IEA IMPLEMENTING AGREEMENT ON
CO-OPERATION ON THE LARGE TOKAMAK FACILITIES
Annual Progress Report (June 2009 to June 2010)
of the Executive Committee

Executive Summary

1. Mission of the Large Tokamak Implementing Agreement and relevance to the international fusion programme

The objective of this Implementing Agreement (IA) is to enhance the scientific and technological achievements of the Large Tokamaks (LT) by means of co-operative actions for the advancement of the tokamak concept. This IA is one of the largest co-operations among the fusion IA's under the IEA. The achievements of the large tokamaks under this IA provided essential data and operating experience for ITER and the advancement of the tokamak concept.

2. Current foci and objectives of the LT IA

Current scientific foci of large tokamak experiments are: ITER baseline discharge simulation (start-up, flat-top, landing); candidate steady state scenarios for ITER and DEMO (long-duration sustainment of high plasma pressure, high bootstrap current discharges); qualification of hybrid scenarios for ITER; cross-machine experiments on plasma edge, L-H power threshold in He plasmas, Internal Transport Barriers; control of disruptions using massive gas injection; control of edge localised modes by perturbing magnetic configuration, using pellet injection and so on; characterisation of plasma instabilities (resistive wall modes, neoclassical tearing modes); effect of ITER Test Blanket Modules on plasma behavior, material erosion, migration re-deposition and fuel retention; effect of wall conditioning; effect of plasma rotation on confinement and MHD.

The objective of these investigations is to advance the scientific basis for the burning plasmas in tokamaks and contribute to the resolution of the issues identified in the ITER Research Plan and to prepare for ITER scientific exploitation. ITER will be the first burning plasma experiment to demonstrate the scientific and technical basis of fusion energy. The IEA LT scientific exchanges to carry out these investigations are accomplished through coordinated experiments and supporting data analysis and computational modeling using JET (EU), JT-60 (Japan), KSTAR (Korea) and the U.S. national devices (DIII-D, CMOD and NSTX), and many university researchers. The International Tokamak Physics Activity (ITPA), operating under the auspices of ITER, identifies high priority research tasks for ITER in close coordination with the ITER Organization, and proposes experiments and modeling activities to resolve them. The IEA LT IA holds annual workshops, in close cooperation with the IEA Poloidal Divertor (PD) and IEA Plasma Wall Interaction in TEXTOR (PWIT) IA's, the tokamak leaders and the ITPA on "Implementation of the ITPA coordinated research recommendations". The 2009 annual workshop was held at NFRI, Daejon, Korea on 15-16 December 2009. In this 8th annual workshop, leaders representing 12 major world tokamak programmes were among the participants.

Current foci of large tokamak technology are the development of negative-ion-source-based neutral beam injector (N-NBI) for JT-60SA, tritium and remote handling in JET (including the installation and tests of the ITER-like Wall materials in JET), as well as diagnostics improvements. In general, it is considered that the interactions between IEA/ITPA/ITER work well, with the primary path for the proposal of experiments being the ITPA Topical Groups.

3. Highlights and accomplishments during the reporting period June 2009-June 2010

In the EU, JET experiments ended on 23 October 2009 (118 two shift days; strong EU involvement (294 researchers, 22 countries, 42 working days/person average); strong International collaborations (US, RF, Japan and Korea; 34 researchers); 39 ITPA ITER high priority coordinated experiments, requiring 60% run-time). Cooperation Agreement between EURATOM and Brazil signed on 27 November 2009. Contributions to ITER ICRH system design and non-active phase heating, IC wall cleaning; ITER coil set and divertor design; qualification in D_2, ^{4}He and H for ITER baseline scenario (to 4.5MA/3.4T, H_{98}~0.9; independent of heating mix (NB/ICRF) despite strong rotation reduction (5-10) and dominant electron heating with ICRF; ELM frequency increased by 3-5 (RMP, kicks, pellets) but no complete suppression, ELM-associated peak heat loads reduced on outer divertor by ~30-40%, pellets penetrate to pedestal top to trigger ELMs; TF ripple <0.5% (preferably 0.2%-0.3%) for adequate τ_E in ITER) and advanced scenario (normalised conditions achieved for ITER steady-state (β_N=2.7, H_{98}=1.2-1.3, T_e=T_i, f_{bs}~0.4, f_{GW}~0.7, but not ρ^*); hybrid matched to AUG/DIII-D, extended to H_{98}~1.4 at ρ^*=0.005, 2.4T and high δ, rotational shear linked to reduced ion stiffness; C wall characterised for ILW (H retention, C source strength and migration; extrinsic seeding (Ne or N) reduces inter-ELM loading to ~1MWm^{-2} for ~10% loss in τ_E; MGI reduces heat loads by ~50% during disruption thermal quench. Subsequent shutdown for installation of ITER-like W divertor and Be wall, NB power upgrade to 30MW long pulse, new/upgraded diagnostics and machine refurbishments will be followed by exploitation in 2011/12 (minimisation of T-retention, material erosion and migration, mixed material effects, melt-layer behaviour and impurity control; development of ITER scenarios fully compatible with ITER-like first wall and divertor materials and ~40MW input power). DT experiments foreseen for subsequent period up to end-2015. Feasibility studies quantified resources for ECRH (~10MW; collaboration with RF) and ELM control coils (collaboration with US). This Alternative Scenario would require significant increase in level of international contributions; international partners would be more actively involved in decision-making. Since 2000, 152 JET FT tasks launched (~23M€ total; ~2.6M€ in 2009), concentrating on tritium in tokamaks, tritium process and waste management, plasma facing components, engineering, and neutronics and safety.

After the shutdown of JT-60U in August 2008, the activities and the structure of JT-60 team were substantially shifted towards modification to the superconducting tokamak JT-60 Super Advanced (SA) while the team also continued physics studies and plasma evaluations for JT-60SA, ITER and Demo based on existing JT-60U data. Objective of JT-60SA being promoted as a joint programme of the Satellite Tokamak programme under Broader Approach (BA) agreement between Japan and EU and a domestic core programme of tokamak development in Japan, is to contribute to ITER Project and also to technical preparations for the decision of DEMO construction, with enhanced performance in plasma duration, plasma shaping control, heat exhaust and particle control, stability control, and heating & current drive capabilities. First plasma is planned for the end of FY2015. Procurements of JT-60SA components are shared by Japan and EU. By March 2010, the first two NbTi superconducting conductors of 450 m for PF coils were manufactured successfully in JAEA Naka Institute. Manufacturing of the first 20 degree sector for the vacuum vessel was on-going as scheduled. As for the European contributions to the procurements, the procurement arrangements for Quench Protection Circuit, High Temperature Superconducting (HTS) current leads and Cryostat-base were signed in FY2009. Removing components in the JT-60 assembly hall and disassembling components in the JT-60 machine hall started in November in 2009 and will be completed in 2012 as scheduled. As for the development of gyrotron aiming at output power of 1MW/100s required for JT-60SA ECRF system, the pulse length was extended up to 17 s (1 MW) with a new improved mode converter in December 2009. As for the NB system, hydrogen negative ion beams of 490keV/3A and 510 keV/1A have been successfully produced in the JT-60 negative ion source by tuning electrode gaps based on newly acquired breakdown voltage data for ITER-like wide electrodes.

The deliberations in the U.S. Fusion Energy Sciences (FES) program continue to evolve, with primary focus on developing pathways for establishing the credibility of fusion energy. The complexity of and challenges in fusion science and technology are great and requires break out from scientific and political isolation. The FES mission continues to be to expand the fundamental understanding of matter at very high temperatures and densities and to develop the scientific foundations needed to develop a fusion energy source.

In his recent presentations to a variety of different forums and stakeholder groups, Ed Synakowski has identified at least the following “three major scientific needs for establishing credibility for fusion energy:

(1) We must generate, study, optimize, and learn to predict the properties of the burning plasma state
(2) We must develop the scientific basis for robust control strategies for the burning plasma state
(3) We must develop the understanding of the material/plasma interface, and the fusion nuclear science needed to endure the fusion environment and to harness fusion power”.

These needs inform the deliberations to evolve the structure and priorities of the US FES program. The U.S. participation in ITER is the highest priority which is aimed at successful demonstration of burning plasmas and understanding its underlying physics and technology integration for extrapolation to the next steps in the development of fusion energy.

Emphasis has to increase in validation of physics basis and computational models with close interaction between theory, modeling and experiments in the ongoing programs. Extrapolation of current results to ITER and beyond, and successful operation of 'steady-state' long pulse plasmas in the future require enhanced international collaborations and closer interaction with other disciplines such as the Advanced Scientific Community (ASC). The initiation of the long-range Fusion Simulation Project (FSP) in the US FES program is aimed developing the tools for such validated computer simulations.

Korea joined the LT IA on February 5, 2010 as a step to combine the IEA LT IA and the IEA PD IA into a single IA for streamlined management. The cool-down for the 2nd operation campaign of KSTAR was started from September, 2009 and the plasma experiments were carried out from October to November same year. During this second campaign, the machine was operated with the toroidal magnetic field of up to 3 T. Cicular plasmas with current of 300 kA and pulse length of 2 seconds have been achieved with limited capacity of PF magnet power supplies. To test the operational limit, the toroidal field coils were operated up to 36 kA corresponding to the toroidal field of 3.6 T at the axis. The second harmonic pre-ionization with 110 GHz, 250 kW gyrotron at 2 T has been studied. Various parameters such as injection angle, position and pressure have been scanned to optimize the effect. The ICRF wall conditioning (ICWC) was routinely applied during the shot to shot interval and the effect of ICWC has been quantitatively assessed. After finishing the 2nd campaign, a significant upgrade of the KSTAR device is made. To achieve D-shape, diverted plasmas, all of the plasma facing components (PFC) including divertor has been installed. The sixteen-segmented in-vessel control coils (IVCC) has also been installed prior to the installation of the PFCs. The IVCCs will be externally connected to form two sets of circular coils for vertical and radial position control, and the IVCCs will have additional capability to be utilized as the RWM/FEC and ELM control coils. The first NBI system, designed to deliver 8 MW deuterium beams into the KSTAR plasmas with three ion sources, is now under commissioning. The 3rd campaign is scheduled to begin July, 2010 from the cool-down of the super-conducting magnet systems.

The physics-related work in the collaboration is conducted under eight Task areas, seven of which cover the Topic areas used in the ITPA. These are Transport Physics and ITB Physics, Confinement Database and Modelling, MHD, Disruption and Control, Edge and Pedestal Physics, SOL and Divertor Physics, Steady State Operation, and Others (including Diagnostics, and also Power Supplies). In addition, Tritium and Remote Handling Technologies are conducted in Task Area 7. Accomplishments in these Task Areas are described in Attachment A2.

Two Workshops were held during the reporting period. These were:

- **W70:** Key ITER Disruption Issues at Culham Science Centre, Abingdon, UK; 7-9 October 2009;
- **W71:** Eighth Joint Workshop of Large Tokamak, Poloidal Divertor and Textor IAs on "Implementation of the ITPA Coordinated Research Recommendations" at KSTAR Research Center, NFRI, Daejeon, KOREA; 15-16 December 2009.

Summary reports from these workshops are included in Attachment A3.

There were 25 personnel assignments and scientific exchanges among the three Parties completed during this period. A list of exchanges is shown in Attachment A4.

The 25th ExCo meeting of the IEA Large Tokamak IA was held at Hotel Aquabella in Aix-en-Provence, France on 9 May 2010. This meeting was held jointly with the IEA PD, as it has been done so for the past 5-6 years. The minutes of this meeting is shown in Attachment A5.

4. Future strategy

The Ex-Co meeting of the LT on 9 May 2010 provided the opportunity to discuss the future strategy of IEA IA as briefly summarized below (with further details available in the minutes of the meeting):

1. Development of a single tokamak IA: The discussions initiated some 6-7 years ago in the IEA Fusion Power Coordinating Committee (FPCC) and the Executive Committees of the IEA LT, PD, and PWIT IA's on "re-structuring" the tokamak related IA's, have come to conclusion. With the amendments discussed extensively at the meeting of 21-22 May 2009 and since, the IEA LT IA will become the single "Implementing Agreement for Co-operation on Tokamak Programmes (CTP)" that would be open to participation by the major tokamaks of the ITER Members. The Executive committee provided an amended text for the CTP IA in February 2010. US, Japan and Korea gave their assent to the amendments before the Executive Committee meeting in May 2010, and EU's assent was expected to be given soon in the meeting (It was done and the CTP IA came into effect in

June 2010.).

2. Extension of the IEA CTP IA: The LT Executive Committee had resolved unanimously to request a five year extension of the CTP-IA from 15 January 2011 to 14 January 2016. It was agreed that the Request for Extension (RfE) would be drafted and distributed to ExCo members for comment before end-June 2010. The final documents would be sent to the Secretariat end-July 2010 for review by the FPCC by written procedure as soon as possible following that date. However, if the CERT approve the request for one-time extension for all IAs by written procedure in its next meeting, the Committee agreed that it would present the RfE to the FPCC in February 2011 and then to the CERT at the meeting June 2011 (The one-time extension until 30 June 2012 was approved by the CERT in December 2010.).
3. Invitation for participations of China, India and Russia: The LT Executive Committee agreed to send invitation letters to China, India and the Russian Federation under the CTP IA.

5. Collaborations inside/outside IEA

The close coupling between the ITPA, the ITER organization, the IEA FPCC, and the IAEA IFRC provide the opportunity to streamline international collaborations in fusion, with its priority for the success of ITER in achieving its key scientific and technological objectives. In recognition of the change of the world fusion programme into this new era, symbolized by the establishment of the ITER Organization, collaborations inside/outside IEA have to be strengthened in view of support and supplement ITER towards DEMO. As for the collaboration inside IEA, Korea joined the LT IA in February 2010 and the CTP IA as an amendment of the LT IA to include the PD IA has come in effect in June 2010. As for the collaboration outside IEA, invitation letters for participation in the CTP IA will be sent to China, India and the Russian Federation. The IEA LT homepage (http://www-jt60.naka.jaea.go.jp/lt/) is open to all IEA IA's and the public.

6. Message to policy makers

The IEA Large Tokamak Implementing Agreement remains one of strongest fusion IA's and has been effective in developing tokamak research to reach break-even conditions and in developing the necessary databases for the next step device ITER and a steady-state tokamak reactor. This Agreement provides leadership in coordinating ITPA joint experiments with other tokamak related IEA IA's. With the Korea's participation as a Contracting Party and revising the LT IA to the CTP IA, tokamak-related activities in FPCC are streamlined. Productive interactions with ITPA, IO and the IFRC will be further enhanced if other fusion countries such as China, the Russian Federation, and India join the CTP Agreement in the future in order to facilitate science and technology exchanges among the domestic programmes of all ITER Members.

7. List of attachments

These reports can be found on the IEA CTP IA web-site, http://www-jt60.naka.jaea.go.jp/lt/index.html, in the 'Internal Use' sub-area. Please contact Kensaku Kamiya (secretary) for password to access this part of the website.

A1 : Status and Plans of Four Parties
A2 : Accomplishments in Task Areas
A3 : Summary Reports on Workshops
A4 : List of Personnel Exchanges
A5 : Minutes of Executive Committee meeting in Aix-en-Provence, France.