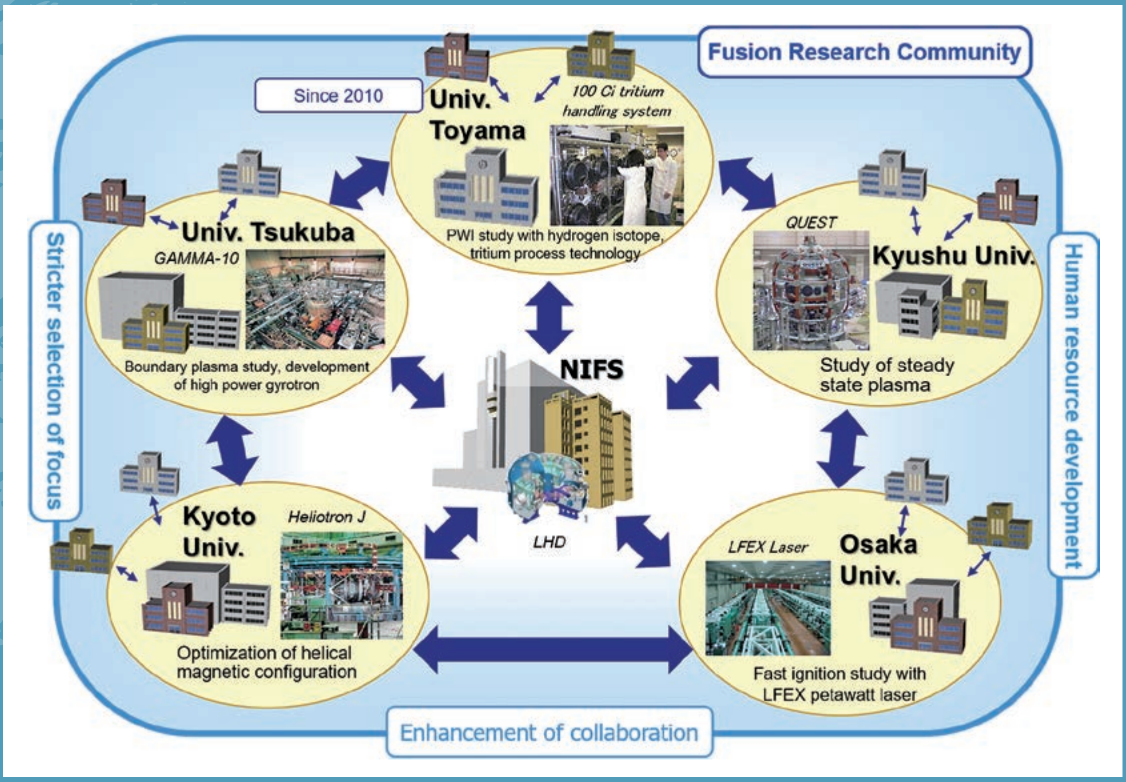
7. Bilateral Collaboration Research

The purpose of the Bilateral Collaboration Research Program (BCRP) is to reinforce the activities of nuclear fusion research in universities by using their middle-size experimental facilities of specific university research centers as joint-use facilities for all university researchers in Japan. The current program involves five university research centers as follows:

- 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, University of Toyama

In the BCRP, each research center can have its own collaboration programs, using its main facility. Researchers at other universities can visit the research center and carry out their own collaboration research there, as if the facility belongs to NIFS. These collaboration research efforts are supported financially by NIFS as research subjects in the BCRP. They are proposed from all over Japan every year. The collaboration research committee, which is organized under the administrative board of NIFS, examines and selects the subjects.

(Y. Todo)


Fusion Research Community
Since 2010
Univ. Toyama
100 Ci tritium handling system
PWI study with hydrogen isotope, tritium process technology
Univ. Tsukuba
GAMMA-10
Boundary plasma study, development of high power gyrotron
QUEST
Kyushu Univ.
Study of steady state plasma
NIFS
LHD
Kyoto Univ.
Heliotron J
Optimization of helical magnetic configuration
LFEX Laser
Osaka Univ.
Fast ignition study with LFEX petawatt laser
Stricter selection of focus
Human resource development
Enhancement of collaboration

University of Tsukuba

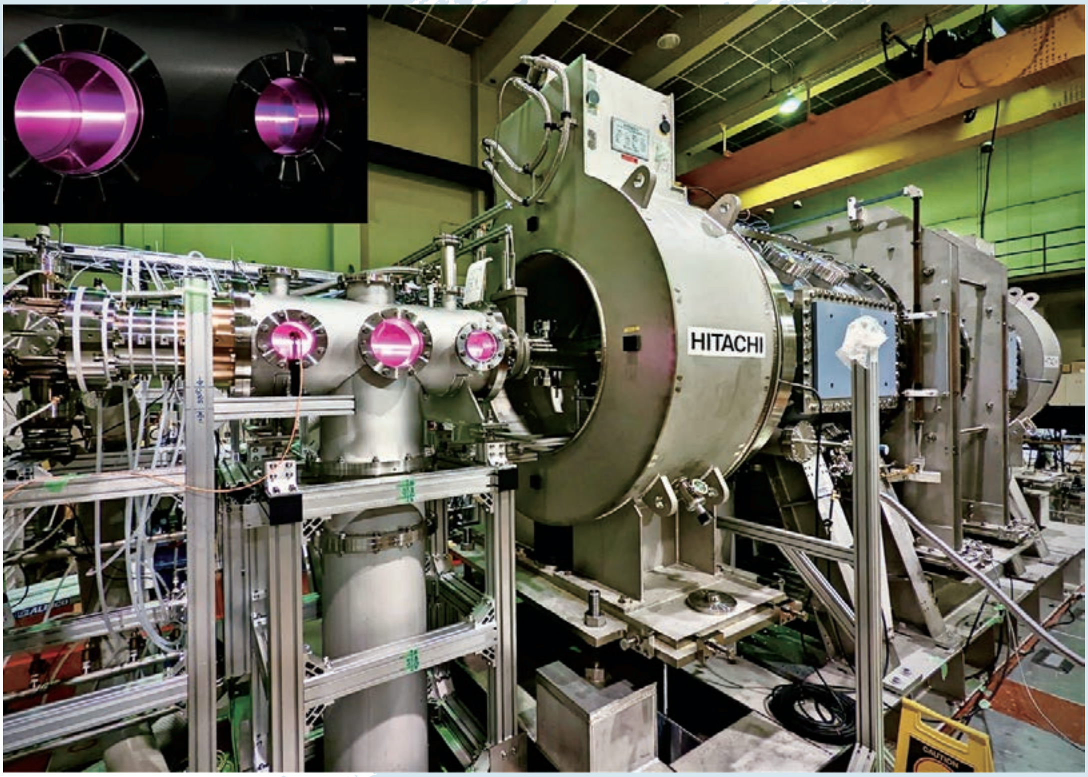


Fig. 1 Bird's eye view of GAMMA 10/PDX.

Highlight

Study of boundary plasmas by making use of open magnetic field configuration and development in high power gyrotrons towards the DEMO project

In the Plasma Research Center, University of Tsukuba, studies of boundary plasma and development of high-power gyrotrons have been performed under a bilateral collaboration research program. In GAMMA 10/PDX, processes of molecular activated recombination (MAR) have been studied by using a fast framing camera system with an arbaa prism to simultaneously measure spatio-temporal structures of four line-emissions in front of a V-shaped target, which is exposed to end-loss plasma. Advanced diagnostic systems such as a multichannel (multi-frequency) Doppler reflectometer and dual-path Thomson scattering have been developed.

A new linear plasma device Pilot GAMMA PDX-SC (Fig. 1) has been constructed. A pair of NbTi superconducting coils and a pair of Cu coils were installed to produce a simple mirror configuration. The first plasma was successfully achieved in October 2022. The source plasma was produced by a hot cathode arc plasma discharge with LaB_6 and it was injected into a main chamber (a central cell). After the first plasma operation, ICRF and ECH antennas were installed in the main chamber.

A divertor simulation study has been carried out by using end-loss plasma of GAMMA 10/PDX. A divertor simulation experimental module (D-module) was installed in the end region of GAMMA 10/PDX to be exposed to the end-loss plasma. Recently, we have developed a fast framing camera system with an arbaa prism to simultaneously measure spatio-temporal structures of four line-emissions in front of a V-shaped target in the D-module. In this time, the emissions of H_{α} (656 nm), H_{β} (486 nm), N_2 1st positive (760 nm) and NI (940 nm) lines were simultaneously measured to investigate processes of molecular activated recombination (MAR) due to additional supply of H_2 and N_2 gases. The intensity ratio of $I_{H\alpha}$ and $I_{H\beta}$ is a good indicator of the occurrence of hydrogen MAR (H-MAR), since $I_{H\alpha}$ is enhanced by the chain processes of H-MAR but $I_{H\beta}$ is not enhanced. When the H_2 gas was supplied in front of the V-shaped target, the intensity ratio of $I_{H\alpha}$ and $I_{H\beta}$ ($I_{H\alpha}$ / $I_{H\beta}$) started to increase on the axis between the upper and lower targets and then the area with the high intensity ratio expanded to radial and upstream directions. This means the spatio-temporal progress of the H-MAR area. In the case of N_2 gas supply, on the other hand, the intensity ratio of $I_{H\alpha}$ and $I_{H\beta}$ did not increase, unlike the case of H_2 gas supply, indicating that H-MAR was suppressed. However, a microwave interference measurement indicated that the electron density at the central region between the targets was significantly decreased. This meant that H-MAR was suppressed but nitrogen MAR (N-MAR) was enhanced by the N_2 gas supply.

ECH experiments have been conducted to generate and control high heat flux to develop an edge localized mode (ELM)-like intermittent heat load pattern for divertor simulation studies. For higher heat flux study, a new mirror antenna was developed to generate higher heat flux and concentrate the heating power on the axis. More than 0.5 MW was injected into GAMMA 10/PDX plasma contributing to producing the endplate potential of above 5 kV and a heat flux of over 30 MW/m^2.

As for advanced diagnostic development, a multichannel (multi-frequency) Doppler reflectometer system has been developed to simultaneously measure turbulent fluctuation flows at different radial locations in the central cell of GAMMA 10/PDX. A flow profile was obtained during ICRF anchor heating, showing a radially sheared structure formation in the edge region. Both fluctuation flow and $E \times B$ flow profiles showed peaks at edge region which indicates the influence of Er on flow structure formation. A dual-path Thomson scattering (DPTS) system has been developed to simultaneously measure the electron temperatures and densities in both the core and edge region of GAMMA 10/PDX. The laser path of the DPTS is divided in two to inject the central cell and end cell plasma. In the central cell TS, a multi-pass TS system has been constructed for improving the signal intensity and time resolution. Moreover, the dual-pass system has been developed in the end cell TS system.

Validation of a plasma fluid model based on an anisotropic ion pressure (AIP model) proceeded from both theoretical and experimental points of view. In GAMMA 10/PDX simulations with the AIP model, the effects of the heat-flux limiting coefficients and particle/heat sources on plasma profiles have been studied. An analytical ion transport model has been updated to compute the electrostatic potential self-consistently. The contribution of magnetic-moment conservation to the parallel ion energy increment in the end region was experimentally estimated by using two kinds of ion energy analyzers.

In order to further promote the divertor simulation study, a new linear plasma device, Pilot GAMMA PDX-SC, (Fig. 1) has been constructed. A pair of NbTi superconducting coils with a bore of 0.9m and a pair of Cu coils with a bore of ~1.5 m are utilized to produce a simple mirror configuration. The maximum magnetic field is 1.5 T and the mirror ratio is 20~30. The first plasma was successfully achieved in October 2022. The source plasma was produced by a hot cathode arc plasma discharge with LaB_6 and it was injected into a main chamber (a central cell). Operating parameters of the cascade arc plasma source were the following: discharge current 20 A, discharge voltage 180 V and gas pressure < 1Pa. After the first plasma operation, ICRF and ECH antennas were installed in the main chamber. Moreover, three concentric ring plates were installed at the end of the main chamber to apply the bias voltage to the peripheral plasma for suppression of MHD instability.

(M. Sakamoto)

Kyoto University

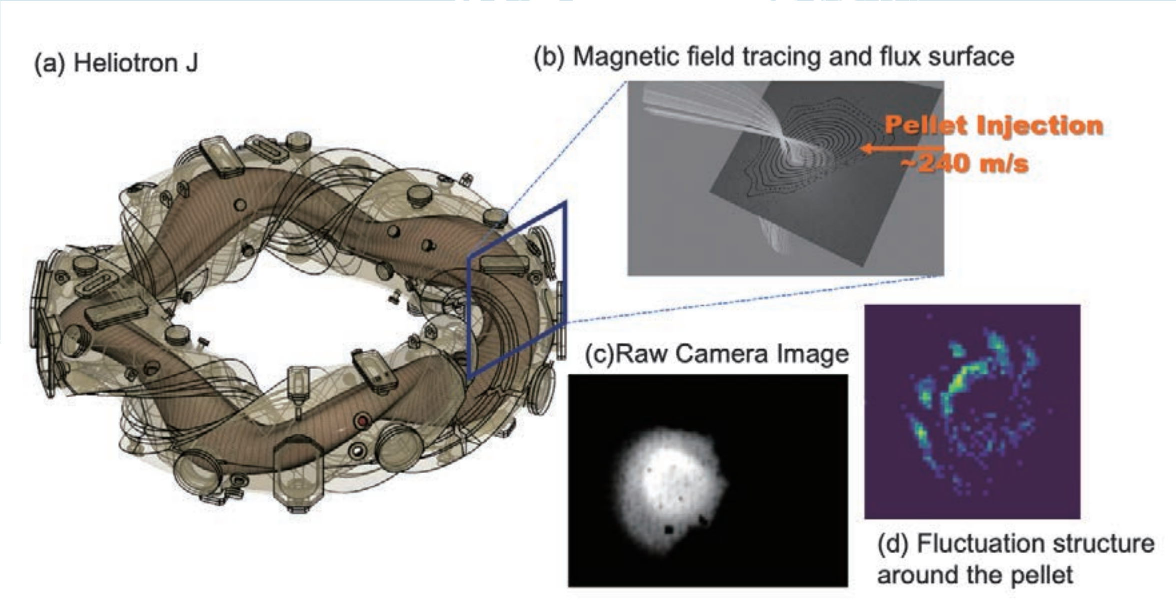


Fig 1. Heliotron J (a) and local magnetic field structure at pellet injection trajectory (b). Fluctuation structure appeared by signal processing of movie image (c) recorded using fast camera (d).

Highlight

Three-dimensional dynamics of fluctuations rotating around pellet appearing during pellet ablation process

The Heliotron J device features a wide flexibility of configuration control. Such flexibility also implies complexity in determining the propagation direction of a transient event in particle fuelling, such as gas puffing or pellet injection, concerning the magnetic field configuration.

This fiscal year, we have reported the formation of fluctuation structures in a pellet plasmoid during the pellet ablation process that had been observed using a fast camera. The fluctuation has a normalized fluctuation level of ~ 15% and propagates around the moving pellet across the magnetic field. Therefore, we applied an algorithm by comparing the fluctuation structures with the shape of magnetic field lines calculated with a field line tracing code, as shown in Fig. 1. We have successfully reconstructed the spatiotemporal structure of the fluctuations during the pellet ablation process. The fluctuations are at locations displaced toroidally from the pellet and propagate in the cross-field direction around the pellet axis along the field line, indicating a three-dimensional behavior and structure of fluctuations. They would be driven by a strong inhomogeneity formed around the pellet and invoke a relaxation of the gradient through a cross-field transport induced by the fluctuations, which could affect the pellet ablation and pellet fueling processes. Such fluctuations can be ubiquitously present at the inhomogeneity formed around a pellet in the pellet ablation process in fusion devices, depending on the magnetic configuration. (S. Ohshima *et al.*, Sci Rep **12**, 14204 (2022))

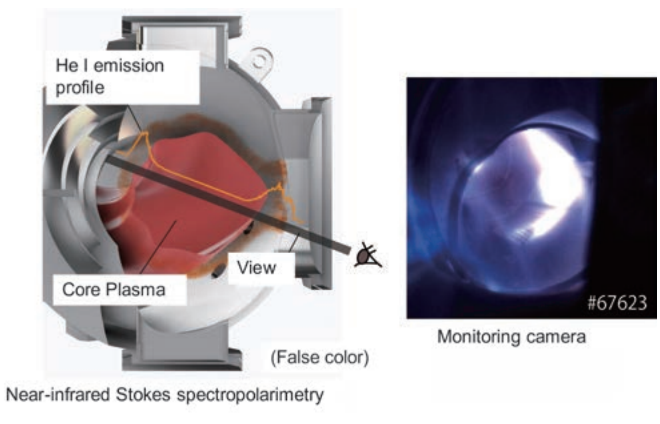
Research Topics from Bilateral Collaboration Program in Heliotron J

The main objectives of research in the Heliotron J device under this Bilateral Collaboration Program are to experimentally and theoretically investigate the transport and stability of fusion plasmas in an advanced helical field and to improve plasma performance through advanced helical-field control. Picked up in FY2022 are the following seven key topics; (1) plasma transport control by magnetic field coordination and related plasma structure formation control in advanced helical plasmas, (2) the ECH/EBW heating mechanism and its performance improvement, (3) high-density NBI plasma generation and high-beta plasma confinement, (4) boundary plasma control in advanced helical plasmas, (5) instability control by magnetic field coordination in advanced helical plasmas, (6) experimental study on plasma current control in advanced helical plasmas, and (7) study on new operating scenarios and a data analysis method.

Twenty-three projects, including our baseline one, were adopted. High magnetic field experiments were conducted for about four months, from late October to the beginning of February.

Spatially resolved measurement of helium atom emission line spectrum in scrape-off layer by near-infrared Stokes spectropolarimetry

Stokes spectropolarimetry is used to spatially invert the viewing-chord-integrated spectrum, based on the correspondence between the given magnetic field profile along the viewing chord and the Zeeman effect appearing on the spectrum. We increase the relative magnitude of the Zeeman effect by observing a near-infrared emission line based on the greater wavelength dependence of the Zeeman effect than of the Doppler effect. Utilizing the increased Zeeman effect, we can invert the measured spectrum with a high spatial resolution by a Monte Carlo particle transport simulation, reproducing the measured spectra with the semiempirical adjustment of the recycling condition at the first walls. The inversion result reveals that when momentum exchange collisions of atoms are negligible, the velocity distribution of core-fueling atoms is mainly determined by the initial distribution at the time of recycling. The inversion result is compared with that obtained using a two-point emission model used in previous studies. The latter approximately reflects the parameters of atoms near the emissivity peak. (T. Chatani *et al.*, Sci Rep **12**, 15567 (2022))



Schematic configuration of near-infrared Stokes spectropolarimetry

Many research topics have continuously made progress with collaborative researchers under the Bilateral Collaboration Program in the Heliotron J project. Progressing are (i) electromagnetic wave measurements such as multi-line-of-sight interferometry and multi-channel reflectometry, (ii) spectroscopic diagnostics such as high sensitivity beam emission spectroscopy for local turbulent fluctuation measurements and fast Stark spectroscopy for pellet ablation clouds, (iii) particle and heat measurements of peripheral plasma flow and heat flux, and (iv) active diagnostics such as multi-pass Thomson scattering measurements, event-triggered Thomson scattering, and laser blow-off spectroscopy.

(K. Nagasaki)

Osaka University

Study on Fusion Fast Ignition System with Ultra-High Dense Plasma

We have performed fundamental research on laser fusion with a fast ignition (FI) scheme, which enables us to separate the laser fusion process into three phases, i.e., compression, heating, and burning, using the GEKKO XII and LFEX laser systems at the Institute of Laser Engineering, Osaka University. The research included (a) a high-density implosion experiment, (b) a fast heating experiment using a mixed laser light of fundamental and second harmonics, and (c) the effects of a kilo-tesla magnetic field on ignition burning in the FI. In FY2022, the following is a summary of our achievements through the Bilateral Collaboration Research Program with NIFS and other collaborators from universities and institutes (NIFS12KUGK057 as the base project).

High-density implosion experiment

Laser fusion requires the generation of high-density plasma more than 1000 times the solid density. In the past, high-density plasma was generated by shell implosion, but in this study, a solid sphere is compressed by multi-stage shock waves because a hot spot in the center is not necessary in fast-ignition laser fusion. The solid sphere is resistant to hydrodynamic instability, but the inhomogeneity of the laser absorption intensity must be as high as that of shell implosion. A ray tracing code is used to calculate the bremsstrahlung absorption while varying the laser irradiation conditions. As shown in Figure 1, the implosion performance is getting better after improving the homogeneity of laser lights by introducing a random plate.

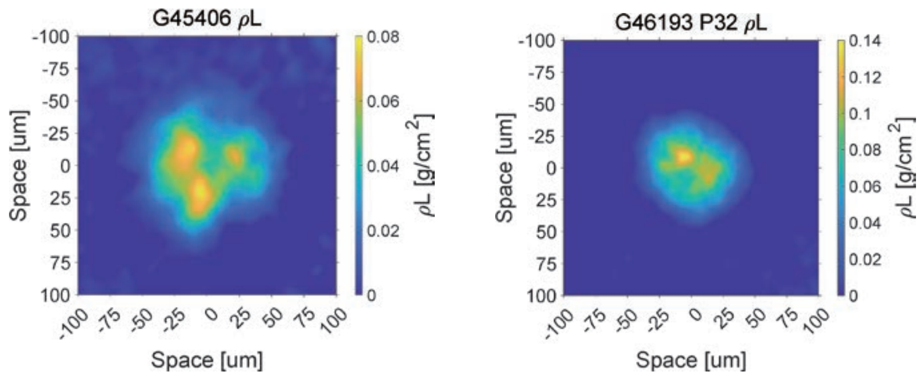


Fig. 1 Observed areal density (left) before improving the uniformity and (right) after improving the uniformity of laser light.

Fast heating experiment using a mixed laser light of fundamental and second harmonics

We have developed a system that can mix 50% second harmonics and 50% residual fundamentals by wavelength conversion of the LFEX laser just before the target. The four beams were successfully converted. In the four-beam experiment, the laser beam became poorly focused after transmission through the wavelength conversion crystal. Since it was not feasible, on a budget, to grind the wavelength conversion crystals for four beams with high precision, we prepared a wavelength conversion crystal with high precision grind for only one beam. The wavefront distortion was corrected using a full-size deformable mirror in the H2 beam of the LFEX, and the light focusing state was close to that of a normal LFEX. Even with wavelength conversion, energy was successfully injected within a diameter of 50 μm.

The most important aspect of heating in fast ignition is the electron energy spectrum, which affects the heating efficiency by increasing the number of electrons below 1 MeV. Figure 2 compares the electron energy spectra of a 5 μm Cu target shot with a wavelength-converted mixed beam and a shot without wavelength conversion. Comparison shots were performed with nearly identical laser energies on the target. The average energy of the electrons in both shots was significantly reduced. The expected result is that the red and green lines intersect at around 0.5 MeV, and the mixed wave produces more electrons in the low energy region. We will further analyze the data in detail to determine the effect on heating.

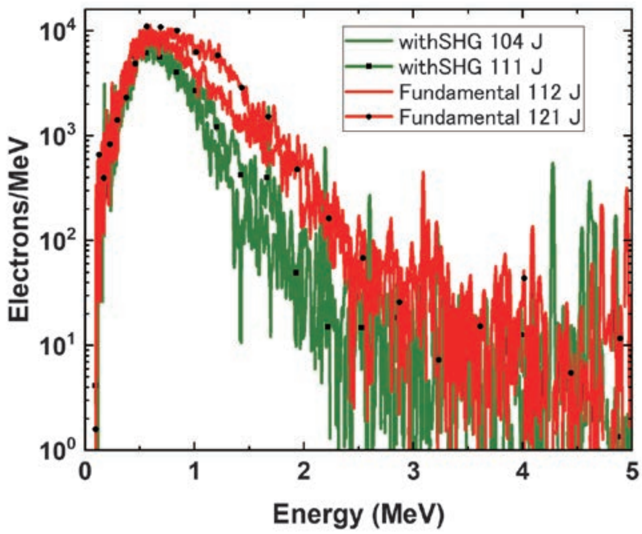


Fig. 2 Electron energy spectra induced by a normal LFEX laser (red) and the converted LFEX laser light (green.)

Effects of kilo-tesla magnetic field on ignition burning in the FI

When a kilo-Tesla magnetic field is applied near laser critical density to efficiently transport relativistic fast electrons to the fuel core, numerical simulations predict that the magnetic field would be compressed to 100 kT in the high density region of the fuel center. The effects of such a strong magnetic field on ignition and burnup characteristics through heat conduction and α-particle transport suppression are analyzed by numerical simulation. This year, we developed our own nuclear burnup code, FIBMET, so that the magnetic field effects could be taken into account in the heat conduction and α-particle transport, and performed the analysis for a high-gain target. Initial conditions for the calculations, after fuel compression and ignition zone formation, were a uniformly compressed (r = 300 g/cm^3) DT plasma sphere (areal density rR = 3 g/cm^2). FIBMET simulations were performed in two cases: one without an applied magnetic field (B_0 = 0) and the other with a uniform magnetic field of B_0 = 100 kT, applied parallel to the axis of symmetry. In the case of applying a uniform magnetic field, it was found that the suppression of electron heat conduction and α-particle transport by the magnetic field (a) promoted temperature rise at the ignition site and increased the nuclear reaction rate during the ignition process, but (b) the opposite suppression delayed the propagation of the burnup wave from the ignition site to the vertical direction of the magnetic field, resulting in an increase in burnup time and a decrease in burnup rate. The results show that (a) the suppression of the nuclear reaction rate increased the nuclear reaction rate.

In the future, we will clarify the dependence of the magnetic field effect, including the ignition formation process, on the magnetic field strength and evaluate how the core heating energy required for ignition and the burn rate changes for compressed fuels of the current experimental class (rR ~ 0.1 g/cm^2) to a high burn rate (rR ~ 3 g/cm^2). The final result is an evaluation of the explosion process. Finally, an integrated simulation that takes into account the detonation process should be performed to evaluate the validity of the simulation results through comparison with experiments, and to improve the code to design a magnetic field-assisted fast ignition laser core with an external magnetic field applied for REB induction.

(Y. Sentoku)

Kyushu University

Research activities on QUEST in FY2022

We will summarize the activities of the Advanced Fusion Research Center at the Research Institute for Applied Mechanics in Kyushu University during April 2022 – March 2023. The QUEST experiments were executed from 28th Jun. – 27th Oct. (2022 Spring/Summer, shot no. 48691-50556) and 1st Dec. – 28th Dec. (2022 Autumn/Winter, shot no. 50557-51205). The main topics of the QUEST experiments in FY2022 are listed below.

1) Co-axial helicity injection (CHI) was applied to achieve an efficient plasma start-up. Improvement of a gas-injection system for CHI worked well and clear formation of a closed flux surface could be achieved at an optimized condition of CHI.
2) In continuation from the previous FY, the effects of convection on particles and heat transport in liquid metals have been investigated this year, using a laboratory-scale steady state plasma facility at Chubu University. and an infrared spot heating gun at Kyushu University. The results have clearly indicated that both particles and heat transport are enhanced by liquid metal convection, the principle of which is believed to be applicable in designing liquid metal plasma-facing components (LM-PFCs) for a future DEMO reactor. These data were presented as part of an invited talk at the 7th International Symposium on Liquid Metals Applications for Fusion (ISLA-7), held at Chubu University. for the period: Dec. 12th – 16th, 2022.
3) A detection-side beamline of HIBP has been installed on QUEST. An injection-side beamline is being designed so that the probe beam can go through a small port. Although the injection port is as small as 30 mm in diameter, the incident angle of the beam needs to be changed by 25 degrees. Thus, two electrostatic deflectors will be used to sweep the beam with the port position as the center of the sweep.
4) A high temperature tungsten (W) first wall for QUEST has been developed by using the original fabrication methods of Advanced Multi-Step Brazing (AMSB). We successfully made a middle scale first wall sample of W/ODS-Cu/SUS joint structure in FY 2022. In addition, a W/ODS-Cu/SUS medium-scale sample was heated to 400°C to check uniform temperature increases and effects on vacuum properties. Consequently, the sample passed those qualifications without any problems.
5) In this study, the current profile of the injector current flowing into each part of the vessel wall during CHI discharge was investigated by installing a magnetic sensor array. The result enabled us to model the CHI flux evolution and to improve the discharge by optimizing the flux condition and electrode configuration. A closed flux formation plasma generated by CHI was measured by an inserted probe without significant disturbance.
6) Glow-discharge optical emission spectrometry has been extensively used to study the global distribution of deposition layers in QUEST and its change with operation history. One of the future tasks is to understand the correlation between the nature of the deposition layer and the recycling behavior of hydrogen. To reach this goal, it is necessary to establish a reliable technique to measure the depth profiles of hydrogen in deposition layers. One of the issues in hydrogen measurement is a high background signal in the measurement system. This year, we identified the origin of the high background signal and prepared a special sample holder to reduce its intensity.
7) The control and data acquisition system of the Thomson scattering measurement system was modified to measure profile evolutions during 1000-second discharges. The measurement comprised many short-period cycles, each of which consisted of 15 seconds of (10 Hz) data acquisition, and the cycle was repeated every minute. It was found that the profiles (six-spatial points) became steady after about 300 second from the start of discharge. The highest temperature and the highest density during the steady state were about 80 eV, 4×10^{17} m^{-3}, respectively.
8) It has been proposed that the CT injector of UH-CTI for advanced fueling in QUEST is employed as a transient heat load simulator for liquid metal Sn. The injector has high performance to produce a CT plasmoid with a power density of about 15 GW/m^2, and the direction of CT plasma irradiation can be changed

by using a curved drift tube. A site survey for setting up the injector with a curved tube was conducted and the latter was designed, then the several rerated parts were produced. A comparative experiment was also prepared at the University of Hyogo.

9) The hydrogen recycling process on a tungsten divertor has been investigated using molecular dynamics simulations. The results indicate the potential for the generation of significant quantities of hydrogen molecules in high rovibrational states on the surface of the tungsten wall when the incident energy is below a few electron volts (eV).

10) A Transient Co-axial Helicity Injection plasma startup was successfully achieved on QUEST. Closed flux surfaces of more than 50 kA were obtained using a simple reactor-relevant biased electrode configuration without needing large vacuum ceramic insulators as on NSTX and HIT-II. The solenoid-free plasma startup discharge evolution on QUEST is similar to that on NSTX.

11) The Ball-pen probe (BPP) is an innovative method for direct measuring space potential and electron temperature in magnetized plasmas. The BPP offers numerous advantages, including a simple and robust design, as well as high temporal resolution of the signals. Hence, we have conducted a feasibility study of the BPP for the QUEST spherical tokamak.

12) A 28-GHz electron cyclotron non-inductive plasma ramp-up involving bulk electron heating has been studied. The 28-GHz wave was quasi-perpendicularly injected and a retarding loop voltage was applied to suppress highly energetic electron growth. Relatively large-sized plasmas were attained with a 100-eV electron temperature with a low vertical magnetic field. High electron temperatures of 1 keV were attained in small-sized plasm a with a high vertical field. In each case, electron densities were about 10^{18} m^{-3}.

13) Application of the plasma shape reconstruction code using the Cauchy condition surface method (CCS) to QUEST plasma has been launched. The latest CCS code for JT-60SA has been modified for QUEST. The accuracy of fluxloop signals, which are used in CCS calculation, were evaluated by the past data of a multiple coil energization test in QUEST.

14) A new combination diagnostic as a hydrogen recycling monitor based on a permeation membrane probe and a Langmuir probe has been developed. The membrane cleaning in Ar plasma and permeation flux calibration in a preparation chamber was tested. A visible spectroscopy of hydrogen emission was used to evaluate the hydrogen recombination coefficient of the membrane. The in-situ calibration results are in a good agreement with ones estimated with a nuclear reaction analysis.

15) A large electrode system (center and shield electrodes) which can withstand high heat flux by water cooling during steady state tokamak operations on QUEST was upgraded to use not only as a diagnostic but also as a low-field side limiter (limiter usage) simultaneously. It is expected that the upgrade enhances the amount of experimental data as a Langmuir probe. First, a movable range of the center electrode was extended, and heat flux to the center electrode could be significantly reduced by the shield electrode during the limiter usage. Second, the number of thermocouples was minimized to enhance vacuum compatibility of the system. Instead, a measurement system of cooling water flow and temperature is now under installation to measure total heat flux to the system during limiter usage.

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EJIRI Akira (University of Tokyo) 7)
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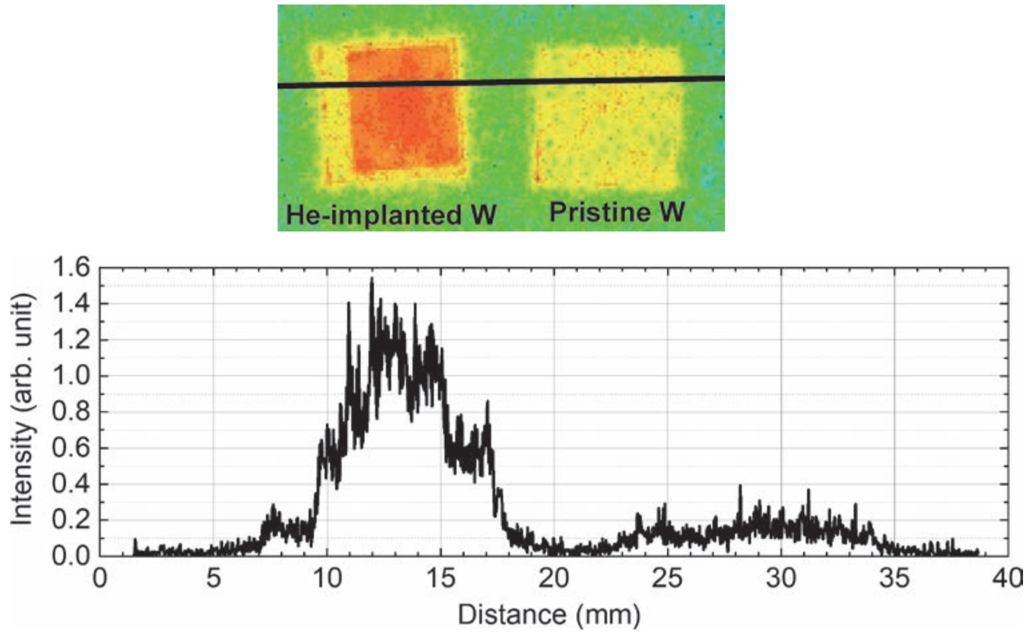

Fig. 1 (top) Two-dimensional (2D) image of photo-stimulated luminescence (PSL) intensity obtained using imaging plate (IP) for He-implanted and non-implanted W samples after exposure to deuterium-tritium (DT) mixture gas at 400°C and (bottom) profile of PSL intensity along black line in 2D image.

Highlight

Research Activities in Hydrogen Isotope Research Center, Organization for Promotion of Research, University of Toyama

Plasma-facing materials of a fusion reactor will be subjected to implantation of D, T and He ions from the plasma. The formation of He bubbles and trapping of T at those bubbles are important safety concerns. In this study, W and W-Mo alloy samples were irradiated with He ions and T trapping was examined using the IP technique after exposure to DT gas. Clear enrichment of T at the He-implanted zone was observed due to trapping effects, as shown in Fig. 1. The effects of Mo on the bubble growth and trapping are under investigation. [*Hydrogen isotope pick-up and retention in He-exposed W-Mo alloys (E. Jimenez-Melero and J. Ashley, The University of Manchester)*]

Tritium transport in fusion reactor materials (Y. Hatano, U. Toyama): A fusion power plant will use a steam turbine to generate electricity. Tritium (T) permeation through steam generator piping results in the risk of uncontrolled T leakage to the environment. Therefore, T permeation must be precisely evaluated and minimized. Nickel alloys are widely used as pipe materials. In this study, the permeation of T from/to high temperature, high pressure water through Inconel 600 film was examined.

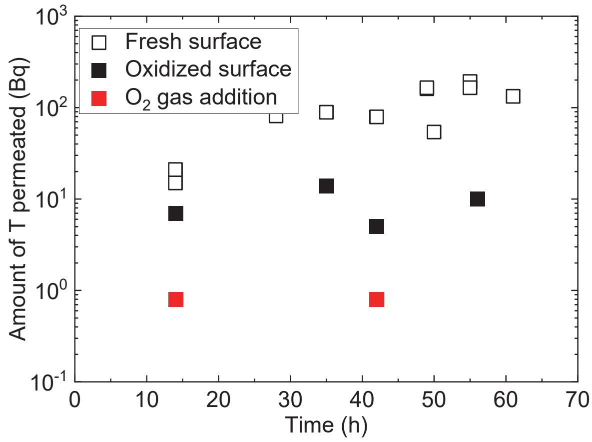

Fig. 2 Change in T permeation with elapse of time.

Permeation devices made of type 316L stainless steel were used with fresh internal surfaces or those covered by protective oxide layers. The device was separated into two chambers by an Inconel 600 sample disk. The upstream chamber was filled with tritiated water (0.9 MBq/cm^3) and the downstream side was filled with non-radioactive water. The device was heated to 280°C in a forced convection oven for 14–60 hours. The vapor pressure of water at this temperature was 6.4 MPa. After heating, the downstream chamber was opened and the concentration of T in water was measured using a liquid scintillation counter. The effects of oxygen were examined by pressuring the water in both chambers by O_2 gas up to 3 MPa. A correlation between heating time and the amount of T permeated to the downstream side is shown in Fig. 2. The permeation rate was high with the fresh internal surfaces of the permeation device and 3 Bq/h on average. Nevertheless, an order of magnitude smaller permeation rate was observed with the internal surfaces covered by protective oxide layers. The addition of O_2 gas resulted in further reduction in the permeation rate. These results indicate that T permeation is sensitively dependent on the partial pressure of HT gas generated by the oxidation of co-existing material in the system (a stainless steel wall in the present case). The T permeation rate in a steam generator can be managed by controlling the oxidation of metals in a primary coolant loop and/or by addition of O_2 gas.

Other experimental studies performed in the Hydrogen Isotope Research Center in the fiscal year 2022 are the following:

- *Nano-fiber formation on tungsten alloy by helium plasma irradiation* (Y. Ueda, Osaka U.);
- *Effect of transmutation or irradiation damage on hydrogen isotope transport dynamics* (Y. Oya, Shizuoka U.);
- *Effective tritium removal under vacuum conditions* (N. Ashikawa, NIFS);
- *Effects of heat and particles load on hydrogen isotope retention in tungsten materials* (K. Tokunaga, Kyushu U.);
- *Release behaviors of hydrogen isotopes from tungsten materials exposed to hydrogen isotope plasma* (T. Otsuka, Kindai U.);
- *Depth analysis of co-deposited H, He and impurity atoms on plasma exposed W by means of GDOES* (N. Yoshida, Kyushu U.);
- *Precise evaluation of tritium profile in solid/liquid tin exposed to tritium plasma* (H. Toyoda, Nagoya U.);
- *Suppression of tritium permeation in metals by laser-doping of impurities* (Y. Nobuta, Hokkaido U.);
- *Measurement of transmission of liquid DT through polymer for development of laser fusion DT fuel* (Y. Arikwa, Osaka U.); and
- *Understanding and optimization of tritium absorption into titanium target for 14 MeV neutron irradiation experiments* (I. Murata, Osaka U.).