4. JSPS-CAS Core-University Program on Plasma and Nuclear Fusion

A bilateral international collaboration program *"JSPS-CAS Core-University Program (CUP) on Plasma and Nuclear Fusion"* was started from FY 2001 as a ten-year collaboration program. This program is supported by the Japan Society for the Promotion of Science (JSPS) on the Japanese side and by the Chinese Academy of Science (CAS) on the Chinese side. National Institute for Fusion Science (NIFS) and Institute of Plasma Physics, Chinese Academy of Science (ASIPP) serve as the core institutes for this program in each country and assist the collaborations between all participating institutes and universities in Japan and China. This was implemented as the first year of the latter five-year program approved by JSPS last fiscal year 2005.

General review of collaboration in FY 2006

In China, a new tokamak EAST device of which all toroidal and poloidal coils are superconducting was completed at the bigining of this fiscal year, and was immediately in an initial tokamak operation successfully. Double-null divertor operation was also successfully demonstrated. A long pulse plasma of 8.5 s duration was produced with ohmic heating alone. Several collaboration experiments on plasma start-up and shape-control have been already started.

In Japan, high density plasma was produced by repetitive ice-pellet injection on LHD. In LHD, various collaboration researches were carried out for better understanding of toroidal plasma confinement. In addition, collaborations on development of heating and diagnostic systems were intensively carried out on LHD and JT-60U for aiming at their application to tokamak devices in China.

The collaboration programs implemented in FY2006 are summarized in Table 1 for each research category.

Main results of the collaborations are summarized as follows.

Table 1 STATISTICAL REVIEW OF CUP collaborations in FY2006

Title		J→C person (person·day)	C→J person (person·day)	**Total** person (person·day)
I-1A	Development of Advanced Plasma Heating for High-Performance Plasma Confinement	7 (44)	2 (56)	9(100)
I-1B	Development of Diagnostic and Control Methods for High-Performance Plasma Confinement	15 (93)	8 (161)	23 (254)
I-2A	Study on Plasma-Surface Interactions and Plasma Facing Materials	4(24)	6 (142)	10 (166)
I-3A	Atomic and molecular processes in plasma	4 (24)	4 (71)	8 (95)
I-4C	Development of High Pressure Plasmas for Environmental Application and Materials Processing	2 (12)	2 (22)	4 (34)
I-4D	Heating Behavior of Blast Furnace Slag Bearing High Ti Under Microwave	0 (0)	0 (0)	0 (0)
I-5A	Research of Ultrahigh Density Plasma (Inertial Confinement Fusion)	6 (36)	5 (39)	11 (75)
I-5B	Theory and simulation on Inertial Fusion Plasmas	4 (24)	3 (25)	7 (49)
II-A	Study on Reduced Activation Materials for Fusion	3 (20)	5 (48)	8 (68)
II-D	Development of superconducting key technology for advanced fusion reactor	5 (36)	5 (50)	10 (86)
II-E	Study of tritium behavior in solid and liquid breeder materials	2 (12)	3(55)	5 (67)
II-F	Advanced reactor design and technological integration	4 (15)	3 (48)	7 (63)
III-A	Study on Theoretical Analysis of MHD and Micro-instabilities in Plasmas	3 (23)	3 (57)	6 (80)
III-B	Study on Transport Theory: Code Development of Numerical Analysis and Confinement Improved Mode in Torus Plasmas	1 (7)	1 (15)	2 (22)
III-C	Physics of self-organization in Complex plasmas	1 (3)	1 (7)	2 (10)
III-D	Modeling of edge and diverter plasma and control of impurities and recycling particles	1 (6)	1 (12)	2 (18)
	Scientist Exchange	2 (8)	6(30)	8 (38)
Grand Total		64 (387)	58 (838)	122 (1225)

I-1A Development of advanced plasma heating for high performance plasma

This subject aims at establishing 1) high efficiency heating and non-inductive current drive, 2) improved confinement by means of profile control, and 3) sustainment of high performance plasma.

K. Saito (NIFS), T. Seki(NIFS) and R. Kumazawa (NIFS) visited to ASIPP hosted by Zhao Yanping made collaboration works for development of 1.5 MW ICRF heating system for the EAST tokamak. In particular, output limitation from an RF oscillator were discussed and found the cause due to parasitic oscillation. A steady-state dummy load with MW-level which is routinely employed on LHD were discussed for application to the system for EAST. Dr. Y. ZHAO (ASIPP) visited NIFS hosted by R. Kumazawa and got the data on the impedance of the dummy load in NIFS around relevant frequency range, of which data are very useful for the application to the ICRF system for EAST.

H .Idei (Kyusyu Univ.) visited SWIP hosted by L. YAN, and discussed the ECH system in HL-2A for further improvement of the operation. He proposed feedback control of applied corrector voltage, and optimum operation scenario of a polarizer for enhanced heating efficiency. Moreover, he showed HL-2A experimental group expected radial profiles of ECH power deposition and ECCD driven current in HL-2A, which are calculated by a ray-tracing code.

I-1B Development of diagnostics and control method for high performance plasma

Collaborations on diagnostic instrument development and improvement of the operational scenario were carried out for expecting applications to newly established tokamak devices such as EAST (ASIPP) and HL-2A (SWIP). Moreover, main research objectives in this category are better understanding of the confinement properties at core and edge plasmas of tokamak and helical devices using advanced plasma diagnostics with high accuracy and reliability.

Applicability of the LHD YAG laser system to the EAST tokamak was also discussed. The fast data processing method for the huge raw data created with the Thomson scattering system was studied using the presently existing new techniques.

Density fluctuation in JT-60U using FIR scattering diagnostics was studied in discharges with L-mode character and MARFE. The results were compared with data obtained from HT-7 tokamak (ASIPP). In the L-mode discharges the density fluctuation in frequency range near 200kHz was observed in both machines.

In EAST, the installation of NBI is planned to obtain the internal transport barrier(ITB). The ITB formation was studied in reversed shear configuration of JT-60U. In this collaboration the radial profile of neutron yield was measured in the ITB operation.

In ITER, the use of a mechanical limiter is now planned in order to reduce the plasma-wall interaction at the current startup phase. The interaction between plasma and the limiter during a start-up phase was analyzed at NIFS, using EMC3-EIRENE code.

Scientific workshop on “Improvement of Core Plasma Property” was held at ASIPP for discussing most influential collaborations of these topics in next 4 years. In the workshop, ten scientists from NIFS and two from JAEA participated for these discussions with Chinese scientists..

I-2A Study on plasma surface interactions and plasma facing materials

N. Ashikawa (NIFS) presented the CUP collaboration results at the international plasma surface interaction hosted by ASIPP. An initial experiment of long-term ICC (Ion Cyclotron wave Conditioning) during a strong magnetic field was successfully carried out in LHD. The removal rate of residual gases depends on the wide energy distributions of high-energy particles accelerated by ICRF power, and controlling this distribution is also important.

G. N. Luo (ASIPP) visited JAEA and carried out collaboration experiments. Tungsten (W) coatings on copper (Cu) substrate have been developed by means of vacuum plasma spraying (VPS) method employing a composition gradient interlayer so as to alleviate mismatch of the physical properties between Cu and W. The gradient interlayer shows dense and lamellar microstructure and the coating surface few micro-cracks. Directly-cooled VPS-W/Cu plasma-facing component (PFC) can withstand e-beam high heat flux irradiation of 20 cycles, 100 s/cycle, and heat loads of 9.6 MW/m^2.

J. S. Hu (ASIPP) visited NIFS and made surface analysis of plasma facing materials exposed in oxygen glow discharge cleaning in EAST. Under a long term plasma operation, the doped graphite tiles with 50~100μm SiC coating has high resistance to physical sputtering, shown by most tiles. The un-smooth surface of

the tiles, installation irregularity and ripples of magnetic field could influence distribution of erosions/depositions. The deposited material filled up the concaves of tiles and gaps of SiC coating.

I-3A Atomic and molecular processes in plasma

The Shanghai EBIT began to operate recently for spectroscopy of highly charged ions (HCIs). H-like and He-like Kr ions were produced, whose dielectronic recombination processes were observed. The size and the energy width of the electron beam were measured to be 70μm and 50eV at the energy of 20keV, respectively.

S. Ohtani (Univ. Electro-Communications) visited Shanghai for 3days in March 2007 to see the activity with the Shanghai EBIT and discussed the HCI research subjects in the collaboration.

Y. Zou (Fudan Univ.) organized the International Conference on Physics of EBIT: Conference on Physics at EBIT and Advanced Research Light Source (PEARL 2007) at Fudan Univ. in March, 2007. Two Japanese members were invited and gave lectures at the conference.

The Tokyo EBIT is operating actively with which many researchers are participating in the experiments. As one of the main subjects, atomic processes of a few electron-HCIs of heavy elements (Bi, W, Er, Ho…) were intensively investigated.

Y.Q. Fu (Fudan Univ.) visited Tokyo for one month from February 2007 to participate in the collaborative experiments. He has accumulated useful experiences in the various kinds of EBIT experiments, some of which were described in the recent publications..

Y.M. Li (Inst. of Appl. Phys. & Comp. Mathematics; IAPCM) is investigating atomic structures and processes of HCIs theoretically, and making collaborations with the Tokyo group intensively, in which several papers have been published.

C.Z. Dong (Northwest Normal Univ.) at Northwest Normal Univ. and F. Koike (Kitasato Univ.) published several papers of their collaborative studies on atomic processes of HCIs.

J.G. Wang (IAPCM) and M. Kimura (Kyushu Univ.) are collaborating for theoretical studies on heavy particle collisions.

J. Yan (IAPCM) visited NIFS for data evaluation of electron-impact ionization of M-shell Fe ions. The data are required to investigate ionization non-equilibrium plasmas in LHD and the solar atmosphere.

I-4D Heating behaviors of blast furnace slag bearing high Ti under microwave

In FY2006, Yoshikawa visited NIFS with H. Wang on 8/22. Discussion was made with M.Sato on the fundamental studies of the glass solidification of wastes containing heavy metals.

Because of three years collaboration works under this program, we obtained information on the steel production status in inland China and the Chinese environmental problems. We performed and finished fundamental researches on the microwave application of processing of wastes. Therefore, the program is to be terminated in this fiscal year.

I-5A Study of ultra-high density plasma (Inertial confinement fusion)

A meeting to summarize collaboration results obtained for last five years was held at Jiuzhaigou. A large progress in the areas of fast ignition and high energy-density science has been made. In particular, a collaboration experiment with a gold form-target is paid much attention from a point of view of enhanced production of fast electrons that play a key role in fast ignition.

II-D Development of superconducting key technology for advanced fusion reactor

W. Wu (ASIPP), L. Wang (ASIPP) and W. Pan (ASIPP) visited NIFS for ten days for discussing the superconducting (SC) key technologies of the electrical insulation, cooling schemes of large-scaled SC magnets and experimental results of the EAST and LHD. L. Xu (Shanhai Jiaotong Univ.) and L. Qiu (Zhejiang Univ.) visited NIFS for ten days for discussing the GM and pulse-tube refrigerators and their cooling methods. Research collaborations for multi-staged pulsed tube refrigerator and its application such as the direct-cooled HTS current-leads were discussed. Workshop on EAST, LHD, cryogenic system and HTS application for fusion research was held in NIFS, and twenty-one researchers participated in this workshop. Cooling technology, large-scaled superconducting magnets, cryogenic systems of EAST and LHD, and related technology for fusion SC magnet were discussed. Application for HTS coil, multi-staged pulse-tube refrigeration system, and advanced technology for fusion power plant were also discussed in this workshop.

T. Takao visited Shanghai Jiao-tong University for

discussing the HTS cable, fault current-limiter, and other components for the SC power applications. F. Sumiyoshi (Kagoshima Univ.), T. Mito (NIFS), Y. Hishinuma (NIFS), and S. Yamada (NIFS) visited IPP-CAS, IEE-CAS, and Tsinghua University for discussing the SC technology of fusion research. Results of commissioning, first plasma production and plasma experiments on the EAST, and overall characteristics of sub-cooled helical coil system on the LHD were discussed. Novel knowledge on new superconductors and their applications in fusion research were also exchanged.

II-E Study of tritium behavior in solid and liquid breeder materials

For the design of fusion blanket, it is important to elucidate the mechanism of hydrogen isotope behavior including tritium from a viewpoint not only experiment but also quantum chemical simulation. In especial, fundamental behaviors of tritium retention and recovery and its isotope effect in solid and liquid breeder materials are not sufficiently understood. Therefore, in this collaboration study, these fundamental knowledges will be accumulated for the blanket design.

In FY2006, defect formation process in solid breeder materials has been studied by using quantum chemical simulation and hydrogen isotope trapping process has been elucidated using XPS and TDS techniques. As a result, it was found that the de-trapping energy of lithium was higher than that of oxygen and that defect formation was controlled by lithium diffusivity. In addition, chemical state of metal in ternary lithium oxide would influence on the hydrogen isotope trapping. Under these results, future collaboration between Japan and China was discussed and more detailed study will be performed.

II-F Advanced reactor design and technological integration

T. Muroga (NIFS), A. Sagara (NIFS), T. Kunugi (Kyoto Univ.) and H. Hashizume (Tohoku Univ.) visited ASIPP for the purpose of initiating a new collaboration activity changing from the key element technology development phase to technological integration phase, with a goal of designing reactor system and extracting key technical issues and strategy for the integration. By the discussion during the visit, blanket thermofluid was designated as a new category in addition to the ongoing collaborations. As the first assignee from China in thermofluid field, Z. Zhu (ASIPP) visited Kyoto University and NIFS and carried out comparison of loop test facilities in China and Japan. J. Chen (SWIP) and Q. Huang (ASIPP) were assigned to NIFS and Hokkaido University, respectively for the purpose of enhancing collaboration on materials database including high temperature strength and irradiation effects.

III-A Study on theoretical analyses of MHD and micro -instability in plasmas

H. Sanuki (NIFS) visited ASIPP(Hefei) and SWIP(Chengdu) and carried out the discussions and collaborations with both theory and experimental group members (S. Zhu, Y. Hu, D. Zhou, G. Xu et al. in ASIPP and J. Q. Dong, A. Wang, theory group members and Q.W. Yang, L. W. Yan and HL-2A group members in SWIP). Sanuki discussed with J.Q. Dong to complete the Sokendai lecture notes associated with “Mathematical Tools to analyze Nonlinear Phenomena”, which has been presented in the seminar at both ASIPP and SWIP and the nonlocal stability analysis of microinstabilities and he also carried out some discussions on the stability of GAM modes, which is discussed together with J.Q. Dong, K. Itoh (NIFS) and Z. Gao (Tsinghua Univ.). He gave the seminar titled “ Selected Topics on Nonlocal Analysis of Plasma Waves and WKB Method”. Y. Kishimoto (Kyoto Univ.) visited ASIPP and SWIP and particularly, discussed with J. Li (SWIP) and others about future collaboration program and exchange plan. Also, he discussed with S. Wang (Fudan Univ.) et al. in ASIPP and J.Q. Dong, A. Wang et al. in SWIP about couple of topics such as 3D simulation on drift–type turbulence with zonal flow. T. Yamagishi (NIFS) visited SWIP and he discussed with not only theory group members(J.Q. Dong, A. Wang et al.) but also experiment group members about topics associated with temperature gradient modes,trapped electron mode(TEM) and related anomalous transport. He gave the seminar titled “ Linear gyrokinetic stability and quasi-linear fluxes in s-α tokamak”.

Z. Gao(Tsinghua Univ.) visited NIFS and had collaboration with H. Sanuki and K. Itoh. Z. Gao discussed theory of zonal flow and GAM under close collaboration with K. Itoh, H. Sanuki and J.Q.Dong. Particularly, he worked on the topics for multiple eigenmodes of geodesic acoustic mode (GAM) in collisionless plasmas and he also discussed with A.

Fujisawa (NIFS) on the experimental observations of Zonal flow in CHS experiments. Y. Hu(ASIPP) visited NIFS and had discussions with H. Sanuki and theory group members. He worked on a couple of topics, (1) Numerical analysis for effects of toroidal rotation on plasma equilibrium such as beta, pressure and current profiles etc., and(2) Current reversal equilibrium configuration in the rotation equilibrium.

III-B Study on transport theory code development of numerical analysis and confinement improvement

S. Toda(NIFS) visited ASIPP and discussed with the theory group members(Y. HU, D. Zhou et al.) and G. Xu(ASIPP) about electric field formation mechanism and related anomalous transport. He gave a seminar titled "Transport Analysis of Electron Internal Transport Barrier in toroidal Helical Plasmas". Particularly, he had a discussion about similarlity and difference between tokamak and helical systems associated with electric field generation and zonal flow. Toda introduced his transport model, which is based on the neoclassical transport model with anomalous effect. He carried out the transport calculation and succeeded to explain the electric field bifurcation phenomena and internal transport barrier for temperature profile.

III-C Physics of self- organization in complex plasmas

R. Horiuchi (NIFS) visited the IAPCM, and gave a lecture entitled "Cross-Hierarchy Model for Magnetic reconnection". This lecture was on the multi-scale simulation to investigate magnetic reconnection as a fundamental process of self-organization in complex plasmas. The numerical scheme is programmed so as to interlock MHD simulation describing macro-scale physics and PIC simulation describing micro-scale physics. R. Horiuchi carried out the collaboration work on the self-organization and the role of magnetic reconnection in rapid energy release in complex plasmas with S. P. Zhu (IAPCM) and his colleagues during his stay in China.

J. Li (IAPCM) visited NIFS and gave a lecture entitled "Radiation Transfer in A Gold Tube filled with Plastic Foam". Based on his talk, he discussed the complexity in plasmas including hydrodynamic, heat conduction, and radiation transport with R. Horiuchi and S. Ishiguro (NIFS). Especially, their discussion was focus on the radiation hydrodynamic simulation model in the cylinder filled with foam, which was developed to simulate the radiation flux experiments carried out on SG-II laser facility.

From these collaboration works it was confirmed that the development of multi-scale simulation scheme is an important task for the analysis of complexity in plasmas controlled by multi-scale and/or multiple physics, and we exchanged important information of numerical simulation techniques and physics of self-organization..

III-D Modeling of edge and Diverter plasma and control of impurities and recycling particles

A.Takayama (NIFS) stayed in SWIPP and constructed the database for the edge-plasma transport code UEDGE to analyze the performance of edge-plasma in HL2A tokamak device. During his stay he gave the seminar entitled "Outline of UEDGE edge-plasma transport code." Y. Pan (SWIPP) stayed in NIFS and carried out the collaboration research with Y. Tomita (NIFS) on "Initial divertor design of HL-2M using B2-EIRENE code", which is designed to operate with elongated plasma cross-sections and in the double null or single null divertor configurations. In this collaboration research the optimum configuration of divertor plates to reduce the heat flow on them was discussed.

(Toi, K., Yamada, S.)