9. Bilateral Collaboration Research Program

Ten years has passed since the bilateral collaboration research program started as the third collaboration framework of NIFS. The purpose of this program is to enforce the activities of nuclear fusion research in university research centers by using their middle-size experimental facilities as the joint-use ones for all the university researchers in Japan. The current program involves six university research centers;

- Plasma Research Center, University of Tsukuba
- Laboratory of Complex Energy Process, Institute of Advanced Energy, Kyoto University
- Institute of Laser Engineering, Osaka University
- Advanced Fusion Research Center, Research Institute for Applied Mechanics, Kyushu University
- Hydrogen Isotope Research Center (HIRC) of University of Toyama
- International Research Center for Nuclear Material Science (IRCNMS), Institute for Material Research, Tohoku University.

The latter two institutes were incorporated in the frame work of bilateral collaboration research program in FY2010 to extend the research field towards the fusion engineering because both institutes have special facility to promote fusion engineering research, that is, neutron irradiation in IRCNMS and tritium handling in HIRC. The facilities in other four institutes are for fusion plasma experiments.

In this collaboration program, each research center can have its own collaboration programs using its major facility so that the researchers of other universities can visit and carry out their collaboration research there as if the facility belongs to the NIFS. It is unique and important that all these activities are supported financially by the NIFS as the research subjects of the NIFS bilateral collaboration research program. The subjects of the bilateral collaboration research program are subscribed from all over Japan every year as one of the three frame works of NIFS Collaboration Program. The collaboration committee, which is organized under the administrative board of NIFS, examines and selects the subjects.

From FY2010, the second mid-term period started in the National Institutes of Natural Sciences as well as in all national universities in Japan. In this plan, the NIFS enounces to promote (1) the pursuit of high performance plasma in LHD, (2) developing of physical models and numerical simulation method to build numerical test reactor, and (3) fusion engineering research to establish technical basis for designing the helical DEMO. These objectives are to be attained by enhancing collaborative research.

The extension of the Bilateral Collaboration towards fusion engineering studies is one of the important actions of the mid-term plan. The IRCNMS Tohoku Univ. and the HIRC Univ. Toyama now collaborate with other four plasma research centers, main topics of which is evaluation of the first wall materials that suffered from high heat or neutron flux.

It is also recommended that the cooperating program among four plasma research institutes is endorsed. The high power gyrotron is the key component in this collaboration. Univ. Tsukuba has capability of developing high performance gyrotron which can be used for driving electric current in the spherical tokamak QUEST in Kyushu Univ. A good result obtained in this collaboration is one of the topics of this year. The topics of this year are as follows;

(1) The GAMMA 10 mirror machine of Univ. Tsukuba is now utilized as the world’s largest divertor plasma simulator (PDX), the distinct feature of which are large diameter and high ion temperature. In this year, additional ICRF antennas have been installed in the anchor and plug/barrier cells in order to increase both particle and heat fluxes at the west end where the PDX is installed. A remarkable increase of the end-loss flux up to 10^{23} $m^{-2}sec^{-1}$ has been observed when ICRF waves are injected in both east and west anchor cells at the same time.
A plasma irradiation experiments onto a new V-shaped target have been started. This experimental module consists of rectangular chamber (cross-section of 500×500 mm, 700 mm in length) with an inlet aperture of 200 mm and two tungsten plates (350×300 mm) are mounted in V-shaped with their variable open angle from 15 degree to 80 degree. The first experiment for realizing detached plasma state from the high-temperature plasmas has been performed using H_2 and noble gas injection. As increasing the amount of injection gas, both particle and heat fluxes continuously decrease. It is observed that T_e is drastically reduced from few tens eV to ~3 eV due to the Ar injection.
As for the Gyrotron development, the output power of 1.25 MW at 28 GHz and 0.87 MW at 35.45 GHz from the <u>same</u> gyrotron tube have been achieved with design improvement, which is the first demonstration of the dual frequency operation in lower frequency tube. The output power of 600 kW for 2 sec at 28 GHz is also demonstrated. This tube is applied to QUEST on Kyushu University and has given a new operating region of EC non-inductive driven current in higher density plasma.

(2) In Heliotron J of Kyoto Univ., the six schemes for the collaboration research have been selected; (1) confinement improvement by controlling magnetic configuration and related plasma self-organization, (2) instability suppression by controlling magnetic configuration, (3) ECH/EBW heating physics, (4) toroidal current control, (5) fueling control and exhaust control of heat and particles, and (6) development of the FIR measurement system and so on. As for the study of high

density plasma operation, high-intensity gas-puff fuelling (HIGP) is effective to produce the plasmas with electron density higher than $1\times10^{20}m^{-3}$, where the plasma is maintained by the balanced NBI heating with 1.1 MW in injection power and the plasma energy reaches about 6 kJ. After stopping HIGP, increases in the ion/electron temperatures and the toroidal co-rotation are simultaneously observed in the peripheral (r/a>0.7) region. At that time, the reduction in the density fluctuation at the edge region is also observed in accordance with the sudden drop of the H_α/D_α intensity. This type of high-density condition is achieved only in the low ε_t configuration. The Electron Cyclotron Current Drive (ECCD) experiments have been made for stabilization of energetic-ion-driven MHD. ECCD has been applied to ECH+NBI plasmas in which Alfven Eigen Modes are excited by energetic ions. The energetic-ion-driven MHD mode has been fully stabilized by centrally localized second harmonic 70-GHz X-mode ECCD.

(3) At ILE Osaka University, elemental researches to develop fast plasma heating applicable to fusion reactor technology development have been conducted using the fast ignition of deuterium targets. The researches consist of target fabrication, laser development, simulation technology and plasma experiments. As for target fabrication, the reproducibility of a foam shell was improved, which supports the solid hydrogen layer. A series of fast-ignition laser-driven inertial fusion researches has been performed to understand energy coupling efficiency from a heating laser to a fuel core. There are two difficulties in the fast-ignition scheme, “unstoppable” and “diverging” of a relativistic electron beam (REB) generated by an intense laser pulse. Guiding of the REB by strong magnetic field produced by a laser-driven capacitor-coil target is essential to overcome these difficulties. Using PIC simulation, it is shown that the hot electrons generated by the intense laser of 10^{18}-10^{20} W/cm^2 are collimated by the strong magnetic field of 1-10kT. Generation of 1 kT of magnetic field was demonstrated by using capacitor-coil. Enhancement of the heating efficiency is expected by implementing this external magnetic field in the fast-ignition experiment.

(4) The studies were proceeded on non-inductive current drive and particle recycling study in steady state divertor configuration in QUEST of Kyushu Univ.. The Electron Cyclotron Current Drive (ECCD) effect was clearly observed. In non-inductive current drive experiments only by the 28 GHz injection, a plasma current of 54 kA was sustained for 0.9 sec in inboard off-axis heating scenario. High non-inductive plasma current of 66 kA was also attained by the 28 GHz ECH/ECCD in the Spherical Tokamak (ST) configuration.
Hydrogen wall pumping is studied in steady state tokamak operation (SSTO) of QUEST. Duration of SSTO is up to 10 minutes. Wall pumping is dominant during most SSTO, and the wall pumping rate is $1\text{-}6\times10^{18}$ H/s. After plasma termination, the wall started to release H_2, and the release rates were in range of 10^{20} H/s. H_2 retention in the fully metal tokamak is found to be around 70-80% of injected particles during SSTO.

(5) It is well known that control of fuel particles in the reactor core is indispensable to make a steady operation for a long term. A part of energetic particles of deuterium and tritium is implanted into the plasma-facing materials (PFMs) and simultaneously released from them during the operation. Therefore, from viewpoint of stable fuel balance, it is of a great important issue to make clear isotope effects on absorption / desorption rate of hydrogen isotopes. From these viewpoints, new irradiation device of tritium ions was prepared in HIRC Univ. Toyama, and isotope effects on desorption behavior of hydrogen isotopes implanted by glow discharge into stainless steel as a model material have been studied using temperature-programmed desorption spectroscopy.

(6) At the IMR-Oarai Center, collaboration researches are conducted to clarify the effects of neutron irradiation on the behavior of hydrogen isotopes and helium in the candidate plasma facing materials including tungsten and its alloys, and then to assess the feasibility of their use in future fusion reactors. As a first step to conduct this key research subject, a Thermal Desorption Spectrometer with an Ion Gun (IG-TDS), was installed in the radiation controlled area at the Center through fiscal 2010-2012. The IG-TDS is open to researchers in Japan and overseas. As the second step, to increase the capability of the IG-TDS device, it is planned to unite the IG-TDS to a linear plasma irradiation device with the range of ion energy and high flux density required for steady state plasma relevant to the divertor plasma condition. The development of a new, compact divertor plasma simulator with a high efficient dc plasma source, designated as C-DPS, was initiated in 2013 at Nagoya University based on the prototype of the C-DPS device. The system of C-DPS integrated with the existing IG-TDS device, C-DPS/IG-TDS, will be completed and installed at the Center in fiscal 2014.

In this year, 116 subjects were adopted in this category, among which were 24 at Tsukuba University, 20 at Kyoto University, 24 at Osaka University, 24 at Kyushu University, 14 at Univ. Toyama, 8 at Tohoku Univ. and 1 at NIFS (Activity on all-Japan ST research program). All of these collaborations have been carried out successfully.

Among these subjects, 23 topics from University of Tsukuba, 17 from Kyoto University, 23 from Osaka University, 23 from Kyushu University, 14 from Univ. Toyama, 8 from Tohoku University are reported.

(Kaneko, O.)