8. Bilateral Collaboration Research Program

The purpose of the Bilateral Collaboration Research Program (BCRP) is to enforce the activities of nuclear fusion research in the universities by using their middle-size experimental facilities of the specific university research centers as the joint-use facilities 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 BCRP started in FY 2003 with 4 plasma research centers listed above. The latter two institutes were incorporated in the frame work of BCRP in FY2010 to extend the research field from plasma research to the fusion engineering because both institutes have special facilities to promote fusion engineering research, that is, neutron irradiation in IRCNMS and tritium handling in HIRC. The facilities in other 4 institutes are for fusion plasma experiments.

In the BCRP, each research center can have its own collaboration programs using its major facility so that the researchers of other universities can visit the research center 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 research 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 BCRP 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 the capability of developing high performance gyrotron which can be used for driving electric current in the spherical tokamak QUEST in Kyushu Univ. Another topic of this year is that a small plasma irradiation device (Compact Divertor Plasma Simulator) developed by Nagoya University has been equipped in the radiation control room in Oarai Center of Tohoku University. It is the world's first facility that the research is possible of the plasma irradiation effect on the neutron irradiated material.

The topics of this year are as follows;

(1) The GAMMA 10 mirror machine of Univ. Tsukuba utilizes its large plasma flow at the end-cell as a divertor plasma simulator (PDX), the distinct features of which are the large diameter, the high ion temperature and the strong magnetic field. The ITER relevant level heat flux of 10 MW/m^2 can be obtained at the end-cell, and the divertor simulation experimental module (D-module) has been installed. The module has a V-shaped target plate as a closed divertor structure. The target plate can be changed the angle and the pumping speed in the D-module is controllable. Two tungsten plates are mounted in V-shaped and these plates can be heated up to 300 degrees centigrade for studying interactions between plasma and wall materials under high temperature.
Formation of detached plasma has been studied in the D-module. The decrease of the electron temperature and the electron density at the corner of the V-shaped target was observed with increase in H_2 gas pressure. The rollover of the electron density was also observed. These results would be due to interaction between incident plasmas and H_2 gas neutrals. The effects by other noble gases (Ar and Xe) are also studied. In the case of Xe injection, the ion saturation current (I_{isat}) measured near the V-shaped corner is reduced to 20 % at the plenum pressure of 1 bar, however the reduction of I_{isat} in the case of Ar remains small in spite of considerable reduction of T_e in both cases. This result indicates that Xe has stronger effect on the detached plasma formation than Ar.
As for the gyrotron development, the design of a dual-frequency gyrotron which can operate at 28 GHz and 35 GHz has been completed. The targets for a 28 GHz operation are 2 MW 3 s and 0.4 MW CW, while that for a 35 GHz operation is 1 MW 3 s. This dual-frequency gyrotron is developed for many users; GAMMA10/PDX,

QUEST, NSTX of Princeton Plasma Physics Laboratory and Heliotron J of Kyoto University.

(2) In Heliotron J of Kyoto Univ., the six schemes for the collaboration research have been selected; (1) confinement improvement through controlling magnetic configuration and related plasma self-organization mechanisms, (2) ECH/EBW heating physics, (3) plasma production by micro-wave assisted NBI heating and high beta plasma confinement, (4) boundary plasma control in an advanced helical device, (5) instability suppression by controlling magnetic configuration, and (6) plasma current control in an advanced helical device.
The parallel flow dynamics was investigated in the tangential NBI plasmas with different magnetic field ripple structure, and it is found that in the core region where the plasma is in the plateau regime the parallel flow velocity under the high magnetic field ripple configuration is smaller than that in the low case. The results are consistent with the neoclassical prediction.
The energetic-ion-driven MHD instabilities such as energetic particle modes (EPM's) are observed in the Heliotron J, and it was demonstrated that the EPMs could be controlled by means of both positive and negative magnetic shear induced by EC driven plasma current.
As for the study on high-density operation, A high density state in the whole confinement region with its steep gradient in the peripheral is realized after high-intensity gas while the electron and ion temperature keep almost the same level, resulting the enhancement of the stored energy. It is indicating transition to an improved confinement mode.

(3) At the 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, integrated implosion experiments, and simulation technology and reactor target design.
By completing a full set of large dielectric gratings in the pulse compressor, the LFEX laser was operated with four beams. The total output energy of 2 kJ was obtained in 1~2 ps pulse duration (FWHM). Temporal pulse waveforms of all four beams have been directly measured in real high power shots. Remarkable was the high intensity contrasts of $\sim 10^{-10}$ at 180 ps before the main pulse, which was measured by using a monitor compressor after the optical parametric amplifiers. Adding a plasma mirror improved the contrast for $<10^{-11}$, which was verified by plasma experiments and theoretical analysis.
The recent experimental results clarify three scientific challenges to achieve high heating efficiency of the fast ignition scheme with the current GEKKO and LFEX systems: (i) suppression of high energy tail of relativistic electron beam (REB), (ii) guiding and focusing of REB to a fuel core, and (iii) formation of a high areal-density core.
As for the target technology, the injection, velocity and pointing achieved their final goal but the "tumbling" of the target was too large.

(4) In the QUEST machine of Kyushu university, successful production of high β_p plasma ($\varepsilon\beta_p \geq 1$) and its long-pulse sustainment by fully non-inductive current drive with the help of a modest power (< 100 kW) Electron Cyclotron Waves is demonstrated. We found that (i) high β_p plasma is naturally self-organized to form a stable natural Inboard Poloidal field Null (IPN) equilibrium, (ii) a critical β_p, which defines the transition boundary from Inboard Limiter (IL) to IPN equilibria and (iii) a new feature of plasma self-organization to enhance its negative triangular shape to sustain high β_p. This result shows a relatively simple method to produce and sustain high β_p plasma close to the equilibrium limit in a stable configuration exploiting its self-organization property. Furthermore, spontaneous toroidal rotation is observed in IPN configurations as well as open magnetic field line under high magnetic curvature, which is sustained in steady state for the entire plasma duration.
Progression from low recycling (LR) to high recycling (HR) was observed in full non-inductive long duration discharges up to 5 minutes on QUEST. Transitional repetitive behavior between LR and HR was induced by periodic gas puffing and the period to recover to LR, τ_{rec}, was gradually prolonged. The period, τ_{rec} normalized by gas rate has a linear relation to time-integrated H_α. The experimental observation indicates that the hydrogen recycling rate is dominantly depending on hydrogen fluence to the wall.

(5) A new irradiation device of tritium ions was established in the HIRC of Univ. Toyama. The device has capable of DT^+ ion flux of $\sim 1 \times 10^{17}$ $m^{-2}s^{-1}$. An air-lock system is also connected with the irradiation device to shorten evacuation time. Three kinds of sample size are applicable to the tritium irradiation, and two or three samples can be simultaneously irradiated under the similar conditions. The effects of radiation damage by pre-irradiation of helium ions on tritium retention were examined. Tritium retention initially decreased with increasing in irradiation fluence of tritium ions, but the increase tendency appeared above some fluence which value increases linearly to the fluence of He ions.
Studies of tritium behavior on various materials (mostly tungsten) were carried out by many collaborators.

(6) At the IRCNMS (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. The Thermal

Desorption Spectrometer with an Ion Gun (IG-TDS) was introduced in 2012 and is open to researchers. In 2014 a linear plasma irradiation device developed by Nagoya University (Compact Divertor Plasma Simulator, C-DPS) was equipped in the radiation controlled area. The C-DPS has the capability of high density plasma generation (4.5 x 10^{18} m^{-3} for He and 1.2 x 10^{18} m^{-3} for D). The TDS is connected with the C-DPS and the material sample irradiated by plasma can be transferred to the TDS without air exposure.

In this year, 120 subjects were adopted in this category, among which were 25 at Tsukuba University, 22 at Kyoto University, 26 at Osaka University, 21 at Kyushu University, 11 at Univ. Toyama, 9 at Tohoku Univ. All of these collaborations have been carried out successfully.

Among these subjects, 23 topics from University of Tsukuba, 19 from Kyoto University, 23 from Osaka University, 23 from Kyushu University, 11 from Univ. Toyama, 8 from Tohoku University are reported.

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