements.

The various IEA implementing agreements, including this Large Tokamak Agreement are the implementing vehicle for these joint experiments. The ITPA structure is used to plan and report these experiments to the various IEA implementing agreements. The ITPA CC chair makes a summary proposal of joint experiments at the meeting of the IEA implementing agreements and the leaders of experimental programs there at the meeting make commitments of necessary resources to carry out the experiments.

5. Information Dissemination

5.1 Dissemination of activities

The most important activity of this cooperation is a publication of the papers to document progress of the research. Participants of this activity are encouraged to acknowledge this IA. Also, an IEA LT Web site has been started to provide information about the activities.

5.2 Increased visibility through IEA LT Web site

At the request of FPCC meeting on 30 January 2003, Executive Committee of IEA Large Tokamak cooperation decided to develop a Homepage of IEA large tokamak implementing agreement to increase our visibility to the public.

Homepage address is http://www-jt60.naka.jaeri.go.jp/lt/. This homepage with IEA LOGO consists of a free access section and an internal use section. In the free access section, the history, annual reports, Executive Committee members, task structure, etc. are available to the public. Access to "Internal use only" containing ExCo materials, workshop materials, and personal assignments is restricted to Ex-Co members. Top page of the Homepage is shown below.

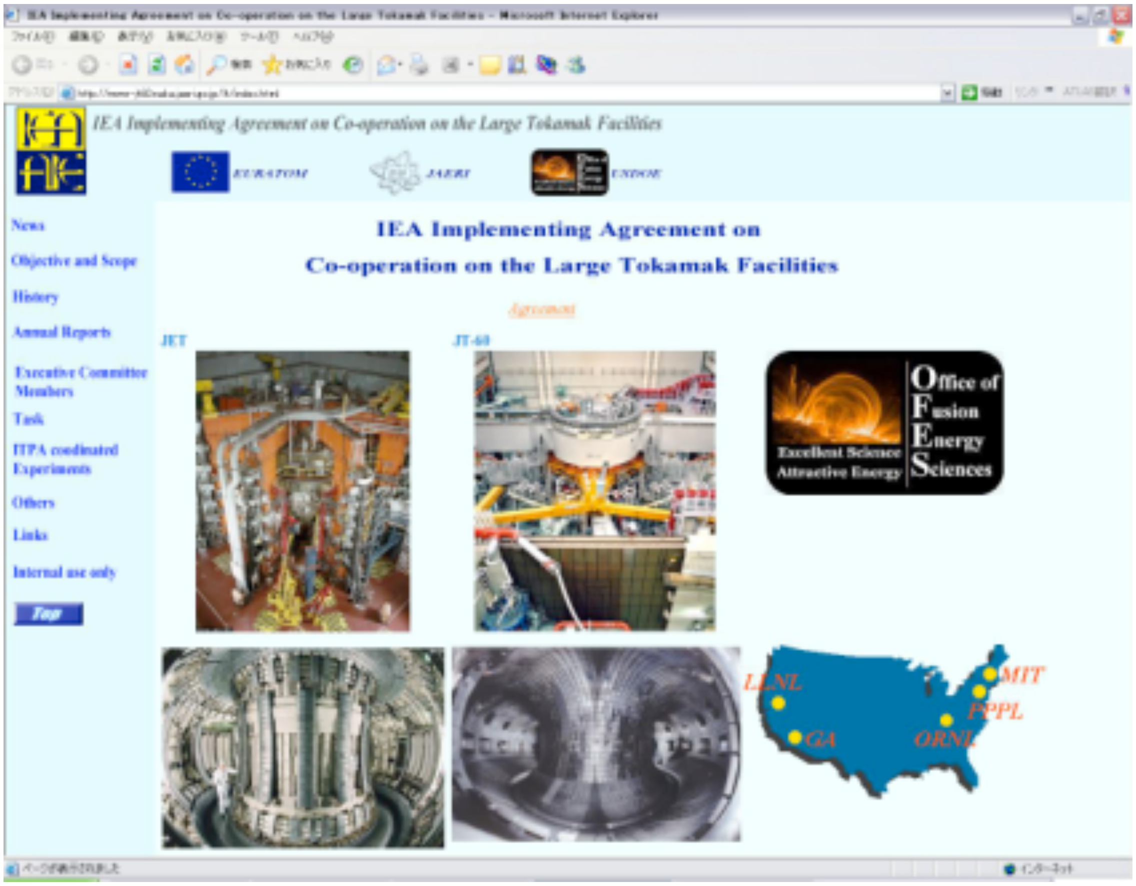

Fig. 4 Top page of IEA LT Homepage

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6. Activities of this agreement

6.1 Executive Committee Meeting

The Executive Committee (ExCo) met on

- May 31st – June 1st, 2001, Naka(JAERI), Japan, for its annual meeting,

  • Chair changed from Dr. J. Pamela (EU) to Dr. H. Ninomiya (JAERI)

  • It was announced that Dr. N. Sauthoff would replace Dr. K. Young as a member, and Dr. R. Stambaugh became a new alternate member.

  • EU party reported that JET had started its operation under the framework of EFDA successfully.

  • the 7 existing task areas(1. Research on High- P and Related Modes of Operation; 2. Disruption Studies; 3. Divertor Plate Technology; 4. Neutral Beam Current Drive Research; 5. Impurity Content of Radiative Discharges; 6. Scaling of access to ITB plasmas; 7. Remote Participation in Experiments) were reconstructed to 5 task areas (1.Transport/Confinement Studies; 2.Tokamak Macroscopic Stability; 3.Divertor and Plasma Boundary Studies; 4.Fast Particle and Current Drive Studies; 5.Tritium and Remote-Handling Technologies).

- June 6th-7th, 2002, Princeton(PPPL), U.S., for its annual meeting

  • Chair changed from Dr. H. Ninomiya (JAERI) to Dr. E. Oktay (U.S.)

  • It was announced that Dr. Y. Miura took the place of Dr. R. Yoshino as an alternate member.

  • There was a discussion of the International Tokamak Physics Activity (ITPA) high priority R&D topics and their relation ship to the IEA Large Tokamak activities.The committee recognized that this IA could promote the implementation of the research topics identified by the ITPA. The interaction between ITPA and this IA was proposed.

- June 4th-5th, 2003, Culham(EFDA-JET), U.K., for its annual meeting

  • Chair changed from Dr. E. Oktay (U.S.) to Dr. J. Pamela (EU)

  • It was announced that Dr. Y. Miura would take the place of Dr. H. Ninomiya as member, and Dr. S. Ishida and Mr. M. Cox became new alternate members. Mr. M. Cox took the place of Dr. D. Robinson.

  • The updated list of the ITPA/IEA LT IA coordinated experiments was introduced by Dr. D. Campbell, chair of ITPA-CC, and the status of ongoing and also planned experiments in JT-60, JET and DIII-D was presented. The committee reviewed the status and progress of coordinated experiments and also plans for next year implementation. Discussion was made on the function and usefulness of Spokespersons for each coordinated experiment from the managerial point of view and with respect to each individual device. The Committee would press ITPA to nominate these spokespersons. It was recognized that a feedback from the ITPA about the scientific outcome from implemented experiments is very useful to the Committee to monitor the execution of the agreed program and decide the extension of existing proposals and implementation of new proposals.

  • At the IEA FPCC meeting in 30th January 2003, it was decided to request IEA fusion IAs that "they should be reconsidered in order to improve 1) Co-ordination and internal coherence between IEA IAs, the FPCC, the CERT, and the international fusion R&D programme, and 2) Visibility of the FPCC and fusion IAs inside and outside the IEA, and communication to the public and policy makers".

  In response to the above request, the Committee decided to streamline and enhance the coordination of activities within the IEA LT IA as well as across IEA IAs and ITPA. The committee also discussed how to increase IEA fusion activities visibility, for example, by means of creating original web pages. (The web page was created as http://www-jt60.naka.jaeri.go.jp/lt/) A number of decisions were made along these two lines that will be implemented in the frame of this IA. Information about these decisions and proposals for wider implementation of these policies would be sent in a letter to chair and secretariat of IEA FPCC, chairs of IAs for the poloidal divertor experiments and the plasma wall interactions in TEXTOR, and also to chairs of other related IEA IAs, within about 3 weeks after the ExCom meeting. (As a result of interaction among those three IEA IAs, a letter was jointly sent from chairs of the three IAs to IEA FPCC dated 30th July 2003.)

• the 5 existing task areas (1.Transport/Confinement Studies; 2.Tokamak Macroscopic Stability; 3.Divertor and Plasma Boundary Studies; 4.Fast Particle and Current Drive Studies; 5.Tritium and Remote-Handling Technologies) were expanded to 7 task areas (1. Transport and ITB Physics; 2. Confinement database and modeling; 3. MHD, disruptions and control; 4. Edge and pedestal physics; 5. SOL and divertor physics; 6. Energetic Particles, Steady State Operation; 7. Tritium and RH Technologies) in order to be aligned with task areas (Topical groups) under ITPA.

- June 14th – 15th, 2004, Naka(JAERI), Japan, for its annual meeting,

• Chair changed from Dr. J. Pamela (EU) to Dr. M. Kikuchi (JAERI)

• It was announced that Dr. K. Ushigusa and Dr. S. Ishida left alternative members, and Dr. Y. Kamada and Dr. T. Fujita became new alternate members. The Committee noted that Dr. Shinohara had replaced Dr. Kawano as the secretariat.

• Task 8 "Others": A new task was added to the existing seven. This task includes diagnostics, and technical issues such as neutral beam technologies.

• The Committee recognized the importance of this IA again, and started the extension procedure for the Implementing Agreement.

6.2 Tasks

In the past three years, coordination with International Tokamak Physics Activity (ITPA) has increased significantly and multi-machine experiments with prescribed parameters (e.g. non-dimensional parameters) have become a significant tool to investigate tokamak physics. Therefore, the number of tasks was increased from five to seven in 2003. Six tasks were named as the corresponding ITPA tasks. In 2004, one task named 'Others' was added. Then there are eight tasks now: (1) Transport Physics, (2) Confinement Database and Modelling, (3) MHD, Disruption and Control, (4) Edge and Pedestal Physics, (5) SOL and Divertor Physics, (6) Energetic Particles, Steady State Operation, (7) Tritium and Remote-Handling Technologies and (8) Others. In this task report, since most of the collaboration works in the five tasks from 2001 to 2002 were put into the present tasks, work summarized according to the present eight tasks.

(1) Transport Physics

International collaborative experiments coordinated through IEA IAs have made significant progress and expanded multi-machine data sets for further analysis on transport properties.

- For improved physics understanding of QDB/QH-mode operation that was observed first in DIII-D, a long ELM free phase with edge harmonic oscillations (EHO) was produced in ASDEX-Upgrade and some indications were observed in JET (with US participation). Analysis of previous JT-60U data has revealed strong evidence for QH-mode like behavior as co/counter-beam balance is varied and this behavior was reproduced in 2003 experiments with detailed measurements on magnetic fluctuations and pedestal structures in collaboration with US scientists.
- For development of hybrid scenario demonstration discharges, which have a flat q profile with q_{min}>~1, experiments were performed in JET and JT-60U in collaboration with DIII-D and ASDEX Upgrade. In JET, β_N=2.4-2.5 and H_{89}=2.1 were obtained at 2 MA (q_{95}=3.9). In JT-60U, β_N =3 was maintained for 6 s and β_N =2.1 for 20 s, both at 1 MA (q_{95}=2.2-3.3).
- Internal Transport Barrier (ITB) comparison experiments have been made in JET and ASDEX Upgrade with similar plasma shape, q_{95}, and target ρ^*, ν^* and β. NB heating in current ramp was employed to form low magnetic shear with q(0)>1. Similar ITB dynamics in two machines was observed; ion ITBs without electron ITBs and ITB termination by giant ELMs.
- For development of steady-state scenario demonstration discharges, which have a large fraction of bootstrap current (>50%), nearly full non-inductive current drive plasma was maintained in JET by the real time control of the gradient of ion temperature, and a bootstrap current fraction of 75% was successfully maintained for 7.4 s in a JT-60U strong reversed shear plasma, while

full non-inductive current drive operation at β_N >3 and HH_{y2}=1.6 was achieved in DIII-D.

- For high performance operation with T_e~T_i, experiments aiming at hybrid scenario discharges with dominant RF heating were performed in JET, resulting in T_e>T_i, moderate β_N ~1.5 and very low ELM activity.

There were many collaboration works outside ITPA coordinated international collaborative experiments.

- Important work on the analysis of access to ITBs and on new techniques to produce ITBs and high density plasmas at high triangularity. Significant activity from US collaborators has focused on analysis of these discharges using TRANSP, the NCLASS, and FULL codes. For JET, a model was developed to include the neoclassical poloidal rotation calculated by NCLASS and the bulk toroidal rotation velocity calculated by JETTO in the ExB shear damping of turbulence. It was found that the rotational shear damping is fairly weak in typical JET ITB plasmas, an observation that is similar to that found on JT-60U. A number of US and Japanese collaborators also participated in working out the ExB shearing rate and turbulence linear growth rate for a range of JT-60U ITB plasmas.
- The full-wave analysis of correlation reflectometry was done for ITBs in JT-60U data. The results were presented by a scientist of PPPL in the APS meeting and a paper was submitted to Science.
- Confinement and transport issues were also investigated on JET via pellet fueling experiments for H-mode plasmas as a reactor relevant demonstration.
- The newly found equilibrium of current hole at the extreme condition of reversed shear plasma has been studied in JT-60U and JET extensively.

There were some diagnostic collaborations for transport and confinement issues.

- A high resolution spectrometer for measuring spectra from pellet light emission was installed on JET with the assistance of the US collaborator and used to collect initial data from centrifuge accelerated pellets injected at speeds of 150 m/s.
- Two US collaborators have begun the design of a new diagnostic for Helium Ash Detection in DT plasmas that will be available for JET-EP.
- The US collaborator for the Motional Stark Effect diagnostic on JET worked with EU scientists to plan a trace tritium experiment designed to observe energetic ion confinement in discharges with zero core current density.
- The US collaborator visited JET to finalize the design of the CER diagnostic and to participate in trace tritium experiments

(2) Confinement Database and Modelling

A key activity for coordinated international investigation under the ITPA and implemented through the IEA IAs has been the design of experiments and the analysis of data as follows.

- To resolve the differences between the beta (β) scaling of confinement as determined from global databases and from dedicated machine parameter scans. Joint experiments on JET (with US participation) and DIII-D (with EFDA-JET participation) showed no confinement degradation with increasing beta. New scaling relations have been derived from the ITPA confinement database and found to be electrostatic and gyro Bohm-like. These scalings predict that the fusion performance in ITER will be improved at high beta, yielding twice the fusion power as compared with operation at the nominal β value.
- To determine by experiments on JET and CMOD whether ν* or n/n_G is the appropriate dimensionless parameter for global confinement scaling. Preliminary results indicate that confinement scales with ν* (i.e., $\sim\nu^{*-0.3}$) and not with n/n_G.
- The effect of NBCD on the performance of JT-60 ELMy H-modes was investigated with the predictive core transport code JETTO and compared to JET H-mode plasmas. Negative ion neutral beam heating (N-NB) was expected to lead to a more peaked central current than positive NB heating (P-NB), which in turn would result in a significantly modified edge current profile, affecting edge stability and global confinement. It was found that plasmas with N-NB generally have good second stability access, whereas pure P-NB plasmas on JET do not. These differences seem to explain the experimentally observed better plasma performance with N-NB.

This work will continue under the ITPA and LTA.

A long term exchange with JET and ORNL has been the development and application of the NCLASS neoclassical transport code. Validation of the JETTO/SANCO/NCLASS code to investigate impurity transport in JET was completed under an LTA exchange. Results were compared with a Fortran 90 version of the FORCEBAL/NCLASS code that was installed on the JET Analysis Cluster (JAC) on an earlier visit. Data analysis from JET showed that impurity behavior in a sequence of plasmas with increasing gas puff is in quantitative agreement with NCLASS neoclassical predictions.

(3) MHD, Disruption and Control

In this task, collaborations concentrated on the stability at high β, Vertical Displacement Event (VDE) and disruption mitigation. In the research of high β, resistive wall mode (RWM) and neo-classical tearing mode (NTM) were extensively studied. These researches have been well continued in the following experiments coordinated international investigation under the ITPA and implemented through the IEA IAs.

- Closely co-ordinated experiments on JET, DIII-D, and ASDEX Upgrade have focused on the scaling of the marginal β, below which 2/1 and 3/2 NTMs become unconditionally stable. Data on NTMs in JT-60U are also being considered in relation to the database.
- Detailed experiments on Electron Cyclotron Current Drive (ECCD) control of NTMs aimed at benchmarking ITER models by understanding the relationship between island size and ECCD deposition widths have commenced on DIII-D and may continue. Effects of early ECCD injection on NTMs was confirmed in JT-60U and further experiments are planned in DIII-D.
- Similarity experiments on JET and DIII-D explored the effects of error fields in lowering 2/1 NTM β-limits, indicating the possible role of the ion polarisation current in the NTM seeding process. Identity experiments on error field thresholds have been conducted on JET and Alcator C-Mod, and are scheduled to take place on DIII-D.
- The control of RWM and the correction of error fields to maintain the stabilising plasma rotation have progressed on DIII-D using the 6 new internal control coils (I-coils). These data, together with Resonant Field Amplification experiments on JET (with US participation) which compared favourably with MARS stability calculations, should elucidate the scaling of the relevant damping terms. Error field experiments at high β may continue on DIII-D. Joint experiments on the effects of the rotation on RWM stability also involve a comparison between DIII-D and JT-60U.
- JET (with US participation) and JT-60U studied the use of noble gases in reducing VDE forces and divertor heat loads, and in avoiding runaway electron generation. In JT-60U, the injection of small amounts of Kr gas mixed with a large amount of hydrogen gas showed the best results. DIII-D (with EFDA-JET participation) demonstrated the benefits of high gas-jet pressures for disruption mitigation. ASDEX Upgrade showed reduced disruption forces and heat loads at lower gas-jet pressures.

There are some activities outside of ITPA/IEA joint experiments.

- VDE study in early 2001 experiments conducted on JET. A reliable regime, at low elongation (to avoid rapid VDEs), was developed to produce disruption induced runaways. It was found that the lower limits in q_{95} and toroidal field for inducing runaways are very similar to JT-60U. The quenching of disruptions with large helium puffs was also studied. It was found that this technique led to slower disruptions and induced on the machine disruptive forces as large as those of non-mitigated disruptions. In dedicated runaway electron prevention experiments, large H_e puffs proved effective.
- MHD which limits performance in the reverse shear regime has been studied on JET. The most fundamental limit to performance, pressure driven disruptions, have been studied partly as a collaboration with PPPL. Other limits to performance are found to be due to n=1 double tearing modes. Other characteristics of the reverse shear regime are q>1 sawteeth and high frequency cascade modes – similar to those observed on JT-60U.
- Concerning JT-60 modification program, the effect of the stabilizing coil on the RWM in the JT-60 modification was evaluated in collaboration with the US using the US stability analysis code VALEN.

(4) Edge and Pedestal Physics

This task was established in 2003, but there were some previous activities under Transport and Confinement task.

- ELM behavior was investigated on JET via pellet fuelling experiments for H-mode plasmas as a reactor relevant demonstration. One observation was that the inner wall launched pellets caused the plasma to produce type III ELMs instead of strong type I ELMs. High upper triangularity configurations resulted in more benign type III ELMs and less of a decrease in confinement.
- There was the attempt on DIII-D and JET to reproduce the enhanced D_α mode seen on C-MOD. It was found that by reproducing the edge dimensionless physics parameters of C-MOD one could indeed obtain discharges in the larger machines which had some similar features to those of the enhanced D_α mode.

International collaborative experiments coordinated through IEA IAs have made significant progress and expanded multi-machine data sets.

- Validity tests have been carried out on models for the width and gradient of the edge (pedestal) profile in H-mode plasmas, as well as allowing the investigation of regimes with different ELMs.
- Collaborative experiments between JET and JT-60U on the width and gradient of the edge pedestal profile in H-mode plasmas, as well as the investigation of regimes with different ELMs, has continued with matched plasma shapes. Improved pedestal pressures have been found in recent JT-60U experiments (January 2004) with similarity shape (with EFDA-JET participation at JT-60U). Taking account of the differences between two devices, new experiments were performed in both devices to investigate the role of aspect ratio and edge rotation, as well as the possible effects of ripple losses, especially at lower plasma current (1.07MA in JT-60U and 1.15MA in JET).

Fig.5 Drs G. Saibene, A. Loarte, J. Lonnroth during their joint experiments at JT-60

- Co-ordinated MHD analysis using a coupling of transport code JETTO and MHD stability codes MISHKA/HELENA (with EFDA-JET participation at JT-60) of selected pairs of discharges and of the recent higher performance plasmas in JT-60U has highlighted possible differences in the access to the second stability regime, possibly correlated with differences in the edge current in the two devices.
- Coordinated experiments between JET and DIII-D on the width of the pedestal barrier have continued, and new experiments on DIII-D, part of a ρ^* scan, are expected in the near term. These should allow a more extensive testing of the neutral penetration model for the density barrier width, as well as continuing the study of ELM energy losses and their dependence on ρ^*.
- Proposals for joint experiments are being prepared. These include further experiments on JT-60U in the similarity configuration to investigate the role of N-NBI in determining the pedestal width, as well as some tests of reduced ripple losses (MHD and transport analyses are included in these proposals). The continuation/extension of earlier collaborative work involving JET and Alcator C-MOD (on the EDA-mode), JT-60U and DIII-D (on the QH- and QDB-modes), and JT-60U and ASDEX Upgrade (on small ELMs and scaling of edge barrier width) are being implemented or under consideration.

(5) SOL and Divertor Physics

SOL and divertor physics tasks proposed by the ITPA and implemented under the IEA IAs are described as follows.

- An important contribution was the joint analysis of disruption energy balance in similar discharges on AUG, DIII-D, JET, MAST, TEXTOR, and TCV. The thermal quench heat load distribution is not consistent yet; 50-100% of W_{th} goes to the divertor in DIII-D, AUG, but only 15-35% in JET.
- The investigation of edge density profiles and parameter scaling of the edge density profile was performed by analysis of data from AUG, C-MOD, DIII-D, JET, JT-60U and MAST. The H-mode separatrix density is found to vary between 0.2 and 0.6 times the line-averaged density depending on plasma conditions, with a trend to larger fractions with increasing fueling.
- Radial ELM propagation studies carried out on AUG, DIII-D, JET, MAST and JT-60U all report radial velocities ~1 km/s.
- Similarities are found in D(T) retention across almost all carbon PFC machines: carbon is driven by poloidal flows into the inner divertor and with large amounts of D(T) found in co-deposits on tile sides - ~50% on JET, TFTR and DIII-D - raising concern about removal. In order to follow carbon migration, $^{13}CH_4$ gas injection experiments are being carried out in JET, TEXTOR, DIII-D, AUG. JT-60 (planned).
- The de-tritiation of JET CFC tiles prepared by TLK (Kahlsruhe) has been the tested by an oxy-gas flame de-tritiation supplied by JET. An oxy-gas burner raised the tile temperature to 750 C, and after 4 passes the tritium concentration was reduced to ~7% of the initial level. A new Flash Lamp device for tile de-tritiation has also been prepared, and in-vessel experiments have been completed successfully on JET, showing efficient in-vessel co-deposited layer removal.

There are many activities outside of ITPA/IEA joint experiments. Some important works are picked up as follows.

- Helium exhaust studies performed in the JET 2000 experimental programme has been analysed by US collaborators. The H_e concentration is measured in the sub-divertor pumping plenum region with a novel species selective Penning gauge. At the same time, H_e-concentration measurements are made in the plasma edge and strike point region with a spectrometer viewing these regions. A global particle balance analysis has been done providing a time history of the wall loading which allows an estimation of the particle-induced de-sorption coefficient which governs the rate of change-over of the wall.
- A scientist at MIT was involved in studying wall recycling and impurity fluxes by visible spectroscopy and neutral pressure measurements.
- A scientist at DIII-D contributed to the Helium plasma programme in 2001 through the analysis of the impurity release behaviour from the main chamber walls and divertor region based on visible and VUV spectroscopy and to compare the behaviour with that in deuterium discharge.
- The effect of plasma drifts on the boundary plasma of JET, JT60-U, and DIII-D has been examined using the UEDGE code. The simulation results have been compared with detailed probe measurements, particularly on the JT60-U experiment. The simulated plasma parallel flow was reasonably consistent with experiment on the high field side of the plasma, but somewhat poorer on the top and low field side. Work is continuing to better understand the differences between measurement and simulation.
- An EU scientist calculated the soft-X ray emission rate coefficients for Kr and Xe. The rate coefficients were used for analysis of Kr and Xe transport at internal transport barriers in JT-60U reversed shear plasmas. By the analysis, it was found that high-Z impurity accumulated inside the internal transport barriers.
- High priority research issues include the scaling of Type-I ELM energy loss, Tritium co-deposition, disruption and effect on materials choices, scaling of radial transport, and parallel transport in the SOL. These involved comparative experiments between JET, DIII-D and AUG. There is a reasonable agreement between these three devices on dimensionless comparison of Type-I ELM energy loss and in scaling of radial transport.

(6) Energetic Particles, Steady State Operation

There are two international collaborative experiments coordinated through IEA IAs. One is the preparation of ITER steady-state scenario, and the other is the preparation of ITER hybrid scenario. The results are summarized as follows,

- Study of ITER steady-state operation relevant discharges, which have a weak shear q profile, has been carried out in JET in collaboration with DIII-D. In JET, a discharge which has a large fraction of bootstrap current (f_{BS} > 50%) in a weak shear discharge with q_{min} ~ 2, nearly full non-inductive current drive plasma was maintained by real time control of the ion temperature gradient while, in DIII-D, full non-inductive current drive operation at $_N$ > 3 was achieved. In JT-60U, high f_{BS} (> 75%) was sustained for 7.4s near full CD (f_{CD} ~ 95%) in a reversed shear discharge.
- For the development of hybrid scenario demonstration discharges, which have a flat q profile with q_{min}>~1, mapping of operational regime in q_{95} and density has been studied in JET in collaboration with DIII-D and ASDEX Upgrade. In q_{95} scan it was found that at low q_{95} = 3.2-3.3 sawteeth remained and β_N limit was lower (β_N = 2.5 in AUG and 2.7 in DIII-D), at moderate q_{95} = 3.8-4 sawtooth-free hybrid regime was established only with dominant off axis NBI in AUG, at higher q_{95} > 4 β_N up to 3.2 was achieved in both DIII-D and AUG (limited by 2/1 NTMs). In JET, hybrid regime achieved at lower ρ* (2.5T/2.1MA) but not at the lowest ρ* value (3.4T/2.8MA). By matching elongation, aspect ratio, triangularity, q profile and ρ*, all AUG features are recovered in JET: $\beta_N \cdot H_{89p}$ ~ 5.9 at q_{95} ~ 3.9 β_N up to 2.8. The required values of $\beta_N \cdot H_{89p}/q_{95}^2$ to operate ITER at Q=10 have been achieved in DIII-D, AUG and marginally in JET. In JT-60U, a long pulse candidate hybrid discharge has been developed and the sustainment of β_N = 2.1 for 19s and β_N = 3 for 6s are achieved in collaboration with DIII-D.

There are many activities outside of ITPA/IEA joint experiments.

- Experiments on JT-60U and JET have shown that plasma configurations with shear reversal are prone to the excitation of unusual Alfvén Eigenmodes by energetic particles. These modes emerge outside the TAE frequency gap, where one might expect them to be strongly damped. US scientists have worked with JET and JT-60U scientists to develop a theory that explains the key features of the observed unusual modes including their connection to TAE's as well as the modifications of TAE's themselves near the shear reversal point. Another new model of the reversed-shear-induced Alfvén Eigenmode (RSAE) provided by JT-60U and experiments with accurate q-profile measurement in JT-60U can explain fast frequency chirping Alfvén Eigenmodes (AEs) observed in reversed shear plasmas. By using neutron profile monitor, redistribution of fast ions in weak shear (WS) plasmas was observed when large bursting AEs were destabilized.
- JET and PPPL have collaborated to provide experimental data on Alfven Eigenmodes in order to benchmark theoretical models such as NOVA-K. The radial mode structure of Alfven cascades has been measured on JET, and a combined analysis of reflectometer data and NOVA-K simulations indicate a density fluctuation level of 0.3% for one of the Alfven cascades. Non-perturbed version of NOVA-K, NOVA-KN, has been developed by Dr. N. Gorelenkov, PPPL. This code will be applied to analysis of JT-60U N-NB AE experiments.

(7) Tritium and Remote-Handling Technologies

Tritium behavior inside tokamak vessel has been extensively studied by JET, JT-60U and TFTR. The results of the collaboration are summarized as follows,

- The main long-term tritium retention mechanism in large tokamaks, especially JET and TFTR, is the co-deposition of tritium (and deuterium) with eroded wall material (principally carbon). Temporary trapping of tritium of up to 60% has been observed.
- The co-deposited layers can become so thick that spalling occurs and flakes are generated. The D:C ratios of TFTR flakes (coming from the plasma facing inner bumper limiter and non plasma facing components) were in the range between 0.11 to 0.25, far lower than the values of 0.7 to 0.8 determined at JET. The vessel temperature, extent of interaction with the plasma and discharge history all play a role in determining the stochiometry of the deposits.
- With a Nd-YAG laser system developed at TFTR detritiation tests of JET MkIIA divertor tiles were performed which were installed during the Deuterium-Tritium Experiment. Up to 87 % of

the tritium in the sample was removed in a rapid scan over the surface with the laser, most of the tritium being released as tritiated hydrogen and the carbon based films remaining basically intact.

- Concerning the characterisation of carbon flakes, 1g of flakes from JET were sent to FZK. An average BET surface of (4.5±0.6) m^2g^{-1} were found in agreement with previous values measured for PTE flakes in TLK ($7m^2g^{-1}$) or with the INEEL measurements for DIII-D dust particles (3±0.2) m^2g^{-1} and TFTR dust particles (6.9 to 26.5) m^2g^{-1}.
- Laser de-tritiation is of crucial importance for future tokamak operation. New laboratory studies on surface detritiation using lasers have been undertaken at JET. Different ablation threshold fluences have been determined for co-deposited layers (0.4±0.1J cm^{-2}) and for the usual CFC surfaces (1±0.1J cm^{-2}). De-tritiation rates of $1m^2$ per hour for a 20 m co-deposited layer using a high repetition Nd-YAG laser beam of 250W mean power have been measured. The eximer laser irradiation method has been studied at TPL (JAERI) using TFTR D-T tiles. $0.4x10^{-6}$ m^{-1} and 4.2 J/cm^2 were determined as the effective absorption coefficient and the ablation threshold respectively for KrF eximer laser irradiation.
- Tritium release from the JT-60U vacuum vessel has been investigated using an air purge in which the water vapour concentration in air was controlled up to 3400ppm. It was observed that the released tritium increased with water vapour concentration.
- The first pumping experiment using the cryosorption pumping panel (PCP) was conducted in October 2003. During trace tritium experiments on JET more than 100barl of gas with 0.8barl of tritium were processed. The PCP was then used during the regeneration of the divertor cryopump (~150barl) with very low tritium content. The measured pumping capacity on the $0.4m^2$ charcoal coated PCP is $23mbarl/cm^2$ for D_2. The PCP will now be exposed to highly tritiated gases in a parametric test programme scheduled for August 2004. The PCP will then be characterised and subjected to de-tritiation treatments.

(8) Others

Task 8 was added at Ex-Co meeting of June 2004. It includes diagnostics and technical issues such as neutral beam technologies.

In 2004, there were some personal exchanges to discuss power supplies and evaluation of the temperature rises of coils for long pulse operation, NBI high-voltage full semiconductor power supplies, or the IGBT power supply for the error field correction coils.

There is longstanding PPPL/JAERI collaboration for the development of N-NBI system. The recent collaboration works are summarized as follows.

- Development of N-NBI system and its use in large tokamaks is one of the important missions in this cooperation. To achieving long pulse injection, beam extractions are limited to 3 segments and two segments are masked and its lines are used to improve neutral pumping. Also cooling capability of beam limiter was increased to reduce temperature rise. With these improvements, extension of the N-NBI pulse duration up to 17 sec has been successfully made. The limitation of the pulse length is not by the heat load, but by the conditioning time. On this technical development, US participation (Dr. L. Grisham (PPPL)) was made four times this year as part of longstanding PPPL/JAERL collaboration. He concentrated on studies of the ion optics and beamlet deflections using a new higher resolution IR camera and also on implementing a system to maintain the ion source cathodes at constant temperature during beam faults, thus enabling longer pulse operation. Successful attempts were made to improve the voltage holding capability of the accelerator system at the upper end of its planned operating range under this cooperation. These activities have been very successful in extending the duration and intensity of negative ion neutral beam injection on JT-60U.

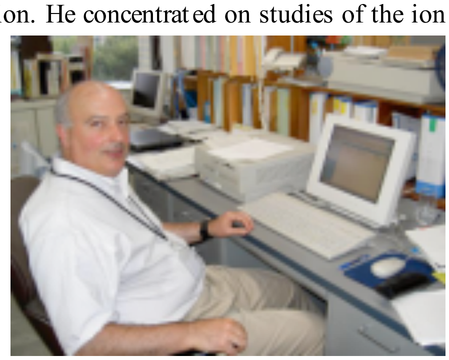

Fig.6 Dr. L. Grisham during his stay in JT-60

6.3 Workshops

The Large Tokamak Workshop has played a core role in the world fusion collaboration. From 2001 to 2005, 14 workshops were held on the key physics and engineering subjects as shown in the table. Total number of participants to these workshops is 395. Since these workshops were open to the fusion society in the world, numbers of the specialists (31 persons in average) contributed to the progress of these research fields. For 2005, a workshop is planned (W61) and others will be discussed at next Ex-Co in May, 2005.

No.	Title		
	Date	location	No. of participants
W47	**Experimental Planning**		
	7-8, February, 2001	JAERI-Naka, Japan	35
W44	**Plasma Shaping**		
	25 - 26 June 2001	Culham Science Centre, UK	16
W49	**Real Time Control of ITB Discharges Approaching Steady-state**		
	4 - 6 February 2002	JAERI-Naka, Japan	36
W50	**Electron Transport**		
	3-6 April 2002	U.S.A	
W48	**ELMS**		
	24 -26 June 2002	Culham Science Centre, UK	31
W51	**In-Vessel Tritium Inventory**		
	19 – 21 March 2003	Culham Science Centre, UK	51
W52	**Implementation of the ITPA Coordinated Research Recommendations**		
	18 – 19 November 2002	MIT, USA	13
W53	**Experience in the Management of Wastes From Fusion Facilities**		
	25 – 26 March 2003	Culham Science Centre, UK	29
W54	**Implementation of the ITPA Coordinated Research Recommendations**		
	23 Nov. 2003	JAERI-Naka, Japan	33
W55	**Physics Needs for High Beta Steady State Tokamak**		
	24 Nov. 2003,	JAERI-Naka, Japan	30
W56	**Physics of Current Hole**		
	3 -4 February 2004	JAERI-Naka, Japan	46
W58	**Implementation of the ITPA Coordinated Research Recommendations**		
	8-9 Dec. 2004	Eynsham Hall, Near Oxford, UK	24
W59	**Shape and Aspect ratio Optimization for High β steady-state tokamak**		
	Feb. 2005	General Atomics, USA	43
W61	**Heating and Control for long pulse operation in large tokamaks**		
	Aug. 30, 2004	Venice, Italy	8
	Number of Completed WS : 12		**Total participants:395**
No.	**Planned workshops**		
W60	**Burning Plasma Physics and Simulation**		
	June. 2005	EPS location	

II. Outline of the Workshops

The purpose of the large tokamak collaboration activity is to give fundamental contributions to ITER/BPX (burning plasma experiments) and the tokamak demo reactors. Towards this goal, we have covered a wide range of the fusion research fields in the workshops. Among them, reflecting the progress of the world research and considering the impacts on the ITER/BPX, we have selected the key physics and engineering areas as the subjects of the workshops. Depending on the subjects, results from medium / small sized tokamaks, helical devices, modeling and theoretical works have been reported in addition to the large tokamak results. These workshops were quite useful in evaluating and improving the research activities not only in the large tokamaks but also in the wider fusion programs in the world.

The workshops held in 2000 - 2004 are categorized in the five areas as follows

i) Plasma Physics
- Fuelling and density control (W45)
- Plasma shaping (W44)
- Edge Localized Modes (ELMs) (W48)
- Real time control of Internal transport barrier for stead-state (W49)
- Electron Transport (W50)
- High beta syeady-state(W55)
- Current Hole (W56)
- Shape and Aspect ratio (W59)

ii) Plasma Diagnostics
- Diagnostics for Burning Plasma Experiments (W46)

iii) Fusion Engineering
- In-vessel tritium inventory (W51)
- Management of wastes from fusion devices(W53)
- Heating and Control for long pulse operation in large tokamaks (W61)

iv) Research Strategy
- Experimental Planning (W47)

v) Inter-machine collaborative experiments
- Implementation of the ITPA coordinated research recommendations (W52, W54, W59)

At each workshop listed above, there was an exchange of information, comparison of research results, identification of the key physics processes and techniques, and discussions on the new large tokamak experiments including the collaborative proposals.

As a typical example, picture of workshop participants is shown below where “Current Hole” discovered in JT-60 and JET was discussed at JT-60 to understand this current hole configuration as a possible operation scenario of tokamak.

Fig. 7W56 workshop participants from Japan, EU and US (46 participants)

As for the international collaborations utilizing the tokamak devices in the world, we have started a new activity in collaboration with the International Tokamak Physics Activity (ITPA) and held three workshops on ' Implementation of the ITPA coordinated research recommendations (W52, W54, W58)'. In addition to the IEA-LT members, the leaders of major world tokamaks and the chair of Coordinating Committee of ITPA and chairs and co-chairs of the ITPA topical groups have participated in these workshops. The purpose was to discuss the implementation of the ITPA proposals that would benefit from coordination of joint experiments among the major world tokamaks. Meeting summaries of these two workshops are attached below.

3) Implementation of the ITPA coordinated research recommendations

i) Summary of W52

About thirteen participants at MIT discussed 40 ITPA experimental proposals. Eleven of these were well-developed for consideration for joint experiments on various tokamaks in 2003. Most of the proposals involve 3 or more tokamaks. The tokamak leaders indicated that they would be interested in considering another 16 proposals for joint experiments if the proposals are further developed in time to be discussed in the 'research forums' of the major tokamaks in December to develop their experimental program plans for 2003. The remaining proposals were considered to be ongoing programmatic activities that have not yet developed plans for joint experiments. This was indeed a unique and successful meeting that provided a productive opportunity for enhanced communication among the major world tokamak leaders, the ITPA leadership, and the IEA-IAs members.

ii) Summary of W54

The purpose of the workshop was to review the status of implementation of ITPA/IEA coordinated experiments among the major world tokamaks and to discuss new proposals. This time, the workshop was held as a joint workshop of three IEA IAs., namely, IEA Large Tokamak IA, IEA Poloidal Divertor IA, and IEA TEXTOR IA. In this workshop, organizing committee consisted by 3 IEA IA's invited leaders of medium-sized tokamaks of China, Russia, EU and Japan in addition to tokamaks participated in W52 workshop (JET, JT-60U, DIII-D, ASDEX-U, C-MOD, NSTX). So program leaders or representatives of JT-60U, JET, DIII-D, ASDEX-U, C-MOD, NSTX, FTU, MAST, JFT-2M, TRIAM-1M, TEXTOR, TCV, Tore Supra, Russian Tokamaks (T-10,T-11M,Globus-M,Tuman-3M,FT-2), and Chinese Tokamaks (HL2A, HT-7) joined to this workshop to discuss results and implementation of ITPA joint experiments to their research programs. There were 33 participants from various tokamaks and ITPA chair and co-chairs. Results of ITPA joint experiments proposed at W52 workshop were reported by W52 workshop organizer (E. Oktay) and ITPA chair (D. Campbell). Then each chair or co-chair of the 6 ITPA topical groups reported their status and near term requirements for Joint Experiments. Then the facility leaders presented their operation and research plans in relation to ITPA joint experiments. Finally, proposed list of ITPA joint experiments are discussed, one by one to call for facility-leader's interests on specific Joint experiments.

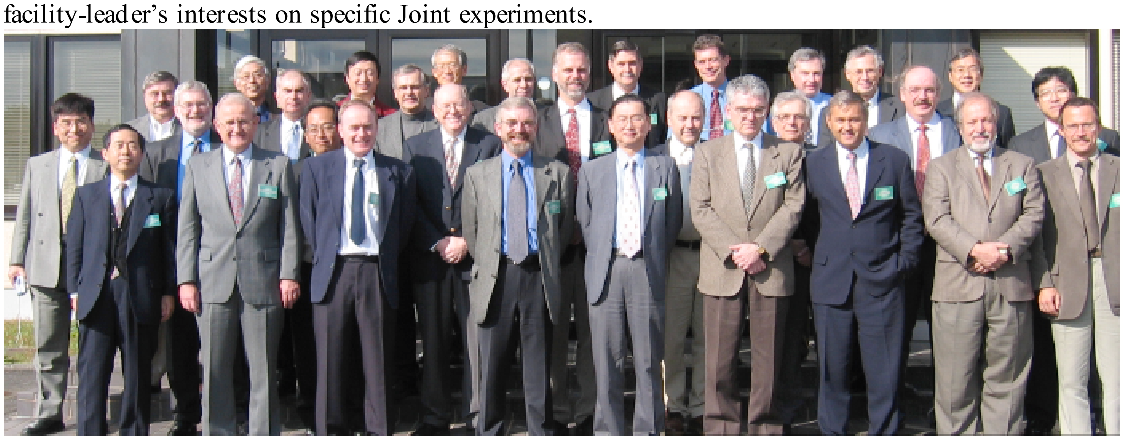

Fig.8 Participants of W54 workshop "Implementation of the ITPA coordinated research recommendations "

iii) Summary of W58

The purpose of the workshop was to review the status of implementation of ITPA/IEA coordinated experiments among the major world tokamaks and to discuss new proposals. The workshop was held as a joint workshop of three IEA IAs., namely, IEA Large Tokamak IA, IEA Poloidal Divertor IA, and IEA TEXTOR IA. The organizing committee invited leaders of medium-sized and large-sized tokamaks in EU, Japan, US, Russian Federation and China (JET, JT-60U, DIII-D, ASDEX-U, C-MOD,

NSTX, FTU, MAST, JFT-2M, TRIAM-1M, TEXTOR, TCV, Tore Supra, T-10, T-11M, Globus-M, Tuman-3M, FT-2, HL2A, HT-7) to consider the implementation of ITPA joint experiments in their research programs. There were 25 participants from the various tokamaks (the representative for the Chinese tokamaks sent his apologies for not being able to attend), together with the ITPA chair and co-chairs (or their representatives). A report on Workshop W54 was made by the Organiser of that Workshop (M. Kikuchi). The ITPA Chair (R. Stambaugh) reported on the status of documentation and implementation, and the ITPA views on Joint Experiments. He then reported on behalf of the six ITPA Topical Groups on their near term requirements for joint experiments. The Programme schedules of each tokamak for 2005 was collated and summarized by O. Gruber. Following break-out sessions and plenary discussions, the Tokamak Programme Leaders gave their commitments to the updated proposals for ITPA Joint Experiments.

Figure 9 Participants of W59 workshop "Implementation of the ITPA coordinated research recommendations

6.4 Personal Assignments

In order to exchange the information for the Large Tokamak Facilities between the Contracting Parties, a large number of the personnel assignments have been carried out. The total number of personnel assignments carried out during the period between Jan. 2001 and Jun 2005 was 155 (U.S.<-->JET (86), JET<-->JT-60 (32), and JT-60<--> U.S. (37). The details are show in the following table.

Table 1 Number of meetings and personnel exchanges organized by the Agreement

	2001	2002	2003	~Sep.2004	2005	Total
Workshops	2	4	4	2		12
Personnel Assignments (Total)	63	35	32	25	-	155
(1) Participation: more than 4 weeks	6	1	0	0	-	7
JET --> U.S.						0
JET --> JT-60						0
JT-60 --> U.S.						0
JT-60 --> JET						0
U.S. --> JT-60	1					0
U.S. --> JET	5	1				7
(2) Participation less than 4 weeks	57	34	32	25	-	148
JET --> U.S.	5	0	9	6		20
JET --> JT-60	1	2	1	6		10
JT-60 --> U.S.	3	3	2	0		8
JT-60 --> JET	5	8	6	3		22
U.S. --> JT-60	13	9	3	4		29
U.S. --> JET	30	12	11	6		59

7. Achievements, Benefits and Issues

7.1 Achievements

During this term, large tokamaks JT-60, JET and US fusion energy science made significant progress in tokamak research supported and enhanced by this cooperation. The scientific progress was motivated through impressive collaboration and healthy competition towards advancing fusion energy science.

The JT-60 discovered so-called "Current Hole (CH)" during negative-shear discharges in 2000. It was found that current drive inside the CH is difficult once it was formed and is maintained stably. JT-60 also achieved a world record of electron temperature 3 hundred million degree with powerful electron cyclotron heating in 2001. It was demonstrated that advanced tokamak plasma can be produced without the use of OH coil in 2001. World highest fusion triple product under full non-inductive current drive is also achieved utilizing powerful negative-ion source based neutral beam injection system in 2001. It also demonstrated active feedback control of NTM stabilization through real-time mirror angle control in 2002. Furthermore, discharge duration of divertor operation was extended to 65 seconds in 2003. With this capability, sustained duration of bootstrap current dominated (75%) near full current drive was also sustained for 7.4 second in 2003. Furthermore, high normalized beta β_N=2.5 under small normalized gyro-radius $\rho^*=6x10^{-3}$ and low collisionality $\nu_e^*=6x10^{-2}$ was sustained for 15.5 second which is ~10 times current diffusion time in 2004.

The JET program also made a significant progress. First experiments with fusion-energy alpha particles produced by ICRF heating of NB injected Helium4 (alpha particles). ITER values of normalized confinement and density was achieved in ITER- shaped plasmas. Divertor discharge lasts record 50 seconds. Real-time feedback control of plasma pressure and current profiles was achieved simultaneously.
Advanced H-mode regime was established and extended towards ITER normalized conditions. ELM characteristics were moderated with impurity seeding. Trace Tritium Experiments were conducted. A new divertor and fourteen new diagnostics were installed, and a new ITER-like ICRH antenna is under construction.

In the US fusion energy science, progress has been made by exploring advanced tokamak regime in DIII-D, by exploring Spherical Tokamak configuration in NSTX, and by exploring high field tokamak in Alcator C-Mod. Concerning decontamination and decommissioning of TFTR, the TFTR device was both activated and contaminated upon completion of the D-T experimental campaign. In 2002, the decontamination and decommissioning of TFTR was successfully completed on time, below cost and safely.

7.2 Scientific discoveries through LT IA

Many scientific discoveries were made through this cooperation such as, scaling of edge transport barrier, internal transport barrier physics, ExB shear stabilization of turbulence, H-mode transition physics, dimensional confinement scaling, turbulence radial correlation, neoclassical tearing mode, resistive wall mode, Alfven eigen-mode, RF current drive physics, neutral beam current drive physics, bootstrap current, current hole, rotation physics, scrape off layer flow, detachment, chemical sputtering, erosion and re-deposition.

7.3 Information exchange through LT IA

Many information exchanges were made through personal exchanges (total number of exchanges 155 persons) and workshop (total number of participants 328 persons. TV conference facilities were also used among the three parties to communicate to each other.

7.4 Contribution to Policy Making through LT IA

This implementing agreement is one of most active fusion IA under IEA. The productivity of large tokamaks such as JT-60 and JET has been greatly enhanced through this cooperation and the fusion energy science programme of US has contributed to and benefited from this collaboration. This cooperation has contributed to the success of large tokamaks in demonstrating equivalent break even conditions and significant DT fusion power production and thus contributed to advance the implementation of the international large scale fusion program, ITER. Thus this IA is significantly contributing to the international political decision of implementing ITER program in the near future.

7.5 Issues

As far as this IA is concerned, there are few issues. But as described in section 4, it would be important to increase coordination with other bodies to enhance our productivity. Interactions with other tokamak related IAs and ITPA is being increased.

8. Overall Significance of Agreement

As we described in section 1, world fusion research is preparing to enter a new phase in the development of fusion devices: the construction of ITER, planned to last for 10 years,. Before the start of ITER operation, large tokamaks will continue to be a key driving force to advance tokamak physics and the tokamak concept with strong cooperation of other IAs. During this term, confirmation and extension of ITER operation scenarios and also further development of AT will be pursued through this cooperation. Thus the overall significance of this IA continues to be quite high.