14. International Collaboraiton

Many research activities in NIFS are strongly linked with international collaborations with institutes and universities around the world. These collaborations are carried out in various frameworks, such as 1) coordination with foreign institutes, 2) bilateral coordination with intergovernmental agreements, and 3) multilateral coordination under the International Energy Agency (IEA).

Coordination with foreign institutes is important as a basis for collaborative research. From 1991, NIFS concluded 32 coordinations through FY2019.

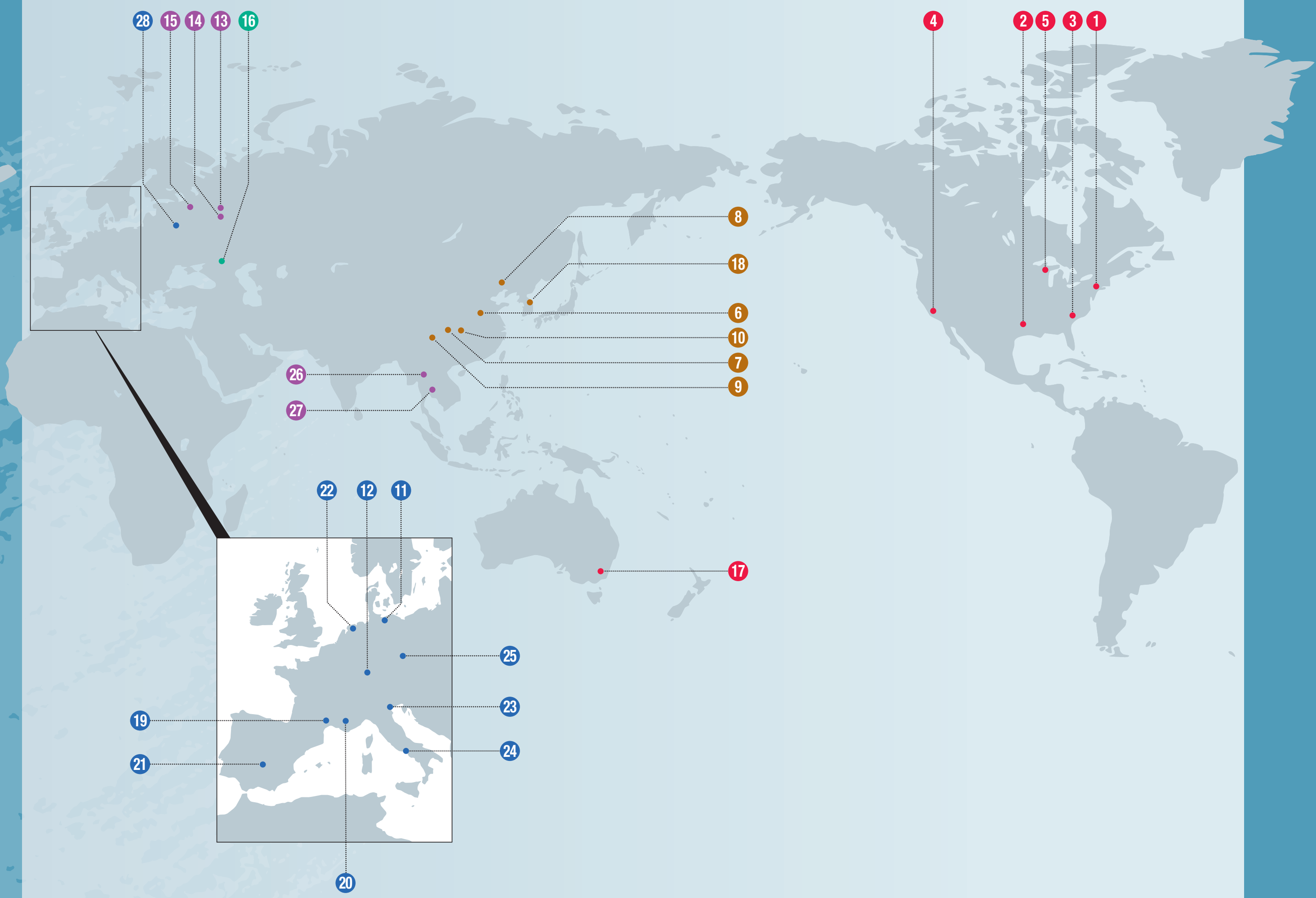
NIFS is the representative institute for three bilateral coordinations with intergovernmental agreements (Japan-US, Japan-Korea, and Japan-China), and four multilateral coordinations under the IEA (Plasma Wall Interactions (PWI), the Stellarator-Heliotron concept, Spherical Tori, and the Steady State Operation). For the three bilateral coordinations, and the multilateral coordination PWI Technology Collaboration Program (TCP), NIFS coordinates the collaborative research between researchers in foreign institutes and researchers in domestic universities and NIFS. The activities of bilateral and multilateral coordination activities are reported in the following subsections.

For the COVID-19 pandemic, social activities have still been strongly limited to prevent its outbreak all over the world since the beginning of 2020. Many international activities with personal exchanges could not be conducted, and many international conferences were postponed or held online. Online communications drastically increased, and people became very familiar with such communications, though the time difference was a serious problem when holding an international online conference.

Under such a situation, the 30th International Toki Conference on Plasma and Fusion Research was held in Toki, Japan from 16 – 19 November 2021, and NIFS hosted the meeting. For reducing the risk of the spread of COVID-19, the conference was held using an online connection for video conferencing. Reflecting the new policy of NIFS, which aims for interdisciplinary development of fusion science, 26 keynote lectures and 111 guest lectures were given by invited researchers, not only from the field of fusion science, but also from a wide range of other fields, and more than 466 researchers from 18 countries participated.

(S. Masuzaki)

Academic Exchange Agreements



U.S.A.
1. Princeton Plasma Physics Labolatory (PPPL)
2. Institute for Studies, The University of Texas at Austin (IFS)
3. Oak Ridge National Laboratory (ORNL)
4. Center for Energy Science and Technology Advanced Research, University of California, Los Angelse (UCLA)
5. College of Engineering, University of Wisconsin, Madison

China
6. Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP)
7. Southwestern Institute of Physics (SWIP)
8. Peking University
9. Southwest Jiaotong University (SWJTU)
10. Huazhong University of Science and Technology

Germany
11. Max Planck Institute for Plasma Physics (IPP)
12. Karlsruhe Institute of Technology (KIT)

Russia
13. Russian Research Center, Kurchatov Institute (KI)
14. A. M. Prokhorov General Physics Institute, Russian Academy of Sciences (GPI)
15. Peter the Great St. Petersburg Polytechnic University

Ukraine
16. National Science Center of the Ukraine Khar'kov Institute of Physics and Technology Institute of Plasma Physics (KIPT)

Australia
17. Australian National University (ANU)

South Korea
18. National Fusion Research Institute (NFRI)

France
19. Aix-Marseille University (AMU)
20. Commissariat à l'énergie atomique et aux énergies alternatives (CEA)

Spain
21. National Research Center for Energy, Environment and Technology (CIEMAT)

Netherlands
22. Dutch Institute for Fundamental Energy Reseearch (FOM)

Italy
23. CONSORZIO RFX
24. Institute of Lonized Gas (IGI)

Czech
25. HiLASE Center, Institute of Physics CAS (FZU)

Tailand
26. Chiang Mai University
27. Thailand Institute of Nuclear Technology (TINT)

Poland
28. Institute of Plasma Physics and Laser Microfusion (IPPLM)

The ITER International Fusion Energy Organization (ITER)

US – Japan (Universities) Fusion Cooperation Program

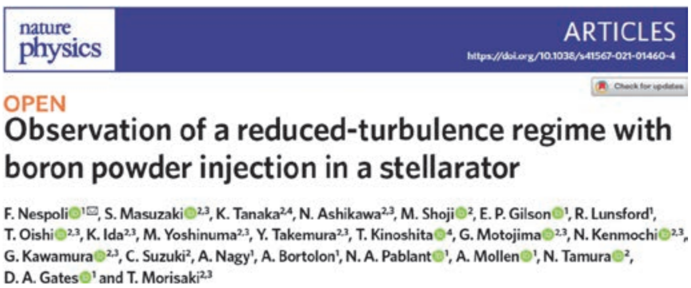
US-Japan Joint Activity has continued from 1977. The 42th CCFE (Coordinating Committee for Fusion Energy) meeting was held on April 13, 2021 via video conference system. Representatives from the MEXT, the DOE, universities and research Institutes from both Japan and the US participated. At the meeting the current research status of both countries was reported, together with bilateral technical highlights of the collaborations. FY 2021 cooperative activities were reviewed, and FY 2022 proposals were approved. It should be noted that because of the continuing COVID-19 pandemic, most of the personnel exchange and workshops were canceled. However, some collaborative activities were maintained by remote participation and web meetings.

(1) Fusion Technology Planning Committee (FTPC)

In this category of US-Japan collaboration, there are six research fields, namely, superconducting magnets, low-activation structural materials, plasma heating related technology, blanket engineering, in-vessel/high heat flux materials and components, and power plant studies and related technologies. In fiscal year 2021, due to the continuation of the COVID-19 pandemic, most of the personal exchanges either differed or were canceled, including four Japan-to-US personal exchanges (differed), one Japan-to-US personal exchange (canceled), and one US-to-Japan personal exchange (differed). One workshop was also canceled. Despite this situation, one US-to-Japan personal exchange was successfully performed online, which had the title “Depth profile of D retention in RAFM steels: effect of surface layers”. In this collaboration, the devices on both sides (the plasma-surface interactions research facility PISCES at UCLA and characterization devices such as the EDX, the TEM, and the GDOES at NIFS) were best utilized for preparing samples and for characterizing them. One workshop was also held online, which was titled “Workshop on fusion reactor design and critical issues of fusion engineering”. There were 18 oral presentations (US: 9, Japan: 9), and a total of 33 participants (US: 15, Japan: 18). Regarding all the differed or canceled collaborations, information exchanges were done among responsible members and participants via e-mails and/or video conferencing to make an agreement about the resumption of each program in the coming fiscal year 2022.

(2) Fusion Physics Planning Committee (FPPC)

In the area of fusion physics, one committee meeting, two workshops and 29 personnel exchanges were performed remotely, amid the continuing COVID-19 pandemic. In a newly established collaboration style during the pandemic, scientists from both sides have endeavored to continue their collaborative research activities. Every experiment was carried out with remote participation, enabled by tele-communication tools and data transport systems which have been drastically improved in this year. As one of the most excellent results, a boron powder injection experiment in LHD, with collaboration between NIFS and Princeton Plasma Physics Laboratory, was summarized and published in Nature Physics (Fig. 1).


nature physics

ARTICLES

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Observation of a reduced-turbulence regime with boron powder injection in a stellarator

F. Nespoli[1✉], S. Masuzaki[2,3], K. Tanaka[2,4], N. Ashikawa[2,3], M. Shoji[2], E. P. Gilson[1], R. Lunsford[1], T. Oishi[2,3], K. Ida[2,3], M. Yoshinuma[2,3], Y. Takemura[2,3], T. Kinoshita[4], G. Motojima[2,3], N. Kenmochi[2,3], G. Kawamura[2,3], C. Suzuki[2], A. Nagy[1], A. Bortolon[1], N. A. Pablant[1], A. Mollen[1], N. Tamura[2], D. A. Gates[1] and T. Morisaki[2,3]

Fig. 1 Cover page of the Nature Physics. https://www.nature.com/articles/s41567-021-01460-4

(3) Joint Institute for Fusion Theory (JIFT)

Some of workshops and personal exchanges that had been scheduled for the 2021–2022 JIFT programs were canceled due to the influence of COVID-19. A workshop

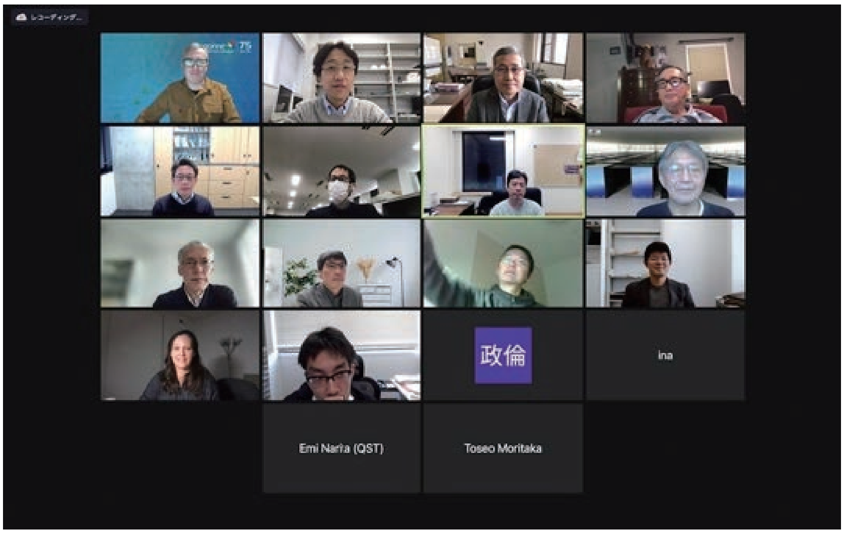


Fig. 2 Snapshot of the Workshop on “US-Japan collaborations on co-designs of fusion simulations for extreme scale computing” held online in January 2022.

“US-Japan collaborations on co-designs of fusion simulations for extreme scale computing” was held online in January 2022 (Fig. 2). A personnel exchange program (Japan to US) for a Visiting Researcher on “Theoretical study related to two-fluid equilibria” was carried out successfully from January to February in 2022. Four Japan to US and three US to Japan personnel exchange programs were carried out as remote collaborations. The status of JIFT activities for 2021–2022 was reviewed and recommendation plans for 2022–2023 were discussed by email among members of the JIFT Steering Committee in December 2021. The JIFT discussion meeting was held online on September 17, 2021, in the Plasma Simulator Symposium.

(4) US-Japan Joint Project: FRONTIER

The FRONTIER collaboration started in April 2019 to provide the scientific foundations for reaction dynamics in interfaces of plasma facing components for DEMO reactors. This project consists of four tasks: Irradiation Effects on Reaction Dynamics at Plasma-Facing Material/Structural Material Interfaces (Task 1), Tritium Transport through Interface and Reaction Dynamics in Accidental Conditions (Task 2), Corrosion Dynamics on Liquid-Solid Interface under Neutron Irradiation for Liquid Divertor Concepts (Task 3) and Engineering Modeling (Task 4). The project performs neutron irradiation in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) and examines neutron-induced modifications in microstructure, mechanical strength, tritium transport, corrosion behavior, etc. Twenty-five irradiation capsules were designed and fabricated, and the majority of them were irradiated in the HFIR at 300, 500 and 800 °C for one and three cycle(s). Post-irradiation examinations will be carried out in the coming years. A corrosion test in flowing Sn was performed for steel specimens using a thermal convection loop for 1000 h at a peak temperature of 400 °C and a 55 °C temperature gradient. Significant mass loss was observed in the hot leg, and specimen characterization is in progress to understand corrosion mechanisms.

(T. Morisaki, N. Yanagi, H. Sugama and Y. Hatano)

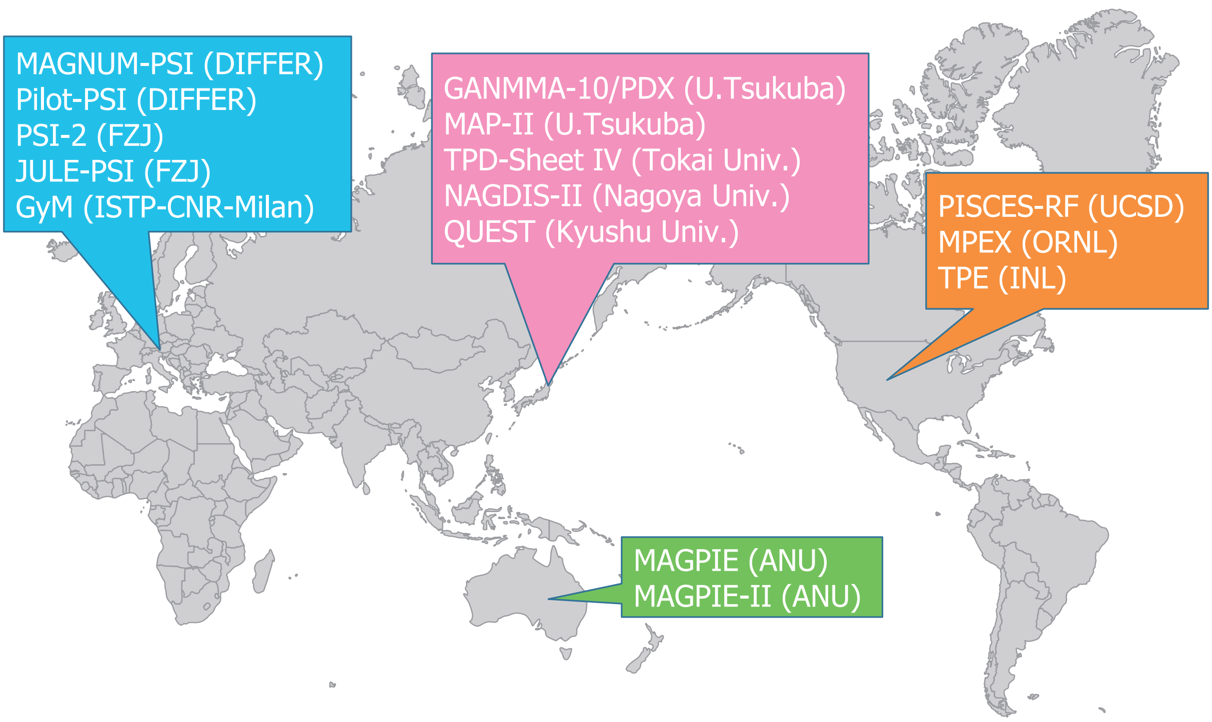
Plasma Wall Interaction (PWI) Collaboration

This collaboration is based on the IEA Technical Collaboration Programme (TCP) of the "Development and Research on Plasma Wall Interaction Facilities for Fusion Reactors" (in short, PWI TCP) which involves Japan, Europe, the United States, and Australia. The objective of this TCP is to advance the physics and technologies of plasma-wall interaction research by strengthening cooperation among plasma-wall interaction facilities (in particular, by using dedicated linear plasma devices), to enhance the research and development effort related to a fusion reactor's first wall materials and components shown in the figure below.

NIFS collects proposals for international collaborative studies based on the PWI TCP, from domestic universities every year. The proposals are reviewed by the PWI technical committee whose members are domestic senior researchers in universities, QST and NIFS, and some of the proposals are approved. Proponents of the approved collaborative research go to foreign institutes with support from NIFS and the conduct the studies.

Unfortunately, for because of COVID-19 pandemic, collaborative activities based on the PWI TCP could not be conducted in FY2021.

(S. Masuzaki)



Main Plasma-Wall Interaction facilities in member countries

IEA (International Energy Agency) Technology Collaboration Programme for Cooperation in Development of the Stellarator-Heliotron (SH) Concept (“IEA SH-TCP”)

Highlight

IEA SH-TCP
Programmatic collaborations have been further extended in the next step of SH research

The SH TCP’s objective is to improve the physics base of the Stellarator-Heliotron concept and to enhance the effectiveness and productivity of research by strengthening co-operation among member countries. All collaborative activities of the worldwide stellarator and heliotron research are combined under the umbrella of this programme, which promotes the exchange of information among the partners, the assignment of specialists to facilities and research groups of the contracting parties, joint planning and coordination of experimental programmes in selected areas, joint experiments, workshops, seminars and symposia, joint theoretical and design and system studies, and the exchange of computer codes. The joint-programming and research activities are organized via Coordinated Working Group Meetings (CWGM), an interactive workshop to facilitate agreements on joint research actions, experiments and publications under the auspices of the SH-TCP.

The Executive Committee (ExCo) of the SH-TCP has been working hard to extend the agreement and has now been granted an extension for the period 2021–2026.

Major achievements in 2021

In 2021, major achievements were the deuterium plasma campaign in the Large Helical Device (LHD) and the start of the first Island Divertor campaign of the Wendelstein 7-X (W7-X). Main highlights will be reported in many presentations at the 23rd International Stellarator-Heliotron Workshop (ISHW) in Warsaw, Poland.

The LHD project will be terminated in March 2023. Until then, it is intended to maximize scientific output by promoting open science and open data, and by further increasing the number of international collaborators above the current record level of 30 %. Colleagues from abroad are strongly encouraged to participate in the next campaign and improved software and a better website have been prepared to facilitate remote participation while the pandemic makes it difficult to come to the site in person. Also, Japan is ready to participate in the next W7-X campaign when the Covid situation improves.

At the Heliotron-J, experiments started in September and will continue until the beginning of February. The current focus is on confinement transport and energetic particle turbulence. Upgrades of the NBI heating system and diagnostics are done. Financial support for personnel exchange was received by the JSPS, but the pandemic makes this difficult to achieve. International collaborators will be invited to participate in Heliotron-J experiments remotely.

Completion of the W7-X is coming to an end. All in-vessel components have been installed – most notably the actively cooled high-heat-flux (HHF) divertor for heat fluxes of up to 10 MW/m^2, with its cooling water supply and helium connections of the cryo pumps. The NBI system has been extended to four sources, and the new ICRH system has been installed. In-vessel components and diagnostics have been hardened for steady state operation. This was important for addressing the mission of the W7-X: to demonstrate high performance plasmas in optimized magnetic fields and go step by step to longer pulses, towards 30 min at 10 MW heating power.

50th S-H TCP executive committee meeting

The 50th Executive Committee (ExCo) meeting of the S-H TCP took place remotely on November 10, 2021, via Zoom. The meeting was attended by representatives from all seven contracting parties: Australia, China, the European Union, Japan, Russia, Ukraine, and the United States of America. A membership invitation to Costa Rica is still pending.

21st Coordinated Working Group Meeting (CWGM)

Coordinated Working Group Meeting activity has been pursued despite the difficulties due to the Covid pandemic. The 21st CWGM was held as a virtual meeting on November. 22–24, 2021. The meeting had its focus the perspectives for stellarators as fusion reactors. About 130 people registered for three consecutive days of one-hour video conferences, to allow attendance from different time zones. In order to facilitate the scientific discussion further, the meeting sessions were recorded. Additionally, the presentation slides and notes were in an electronic documentation system running INDICO software. The material is available for registered participants working in laboratories that are members of the IEA TCP.

Each of the three sessions had introductory presentations addressing ‘Open questions for a fast track to stellarator reactors (Allen Boozer, Columbia University, USA), ‘What can we learn for the first W7-X campaigns for a HELIAS reactor?’ (Robert Wolf, Max-Planck-Institut für Plasmaphysik, Greifswald, Germany) and ‘Multi-ion physics and isotope effects in helical devices’ (Hiroshi Yamada, University of Tokyo, Japan). An essential outcome of the sessions was ensured by structured discussions guided by expert chairpersons (Arturo Alonso (CIEMAT), Felix Warmer (IPP) and Friedrich Wagner (IPP)).

(Y. Suzuki (Hiroshima Univ.), K. Ida, and K. Nagasaki (Kyoto Univ.))

Japan-China Collaboration for Fusion Research (Post-CUP Collaboration)

I. Post-CUP collaboration

The post-Core University Program (Post-CUP) collaboration is motivated by collaboration on fusion research with institutes and universities in China, including the Institute of Plasma Physics, the Chinese Academy of Science (ASIPP), the Southwestern Institute of Physics (SWIP), Peking University, Southwestern Jiaotong University (SWJTU), Huazhong University of Science and Technology (HUST) and other universities both in Japan and China. Post-CUP collaboration is carried out for both studies on plasma physics and fusion engineering. Based on the following implementation system, Post-CUP collaboration is executed.

Table 1 Implementation system of Japan-China collaboration for fusion research

Category	① Plasma experiment				② Theory and simulation	③ Fusion engineering research
Subcategory	①-1	①-2	①-3	①-4	—	—
Operator	A. Shimizu	Y. Yoshimura	M. Isobe	T. Oishi	G. Kawamura	T. Tanaka

①-1: Configuration optimization, transport, and magnetohydrodynamics, ①-2: Plasma heating and steady-state physics, ①-3: Energetic particles and plasma diagnostics, ①-4: Edge plasma and divertor physics, and the atomic process

II. Primary research activities of collaboration in FY 2021

The fourth steering committee meeting for the NIFS-SWJTU joint project for the CFQS quasi-axisymmetric stellarator, was held on Nov. 12, 2021, online as shown in Fig. 1. The progress of engineering design, the current status of the construction of modular coils (MCs), and the vacuum vessel (VV) were reviewed [1]. At this time, the first vacuum pressure impregnation process for five MCs has been completed. For the VV, one quarter of a toroidal section has been manufactured. Completion of renovation of an experiment building in the Jiuli campus

Fig. 1 The 4th steering committee meeting of the NIFS-SWJTU joint project for the CFQS, held on Nov. 12, 2021 online. Top left, top right and bottom pictures show participants from NIFS, Hefei Keye, and SWJTU, respectively.

in SWJTU was also reported. Also, it was decided that the first plasma will be produced in this experiment building under conditions of 0.1 T operation.

In the research of energetic particles, NIFS and ASIPP have been discussing execution of collaborative research to measure a velocity distribution function of neutral beam (NB)-injected energetic ions in EAST and LHD through deuterium-deuterium (DD) fusion born neutron spectroscopy, based on ^{7}Li-enriched Cs_2LiYCl_6: the Ce (CLYC-7) fast-neutron scintillation detector having a tangential sightline in LHD. A significant shift of DD neutron energy, according to the direction of tangential NB injection, was clearly observed. This result was summarized and published as a joint outcome between NIFS and ASIPP [2]. As for DD fusion born 1 MeV triton confinement research, NIFS developed a scintillating-fiber (Sci-Fi) detector optimized for the HL-2M, and the Sci-Fi detector was exported to SWIP.

In research of edge and divertor plasmas, M. Sakamoto of Tsukuba Univ. and N. Ashikawa joined the EAST experiment on “Hydrogen recycling properties by fueling termination in EAST” by remote communication in 2021. Density decay after fueling termination was measured in a lower single null (LSN) configuration. It is clearly shown that hydrogen recycling is enhanced by a repeat of the discharge. The density decay time of the ohmic discharge does not depend on the fitting period, in contrast to the density decay of the LHCD discharges, suggesting a difference in hydrogen recycling properties without fueling, in the both discharges [3]. A collaborative study on extreme-ultraviolet (EUV) and vacuum-ultraviolet (VUV) spectroscopy has also continued progress. The results of emission line spectra measurement of tungsten impurity ions over a wide range of charge states, from neutral to 46+ are compared, and an extension of the observable charge states is discussed. A paper summarizing tungsten emission line spectra measured at LHD, EAST, and HL-2A was also published [4].

In research of theory and simulation, a Particle-In-Cell (PIC) simulation model for the estimation of tritium flux distribution on a divertor tile with a spherical dust grain has been developed by G.J. Niu of ASIPP and G. Kawamura, and geometric and physical factors on deposition distribution were discussed [5].

In research of fusion engineering, tritium release characteristics from Li_4TiO_4-Li_2TiO_2 mixed materials developed in SWIP have been examined in Shizuoka University. The results have been presented orally at ICFRM-20 (online, Nov. 2021). In association with this work, the Japan-China joint paper was published [6].

[1] The CFQS TEAM, “*NIFS-SWJTU JOINT PROJECT FOR CFQS – PHYSICS AND ENGINEERING DESIGN – VER. 4.1*.” NIFS-PROC-122, 2022.

[2] S. Sangaroon, K. Ogawa *et al*., “*Neutron energy spectrum measurement using CLYC7-based compact neutron emission spectrometer in the Large Helical Device*”, JINST **16**, C12025 (2021).

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[5] Guo-Jian Niu, Gakushi Kawamura *et al*., “*A numerical study on the effect of dust particles on tritium deposition on plasma-facing materials*”, Nuclear Materials and Energy **31**, 101169 (2022).

[6] S. Hirata, K. Ashizawa, F. Sun *et al*., “*Tritium recovery behavior for tritium breeder Li_4SiO_4-Li_2TiO_3 biphasic material*”, Journal of Nuclear Materials **567**, 153838 (2022).

(M. Isobe, A. Shimizu, K. Ogawa, T. Oishi, G. Kawamura and T. Tanaka)

Japan-Korea Fusion Collaboration Programs
FY 2021 Japan-Korea Diagnostics Collaboration

Japan and Korea have been collaborating on the development of plasma diagnostics since 2004. The topics have included Thomson scattering, ECE, CXS, bolometer, energetic ion and neutron diagnostics, ECEI and RF diagnostics, SXCCD and VUV cameras and automated integrated data analysis. On January 25th, 2022, we held an online meeting to discuss the collaboration (See Figure 1).

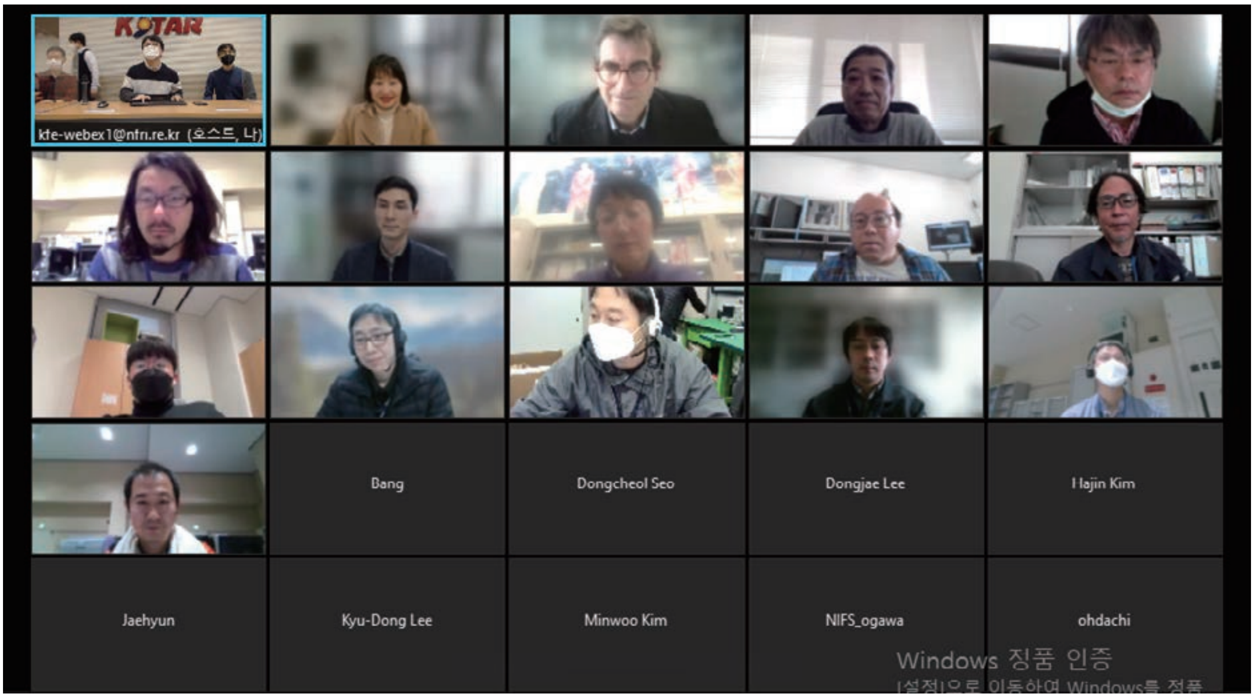

Fig. 1 Image from online meeting regarding the Japan-Korea diagnostics collaboration

Bolometer diagnostics

At KSTAR, disruption mitigation experiments by Shattered Pellet Injection (SPI) will be carried out in preparation for the ITER experiment. We discussed with the KSTAR team about the applicability of the bolometer to the radiation intensity measurement. We also discussed the re-installation of the resistive bolometer on KSTAR. In addition, we introduced various equipment necessary for fabricating and calibrating thin-film detectors for infrared imaging video bolometers and improved the method for evaluating the calibration coefficients of the fabricated detectors. Conventionally, regarding the temperature distribution when irradiating a thin film with a laser, ANSYS heat transfer calculations assuming a calibration coefficient are compared with experimental data, and the calibration coefficient is evaluated by changing the ANSYS calibration coefficient and converging iteratively. This time, we created a temperature distribution database for various calibration coefficients by ANSYS in advance and changed the method to determine the calibration parameters by error evaluation. As a result, we were able to shorten the analysis time from about a week to just a few minutes. In addition, the analysis environment can be migrated to Python, which does not require a software license, and joint research can be conducted smoothly in the future.

Charge Exchange Recombination Spectroscopy (CXS)

At KSTAR, experiments are being conducted to suppress the occurrence of edge localized modes (ELMs) in the H mode by applying perturbation magnetic fields to the periphery of the plasma. When a resonant perturbation magnetic field (RMP) is applied, the heating power required for the transition from L-mode to H-mode increases as the perturbation magnetic field strength increases. One of the reasons for this is thought to be that the rotational shear of the peripheral plasma is reduced by the perturbation magnetic field. However, when a non-resonant magnetic perturbation (NRMP) is applied, even if the perturbation magnetic field strength is increased, the power threshold does not increase. Therefore, investigating the difference in the depth of influence of the resonant perturbed magnetic field (RMP) and the non-resonant perturbed magnetic field (NRMP) on the plasma rotation shear is the key to understanding the power threshold difference.

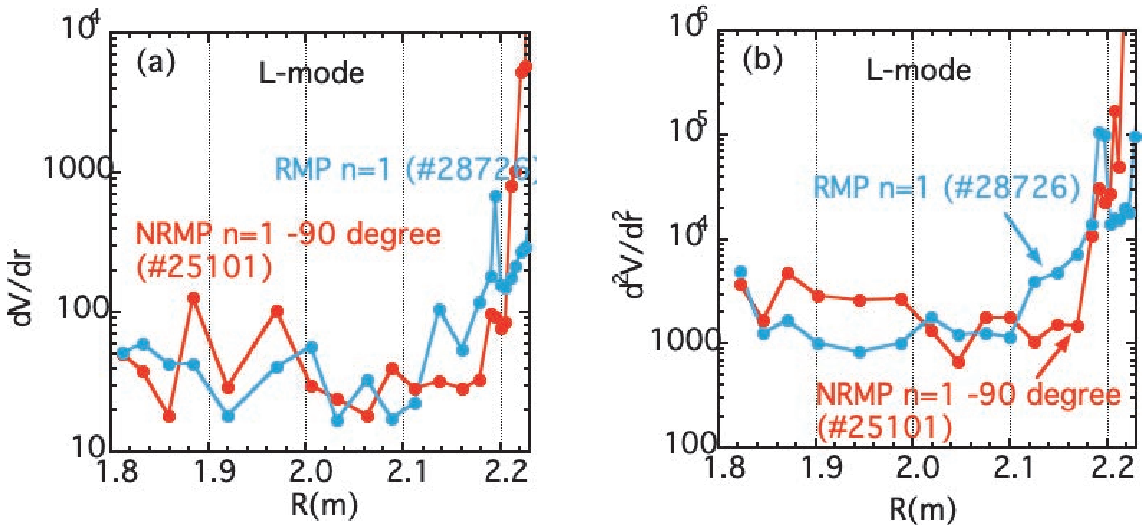

Fig. 2 Spatial distribution of (a) gradient of toroidal rotation velocity and (b) modulation amplitude of curvature due to resonant perturbation magnetic field (RMP)

Figure 2 shows the responses of the resonant perturbed magnetic field (RMP) and the non-resonant perturbed magnetic field (NRMP) to the toroidal rotational velocity gradient and curvature in an L-mode plasma. Compared to the resonant perturbed magnetic field (RMP), the non-resonant perturbed magnetic field (NRMP) causes the rotational shear (decrease in rotational shear due to the perturbed magnetic field) to be localized in the periphery and not to the interior.

(Byron Peterson - High Temperature Plasma Research Division)