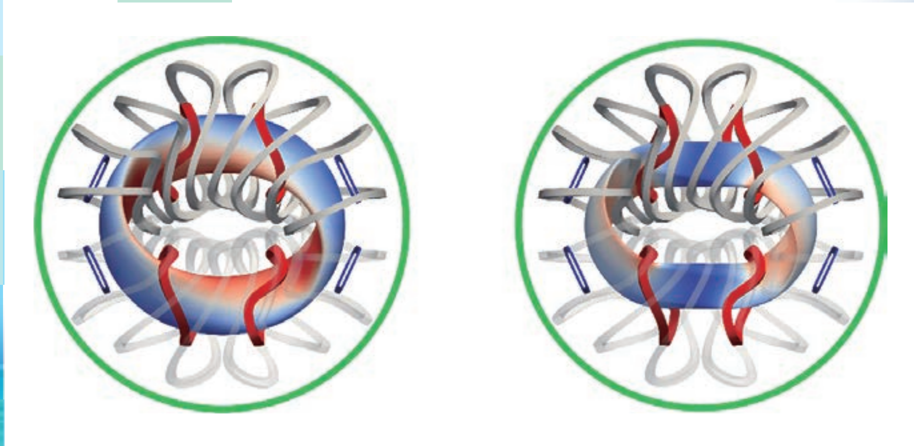
ISSN 0917-1185

# ANNUAL REPORT OF NATIONAL INSTITUTE FOR FUSION SCIENCE

April 2024 – March 2025



NATIONAL INSTITUTE FOR FUSION SCIENCE
**TOKI CITY, JAPAN**

**Front Cover Caption:**
The coil design and magnetic surfaces with different symmetry that can be generated by the same coils.



All articles in this Annual Report were proofread by STEPHEN CARR




Printer: Arakawa Printing Co., Ltd.
2-16-38 Chiyoda, Naka-ku, Nagoya-shi 460-0012, JAPAN
Phone: +81-52-262-1006, Facsimile: +81-52-262-2296

Printed in Japan, ISSN 0917-1185

# ANNUAL REPORT OF NATIONAL INSTITUTE FOR FUSION SCIENCE

April 2024 – March 2025

**December 2025**

Inter-University Research Institute Corporation
National Institutes of Natural Sciences

**NATIONAL INSTITUTE FOR FUSION SCIENCE**

Address : Oroshi-cho, Toki-shi, Gifu-ken 509-5292, JAPAN
Phone : +81-572-58-2222
Facsimile : +81-572-58-2601
Homepage on internet : URL = https://www.nifs.ac.jp/

# Contents

# National Institute for Fusion Science
# April 2024 – March 2025

## Towards a new era of fusion science

Fusion science is driven by the aspiration to realize the dream of harnessing fusion energy—the "sun on Earth." This profound motivation stems from both a sense of mission and the innate curiosity of humanity, and it is this blend that gives fusion science its remarkable appeal as a transformative scientific and technological endeavor to bring about a new era in human history.

Fusion science is a comprehensive scientific field with tremendous potential. The journey toward achieving fusion burning experiments, which now lie within our reach, has been replete with encounters of numerous formidable challenges—each one overcome through persistent effort. Solving one problem often leads to the emergence of new mysteries, demonstrating the profound depth and expansive reach of fusion science in enhancing our understanding of nature.

While the fusion reaction itself is already well understood, the "system" required to sustain it—the behavior of ultra-high-temperature plasma—remains abounding with unanswered questions. One of the central goals of fusion science is to unravel the mechanisms of this macroscopic system, which operates autonomously and continuously with immense energy. In parallel, it is also essential to develop the extraordinarily complex engineering systems that will constitute future fusion reactors.

Viewed from this perspective, fusion science is not only about physical principles—it also touches upon the fundamental principles of the universe, of society, and of life itself. With this grand context in mind, we aim to carve a broad path forward through the landscape of academic research and technological development.

The road toward fusion—the ultimate source of energy—is sure to lead us into new realms of unknown science and technology, presenting countless intersections of discovery along the way.

A fusion reaction is, quite literally, a process in which atomic nuclei combine. Since atomic nuclei are ions that carry a positive charge, they naturally repel each other. However, if these nuclei can be brought extremely close—within one quadrillionth of a meter ($10^{-15}$ m)—a different force known as the nuclear force overcomes this repulsion, allowing them to fuse. Achieving this requires the fuel to be heated to an extraordinarily high temperature—over 100 million degrees Celsius.

It is well known that matter transitions through three states—solid, liquid, and gas—as temperature increases. When temperatures exceed several thousand degrees, molecules break apart into atoms. As temperatures climb into the tens of thousands of degrees, atoms themselves become ionized, separating into nuclei (ions) and electrons, forming an ionized gas known as plasma. While plasma might seem rare in nature—lightning is a familiar example—it is actually the most common state of matter in the universe. In fact, 99% of the visible matter in the cosmos exists in a plasma state. The Sun, too, is a massive ball of hydrogen plasma, within which hydrogen nuclei fuse into helium through nuclear fusion, releasing an enormous amount of energy. In other words, a "star" is a self-sustaining and stable system in which fusion reactions continuously occur within a mass of plasma.

On Earth, however, achieving fusion requires a fundamentally different system from that of a star. Fusion science faces the challenge of creating an artificial mechanism—one that doesn't exist in nature—that can sustain stable fusion reactions. In stars, it is gravity, made possible by their enormous dimensions, that confines the plasma. For the much more compact "fusion on Earth," magnetic fields are used to confine the plasma instead. Magnetism is a mysterious force that acts like a vortex, and understanding how it forms macroscopic structures remains one of the major unsolved problems in modern science.

To realize fusion energy, both advanced plasma physics and groundbreaking engineering must work together like the two wheels of a cart. For example, just one or two meters away from the ultra-high-temperature plasma core where fusion occurs, cryogenic superconducting magnets are installed to create strong magnetic fields. Additionally, facilities designed to divert and filter out the "ash" (helium) produced by fusion must endure heat levels comparable to those experienced by satellites or meteors during atmospheric re-entry. These systems must effectively remove the heat while ensuring the stability and safety of the surrounding equipment.

The path toward realizing fusion energy has been fraught with challenges—many of which could not have been foreseen when research first began in the mid-20th century. However, encountering unexpected difficulties is not necessarily a misfortune. As many great researchers have testified, "failures often lead to discovery," because truths that transcend human understanding often lie in the most unexpected places.

Fusion can be seen as a steep and formidable peak for those engaged in development and engineering, and at the same time, as a treasure trove for academic researchers. The very essence of academic inquiry lies in transforming difficult problems into entirely new knowledge. The first generation of fusion reactors—designed and built based on our current knowledge—will be massive in scale and generate extremely powerful magnetic fields. This is due to the uncertainties inherent in our understanding. In the future, continued academic research will be essential in building a more precise and reliable scientific foundation, which will serve as the basis for improving economic viability and ensuring safety.

Moreover, in the process of overcoming these challenges, we can expect to make unexpected discoveries that lead to deeper understanding of nature and technological innovation.

At the National Institute for Fusion Science (NIFS), we are uniting the efforts of all our staff to serve as a beacon illuminating new directions in fusion science within the broader currents of academic research. We aim to form a grand concourse where researchers from across disciplines and borders can come together, collaborate, and expand the scope of fusion science across the vast horizon of academic exploration.

We warmly invite you to take interest in the work of NIFS and to engage with us in a variety of ways as we pursue this exciting endeavor.

YAMADA Hiroshi
Director General of National Institute for Fusion Science

# 1. Department of Research

As an inter-university research institute, the National Institute for Fusion Science (NIFS) is required to continue to conduct cutting-edge academic research that supports the development of fusion science as an interdisciplinary collaboration with the active participation of researchers and students from a wide range of fields. To strengthen and expand collaboration between NIFS and universities through interdisciplinary research, a new “Unit System” was established over two years of discussion and implemented in FY2023.

In FY2024 there were new appointments that included an associate professor, two cross-appointmented researchers, five specially appointed researchers, and four visiting professors from abroad. Additionally, a total of 246 Unit members, which included 125 external members of the Unit Research Strategy Committees, conducted research activities alongside 1,649 co-researchers from domestic and international research institutions. In the second year since the Unit system was implemented, it is becoming well-established, and the results of the reform are starting to show, such as a 30% increase in the number of research papers published.

To foster opportunities for research collaboration, we organize open seminars at different levels. Each Unit has planned and conducted a total of fifty-nine seminars, while the Department of Research and the Institute has hosted eight additional seminars. All these seminars are accessible to the research community and the public through our website (https://www.nifs.ac.jp/about/reio/all/) and mailing list. Participants can join both online and in person. The Units have actively communicated their research activities to the public by issuing 13 press-releases, and using EurekAlert! for international information dissemination. Additionally, the Units and the LHD project have created a website (https://www-lhd.nifs.ac.jp/pub/Science.html) that offers easy-to-understand summaries of scientific papers, effectively communicating the research activities.

The findings from the Units’ research in FY2024 were reported during the Unit Research Results Reporting Meeting, held from May 28–29, 2025. The presentations and meeting minutes can be accessed on the following website (https://unit.nifs.ac.jp/research/archives/articles/articles-9271). A detailed overview of the Units’ research results in FY2024 is presented in the following pages.

(R. Sakamoto)

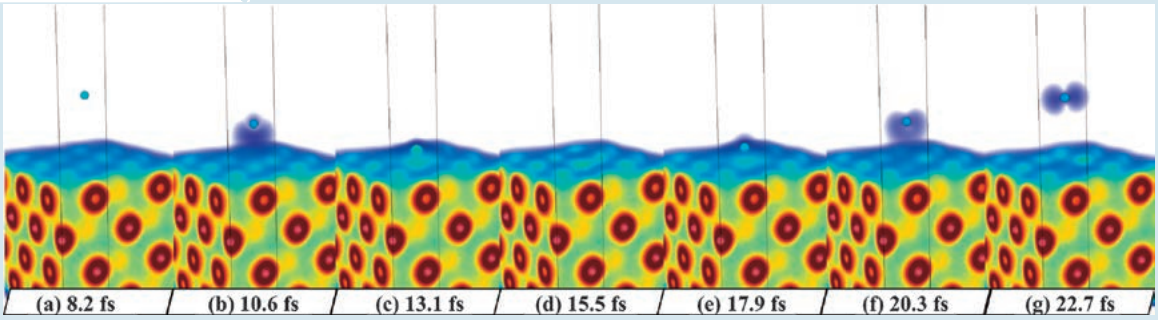
# Meta-hierarchy Dynamics Unit

## Highlight

### Helium Ion Neutralization on Tungsten: An Ehrenfest Molecular Dynamics Approach

Plasma-material interactions (PMI) encompass a broad spectrum of physical phenomena. Among these, we previously examined within the context of meta-hierarchy dynamics is gradual surface morphology evolution, such as fuzz formation, induced by long-time exposure to helium plasma. Another interpretation of PMI within meta-hierarchy dynamics is the neutralization of ions, where incident ions capture electrons from the solid surface. Unlike conventional models treating plasma particles as classical mechanics, this process requires a quantum-mechanical description of electron transitions from the surface.

Historically, PMI simulation has been performed using binary collision approximation (BCA) and molecular dynamics (MD), both of which are fundamentally classical approaches. Even density functional theory (DFT), when applied within the Born–Oppenheimer approximation, fails to capture the quantum dynamics of the electron transfer required for ion neutralization. To address this, we developed the QUMASUN code, which solves time-dependent Kohn–Sham equations for electronic quantum dynamics and Newton's equation for nuclei, following Ehrenfest molecular dynamics formalism. The figure illustrates the electron capture of an incident $He^{2+}$ ion on a tungsten surface. Notably, the reflected He exists as a superposition of $He^{2+}$, $He^{+}$, and neutral He states. This highlights the potential of PMI phenomena, when viewed through the lens of meta-hierarchical dynamics, to serve as an testbed for investigating coupled classical and quantum dynamical systems.




(A.M. Ito (NIFS, SOKENDAI), Y. Toda (SOKENDAI) and A. Takayama (NIFS, SOKENDAI))

Highlight

# Beam divergence degradation with the RF field at the beam extraction region

The convergence of negative ion beams is a critical issue in the development of the ITER neutral beam injector (NBI). The beam divergence angle produced by the RF-driven negative ion source currently remains nearly twice as large as the specification required by the ITER design. To address this discrepancy, we conducted an experimental investigation using the NIFS Negative Ion Beam Test Stand (NIFS-NBTS). Our study identified a direct response of the beam divergence to the externally applied RF field in the beam extraction region.

Figure 1 presents a schematic diagram of the experimental setup, and a typical waveform is shown in Figure 2. Notably, oscillations in the beam width were observed at a frequency matching that of the applied RF field. This observation strongly suggests that RF perturbations in the extraction region can degrade beam convergence.

A detailed analysis revealed that the oscillatory behavior of the beam divergence angle can be understood in terms of its dependence on beam perveance. Furthermore, we identified optimal operational conditions under which the influence of RF perturbations on beam convergence is minimized.

These findings contribute not only to the improvement of beam convergence in ITER NBI systems, but also to the broader application of negative ion beams in areas such as medical accelerator facilities and materials science.

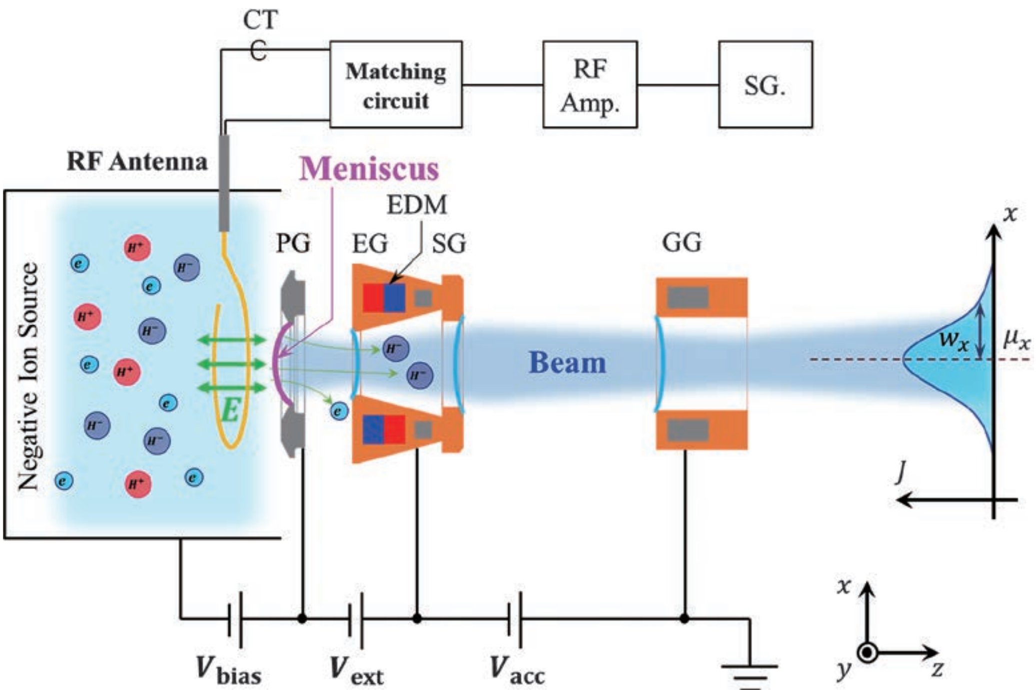



Fig. 1 Schematic of the present experimental setup. The beam width is evaluated by the Gaussian fitting of the beam profile measured at 0.92 m downstream of the ion source.

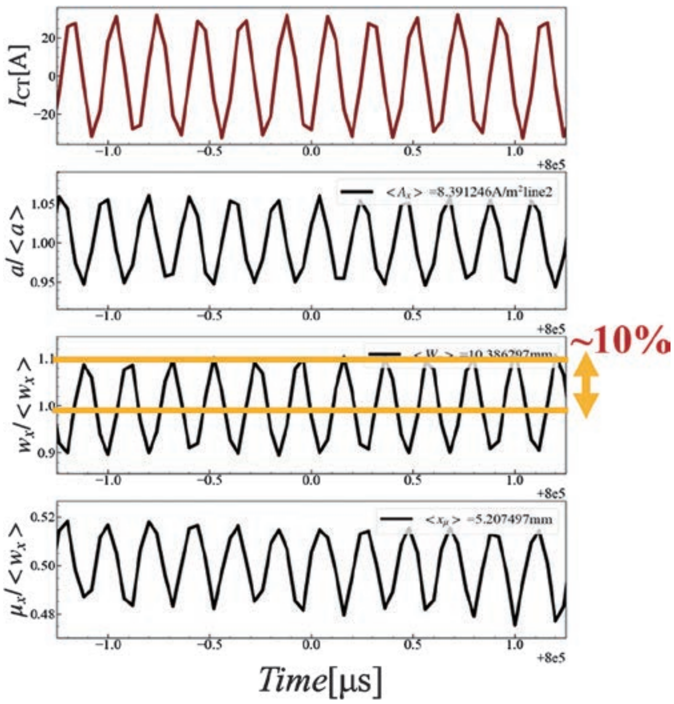



Fig. 2 A typical waveform of (top) externally driven RF current to the antenna, (second) the peak current density, (third) the beam width, and (bottom) the position of the beam center obtained by the Gaussian fitting.

(K. Nagaoka)

Highlight

# Reconstruction of electron velocity distribution function and Gibbs entropy from electron cyclotron emission spectrum in optically thin plasmas

The Kolmogorov theory of energy cascades in neutral three-dimensional turbulence—characterized by the –5/3 power law in the wavenumber spectrum of energy—is an exemplary model illustrating the universality of nonlinear, strongly correlated systems.

In magnetized plasma turbulence, correlations arise not only in configuration space but also between configuration and velocity space. Gyrokinetic theory predicts phase-space entropy cascades with scaling laws reflecting the universality of this turbulence. Our goal is to reveal such universal behavior at electron scales.

This year, we developed a method to obtain electron Gibbs entropy $-\int \delta f_e(v_\perp) \ln \delta f_e(v_\perp)\, dv_\perp$, where $\delta f_e(v_\perp)$ is the fluctuation of the electron velocity distribution function (EVDF), from the electron cyclotron emission (ECE) spectrum [1], and conducted an experimental validation using the LHD device, where $v_\perp$ is the electron velocity perpendicular to the magnetic field.

We used the maximum entropy method (MEM) in velocity space with the Hankel transform (HT), converting $v_\perp$ to $p$, the velocity-space wavenumber. Combined with spatial diagnostics, this method reconstructs entropy distribution in k-p space, enabling analysis of entropy transport in magnetized plasmas.

Figure 1 shows (left) $\delta f_e(\omega, v_\perp)$ and (right) the entropy distribution $S(\omega, p)$ in $\omega$–$p$ space, reconstructed via the MEM-HT method from ECE spectra in an LHD plasma, where EVDF is perturbed by a 10 Hz-modulated neutral beam injection. Signatures of the perturbed EVDF and $S(\omega, p)$ are evident. In the next LHD experimental campaign, we plan to use this method to study entropy linked to electron-scale turbulence.

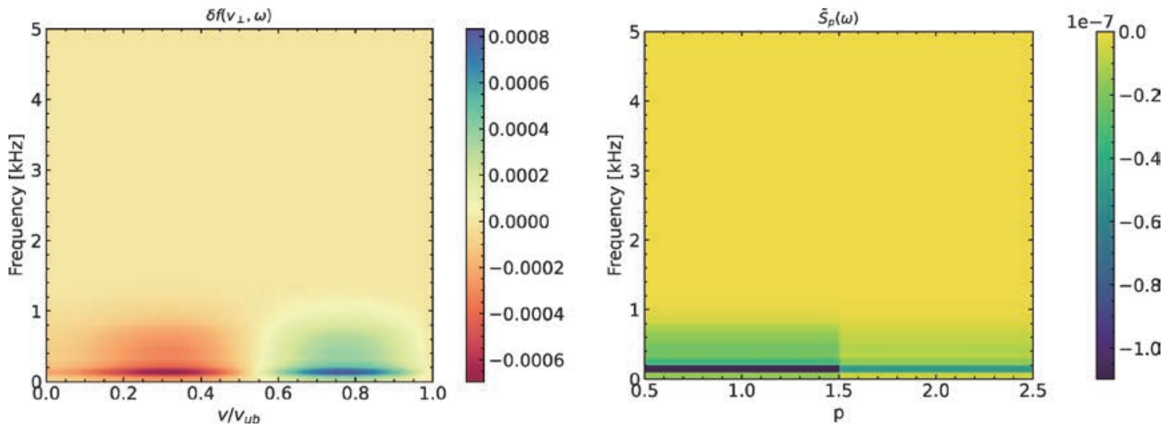



Fig. 1 (left) $\delta f_e(\omega, v_\perp)$ and (right) the entropy distribution $S(\omega, p)$, reconstructed using the MEM-HT method for the ECE spectrum measured in an LHD plasma in which external perturbations were applied to the EVDF by modulating the neutral beam injection at 10 Hz, where $\omega$ and $p$ denote frequency and wave-number index in velocity space, respectively.

[1] Eiichirou Kawamori, Nucl. Fusion **65**, 026024 (2025).

(E. Kawamori)

# Structure Formation and Sustainability Unit

## Highlight

## Development of synthetic diagnostics for energetic particle confinement study

Understanding energetic particle confinement is one of the key issues in achieving high-temperature and high-density plasma. To investigate energetic particle behavior in magnetically confined fusion plasma, information on energetic particle distribution is essential. To measure the energy and spatial profiles of energetic particles, an imaging neutral particle analyzer (INPA) for the Large Helical Device (LHD) has been developed as part of a Ph.D. program for a SOKENDAI student through international collaboration among NIFS, General Atomics (USA), and Mahasarakham University (Thailand) (Fig. 1 Left). The imaging neutral particle analyzer, originally developed in the USA, consists of an aperture, a stripping carbon foil, and a scintillator. Energetic neutrals, which escape from the plasma due to charge exchange reactions, pass through the aperture and are reionized by the stripping foil. The re-ionized energetic particles bombard the scintillator according to the charge-exchanged position and energy. We obtain the energy and spatial distribution of energetic neutrals to the INPA by measurement of the scintillation pattern by a fast camera. The imaging neutral particle analyzer in LHD was designed to have two apertures to measure energetic neutrals under both toroidal magnetic field conditions [1]. In high-temperature plasma discharges performed under relatively low-density conditions in LHD, this high-temperature state is often terminated by a magnetohydrodynamic instability, the energetic ion driven resistive interchange mode (EIC), excited by steep pressure gradients of helically trapped energetic ions. The INPA was used to investigate changes in the energetic ion distribution. We found that the distribution of energetic neutrals to the INPA changed due to the excitation of the EIC [2] (Fig. 1 Middle and Right). Advances in synthetic diagnostics further enhance the understanding of energetic particle confinement as well as making a significant contribution to developing human resources for the future.

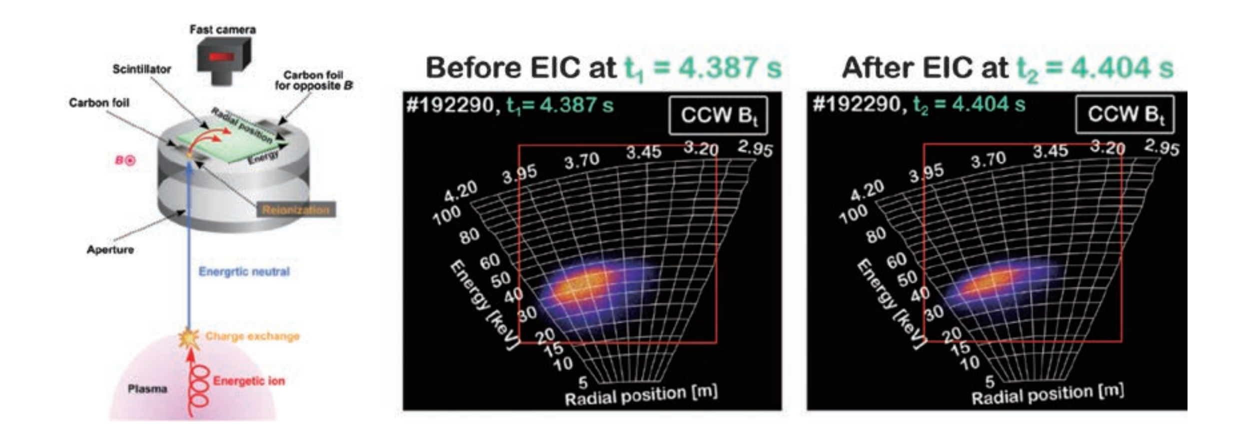



Fig. 1 (left) INPA conceptual diagram. (middle) Energy and spatial distribution of energetic neutrals before EIC excitation. (right) Distribution after EIC excitation. Energetic neutral distribution changed.

[1] W. Paenthong *et al.*, “Design and initial results of the imaging neutral particle analyzer in large helical device”, Review of Scientific Instruments **95**, 083547 (2024).
[2] W. Paenthong *et al.*, “Observation of Helically-Trapped Energetic Particle Transport Induced by Energetic-Ion-Driven Resistive Interchange Mode using Imaging Neutral Particle Analyzer in Large Helical Device”, 51st European Physical Society Conference on Plasma Physics 2025, EPS25-0108.

(K. Ogawa)

# Analyzing physics properties of plasma in newly designed device that controls hidden symmetry of magnetic field

Non-axisymmetric toroidal magnetic configurations that exhibit "hidden symmetry" in magnetic field strength have attracted particular attention, as they offer a steady-state operation while maintaining good particle confinement. To elucidate how magnetic configuration affects the degradation of plasma confinement due to collective phenomena such as instabilities, a comparative study between different magnetic configurations is demanded. We have designed a new experimental device that can control the hidden symmetry of a magnetic configuration, as shown in Fig. 1, applying an advanced coil optimization technique developed in the SFS Unit. We have conducted numerical analyses to predict the experimental capabilities of this device from various aspects, including magnetohydrodynamic (MHD) equilibrium, MHD stability, micro-instabilities and turbulence, particle orbits, and plasma heating [1]. One notable finding was the difference in the confinement of energetic particles between the two representative magnetic configurations. In the quasi-axisymmetric configuration, energetic ions with small velocity in the direction of the field line are easily lost due to the imperfection of axisymmetry. In the other configuration that exhibits a strong toroidal mirror, those energetic ions are found to be confined well. We also confirmed that MHD equilibria of different magnetic configurations can be achieved at a peak beta of approximately 4% without a significant break of magnetic surfaces. These findings enable us to plan plausible experimental scenarios, including academic research, such as observing phase-space dynamics during instabilities excited by energetic particles.

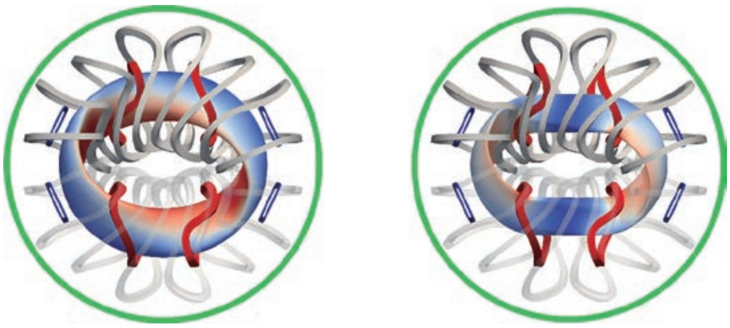


Fig. 1 The coil design and magnetic surfaces with different symmetry that can be generated by the same coils.

[1] H. Yamaguchi *et al.*, The 41st JSPF Annual Meeting, Nov. 17–20, 2024, Tokyo.

(H. Yamaguchi)

# Phase Space Turbulence Unit

## Highlight

### Phase-space decomposed plasma distribution measurement and bifurcation in wave-particle interaction

A high-speed measurement of plasma distribution in phase-space was achieved using a data analysis method called phase-space tomography. Phase-space is expressed in terms of the coordinates of the position and velocity of plasma particles. Distortion of the plasma phase-space distribution can occur in high-temperature plasmas and is believed to have a significant impact on plasma performance. Spectroscopic measurements were applied to analyze the light emitted from plasma using three different types of devices, and a distortion of the plasma phase-space distribution was identified with high precision, using phase-space tomography. The distortion was found to form as a result of efficient plasma heating mediated by waves. Observation of plasma phase-space distribution is an important theme not only in fusion plasmas but also in plasma research on celestial bodies, the sun, and auroras, and is expected to have a ripple effect.

Fusion energy is being developed as a new source of clean electricity to help realize a carbon-neutral society. Plasma differs from regular gases in that it is extremely low in density—about one-millionth that of the atmosphere—so particle collisions are rare. As a result, the histogram of particle motion, called the velocity distribution function, can be distorted from the so-called Maxwell-Boltzmann distribution (equivalent to normal distribution). Such distortions can trigger unexpected plasma behavior, including sudden temperature changes and current generation, making it vital to understand these dynamics.

To analyze plasma motion, scientists commonly use spectroscopy to measure light emitted by plasma. However, because only a limited amount of light is available, spatial resolution has to be given up to measure quick time variations of the velocity distribution function. Yet, understanding how plasma evolves in both space and velocity (phase space) is key for controlling it and achieving efficient fusion power.

A high-speed measurement of plasma phase distribution with high precision was recently achieved by utilizing tomography technology used in the medical field. By combining a newly developed "high-speed luminescence intensity monitor" with existing spectrometers and synchronizing their operation, the plasma's phase-space distribution was reconstructed. This enabled measurements at an unprecedented speed of 10,000 Hz—50 times faster than the previous 200 Hz standard.

Using this technique, energy exchanges between plasma and injected beam particles were observed in the LHD. Particles traveling at speeds close to wave velocities were accelerated, much like surfers riding ocean waves. These wave-particle interactions are crucial for heating plasma in fusion reactors. The study also revealed that waves propagating in opposite directions can occur simultaneously, enhancing particle acceleration and potentially improving heating efficiency [1] (Fig. 1).

This research demonstrates that coordinated diagnostics and data integration can achieve breakthroughs beyond the capabilities of individual instruments. The new method offers a powerful tool for future plasma control and fusion research. Furthermore, because collisionless plasmas also exist in astrophysical phenomena like the Sun and auroras, phase-space tomography may contribute to a wide range of scientific fields.

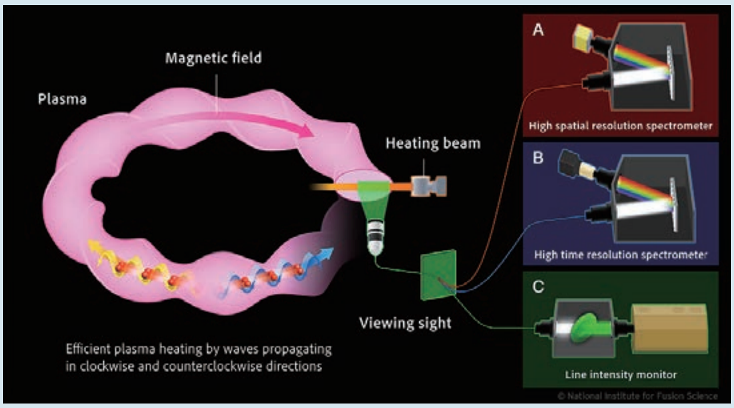



Fig. 1 Image of obtained physical picture by the phase-space tomography.

[1] Tatsuya Kobayashi, Mikirou Yoshinuma, Wenqing Hu, and Katsumi Ida, Detection of bifurcation in phase-space perturbative structures across transient wave – particle interaction in laboratory plasmas, The Proceedings of the National Academy of Sciences (PNAS) **121**, e2408112121 (2024).

(T. Kobayashi)

# Development of Hyperspectral Camera for Auroral Imaging

The aurora is a natural luminous phenomenon caused by interactions between precipitating particles and the constituents of the upper atmosphere. The interaction between electromagnetic waves and particles that occur in the Earth's magnetosphere is thought to be an important mechanism for accelerating electrons, which causes the aurora to glow. This phenomenon of particles accelerating due to the interaction between electromagnetic waves and particles has also been observed in the Large Helical Device (LHD) and has attracted attention as a common energy transport process.

Based on the knowledge gained through the development of diagnostics to investigate such acceleration mechanisms, we developed a hyperspectral camera (HySCAI) for observing the aurora, to study auroral emission processes and colors in detail [1]. A hyperspectral camera can obtain a two-dimensional distribution of the spectrum, and is effective for observing the spectrum of auroras, which appear freely across the sky.

To actualize the hyperspectral camera, a galvanometer mirror scanner was used to scan the slit image on an all-sky image plane in a direction perpendicular to the slit. A high throughput lens spectrometer with an EMCCD detector was used to acquire the spectra image of the light coming from the slit. The spectrometer was equipped with two gratings, one 500 grooves/mm for a wide spectral coverage of 400–800 nm, and the other 1500 grooves/mm for a higher spectral resolution. By changing these grating constants and acquiring hyperspectral data with wide spectral coverage or higher wavelength resolution, new applications of hyperspectral data in aurora observation can be explored.

Initially, HySCAI had been designed to cover only half the sky for higher elevation angles. At the start of the season in 2024, it was redesigned and succeeded in acquiring spectral hyper data covering all the sky.

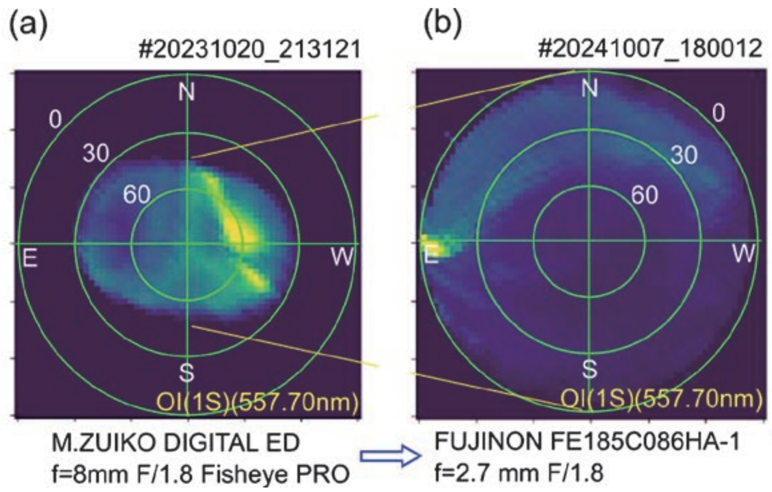



Fig. 1 Two-dimensional distribution images of OI(557.7nm) taken with HySCAI (a) before and (a) after expanding the field of view. This modification made it possible to obtain hyperspectral data covering all the sky.

[1] Yoshinuma, M., Ida, K. and Ebihara, Y. Development of hyperspectral camera for auroral imaging (HySCAI). *Earth Planets Space* **76**, 96 (2024). https://doi.org/10.1186/s40623-024-02039-y

(M. Yoshinuma)

# Discovery of Spontaneous Inflow and Outflow States in High-Temperature Plasma Induced by Energetic Ion Anisotropy

In fusion research, the performance of magnetically confined plasma is determined by its density, temperature, and confinement time, all of which are strongly influenced by the heating conditions. Achieving a high-performance fusion reactor requires improving the confinement of particles and heat and maintaining high density and temperature in the core region, where fusion reactions occur.

In this study, we employed a neutral beam injection (NBI) system to heat the plasma and investigated how varying the ratio of tangential to perpendicular beam powers affected plasma behavior. We discovered that the inflow and outflow of high-temperature plasma are spontaneously regulated by a distinct state of energetic ions [1-4]. This novel finding may lead to the development of high-performance plasmas, reduction in reactor size, enhanced fusion power output, and improved control of plasma burning conditions.

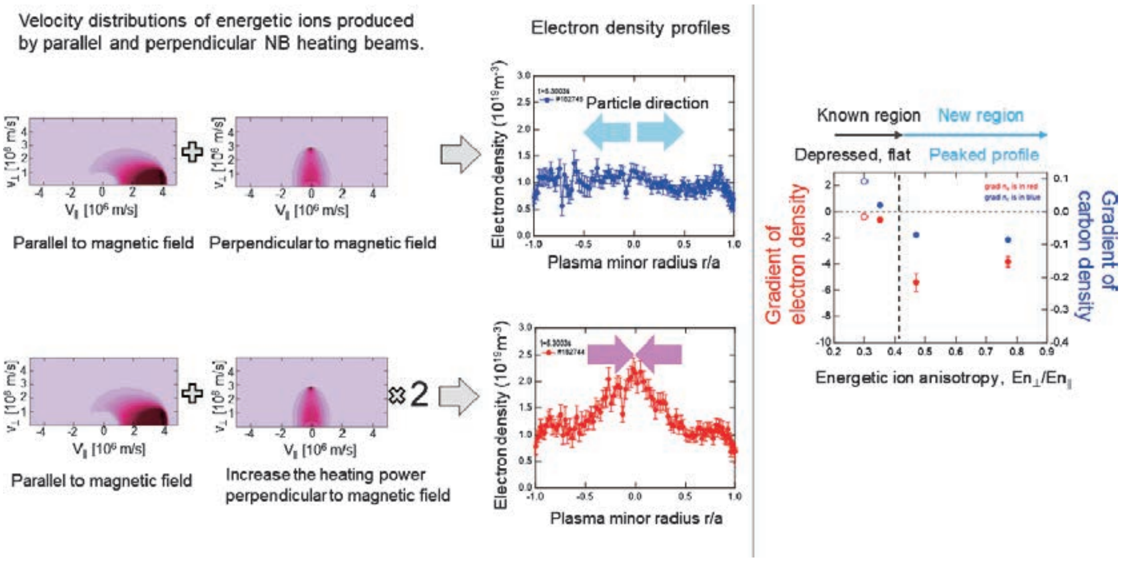



Fig. 1 (Left) Velocity distributions of heating beams injected parallel and perpendicular to the magnetic field. By varying the anisotropy of energetic ions, the electron density profile transitions between peaked and flattened shapes. The spatial profile is plotted as a function of the normalized plasma radius *r/a*, where *r/a* = *0* corresponds to the plasma center and *r/a* = *1* to the edge of the confinement region in the LHD. (Right) Electron and impurity density gradients as a function of the anisotropy parameter $En_\perp/En_\parallel$, where $En_\perp$ and $En_\parallel$ are evaluated from the total energy of particles in velocity space ($v_\perp$, $v_\parallel$). The results indicate that stronger anisotropy (higher $En_\perp/En_\parallel$) enhances central particle accumulation, while more isotropic distributions lead to flatter profiles and reduced confinement.

The Large Helical Device (LHD) is equipped with five NBI systems. NB#1 to NB#3 inject beams tangentially to the magnetic field, while NB#4 and NB#5 inject beams perpendicularly (Figure 1). Although the ratio of tangential to perpendicular power varied significantly, the ion temperature profile remained essentially unchanged. However, the middle panel of Figure 1 reveals that the electron density profile transitioned between peaked (red) and flat (blue) states, depending on the beam configuration.

By varying the power ratio of tangential and perpendicular beams, the velocity distribution of energetic ions shifts from isotropic to anisotropic. The right panel in Figure 1 shows how the electron density profile depends on the energetic ion anisotropy, represented by the ratio of stored energy in the perpendicular and parallel components ($En_{\perp}/En_{\parallel}$), derived from the injected beam powers. When $En_{\perp}/En_{\parallel}$ was adjusted from 0.3 to 0.8, we found that profiles remained flat for $En_{\perp}/En_{\parallel} < 0.4$ and became centrally peaked for $En_{\perp}/En_{\parallel} > 0.4$. To further examine this effect, a carbon pellet was injected, and the resulting carbon ion density profiles were observed. The profile was hollow for $En_{\perp}/En_{\parallel} < 0.4$ but became peaked when $En_{\perp}/En_{\parallel} > 0.4$.

These results demonstrate that plasma transport and the balance of particle inflow and outflow can spontaneously change in the presence of anisotropic energetic ions. This has important implications for the control of the confinement region in fusion plasmas. To explore the underlying physics, simulation studies were carried out. First, we analyzed the radial electric field in the plasma core, which was found to be approximately −5 kV/m, consistent with heavy ion beam probe measurements. Although this field strength alone is unlikely to affect particle transport significantly, we further investigated the role of turbulence. The results suggest that turbulent transport plays a key role in determining whether the density profile is peaked or flat.

Our discovery reveals that the direction and magnitude of particle inflow and outflow within the confinement region can be effectively controlled by leveraging the anisotropic properties of energetic ions. This represents a significant advancement in the understanding of plasma transport physics and opens new pathways for optimizing confinement in future fusion reactors. In future work, we aim to elucidate the detailed physical mechanisms behind this phenomenon and apply our findings to enhance fusion plasma performance, downsize reactor designs, improve energy output, and enable robust control of burning plasmas.

[1] M. Nishiura, "Core density profile control by energetic ion anisotropy in LHD", 65th Annual Meeting of the APS Division of Plasma Physics, October 30–November 3, 2023 (invited).

[2] M. Nishiura, "Particle transport control by auxiliary heating systems in LHD", 24th International Stellarator Heliotron Workshop, 9–13 September 2024, Hiroshima, Japan (invited).

[3] M. Nishiura *et al.*, "Core density profile control by energetic ion anisotropy in LHD" *Phys. Plasmas* **31**, 062505 (2024). https://doi.org/10.1063/5.0201440

[4] Press Release, June 24, 2024, National Institute for Fusion Science and Kyushu University:
https://www.nifs.ac.jp/news/collabo/240624.html
https://www.kyushu-u.ac.jp/ja/researches/view/1102/
https://www.eurekalert.org/news-releases/1048779

(M. Nishiura)

# Plasma Quantum Processes Unit

The goals of the Plasma Quantum Processes Unit are to advance interdisciplinary plasma research based on quantum processes and to promote international collaborations. Toward these goals, each member of the Unit is pursuing research with the following academic strategies.

Advancement

- Advancement of plasma measurement based on highly charged ion spectroscopy/quantum processes
- Inclusion of quantum physics in plasma kinetics and enhancement of the accuracy of kinetic transport calculations, including highly charged ions
- Fusion reactor edge plasma modeling, including atom-molecule processes and plasma-wall interactions

Interdisciplinary

- Collaboration with other fields using atomic and molecular data/promoting applications by developing databases
- Research on ultra-relativistic plasma dynamics, including quantum electrodynamics processes, and development of laboratory astrophysics using intense lasers
- Promoting collaboration with other Units and interdisciplinary research with physics fields other than fusion from the viewpoint of data-driven science and materials informatics for advanced measurements
- Interdisciplinary collaboration with particle physics fields through research on quark-gluon plasma, and obtaining hints for new measurements in fusion plasma experiments from detectors in high-energy accelerator experiments
- Applying cryogenic engineering technology developed in fusion research to high-energy density sciences

To ensure that the Unit's research activities are carried out with the participation of the broader academic community, a Unit Research Strategy Council was organized, inviting 15 external members from various research fields.

The Unit regularly holds seminars with external collaborators to disseminate its research activities. Between April 2024 and March 2025, seven seminars were held on relevant topics, including atomic structure calculations of highly charged ions, highly charged ion spectroscopy, data-driven science, and lattice QCD simulations for quark-gluon plasma.

The Unit is developing numerical databases of atomic collisions and ion surface collisions for fusion and plasma applications through international collaborations. The databases are available on the internet (https://dbshino.nifs.ac.jp/index-j.html).

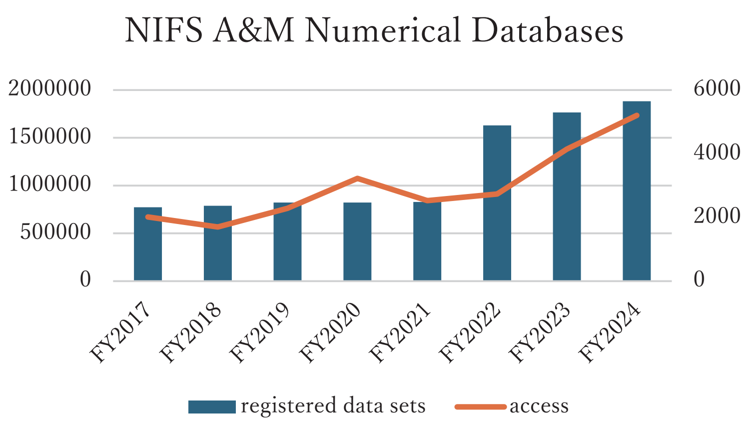



Fig. Annual changes in the number of registered data sets (left) and access (right) to the NIFS database. The number of data sets is as of the end of each fiscal year, and total access was counted in each fiscal year.

(I. Murakami)

Highlight

# Development of Open Data Analysis Tool for Science and Engineering (ODAT-SE) in measurement informatics

A fundamental topic in fusion science and other scientific fields is measurement informatics, the methodology of data analysis in experimental measurements. As an interdisciplinary research activity, we have released an open-source software Open Data Analysis Tool for Science and Engineering (ODAT-SE), formerly known as 2DMAT, for the data analysis of many advanced experimental measurements (https://github.com/issp-center-dev/ODAT-SE). ODAT-SE can be applied to a new experimental measurement method by adding a model for the experimental measurement. Currently, ODAT-SE offers five analysis methods: (i) grid search, (ii) Nelder-Mead optimization, (iii) Bayesian optimization, (iv) the replica exchange Monte Carlo method, and (v) the population-annealing Monte Carlo (PAMC) method. In particular, the PAMC method uses massively parallel Bayesian inference and is suitable for supercomputers like Fugaku. In general, the Bayesian inference gives posterior probability distribution $P(X|Y)$, as a histogram of Fig. 1(a), where $X \equiv (X_1, X_2, \ldots, X_n)$ is the target quantity (vector), the quantity that we would like to know, and $Y \equiv (Y_1, Y_2, \ldots, Y_m)$ is the experimentally observed quantity (vector). Since the PAMC method is a global search algorithm, one can find global and local solutions in the data space of $X$. In a recent paper, the PAMC method was used to determine the surface structure of the 3×3-Si phase on the Al (111) surface using total reflection high-energy positron diffraction (https://www2.kek.jp/imss/spf/eng/, Fig. 1(b)) and core-level photoemission spectroscopy [1]. The analysis finds the global solution as a flat surface structure shown in Fig. 1(c) and local solutions, which indicates the crucial importance of the global search algorithm. As a future project, ODAT-SE will be developed further and used both in plasma and material science, for example, through our project launched recently in the Moonshot R&D Program (https://www.jst.go.jp/moonshot/en/program/goal10/A3_hoshi.html).

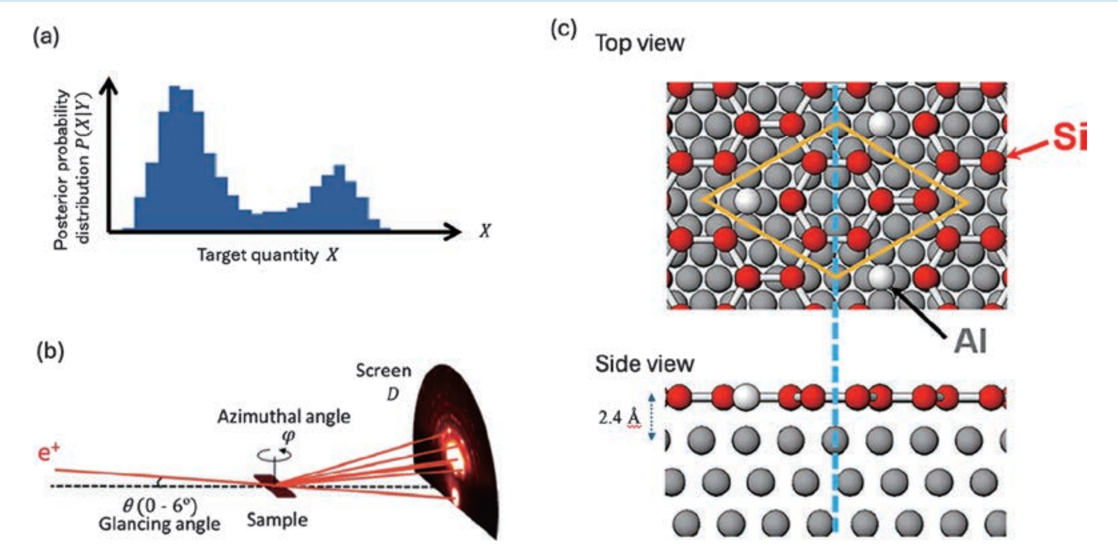



Fig. 1 (a) Schematic diagram of posterior probability distribution $P(X|Y)$ (b) Schematic diagram of total reflection high-energy positron diffraction experiment (c) Top view (upper panel) and side view (lower panel) of surface structure of the 3×3-Si phase on Al (111) surface [1].

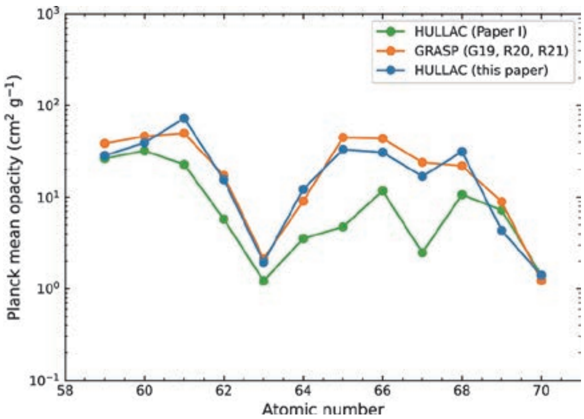
[1] Y. Sato *et al.*, Phys. Rev. Materials **9**, 014002 (2025).

(T. Hoshi)

# Systematic opacity calculations for kilonovae – II. Improved atomic data for singly ionized lanthanides [1]

Lanthanides play most important roles in the opacities for kilonovae, ultraviolet-optical-infrared emissions from neutron star mergers. Although several efforts have been made to construct atomic data, the accuracy of the opacity has not been fully assessed and understood. Due to the complexity of the atomic structures of the lanthanides, theoretical atomic calculations covering many elements and ionization stages often involve simplifications in the calculations, such as a parametrized effective potential. In this paper, we aim to obtain a deeper understanding of the lanthanide opacities in kilonova ejecta, and at finding a strategy to provide accurate atomic data with the parametric potential method using the Hullac code, which has been utilized for spectral analysis of impurity ions in LHD plasmas.

Firstly, we identified transition arrays which are relevant to structures in the opacities, for which derivation of accurate energy level distribution is important to obtain reliable opacities. Then, we optimized the parametric potential to minimize configuration averaged energies of the transition arrays. The opacities evaluated with our new results were higher by a factor of up to 3–10 compared with our previous work [2] (Paper I, see Figure), which agreed with opacities obtained by more time-consuming benchmark calculations using the Grasp2K code [3-5].




Plank mean opacities of singly ionized lanthanides for density of $10^{-13}$ g/cm$^3$ and temperature of 5,000 K at 1 day after the merger [1].

[1] D. Kato, M. Tanaka, G. Gaigalas, L. Kitovienė, P. Rynkun, Monthly Notices of the Royal Astronomical Society **535**(3), 2670–2686 (2024).
[2] M. Tanaka, D. Kato, G. Gaigalas, K. Kawaguchi, Monthly Notices of the Royal Astronomical Society **496**(2), 1369–1392 (2020).
[3] G. Gaigalas, D. Kato, P. Rynkun, L. Radžiūtė, M. Tanaka, The Astrophysical Journal Supplement Series **240**, 29 (2019).
[4] L. Radžiūtė, G. Gaigalas, D. Kato, P. Rynkun, M. Tanaka, The Astrophysical Journal Supplement Series **248**, 17 (2020).
[5] L. Radžiūtė, G. Gaigalas, D. Kato, P. Rynkun, M. Tanaka, The Astrophysical Journal Supplement Series **257**, 29 (2021).

(D. Kato)

# Transport in Plasma Multi-phase Matter System Unit

The term “multi-phase” refers to the three states of matter: solid, liquid, and gas. In the region where the fourth state of matter, plasma, meets the other three, many interesting phenomena occur. In a fusion reactor, relatively cold plasma surrounding the hot core plasma comes into contact with the reactor wall made from solid or sometimes liquid materials.

The research objective of this unit is to investigate the behavior of plasma, gases and wall materials in the region where they interact with each other, through experiments and computer simulations. To be more specific, our research goal is to understand the particle and energy transport of boundary plasma and to investigate the effects of plasma interactions on materials that alter these properties.

Knowledge and techniques gained in our study are applied not only to plasma and fusion research but other research fields, e.g., materials science, bioengineering and various industrial technologies. Many domestic and international collaborations with universities, laboratories and private sectors are being conducted.

The following are the results obtained in this Unit.

**1. Spatial Distribution of Hydrogen Molecules in the Divertor Region of JA-DEMO**

Seiki Saito, Hiroaki Nakamura *et al.* performed a molecular dynamics simulation to estimate the rovibrational states of recycled hydrogen molecules in the divertor region of the JA-DEMO reactor under detached plasma conditions. In this region, it is well known that the rate coefficient of molecular-assisted recombination (MAR) varies by several orders of magnitude, depending on the rovibrational states of the hydrogen molecules.

They revealed in the simulations that molecules in higher rovibrational states (more than 15) are released even with low incident energy, which is expected to be the dominant condition under detached plasma conditions. Molecules generated in this way can strongly affect the formation of the detached plasma via a molecular assisted-process such as MAR.

These findings mentioned above were published in Nucl. Fusion 64 (2024) 126067.

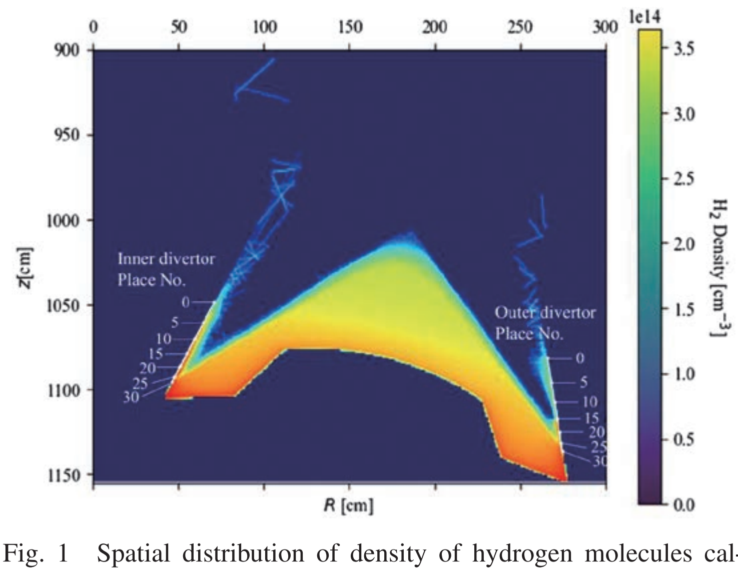



Fig. 1 Spatial distribution of density of hydrogen molecules calculated by the neutral transport (NT) simulation with the emission distribution at the wall calculated by the MD simulation.

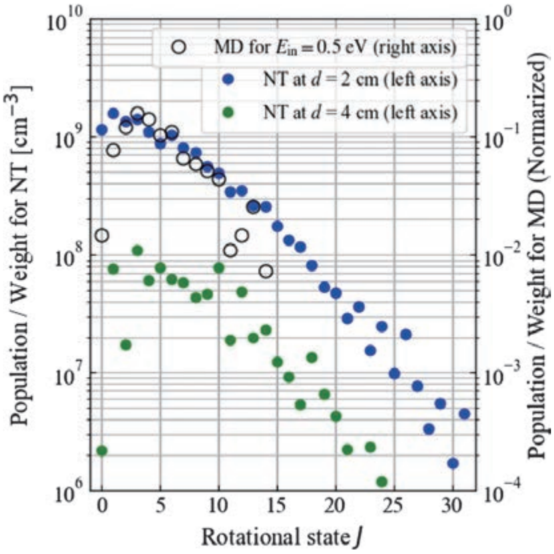



Fig. 2　Distributions of rotational states J of hydrogen molecules.

**2. Propagation characteristics of the millimeter-wave vortex in magnetized plasma**

Chenxu Wang, Hideki Kawaguchi, Hiroaki Nakamura and Shin Kubo investigated the propagation characteristics of a millimeter-wave vortex of a hybrid mode of a cylindrical corrugated waveguide in the magnetized plasma by using three-dimensional numerical simulations with the finite-difference time-domain (FDTD)

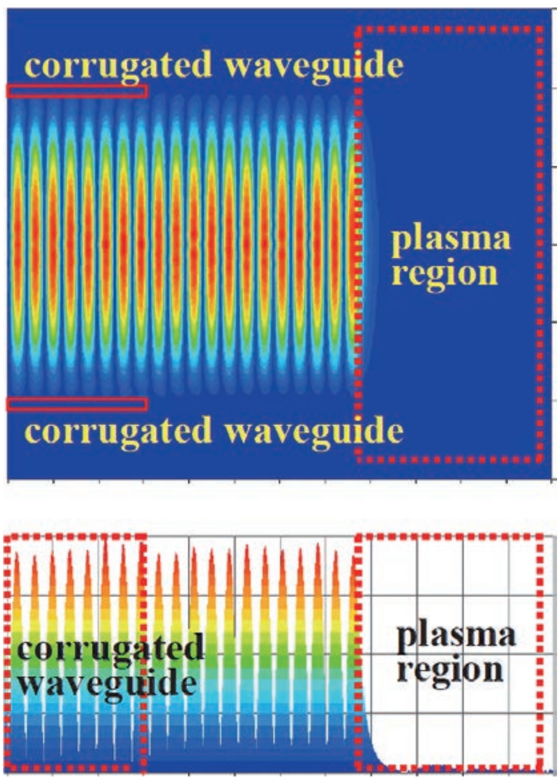



Fig. 3　Electric field intensity in the y-z plane with $l$ = 0 (plane wave).

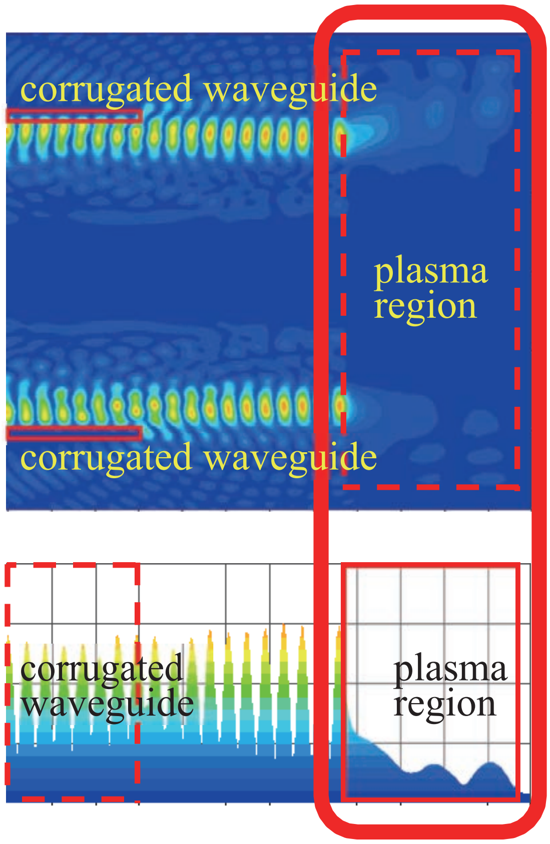



Fig. 4　Electric field intensity in the y-z plane with $l$ = 20 (millimeter-wave vortex of a hybrid mode).

method. They revealed that the millimeter-wave vortex of the hybrid mode can propagate in magnetized plasma even under conditions where a normal plane wave is cut off. Moreover, the propagation power in the plasma is highly dependent on the topological charge.

These findings mentioned above were published in Japanese Journal of Applied Physics 63, 09SP08 (2024).

### 3. Real-Time Boronization Using an Impurity Powder Dropper in LHD

Suguru Masuzaki, Mamoru Shoji *et al.*, performed a real-time boronization using an impurity powder dropper (IPD) during discharges. The result was compared with that of a conventional glow discharge boronization with diborane gas, performed before each experimental campaign.

In both methods, oxygen and iron impurities were effectively reduced. In glow discharge boronization, the reduction in oxygen levels persisted until the end of the experimental campaign. On the other hand, reduction in iron levels only lasted a few days. In the case of the real-time boronization with the IPD during long pulse discharges, suppression of both the oxygen and iron was observed. The effect on the iron quickly diminished within several seconds after the injection ended, whereas the effect on the oxygen lasted more than 100 s.

These findings mentioned above were published in Nuclear Materials and Energy 42 (2025) 101843.

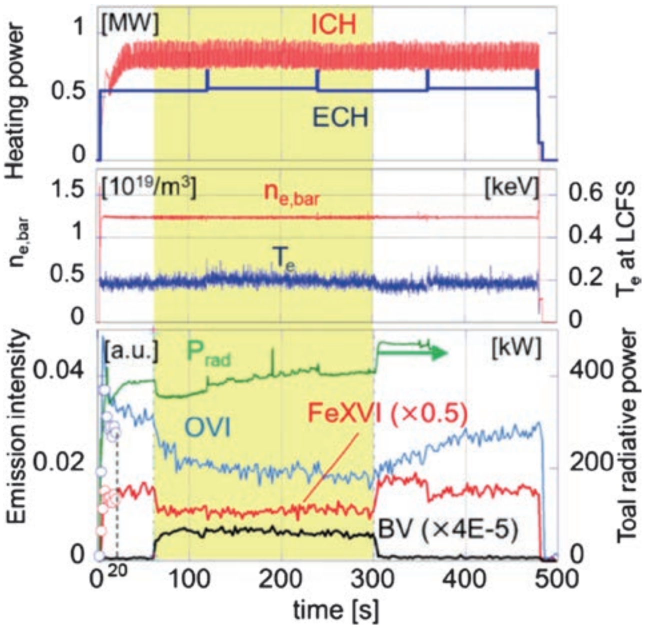



Fig. 5 Time evolutions of heating power, line average density and electron temperature at LCFS, radiative power, line emission intensities of iron, oxygen, and boron during discharge #176017. B dropped from 60.8 s to 300.8 s. Blue and red open circles represent the OVI and FeXVI intensities, respectively, for discharge #176018, where the discharge conditions were identical to those of discharge #176017 for the first 20 s.

# Sensing and Intellectualizing Technology Unit (S&I)

This chapter reports on the two major results achieved by the S&I Unit in FY2024. The S&I unit consists of plasma scientists from various fields. Collaborations and discussions within this group produce synergistic effects for new findings and developments. One result concerns the MHD physics of high-temperature magnetic confinement. The other is the development of new nano-manufacturing technology.

Both results are based on precise plasma diagnostics and laser engineering developed within this unit.

## Parity transition of radial structure of MHD instability in magnetically confined torus plasmas

The parity transition of radial displacement profiles associated with MHD instabilities is closely related to the formation and stabilization of magnetic islands in magnetically confined plasmas. Odd parity typically indicates the presence of a distinct magnetic island, while even parity suggests its absence. This study investigates the influence of externally applied resonant magnetic perturbations (RMPs) on the characteristics of parity transitions, with the aim of achieving active control of magnetic islands via parity modulation.

Odd-to-even parity transitions have never been observed in other devices. In this study, both even-to-odd and odd-to-even transitions were identified within a single discharge in the Large Helical Device (LHD). In discharges where the $m/n$ = 1/1 resistive interchange mode (RIC), an even-parity MHD instability, remains unstable, an increase in electron density leads to the emergence of an $m/n$ = 1/1 instability accompanied by a magnetic island—referred to as the “Edge” MHD instability—which then triggers a parity transition from even to odd. When the Edge instability subsequently stabilizes while RIC remains dominant, a transition from odd to even parity occurs. These observations indicate that the competition between the RIC and Edge instabilities governs the occurrence of parity transitions. Here, $m$ and $n$ represent the poloidal and toroidal mode numbers, respectively.

Figure 1 shows the time evolution of the magnetic island width (red symbols) in a large external RMP discharge. The island width was evaluated based on the peak-to-peak distance of the odd-parity structure measured by high-spatial-resolution $CO_2$ interferometry. Zero island width indicates even parity, while a finite width corresponds to odd parity. Figure 2 shows the dependence of odd-to-even parity transition frequency on the strength of external RMP. Although odd-to-even parity transitions can occur even with relatively small RMPs, their frequency increases sharply once the RMP amplitude exceeds a certain threshold. One possible explanation is that a stronger external RMP shortens the island formation time,

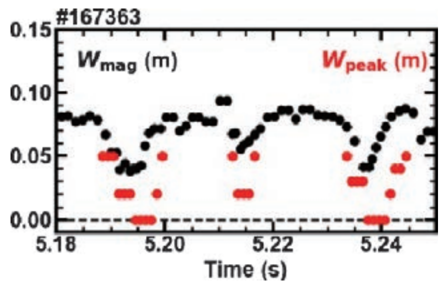



Fig. 1 Time evolution of magnetic island width in a discharge with a large RMP, showing frequent parity transitions. (Reproduced from Takemura *et al.*, *Sci. Rep.* **15**, 14890 (2025))

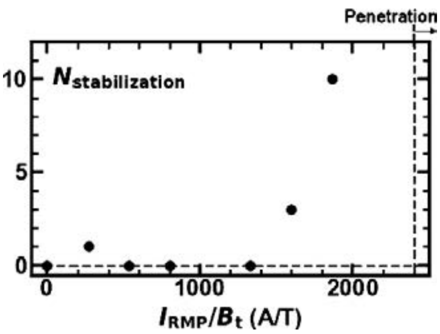



Fig. 2 The number of occurrences of the odd-to-even parity transition in discharges with the same experimental conditions except for external RMP amplitude. (Reproduced from Takemura *et al.*, *Sci. Rep.* **15**, 14890 (2025))

thereby increasing the transition frequency.

In summary, our results show that the frequency of parity transitions—including the newly observed odd-to-even type—can be actively controlled by external RMPs. This provides new insights into magnetic island dynamics and suggests strategies for active control of magnetic islands in future fusion reactors.

[1] Y. Takemura *et al.*, *Scientific Reports* **15**, 14890 (2025).

(Y. Takemura)

## Plasma Nanofabrication on Various Semiconductors by the Codeposition Etching Technique [2]

This study explores a lithography-free nanofabrication method known as Codeposition Etching (CoDE), applied for the first time to various compound semiconductors using argon plasma and molybdenum (Mo) impurities. Unlike conventional nanostructure fabrication that relies on complex techniques like photolithography and reactive ion etching, CoDE offers a simple, one-step alternative to create nano/microstructures based on the interaction between impurity deposition and plasma etching.

In the CoDE process, Mo atoms are co-deposited onto semiconductor surfaces during Ar plasma irradiation. These atoms act as nanomasks due to their lower sputtering yield compared to the substrate, enabling the selective formation of nanostructures through preferential sputtering. Experiments were performed on six different semiconductors: Si, SiC, Ge, GaAs, ZnSe, and GaN. Structures were successfully formed on Ge, GaAs, ZnSe, and GaN, but not on Si and SiC, consistent with their lower sputtering yields relative to Mo.

The study investigates the effects of impurity flux and deposition time. Increasing the Mo deposition rate (via a biased Mo wire) resulted in higher density and smaller-size structures, although their height was reduced due to decreased selectivity in sputtering. Notably, the structures evolved from conical shapes to more complex hillock or dislocation forms at higher impurity concentrations, suggesting a shift in the nucleation mechanism. Time-dependent experiments revealed a threshold behavior in structure formation, indicating a critical impurity concentration required to trigger uniform nucleation—akin to crystal growth in supersaturated solutions.

The authors propose a four-step mechanism: (1) impurity deposition, (2) surface diffusion, (3) nucleation via either defect trapping or supersaturation, and (4) preferential sputtering. This model highlights the tunability of structure size and density through control of impurity flux and substrate properties.

In conclusion, CoDE proves to be a promising approach for scalable, cost-effective nanofabrication on a broad range of semiconductor materials. It holds potential for applications in photovoltaics, optoelectronics, and random lasers, where surface morphology rather than precise patterning is critical. Future research will address the roles of temperature, impurity species, and further optimization for practical applications.

[2] Q. Shi, S. Kajita, N. Ohno, H. Tanaka, R. Yasuhara, H. Fujiwara, and H. Uehara, Lithography-Free Nanofabrication on Various Semiconductors by the Codeposition Etching Technique. *Langmuir* **40**(24), 12437–12442 (2024).

(H. Uehara)

# Plasma Apparatus Unit

The plasma apparatus (PA) unit, a core component of plasma science and technology, started in fiscal 2023. The importance of disruptive innovation as a game-changer in fusion research has been pointed out. To this end, the PA unit will aspire to create innovative plasma technologies by deepening scientific knowledge of the complex collective phenomena of plasma. By developing novel applications of plasma as working hypotheses, the PA unit will promote collaboration in fusion with other fields and shed light on the unexplored emergent nature of collective phenomena. Innovations in plasma science and technology will open a new horizon for various natural science research, other disciplines and technologies.

Toward the above end, the following research topics were pursued: neutral beam injection, anti-matter and dipole plasma, and muon science.

(H. Nakano)

## Neutral Beam Injector

One of the issues in ITER Neutral-Beam (NB) development is reducing the beam divergence of the Radio Frequency (RF) negative hydrogen ion source. Especially in the Diagnostic NB (DNB) with 100 keV in beam energy, the beam divergence has not met the ITER requirement with which the NIFS-NB Filament-driven Arc (FA) ion source is satisfied. The beam divergences of FA and RF ion sources have been compared using the FA/RF hybrid Research and development Negative Ion Source (NIFS-RNIS), upgraded from the original NIFS-RNIS, a FA negative ion source, through collaboration with NIFS, the ITER organization, and the Max Planck Institute for Plasma Physics. This year, an increase in negative hydrogen ion density by cesium seeding was observed for the first time. In a well-cesiated condition, the original FA NIFS-RNIS and the FA/RF hybrid NIFS-RNIS with RF-mode, with around 50 keV in beam energy, formed a beam with a similar beam divergence angle of 9 mrad under the assumption of a beam size as a point at the grounded grid electrode (GG) of the ion source accelerator. The beam divergence of 9 mrad satisfies the ITER requirement of 7 mrad when the beam diameter at the GG is 5 mm.

Low-pressure operation in the ion source discharge chamber enhances efficiency by reducing stripping losses in the beam extraction and acceleration regions. In exploring the lowest operating pressures for hydrogen and deuterium in the current setup, the FA/RF hybrid NIFS-RNIS, it was found that the minimum operating pressure for deuterium was lower than that for hydrogen in RF-mode. Another isotope effect was also observed in the investigation using the original FA NIFS-RNIS, where the line-averaged negative ion density of the deuterium was higher than that of hydrogen in RF mode.

Toward the realization of a cesium-free negative-ion source, C12A7 electride was tested as the plasma-facing grid of the ion source accelerator using an induced-coupled plasma ion source with 1 kW discharge power installed in the Equipment with Versatility for Ion Source Study (EVISS). Comparing the reference material for aluminum alloy, a 70 % larger beam current was observed.

(H. Nakano)

## Anti-Matter and Dipole Plasma

In the development of an electron–positron plasma experiment, a positron trap employing a 5 T superconducting magnet was successfully operated, demonstrating stable confinement of pure electron plasmas. The trap has been integrated with a low-energy positron beamline at AIST, and preliminary positron injection tests have been conducted. In parallel, a levitated high-temperature superconducting dipole device has been designed and fabricated, including cryogenic and vacuum components. Numerical orbit analyses revealed that the radial mixing between electrons and positrons is intrinsically difficult but can be enhanced by introducing chaotic orbits and rotating electric fields, suggesting a viable pathway toward creating confined pair plasmas. In a laboratory study of wave particle interactions and transport in a dipole field, experiments with the RT-1 device at the University of Tokyo demonstrated radial particle transport driven by low-frequency electrostatic fluctuations. Synchronous measurements of magnetic fluctuations and energetic electron losses confirmed inward transport correlated with chorus emissions. The occurrence frequency of chorus emissions was found to depend on the magnetic field curvature, providing new insight into the link between magnetic geometry and self-organized plasma dynamics. These results indicate significant progress toward realizing laboratory pair plasmas and deepening the understanding of wave-driven transport common to both laboratory and space plasmas.

(H. Saito, Univ. Tokyo)

## Muon Science

We have advanced muon science using superconducting transition-edge sensor (TES) microcalorimeters, achieving an unprecedented relative energy resolution of ΔE / E ~ 10^-3. This technique enables precision X-ray spectroscopy of muonic atoms, offering a new approach to studying highly charged ions and providing a platform to explore quantum dynamics involving negatively charged particles such as muons and electrons bound to a single nucleus.

In FY2024, we achieved the first experimental observation of multicharged muonic ions, a novel atomic system where a negative muon replaces inner-shell electrons. Using high-resolution TES spectroscopy of low-pressure argon gas, we resolved X-ray peaks corresponding to one-, two-, and three-electron μAr states. These results confirm theoretically predicted structures and open the way to femtosecond-scale studies of muon–electron coupled dynamics.

We also conducted muonic X-ray experiments with newly developed high-energy TES detectors (up to 100 keV) to explore strong-field QED phenomena. In parallel, low-energy TES detectors (< 10 keV) are being applied to precision measurements that aim to elucidate the microscopic mechanisms of muon-catalyzed fusion (μCF).

This research, currently under consideration for inclusion in the JST Moonshot Goal 10 program, is expected to deepen fundamental understanding and contribute to the realization of high-efficiency μCF.

(S. Okada, Chubu Univ.)

# Complex Global Simulation Unit

To understand the behavior of a multi-hierarchy system, individual simulations of each level are not sufficient. Global simulations that account for inter-hierarchy interactions are essential in nuclear fusion research and in many academic fields. They are challenging due to the vast differences in time and spatial scales. This unit develops methods that couple different hierarchies and physical models to overcome this difficulty. The unit focuses on (1) global simulations of magnetic confinement fusion plasmas—covering both core and edge—via kinetic-MHD hybrid methods, and (2) broadly applicable approaches to overcome computational limits and better reproduce real-world behavior. Notable progress was made in 2024–2025, as described below.

(H. Miura)

## Strong impact of energetic ions on edge-localized modes in tokamak plasmas

The effects of energetic ions on the edge localized mode (ELM), a heat and particle ejection phenomenon in fusion plasmas was investigated using a kinetic-magnetohydrodynamic hybrid simulation code, MEGA [1], by an international collaboration involving researchers from the University of Seville, Spain, and the Complex Global Simulation Unit of the National Institute for Fusion Science.

The simulation reproduced an abrupt and large crash that characterizes ELMs, and revealed that energetic ions have a significant effect on the amplitude and frequency spectrum of ELMs [2]. A resonant interaction between the energetic ions at the plasma edge and the electromagnetic perturbations from the ELM leads to an energy and momentum exchange. This study advances the understanding of the physics underlying ELM crashes in the presence of energetic ions and highlights the importance of these ions in the optimization of ELM control techniques.

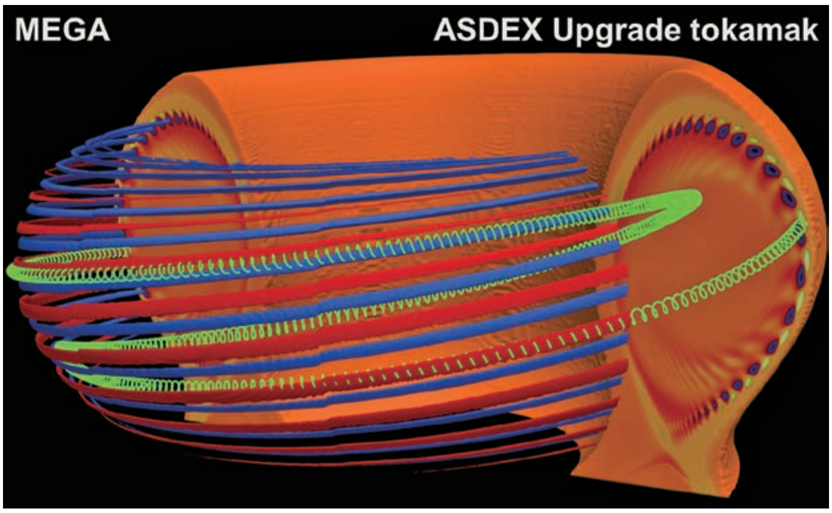



Fig. 1 3D visualization of an ELM in the ASDEX Upgrade tokamak, as simulated with the MEGA code. The tokamak volume is colored according to the ELM structure. The ELM interacts with the energetic ions whose orbit is shown in green. Figure adapted from J. Dominguez-Palacios *et al.*, Nat. Phys. (2025), under a Creative Commons license CC BY 4.0, http://creativecommons.org/licenses/by/4.0/.

[1] Y. Todo and T. Sato, Physics of Plasmas **5**, 1321 (1998).
[2] J. Dominguez-Palacios *et al.*, Nature Physics (2025). https://doi.org/10.1038/s41567-024-02715-6

(Y. Todo)

# The nonlinear excitation of instability via resonance overlap in ASDEX-Upgrade tokamak

The Alfvén instability can nonlinearly excite the energetic-particle-driven geodesic acoustic mode (EGAM) on the ASDEX-Upgrade tokamak, as demonstrated experimentally. The mechanism of the EGAM excitation and its nonlinear evolution are not yet fully understood. In the present work, a first-principles simulation using the MEGA code investigated the mode properties in both the linear growth and nonlinear saturated phases, utilizing realistic parameters. The simulation successfully reproduced the experimental observations, including the excitation and coexistence of the Alfvén instability and EGAM [3]. The simulated mode properties are consistent with experimental results, achieving excellent validation. Conclusive evidence from the simulation identified resonance overlap as the excitation mechanism for the EGAM. In the linear growth phase, energetic particles satisfying different resonance conditions excited the Alfvén instability, leading to their redistribution in phase space. Subsequently, in the nonlinear saturated phase, these redistributed energetic particles moved into the EGAM resonance region, causing an overlap and thereby exciting the EGAM. Analysis of the total energetic particle distribution $f_{total}$ confirmed the existence of regions with positive $\partial f/\partial E$ along conserved quantities, which are conducive to EGAM excitation. The above process is illustrated in Fig. 2. This work clarifies the mechanism of EGAM excitation by Alfvén instability, providing a robust explanation for the experimental observations.

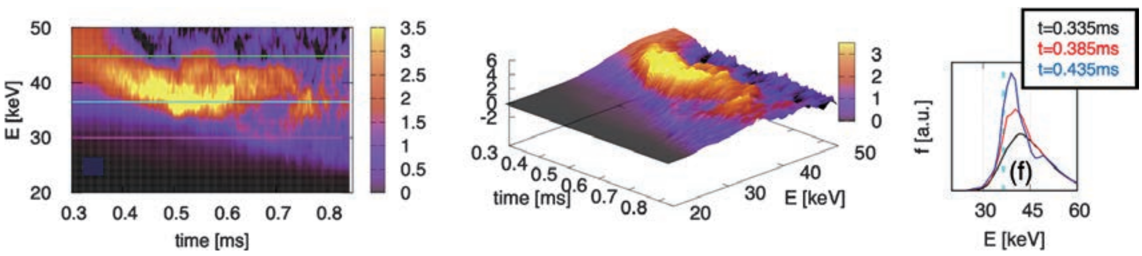



Fig. 2 (Left) The time evolution of $f_{total}$. The blue and cyan lines represent the Alfvén instability and EGAM resonance lines, respectively. (Middle) A 3-D bird's-eye view of the left subfigure. (Right) The $f_{total}$ at different times, with the cyan dotted line indicating the EGAM resonance line.

[3] H. Wang, Ph. Lauber, Y. Todo *et al.*, Scientific Reports **15**, 1130 (2025).

(H. Wang)

# The time evolution of information entropy and mutual information during the Landau damping process is elucidated

This study explores information entropy dynamics during Landau damping in a 1D Vlasov–Poisson system. Starting from a Maxwellian distribution with a cosine density perturbation, it derives linear and quasilinear solutions to describe early and late-time behavior, validated by contour dynamics simulations. Entropies of position and velocity distributions, and their mutual information, reveal statistical correlations beyond macroscopic descriptions. In weakly collisional regimes, mutual information vanishes while total entropy increases, consistent with the H-theorem. This work was published as K. Maekaku, H. Sugama, and T.-H. Watanabe, "Time evolutions of information entropies in a one-dimensional Vlasov–Poisson system", Phys. Plasmas **31**, 102101 (2024) and was selected as a Featured Article.

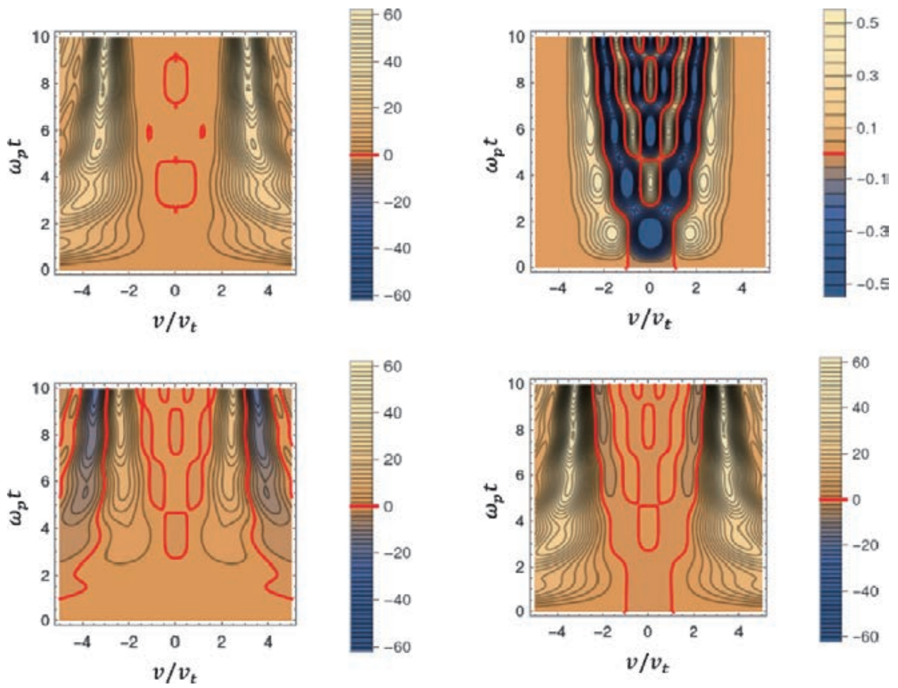


Fig. 3 Contours of the change in kinetic energy (top-left), self-entropy (bottom-left), deviation of the velocity distribution function from Maxwellian equilibrium $f_2(v,t)/(\alpha^2 n_0 v_t^{-3})$ (top-right), and $f_2(v,t)/(\alpha^2 f_{0M}(v))$ (bottom-right) on the $(v,t)$ plane for $k\lambda_D = 1/2$. [Reproduced from K. Maekaku, H. Sugama, and T.-H. Watanabe, Phys. Plasmas **31**, 102101 (2024); licensed under CC BY).]

(H. Sugama)

# Ultrahigh-flux Concerting Materials Unit (UlCoMat)

## Highlight

## Prediction, synthesis, and properties of accident-tolerant hybrid ceramics for fusion breeding blanket

In a deuterium–tritium fusion reactor, the breeding blanket surrounding the plasma contains Li compounds as tritium breeders in either solid or liquid form to convert the kinetic energy of the neutrons into heat and produce tritium fuel. In water-cooled ceramic breeding blankets for fusion reactors, hydrogen gas generation by steam oxidation of metallic Be compounds (i.e. neutron multipliers) in a loss-of-coolant accident (LOCA) raises major safety concerns. Li–Be hybrid ceramics have the potential to reduce hydrogen generation significantly. However, stable compositions and structures for quaternary compositions have not been comprehensively understood. In this work, as a collaboration study with the National Institutes for Quantum Science and Technology, we employed a machine-learning based prediction model CSPML (crystal structure prediction with machine learning-based element substitution) and experimentally synthesized chemically stable two-phase Li–Be–X–O hybrid ceramics [1]. The steam exposure tests demonstrated a negligibly small $H_2$ generation from the two-phase powder of $Li_2BeSiO_4$ with 5 at.% BeO below 1473 K. The stability is explained by the intrinsic ionic/covalent bonding characteristics and little capacity for further oxidation by steam. Particle transport calculations using the PHITS code with a simplified one-dimensional model showed that the $Li_2BeSiO_4$–BeO mixture had comparable or slightly higher breeding performance without the use of metallic Be-based neutron multipliers. The hybrid ceramics represent the first example of a multi-functional oxide that can breed sufficient tritium fuel with no metallic neutron multiplier, enabling a novel design of ceramic breeding blankets with enhanced safety margins during in-box LOCA conditions.

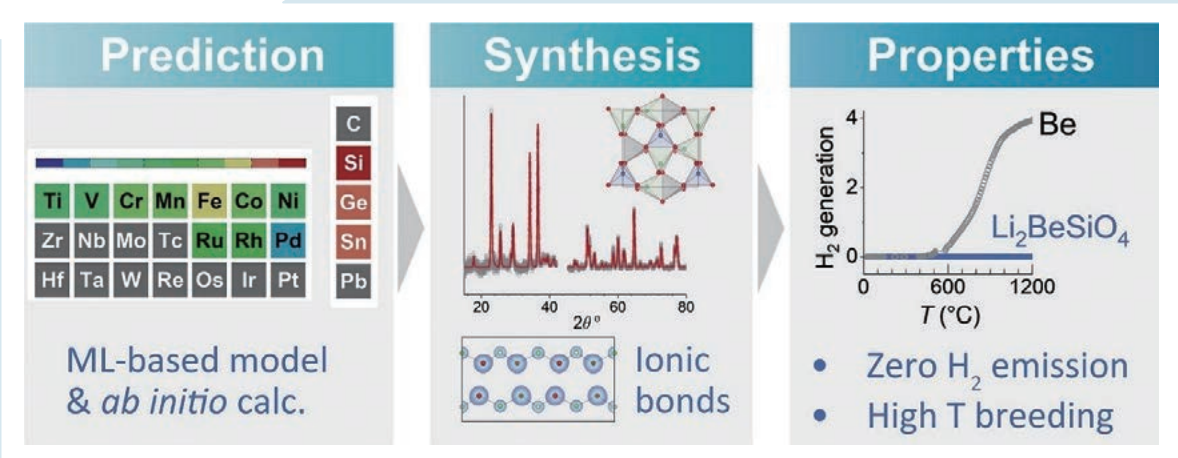



Fig. 1 Machine learning-based prediction, synthesis, crystal structure, high temperature chemical stability, and breeding performances of Li–Be hybrid ceramics.

(K. Mukai)

## Small specimen test technique for fusion reactor materials

A small specimen test technique is essential to develop fusion reactor materials using a limited irradiation volume in a high-flux neutron field. An international collaboration activity “Towards the Standardization of Small Specimen Test Techniques for Fusion Applications” has been initiated under the framework of the International Atomic Energy Agency (IAEA) Coordinated Research Project (CRP). The project includes tensile, creep, low cycle fatigue, fracture toughness, and fracture crack growth rate testing. NIFS is taking part in the tensile and creep testing [2]. F82H IEA heat, an international reference RAFM steel, was evaluated at 550 and 650°C, using flat-plate specimens with gauge thickness ranging from 0.14 to 1.2 mm, while the gauge length and width were 5 and 1.2 mm, respectively. Tensile yield stress, ultimate tensile strength and uniform elongation were independent of the gauge thickness, and agreed with standard size specimen data. On the other hand, total elongation decreased with diminishing thickness. This behavior is attributed to the transition from symmetric diffuse necking to localized necking under plane stress conditions for the thinner specimens. Creep rupture time decreased with lessening gauge thickness. This is generally explained by enhanced creep deformation due to the annihilation of mobile dislocations around the surface.

(T. Nagasaka)

## Influences of minor Ti addition on microstructure and tensile properties of high-purity V-10Cr alloys

V-4Cr-4Ti alloy is regarded as a promising candidate structure material for blanket applications in fusion reactors. To reduce the recycling period of vanadium alloy after use, high-purity vanadium alloys were developed. They contained much lower levels of high radioactive elements that could create long-lived isotopes under fusion neutron irradiation, such as cobalt, niobium, molybdenum, nickel, etc., and interstitial impurities (i.e., carbon, nitrogen, oxygen). Moreover, it suggested that further reducing the Ti concentration would shorten the cooling time of V-4Cr-4Ti alloy. However, the reduction of Ti decreased the strength, while increasing Cr concentration was expected to enhance it. Hence, a lower level of Ti (0.1 – 2 wt%) was added in vanadium alloys with a high-Cr level, and its effect on microstructure and tensile properties was investigated [3]. Results showed that precipitation was dependent on Ti concentration. Adding 0.5 wt% Ti was necessary to absorb those interstitial impurities forming Ti-rich precipitates, while a higher Ti content of 2 wt% prevented grain growth during thermal annealing. Furthermore, tensile strength increased with rising Ti concentration at both room temperature and 973 K, and elongation was not obviously changed. A minor Ti addition had a more evident effect on tensile strength at 973 K than that at room temperature. Additionally, further investigations on the microstructure evolution and irradiation hardening behaviors of those alloys after ion irradiation are in progress.

(J.J. Shen)

# Application of a single crystal diamond detector for fast neutron measurements under high dose and mixed radiation fields

The developments of advanced scientific/engineering systems, including fusion reactors, usually require neutron measurements under a mixed and high-dose radiation field. In this study, we have developed a method to evaluate the fast neutron energy spectrum using a single-crystal chemical vapor deposition (CVD) diamond detector (SCDD), which can work under a high radiation dose field [4]. Also, a combination of pulse shape discrimination (PSD) based on the shape and width of a pulse with an unfolding technique for the measured spectrum could reject pulses by gamma-ray, and deduce the neutron energy spectrum.

For a demonstration of the present method, monoenergetic 14.1 MeV or 5.5 MeV neutron irradiation were carried out. The PSD was applied to a successful extraction of pulses induced solely by fast neutrons. The response matrix of the single-crystal diamond for fast neutrons was evaluated using Geant4, and applied to the energy deposition spectrum in the SCDD induced by fast neutrons. The results indicated the deduced neutron energy spectrum by the present method were consistent with the radiation transport calculation.

[1] K. Mukai *et al.*, Materials & Design **253**, 113964 (2025).
[2] T. Nagasaka *et al.*, Nuclear Science and Technology Open Research **2**, 56 (2024).
[3] J.J. Shen, Materials Science and Engineering: **A 915**, 147263 (2024).
[4] M.I. Kobayashi *et al.*, IEEE Trans. Instrum. Meas. **73**, 6010808 (2024).

(M. Kobayashi)

# Applied Superconductivity and Cryogenics (ASC) Unit

## Highlight

The Applied Superconductivity and Cryogenics (ASC) Unit has conducted various research projects in fiscal year 2024 on applied superconductivity, including superconducting magnet technology, and cryogenics, such as those related to liquid hydrogen. Here are some of the highlights:

For the development of large-current High-Temperature Superconducting (HTS) conductors, experiments were conducted on REBCO-stacked conductor samples in collaboration with Helical Fusion, a startup company. A numerical analysis of the non-uniform current distribution has continued for the stacked conductor, STARS, which has been developed at NIFS for over fifteen years with continuous innovation.

For the HTS magnet, inspection of winding conductors is also a key technology. We employ a method of rotating magnetization for non-destructive, non-contact inspection of areas of critical current degradation in conductors made of laminated REBCO tapes. The details are described in the following section.

Low-Temperature Superconducting (LTS) conductors have also been developed to an advanced stage. A detailed description of a mechanically reinforced niobium-tin conductor is given in the following section. We are also proceeding with a collaboration with the National Institute for Materials Science (NIMS) to produce an $Nb_3Al$ ultra-fine wire with a diameter of 50 μm. We have successfully made a single-cored wire of over 6 km in length without breakage or abnormal deformation during processing.

Liquid hydrogen cooling is the focus of a new approach for superconducting magnet technology. A series of experiments using liquid hydrogen for cooling a superconducting magnet has been conducted at the JAXA site in Noshiro, Akita Prefecture, in collaboration with Kyoto University and the Japan Aerospace Exploration Agency (JAXA), utilizing a liquid hydrogen testing facility. A cryostable condition was observed and investigated, where a normal-conducting transition does not lead to a thermal runaway due to the excellent cooling properties of liquid hydrogen.

A deep learning model has been developed and applied to predict the cooling characteristics of the LHD helical coils based on measurement data accumulated over the long years of LHD operation. We have succeeded in highly accurate predictions of temperature changes that occur when the helical coils are energized.

When cooling cryogenic equipment components, such as pipes and tanks, using a saturated liquid, like liquid nitrogen, it is essential to minimize the pre-cooling time to reduce refrigerant consumption. In past studies, it has been experimentally demonstrated that coating heat-transfer surfaces with low thermal conductivity material, such as resin, promotes boiling heat transfer and reduces the pre-cooling time. This is called the “insulation layer paradox”. We conducted rapid cooling experiments using copper plates coated with various fluoropolymers to elucidate the mechanism of heat transfer enhancement.

(N. Yanagi)

# HIP process on mechanical strength improvement for internal matrix reinforced $Nb_3Sn$ superconducting wire

The high mechanical strength of superconducting wires such as Niobium-Tin ($Nb_3Sn$) and HTS is an extremely urgent research issue for future fusion magnets with high magnetic fields. We previously demonstrated the high mechanical strength of conventional bronze-processed $Nb_3Sn$ wire by an innovative internal matrix reinforcement method using Cu-Sn-X ternary alloy as the wire matrix component, as shown in Fig. 1. The third additional element, “X”, remained homogeneously distributed within the wire matrix after $Nb_3Sn$ phase synthesis. It contributed to forming a high-mechanical-strength (Cu, X) solid solution as a reinforcement material. For further improvement in mechanical strength, the effect of Hot Isostatic Pressing (HIP) treatment after the $Nb_3Sn$ phase synthesis was investigated. The HIP treatment was performed at a temperature of 650°C for two hours under a high pressure of 200 MPa in an argon atmosphere using the NIFS-HIP facility. Transport critical current (*Ic*) measurements under uniaxial tensile deformation were carried out using a special *Ic* probe with a uniaxial tensile deformation mechanism at the Institute for Materials Research, Tohoku University. Comparisons of the major mechanical strength properties in internal matrix-reinforced $Nb_3Sn$ wire samples using Cu-Sn-In ternary alloys were investigated with and without HIP processing. HIP treatment improved all the major mechanical strength parameters. This was caused by the removal of Kirkendall voids in the wire matrix, which formed due to volume changes in the matrix during the $Nb_3Sn$ synthesis heat treatment. On the other hand, the degree of improvement in mechanical strength achieved by the HIP treatment varied significantly depending on the composition of the ternary alloy used as the wire matrix. In the future, the primary reason for this dependence will be clarified through microstructural observation and crystallographic analyses.

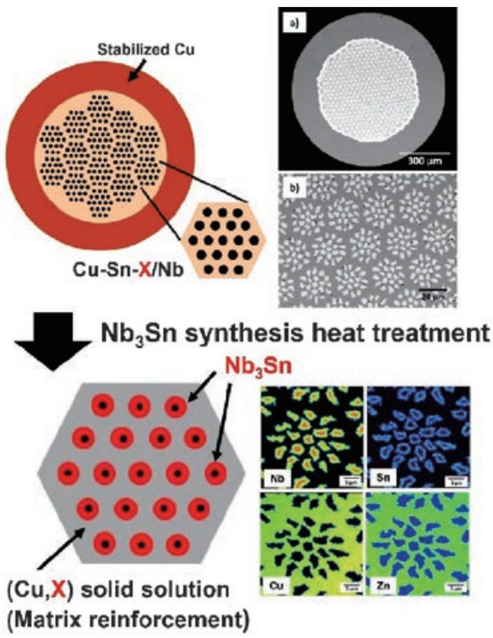



Fig. 1 Illustrative image of the “internal matrix reinforcement method” for producing niobium-tin wire via the solid solution hardening mechanism.

(Y. Hishinuma)

# Non-destructive detection of degraded regions in stacked HTS conductors using rotating magnetization method

The development of superconducting magnets for fusion reactors requires conductors that can carry large currents stably and reliably. High-temperature superconductors (HTS), such as REBCO tapes, are promising candidates due to their high critical current density under high magnetic fields. However, performance degradation can occur during the fabrication of HTS-based multilayer high-current conductors, which makes the development of non-destructive evaluation techniques essential. In multilayer REBCO structures, even localized reductions in critical current can significantly impact overall performance, underscoring the need for internal diagnostic methods. In this study, we applied a non-destructive technique based on the rotating magnetization method, which evaluated the conductor's magnetic response under an externally applied rotating magnetic field. A test sample consisting of ten stacked REBCO tapes was fabricated, with a localized degradation site intentionally introduced. The degraded region was identified through both experimental measurements and numerical analysis, demonstrating the feasibility and reliability of the proposed method.

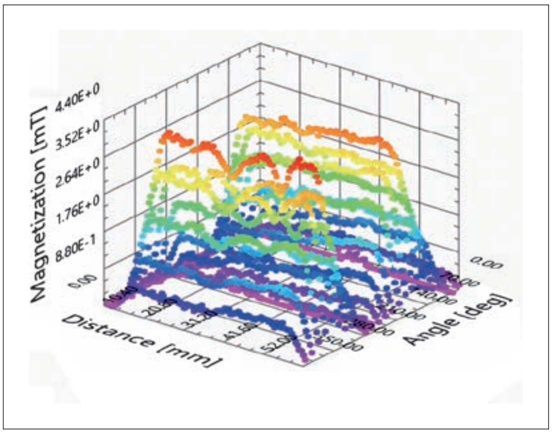



Fig. 2 Measured magnetization signal on the HTS conductor sample obtained from the rotating magnetization test.

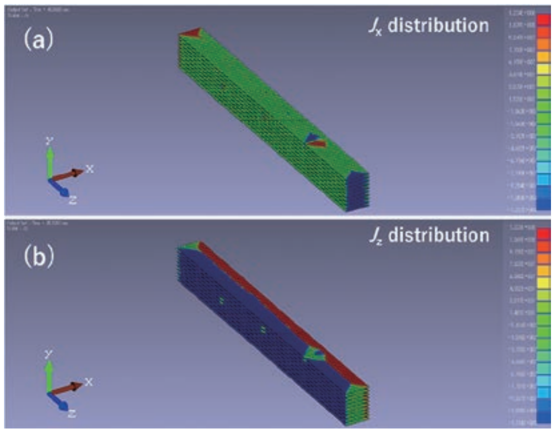



Fig. 3 In-plane current distribution in the HTS conductor sample obtained by a finite element analysis: (a) across the tape width; (b) along the longitudinal direction.

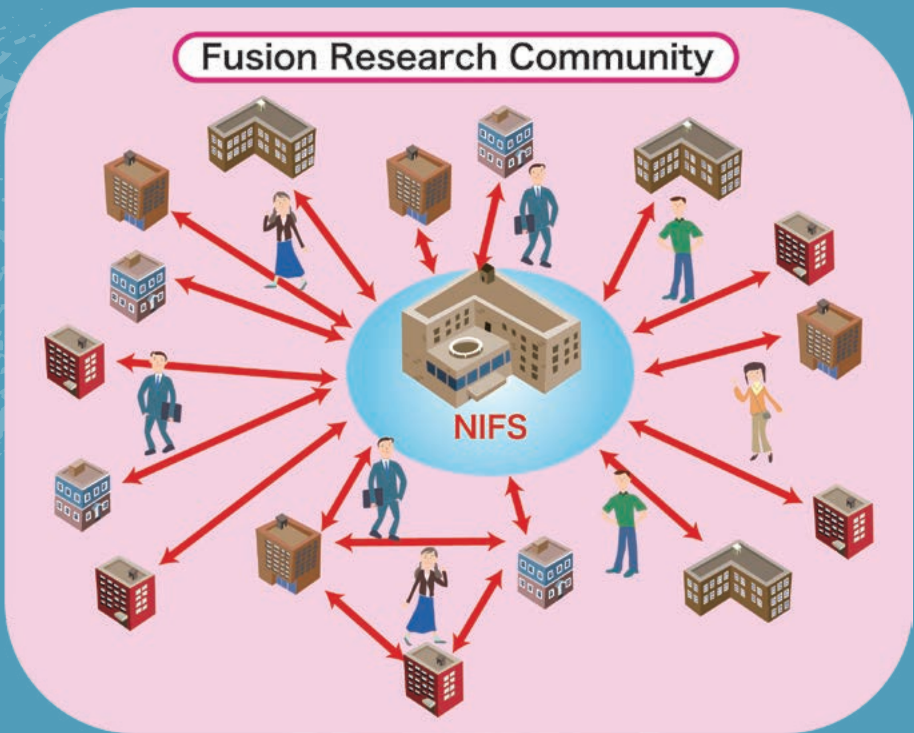
(Y. Onodera)

# 2. General Collaboration Research

General Collaboration Research is a system for collaborators to carry out their research by using the facilities or resources of NIFS, including experimental devices, diagnostics, the supercomputer, databases, and others. Because nuclear fusion encompasses a wide area of research in physics and technology, from fundamental research to application, General Collaboration Research has various categories: Network-type Research, Interdisciplinary Fusion Science Research, Fusion Plasma Science Research, Fusion Technology Research, Plasma Simulator Collaboration Research, and Workshops. In FY2024, 357 projects were conducted under General Collaboration Research.

The academic positioning and role of fusion science are undergoing a major transition due to advances in fusion energy development. NIFS transitioned to a new system in FY2023, forming units as collaborative research teams that involve experts from various fields outside the institute. In the call for General Collaboration Research proposals, each unit proposed research themes, and collaborative research projects were promoted through cooperation with the units.

(Y. Todo)


Fusion Research Community
NIFS

# Network-Type Research

This research is eligible for collaboration with facilities owned by the National Institute for Fusion Science and multiple universities. In the fiscal year of 2024, the research shown below was steadfastly carried out. The titles and brief summaries of the research topics are described.

## Active measurement of MHD instabilities and related MHD studies in magnetized torus plasmas

The aim of this study is to develop an active measurement method of MHD instabilities, predicting them before they occur, by using a small tokamak device, HYBTOK-II. As a result, in the second year of a three-year plan, the magnetic field response on the imposed resonant magnetic perturbation (RMP), i.e., a change in the amplitude, was observed before and after the $m/n = 2/1$ tearing instability. Figure 1 shows the typical wave form of the discharge where the tearing instability is observed. As plasma current increases, the peripheral safety factor ($q$) value decreases, and magnetic fluctuation with the $m/n = 2/1$ structure appears from 14.5 ms. The mode frequency is between 20 and 25 kHz. Figure 2 shows the magnetic fluctuation amplitude, which highly correlates with imposed external RMP. Figures 2(a), (b), and (c) correspond to data collected a sufficient time before, just prior to, and during the onset of the tearing instability, respectively. A sufficient time before the instability occurs, the magnetic fluctuation highly collated with external RMP, increases with the imposed RMP frequency (Fig. 2(a)). Also, the magnetic fluctuation reaches its maximum around the frequency of the tearing instability (Fig. 2(c)). In contrast, just before the tearing instability occurs, the magnetic fluctuation amplitude around the expected instability frequency increases (Fig. 2(b)). This observation may indicate an imminent onset of the tearing instability. We should analyze the change in the magnetic fluctuation phase just before the instability, in addition to the amplitude. This is a future subject of study.

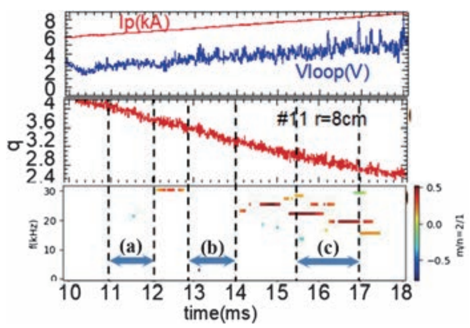



Fig. 1 Typical wave form of the discharge imposed by RMP. (a) Plasma current, $I_p$ and one-turn voltage, $V_{loop}$. (b) Safety factor value at $r/a$~0.7. (c) Power spectrum of $m/n = 2/1$ magnetic fluctuation.

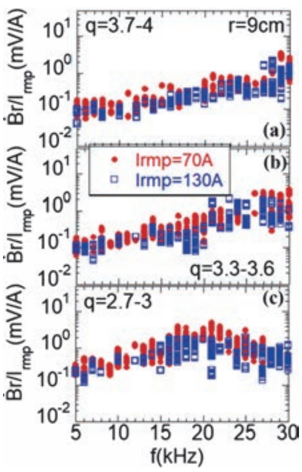



Fig. 2 Frequency dependence of power spectrum of magnetic fluctuation highly correlated with injected RMP by antenna during (a) 11–12 ms, (b) 13–14 ms, and (c) 15.5–17 ms.

(M. Okamoto, National Institute of Technology, Ishikawa College)

## Elucidation of ion turbulence in multi-ion species plasmas by inter-university device network

In a fusion plasma of multi-ion species, a transition from a non-mixing state, where the ratios of ion species are different, to a mixing state, where the ratios are equal, was observed. The transition was found to occur faster than the time scale determined by conventional transport theory based on particle diffusion. This fast transition suggests that the dominant transport is not diffusive due to collisions between ions. But it indicates anomalous non-diffusive transport created by "ion turbulence," which is fluctuations of the field interacting with the ion motion. In this study, the behavior of the ion turbulence is examined by developing an inter-university device network, which consists of several university-scale experimental devices. The plasmas in university-scale devices are not relevant to fusion plasma, but high spatial accuracy measurements become possible. From these measurements and inter-machine comparisons, the physics underlying the transition process of a multi-ion plasma to the mixing state, discussed in this project, is expected to be extended to the non-diffusive behavior observed in other general physical phenomena. In FY2024, to measure ion turbulence, a tomographic reconstruction based on an innovative idea, which consisted of L1 regularization and sparse modeling, was developed. Developed tomography was applied to the PANTA experiment in Kyushu University, and it could successfully reconstruct drift wave turbulence. This new tomographic reconstruction technique will apply to two-ion species plasma in FY2025.

(Y. Suzuki, Hiroshima University)

## Network survey of tritium concentration in precipitation in Japan

Disseminating knowledge on the physicochemical properties and behavior of tritium, as well as its relevance to fusion research, is one of the important challenges in public communication. Therefore, by establishing an observation network with related institutions, samples of precipitation and tap water will be collected. Measuring tritium concentrations in these water samples will allow us to understand the distribution of tritium levels in environmental waters across Japan. Furthermore, the network will promote exchanges among students belonging to the participating institutions, thereby fostering the development of young researchers who will lead the next generation. In this study, a collaborative research network among researchers was utilized to establish an environmental water sampling network covering the entirety of Japan from north to south. As a result, tritium concentration has a clear seasonal trend, which is high in spring and low in summer. Furthermore, concentrations are higher in spring in northern Japan, with the highest values observed in Hokkaido.

As part of this network-type collaboration research, a "Workshop on Environmental Radioactivity" was held from December 5–6, 2024, with the aim of fostering young researchers in the field of environmental radioactivity. In cooperation with the NIFS, a tour of the Large Helical Device was also organized. The workshop featured 20 presentations by students from Hirosaki University, Kindai University, and Kobe Pharmaceutical University (including international students), as well as by young technical staff members of the National Institute for Fusion Science. Lively discussions were conducted among the participating students.

(N. Akata, Hirosaki University)

# Interdisciplinary Fusion Science Research

As one of the NIFS collaboration categories, the interdisciplinary fusion science research has been established since FY2022. This category covers research that expands the knowledge, research methods, simulations, and equipment developed in fusion research to other fields, as well as research that will be the seeds for future fusion-related activities. In addition, research in the fields of sociology and informatics, such as the relationship between fusion and society and archives, is also eligible. Research in the field of astronomy, etc., using data obtained by the LHD, and research on social structural changes when nuclear fusion is realized fall into this category. In FY2024 109 collaborative programs were performed in various fields, such as atomic physics, astrophysics, informatics, laser development, space propulsion, negative ion sources, environmental isotopes, plasma-material interaction, plasma-biology, agriculture, historical studies, science education, etc.. Among them, three topics are introduced here.

(I. Murakami)

## Formation of semiconductor nanostructures by plasma irradiation and their device applications

Silicon (Si) is a promising negative electrode material for lithium-ion batteries (LIBs) due to its capacity, nearly ten times higher than graphite. Its use, however, is limited by ~400% volume expansion during cycling, which causes electrode damage. To address this, we developed porous Si thin films using helium (He) plasma. Si was sputter-deposited in a linear plasma device with high-density He plasma (~$10^{18}$ $m^{-3}$) onto Cu substrates, forming porous Si–He co-deposited layers with ~0.5 porosity and ~1.5 $\mu$m thickness (See Fig. 1). A Transmission Electron Microscope (TEM) showed 100–200 nm Si clusters separated by nanopores, yielding an amorphous structure. Electrochemical testing gave ~3000 mAh $g^{-1}$ initially. The 523 K film maintained ~1800 mAh $g^{-1}$ after 100 cycles and ~1200 mAh $g^{-1}$ after 250 cycles. These findings indicate that He–Si co-deposition is a promising method for fabricating porous amorphous Si thin films with high cycling stability for advanced LIB anodes [1]. (S. Kajita, Univ. Tokyo)

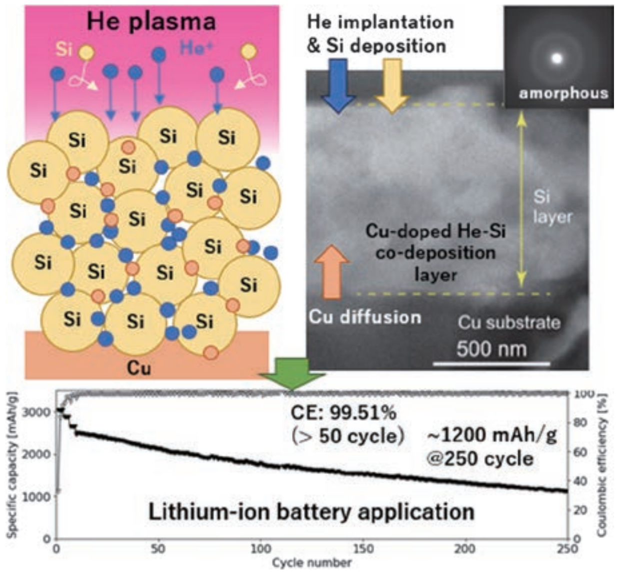



Fig. 1 A graphical overview of the porous Si amorphous layer with a TEM micrograph and the evolution of the discharge capacity and coulombic efficiency of the fabricated Si thin film [1].

## Application of singular spectrum analysis to a biological time-series data

Chronobiology is a discipline that investigates biological rhythms and often analyzes actograms, which are binary time-series data representing the timing of activity and rest. To detect periodicity in such time-series data, methods such as Fourier analysis, the chi-square periodogram, and the Lomb–Scargle periodogram have traditionally been employed. However, these methods assume stationarity of the data, and thus cannot be applied to non-stationary datasets in which the periodicity substantially changes. To address this limitation, the present study applied singular spectrum analysis, which is a nonparametric time-series analysis method primarily used in plasma hydrodynamics, to non-stationary actogram data [2]. As a result, periodicity could be successfully extracted from non-stationary data, which had previously been difficult to analyze with conventional approaches.

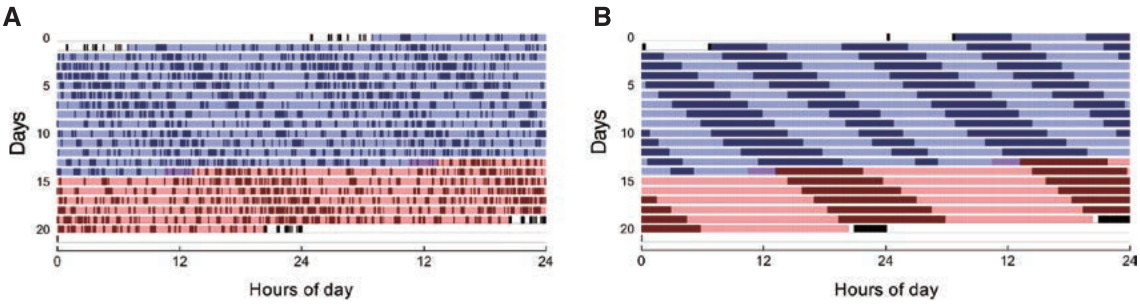



Fig. 2 A representative actogram of locomotor activity in the mangrove cricket *Apteronemobius asahinai*. (A) shows the actogram before denoising by singular spectrum analysis (SSA), and (B) shows the actogram after denoising by SSA. Unimodal and bimodal daily rhythms are significantly detected in the red and blue regions, respectively. The figure was created with the data presented in Ref. [2].

(K. Sakura, NIBB)

# Direct observation of highly charged muonic ions

A highly charged ion (HCI) plays a crucial role in various scientific fields, including plasma physics and astronomy. In this study, we propose a new type of HCI: the highly charged muonic ion (HC$\mu$I). An HC$\mu$I is a unique few-body atomic system in which a negatively charged muon and a few electrons are simultaneously bound to a single nucleus. However, no experimental methods for its direct observation have been available until now.

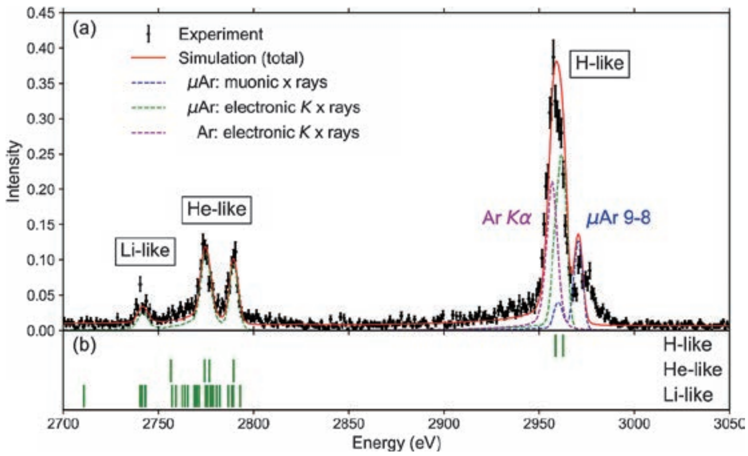



Fig. 3 (a) An electronic $K$ x-ray spectrum measured with the TES detector. (b) Theoretical x-ray energies for the electronic transition of H-, He-, and Li-like Cl.

We report the first state-selective observation of highly charged muonic argon ($\mu$Ar) using high-resolution electronic K x-ray spectroscopy with an array of transition-edge sensor (TES) microcalorimeters [3]. The TES microcalorimeter is a state-of-the-art x-ray detector that combines high energy resolution with high detection efficiency—ideal characteristics for HC$\mu$I spectroscopy. Fig. 3 shows the x-ray spectrum of $\mu$Ar measured with the TES detector. The high-precision K x-ray spectrum clearly reveals the presence of HC$\mu$Is with one, two, and three electrons, corresponding to H-like, He-like, and Li-like $\mu$Ar, respectively.

[1] S. Kajita *et al.*, Adv. Energy Sustainability Res. 2024, 2400300.
[2] K. Sakura *et al.*, Biol. Rhythm Res. 1–11 (2025).
[3] T. Okumura et al., Phys. Rev. Lett. **134**, 243001 (2025).

(T. Okumura, Tokyo Metropolitan Univ.)

# Fusion Plasma Research

General Collaboration Research is a system for collaborators to carry out their research by using the facilities or resources of the National Institute for Fusion Science (NIFS), including experimental devices, diagnostics, the supercomputer, databases, and others. Because nuclear fusion includes a wide study area in physics and technology, from fundamental research to application, the system has a variety of categories. Regarding general collaboration research on fusion plasma in FY2024, NIFS received 63 applications from both home and abroad, and 59 collaboration research subjects were methodically undertaken. In this report, the following three collaboration research projects, highly evaluated in the screening process, are highlighted.

## Study of neoclassical transport using FORTEC-3D in CFQS

The 3D-global δf Monte Carlo simulation code, FORTEC-3D, is utilized to investigate isotope effects on neoclassical transport in the CFQS-axisymmetric stellarator under self-consistent and biased radial electric fields ($E_r$) for the first time. Key numerical results reveal: (1) With self-consistent ambipolar $E_r$, hydrogen (H) plasmas exhibit higher neoclassical transport than deuterium (D) plasmas. This result is broadly consistent with experimental isotope results in tokamaks, as shown in the following figure: (2) Under biased $E_r$, a radial reversal emerges: H plasma transport is lower than D plasma transport in the core but higher in the periphery. This reversal is driven fundamentally by neoclassical poloidal viscosity (a momentum damping mechanism), which propagates radially from the periphery to the core, significantly faster in D plasmas than in H ones due to isotope mass effects. The non-local propagation of poloidal viscosity is caused by radial $E_r$ gradients unobtainable in local theory, demonstrating a critical link between viscosity dynamics, $E_r$ modulation, and isotope mass.

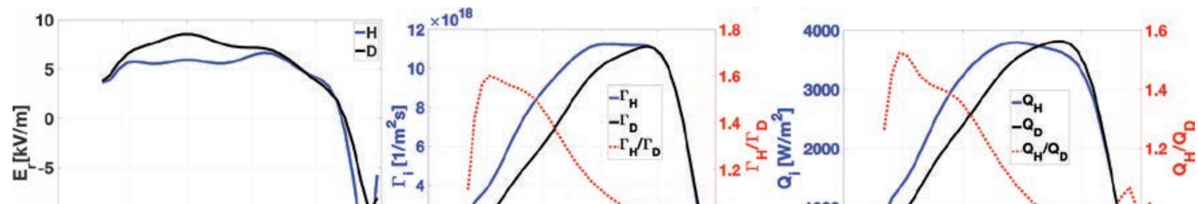



Fig. 1 (left) ambipolar radial electric field profiles, (middle) radial particle fluxes and (right) radial energy fluxes in hydrogen (blue) / deuterium (black) plasmas obtained with FORTEC-3D.

(H.F. Liu, Southwest Jiaotong University)

## Investigation of nuclear elastic scattering effect on fusion plasma

Coulomb scattering dominates ion collisions in fusion plasmas, but at higher ion energies, nuclear elastic scattering from the nuclear force becomes significant. Unlike Coulomb scattering, which involves small angles and minimal energy transfer, nuclear scattering produces large angles and high energy transfer, enhancing ion heating and altering ion distributions—potentially improving fusion reactivity. Predictions from the Boltzmann collision integral and two-dimensional Fokker-Planck simulation indicate that the gamma-ray emission rate from the $^6$Li(d, p$\gamma$)$^7$Li reaction strongly depends on the magnitude of the knock-on tail [1]. Investigation of the knock on tail formation via nuclear elastic scattering was performed in LHD [2] using $LaBr_3$:Ce gamma ray diagnostics. Following $^6$LiF pellet injection into hydrogen-beam-heated deuterium plasma, we observed a gamma-ray peak of around 0.48 MeV. The peak seemed to correspond to the $^6$Li(d, p$\gamma$)$^7$Li reaction. We are continuously improving the $^6$LiF pellet size and discharge scenarios to obtain γ-ray spectra with higher statistical accuracy.

[1] H. Matsuura *et al.*, Plasma Fusion Res. **11**, 1403105 (2016).
[2] H. Matsuura *et al.*, J. Plasma Fusion Res. **99**, 120 (2023).

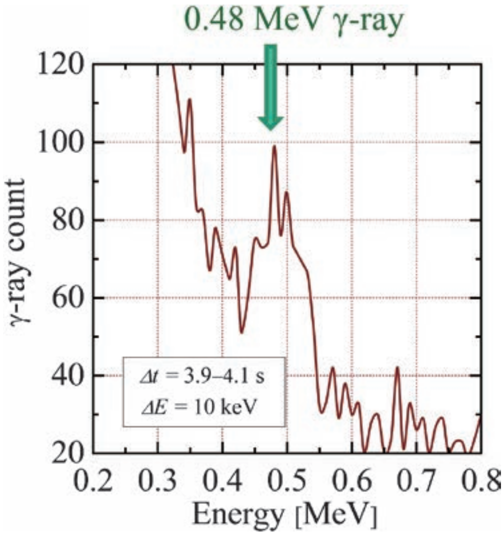



Fig. 1 Gamma-ray spectrogram obtained by summing signals from 20 $^6$LiF pellet injection plasma discharges.

(H. Matsuura, Kyushu University)

# Energetic ion charge exchange spectroscopy using higher energy beam

We conducted development of Fast Ion D-alpha (FIDA) spectroscopy, which detects Doppler-shifted Balmer-α emissions from fast ions that undergo charge exchange with neutral beam atoms, from a high-energy negative-ion source. Until now, FIDA measurements have been primarily demonstrated using positive-ion source neutral beams with relatively low energies. However, large-scale experimental devices, such as ITER/JT-60SA, will predominantly employ high-energy negative-ion source neutral beams. Our issues are whether FIDA diagnostics remain feasible under such conditions. In LHD, we implemented a new geometry with a reduced angle between the line of sight and the beam direction, and we successfully detected Doppler-shifted lights attributed to charge exchange of high-energy ions. The measured emission spectra showed qualitative agreement with results from FIDASIM, a numerical simulation code widely used for FIDA diagnostics. This consistency confirmed the first experimental verification that FIDA measurements are achievable with high-energy negative-ion neutral beams [1].

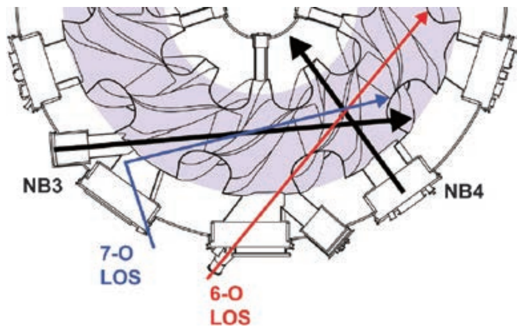



Fig. 1 Top view of FIDA measurement at LHD. The old 6-O LOS line of sight made it difficult to conduct FIDA measurements, but by adding a new 7-O LOS with a smaller angle to the neutral beam NB3.

[1] W.H.J. Hayashi *et al.*, “Charge-exchange measurements of high-energy fast ions in LHD using negative-ion neutral beam injection”, Journal of Instrumentation **19**, P12006 (2024).

(W. Hayashi, University of California, Irvine)

# Fusion Technology Research

## Highlight

## Investigations on energization characteristics of liquid hydrogen-cooled high-temperature superconducting cable conductors for fusion reactors

Driven by helium depletion and an emerging hydrogen-based society, high-temperature superconducting (HTS) coils for fusion reactors, cooled by liquid hydrogen, are eagerly anticipated. Cable-in-conduit (CIC) conductors of REBCO wires with forced liquid hydrogen cooling, are particularly promising. A critical challenge is designing for stabilization to prevent thermal runaway, even in the event of quenching from cooling degradation, necessitating a clear understanding of conductor stability in liquid hydrogen. Using an external magnetic field coil fabricated in FY2023, a 6 kA-scale AC induction energization test setup was built in FY2024. Its principle was validated with a 1-turn short-circuited secondary coil made from a single REBCO wire. Another secondary coil was fabricated by short-circuiting three spirally wound REBCO single-layer conductors. Its AC inductive energization was examined under liquid hydrogen cooling. As shown in the figure, the maximum peak value of the secondary current $I_{2,peak}$ was 4,424 A in 1 Hz tests. This value showed a high degree of similarity with the simulated conductor $I_C$ of 4,224 A (20 K, 0.1 T) from its $I_C$-B-T correlation. This successfully demonstrated HTS conductor energization exceeding 4 kA and validated the AC induction method for $I_C$ evaluation. Future plans include inductive energization tests on multi-layer conductors.

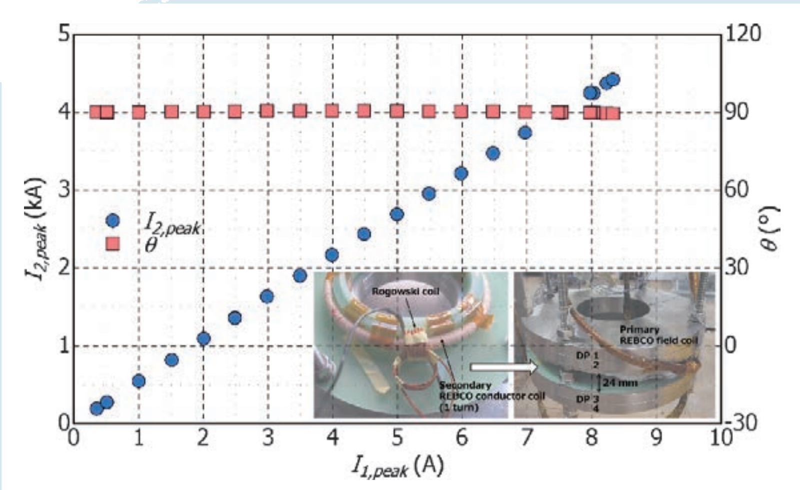



Fig. Results of AC induction energization test under liquid hydrogen cooling ($I_{1,peak}$ and $I_{2,peak}$ are the peak values of the primary and secondary current, respectively, and $\theta$ is the phase difference between the Rogowski coil voltage and the primary current)

(M. Ohya, Kwansei Gakuin University)

## Formation of Laser Induced Periodic Surface Structures (LIPSS) for Fusion Rector Divertor and Optical Device Applications

Tungsten is a crucial material for plasma-facing components (PFCs), and the ITER project utilizes divertor structures where tungsten is joined with copper alloy cooling pipes. A key challenge in developing fusion reactors is improving the properties of dissimilar metal joints and coatings for tungsten. One approach aims to improve joint performance, including heat removal, by creating micrometer-scale textured surfaces on tungsten using laser irradiation before joining it with copper. This increases the anchoring effect and expands the contact area. In FY2024, the joining of laser surface-modified tungsten with copper was examined. NDB (Non-Defective Bonding) is a unique joining technology from Nippon Tungsten Co., Ltd. that directly bonds tungsten and copper. It has been adopted in the ITER divertor for joining tungsten to oxygen-free copper interlayers. In collaboration with the industry, NDB joining of laser surface-modified pure tungsten with oxygen-free copper was examined. Another joining method, Hot Isostatic Pressing (HIP) was also attempted. Microstructural analysis of the cross-section indicated no defects in the copper surrounding the laser-processed indentation to a depth of about 80 µm. However, in the tungsten, crack defects with opening widths from sub-micrometers to several micrometers formed radially from the interface. Notably, with the NDB method, copper infiltrated these crack openings, thus repairing them and making the interface structure more complex. This is expected to improve the anchoring effect and reduce thermal and electrical resistance. As a next step, evaluation of the bonding strength is planned through tensile and high-heat loading tests.

(R. Miyagawa, Nagoya Institute of Technology)

## Corrosion of Vanadium Alloys in Liquid Lithium and Its Effect on Tritium Behavior

Fusion reactor blankets with vanadium (V) alloy structures and liquid lithium, which serve as both coolant and tritium breeder, are expected to provide excellent tritium breeding performance, high thermal efficiency, and low-activation characteristics. From the perspectives of safety evaluation and tritium balance design, research on tritium behavior affected by corrosion, is essential. However, such research has been limited due to the difficulties in handling liquid lithium and tritium. In FY2024, the primary objective was to understand the corrosion characteristics of vanadium alloys in liquid lithium without tritium.

In recent years, V alloys with reduced Ti concentration and increased Cr concentration have been developed to improve low-activation characteristics. In order to clarify the effects of the alloying elements, corrosion properties were investigated in liquid lithium by varying the composition within the range of V-(4-8 wt%)Cr-(1-4 wt%) Ti. As the Ti concentration decreased from 4 to 2 wt%, the mass gain rate due to lithium immersion decreased, and at 1 wt%, a mass loss was evident. Since the mass gain for 8Cr-2Ti and 6Cr-2Ti alloys was almost the same, it is thought that the Ti concentration had a greater influence than the Cr concentration. Observations of the 8Cr-1Ti alloy surface revealed the formation of numerous pits, corrosion products, and greater roughness, suggesting significant dissolution of metallic elements and enhanced corrosion thinning. Based on these experimental results, it is advantageous to maintain a Ti concentration of 2 wt% from the perspective of suppressing corrosion thinning.

(K. Katayama, Kyushu University)

# Plasma Simulator Collaboration Research

Plasma Simulator Collaboration Research promotes fusion science research using the supercomputer Plasma Simulator. It also covers subjects that could contribute to the development of simulation science as a new academic field, as well as collaboration research on the development of new algorithms and parallelization techniques from the viewpoint of computational science. In FY2024, 83 research projects on the Plasma Simulator Collaboration Research were conducted by 258 researchers at NIFS and universities.

(Y. Todo)

## Thermal equilibration in collisionless magnetospheric plasmas via entropy-mode turbulence

A planetary magnetosphere is a peculiar plasma environment where a high-temperature plasma is confined in a strongly inhomogeneous dipolar magnetic field generated by a planet. In such systems, turbulence driven by magnetic curvature and density gradient, called the *entropy mode*, is known to cause an inward particle pinch, whereby particles are transported against the density gradient to achieve high confinement. Although this phenomenon has been recognized for some time, a consistent and comprehensive understanding of how global plasma confinement in magnetospheres is maintained remains incomplete.

In our recent study [1], we discovered that the entropy-mode turbulence leads to thermal equilibration between species in magnetospheric plasmas, even without collisions. A classical stability analysis in terms of energetic considerations reveals that the roles of electrons and ions in destabilizing the system, through resonance with drift waves, interchange depending on their temperature ratio. The species with the lower temperature carries negative energy, extracting free energy from the background density gradient to drive turbulence. This turbulence, originating from a microscopic (kinetic) instability, naturally redistributes internal energy between species, predominantly via linear wave-particle interactions. As a result, the system tends to evolve toward a state of equal temperatures for electrons and ions.

To verify this thermal equilibration mechanism, we conducted numerical simulations using the gyrokinetic code GS2. The simulation results clearly show that the turbulent heating of ions (equivalently, the cooling of electrons) reverses sign as the temperature ratio of ions to electrons ($\tau$) crosses unity (see Fig. 1). In other words, the hotter species consistently transfers energy to the colder species through turbulence, demonstrating that thermal equilibration occurs spontaneously.

This finding introduces a new ingredient into the energy transport processes in magnetospheric plasmas. It provides a more consistent and physically grounded explanation of the global self-organization phenomena observed in space plasma environments. Furthermore, this mechanism may also play a role in other magnetically confined plasmas, such as dipole fusion devices or astrophysical systems where collisionless conditions prevail.

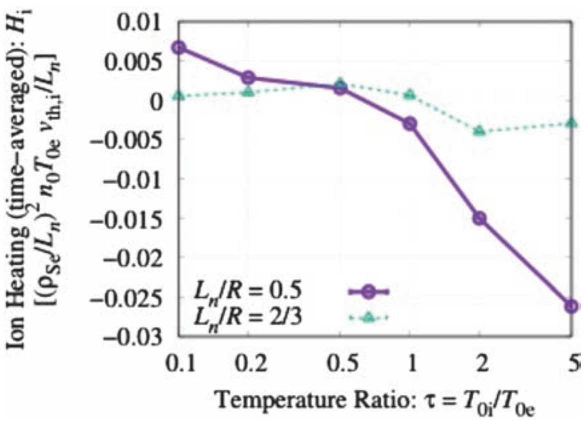



Fig. 1 The time-averaged ion heating $H_i$ in the saturated states obtained from non-linear gyrokinetic simulations. Ions will be cooled (heated) for $\tau > 1$ ($\tau < 1$) to approach the equal temperature state [1].

[1] R. Numata, Mon. Not. R. Astron. Soc. Lett. **538**, L94–L99 (2025).

(R. Numata, University of Hyogo)

# Spatio-temporal decomposition of abrupt particle transport via data-driven modal analysis

Understanding abrupt phenomena in magnetized plasmas is critical for predicting transport events that impact confinement. In this study we analyzed the onset of abrupt transport driven by turbulence using a three-dimensional numerical simulation, based on the Hasegawa–Wakatani model, by using data-driven modal analysis [2]. A limit cycle behavior of Kelvin–Helmholtz (KH) turbulence, in which an abrupt transport is driven, is realized by introducing an externally applied vorticity source.

To identify the underlying physical processes, we applied multi-field singular value decomposition (SVD) [3, 4] to simultaneously decompose the density and electrostatic potential fields in combination with hierarchical clustering [5, 6], as shown in Fig. 2. This technique enabled us to extract common spatio-temporal structures from the two fields and to classify the modes into four categories: background, zonal flow, coherent KH mode, and incoherent mode.

By computing the mode-wise product of density and radial E × B flow, we constructed a transport matrix to quantify the contribution of each mode coupling to the net radial transport. We found that abrupt transport events are driven by nonlinear interactions between the background density and the incoherent radial flow component.

Temporal analysis revealed that abrupt transport occurs when the phase alignment between density modes and the incoherent radial flow mode is satisfied. This study demonstrates that multi-field SVD is a powerful tool for disentangling complex mode interactions and elucidating the physical mechanisms underlying abrupt transport phenomena in magnetized plasmas.

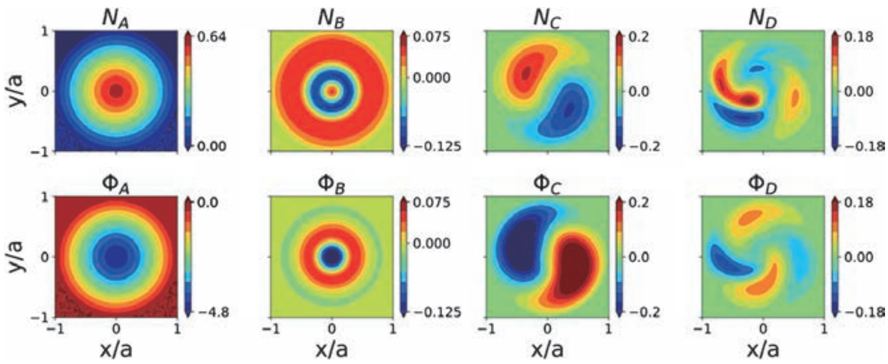



Fig. 2 Decomposed SVD modes [2]. Upper and Below panels correspond to the modes of density and electrostatic potential, respectively. Copyright 2025 IOP Publishing

[2] T. Kodahara, M. Sasaki, +, Plasma Phys. Control. Fusion **67**, 065012 (2025).
[3] T. Kodahara, M. Sasaki, +, Plasma Fusion Res. **18**, 1202036 (2023).
[4] G. Yatomi, M. Nakata, M. Sasaki, Plasma Phys. Control. Fusion **65**, 095014 (2023).
[5] A. Okuno, T. Kodahara, M. Sasaki, Plasma Fusion Res. **19**, 1201035 (2024).
[6] A. Okuno, M. Sasaki, Phys. Plasmas **32**, 032502 (2025).

(M. Sasaki, Nihon University)

# 3. 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 at 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. These proposals are received from all over Japan every year. The collaboration research committee, which is organized under the administrative board of NIFS, examines and selects the subjects.

In FY2024, it was decided that Bilateral Collaboration Research be integrated with Network-type Research of General Collaboration Research and reformed into three categories: Fundamental Facility Type Collaboration Research, Subject Proposal Type Collaboration Research, and Research Core Proposal Type Collaboration Research. Bilateral Collaboration Research was closed in FY2024.

(Y. Todo)

# University of Tsukuba

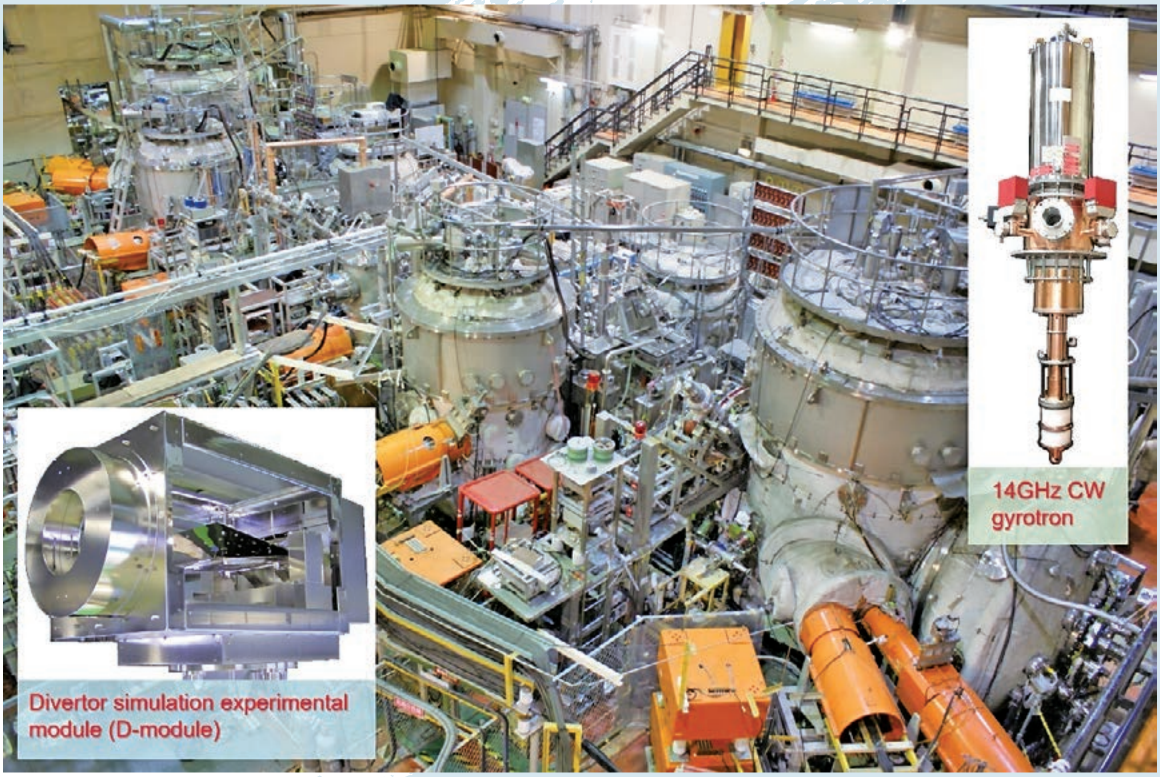



Fig. 1 Bird's eye view of GAMMA 10/PDX. The inserted pictures are a divertor simulation experimental module (D-module) and a 14 GHz CW gyrotron.

## 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, research on boundary plasma and the development of high-power gyrotrons has been conducted under a bilateral collaboration research program. Processes of plasma detachment have been studied by introducing hydrogen and impurity gases into the end-loss plasma in a divertor simulation experimental module (D-module) located at the west end of GAMMA 10/PDX (Fig. 1). In FY2024, we studied the influence of ion temperature on the process of detached plasma formation, and observed three-body and radiative electro-ion recombination (EIR) by increasing $H_2$ gas pressure. A new 1 MW 14 GHz CW gyrotron for low-field fusion devices was developed. In the first experimental test, an output power of 1.05 MW for 2 ms was achieved at a beam current of 42.6 A, which is a world record in the 14 GHz frequency range. In the superconducting mirror device, Pilot GAMMA PDX-SC (PGX-SC), an ion cyclotron range of frequencies (ICRF) wave with a frequency of 1.8 MHz and a power of 160 kW was applied, suggesting the ion temperature was increased.

A divertor simulation study has been carried out by using end-loss plasma in GAMMA 10/PDX (Fig.1). A divertor simulation experimental module (D-module) was installed in the end region of GAMMA 10/PDX, and a V-shaped tungsten target in the D-module was exposed to the end-loss plasma. The ion and electron temperatures of the end-loss plasma were several hundred eV and several tens of eV, respectively. Utilizing the fact that plasma is a high-temperature state of matter, we have examined how the processes of detached plasma formation depend on ion temperature by adjusting the radio-frequency (RF) heating power. In the experiment on detached plasma formation leading to hydrogen molecular activated recombination (H-MAR), we compared differences in the detached plasma across three different diamagnetism (DM) levels of the central cell, ranging from 0.1 to 0.5 × $10^{-4}$ Wb. The spatiotemporal distribution of the Balmer $H_\alpha$ and $H_\beta$ emission intensity ratios, observed simultaneously with a high-speed camera, along with measurements from the electrostatic probe array on the target plate, indicated that the recombination region shifted downstream with higher DM plasmas.

The importance of hydrogen molecules in vibrationally excited states during recombination reactions has been highlighted, with the intensity ratio of Balmer $\alpha$ to $\beta$ serving as a key indicator. Recently, we observed three-body and radiative electro-ion recombination (EIR) by increasing $H_2$ gas pressure. A detailed analysis shows that both EIR and the mutual neutralization between $H_2^+$ and $H^-$ play significant roles in emissions from highly excited levels.

Progress has been made in modeling the kinetic effects of ion-conductive heat flux along magnetic field lines in the scrape-off layer (SOL) of a DEMO reactor. A transport equation derived from the Boltzmann equation has been implemented in a plasma fluid code and verified. Comparison with a first-principles particle-in-cell code shows that the heat flux is qualitatively and semi-quantitatively reproduced under a uniform magnetic field and high collisionality.

Regarding advanced diagnostic development, we upgraded the Dual-Path Thomson Scattering (DPTS) system to study non-invasive plasma structures in both the upstream core plasma and the end region D-module. In this system, the probe laser of the central-cell (CC) TS system is split into two paths: one directed to the central cell and the other transmitted about ten meters downstream to the end cell. Probe laser light is thus injected simultaneously into both the central and end cells.

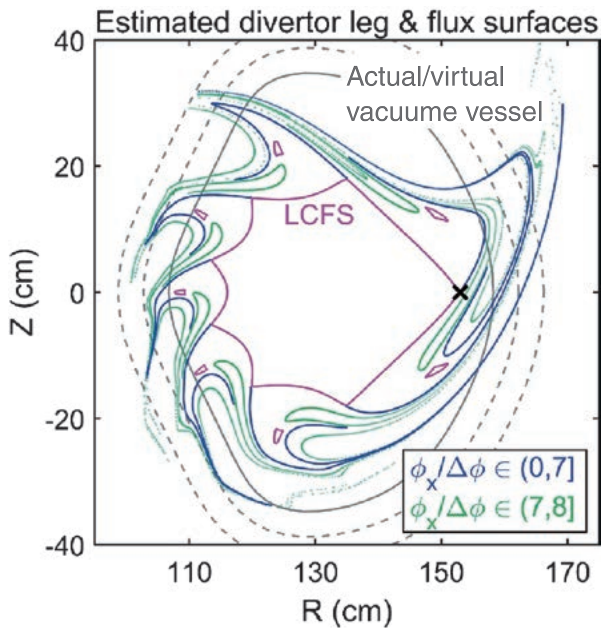
In the end region, the TS system uses a laser beam branched from the CC-TS system, which introduced beam alignment issues due to long-distance transmission. This made it difficult to obtain stable Thomson scattering signals. To resolve this, we introduced a laser beam alignment stabilization system (Aligne, TEM Messtechnik), which enabled precise stabilization of the beam position. By adjusting the beam alignment before plasma experiments, a stable probe beam path was successfully maintained.

The development of gyrotrons that are high-power microwave sources for electron cyclotron resonance heating (ECRH) is one of the most important areas of research at the plasma research center. Megawatt (MW) gyrotrons with a wide frequency range from 14 to 300 GHz are being developed for fusion devices in collaboration with fusion research institutes. A novel 1 MW 14 GHz CW gyrotron for low-field fusion devices has been developed. The design results showed that, despite a 14 GHz RF beam with high divergence, a transmission efficiency of 94% was obtained for the corrugated waveguide coupling position by employing a direct coupling design strategy using a built-in waveguide to minimize the RF transmission path. By installing a double-disk sapphire window, a 1 MW CW operation was possible at 14 GHz. In the first experimental test, the output power $P_o$ increased with an increase in the beam current $I_k$, and 1.05 MW for 2 ms was obtained at $I_k = 42.6$ A, which is a world record in the 14 GHz frequency range. A maximum output efficiency $\eta_o$ of 40.6% was obtained at $I_k = 25.3$ A. The successful development of this gyrotron will reduce the cost of gyrotron systems because it eliminates the need for a Matching Optics Unit (MOU) to connect the gyrotron and the waveguide. Furthermore, achieving a megawatt-class output at 14 GHz, which is the operating boundary frequency between gyrotrons and klystrons, can be useful in various fields, including nuclear fusion research, particularly in the development of compact fusion reactors.

To further advance the divertor simulation study, a new linear plasma device, Pilot GAMMA PDX-SC (PGX-SC), was constructed, and plasma production and heating experiments are in progress. A cascade arc plasma source and a helicon plasma source have been developed. Regarding plasma heating, ICRF and electron cyclotron heating (ECH) antennas are installed in the vacuum vessel. An ICRF wave with a frequency of 1.8 MHz and a power of 160 kW was applied to plasma sustained by a cascade arc plasma source. An ion-sensitive probe showed an increase in ion temperature due to ICRF heating.

(M. Sakamoto)

# Kyoto University




Calculated divertor leg (blue, green), last closed flux surface and magnetic islands (magenta), and vacuum vessel (gray solid/ dashed) in Heliotron J.

## Highlight

# Divertor Topological Structure Arising from Hidden Stochasticity in Heliotron J

Based on the stochasticity of the vacuum magnetic field, the divertor in helical devices is categorized into helical (or ergodic) and island divertors. The distinction between a helical and island divertor, however, is sometimes ambiguous. Therefore, it is useful to give a distinctive categorization of the divertors' topological structures based on distribution, in addition to field stochasticity. The stochastic feature of the magnetic field can be seen in an edge surface layer region outside the LCFS, which exhibits a "fold and stretch" effect on any topological structure in the region, as has been shown in Large Helical Device (LHD) [G. Kawamura *et al.*, Plasma Phys. Control. Fusion **60**, 084005 (2018)].

We have utilized an estimation method for the shape of divertor legs by tracing the field lines that originate from positions near an X-point, as indicated by the black "X" marker in the figure. Due to the stretch effect along the divertor leg and the divergence-free nature of the magnetic field, the distance between those field lines and the actual divertor leg reduces with the increasing tracing distance. This is also the reason why the edge surface layer can be observed in the Poincaré plot, where field line trajectories on a toroidal cross-section show some unique structures, regardless of their starting position. Hence, such field lines can be a reliable estimate of the shape of the divertor leg even if they are chaotically folded with massive details. A divertor leg in the Heliotron, calculated using this estimation method, is illustrated in the figure, where >φ is the traced toroidal angle of a field line in the positive-toroidal direction from an estimated X-point. Note that the estimated divertor leg is discontinuous, owing to the limited calculation domain. Small regions with nested flux surfaces also exist at the O-points outside the LCFS. [F. Cai *et al.*, Contrib. Plasma Phys. **64**, e202300145 (2024)].

# Electron Internal Transport Barrier (e-ITB) formation in NBI plasmas

It is important to control heat transport in order to achieve high performance in magnetic confinement fusion plasma. Methods for controlling heat transport in fusion-grade plasma confinement devices have not yet been fully established due to the complex heat deposition and profile formation. In this respect, clarifying the interactions between temperature gradients, turbulence, and flow is a crucial challenge for controlling heat transport. In this study, we have identified confinement conditions that improve heat transport in high-collisionality plasmas with a broad heating distribution by applying high-intensity gas puffs (HIGPs) to neutral beam injection (NBI) heating, [C. Wang *et al.*, 2024 Plasma Phys. Control. Fusion **66**, 022001]. Furthermore, we calculated the radial electric field via simulation and evaluated the differences between CERC and simulated plasmas from temperature and density profiles obtained from a Thomson scattering system and charge exchange recombination spectroscopy.

Figure 1 shows the time evolution of the electron temperature ($T_e$) profile for both conventional gas puffs and HIGPs. A plasma is heated by a balanced NBI with an injection pulse of 190 – 260 ms and an injection power of 280 kW. HIGP introduces a large amount of working gas ($D_2$) in the short time of 230 – 240 ms, followed by an abrupt stop to the gas puff. After an HIGP, the $T_e$ profile initially shrinks and forms a centrally peaked one. Subsequently, the central region becomes steep at 260 – 270 ms, forming an e-ITB structure with $T_e$ (0) = 370 eV. Compared to a gas puff (GP) experiment, the difference in central temperature is significant. At this point, the electron density rises to $6\times10^{19}$ $m^{-3}$ (although the central region is flat), and the collision frequency is higher than that of CERC plasma. After an HIGP, the ion temperature profile also sharpens with a similar time variation, but to a lesser extent. Using the DKES PENTA code to calculate the neoclassical bipolar electric field (see Figure 2), we found that (i) the sign is negative (ion root), and that (ii) there is no significant difference in the electric field profile between a conventional gas puff and an HIGP. Therefore, it is speculated that the electron transport barrier is formed by a different physical process during the HIGP than in CERC. Currently, in addition to measuring turbulence in the central region, we are investigating the effects of lower-order rational surfaces based on their relationship with electron transport barriers revealed in Heliotron J [N. Kenmochi *et al.*, Sci. Rep. **10**, 5 (2020)].

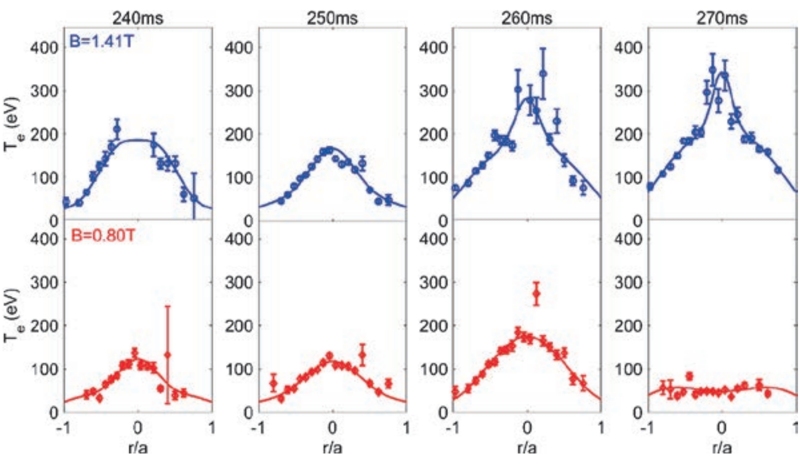



Fig. 1 Time variation of electron temperature profiles in upper (HIGP) and lower (Gas Puff) cases.

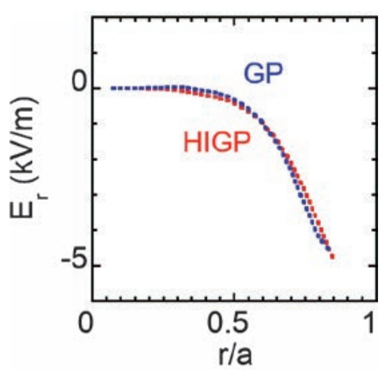



Fig. 2 Comparison of the radial electric field between HIGP and gas puff cases calculated by DKES PENTA code.

(Kazunobu Nagasaki)

# Osaka University

## Study on high-density core plasma formation and laser fusion with fast ignition scheme

The Institute of Laser Engineering (ILE) at The University of Osaka has been collaborating with NIFS and related universities to advance research on high-density plasma in laser fusion and to clarify the path to efficient fusion plasma through the FIREX-1 project. Starting in fiscal year 2021, ILE has launched the FIREX-NEO (Numerical Experiment Optimization) project, which aims to develop high-gain designs through numerical simulations. This project focuses on enhancing the accuracy of simulation codes for the three critical processes in high-energy laser fusion, i.e., implosion, heating, and burning, and conducting the necessary fundamental experiments to achieve this. Additionally, by incorporating research related to high-repetition laser technology development, plasma diagnostic development, and fusion reactor engineering, we are comprehensively advancing laser fusion research. By leveraging domestic and international researcher networks and collaborating with bilateral joint research projects, we are academically advancing high-energy-density science and striving to cultivate the next generation of researchers.

### 1. Improvement of compression ratio in high-density fusion fuel core formation

Laser fusion requires the generation of high-density core plasma that is more than 1,000 times denser than solid matter. In the central ignition scheme, the core plasma is generated by imploding a thin shell, but in the fast ignition scheme, there is no need to form a hot spot at the center. Therefore, we can adapt a solid ball and compress it using three shock waves. By introducing a random phase plate to improve the non-uniformity of laser irradiation, we have been able to achieve an implosion of the solid sphere, but the compression ratio has not been high enough. One possible cause was suspected to be an imbalance in energy conversion between the GEKKO-XII beams. This year we coated the solid sphere with aluminum to increase the Coulomb collision rate in the ablation plasma, thereby attempting to suppress cross-beam energy transfer between the beams. As a result, we successfully achieved a higher compression ratio than last year.

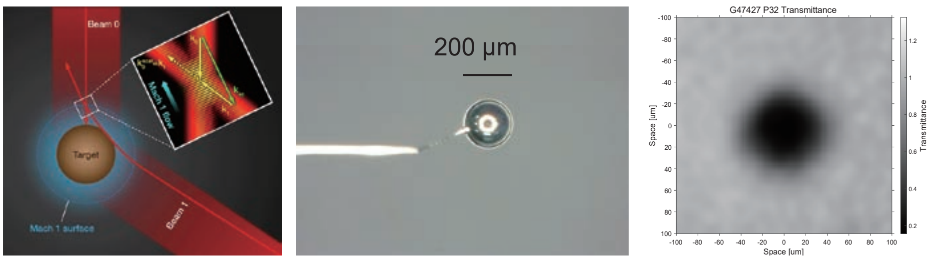



Fig. 1 (Left) Image of energy conversion between beams accompanying the overlap (beat) of implosion laser beams. (Center) Al-coated target used in the experiment. (Right) Improved compression performance (backlight image of implosion plasma).

### 2. Suppression of laser-plasma instability

In implosion, shock-wave ignition-laser fusion requires laser intensities exceeding $10^{15}$ W/cm$^2$. Even with the fast ignition scheme at the ignition scale, the final stage laser intensity can reach similarly high levels. In such high-intensity laser-plasma interactions, high-energy electrons with energies of several hundred keV, which are two orders of magnitude higher than the laser field's vibrational energy, have been observed. It is important to understand the physics of such high-energy electron generation. In this study, we achieved high-intensity blue (3w) lasers by simultaneously irradiating multiple beams using the GEKKO-XII laser. Additionally, by using green (2w) lasers as pre-pulses, we generated plasma with different scale lengths and investigated the laser-plasma interactions of blue lasers. The time evolution of the scattered light observed at time intervals of 0.2 ns (short-scale plasma) and 0.8 ns (long-scale plasma) between the green laser and blue laser is summarized in Figure 2. Scattered light with a wavelength of approximately twice that of the blue laser (351 nm) is observed at the timing of the main pulse irradiation. The intensity of the scattered light is stronger than that observed for the short-scale plasma (0.2 ns). Additionally, the energy spectrum of the high-energy electrons observed simultaneously (Figure 2, right) confirms that the number of high-energy electrons generated in the long-scale (0.8 ns) experiment is nearly two orders of magnitude lower. From this, it can be inferred that the high-energy electrons were accelerated by plasma waves generated during the process of parametric decay. The above results suggest the possibility of suppressing parametric instability in implosion lasers by adjusting the plasma scale length.

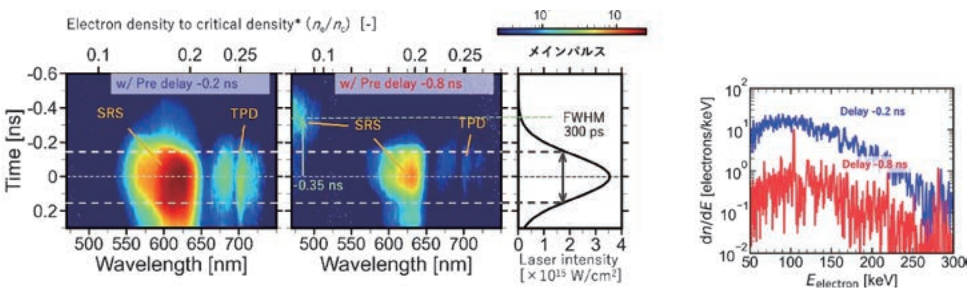



Fig. 2 (Left) Time evolution of the wavelength of scattered electromagnetic waves when the irradiation interval between the pre-pulse and main pulse is changed. (Right) Energy spectrum of high-speed electrons observed at that time.

### 3. Kinetic effects in DT fusion burning

In the ignition experiment conducted by the US National Ignition Facility (NIF), it has been reported that the observed neutrons contained non-thermal components. This indicates the presence of non-thermal high-energy ions in the fusion burning process. We evaluated how non-thermal ions with energies above several tens of keV are generated through Coulomb collision calculations between alpha particles and DT ions. In the calculations, we examined how the energy of α particles (3.5 MeV) initially present at a concentration of 1% in a DT plasma with an initial temperature of 3 keV and a density equivalent to 200 g/cc, was converted into plasma electrons and DT ions using a two-body collision model. First, we confirmed that the energy of the α particles decreases due to deceleration caused by electron heating. On the other hand, by considering large-angle scattering, it was found that non-thermal components of D ions are generated, and the time required for thermal relaxation of the α particles is boosted to one-third. The theoretical predictions also show good agreement with the reason why non-thermal components of D ions are generated first, compared to T ions.

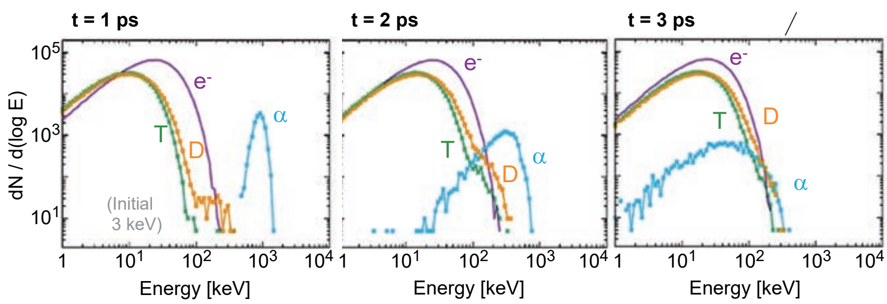



Fig. 3 Time evolution of the energy distribution in the energy relaxation process of alpha particles in a 3 keV DT plasma in the early stage.

(Y. Sentoku)

# Kyushu University

## Research activities of QUEST in FY2024

Here we summarize the activities of the Advanced Fusion Research Center, Research Institute for Applied Mechanics at Kyushu University from April 2024–March 2025. QUEST experiments were executed from 5th Apr. – 22nd Aug. (2024 Spring/Summer, shot no. 53077-53571) and 11th Sep. – 16th Jan. (2024 Autumn/Winter, shot no. 53572-54445). The main topics of the QUEST experiments in FY2024 are listed below.

1) A non-inductive 28 GHz electron cyclotron plasma ramp-up with multiple fundamental and second harmonic resonances has been planned to achieve both a highly efficient plasma ramp-up and significant central bulk electron heating. A 100 kA DC power supply has been developed to double the toroidal magnetic field from 0.25 T to 0.5 T, enabling these goals to be met simultaneously. All the control systems for 125 modules of the power supply have been developed, and a 7.2 kA DC current was successfully attained by using 9 modules for a planned few seconds. Divertor plasmas with clear divertor legs were non-inductively ramped up with the 28-GHz electron cyclotron heating through the proper plasma equilibrium control.
2) Middle-scale W/ODS-Cu/SUS joint structure samples for the QUEST first wall was successfully fabricated. A middle-scale sample was installed at the first wall position of QUEST, and then, exposed to 4016s of tokamak discharges in total, while maintaining a temperature of around ~350°C. There was no specific damage to the middle-scale sample, such as delamination or cracks, after the irradiation test in QUEST.
3) Using molecular dynamics simulations, we analyzed the energy distribution of hydrogen isotope (H, D, T) emissions and incorporated a machine learning model for hydrogen release into a neutral particle transport code in the case of protium. In addition, we developed a web-based VR system to visualize magnetic field lines in 3D within the QUEST device. These efforts are expected to contribute to the establishment of a technique for dynamically analyzing hydrogen release behavior from fusion reactor walls.
4) The ball-pen probe (BPP) is a new method for directly measuring space potential and electron temperature in magnetized plasmas. It has several advantages, such as a simple design, strong structure, and fast signal response. To test if it works well for the QUEST spherical tokamak, we built a new two-channel BPP and successfully tested it in the PANTA device.
5) The plasma shape reconstruction code using the Cauchy condition surface method (CCS) modified from the latest version for JT-60SA was applied to the QUEST plasma. A selected flux loop signal whose accuracy was confirmed by a coil energization test was applied and the drift of each signal was carefully compensated for. Fixing bugs in the code is continuing.
6) A new Permeation and Langmuir Probe (PALP) was developed and installed in QUEST to evaluate atomic and ionic hydrogen fluxes to plasma-facing components. Contamination effects were addressed using a dedicated calibration chamber, with lab studies showing that oxygen and tungsten alter the crystal structure and hydrogen permeation in Pd and Ni membranes.
7) Edge fluctuation measurements using the limiter-like electrode system were performed for Inboard Poloidal Null (IPN) configuration tokamaks produced by the 28 GHz gyrotron system.
   At the major radius of 1.1 m, intermittent low frequency kV order floating potential spikes and intermittent envelopes of MHz range floating potential fluctuations were observed during a single discharge. The spikes could be indicators of high energy electron flux, and the existence of the envelopes suggests wave excitation phenomena. Correlation between the spikes and the envelopes is suggested. Now the statistical significance

of the correlation is under investigation.

8) Improvements in hot wall heaters at the lower side were carried out to control the hot wall temperature locally. This improvement allowed for a more detailed investigation of the effect of wall temperature on particle balance. In addition, the modeling of hydrogen recycling, including trapped hygrogen into the plasma facing material, has been improved.
9) The injection port of the HIBP was modified to allow a wider sweep of the probe beam's incident angle, and the beamline installation was completed. A Cs+ beam has been successfully emitted from the ion source and accelerated. The next step is to compensate for the beam deflection caused by the toroidal magnetic field in order to inject the beam into QUEST.
10) To measure ion-scale turbulence and plasma poloidal rotation, a Doppler Backscattering (DBS) system was developed. The system used 10 GHz, 14 GHz, and 18 GHz microwaves, selected to match the plasma density range of QUEST. A successful benchtop experiment was first conducted using a simple metal reflector and a rotational scattering setup. The system was then installed in QUEST; however, no signal was detected. To address this, a focusing mirror system is being introduced for the next experimental campaign.
11) A transient heat-load test on GaInSn liquid metal has been proposed for development of advanced divertor concepts. The plasma irradiation will be conducted by using the CT injector of UH-CTI for fueling in QUEST. In the test for investigating the basic characteristics, in order to accommodate the fluidity of liquid metals, it is necessary to place the stationary liquid metal in a container in a horizontal position and irradiate it with a CT plasma from the vertical direction, passing through a curved drift tube. The drift tube equipped with observation ports has been designed and manufactured, and the stationary work platform has been modified to avoid interfering with the positioning of the drift tube in QUEST.
12) The Thomson scattering (TS) system has been upgraded. The number of simultaneous spatial measurement points has been increased from six to eight, by adding two polychomators and introducing new digitizers. Some related modifications have also been carried out. As a result, we can now measure eight spatial points simultaneously. Improvements in calibration and in the automatic alignment system were also carried out, leading to improved accuracy in temperature and density measurements.
13) The experimental result of the t-CHI current start-up in QUEST showed a definite current scaling relation, in which the driven toroidal current was proportional to the injector flux and the injector current was proportional to the square of the injector flux. In this study, the injector current profile was obtained by measuring the change in the toroidal field. The current and flux configuration during the flux evolution of the t-CHI discharge was estimated from the data of the scaled toroidal current and the injector current profile, which showed closed flux surfaces forming according to the trace of injector current.

IDEI Hiroshi (Kyushu University) 1)
TOKITANI Masayuki (NIFS) 2)
SAITO Seiki (Yamagata University) 3)
MOON Chanho (Kyushu University) 4)
TAKECHI Manabu (QST) 5)
KUZMIN Arseniy (Kyoto University) 6)
NAGASHIMA Yoshihiko (Kyushu University) 7)
HANADA Kazuaki (Kyushu University) 8)
IDO Takeshi (Kyushu University) 9)
KINOSHITA Toshiki (Kyushu University) 10)
FUKUMOTO Naoyuki (University of Hyogo) 11)
EJIRI Akira (University of Tokyo) 12)
KURODA Kengoh (Japan Coast Guard Academy) 13)

(H. Idei)

# University of Toyama

Fig. 1 Low energy X-ray spectrum measurement system.

## Highlight

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

Measurement of tritium in solids is an important issue for the safe management of radioisotopes in fusion reactors. Tritium beta-ray induced X-ray spectrometry (BIXS) is one of the methods used for tritium analysis in solids, although it is currently a qualitative method. Since other methods for analyzing tritium in solids are destructive, non-destructive methods such as BIXS must be developed. We aim to develop a BIXS simulation system to upgrade the technique from qualitative to quantitative analysis for tritium in solids. The simulation program (GALET-BIXS) using the Geant4 toolkit has been created and optimized. The simulation program is designed to match the geometric configuration of the beta-ray induced X-ray (BIX) measurement system. GALET-BIXS can fully reproduce the low-energy X-ray spectrum observed by the measurement system. The spectrum shape of BIX generated from tritium in solids changes, depending on the tritium distribution within the solid. GALET-BIXS can calculate the spectrum shape changes as the tritium distribution in solids also changes, making it possible to quantify the tritium amount in the solid by measuring the BIX spectrum and its counting rate.

# Development of Tritium Measurement System

In this study, we measured low-energy X-ray spectra using a sealed source and performed Monte Carlo simulations to reproduce the observed spectra. The refined simulation program is intended to be used for determining the depth profile of tritium via BIX spectrum analysis.

For the X-ray spectrum simulation, a Monte Carlo simulation program (GALET-BIXS) was developed using the Geant4 toolkit. The measurement device used in the actual experiments is shown in Figure 1. A silicon drift detector was used, and the radiation source was $^{57}$Co. The geometric configuration of the sample and detector in the device was incorporated into GALET-BIXS.

Figure 2 shows both the measured X-ray spectrum and the spectrum calculated by GALET-BIXS. The intensity of the simulated spectrum was adjusted using a scaling factor to match that of the measured spectrum. The characteristic X-rays and gamma rays of iron emitted from the $^{57}$Co source were successfully reproduced by our Monte Carlo simulation program (GALET-BIXS) for low-energy X-rays using the Geant4 toolkit.

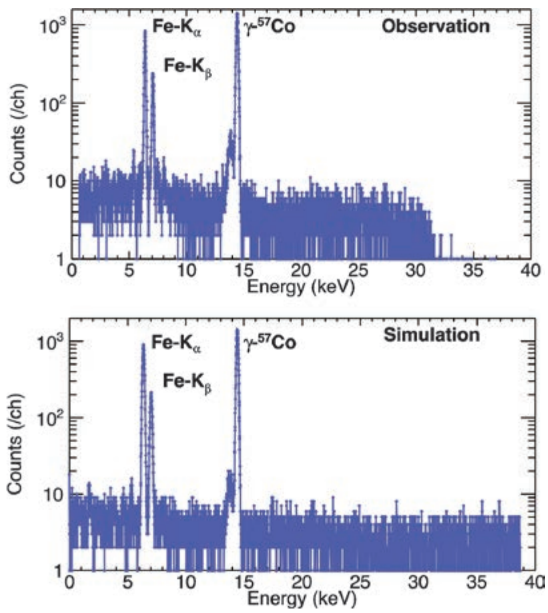


Fig. 2 Observed X-ray spectrum of $^{57}$Co and simulated one.

Other experimental studies performed in the Hydrogen Isotope Research Center in the fiscal year 2024 are listed below.

- Release behaviors of hydrogen isotopes from tungsten materials exposed to hydrogen isotope plasma during oxidation (T. Otsuka, Kindai University)
- Understanding and optimization of tritium absorption into tritium target for 14 MeV neutron irradiation experiments (I. Murata, Osaka University)
- Effects of transmutation or irradiation damage on hydrogen isotope transport dynamics (Y. Oya, Shizuoka University)
- Depth Analysis of Co-deposited H, He and Impurity Atoms on Plasma Exposed W by Means of GDOES (N. Yoshida, Kyushu University)
- Development on liquid DT nuclear fusion fuel for high repetition laser fusion reactor (Y. Arikawa, Osaka University)
- Correlation between hydrogen isotopes trap density and vacancy concentration in tungsten (M. Kobayashi, NIFS)
- Effects of repeated short pulse hydrogen beam irradiation on hydrogen isotope retention in tungsten materials (K. Tokunaga, Kyushu University)
- Precise evaluation of tritium retention and permeation in solid/liquid tin exposed to tritium plasma (H. Toyoda, Nagoya University)
- Hydrogen isotope retention behavior in tungsten-rhenium layer created by pulse laser irradiation (Y. Nobuta, Hokkaido University)

(M. Hara)

# 4. International Collaboration

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, as follows,

1) Multinational coordination in Fusion Power Coordinating Committee (FPCC) under International Energy Agency (IEA),
   - Stellarator-Heliotron Technology Cooperation Program (TCP)
   - Plasma-Wall Interactions TCP
   - Spherical Tori TCP

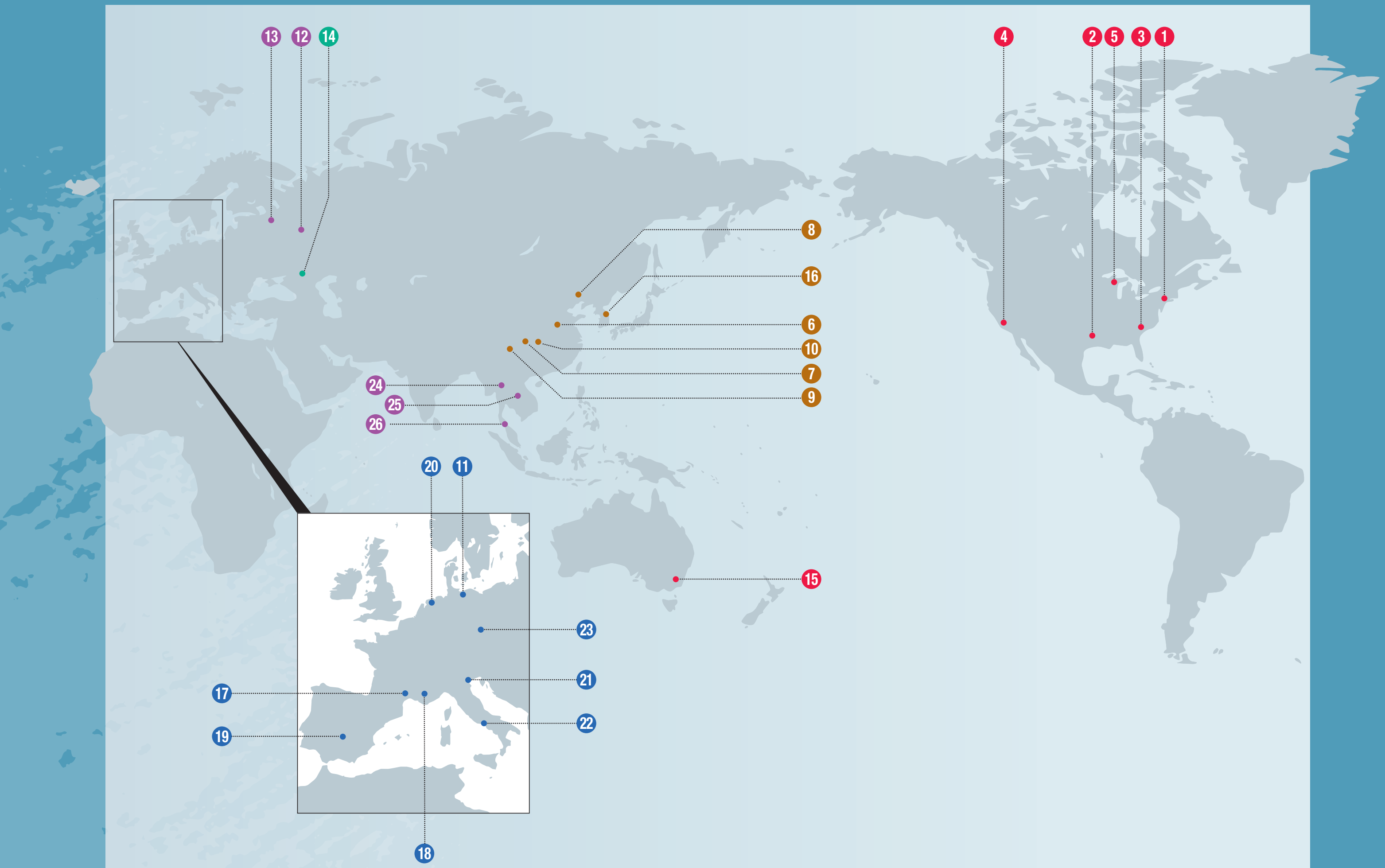
2) Binational coordination,
   - Japan-United States Collaborative Program
   - Japan-Korea Fusion Collaboration Programs
   - Japan-China Collaborative Program
   - Japan-EU Cooperation

3) Coordination with other institutions
   - 32 international academic exchange agreements

The geographical distribution of international collaborations and summary of each activity are shown in following pages.

(T. Morisaki)

# Academic Exchange Agreements



**U.S.A.** ❶ Princeton Plasma Physics Labolatory (PPPL)
❷ Institute for Studies, The University of Texas at Austin (IFS)
❸ Oak Ridge National Laboratory (ORNL)
❹ Center for Energy Science and Technology Advanced Research, University of California, Los Angelse (UCLA)
❺ Letters & Science and College of Engineering, University of Wisconsin–Madison College (UWM)

**China** ❻ Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP)
❼ Southwestern Institute of Physics (SWIP)
❽ Peking University
❾ Southwest Jiaotong University (SWJTU)
❿ Huazhong University of Science and Technology

**Germany** ⓫ Max Planck Institute for Plasma Physics (IPP)

**Russia** ⓬ A. M. Prokhorov General Physics Institute, Russian Academy of Sciences (GPI)
⓭ Peter the Great St. Petersburg Polytechnic University

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

**Australia** ⓯ Australian National University (ANU)

**South Korea** ⓰ National Fusion Research Institute (NFRI)

**France** ⓱ Aix-Marseille University (AMU)
⓲ Commissariat à l'énergie atomique et aux énergies alternatives (CEA)

**Spain** ⓳ National Research Center for Energy, Environment and Technology (CIEMAT)

**Netherlands** ⓴ Dutch Institute for Fundamental Energy Reseearch (FOM)

**Italy** ㉑ CONSORZIO RFX
㉒ Institute of Lonized Gas (IGI)

**Czech** ㉓ HiLASE Center, Institute of Physics CAS (FZU)

**Tailand** ㉔ Chiang Mai University (CMU)
㉕ Mahasarakham University (MSU)
㉖ Thaksin University (TSU)

The ITER International Fusion Energy Organization (ITER)

# Japan (Universities) – US Fusion Cooperation Program

In 1977, US President Carter and Japanese Prime Minister Fukuda discussed new bilateral cooperation on fusion. A governmental agreement on Japan and US joint activity in the field of fusion research and development was established, and the Japan-US Coordinating Committee for Fusion Energy (CCFE) was established in August 1979. This cooperation has been continuing for 45 years, producing many excellent results across a wide range of activities.

This joint planning program consists of three categories, each of whose main results in FY2024 are shown, as follows:

**(1) Fusion Technology Planning Committee (FTPC)**

The FTPC deals with collaborations on fusion technology, that is, superconducting magnets, plasma heating technologies, in-vessel/high heat flux materials and components, etc.

In 2024, Takumi Seto (DC2, Univ. Tsukuba) was dispatched to the University of California, San Diego (UCSD). In two separate visits, he installed two fast reciprocating probe systems in PISCES-RF in UCSD, which were fabricated in Tsukuba university, and performed an experiment to evaluate wave property in PISCES-RF helicon plasma. A data acquisition system was prepared by UCSD.

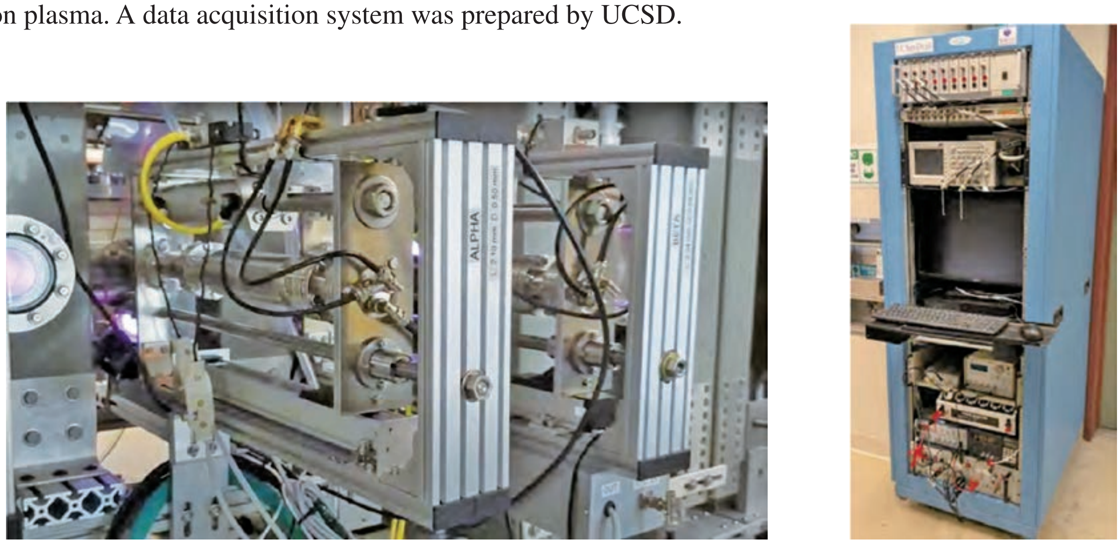



Fig. 1 (left) two fast reciprocating probe systems by U. Tsukuba, and (right) data acquisition systems by UCSD.

**(2) Fusion Physics Planning Committee (FPPC)**

The FPPC deals with collaborations in the experimental research of fusion plasma physics, consisting of steady-state operations, MHD and high beta, confinement, diagnostics, and high energy density science.

In 2024, Kunihiro Ogawa (Assoc. Prof., NIFS) was dispatched to General Atomics (GA) to study “the inter-

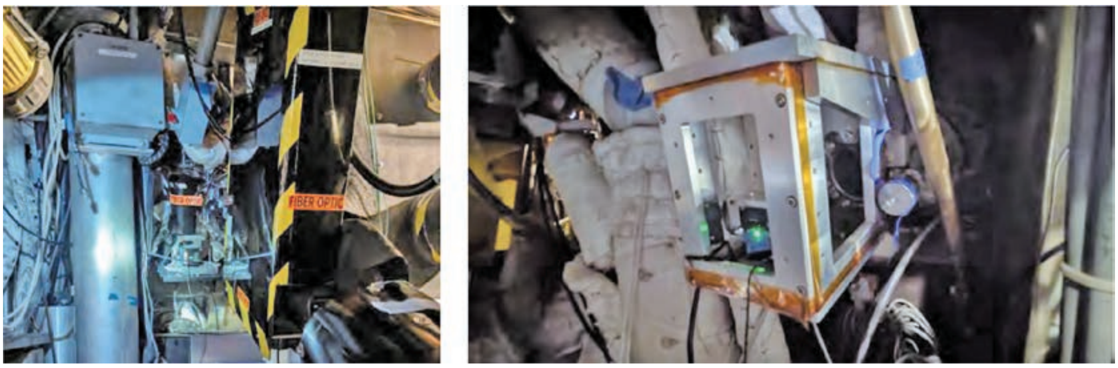



Fig. 2 Imaging neutral particle analyzer for (left) vertical and (right) tangential viewing in DIII-D.

action between energetic ions and energetic ion-excited waves in toroidal plasmas" for one week. During the stay at GA, with Drs. Michael Van Zeeland, Deyong Liu and Xiaodi Du he discussed neutron diagnostics and an imaging neutral particle analyzer for high-energy ion measurement in DIII-D (GA) and LHD (NIFS).

**(3) Joint Institute for Fusion Theory (JIFT)**

The JIFT deals with collaborations to advance theoretical understanding of plasmas and to develop fundamental theoretical and computational tools.

In FY2024, one workshop was successfully held, and one visiting professor and three visiting scientists made exchange visits. As for the workshop, the "US-Japan Joint Institute Fusion Theory (JIFT) Collaboration Meeting on Exascale Computing" was held at Princeton Plasma Physics Laboratory (PPPL), Princeton, NJ, USA, on February 27–28, 2025. There were 15 oral presentations (six from Japan and nine from US). The presentation topics covered: (1) Simulation code developments and applications, (2) Data science software for extreme scale computing, (3) US SciDAC projects for high-fidelity integrated simulations, and (4) The latest status of flagship high-performance computers in Japan and the US.

**(4) Joint Project (FRONTIER)**

The FRONTIER project 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 modelling (Task 4).

The FRONTIER project successfully completed its sixth year in 2024. The experimental and theoretical studies being planned in the following year as follow-up research will address key issues for plasma-facing components of common interest to Japan and the U.S. The accomplishments of FRONTIER will provide important and essential elements toward realizing attractive fusion energy options. In October 2024, the final year of the project, a concluding workshop was held in Kyoto with 24 participants.

Fig. 3 Group photo at the workshop.

(T. Morisaki, S. Masuzaki, 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" (PWI TCP) which involves Japan, Europe, the United States, Australia, and England. The objective of this program 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 conduct the studies.

In the fiscal year of 2024, two collaborations on PWI experiments were conducted.

## Comparison of deuterium desorption from tungsten fuzz between multiple plasma devices

A low-temperature deuterium (D) desorption around 350 K from a tungsten (W) surface with a fibrous nanostructure (fuzz, see Fig. 1) during thermal desorption spectroscopy (TDS) has been observed in the small RF plasma device APSEDAS at the University of Tsukuba and the small DC discharge plasma device Co-NAGDIS at Nagoya University. However, no such low-temperature D desorption has been reported in D plasma irradiation experiments on fuzz samples prepared by other plasma irradiation devices. The purpose of this study is to understand the mechanism of the low-temperature D desorption in detail by searching for conditions under which such desorption from the fuzzy layer occurs. In this study, APSEDAS, which has already confirmed the low-temperature D desorption, PISCES-A, a DC discharge plasma device at the University of California, San Diego (UCSD), which has many research achievements but has not observed low-temperature D desorption, and PISCES-RF, a new RF plasma system at UCSD, were used to obtain more experimental data.

First, helium (He) plasma was irradiated on two W specimens at APSEDAS to form fuzz on each surface. Then, the sample temperature was kept at 400 K, and D plasma was irradiated in APSEDAS. TDS was performed on one sample at the University of Tsukuba and the other sample at UCSD. The TDS results are consistent with each other, and low-temperature D desorption was observed in both cases at about 315 K.

In PISCES-A, W-fuzz samples prepared at APSEDAS were irradiated with D plasma (sample temperatures of 400 K and 600 K), and fuzz samples were prepared by He plasma irradiation and irradiated with D plasma (sample temperatures of 400 K and 600 K). Some of the fuzz samples prepared in PISCES-A were brought back to Japan and irradiated with D plasma (sample temperature: 400 K) at APSEDAS. In PISCES-RF, preparation of a fuzz sample and D plasma irradiation (sample temperature: 400 K, see Fig. 1) were performed.

No low-temperature D desorption was observed from the fuzz samples irradiated with D plasma at 600 K, while it was observed from the samples irradiated with D plasma at 400 K. These results indicate that the desorption characteristics of TDS may change depending on the sample temperature during D plasma irradiation. The trapping site that causes the low-temperature D desorption peak is considered to be less likely to trap D atoms when the sample temperature at the time of plasma irradiation is as high as about 600 K. The trapping site is also considered to be less likely to trap D atoms immediately after plasma irradiation. It is also possible that D atoms may have already been desorbed during the process of cooling the sample from a temperature of about 600 K immediately after plasma irradiation down to around 400 K.

Differences in the fuzz created in APSEDAS, PISCES-A, and PISCES-RF should be checked by using surface analysis methods such as scanning electron microscopy and X-ray photoelectron spectroscopy.

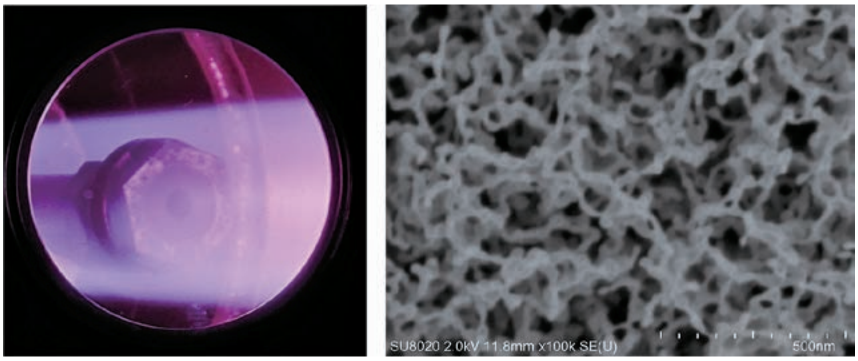



Fig. 1 A sample irradiated by D plasma in PISCES-RF, and a SEM image of fuzz

(K. Saito, University of Tsukuba)

## Direct Measurements of the plasma potential and Electron Temperature using the Ball-pen Probe in VINETA

To investigate fluctuations in plasma space potential and electron temperature, a Ball-pen Probe method has been developed at Kyushu University. This collaborative research aims to test the Ball-pen probe on VINETA (see Fig. 2), the linear plasma device at the Institute for Physics at Greifswald University. VINETA has produced many excellent experimental results, primarily using electrostatic probe diagnostics. However, accurately measuring fluctuations in plasma space potential with conventional probes has proven difficult. Observing these fluctuations in space potential and electric field with high speed and accuracy is crucial for studying plasma instability.

By applying the Ball-pen probe, which is currently being developed for the linear plasma device PANTA at Kyushu University, to experiments on VINETA—similar in plasma generation method and device size to PANTA—the reliability and accuracy of the Ball-pen probe can be verified.

First, the plasma in VINETA needed to be characterized using a simpler Langmuir probe. A Langmuir probe was assembled to measure profiles of electron density, electron temperature, plasma potential, and floating potential. The probe was equipped with a compensating circuit to eliminate any RF signals. A 2D movable system was employed to position the probe, allowing for 2D profiling of the entire plasma column cross-section. To fit the probes onto the 2D system, a specific mounting arm was designed.

As VINETA has not yet demonstrated high-performance helicon plasma, it was decided not to install the Ball-pen probes at this time; however, this remains an option for future collaboration.

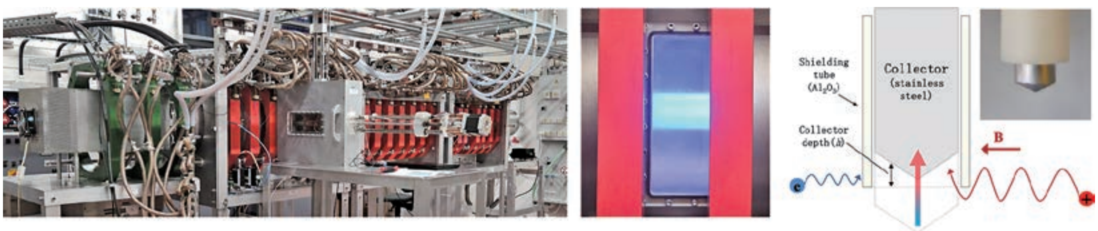



Fig. 2 VINETA and plasma generated in it, and a schematic view of a Ball-pen probe

(D.M. Donato, Kyushu University)

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

The world Stellarator-Heliotron community has been promoting international collaborations under the auspices of the IEA TCP for Cooperation in Development of the Stellarator-Heliotron (SH) Concept. The participating countries and bodies in this program are Australia, China, EURATOM, Japan, Ukraine, and the United States. The Stellarator-Heliotron Executive Committee (ExCo) conducts arrangements of collaboration and endorses proposed activities. The 53rd ExCo meeting was held (on September 9, 2024) in Hiroshima in conjunction with the 24th International Stellarator-Heliotron Workshop. The Max-Planck Institute for Plasma Physics (Germany) hosts the web page of this activity at http://www.ipp.mpg.de/sh-tcp, and related content can be found on the webpage of the IEA, https://www.iea.org/articles/new-milestones-in-magnetic-fusion-power.

## Highlights of recent activities

In FY2024, Hiroshima University successfully organized major meetings and workshops, with Prof. Yasuhiro Suzuki serving as the chair of the local organizing committee.

One of these was the 24th Coordinated Working Group Meeting (CWGM) held on September 5–6, 2024 at Hiroshima University (Higashi-Hiroshima city), which was composed of regular sessions such as "Core transport and confinement in multi-ion plasmas (chaired by D. Carralero / M. Nunami)", "Energy, particle and impurity transport in the SOL and divertor (chaired by V. Winters / A. Bader)", and "Energetic Particles, MHD and high-beta (Chaired by A. Knieps / A. Wright)", followed by a specially organized session with private companies (chaired by N. Pablant) reflecting emerging interactions between public and private sectors in overall fusion research worldwide. Six companies presented their activities, stressing their visions and short-term plans for the development of the SH concept. How public-private partnerships could be formulated in the CWGM activities, and furthermore in the entire SH activities, was discussed.

The other meeting was the 24th International Stellarator-Heliotron Workshop (ISHW), which was held on September 9–13, 2024, at the International Conference Center Hiroshima (Hiroshima city). A record number of participants (231) was counted, with a marked increase in participation from China (32) being particularly noteworthy. Moreover, alongside the special session in the CWGM, participation from the private sector, including companies involved in the supply chain, was also highlighted. A detailed report (in Japanese) by the chair of the local organizing committee can be found at https://www.jspf.or.jp/Journal/PDF_JSPF/jspf2025_03/jspf2025_03-139.pdf.

The next ISHW (25th in 2026) will be held in Spain, as agreed in the ExCo meeting.

## Highlighting remarks from the ExCo report (summarized in late 2024.)

As for the CWGM framework, regarding the current status and future development of the Stellarator-Heliotron Databases, efforts should be made to enhance them, especially the profile and confinement database. There have been discussions about broadening the scope of databases reflecting evolving research needs. Thus, a joint action is ongoing. It was also reported on challenges in maintaining and expanding the databases, including reliance on individual institutes to archive and submit data, and the technical challenges of archiving data from older or decommissioned devices.

## Status of domestic activities and international collaborations

China: Southwest Jiaotong University (SWJTU) has successfully achieved a precise quasi-axisymmetric magnetic configuration in the CFQS-T experiments with 0.1T operation. The University of South China (USC) reported significant progress on the H1 stellarator (shipped from Australia), now called CN-H1. Coil assembly is nearly complete and the device is close to entering operational status, with first plasma anticipated in 2025.

Japan: Hiroshima University is recommissioning a small Heliac (the former Tohoku University (TU) Heliac). First plasma is envisaged in 2025; Kyoto University continues operation and maintenance of Heliotron J, collaborating with both the Large Helical Device (LHD) and international partners. LHD is preparing for its 26th and final campaign.

Ukraine: Experimental tests on ion cyclotron frequency range (ICRF) plasma production in a hydrogen minority regime were conducted on the U-2M device and qualified at the Large Helical Device (LHD). Initial experiments were successful in creating plasma using a radio frequency discharge above the ion cyclotron frequency at low magnetic fields in LHD. The findings suggest new operational possibilities for the LHD, which are also relevant to W7-X. The concept of a stellarator-mirror hybrid reactor is pursued further.

United States: The US has four active stellarator experiments (located at University of Wisconsin-Madison, Auburn University, University of Illinois Champaign-Urbana, and PPPL) and three more devices under construction (at Hampton University, Columbia University, and another at University of Wisconsin-Madison). US researchers continue to play a significant role in international campaigns, including the LHD and the upcoming W7-X campaign. The stellarator theory community is preparing for some changes as the Simons Foundation grant approaches its conclusion in 2025.

Germany: W7-X is entering a new operational phase with ambitious goals: higher ion temperatures, advanced detachment at high heating power, and longer pulse scenarios. Strong international collaboration, particularly from Europe and the US, is supporting experimental campaigns. Technical upgrades are being made to improve the reliability of operation.

Spain: TJ-II was operated until June 2024. Now, maintenance is underway in the power generator building. A call for proposals for the next campaign will be launched in early 2025. Collaboration with W7-X remains a strong priority.

(M. Yokoyama, K. Nagaoka, Y. Suzuki (Hiroshima Univ.) and K. Nagasaki (Kyoto Univ.))

# Japan-China Collaboration for Fusion Research

Japan-China collaboration on fusion research is motivated by (1) the joint working group (JWG) for implementing the arrangement between MEXT of Japan and MOST of China for cooperation in the area of magnetic fusion energy research and development and related fields. It is also, (2) a collaboration on fusion research with institutes and universities in China, including the Institute of Plasma Physics, the Chinese Academy of Sciences (ASIPP), the Southwestern Institute of Physics (SWIP), Peking University, Southwestern Jiaotong University (SWJTU), Huazhong University of Science and Technology (HUST) and other universities. The Japan-China collaboration is carried out both for studies on plasma physics and fusion engineering. Based on the following implementation system, the Japan-China collaboration for fusion research in FY 2024 was executed.

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

| Category | ① Plasma experiment | | | | ② Theory and simulation | ③ Fusion engineering research |
|---|---|---|---|---|---|---|
| Subcategory | ①-1 | ①-2 | ①-3 | ①-4 | — | — |
| Operator | A. Shimizu | H. Takahashi | M. Isobe | M. Goto | H. Wang | 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 atomic process

## Primary joint research activities in FY 2024

The first plasma of CFQS-T was successfully achieved in July, 2024. Subsequently, the first CFQS-T workshop was held on Nov. 13th and 14th, 2024 at the SWJTU Jiuli campus, as shown in Fig. 1. The number of participants was 87 in total from both NIFS and SWJTU. Two primary topics, i.e., research progress on CFQS and scientific achievements at CFQS-T and the joint design and construction of CFQS, as well as its perspective in the future, were presented from both sides and discussed [1-4].

Fig. 1 The 1st CFQS-T workshop held on Nov. 13th and 14th, 2024 at SWJTU Jiuli campus.

In the research of energetic particles (EPs), NIFS and ASIPP conducted joint studies on energetic ion anisotropy in LHD using a compact neutron spectrometer [5], as well as triton burnup experiments in EAST using a scintillating fiber detector [6]. In addition, NIFS and ASIPP have collaborated on the development of neutron diagnostics [7] and lost energetic ion diagnostics [8] for EAST and BEST. NIFS and SWIP have been discussing neutron diagnostics, hard X-ray diagnostics, and E||B neutral particle analyzers. Furthermore, NIFS and SWIP carried out triton burnup and runaway electron experiments in HL-3. Five joint papers related to EP diagnostics and physics were published in FY2024 [5-8].

At EAST, preparations are underway for imaging observations of multiple impurity emission lines and for measuring the spatial distribution of electron temperature and density using their intensity ratios. As a proof-of-concept for this measurement technique, we investigated the use of spectral data acquired by LHD. The LHD routinely measures spectra between approximately 30 nm and 300 nm with a time resolution of 5 ms. This allows the emission line intensity ratio to be correlated with the electron temperature and electron density obtained from Thomson scattering measurements. We plan to use the results from analyzing this LHD experimental data to validate the ADAS database and subsequently apply it to evaluate EAST experimental data.

Collaborations on theory and simulation have been carried out with several institutions to investigate key topics in plasma physics. With SWIP and ASIPP, a MEGA simulation was performed to investigate $\beta$-induced Alfvén eigenmode instabilities and mode transition in HL-3 and bursting core-localized ellipticity-induced Alfvén eigenmodes driven by energetic electrons in EAST. With the University of Science and Technology of China (USTC), analytical investigations were carried out on the electromagnetic perturbations of geodesic acoustic modes in tokamak plasmas. With the Dalian University of Technology (DLUT), a neoclassical tearing mode simulation was performed to investigate the enhancement of Electron Cyclotron Current Drive (ECCD) for controlling neoclassical tearing modes in tokamak plasmas [9-13].


[1] T. Fu, X.Q. Wang, X. Su, Y. Xu, S. Okamura, A. Shimizu, M. Isobe, J. Cheng, H.F. Liu, J. Huang, X. Zhang, H. Liu, and C.J. Tang, “*Suppression of equilibrium magnetic islands by density profile effect in quasi-axisymmetric stellarator plasmas*”, Plasma Physics and Controlled Fusion **66**, 065026 (8pp) (2024).

[2] X. Su, X.Q. Wang, Y. Xu, S. Okamura, A. Shimizu, M. Isobe, J. Cheng, H.F. Liu, J. Huang, X. Zhang, H. Liu, Y. Luo, J.F. Shen, J. Hu, and C.J. Tang,“*Controlling three-dimensional magnetic island appearance with external current drive in the Chinese first quasi-axisymmetric stellarator*”, Nuclear Fusion **64**, 076023 (12pp) (2024).

[3] Xin Zhang, Akihiro Shimizu, Sho Nakagawa, Yuhong Xu, Takanori Murase, Hiroyuki Tanoue, Kazuki Nagahara, Mamoru Shoji, Zilin Cui, Hiromi Hayashi, Kunihiro Ogawa, Hiromi Takahashi, Mitsutaka Isobe, Shoichi Okamura, Haifeng Liu, Xianqu Wang, Hai Liu, Jun Hu, Jun Cheng, and Changjian Tang, “*Investigation of modular coil misalignment on magnetic flux surface in the CFQS quasi-axisymmetric stellarator*”, Fusion Engineering and Design **211**, 114820 (2025).

[4] Hiroyuki Tanoue, Sho Nakagawa, Kazuki Nagahara, Takanori Murase, Akihiro Shimizu, Kunihiro Ogawa, Hiromi Takahashi, Mamoru Shoji, Shoichi Okamura, Mitsutaka Isobe, Masaki Osakabe, Dapeng Yin, Haifeng Liu, and Yuhong Xu, “*Engineering design and manufacturing of the modular coil system for the quasi-axisymmetric stellarator CFQS-T*”, Fusion Engineering and Design **212**, 114853 (2025).

[5] K. Ogawa, M. Isobe, S. Sangaroon, L. Liao, G. Q. Zhong, R. Seki, H. Nuga, and M. Osakabe, “*Observation of Energetic Ion Anisotropy Using Neutron Diagnostics in The Large Helical Device*”, Nuclear Fusion, **64**, 076010 (2024).

[6] Kunihiro Ogawa, Guoqiang Zhong, L. Y. Liao, Weikun Chen, Ruijie Zhou, Kai Li, Eiji Takada, Siriyaporn Sangaroon, Liqun Hu, and Mitsutaka Isobe, “*Time-resolved deuterium-deuterium fusion born 1 MeV triton confinement study in EAST deuterium plasma*”, Plasma Physics and Controlled Fusion **67**, 025001 (2025).

[7] Yubo ZHANG, Guoqiang ZHONG, Liangsheng HUANG, Mingyuan Xu, Liqun Hu, Juan Huang, Kun Xu, Ruixue Zhang, Li Yang, Chaowei Mai, Yongqiang Zhang, Weikun Chen, K. Ogawa, M. Isobe, Tieshuan Fan, and Mengjie Zhou, “*Study on the contribution matrix for the EAST radial neutron camera system*”, Fusion Engineering and Design **206**, 114602 (2024).

[8] Mingyuan Xu, Guoqiang Zhong, Yubo Zhang, Liangsheng Huang, Liqun Hu, Ruixue Zhang, Li Yang, Yongqiang Zhang, Weikun Chen, S. Sangaroon, K. Ogawa, M. Isobe, and Tieshuan Fan, “*Investigation of Cs27LiYCl6:Ce scintillator energy response for D-D fusion neutron spectrometer*”, Fusion Engineering and Design **204**, 114490 (2024).

[9] Yunpeng Zou, Vincent S Chan, Yasushi Todo, Ruirui Ma, Miao Xue, Xiaoran Zhang, Yiren Zhu, and Wei Chen, “*Simulation of $\beta$-induced Alfvén eigenmode instabilities and mode transition for HL-3 hybrid scenario*”, Nucl. Fusion **65**, 026034 (2025).

[10] P. Su, H. Lan, C. Zhou, J. Bao, A. Liu, X. Zhu, M. Wu, C. Luo, J. Han, J. Wang, H. Liu, T. Zhang, R. Zhou, S. Lin, H. Zhao, Y. Sun, Z. Qiu, N. Chu, T. Tang, Y. Tan, L. Zeng, and Z. Gao, “*Bursting core-localized ellipticity-induced Alfvén eigenmodes driven by energetic electrons during EAST ohmic discharges*”, Nuclear Fusion **64**, 036019 (2024).

[11] Zhe Chen, Yixiang Li, Haijun Ren, and Hao Wang, “*MHD analysis of electromagnetic GAMs in up-down asymmetric tokamaks*”, Nuclear Fusion **65**, 044001 (2025).

[12] Zhe Chen, Haijun Ren, Hao Wang, and Colin M. Roach, “*On electromagnetic perturbations of geodesic acoustic modes in anisotropic tokamak plasmas*”, Plasma Physics and Controlled Fusion **67**, 045008 (2025).

[13] Tong Liu, Zheng-Xiong Wang, Lai Wei, Jialei Wang, and Allan Reiman, “*Enhancement of ECCD by the current condensation effect for stabilizing large magnetic islands caused by neoclassical tearing modes in tokamak plasmas*”, Nuclear Fusion **64**, 036001 (2024).


(M. Isobe, K. Ogawa, M. Goto and H. Wang)

# Japan-Korea Fusion Collaboration Programs

## I. KSTAR Collaboration in FY 2024

**Workshop on Physics and Technology of Heating and Current Drive**

This workshop was held from 17th to 18th February 2025, at the National Institute for Fusion Science (NIFS) in Toki as a hybrid of face-to face and remote participation. There were 19 oral presentations (JA: 10, KO:9) including three by students (JA:1, KO:2). Three people including one student traveled to NIFS from their affiliated institutions for on-site participation. There were 29 participants (JA:17, KO:15) in total. The topics were electron cyclotron resonance heating/current drive, helicon wave heating/current drive, neutral beam heating/current drive, theoretical study for wave heating/current drive, and diagnostics related to heating.

**KSTAR collaboration on plasma diagnostics**

**1st Asian School on Advanced Plasma Diagnostics for Magnetic Fusion Experiments:** As a successor to the *Korea-Japan Seminar on Advanced Diagnostics for Steady-State Fusion Plasmas*, which had been held biennially in Japan and Korea, the *1st Asian School on Advanced Plasma Diagnostics for Magnetic Fusion Experiments* (APDS) was held from 19th to 21st February 2025 at NIFS. The school consisted of 20 lectures by scientists from Japan (7), Korea (7) and the China (6), two poster sessions for students and a tour of NIFS including LHD. Young researchers in attendance totaled 38 including from Japan (12), the Republic of Korea (9), China (10), Taiwan (5) and Thailand (2).

Fig. 1 Image of 1st APDS

**Thomson scattering diagnostics:** Two participants from Japan attended the *3rd International Fusion Plasma Conference (iFPC 2024)* held in Seoul, Korea, in June 2024, and delivered single oral and poster presentations. In addition, discussions on Thomson scattering diagnostics were held with three participants from the Korea Institute of Fusion Energy (KFE), who also attended the conference. Information exchange and discussion regarding polychromators were conducted.

**RF Spectrometer:** In May 2024, an LHD experiment was conducted as a joint project with Korea. By changing the helium neutral beam penetration region, energy, and particle number, systematic data were obtained to investigate whether variations appeared in the frequency range and intensity of non-thermal emissions in the ion cyclotron higher harmonic range, as well as in the burst-like enhancement of emission intensity.

**SXCCD Camera:** One person visited KFE to discuss with the person in charge of SXCCD measurements, aiming to explore the possibility of a new research collaboration on the measurement of tungsten multicharged ions using the existing visible spectroscopy system.

**Japan-Korea KSTAR Diagnostics Collaboration Meeting:** This meeting was held on February 13, 2025, at KFE. Two people from NIFS traveled to Korea to take part on-site and eight engaged remotely from NIFS. Thirteen participated from Korea. The status of each diagnostics collaboration was reported and discussion on Japan-Korea diagnostic collaboration was conducted.

**Collaboration of RF plasma heating in KSTAR**

In December 2024, one person visited KFE and the Ulsan National Institute of Science (UNIST) to carry out research collaboration on propagation mode identification analysis in the KSTAR electron cyclotron heating

(ECH) system. In the same month, another visited KFE to conduct a joint Japan–Korea research experiment on the observation of non-thermal electron emissions during electron cyclotron heating/current drive. In March 2025, one person visited KFE to carry out research collaboration on the Compact ICRF Antenna (CIA), the Helical Loop Antenna (HLA), and the Solid-State Power Amplifier (SSPA). An HLA was subsequently installed in KSTAR and utilized in plasma experiments.

## II. Human Resource Development in FY 2023

**Studies on multi-scale and multi-species transport in fusion plasma**


Fig. 2 Image of 2024 *Japan–Korea Workshop on Fusion Theory*

The *Japan–Korea Workshop on Fusion Theory* was held at Nagoya University from July 29th to 30th, 2024 as a hybrid of face-to face and remote participation. The workshop addressed theoretical issues of magnetically confined fusion plasmas, with a particular focus on transport phenomena involving multiple spatiotemporal scales and multiple particle species, while also covering broader themes including DEMO reactor design. At the opening of the workshop, a review was presented on the latest progress in kinetic magnetohydrodynamic (MHD) simulation studies using the MEGA code. A keynote lecture from the Korean side was delivered on DEMO reactor design activities in Korea.

There were 26 oral presentations (JA: 15, KO:11). There were 29 participants (JA:17, KO:12) in total including online participation (JA:2 KO:1).

**Evaluation of Tritium behavior for reactor design in fusion (VI)**

*The 2024 Japan-Korea Tritium Workshop* was held from 15th to 16th January 2025 at Paradise Hotel in Busan as a hybrid of face-to face and remote participation. There were 27 on-site participants (JA:6, KO:22) and one online participant (JA:1) including students and members from a Korean start-up company. As ITER procurement-related technology development, Korea presented the status of the development of the tritium storage and supply system (SDS), while Japan reported on the status of the development of the detritiation system (DS). In recent years, design activities have also been advanced using 3D printing technology, including the optimization of the SDS glovebox and the design optimization of uranium beds. In addition, reports were presented on fundamental studies of hydrogen behavior in metals containing tritium, simulations of microstructural changes on tungsten surfaces under helium irradiation, and efforts to establish a database on hydrogen behavior.

Fig. 3 As part of the program of 2024 *Japan-Korea Tritium Workshop*, a visit was made to a Korean tritium start-up company

(H. Igami, B. Peterson, T. Seki, T.H. Watanabe and Y. Oya)

# 5. Fusion Science Interdisciplinary Coordination Center

The Fusion Science Interdisciplinary Coordination Center was established in April 2023 to advance interdisciplinary collaboration in fusion science and development research, and to foster the societal implementation of fusion technologies through close cooperation among industry, academia, and government.

As a comprehensive hub that leads and supports collaborative research with universities, research institutes, and industrial partners, the Center connects three newly defined interdisciplinary domains with a network of specialized Units to pursue ambitious, cross-cutting projects that transcend traditional disciplinary boundaries.

In particular, the Center aims to establish a broad research network integrating cutting-edge academic disciplines, promote open science, strengthen collaborations with international research initiatives, and accelerate the transfer of fusion-related technologies to society. To realize these goals, the Center comprises three dedicated divisions:

- Advanced Academic Research Coordination Section
- Development Research Coordination Section
- Industry–Academia–Government Coordination Section

Each section works in synergy with the Units to facilitate a wide range of joint research activities that bridge science, technology, and innovation.

(R. Yasuhara)

## Advanced Academic Research Coordination Section

The Advanced Academic Research Coordination Section supports the promotion of interdisciplinary collaboration between the Units and universities in diverse academic frontier fields. The section facilitates the establishment of a research network with universities and institutes both domestically and internationally. It activates research in fusion science and joint research with those in a wide range of cutting-edge fields by sharing experimental data and promoting open science. In FY2024, the section supported three budding collaborative research proposals for travel expenses and five interdisciplinary mini-projects for their initial and development phases.

(I. Murakami)

***Aurora observation project***

As one of the interdisciplinary collaborative projects, researchers from the Phase Space Turbulence Unit and the Meta-Hierarchical Dynamics Unit of the National Institute for Fusion Science, the Research Institute for Sustainable Humanosphere of Kyoto University, and Tohoku University have cooperated in launching an aurora observation project. In this project, a hyperspectral camera that can acquire data in two spatial dimensions plus wavelength and a liquid crystal filter camera that can observe images of any emission lines were installed at the KEOPS (Kiruna Esrange Optical Platform Site) of the SSC (Swedish Space Corporation) in Kiruna, Sweden (67°51′ north latitude).

The hyperspectral camera for auroral imaging (HySCAI), which can provide a two dimensional (2D) aurora image with full spectrum, was developed to study auroral physics. HySCAI consists of an all-sky lens, monitor camera, galvanometer scanner, grating spectrograph, and electron-multiplying charge-coupled device (EM-CCD). The galvanometer scanner can scan a slit image of the spectrograph on the all-sky image plane in the direction perpendicular to the slit. This system has been installed at the KEOPS (Kiruna Esrange Optical Platform Site) of the SSC (Swedish Space Corporation) in Kiruna, Sweden [1,2,3]. HySCAI can provide a monochromatic image at a given wavelength and spectrum at any point in the image with a spectral resolution (FWHM) of 2.1

nm, as seen in Fig. 1. We estimate the precipitating electron energy from a ratio of I(630.0 nm)/I(427.8 nm) to be 1.6 keV at the auroral breakup [4].

Quantitative measurements of aurora emissions during astronomical twilight are difficult using the all-sky camera equipped with a bandpass filter, because of the contamination of background emissions due to sunlight. In contrast, the HySCAI gives the precise aurora emission intensity by subtracting the background of the spectrum. The spectrum of high-altitude blue auroral emissions has been observed with HySCAI during morning astronomical twilight [5,6].

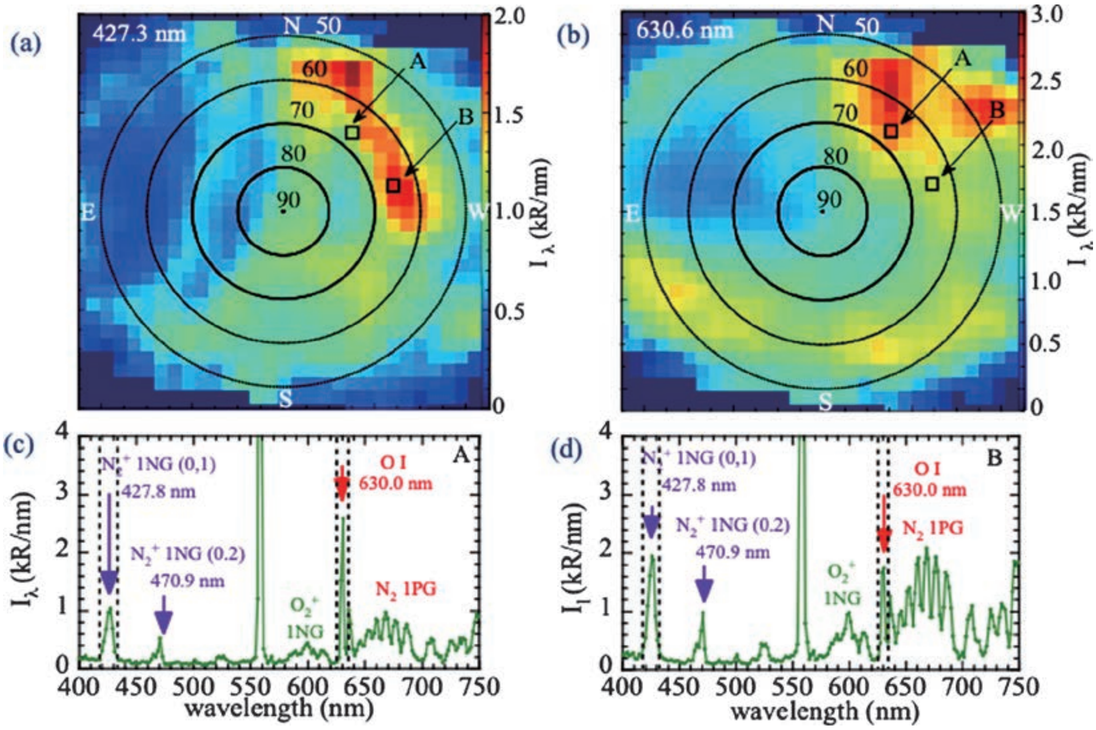



Fig. 1 Monochromatic images at (a) 427 and (b) 630 nm image and spectrum at position A and B. Reproduced from [4]. ©The author(s). Published by Springer Nature. CC By 4.0.


[1] https://projects.nifs.ac.jp/aurora/en/

[2] https://www.eurekalert.org/news-releases/1052684

[3] https://sj.jst.go.jp/news/202410/n1007-01k.html

[4] M.Yoshinuma, K.Ida, Y.Ebihara, Earth, Planets and Space **76**, 96 (2024).

[5] K. Ida, M. Yoshinuma, Y. Ebihara, “Development of hyperspectral camera for auroral imaging (HySCAI) [plenary talk]”, 6th European Conference on Plasma Diagnostics, Prague, Czech Republic. 07–10 April, 2025.

[6] K. Ida, M. Yoshinuma, Y. Ebihara, K. Shiokawa, Milan Šimek, Jiří Fujer, “Development of Hyper Spectral Camera for Aurora Imaging (HySCAI) and initial aurora observation result in Kiruna, Sweden, [plenary talk]” 4th International Fusion and Plasma Conference, Daejeon, Convention Center, Daejeon, South Korea. 09–13, June 2025.


(K. Ida, M. Yoshinuma and Y. Ebihara)

## Development Research Coordination Section

Collaborating with the National Institute for Quantum Science and Technology (QST), EUROfusion and the ITER Organization, four development research ventures were undertaken as a single year project. Nevertheless, they are to be continued.

**(1) Neutron and Gamma-ray detector development for LiPAC**

Experimental investigation and development of radiation detector systems are underway for an intensive fusion neutron source. NIFS and QST jointly conducted measurements of fast neutrons and gamma rays at the Linear International Fusion Materials Irradiation Facility Prototype Accelerator (LIPAc), located at the QST Rokkasho Fusion Institute. These measurements were carried out to support the development of a radiation monitoring system for the Advanced Fusion Neutronics Source (A-FNS). Neutron and gamma-ray spectra, as well as neutron flux from the beam target, were measured using detectors developed through domestic/international collaborations between NIFS and universities. Graduate students from SOKENDAI and NIFS technical staff participated in the measurements, contributing to both the research and the development of human resources.

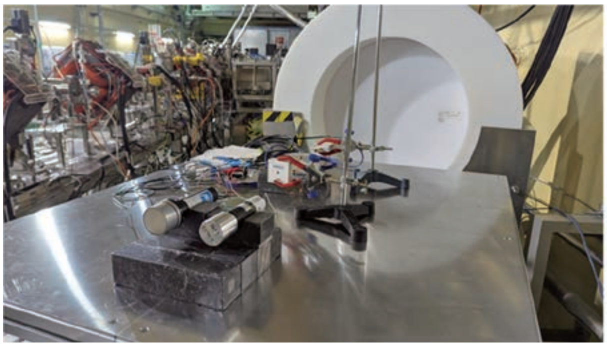


Fig. 1 (left) Radiation detector setups in LIPAc, (right) NIFS technical staff and SOKENDAI student in the LIPAc control room.

[1] Kunihiro OGAWA *et al.*, "Progress in the Development of Radiation Detectors for Fusion Neutronics Source A-FNS", Fusion Engineering and Design **218**, 115214 (2025).

**(2) Upgrading NIFS-RNIS for DEMO NBI R&D**

A giant radio frequency (RF) negative ion source for a neutral beam injector needs low beamlet divergence, such as a filament-driven arc (FA) source, for application to DEMO because of its long beam transport length. In the RF operation mode of the NIFS-RNIS (Research and development Negative Ion Source) at NIFS with an RF/FA hybrid source, the beamlet divergence in the horizontal direction was found not to be significantly different from that in the FA operation mode.

**(3) Development research of bonding technique for JT-60SA divertor**

For JT-60SA, we have developed a divertor component that is compatible with a high-power-injection experiment, collaborating with QST and EUROfusion. To accomplish the requirement from the JT-60SA project team, establishing a bonding technique between armor and heat sink is essential. By using the SPS (Spark Plasm Sintering) method, we have obtained quite favorable results in bonding tungsten to copper alloy, that is, tolerable to a heat flux more than 15MW/m$^2$ for 10s.

Fig. 2 Divertor test module with the same cross-section as the actual divertor module in JT-60SA.

As the next step, we manufactured a larger test module with the same cross-section as the actual divertor module in JT-60SA, as shown in Fig. 2. We are planning to perform the heat load test with a facility of EUROfusion in France.

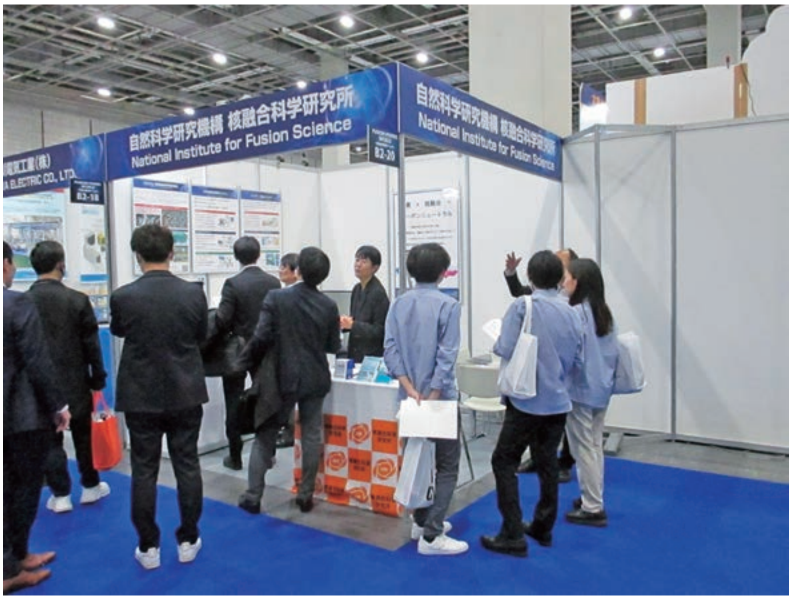
**(4) Statistical-mathematics fusion research based on data-driven approach**

It is important to incorporate data science and statistical mathematics methods as research tools to effectively utilize the large amounts of data generated by fusion-related experiments and simulations, and to link this to the development of control methods and/or an integrated control simulator for future fusion reactors. The "QST Research Collaboration for Fusion DEMO" entitled "development of learning and estimation tools using data science and statistical mathematical methods and their utilization for control-based simulators", among researchers of QST Rokkasho Fusion Institute, universities and NIFS, has continuously aimed to develop and improve modeling methods towards such goals. Specifically, we have worked on anomaly detection based on plasma images, and dimension reduction of numerical simulation data, such as turbulence and heat transport issues, for realizing real-time (or faster time scale) control compared to the physics integration approach.

(T. Morisaki, K. Ogawa, H. Nakano and M. Yokoyama)

## Industry Academia Government Coordination Section

The Industry Academia Government Cooperation Section is in charge of supporting the social implementation of fusion technology through industry academia government cooperation. Specifically, this section works on: ①Activities related to joint research with private companies, commissioned research, use of platforms, creation of opportunities for collaboration. ②Accumulation of know-how, collection of information, acquisition of external funding for industry academia government cooperation. ③Establishment of a system for industry-academia-government cooperation activities. ④AManagement and coordination of strategy for the Mission Realization Project.




(R. Yasuhara)

# 6. Health and Safety Promotion Center

The Health and Safety Promotion Center aims to prevent work-related accidents, to ensure safe and sound operation of machinery and equipment, and to maintain a safe and healthful environment for researchers, technical staff, co-researchers, and students. It also ensures that research activities conducted by NIFS do not affect the surrounding environment. This center consists of ten offices, and various subjects related to health and safety are discussed by office chiefs once a month.

1. Health Management Office

The main role of this office is to keep the workers in the institute healthy, including co-researchers and students. Its responsibilities are:

A) Medical checkups both for general and special purposes and immunization for influenza.
B) Mental health care services and health consultation.
C) Accompaning the inspections of the health administrator and the occupational physician.
D) Maintenance of AEDs.
E) Alerts and response to infectious disease.

Various lectures were held on physical and mental health. An online stress-check was held in October 2024.

2. Fire/Disaster Prevention and Security Management Office

The main role of this office is to prevent or minimize damage caused by various disasters.

A) Making self-defense plans for fires and disasters, and implementation of various training.
B) Promotion of first-aid workshops and an AED class.
C) Maintenance of fire-defense facilities and attending on-site inspections by the local fire department.
D) Reviewing and updating disaster prevention rules and disaster prevention manuals.
E) Maintenance of the card-key system for the entrances of buildings and controlled areas.

All workers must attend disaster prevention training held every year, and a disaster simulation exercise was also held on July 8th, 2024. Figure 1 shows the disaster prevention training in 2025.

3. Radiation Control Office

The main role of this office is to maintain radiation safety for researchers and the environment. Legal procedures for radiation safety and regular education for radiation area workers are also important roles of this office.

A) Maintaining radiation safety for the workers.
B) Registration and dose control of radiation area workers.
C) Observation of radiation in radiation-controlled and peripheral areas.
D) Maintenance of the radiation monitor.
E) Applications for radiation equipment to national agencies and the local governments.
F) Revising official regulations and establishing new rules.

Fig. 1 Disaster prevention training

An educational lecture for radiation area workers was held on March 5, 2025. We provided an opportunity for DVD viewing for absentees. Non-Japanese workers were educated and trained in English.

4. Electrical Equipment and Work Control Office

The main role of this office is to maintain electrical safety for researchers, technical staff members and students.

A) Checking and controlling electrical facilities according to technical standards.
B) Safety lecture for researchers and workers.
C) Annual check of electric equipment during blackouts.

The annual inspection for electrical power receiving facilities was carried out on October 19–20, 2024.

5. Crane Management Office

The main role of this office is to maintain the safe operation of cranes. The tasks of this office are as follows.

A) Inspection and maintenance of cranes.
B) Management of crane license holders and safety lectures for crane users.
C) Schedule management of crane operations.
D) Safety related to working at height.

6. High Pressure Gas Control Office

The main role of this office is for safety operation and maintenance of high pressure facilities with cooling systems such as LHD.

A) Safety operation and maintenance of high-pressure gas handling facilities in NIFS.
B) Daily operation, maintenance, system improvement, and safety education according to the law.
C) Safety lectures for researchers and workers.

7. Hazardous Materials Control Office

The main role of this office is safe management of hazardous materials and maintaining safety for researchers against hazardous events.

A) Research requests for hazardous materials and their storage status.
B) Management to ensure safe storage of waste.
C) Implementation of chemical substance risk assessment.

8. New Experimental Safety Assessment Office

The main role of this office is to check the safety of experimental devices except for LHD. For this purpose, researchers who want to set up new experimental apparatus must apply for a safety review. Two reviewers are assigned from members of this office and other specialists to check the safety of these devices.

A) Examine new experiments for safety problems and advise on safety measures.
B) Improve safety in each experiment and reinforce the safety culture at NIFS with annual reviews by NIFS employees.

9. Safety Management Office

The main task of this office is publication of the Safety Handbook in Japanese and English, and its update every year. The organization of regular safety lectures is also a task of this office. Lectures were held on May 24, 2024. All workers including co-researchers and students must attend this safety lecture every year.

10. Environmental Conservation Office

On March 28, 2013, NIFS together with the Gifu prefectural government and three local cities (Toki, Tajimi, and Mizunami), concluded an “Agreement on Environmental Conservation around the National Institute for Fusion Science” and a “Memorandum of Understanding on Environmental Conservation around Fusion Science”. The main tasks of this office are to maintain and to check environmental conservation around NIFS, according to this agreement.

(M. Osakabe)

# 7. Information Systems and Cyber Security Center (ISCSC)

## Information network, systems and security

NIFS research activities generate vast amounts of experimental and computational data. An information system linked to an information network analyzes these data, and the results are published externally.

The Information Systems Security Center is an organization that coordinates information systems and information networks. The center is divided into three groups: Information Networks, Information Systems, and Cyber Security (Information Security) and each operate under the direction of a group leader. There is some overlap in the areas of responsibility, so some members belong to multiple groups.

The Information Network Group is committed to providing a stable information network environment. Information networks are the foundation of research activities, but simply connecting devices is insufficient to create a reliable infrastructure. Therefore, it is imperative to thoroughly verify the functionality of network devices and to consider security.

We have performed necessary maintenance on equipment to ensure a stable operation of the information network. In the 2024 fiscal year, we installed wireless access points (APs) in some buildings of NIFS. This enabled Wi-Fi access in the usual usage areas within the target buildings. As before, we use eduroam for authentication, and institutions that are members of eduroam can use it without prior setup. This wireless AP installation is planned to be implemented over multiple years, and we will continue to proceed with it in the 2025 fiscal year and beyond.

An information network requires multiple servers to operate. Our group has been building a private cloud using VMware vSphere from VMware, but with Broadcom's acquisition of VMware, the licensing system has changed significantly. This has led to a significant increase in licensing costs. The servers and storage components of the private cloud are nearing the end of their maintenance period. We have therefore decided to transition away from VMware vSphere in conjunction with hardware updates and are currently conducting research for procurement in the 2025 fiscal year.

A firewall and an access gateway that performed security checks on terminals connected to the firewall in advance had been installed between the LHD experimental network (LHD-LAN) and the research infrastructure network (NIFS-LAN). We discontinued the operation of the access gateway and updated it to a firewall compatible with Active Directory authentication. This change shifted the authentication method from device-based to user-based authentication. We also expanded the connection bandwidth and installed optical fiber between buildings.

The Information Systems Group develops, operates, and maintains various information systems that form the foundation of the institute, as well as those related to public relations, evaluation, and research support. At the stage of developing information systems, we conduct appropriate system development, such as clarifying requirements through interviews with relevant parties, to facilitate and improve the efficiency of research activities. On the other hand, in order to improve the operational efficiency of the entire institute, it is not necessarily appropriate to have a system in which only the Information System Group conducts system development, and we believe that it is necessary for the field staff, who are familiar with the business, to create their own tools. For supporting this concept in the near future, we are working to build up knowledge and technology.

In FY2024, the NIFS Research Activity Database (NRAD), a database of the Institute's research activities, was established. NRAD also references multiple external databases, allowing for the inclusion of achievements that were previously missing from the NIFS Article Information System (NAIS), as well as improving the accuracy of the data for each achievement itself. We have shut down a research-related-event support system "Workshop", which we had developed and operated independently. Instead, we have introduced the open-source software "Indico", which is also used by many other institutions. The "Workshop" system required users to create a user account for each workshop, but by linking with a Google account, users can now participate in multiple workshops by creating an account only once. This has improved convenience for users.

The Cyber Security Group works with the Information Network Group and Information Systems Group to build a robust security system that includes user education. The group's members serve as the Computer Security Incident Response Team (NIFS-CSIRT). They respond to security incidents by investigating their causes and minimizing damage. The group works directly with the institution's Chief of Information Security Officer (CISO) and information security managers to respond to incidents. NIFS-CSIRT is a member of the National Institute of Natural Sciences CSIRT (NINS-CSIRT) and regularly shares information with them.

In fiscal 2024, we introduced SPC Leak Detection, an account leakage management service provided by SourcePod. Leaked account information is traded on the dark web, which cannot be accessed with a normal web browser. The newly introduced service investigates whether information using the institute's email address, such as the account name, has been leaked onto the internet or dark web. If a leak is detected, the service notifies the individual via email and records the incident on the management site.

As in previous years, we also conducted information security training via video on demand. Fortunately, there were no serious incidents in fiscal 2024. We also collaborated with NINS to conduct information incident response training, targeted email training, and internal audits related to information security.

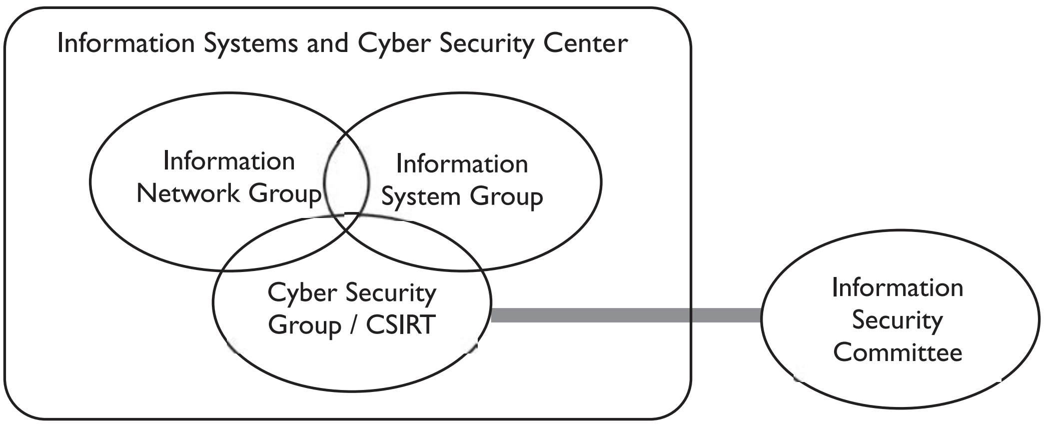



Fig. 1 Structure of Information Systems and Cyber Security Center.

(T. Yamamoto)

# 8. Activities of Rokkasho Research Center (RRC)

The Rokkasho Research Center (RRC, established in May 2007) promotes cooperation and joint research with the Broader Approach (BA) activities that are being undertaken in parallel with the ITER project and builds the technical foundation for the development of a prototype fusion reactor, by supporting the participation of collaborators of NIFS and universities based on academic standpoints. Furthermore, to promote the interdisciplinary expansion of issues being tackled in fusion research, we are focusing on disseminating research issues to a range of academic fields, inviting interdisciplinary meetings, and promoting interdisciplinary joint efforts. As an example, the fourth mid-term strategic project of the Research Organization of Information and Systems (ROIS), “Statistical-mathematical modeling for plasma data, complementary to plasma physics,” has been established and we are deepening/widening collaborations with communities such as statistical-mathematics and data science. In addition, we are actively working on to contribute to human resource development through establishing and deepening cooperation with neighboring educational institutions.

RRC’s Homepage: https://www.nifs.ac.jp/en/about/rrc.html

## Highlighted Activities in FY2024

The RRC has been a hub for promoting the research project; Research Organization of Information and Systems (ROIS), The 4th Mid-Term Strategic Projects, “Statistical-Mathematical Modelling on Plasma Data: Complementary to Plasma Physics”. The project ended (after the approved fixed-term), by holding a concluding workshop at NIFS (Toki) on February 13-14, 2025. This interdisciplinary collaboration body, then, was selected as the Open Mix Laboratory (OML) project “Creation and Development of Statistical Mathematical Fusion Studies” of the National Institutes of Natural Sciences (NINS). Based on the results of the ROIS project, we will further expand the scope of our collaborative activities between fusion and statistical-mathematics, utilizing diverse and numerous data on fusion research and innovative methodologies in the statistical- mathematics study.

The “School to Experience Japan’s DEMO Fusion Reactor – Manufacturing, Integrated Innovation –”, which was selected for the 2024 National Institute for Fusion Science Schooling and Networking Initiative, was held for two days on March 3-4, 2025, at the Aomori City Cultural Tourism Exchange Facility, Nebuta Museum “Wa Rasse”. This school was organized by forming an executive committee, participating with the Rokkasho Fusion Energy Institute of the National Institutes for Quantum Science and Technology (hereafter, QST Rokkasho Institute) and the University of Tokyo, chaired by the Director of the NIFS RRC. More than one hundred people participated, mainly from a range of domestic industries. In addition to the keynote speech on the progress of fusion research and expectations for the industry, and a lecture on Japan’s DEMO fusion reactor design research, the event included a lecture on the basics of DEMO reactor components and elements, and a tour of the QST Rokkasho Institute, which is the research and development center for the DEMO reactor. The event embodied the intention of stimulating participants’ desire to get involved in fusion research and allowing them to gain an overall understanding and recognition of the positioning of each company and individuals areas of expertise and interest in the overall design, as well as the relationships with others’ efforts (which should be the foundation of “integrated innovation”).


Fig. 1 Group photo after the opening ceremony and keynote speech of the "School to Experience Japan's DEMO Fusion Reactor – Manufacturing, Integrated Innovation –"

We also continue collaboration with nearby educational institutions. In May 2024, a RRC member gave a lecture entitled "Challenges to the unexplored, towards the realization of fusion energy" at the class of Engineering Design (ED) I for advanced-course first-year students at the National Institute of Technology (KOSEN), Hachinohe College. The contents are designed so that students can feel that their nearby area (Rokkasho village) has been and will further evolve as the world-leading base for fusion research. A lecture is also planned for 2025.

In addition, we are working to promote regional collaboration by participating in events and holding seminars related to the "Aomori Prefectural College" initiative, which we joined as a partner institution in 2023.

Fig. 2 At the beginning of the lecture at the National Institute of Technology (KOSEN), Hachinohe College, the fusion technology map (material from the Cabinet Office's Fusion Strategy Experts Meeting) was shown and then it was emphasized that a range of technology elements (for which students can lead and contribute in the near future) are necessary to realize fusion energy.

(M. Yokoyama)

# 9. Research Enhancement Strategy Office

The Research Enhancement Strategy Office (RESO) was established on November 1, 2013, to strengthen the research activities of the Institute by planning various support programs for the researchers and conducting public relations programs for making fusion science more understandable in society. Two University Research Administrators (URAs) are working in the following five Task Groups:

(1) IR (Institutional Research)/Evaluation Task Group
(2) Collaboration Research Enhancement Task Group
(3) Human Resource Development Strengthening Task Group
(4) Public Relations Enhancement Task Group
(5) Financial Basis Strengthening Task Group

**(1) IR/Evaluation**

The task group for the IR and evaluation continued its role to make systematic analyses of the present research activities of NIFS. The statistical data from publications and scientific reports were collected using the NIFS article information system (NAIS), with complementary data obtained through SCOPUS and WoS, companies that supply public research resources. Unique indicators that can demonstrate the strength of the research capabilities of NIFS were investigated.

By collaboration with the Self-inspection Committee, the task group compiled the draft annual FY2023 self-examination report for the fourth mid-term goals and assisted in compiling the materials to be submitted to the External Evaluation Committee for evaluation of "External Funding" and the "Fusion Science Interdisciplinary Research Center, Advanced Academic Research Coordination Section (AARCS)".

**(2) Supporting Enhancing Collaboration Research**

1) Promotion of Domestic and International Collaborative Research

Actively facilitated and supported both domestic and international collaborative research initiatives.

2) Interdisciplinary and Collaborative Research Support

Implemented support measures for interdisciplinary and collaborative research across different fields.

3) Support for Collaborative Research Activities

Supported collaborative research activities domestically and internationally through the National Institutes of Natural Sciences (NINS) joint usage/research teams and international collaboration teams.

**(3) Supporting Young Researchers**

As the activities for developing young researchers, RESO and Human Resource Development committee in NIFS supports their startup studies for them to enhance the basic research skills by setting Start-up Support Program for Young Researchers. A tutor is assigned for each selected young researcher in this program, who is expected to give suggestions and advices to the researcher in appropriate timing. The selected program in FY2024 is as follows:

1. *Understanding self-scattering of ultraintense laser-produced plasmas for non-equilibrium plasma diagnostics* (Kentaro Sakai), (Fig. 1): The imaging measurement of a scattered intense laser beam reveals that the electron becomes less dense around the focal spot because of the competition between target preheating and electron evacuation by the pre-pulse and main pulse.

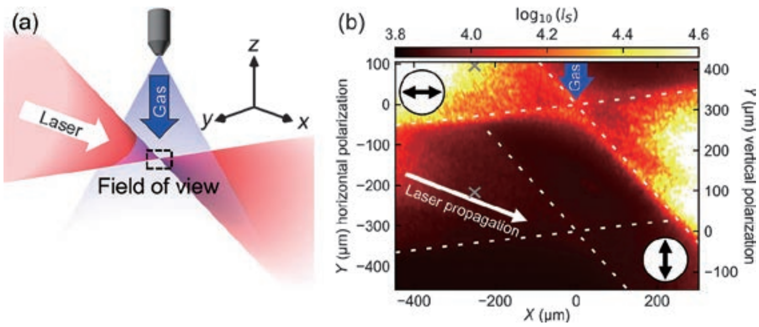



Fig. 1 Polarization-separated imaging measurement showing that the signal is polarized and consistent with the scattered intense laser beam, provided by K. Sakai. (Fig. 2 of "K. Sakai *et al.,* Contrib. Plasma Phys. e70020, 2025").

A debriefing meeting was held in March 2024 for the three people who received support in FY2023.

RESO also assisted the applications of young scientists to the International Research Exchange Support Program of the National Institutes of Natural Sciences.

**(4) Enhancing Public Relations**

The policy for public relations activities was discussed at a RESO meeting. Regarding publicity events, depending on geographical spread, (1) participation in local festivals, (2) participation in events organized by Toki City, (3) holding science events in large shopping malls, and (4) the Open Campus were organized. In addition, an exhibition of the institute's research was held at the new building of the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

The Altmetric score has definitely increased since the international news sites picked it up when we posted it on EurekAlert! From now on, we will actively utilize EurekAlert!

We were given the opportunity to contribute to online media. Although broadcast media is often considered the most effective advertising medium, online media can also be effective enough if targeted.

**(5) Strengthening Financial Basis**

1) Support for Securing Competitive Research Funds

Organized briefing sessions to obtain competitive research funds such as Grants-in-Aid for Scientific Research (KAKENHI), JST, and NEDO, and provided support for the preparation of application forms.

2) Support for the Operation of the Financial Base Strengthening Task Force

Provided operational support for the Financial Base Strengthening Task Force and supported activities of the Industry-Academia-Government Collaboration Headquarters.

3) Support for Industry-Academia-Government Collaboration Activities

One such initiative was our support for the NIFS exhibition at Fusion Power World, held at INTEX Osaka. The event drew strong interest from industry, with two to three groups of visitors consistently engaging with the NIFS booth and asking questions. Many visitors expressed a desire to tour the institute following their experience at the exhibition.

(Y. Todo, T. Muroga, T. Mito, K. Ichiguchi and K. Takahata)

# 10. Platform Management Office

As an inter-university research institute, the National Institute for Fusion Science (NIFS) provides research equipment, including extensive facilities such as the Large Helical Device (LHD) and the Plasma Simulator, for shared use and conducts collaborative research with domestic and international universities and research institutes. The Platform Management Office, which comprises three sections: the Large Helical Device (LHD), Computer, and Engineering Facilities, was established in FY2023 to manage and operate the research facilities at NIFS.

In 2024, with the support of a supplementary budget for promoting research and development toward the realization of fusion energy, we were able to launch projects for high-temperature plasma experiments and a fusion energy nano platform. Regarding the high-temperature plasma experiments, we have begun work on refurbishment of the Compact Helical System (CHS), which was shut down in 2006. We aim to initiate plasma experiments in FY2026 with the Compact Helical Device(CHD), a new high-temperature plasma experimental device. This device will undergo refurbishment and be equipped with advanced diagnostics instruments, enabling a wide range of collaborative research that will serve as a foundation for high-temperature plasma research as a follow-on to the LHD. The core research theme is the “Micro-Collective Phenomena of Ultra-High Temperature Plasma and Fusion Science,” as listed in the MEXT Roadmap 2023. We will further develop the advanced plasma measurement techniques cultivated in the LHD project to establish a system for high-performance plasma experiments. Regarding the fusion energy nano platform, we will enhance our capabilities as a collaborative research core for plasma-wall interactions in fusion science by building a group of nanoscale material analysis devices, including high-performance transmission electron microscopes and a focused ion-beam processing facility, and will expand this knowledge into other fields.

## LHD Section

In the 2024 fiscal year, the second year of the three-year Academic Research Platform project, the 25th cycle experiment campaign continued until 20 June 2024. Based on 165 experimental proposals submitted by both domestic and international collaborators from 33 institutions, we have conducted interdisciplinary research on the main theme of the Academic Research Platform LHD project and promote the publication of its data. Some of the research results are documented in Units’ research reports, so please refer to them.

In addition, as a means for the removal of tritium generated during the deuterium experiment campaigns, we have carried out a complete replacement of 3,000 carbon tiles installed inside the vacuum vessel during the maintenance period after the 25th cycle experiment campaign. The replacement ensures that the LHD, which will shut down plasma experiments at the end of the fiscal year 2025, can be safely shut down and stored for the long term.

(R. Sakamoto)

## Computer Section

The Computer Section is composed of the Plasma Simulator, Database, and Data Analysis Equipment Task Groups (TGs).

The Plasma Simulator “Raijin” is a massively parallel supercomputer system utilized to promote academic simulation research on nuclear fusion science and to support research and development that can contribute to progress in simulation science. The Plasma Simulator “Raijin” consists of 540 computers, each of which is equipped with one scalar processor for controlling the system and eight “Vector Engine” accelerators for high-speed computing. The 540 computers are connected to each other by a high-speed interconnected network. The computational performance of the system with Vector Engines is 10.5 petaflops. The capacities of the main memory and the external storage system are 202 terabytes and 32.1 petabytes, respectively. The supercomputer system is capable of large-scale simulation of fusion and other complex plasma phenomena. The Plasma Simulator was operated for 353 days and supplied 37 million VE hours of computational time to 83 subjects and 258 users in FY2024. The Plasma Simulator TG provides comprehensive support for the Plasma Simulator, including operation scheduling, maintenance, user simulation code development, code execution, and additional services.

The Database TG provides the NIFS Atomic and Molecular Numerical Database at http://dbshino.nifs.ac.jp/ for researchers worldwide, which contains numerical data, such as cross-sections, for collision processes between electrons, atoms, and molecules in plasmas. The number of stored data, which totals 1,767,381 as of 1 April 2025, increased from 1,765,059 (4 April 2024) and is the largest among databases of collision cross-sections provided worldwide. Many researchers access the data in our database for their work. We are also making databases, e.g., the Atomic Data and Analysis Structure (ADAS), available for domestic collaborators, which are provided under international collaboration.

The Data Analysis Equipment TG operates the experiment data acquisition and analysis system, the SNET fusion research collaboration network, and the CompleXcope immersive virtual reality system. The experiment data system accumulates over 3 petabytes of diagnostic and analyzed data from NIFS LHD, CHS, and other universities' devices via SNET. The entire 2 petabytes of compressed LHD data are openly accessible to anyone, together with hundreds of analysis programs, device operation parameters, and related documents such as experiment proposals and summary reports, to constitute the "Plasma and Fusion Cloud." It is expected to be used for fusion energy developments and for multi-disciplinary data-driven sciences to promote the "Open Science" of nuclear fusion research. These data have been registered with Digital Object Identifiers (DOIs) to make them FAIR (Findable, Accessible, Interoperable, Reusable), and as of December 2024, we have achieved the world's first registration of ten million DOIs for research data. CompleXcope and a head-mount display (HMD) enable us to enter 3-D data space and observe plasma from various directions to study its complex structures. Omnidirectional images and 3D models of the LHD building have been created for display on HMDs and implemented in VRiderCOMMS to enable multi-user access within a shared VR space. We have also created 3D scan images of the CHS device and begun researching a way to utilize point cloud data in an HMD. Work is ongoing to port the CompleXcope software to HMDs, with the aim of establishing it as a future research platform.

(Y. Todo, H. Miura, I. Murakami and H. Nakanishi)

# Engineering Facilities Section

The Engineering Facilities Section has managed experimental facilities in the Plasma Diagnostics Laboratories, the Superconducting Magnet System Laboratory, the Fusion Engineering Research Laboratory, the R&D Laboratories, and the radiation-controlled area in the LHD building. A task group was assigned to each laboratory building to coordinate the experiment days and laboratory usage. From FY2023, users have been responsible for the electricity charges used in experiments, and a usage fee has been set for the main experimental facilities. Users must report time or power usage to the office of the Engineering Facilities Section every month. To maintain the common areas and safety equipment of the buildings, each laboratory building is allocated an annual budget equivalent to 15 to 20 kW of electricity.

In 2024, the framework for the paid use of the platform has been modified to allow broader utilization by private companies, not only for profit-making activities but also for academic research and other purposes.

(S. Imagawa)

# 11. Research and Education Innovation Office

The Research and Education Innovation Office comprises six committees, as shown in Figure 1. The three crucial activities of this office for the 2024 fiscal year are reported below.


Fig. 1 Composition of the Research and Education Improvement Office and the committees positioned within it.

**<Fusion Science Seminar and NIFS Colloquium> (Academic Planning Committee)**

The Fusion Science Seminar (FSS) is a scientific seminar with distinguished lecturers from a wide scientific research field. The NIFS Colloquium is an opportunity to learn about topics in which the communities are interested. Three FSSs and four NIFS Colloquiums were held in a hybrid format, and many scientists, students and staff (almost 100 participants on average) participated and discussed their themes deeply and widely. (Figs. 2 and 3). The information of these seminars and colloquiums can be seen in NIFS webpage (https://www.nifs.ac.jp/about/reio/all/index.html).

FSS-4 "Current Status and Future Prospects of Quantum Information Processing", Nobuyasu Ito (Team Leader, Discrete Event Simulation Research Team, RIKEN Center for Computational Science)

FSS-5 "Quantum High-Temperature Superconductivity: Realizing the Dream", Setsuko Tajima (Professor Emeritus, Osaka University)

FSS-6 "The Science of Traffic Jams: Types and Solutions", Katsuhiko Nishinari (Professor, University of Tokyo)

NIFS-Coll-5 "Collective Fusion", Toshiki Tajima (TAE Technologies, Inc., Distinguished Rostoker Professor at University of California, Irvine)

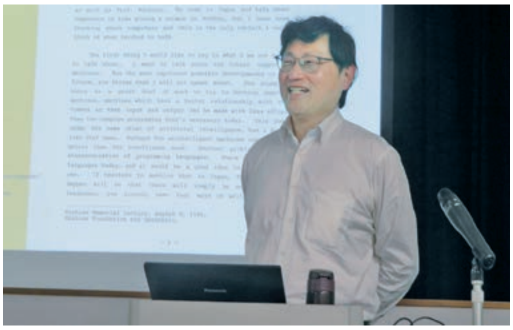


Fig. 2 Picture at FSS-4.

Fig. 3 Picture at FSS-6.

**<13th ITER International School>**

NIFS held the 13th ITER International School (IIS2024) in Nagoya, Japan, from December 9 to December 13, 2024. The topic 'Magnetic Fusion Diagnostics and Data Science' was picked as the theme of this school. A total of 199 participants gathered from 21 different countries (Fig. 4). Sixteen splendid lectures widely covered the fields of diagnostics and data science, including cutting-edge contents. Most of the participants showed their own works in the poster sessions, of which the best posters were awarded the '13th ITER International School Outstanding Student Poster Award'. Networking among the participants was encouraged in the special sessions and the banquet. The participants also enjoyed a NIFS tour and were excited to see the facilities, such as LHD. Thus, NIFS strongly contributed to worldwide human resources development through holding IIS2024.


Fig. 4 Group photo of IIS2024.

**<1st Asian School on Advanced Plasma Diagnostics for Magnetic Fusion Experiments (APDS) 1st NIFS College>**

In fiscal year 2024, the Academic Program Committee initiated a new support scheme for hosting international research meetings. This program continuously accepts applications under three categories: the *NIFS Conference, NIFS Workshop*, and *NIFS College*.

The **NIFS Conference** category supports large-scale international meetings aimed at disseminating research outcomes and facilitating broad scientific exchange. These conferences typically focus on specific research themes and encourage distinctive and impactful academic discussions.

The **NIFS Workshop** category is designed for more specialized topics, promoting in-depth discussions among a limited number of participants in an international setting.

The **NIFS College** category targets graduate students and early-career researchers, supporting the organization of international schools that provide educational and research training opportunities.

Under this new program, the **1st Asian School on Advanced Plasma Diagnostics for Magnetic Fusion Experiments (APDS)**, designated as the **1st NIFS College**, was successfully hosted on February 19–21, 2025, by Prof. Byron Peterson at the National Institute for Fusion Science. The school lasted three days and consisted of 20 lectures on plasma diagnostic techniques by scientists from Japan (7), Korea (7) and China (6), 37 posters in two poster sessions for young researchers and a tour of NIFS including LHD. Young researchers in attendance totaled 38, including from Japan (12), the Republic of Korea (9), China (10), Taiwan (5) and Thailand (2). We hope to hold the 2nd APDS in China in 2026. An image of the attendees is shown in Figure 5. In addition to educating the young researchers regarding plasma diagnostics, this school provided an invaluable opportunity for researchers and students to meet each other and form friendships as a basis for future scientific collaborations.

Fig. 5 Picture at 1st APDS.

(K. Nagaoka, K. Ichiguchi and B. Peterson)

# 12. Public Relations Office

The Public Relations Office, as the core organization responsible for public relations and outreach activities, promotes the disclosure and sharing of research achievements with society, including the local community, through a variety of activities. Since the restructuring of this organization in FY2023, there are now four committees: the Scientific and Public Relations Committee, the Social Engagement Committee, the Archives Committee, and the Educational Collaboration Committee. A summary of the committees is depicted in the illustration below (Fig. 1).

Many NIFS staff are active as members of the office. Principal activities include issuing press releases (Fig. 2), publishing public relations magazines, holding scientific events (Fig. 3), providing tours of NIFS facilities (Fig. 4), scientific classroom activities (Fig. 5), organizing and storing historical materials related to fusion science research in Japan, and educational collaboration activities with high schools.

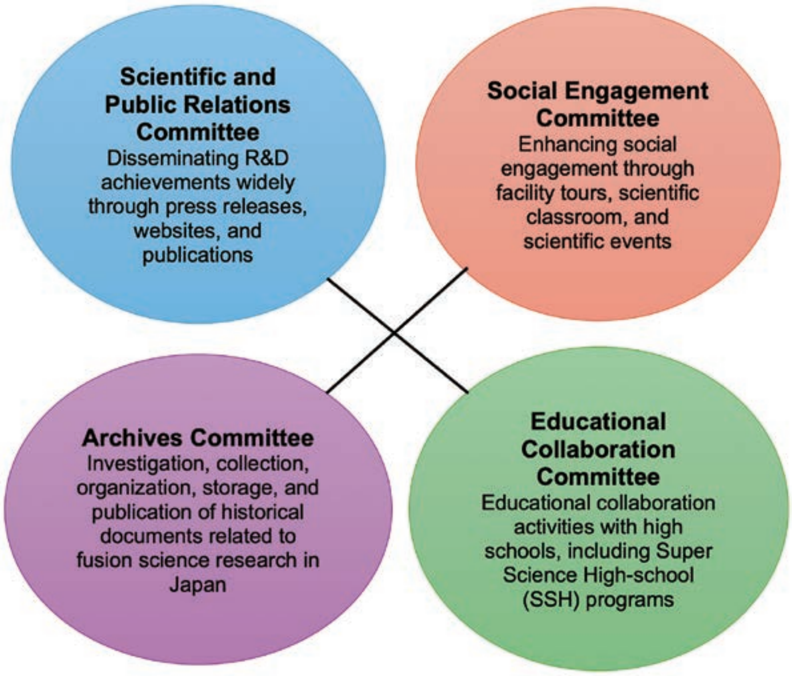



Fig. 1 Organization chart of Division of External Affairs

Activities held in FY2024 include the following.

- Tours of NIFS facilities (any time) held 395 times; 2,910 people participated
- Science classroom activities, held 33 times
- Release of information through web pages, mailing lists, and SNS (X and Facebook)
- Publication of NIFS official pamphlet (in Japanese and English)
- Publication of public relations magazine: NIFS News (5 issues)
- Publication of public relations magazine: Letters from Helica-chan (4 issues)

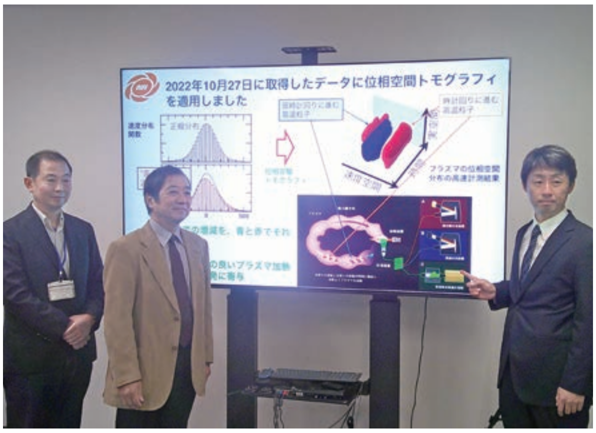



Fig. 2　Press release

Fig. 3　Scientific events in shopping malls, “Machikado (street corner) Science Lab”

Fig. 4　Tour of the NIFS facilities

Fig. 5　Scientific classroom

# 13. Fusion Science Archives (FSA)

The Fusion Science Archives were established in 2005 to learn lessons from preserved past fusion science archives and to maintain collections of historical documents and materials that are related to fusion research in Japan. These activities are important from the viewpoint of the historical evaluation of fusion research, its social accountability, and making references for seeking future directions. Since then, historical materials on fusion research and/or organizations related to it have been collected and preserved at the FSA. They are stored in acid-free folders and boxes. Catalogs of registered items are available to the public through the Internet in a hierarchical structure. The cataloged database of about 33,800 items is stored in the form of FileMaker for internal use. Among them, the catalogs of about 2,000 items are available through the web page from outside NIFS.

The following are summaries of selected collaborative works performed this fiscal year.

- **Analysis of the dawn of fusion research based on historical documents**

T. Amemiya (CST Nihon Univ.) *et al.*

The purpose of this collaborative research is to find the new historical interpretations of fusion research in Japan between the 1950s and 60s utilizing the historical documents in NIFS FSA and other archives. The subjects specifically investigated in fiscal year 2024 are as follows: 1) on the struggle for leadership in the establishment of a "researcher community" at the dawn of fusion research, 2) comparison of members of "researchers' organizations" established during the 1950s and 3) history of the establishment of the Japan Research-Group of Electrical Discharge (JRED) based on the Journal of JRED.

- **Collection of oral history on plasma and fusion research**

T. Amemiya (CST Nihon Univ.) *et al.*

It is the purpose of this collaborative research to collect "materials of oral history" through interviews with fusion researchers who have played important roles in the past. We have started preparatory work for an interview with Dr. Atsuo Iiyoshi, the first Director General of NIFS. At present, questions from collaborators (interviewers) are gathered and summarized. The contents of the current questionnaire are 1) plasma confinement studies in the quadrupole magnetic field by Iiyoshi's group at Keio University, 2) the Third Project (started around 1975) at the Institute of Plasma Physics, Nagoya University and 3) the background of the establishment of NIFS.

- **Historical Study of Nuclear Energy Development and Utilization Policies in Japan**

S. Kobori (Kyoto University) *et al.*

This study seeks to illuminate the history of nuclear power development policy in Japan through the organization and analysis of historical materials housed in the Fusion Science Archives. During fiscal year 2024, we cataloged over 400 documents from the Kazuhisa Mori Papers and conducted an analysis centered on three key themes: (1) the origin and development of the subsidy system under the Three Power Source Development Laws during the 1970s; (2) the development of new reactor types in the 1970s; and (3) the formulation of energy and global environmental policies in the 1980s.

- **Investigation on the trend of light source for plasma spectroscopic research in Japan from the chronicle of collaborative research meeting on plasma spectroscopy**

N. Yamaguchi (Comprehensive Research Organization for Science and Society (CROSS)) *et al.*

A collaborative meeting on plasma spectroscopy has been hosted by the Institute of Plasma Physics, Nagoya University (IPPJ) and NIFS over half of a century from 1969. Keywords relevant to light sources for spectroscopic research have been extracted from about 1300 papers were presented at the meeting from 1969 to 2017. The light sources identified have been classified into five categories: laboratory scale discharge plasma, laser-plasma, tokamak, LHD, and others (including heliotron, GAMMA10 and other confinement devices, synchrotron radiation (SR) sources, solar or astronomical plasma, ion-trap and so on). All the categories appear constantly for about 50 years after the 1970s (except LHD after the 1999 completion of its facility). This shows that a diversity of plasma spectroscopic research has been kept in Japan.

- **Analysis of materials related to the early days development of nuclear power development in Japan preserved in the Fushimi Koji archives**

Y. Narushima (NIFS) *et al.*

One famous episode in the history of the early days of nuclear development in Japan is the so-called “Nakasone’s Satsutaba (wad of cash) remark.”. In March 1954, Yasuhiro Nakasone, the future Prime Minister of Japan and others submitted a nuclear budget to the Diet, which was passed. At the time, Nakasone was said to have said, “The scholars were hesitating, so I slapped them across the face with a wad of cash.” However, Nakasone himself denied making this statement. While analyzing the Fushimi documents on this matter, a new discovery was made. The Osaka Teachers’ Union’s journal, “Osaka Education” (ID:503-03-12), published immediately after the budget was submitted, recorded Kawasaki Shuji making the above-mentioned remarks in a radio program. This appears to be the truth behind the episode known as Nakasone’s Satsutaba remark.

- **Organization, registration and analysis of historical documents and materials of Tihiro Ohkawa**

S. Kubo (Chubu Univ.)

Dr. Tihiro Ohkawa’s materials, which had been left in his study after his death, were transferred to the NIFS Fusion Science Archives (FSA) in 2016. These materials include notes, manuscripts, memos, papers, and his book collections on a wide range of fields. The main progress of this fiscal year consists of sorting and categorizing handwritten memos and notes to identify their relation to the preprint and publication, and ultimately to clarify the research process of Tihiro Ohkawa. In this process, materials are categorized into 1. handwritten notes, 2. handwritten manuscripts, 3. typed manuscript with handwritten memo, 4. proofreading manuscript with handwritten memo, 5. preprint and so on. Books are taken out of the stored box and arranged on separate shelves.

# 14. Industry-Academia Collaboration Laboratory

The Industry-Academia Collaboration Laboratory is an innovation research center focused on fusion energy, where industry, academia, and government collaborate to advance the practical application of fusion energy — widely regarded as the world's next-generation energy source. The center also aims to create new social value through partnerships with external organizations.

The National Institute for Fusion Science has long fostered cooperative relationships with private companies and industries to promote the social implementation of fusion energy, anticipated to become a sustainable and environmentally friendly energy source. To further strengthen these initiatives, the Fusion Energy Industry-Academia Collaboration Laboratory was established in 2023.

In addition, we are actively collaborating with emerging fusion start-up companies, which have gained significant momentum in recent years. To support these efforts, we have formed an internal "HF Collaborative Research Group" to conduct joint research with Helical Fusion, Inc (Fig. 1). This group is doing joint research on superconducting magnets, etc., with the aim of commercializing helical fusion reactors.


Fig. 1 Simplified schematic diagram HF Collaborative Research Group

(R. Yasuhara)

# 15. Department of Engineering and Technical Services

The Department of Engineering and Technical Services (DETS) is involved in the operation and maintenance of research platforms such as the Large Helical Device (LHD) and information facilities such as the research infrastructure network, as well as the design, development, and fabrication of equipment, radiation control, and safety promotion. The DETS contributes greatly to the creation of results in fusion research through advanced and specialized technical support. It consists of five technical divisions. and the total number of staff is now 50 (2025.6).

The FY2024, 25-cycle LHD Campaign was conducted from March 13, 2024 to June 20, 2024. The experimental schedule was successfully carried out, with no trouble, and almost 100% uptime was achieved, which was evaluated as a considerable achievement of the activities of the DETS.

The following is a report on its activities.

(H. Hayashi)

## Mechanical Systems Technology Division

The main work of this division is the fabrication of experimental equipment. For example, we fabricated a type of notch filter and mirrors for micro-waves using a cutting process. Other processes such as welding and drilling were performed with vacuum parts and equipment mounting fixtures, etc. We also took care of technical consultation related equipment for design and drawing. The number of machined requests was 72 in this fiscal year (FY).

In order to supply some commonly used experimental parts, we operate and manage a parts room on the premises. The parts room handles about 1000 parts related to electric, vacuum functions etc.

In addition, we manage the administrative procedures of the technical department.

(T. Kobuchi)

**(1) Focusing mirror for micro-waves for Q-shu University Experiment with Steady-State Spherical Tokamak (QUEST)**

We have fabricated a focusing mirror for QUEST (Fig. 1). It has a spherical shape of a 800 mm radius. The material of the mirror is an aluminum alloy; the mirror is 270 mm in length and 270 mm in width. It took 12 hours to complete the cutting process.

(K. Okada and T. Shimizu)

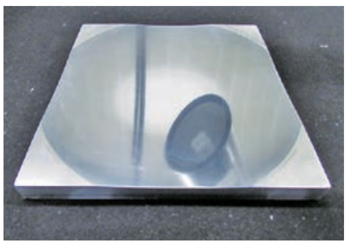


Fig. 1 Focusing mirror for micro-waves fabricated with a cutting process.

**(2) Maintenance and modification of LHD-related equipment**

We perform maintenance and modification of LHD-related equipment. The main equipment includes a cooling water system, water leak detection equipment, and a power-supply system for the Local Island Divertor (LID). We also carry out the installation management of vacuum flanges. The CAD office provides LHD drawings and other services.

(M. Kawai)

# Design and Development Technology Division

This Division provides technical support for the operation, improvement, and maintenance of LHD, as well as support for collaborative and commissioned research.

(N. Suzuki)

**(1) LHD vacuum pumping system**

To carry out the 25th LHD experimental campaign, we started the vacuum pumping system operation for the cryostat vessel on February 1, 2024, and for the plasma vacuum vessel on February 2, 2024. The pressure of the cryostat vessel reached an adiabatic condition (< 2e-2 Pa) on February 2, 2024. After the initial pumping of the plasma vacuum vessel was completed, a leak check was conducted, and one leak was found. The leak was repaired by retightening the bolts. After approximately five days of baking the vacuum vessel, the pressure required for conducting a plasma experiment, below 1e-5 Pa, was reached. Fig. 2 shows the pumping process from the 23rd to the 25th campaigns. The operation of the vacuum pumping system was conducted until July 12, 2024 without any problems.

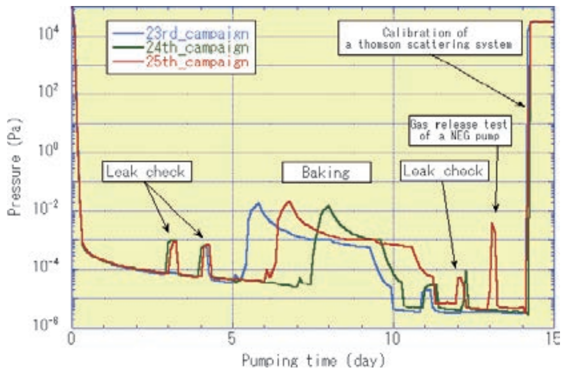



Fig. 2 The pumping process from the 23rd to the 25th campaign

(N. Suzuki)

**(2) Tritium emission rate measurement method for plasma-facing walls in the LHD vacuum vessel**

In the LHD, deuterium plasma experiments have been carried out for six years, during which tritium was produced in the vacuum vessel, with some remaining at the plasma-facing walls. In order to identify the location of tritium emission in the vacuum vessel, some parts of the plasma-facing walls were demounted and the tritium emission rate from them was calculated.

The demounted parts of the plasma-facing walls were set one by one in a vacuum desiccator and allowed to stand for one week. After that, the gas in the vacuum desiccator was exhausted into an aluminum bag using a vacuum pump, as shown in Fig. 3. The gas in the aluminum bag was collected to capture tritium using a water bubbler device (MARC7000, SDEC France). A flow diagram of the water bubbler device is shown in Fig. 4. The collected water was mixed with a liquid scintillator (Ultima GOLD LLT, Revvity) and measured with a low background liquid scintillation counter (LSC-LB-7, Aloka) to quantify the tritium content. The tritium emission rate per unit area

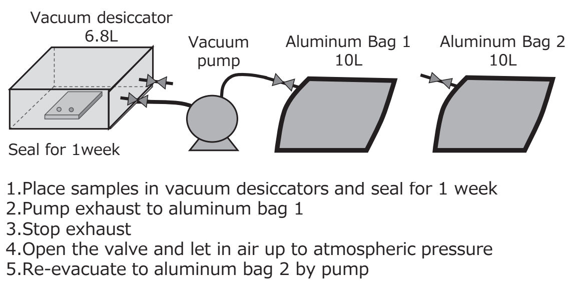



Fig. 3 Emission procedure

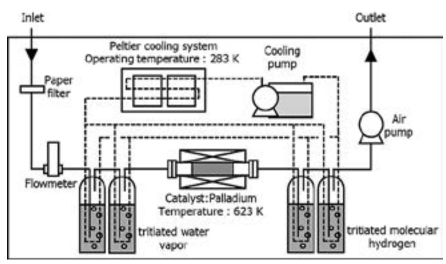



Fig. 4 Flow diagram of water bubbler system

was calculated and estimated based on the measured tritium amount, collected time, and sample area.

A total of 33 plasma-facing walls were evaluated.

(H. Kato)

**(3) Development of a prototype pulsed magnetic field generator**

This report is about the development of a prototype pulsed magnetic field generator. As an initial step, we developed a prototype capable of generating pulsed magnetic fields by momentarily applying a large current to a solenoid coil made of copper wire. The power supply system employed a capacitor charge/discharge method, where energy stored in a capacitor was rapidly released into the coil. Two sets of Insulated Gate Bipolar Transistors (IGBTs) were used as the switching device for both charging and discharging processes. The electrolytic capacitors with 2350 μF in total could be charged up to a maximum voltage of 140 V. The solenoid coil had a diameter of 40 mm and was wound with copper wire of 1 mm in diameter, totaling 75 turns. The fabricated coil resistance showed approximately 0.2 Ω. The circuit diagram of the prototype is shown in Fig. 5.

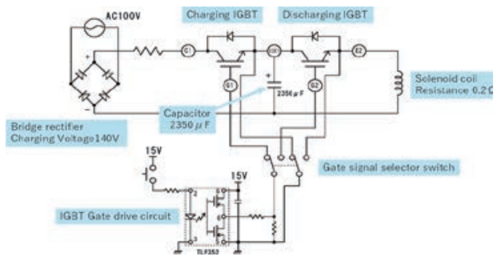



Fig. 5 Circuit diagram of the prototype pulsed magnetic generator

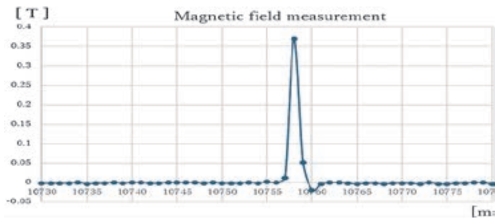



Fig. 6 Magnetic field measurement graph

In this prototype, the maximum current applied to the coil was 300 A. Magnetic field measurements on the coil using a gaussmeter revealed a peak field strength of approximately 0.37 T, with a pulse width of around 2 ms. The magnetic field measurement graph is shown in Fig. 6. In this investigation, a solenoid coil wound with copper wire was used, but in the future, we aim to develop another prototype using a High-Temperature Superconducting (HTS) coil to enhance the magnetic field strength.

(H. Noguchi)

# Electrical and Electronic Technology Division

The main tasks of this division are the operation and maintenance of plasma-heating devices using high-voltage and high-frequency power supplies and their common facilities. We have also provided technical support for experimental equipment, including electrical and electronic circuits. The details of these activities are as follows.

(T. Kondo)

**(1) Electrical and electronic work for experimental equipment**

(a) GaN-FET inverter for RF-NBI

Fig. 7 shows a component of the high-frequency power supply for an NBI's RF ion source. This board has two GaN-FETs and operates at a switching frequency of 500 kHz to 4 MHz, with an output of up to 2 kW. This power supply forms a bridge circuit on two boards, and eight such boards make up one set. Four sets will connect in parallel to output more high-frequency power.

(Y. Ito)

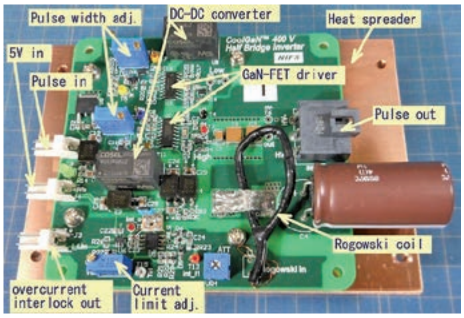



Fig. 7 Inverter power supply circuit board

(b) Installation of an auto-drain timer for a compressed air system

We modified a compressed air system in R & D Laboratories to enable the automatic drainage of water from the air compressor (Fig. 8). The new system has a solenoid valve and two timer relays, and it is possible to drain water for a fixed period on a regular basis by combining a timer, TMR1, for setting the repeat interval and another timer, TMR2, for setting the drainage time (Fig. 9).

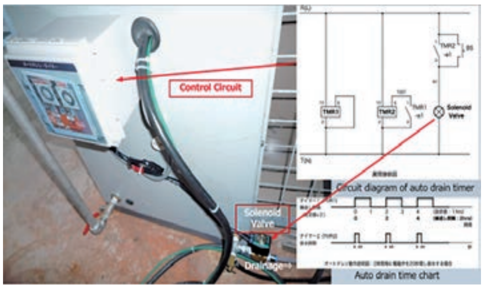



Fig. 8 Installation of auto drain timer

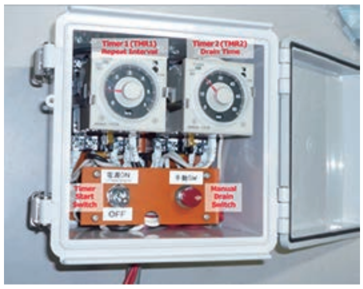


Fig. 9 Auto-drain timer circui

(K. Yasui)

**(2) The operation and maintenance of plasma-heating devices for LHD**

(a) ECH

During the 25th experimental campaign, we injected power up to 4MW to assist the plasma experiments. Major trouble in this experimental campaign occurred in the grounding device of the gyrotran's collector power source and its anode power supply. The reason for each was the deterioration over time of small switching power supplies for control boards. This trouble was resolved quickly by replacing them with spare switching power supplies.

(Y. Mizuno)

(b) ICRF

In the 25th experimental campaign, we carried out the LHD experiment with a total of two antennas with four antenna straps, that is, a handshake type (HAS) antenna with two antenna straps at the 3.5U&L ports and a Field-Aligned Impedance-Transforming (FAIT) antenna with two antenna straps at the 4.5U&L ports of the LHD. We changed the combination of an RF transmitter and an antenna strap. So, transmitters #3 and #4 connected to the 3.5U&L antenna straps and transmitters #6A and #5B connected to the 4.5U&L antenna straps. However, a problem began to occur early in the 25th experimental campaign when an oscillation of the #4 transmitter triggered an interlock in its high-voltage DC power supply, causing the #4 transmitter to stop operation. Therefore, a steady-state experiment was conducted with three antennas, excluding the HAS antenna at the 3.5L port. The resulting injection power and pulse length were 1.12 MW/114 sec.

(G. Nomura)

(c) NBI

In the 25th experimental campaign, we injected into the LHD plasmas approximately 6,000 shots of neutral beams. The negative-NBIs' (BL1, BL2, and BL3) maximum total injection power was about 14 MW. The positive-NBIs' (BL4 and BL5) maximum total injection power was about 10 MW. There were serious problems or trouble in the LHD plasma experiments.

(M. Sato)

(d) Motor-Generator (MG)

The MG has been used for supplying pulsed power to NBI and ECH for 3,623 shots in this fiscal year and 723,733 shots since its construction. The operation time was 184 hours. Brushes for the MG's drive motor have become shorter than the reference dimensions through wear, so all of them were replaced with spares. And we made a renewal plan for equipment including capacitor filters that were suspected of PCB contamination.

(Y. Mizuno)

(e) Cooling water equipment for plasma-heating devices

The measurement units of the outlet water temperature of the cooling tower and valve position did not work well. Our investigation found failure of parts for measurement, so we replaced them. Water sprinkler pumps for the cooling tower underwent disassembly and inspection work, including replacing V-belts and pulleys for the fan and a casing for pumps.

(Y. Mizuno)

# Diagnostics and Analysis Technology Division

We are engaged in the development and maintenance of diagnostic devices and a data acquisition system. We also conduct radiation measurements and are responsible for radiation control.

From March to June 2024, the LHD experiment was conducted, during which we supported the startup, shutdown, and monitoring of the diagnostic devices related to the LHD device. Until now, these tasks had been carried out by operators, but due to the end of their contracts, this was the first time that technical staff handled the operations independently. Although there were concerns about potential operational errors, the manuals that had been developed since the previous fiscal year contributed to the successful execution of support activities without major issues.

The following describes modification of the Heavy Ion Beam Probe (HIBP) which is a main diagnostic device for the LHD, new RAID storage devices of the LHD data acquisition system and activities related to radiation management.

(H. Hayashi)

**(1) Modification of Cesium Oven for HIBP Negative Ion Source**

The cesium oven manufactured for use with negative ion sources has a double-walled structure for thermal insulation, with a cesium filled innermost chamber. However, a phenomenon occurs where the evaporated cesium condenses upon cooling and accumulates between the two layers. If the oven flange is removed while residual cesium remains between the double walls, it reacts chemically with moisture in the air, ignites, and may cause fire to spread. To prevent this, the cesium tank was modified to a single-walled structure.

(H. Takubo)

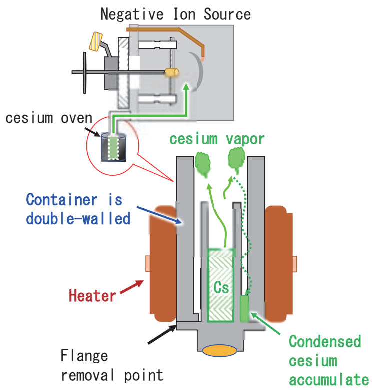



Fig.10 Cross-section of cesium oven

**(2) LHD data acquisition (DAQ) system**

For the DAQ operation in the 26th campaign of the LHD experiment, additional RAID storage devices with sufficient capacity for data to be generated were set up. The storage network has also been speeded up (mainly to 100Gbps) to enable efficient storage, transfer, and utilization of data which continues to grow in size year by year. In addition, three high-capacity storage devices with 106 HDDs have been installed for long-term storage and open access (OA), and all data stored in the LHD DAQ system are being copied to these units and made available as the OA system.

Fig. 11 New RAID storage devices in isolation racks

(M. Ohsuna)

**(3) Online system for radiation measurement**

To ensure radiation safety management for work conducted within the controlled area, contamination inspections using the smear method have been carried out. Since 2021, the entire process from application to approval for contamination inspections has been available online, and 438 requests have been received to date. A survey was conducted on the newly introduced online system with the aim of making improvements in the future. 86% of respondents said that the online system was easy to use, and the posted content that was requested to be improved was reviewed and updated.

(M. Nakada)

**(4) Activation evaluation**

In order to evaluate the degree of activation of the LHD torus hall and its basement due to the deuterium plasma experiment, NIFS has been conducting a survey in collaboration with the High Energy Accelerator Research Organization (KEK) since 2022. In the last fiscal year, neutron activation analysis was conducted in the Kyoto University Research Reactor (KUR) to analyze the constituent elements of concrete. Based on the results of these measurements, the validity of the radiation measurement results from the LHD in the previous year is being evaluated.

(M. Nakada and S. Kurita)


Fig. 12 Concrete sample of KUR

# Control and Information Technology Division

The Control and Information Technology Division is in charge of important engineering tasks in the LHD project, such as system development, project management and system operation which are targeted at central control systems, cryogenic systems, coil power supply and super-conducting coils. We are also responsible for IT infrastructure, e.g., the LHD experiment network, the NIFS campus information network and internet servers in every phase of the project, including analysis, system design, implementation, operation and user support. The main activities for the last fiscal year are described below.

(K. Oba)

**(1) LHD cryogenic system for superconducting coils**

The cryogenic system operation in the 25th experimental campaign was performed without serious accident. Fig. 13 shows the operation result. On February 2nd, 2024, the He purification operation began. After that, a coil cool-down operation was performed for 600 hours. After approximately three months of plasma experiments, a coil warm-up operation was performed from June 21th to July 12th, 2024. The total operation time of the He compressors was 3860 hours.

(K. Oba)

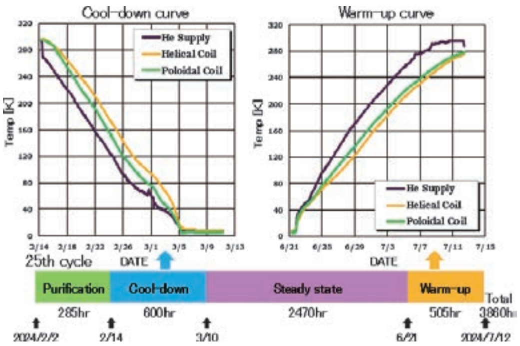



Fig. 13 Results of the 25th cycle operation of the LHD cryogenic system

**(2) Management of utilities at the control building**

The LHD Central Control System began in 1996 and had been operating without any major problems until the 25th experiment campaign. However, problems due to deterioration have occurred occasionally after more than ten years have passed since the core components consisting of the PLC and VME were updated in 2012. A communication error of the interlock signal between the PLC and remote terminal modules was a serious error which would interrupt a plasma experiment. Fig. 14 shows the part of the PLC configuration diagram that relates to the error. To solve the problem, we tried to identify its cause. Also, redesigning the entire PLC system was considered concurrently since some of the PLC components were no longer in production. Finally, the cause was determined by the optical-electrical converter, and the problem was solved by simply replacing the device. As the next experiment campaign will be the last campaign of the LHD project, we will continue maintaining the system to keep it in best condition.

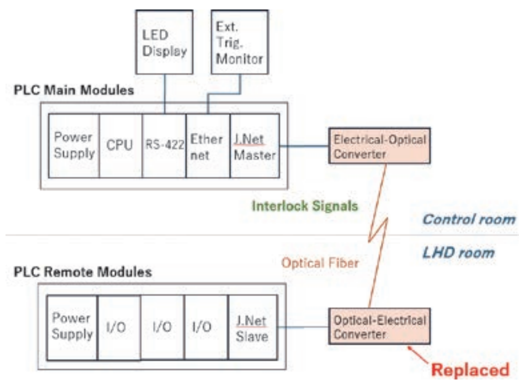



Fig. 14 Configuration diagram that relates to the error

(H. Ogawa)

**(3) Network Management**

NIFS campus information networks consist of several clusters. We manage the Research Information Cluster (NIFS-LAN) and the LHD Experiment Cluster (LHD-LAN).

The achievements in FY 2024 were as follows:

(a) Server migration due to end of life for CentOS 7

CentOS Linux 7 reached the end of its life on June 30, 2024. The web servers related to the Public Relations Office and network operation servers running on CentOS 7 were updated. AlmaLinux 9 was selected as the distribution to be migrated. After creating an installation template to improve work efficiency, efforts began in early April and were completed by the end of June.

(b) Wireless LAN Upgrade

The wireless network infrastructure has been upgraded in Research Building 1, the Administration Building and the Library Building. As part of this upgrade, we implemented Aruba Central, a cloud-based wireless LAN controller and deployed Aruba AP-615 (Fig. 15) units as new wireless access points. To provide power to the access points via Power over Ethernet (PoE), we introduced Aruba 6000 PoE switches (Fig. 16).


Fig. 15 Wireless access point (AP-615)

Fig. 16 PoE switch (Aruba 6000)

(c) LHD-LAN

Our security policy requires that network management staff must be present when connecting a new device to the the LHD-LAN. In FY2024, 25 new devices were connected to LHD-LAN, 28 devices were updated and 6 IP addresses were returned due to device removal.

(T. Inoue and O. Nakamura)

## Technical Exchanges

Eight technical exchange meeting: “computation technology using finite element method”

On February 21, 2025, we held a technical exchange meeting to discuss numerical computation technologies based on the finite element method. This meeting, the eighth in the series, was attended by seven presenters and 27 participants, including those who joined remotely via the web conferencing platform Zoom, as shown in Fig. 17. The meeting featured two invited talks titled “Application of VR to Numerical Analysis and Evaluation, and Future Prospects in Combination with AI” and “High-Intensity Positron Source and Simulation.” In addition, five general presentations were given, all of which prompted lively discussions.

Fig. 17  Group photos of the technical exchange meeting

(T. Murase)

## Internship

We have accepted internships from high schools as part of the institute’s outreach activities every year. One example is as follows.

The Electrical and Electronic Technology Division accepted two second-year students from the electrical engineering department of Tajimi technical high school and taught them for two days. The practical training consisted of making a miniature car that moved toward light by controlling a stepping motor with a PIC microcomputer (Fig. 18). The first day consisted of a lecture on stepping motors and a motor drive system, and soldering electronic components to printed circuit boards. The second day consisted of a lecture on PIC microcomputers and their development environment, and the writing of a program for a PIC microcomputer in C Programming language. The students applied trial-and-error to control the appropriate rotation speed of two stepping motors according to the amount of light received by each of two sensors.

Fig. 18  Students in internship

(T. Kondo)

# 16. Department of Administration

The Department of Administration handles planning and external affairs, general affairs, accounting, research support, and facility management work.

The major operations of this department are to support the promotion of the Institute's regular research and the development of the collaborative research.

The department consists of the following four divisions, namely, the General Affairs Division, the Financial Affairs Division, the Research Support Division, and the Facilities and Safety Management Division. Details of these divisions are described below.

**General Affairs Division**

The General Affairs Division handles administrative work and serves as the contact point with the outside. This Division consists of four sections. The General Affairs Section is in charge of secretarial work for the Director General and the Deputy Director General, support for the Advisory Committee meetings, and enacting rules and regulations. The Planning and Evaluation Section is in support for assessment of the institution's performance including scientific achievement and management efficiency. The Personnel and Payroll Section is in charge of general personnel affairs, salary, and public welfare. And the Communications and Public Affairs Section focuses on outreach and publicity activities.

Number of Staff Members

| | |
|---|---|
| Director General | 1 |
| Researchers | 102 |
| Technical and Engineering Staff | 43 |
| Administrative Staff | 41 |
| Employee on Annual Salary System | 24 |
| Research Administrator Staff | 2 |
| Visiting Scientists | 5 |
| Total | 218 |

**Financial Affairs Division**

The Financial Affairs Division consists of six sections: The Audit Section, the Financial Planning Section, the Accounts and Properties Administration Section, the Contracts Section, the Procurement Section, and the Purchase Validation Section.

The major responsibilities of the division are to manage and execute the budget, to manage corporate property, revenue/expenditure, and traveling expenses of staff, and to purchase supplies and receive articles.

The budget is 7,000,000,000 yen. (JFY 2024)

**Research Support Division**

The Research Support Division consists of four sections and one center. These are the Graduate Student Affairs Section, the Academic Information Section which includes the Library at NIFS, the Research Support Section and the International Collaboration Section, which is in charge of inter-university coordination and arranging international cooperation. The Visitor Center assists collaborating researchers and visitors.

*Collaboration Research Programs*

| | Applications Applied | Applications Accepted | Researchers Accepted |
|---|---|---|---|
| Network-Type Collaboration Research | 5 | 3 | 58 |
| Interdisciplinary Fusion Science Collaboration Research | 109 | 109 | 859 |
| Fusion Plasma Collaboration Research | 63 | 59 | 680 |
| Fusion Technology Collaboration Research | 83 | 78 | 399 |
| Plasma Simulator CollaborationResearch | 83 | 83 | 497 |
| Workshops | 28 | 27 | 780 |
| Bilateral Collaboration Research | 99 | 99 | 1,494 |
| Total | 470 | 458 | 4,767 |

*Number of Graduate School Students*
*(SOKENDAI: The Graduate University for Advanced Studies)*

| Doctoral Course | | | | | |
|---|---|---|---|---|---|
| Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 | Total |
| 2 | 2 | 3 | 3 | 8 | 18 |

*(The Joint Program of Graduate Education)*

Graduate course education is given in NIFS apart from SOKENDAI in joint programs with the Department of Energy Science and Engineering of the Graduate School at Nagoya University, Division of Particle and Astrophysical Science of the Graduate School of Science at Nagoya University, Division of Quantum Science of the Graduate School of Engineering at Hokkaido University, Department of Energy Science of the Graduate School of Science and Engineering at University of Toyama, Interdisciplinary Graduate School of Engineering Science in Kyushu University and the Graduate School of Engineering at Tohoku University. In total, 31 graduate students are involved in the programs as of March 31, 2025.

*The Special Research Collaboration Program for Education*

| Affiliation \ Degree | Bachelor's Course | Master's Course | Doctoral Course | Total |
|---|---|---|---|---|
| National Graduate School | 0 | 21 | 10 | 31 |
| Public Graduate School | 0 | 0 | 0 | 0 |
| Private Graduate School | 0 | 0 | 0 | 0 |
| Total | 0 | 21 | 10 | 31 |

*Books and Journals*

| | |
|---|---|
| Books in Japanese | 21,111 |
| Books in Other Languages | 51,411 |
| Total (volumes) | 72,522 |
| Journals in Japanese | 300 |
| Journals in Other Languages | 935 |
| Total (titles) | 1,235 |

**Facilities and Safety Management Division**

The Facilities and Safety Management Division consists of three sections: The Safety and Health Management Section, the Facilities Planning Section, and the Facilities Maintenance Section. They are in charge of planning, designing, making contracts, supervising the construction and maintenance of all facilities at NIFS, such as buildings, campus roads, electricity, telephone, power station, air conditioning, water service, gas service, elevators, and cranes. The Facilities and Safety Management Division submits a budget request and administers the budget for those facilities.

The Safety and Health Management Section also arranges medical examination and disaster drills. These three sections promote facilities' environment better for all staff.

*Site and Buildings*

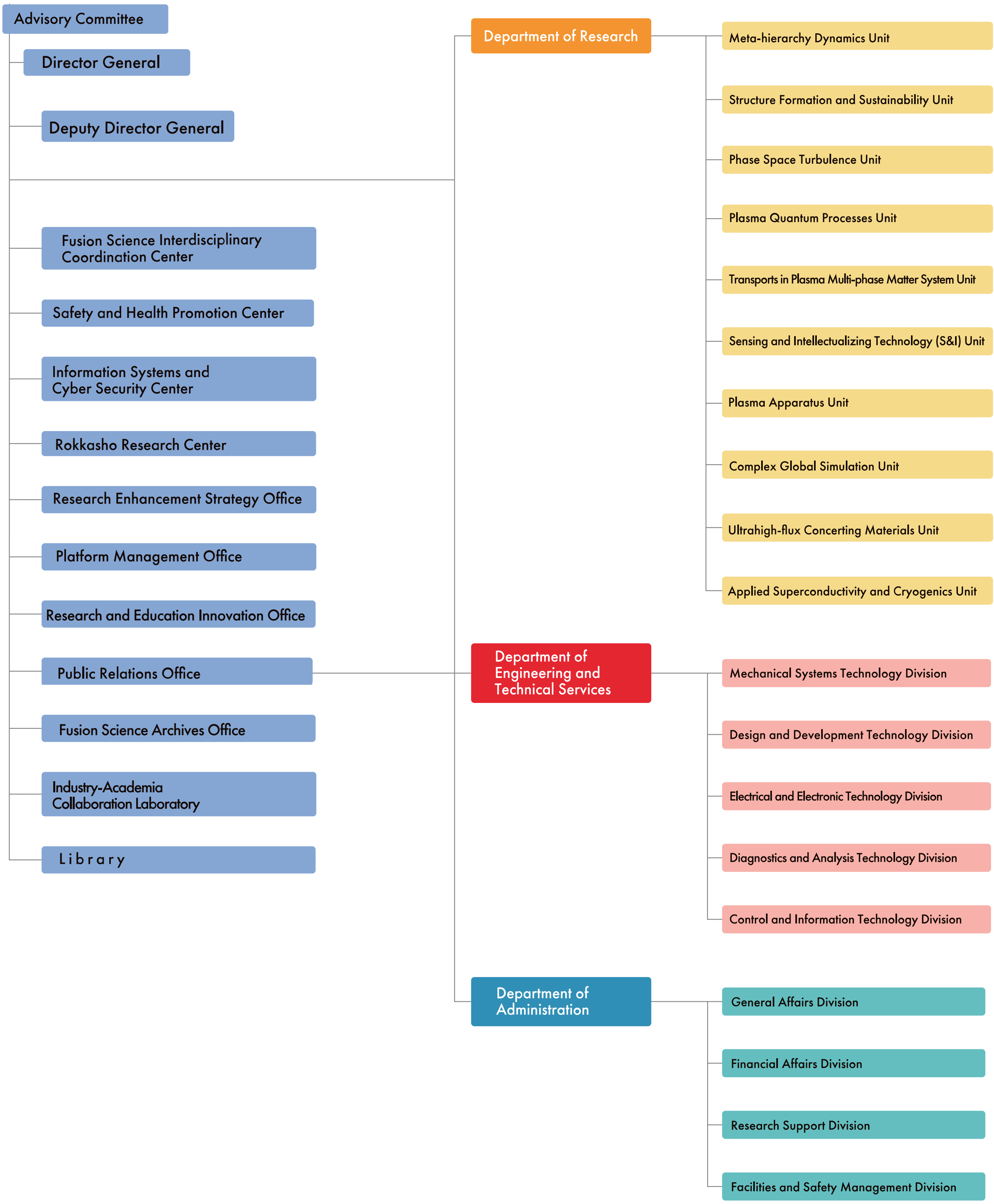
| Toki | |
|---|---|
| Site | 464,445 $m^2$ |
| Buildings | |
| Total Building Area | 39,557 $m^2$ |
| Total Floor Space | 71,830 $m^2$ |

※ All statistical data is as of March 31, 2025

# APPENDIX

## APPENDIX 1. Organization of the Institute

April 2024



# APPENDIX 2.   Members of Committees

**Advisory Committee**

| | |
|---|---|
| ISHIDA, Shinichi | Vice Director<br>National Institute for Quantum Science and Technology |
| UEDA, Yoshio | Professor<br>Faculty of Science and Engineering, Otemon Gakuin University |
| OZAWA, Tohru | Professor<br>Faculty of Science and Engineering School of Advanced Science and Engineering, Waseda University |
| KANEKO, Toshiro | Professor<br>Graduate School of Engineering, Tohoku University |
| FUJISAWA, Akihide | Professor<br>Research Institute for Applied Mechanics, Kyushu University |
| FUJITA, Takaaki | Professor<br>Graduate School of Engineering, Nagoya University |
| MATSUOKA, Ayako | Professor<br>Graduate School of Science, Kyoto University |
| MORII, Takashi | Professor<br>Faculty of Health Science, Department of Health and Nutrition, Kyoto Koka Women's University |
| YAMADA, Hiroshi | Professor<br>Graduate School of Frontier Sciences, The University of Tokyo |
| YONEDA, Hitoki | Professor<br>Institute for Laser Science, The University of Electro-Communications |
| WATANABE, Tomohiko | Professor<br>Graduate School of Science, Nagoya University |

※ This list was compiled as of March 31, 2025

# APPENDIX 3. Professor Emeritus

**Professors Emeritus**

ICHIKAWA, Yoshihiko (1993)
MIZUNO, Yukio (1994)
FUJITA, Junji (1996)
KURODA, Tsutomu (1997)
AMANO, Tsuneo (1998)
MOMOTA, Hiromu (1998)
IIYOSHI, Atsuo (1999)
HATORI, Tadatsugu (1999)
SATO, Tetsuya (2001)
FUJIWARA, Masami (2002)
KAMIMURA, Tetsuo (2003)
HAMADA, Yasuji (2007)
KATO, Takako (2007)
NODA, Nobuaki (2008)
WATARI, Tetsuo (2008)
MOTOJIMA, Osamu (2009)
SATOH, Kohnosuke (2010)
MATSUOKA, Keisuke (2010)
TOI, Kazuo (2012)
NARIHARA, Kazumichi (2012)
KUMAZAWA, Ryuhei (2012)
UDA, Tatsuhiko (2012)
SATO, Motoyasu (2012)
YAMAZAKI, Kozo (2013)
KAWAHATA, Kazuo (2013)
OKAMURA, Shoichi (2014)
KOMORI, Akio (2015)
SUDO, Shigeru (2015)
SKORIC, Milos (2015)
MUTO, Takashi (2016)
NAGAYAMA, Yoshio (2017)
NAKAMURA, Yukio (2017)
SAGARA, Akio (2017)
ITOH, Kimitaka (2017)
HORIUCHI, Ritoku (2017)
MORITA, Shigeru (2019)
NISHIMURA, Arata (2019)
TAKEIRI, Yasuhiko (2021)
KUBO, Shin (2021)
MITO, Toshiyuki (2021)
NISHIMURA, Kiyohiko (2021)
KANEKO, Osamu (2022)
MURIGA, Takeo (2022)
ISHIGURO, Seiji (2022)
NAKAJIMA, Noriyoshi (2022)
SHIMOZUMA, Takeshi (2022)
IDA, Katsumi (2023)
SAKAGAMI, Hitoshi (2023)

※ This list was compiled as of March 31, 2025

# APPENDIX 4. List of Staff

**Director General**

YOSHIDA, Zensho

**Deputy Director General**

TODO, Yasushi

**Department of Research**

Prof. SAKAMOTO, Ryuichi (Director)

**Meta-hierarchy Dynamics Unit**

Prof. GOTO, Motoshi (Chief)
Prof. SAKAMOTO, Ryuichi
Prof. NAGAOKA, Kenichi
Prof. NUNAMI, Masanori
Assoc. Prof. IGAMI, Hiroe
Assoc. Prof. ITO, Atsushi
Assoc. Prof. SATO, Naoki
Assoc. Prof. SEKI, Tetsuo
Assoc. Prof. TODA, Shinichiro
Assoc. Prof. MAEYAMA, Shinya
Assist. Prof. ISHIKAWA, Ryohtaro
Assist. Prof. TAKAYAMA, Arimichi
Assist. Prof. HASEGAWA, Hiroki
COE Researcher LIN, Keren
COE Researcher YANG, Shudi
Guest Prof. KATO, Yuto (Tohoku Univ.)

**Structure Formation and Sustainability Unit**

Assoc. Prof. YAMAGUCHI, Hiroyuki (Chief)
Prof. ISOBE, Mitsutaka
Prof. ICHIGUCHI, Katsuji
Prof. OSAKABE, Masaki
Assoc. Prof. OGAWA, Kunihiro
Assoc. Prof. SATAKE, Shinsuke
Assoc. Prof. TAKAHASHI, Hiromi
Assist. Prof. ITO, Atsushi
Assist. Prof. KAWAMOTO, Yasuko
Assist. Prof. SHIMIZU, Akihiro
Assist. Prof. NISHIMURA, Shin
Assist. Prof. NUGA, Hideo
Project Prof. IDO, Takeshi
Guest Researcher YOSHIMURA, Yasuo (QST)

**Phase Space Turbulence Unit**

Assoc. Prof. TOKUZAWA, Tokihiko (Chief)
Project Prof. IDA, Katsumi
Assoc. Prof. KENMOCHI, Naoki
Assoc. Prof. KOBAYASHI, Tatsuya
Assoc. Prof. NISHIURA, Masaki
Assoc. Prof. YAMADA, Ichihiro
Assist. Prof. YANAI, Ryohma
Assist. Prof. YOSHINUMA, Mikiro
Project Prof. FUJISAWA, Akihide
Project Researcher UEDA, Kenji
Project Researcher NASU, Tatsuhiro
COE Researcher NISHIMURA, Daiki
Guest Prof. EBIHARA, Yusuke (Kyoto Univ.)
Guest Assoc. Prof. SASAKI, Makoto (Japan Univ.)

**Plasma Quantum Processes Unit**

Prof. KATO, Daiji (Chief)
Prof. HOSHI, Takeo
Prof. MURAKAMI, Izumi
Assoc. Prof. KIMURA, Naoki
Assist. Prof. SAKAI, Kentaro
Assist. Prof. SAKAUE, Hiroyuki
Assist. Prof. SUZUKI, Chihiro
Assist. Prof. FUNABA, Hisamichi
Assist. Prof. MUTO, Sadatsugu
Assist. Prof. MORITAKA, Toseo
Assist. Prof. YAMAGISHI, Osamu
Guest Prof. FUJIOKA, Shinsuke
Research Support KATO, Masatoshi

**Transports in Plasma Multi-phase Matter System Unit**

Prof. MASUZAKI, Suguru (Chief)
Prof. NAKAMURA, Hiroaki
Prof. MORISAKI, Tomohiro
Assoc. Prof. USAMI, Shunsuke
Assoc. Prof. KANNO, Ryutaro
Assoc. Prof. KOBAYASHI, Masahiro
Assoc. Prof. SHOJI, Mamoru
Assoc. Prof. TOKITANI, Masayuki
Assoc. Prof. MOTOJIMA, Gen
Assoc. Prof. YOSHIMURA, Shinji
Assist. Prof. GOTO, Yuki
Assist. Prof. HAMAJI, Yukinori
Assist. Prof. YAJIMA, Miyuki
Project Prof. TOYODA, Hirotaka
COE Researcher WANG, Chenxu
Guest Prof. KAWAGUCHI, Hideki (Muroran Inst. Tech.)
Guest Assoc. Prof. TERASAKA, Kenichiro (Sojo Univ.)
Guest Researcher KOVTUN, Yurii (KIPT)
Professional Staff YOSHIDA, Shigeru

**S&I: Sensing and Intellectualizing Technology Unit**

Assoc. Prof. UEHARA, Hiyori (Chief)
Prof. SAKAKIBARA, Satoru
Prof. TANAKA, Kenji
Prof. BYRON, Peterson
Prof. YASUHARA Ryo
Prof. YOKOYAMA, Masayuki
Prof. WATANABE, Kiyomasa
Assoc. Prof. OHTANI, Hiroaki
Assoc. Prof. TANAKA, Masahiro
Assoc. Prof. NAKANISHI, Hideya
Assoc. Prof. SAZE, Takuya
Assist. Prof. EMOTO, Masahiko
Assist. Prof. OHTA, Masato
Assist. Prof. KAWAGUCHI, Haruki
Assist. Prof. TAKEMURA Yuki
Assist. Prof. MUKAI, Kiyofumi
Project Assoc. Prof. MIYAKAWA, Reina
Project Assoc. Prof. ZANGPO, Jigme
Project Researcher ZHAO, Mingzhong
Project Researcher YU, Linpeng
COE Researcher FABIEN, Sanchez
Research Fellowship SAKAI, Hikona
Guest Prof. TAIRA, Takunori
Guest Prof. TOKITA, Shigeki
Guest Assoc. Prof. YANO, Keisuke (ISM)

**Plasma Apparatus Unit**

Assoc. Prof. NAKANO, Haruhisa (Chief)
Project Prof. OKADA, Shinji
Project Assoc. Prof. SAITO, Haruhiko
Project Assoc. Prof. SHIBATA, Takanori
Guest Assoc. Prof. TAKAHASHI, Kazunori

**Complex Global Simulation Unit**

Prof.TOIDA, Mieko (Chief)
Prof. SUGAMA, Hideo
Prof. TODO, Yasushi
Prof. MIURA, Hideaki
Assoc. Prof. HORI, Kumiko
Assoc. Prof. SATO, Masahiko
Assoc. Prof. MIZUGUCHI, Naoki
Assoc. Prof. YAMAMOTO, Takashi
Assist. Prof. ISHIZAKI, Ryuichi
Assist. Prof. SEKI, Ryosuke
Assist. Prof. WANG, Hao
Assist. Prof. WANG, Jialei
COE Researcher LI, Hangzen
COE Researcher WEI, Shizhao
Guest Prof. GOTO, Susumu

**Ultrahigh-flux Concerting Materials Unit**

Prof. NAGASAKA, Takuya (Chief)
Assoc. Prof. KOBAYASHI, Makoto
Assoc. Prof. MUKAI, Keisuke
Assoc. Prof. TAKAYAMA, Sadatsugu
Assoc. Prof. TANAKA, Teruya
Assist. Prof. SHEN, Jingjie
Assist. Prof. NOTO, Hiroyuki
Guest Prof. KASADA, Ryuta
Guest Assoc. Prof. OONO, Naoko

**Applied Superconductivity and Cryogenics Unit**

Prof. HIRANO, Naoki (Chief)
Prof. IMAGAWA, Shinsaku
Prof. TAKAHATA, Kazuya
Prof. YANAGI, Nagato
Assoc. Prof. CHIKARAISHI, Hirotaka
Assoc. Prof. HAMAGUCHI, Shinji
Assoc. Prof. HISHINUMA, Yoshimitsu
Assoc. Prof. OBANA, Tetsuhiro
Assist. Prof. ONODERA, Yuta
Assist. Prof. NARUSHIMA, Yoshiro
Assist. Prof. TAKADA, Suguru
Guest Prof. KIKUCHI, Akihiro
Professional Staff YOSHIDA, Shigeru*

**Fusion Science Interdisciplinary Coordination Center**

Prof. MURAKAMI, Izumi (Director)*
Prof. MORISAKI, Tomohiro*
Prof. YASUHARA, Ryo*
Project Prof. IDA, Katsumi*
Project Assoc. Prof. NAKAMURA, Naoko
Project Assist. Prof. KUSABA, Minoru

**Safety and Health Promotion Center**

Prof. OSAKABE, Masaki (Director)*
Specially Appointed Senior Specialist SAZE, Takuya*

**Information Systems and Cyber Security Center**

Assoc. Prof. YAMAMOTO, Takashi (Director)*

**Rokkasho Research Center**

Prof. YOKOYAMA, Masayuki (Director)*

**Research Enhancement Strategy Office**

Prof. YOSHIDA, Zensho (Chief)*
Project Professor MITO, Toshiyuki
Project Professor MUROGA, Takeo
Specially Appointed Senior Specialist CARR, Stephen

**Platform Management Office**

Prof. SAKAMOTO, Ryuichi (Chief)*
Prof. IMAGAWA, Shinsaku*
Prof. TODO, Yasushi*

**Research and Education Innovation Office**

Prof. NAGAOKA, Kenichi (Chief)*

**Public Relations Office**

Prof. TAKAHATA, Kazuya (Chief)*

**Fushion Science Archives Office**

Prof. MURAKAMI, Izumi (Chief)*

**Industry-Academa Collaboration Laboratory**

Prof. YASUHARA Ryo (Chief)*
Prof. YANAGI, Nagato*
Assist. Prof. NARUSHIMA, Yoshiro*

**Library**

Prof. MURAKAMI, Izumi (Chief)*

* concurrent post

※ This list was compiled as of March 31, 2025

**Department of Engineering and Technical Services**

| | | |
|---|---|---|
| | HAYASHI, Hiromi | Director |
| Mechanical Systems Technology Division | YOKOTA, Mitsuhiro | Manager |
| Design and Development Technology Division | SUZUKI, Naoyuki | Manager |
| Electrical and Electronic Technology Division | KONDO, Tomoki | Manager |
| Diagnostics and Analysis Technology Division | HAYASHI, Hiroshi | Manager |
| Control and Information Technology Division | MORIUCHI, Sadatomo | Manager |

※ This list was compiled as of March 31, 2025

**Depertment of Administration**

| | | |
|---|---|---|
| | IINO, Michiko | General Manager |
| General Affairs Division | URUSHIHARA, Rina | Manager |
| | MATSUBARA, Tomohisa | Deputy Manager |
| | UESUGI, Kohtaro | Leader/General Affairs Section |
| | MATSUZAKA, Takehiro | Leader/Planning and Evaluation Section |
| | INAGAKI, Tomoko | Leader/Employee Section |
| | SASAKI, Mitsuru | Leader/Personnel and Payroll Section |
| | HOSOE, Tsunenari | Leader/Communications and Public Affairs Section |
| Financial Affairs Division | HIROI, Noriaki | Manager |
| | ARAI, Masanori | Deputy Manager |
| | HIBINO, Atsushi | Leader/Audit Section |
| | SUZUKI, Takayuki | Leader/Financial Planning Section |
| | KONDO, Takahiko | Leader/Accounts Section |
| | OHTAKE, Hirokazu | Leader/Procurement Section |
| Research Support Division | SHOJI, Madoka | Manager |
| | FUKAYA, Yohsuke | Deputy Manager |
| | SOGA, Shihoko | Leader/Research Support Section |
| | FUKUOKA, Miwa | Leader/International Collaboration Section |
| | KAWAI, Sanae | Leader/Graduate Student Affairs Section |
| | FUKAYA, Yohsuke | Leader/Academic Information Section |
| | FUKAYA, Yohsuke | Director/Visitor Center |
| | HAYASHI, Tomomi | Leader/Visitor Center |
| Facilities and Safety Management Division | | |
| | YASUE, Akihito | Manager |
| | FURUI, Norihiro | Deputy Manager |
| | IWASHIMA, Itsuki | Leader/Facilities Planning Section |
| | NAITO, Kazuhiro | Leader/Facilities Management Section |

※ This list was compiled as of March 31, 2025

# APPENDIX 5. List of Publications I (NIFS Reports)

**NIFS-1130**
Development of the operation scenarios based on the vertical plasma position control in QUEST
Osamu MITARAI, Kazuo NAKAMURA, Makoto HASEGAWA, Takumi ONCHI, Kengou KURODA, Hiroaki TSUTSUI, Aki HIGASHIJIMA, Hiroshi IDEI, Kazuaki HANADA, and Suguru MASUZAKI
Jan. 14, 2025 (In Japanese)

**NIFS-PROC-130**
Proceedings of the meetings on Archives in Fields of Natural Sciences in FY2023
Edited by Y. Takaiwa (KEK) and I. Murakami (NIFS)
Mar. 04, 2025 (In Japanese)

**NIFS-PROC-129**
NIFS-SWJTU JOINT PROJECT FOR CFQS -PHYSICS AND ENGINEERING DESIGN- VER. 6.1 2024. SEP.
CFQS Team
National Institute for Fusion Science, National Institutes of Natural Sciences
Institute of Fusion Science, School of Physical Science and Technology, Southwest Jiaotong University
Hefei Keye Electro Physical Equipment Manufacturing Co. Ltd.
Feb. 21, 2025

**NIFS-PROC-128**
Frontier of pulsed power technology and pulsed-power-produced plasmas/quantum-beams technology
Edited by Douyan Wang and Sadatsugu Muto
Dec. 20, 2024

**NIFS-PROC-127**
Conceptual Design of a Heavy Ion Inertial Fusion Reactor Based on Circular Induction Accelerators
Edited by Jun Hasegawa and Tetsuo Ozaki
May 29, 2024

※ This list was compiled as of March 31, 2025

# APPENDIX 6. List of Publications II (Journals, etc.)

1. Akiyama Y., Ohta A., Manabe Y., Sato F., Iwamoto A., Imagawa S., Utoh H., Nishijima S.
Study on irradiation effect of insulating materials for fusion superconducting magnets: temperature dependence of mechanical strength
IOP Conference Series: Materials Science and Engineering 1302 12003 -2024

2. Banerjee S., Tanaka M., Kato D., Gaigalas G.
Diversity of Early Kilonova with the Realistic Opacities of Highly Ionized Heavy Elements
The Astrophysical Journal 968 2 64 -2024

3. Cui Z., Zhang X., Xu Y., Shimizu A., Ogawa K., Takahashi H., Isobe M., Lei G., Liu S., Li H., Hu J., Zhu Y., Li X., Zheng H., Liu X., Liu H., Wang X., Liu H., Tang C.
The evolutionary process of W-V mixed dumbbell in tungsten crystals: A study about W-V alloy as a plasma-facing material in fusion devices
Fusion Engineering and Design 208 114655 -2024

4. Emoto M., Nakanishi H., Ohsuna M., Imazu S., Yoshida M., Nonomura M., Sakamoto R.
Plasma and Fusion Cloud Data Analysis Environment
Fusion Engineering and Design 211 114789 -2025

5. Fu T., Wang X., Su X., Xu Y., Okamura S., Shimizu A., Isobe M., Cheng J., Liu H., Huang J., Zhang X., Liu H., Tang C.
Suppression of equilibrium magnetic islands by density profile effect in quasi-axisymmetric stellarator plasmas
Plasma Physics and Controlled Fusion 66 6 65026 -2024

6. Fujita Y., Nakamura H., Kawaguchi H., Goto Y., Kubo S.
Generating optical vortex beams using cylindrical waveguides
Japanese Journal of Applied Physics 63 10 10SP07 -2024

7. Goto M., Nojiri K., Simons J., Kawate T., Oishi T., Yatsuka E., Yanagihara Y., Isobe M., Nunoya Y.
Influence of Stark Broadening on Ion Temperature Measurement for ITER Divertor Diagnosis
Plasma and Fusion Research 20 Special Issue 1 2401012 -2025

8. Goto Y., Tsujimura T., Kubo S.
Azimuthal mode decomposition of millimeter-wave integer and non-integer optical vortices generated by a spiral mirror
AIP Advances 15 2 25225 -2025

9. Goya K., Noda S., Ishida G., Tachibana K., Uehara H., Tokita S.
Mid-infrared refractometer based on side-polished indium fluoride fiber for monitoring relative humidity
Applied Physics Express 18 3 32003 -2025

10. Habara H., Ueyama Y., Nakamura Y., Sakagami H.
Stable creation of a single plasma channel and collimated fast electrons using large-scale PIC simulations with new dynamic load-balancing technique
High Energy Density Physics 53 101147 -2024

11. Hamaji Y., Hayashi Y., Masuzaki S.
Development of a heated liquid Sn flowing system and preliminary results of wettability improvement by inter-metallic layer
Fusion Engineering and Design 210 114727 -2025

12. Hayashi W., Heidbrink W., Muscatello C., Lin D., Osakabe M., Ogawa K., Kawamoto Y., Yamaguchi H., Seki R., Nuga H., Isobe M., Fujiwara Y., Kamio S.
Charge-exchange measurements of high-energy fast ions in LHD using negative-ion neutral beam injection
Journal of Instrumentation 19 P12006 -2024

13. Hayashi Y., Masuzaki S., Kobayashi M., Kawamura G., Mukai K., Tanaka H., Murase T.
Heat flux mitigation characteristics in the radiative divertors with multi-peaks of heat flux in the large helical device
Plasma Physics and Controlled Fusion 67 2 25010 -2025

14. Hu J., Zhang X., Xu Y., Lei G., Liu S., Tsumori K., Nakano H., Osakabe M., Isobe M., Okamura S., Shimizu A., Ogawa K., Takahashi H., Li H., Cui Z., Zhu Y., Li X., Zheng H., Liu X., Geng S., Chen X., Liu H., Wang X., Liu H., Cheng J., Tang C.
Theoretical investigation of structural, electronic, mechanical, surface work function and thermodynamic properties of La1-xMxB6 (M = Ba, Sr, Ca) compounds: Potential plasma grid materials in N-NBI system
Nuclear Materials and Energy 41 101813 -2024

15. Ida K.
Overview of Large Helical Device experiments of basic plasma physics for solving crucial issues in reaching burning plasma conditions
Nuclear Fusion 64 11 112009 -2024

16. Imagawa S.
Effect of Magnetic Field Distribution on Recovery Currents of NbTi Superconducting Conductors
低温工学 (Journal of the Cryogenic Society of Japan) 59 3 114-122 -2024

17. Inomoto M., Suzuki T., Jin H., Maeda Y., Togo Y., Cho S., Tanabe H., Ono Y., Kawamori E., Usami S., Yanai R.
The role of an in-plane electric field during the merging formation of spherical tokamak plasmas
Nuclear Fusion 64 8 86060 -2024

18. Ishikawa R., Katsukawa Y.
Origin of Line Broadening in Fading Granules: Influence of Small-scale Turbulence
The Astrophysical Journal 975 1 98 -2024

19. Ishizawa A., Kishimoto Y., Imadera K., Nakamura Y., Maeyama S.
Plasma beta dependence of turbulent transport suggesting an advantage of weak magnetic shear from local and global gyrokinetic simulations
Nuclear Fusion 64 6 66008 -2024

20. Ito A., Toda Y., Takayama A.
Quantum Electron Dynamics in Helium Ion Injection onto Tungsten Surfaces Based on Time-Dependent Density Functional Theory
Nuclear Materials and Energy 42 101836 -2025

21. Kajita S., Hiraiwa K., Tanaka H., Iwai R., Aramaki M., Yasuhara R., Ohno N.
TALIF measurements of atomic deuterium in toroidal divertor simulator NAGDIS-T
Nuclear Materials and Energy 42 101898 -2025

22. Kang B., Sugama H., Watanabe T., Nunami M.
Comprehensive gyrokinetic study of eigenstate transitions in fast ion-driven electrostatic drift instabilities
Physics Letters A 535 130278 -2025

23. Kataoka K., Mukai K., Yagi J., Nakajima M., Jae-hwan K., Nozawa T.
Corrosive behavior of structural F82H RAFM steel by LTZO ceramic breeder pebbles
Nuclear Materials and Energy 42 101875 -2025

24. Kato D., Tanaka M., Gaigalas G., Kitoviene L., Rynkun P.
Systematic opacity calculations for kilonovae – II. Improved atomic data for singly ionized lanthanides
Monthly Notices of the Royal Astronomical Society 535 3 2670-2686 -2024

25. Kato T., Sugama H., Watanabe T., Nunami M.
Energy exchange between electrons and ions in ion temperature gradient turbulence
Physics of Plasmas 31 6 62510 -2024

26. Kawate T., Goto M., Oishi T., Kawamoto Y., Yamada I., Funaba H., Takahashi H.
Detection of electron temperature anisotropy by an x-ray crystal spectrometer in the Large Helical device
Physica Scripta 100 3 35612 -2025

27. Kenmochi N., Ida K., Tokuzawa T., Mizuno Y., Yasuhara R., Funaba H., Uehara H., Den hartog D., Yoshinuma M., Takemura Y., Igami H., Yanai R.
Fast nondiffusive response of heat and turbulence pulse propagation
Scientific Reports 14 13006 -2024

28. Kimura N., Miya Y., Ito D., Vishwakarma P., Kato D., Baba M., Kuma S., Azuma T., Nakamura N.
Laboratory Transition-rate Measurement of the Coronal Intercombination Line of Ar xv by Time-resolved Laser Spectroscopy
The Astrophysical Journal 972 1 12 -2024

29. Kinoshita T., Tanaka K., Ishizawa A., Sakai H., Nunami M., Ohtani Y., Yamada H., Sato M., Nakata M., Tokuzawa T., Yasuhara R., Takemura Y., Yamada I., Funaba H., Ida K., Yoshinuma M., Tsujimura T., Seki R., Ichiguchi K., Michael C.
Turbulence Transition in Magnetically Confined Hydrogen and Deuterium Plasmas
Physical Review Letters 132 23 235101 -2024

30. Kobayashi M., Takahashi J., Ota H., Matsuo K., Ibrahim M., Minato T., Fujimori G., Katoh M., Kobayashi K., Kebukawa Y., Nakamura H.
Emergence of optical activity and surface morphology changes in racemic amino acid films under circularly polarized Lyman-α light irradiation
Chirality 36 11 e70004 -2024

31. Kobayashi M., Yoshihashi S., Ogawa K., Isobe M., Aso T., Hara M., Sangaroon S., Kusaka S., Tamaki S., Murata I., Toyama S., Miwa M., Matsuyama S., Osakabe M.
Application of a Single-Crystal CVD Diamond Detector for Fast Neutron Measurement in High Dose and Mixed Radiation Fields
IEEE Transactions on Instrumentation and Measurement 73 6010808 -2024

32. Kobayashi M., Yoshihashi S., Ogawa K., Isobe M., Aso T., Hara M., Sangaroon S., Tamaki S., Murata I., Miwa M., Toyama S., Matsuyama S., Osakabe M.
Simultaneous measurements for fast neutron flux and tritium production rate using pulse shape discrimination and single crystal CVD diamond detector
Nuclear Fusion 64 6 66026 -2024

33. Kobayashi M., Yoshimura S., Iwayama H., Kondo N., Takahashi J., Ota H., Katoh M., Kobayashi K., Nakamura H.
First Attempt at Photoionized Plasma Production with VUV Radiation in Synchrotron Light Source UVSOR-III
Plasma and Fusion Research 19 Regular Issue 1301028 -2024

34. Kobayashi T., Kobayashi M., Narushima Y., Suzuki Y., Tanaka K., Motojima G., Watanabe K., Mukai K., Hayashi Y.
New type of self-sustained divertor oscillation driven by magnetic island dynamics in Large Helical Device
Nuclear Fusion 64 7 76059 -2024

35. Kobayashi T., Yoshinuma M., Hu W., Ida K.
Detection of bifurcation in phase-space perturbative structures across transient wave–particle interaction in laboratory plasmas
Proceedings of the National Academy of Sciences 121 46 e2408112121 -2024

36. Kotani T., Toida M., Moritaka T., Taguchi S.
Generation of the Harmonic Structure of Upper Hybrid and Electron Cyclotron Waves Driven by Energetic Electrons
Plasma and Fusion Research 19 Regular Issue 1201033 -2024

37. Kotani T., Toida M., Moritaka T., Taguchi S.
Parametric Study of the Harmonic Structure of Lower Hybrid Waves Driven by Energetic Ions
Journal of Geophysical Research: Space Physics 129 9 e2024JA032824 -2024

38. Lazerson S., Geiger J., Kulla D., Leviness A., Bozhenkov S., Killer C., Ogawa K., Isobe M., Mcneely P., Rust N., Hartmann D., W7-x team T.
Fast ion confinement in the presence of core magnetic islands in Wendelstein 7-X
Plasma Physics and Controlled Fusion 66 7 75017 -2024

39. Le T., Suzuki Y., Ohtani H., Hasegawa H., Moritaka T.
Poloidally asymmetric potential formation on plasma boundary in axisymmetric magnetic field
Frontiers in Physics 12 1398172 -2024

40. Leviness A., Lazerson S., Jansen van vuuren A., Rueda-Rueda J., Ayllon-guerola J., Bozhenkov S., Corl D., Ellis R., Galdon-Quiroga J., Garcia-dominguez J., Garcia-Munoz M., Hidalgo-salaverri J., Ogawa K., Pablant N., Segado-fernandez J., W7-x team T.
Simulation of a scintillator-based fast ion loss detector for steady-state operation in Wendelstein 7-X
Review of Scientific Instruments 95 7 73529 -2024

41. Leviness A., Lazerson S., Jansen van vuuren A., Rueda-Rueda J., Beurskens M., Bozhenkov S., Brunner K., Ford O., Fuchert G., Garcia-Munoz M., Isobe M., Killer C., Knauer J., Ogawa K., Pablant N., Pasch E., Poloskei P., Romba T., W7-x team T.
Validation of a synthetic fast ion loss detector model for Wendelstein 7-X
Nuclear Fusion 64 9 96034 -2024

42. Li H., Fujiwara S., Nakamura H., Mizuguchi T., Saito S., Sakai W.
Reactive molecular dynamics simulations of the intra- and intermolecular reactions of hydrogen-abstracted polyethylene chains
Molecular Simulation 51 2 122-127 -2025

43. Li H., Zhang X., Xu Y., Lei G., Liu S., Tsumori K., Nakano H., Osakabe M., Isobe M., Okamura S., Shimizu A., Ogawa K., Takahashi H., Cui Z., Hu J., Zhu Y., Li X., Zheng H., Liu X., Geng S., Chen X., Liu H., Wang X., Liu H., Tang C.
Effect of oxygen or copper impurities on the work function of cesiated surfaces under co-existence with hydrogen: A study about negative hydrogen ion sources for neutral beam injection systems
Nuclear Materials and Energy 41 101792 -2024

44. Liao L., Ogawa K., Sangaroon S., Paenthong W., Kusaka S., Tamaki S., Murata I., Isobe M.
The initial measurement of a compact D–T neutron spectrometer based on a single-crystal chemical vapor deposition diamond stack for fusion plasma diagnostic
Review of Scientific Instruments 95 7 73533 -2024

45. Maekaku K., Sugama H., Watanabe T.
Time evolutions of information entropies in a one-dimensional Vlasov–Poisson system
Physics of Plasmas 31 10 102101-1-25 -2024

46. Maeyama S., Honda M., Narita E., Toda S.
Multi-Fidelity Information Fusion for Turbulent Transport Modeling in Magnetic Fusion Plasma
Scientific Reports 14 28242 -2024

47. Maeyama S., Howard N., Citrin J., Watanabe T., Tokuzawa T.

Overview of multiscale turbulence studies covering ion-to-electron scales in magnetically confined fusion plasma
Nuclear Fusion 64 11 112007 -2024

48. Maeyama S., Watanabe T., Nakata M., Nunami M., Asahi Y., Ishizawa A.

Rotating flux-tube model for local gyrokinetic simulations with background flow and magnetic shears
Journal of Computational Physics 522 113595 -2025

49. Masuzaki S., Shoji M., Nespoli F., Lunsford R., Motojima G., Yajima M., Tokitani M., Oishi T., Kawate T., Goto M., Kasahara H., Yoshimura Y., Gilson E., Pablant N., Morisaki T.

Glow Discharge Boronization and Real-Time Boronization Using an Impurity Powder Dropper in LHD
Nuclear Materials and Energy 42 101843 -2025

50. Minagawa H., Yoshimura S., Terasaka K., Aramaki M.

Data-volume reduction of optical vortex laser absorption spectroscopy by coarse-graining using a quadrant photodiode
Japanese Journal of Applied Physics 63 5 56002 -2024

51. Miura H.

Formation of fine structures in incompressible Hall magnetohydrodynamic turbulence simulations
Plasma 7 4 793-815 -2024

52. Nagasaka T., Shen J., Ando M., Kato T., Nozawa T., Tanigawa H.

Tensile and creep properties of small specimens of reduced-activation ferritic steel F82H, and the correlation to standard specimen data
Nuclear Science and Technology Open Research 2 56 -2024

53. Nakamura H., Ishiguro K., Nakata A., Usami S., Saito S., Fujiwara S.

Reactive molecular dynamics simulation on DNA double-strand breaks induced by hydrogen elimination
Japanese Journal of Applied Physics 63 12 12SP09 -2024

54. Nasu T., Tokuzawa T., Nakata M., Ida K., Inagaki S., Nishiura M., Yoshimura Y., Yanai R., Tanaka K., Yoshinuma M., Kobayashi T., Ejiri A., Watanabe K., Yamada I., LHD Experiment Group .

Electron-scale turbulence characteristics with varying electron temperature gradient in LHD
Nuclear Fusion 64 9 96008 -2024

55. Nishimoto S., Nagaoka K., Nakata M., Yoshimura S., Tanaka K., Yokoyama M., Nunami M., Tokuzawa T., Suzuki C., Seki R., Yoshinuma M., Motojima G., Ida K., Suzuki Y.

Experimental study of the effect of geodesic curvature on turbulent transport in magnetically confined plasma
Plasma Physics and Controlled Fusion 66 4 45010 -2024

56. Nishimura R., Oishi T., Murakami I., Kato D., Sakaue H., Gupta S., Ohashi H., Goto M., Kawamoto Y., Kawate T., Takahashi H., Tobita K.

Collisional-Radiative modeling of unresolved transition array spectra near 200 Å from W17+-W25+ emissions for diagnostics of ITER edge plasma
Nuclear Materials and Energy 41 101740 -2024

57. Nishimura R., Oishi T., Murakami I., Kato D., Sakaue H., Gupta S., Ohashi H., Goto M., Kawamoto Y., Kawate T., Takahashi H., Tobita K.

Observation and identification of W19+-W23+ spectra in the EUV wavelength region in the vicinity of 200Å
Plasma and Fusion Research 19 Regular Issue 1402022 -2024

58. Nishiura M., Shimizu A., Ido T., Satake S., Yoshinuma M., Yanai R., Nunami M., Yamaguchi H., Nuga H., Seki R., Fujita K., Salewski M.

Core density profile control by energetic ion anisotropy in LHD
Physics of Plasmas 31 6 62505 -2024

59. Noto H., Wakai E.

Overview of strengthening and working technique on Fusion materials
Research & Development in Material Science 21 1 2493-2496 -2024

60. Nuga H., Seki R., Ogawa K., Yamaguchi H., Kamio S., Fujiwara Y., Kawamoto Y., Yoshinuma M., Kobayashi T., Takemura Y., Isobe M., Osakabe M., Yokoyama M.

Degradation of fast-ion confinement depending on the neutral beam power in MHD quiescent LHD plasmas
Nuclear Fusion 64 6 66001 -2024

61. Obana T.

Investigating the Effect of Coil Length, Alignment Errors and Cooling Down on a Superconducting Magnet With Active Shielding for Rotating Gantry
IEEE Transactions on Applied Superconductivity 34 5 4401105 -2024

62. Ogawa K., Isobe M., Sangaroon S., Liao L., Zhong G., Seki R., Nuga H., Osakabe M.

Observation of energetic ion anisotropy using neutron diagnostics in the Large Helical Device
Nuclear Fusion 64 7 76010 -2024

63. Ogawa K., Jo J., Kim J., Liao L., Sangaroon S., Takada E., Isobe M.

A scintillating-fiber detector for making high-time-resolution secondary D–T neutron measurements in KSTAR
Review of Scientific Instruments 95 7 73539 -2024

64. Ogawa K., Magee R., Tajima T., Gota H., Mccarroll P., Allfrey I., Nuga H., Isobe M., Osakabe M.

Demonstration of aneutronic p-11B reaction in a magnetic confinement device
Nuclear Fusion 64 9 96028 -2024

65. Ogawa K., Zhong G., Liao L., Chen W., Zhou R., Li K., Takada E., Sangaroon S., Hu L., Isobe M.

Time-resolved deuterium–deuterium fusion born 1 MeV triton confinement study in EAST deuterium plasma
Plasma Physics and Controlled Fusion 67 2 25001 -2025

66. Ohno N., Takano F., Yamanaka A., Ohtani H., Kageyama A.

Digital-LHD: LHD Visualizer for Head-Mounted Display Systems
Plasma and Fusion Research 19 Regular Issue 1401029 -2024

67. Ohya M., Imagawa S., Shirai Y., Kobayashi H.

Energization test apparatus of HTS coils cooled by liquid hydrogen and manufacture of split-type REBCO external field coil
Journal of Physics: Conference Series 2776 12010 -2024

68. Oishi T., Morita S., Kato D., Murakami I., Sakaue H., Goto M., Kawamoto Y., Kawate T., Nishimura R., Takahashi H., Tobita K.

Observation of tungsten emission spectra up to W46+ ions in the Large Helical Device and contribution to the study of high-Z impurity transport in fusion plasmas
Nuclear Fusion 64 10 106011 -2024

69. Pégourié B., Geulin E., Goto M., Matsuyama A., Motojima G., Sakamoto R.

Structure of pellet cloud emission and relation with the local ablation rate
Nuclear Fusion 64 5 56026 -2024

70. Paenthong W., Ogawa K., Sangaroon S., Du X., Liu D., Liao L., Wisitsorasak A., Onjun T., Isobe M.

Design and initial results of the imaging neutral particle analyzer in large helical device
Review of Scientific Instruments 95 8 83547 -2024

71. Petrosky T., Goto Y., Garmon S.

Classicalization of Quantum Mechanics: Classical Radiation Damping Without the Runaway Solution
Physics 6 4 1191-1203 -2024

72. Rattanawongnara E., Osakabe M., Nakano H., Tsumori K., Nagaoka K., Takeiri Y.
Evaluation of H-/D- Density Using Langmuir Probe Measurement in a Cs Seeded Negative Ion Source
Journal of Physics: Conference Series 2743 1 12084 -2024

73. Rongpuit K., Wisitsorasak A., Sangaroon S., Ogawa K., Pattanaboonmee N., Chewpraditkul C., Tangwancharoen S., Suksaengpanomrung S., Tamman A., Chatthong B., Poolyarat N., Isobe M.
Initial results of hard X-ray spectroscopy by LaBr3(Ce) detector for runaway electron study in Thailand Tokamak-1
Radiation Physics and Chemistry 227 112346 -2025

74. Saito S., Nakamura H., Sawada K., Hoshino K., Kojima Y., Doi T., Kobayashi M., Hasuo M., Homma Y., Yamoto S.
Emission of high rovibrational hydrogen molecules under detached plasma conditions by recycling on the tungsten wall
Nuclear Fusion 64 12 126067 -2024

75. Saito S., Sato S., Nakamura H., Takahashi C., Sawada K., Hoshino K., Kobayashi M., Hasuo M.
Deep learning model for predicting the spatial distribution of binding energy from atomic configurations
Japanese Journal of Applied Physics 63 9 09SP03 -2024

76. Saito S., Takahashi T., Mizuguchi N.
First Confinement Time Evaluation for Particles Axially Injected into a Non-Adiabatic Trap
Plasma and Fusion Research 20 Regular Issue 1203023 -2025

77. Sakai K., Huang T., Khasanah N., Bolouki N., Chu H., Moritaka T., Sakawa Y., Sano T., Tomita K., Matsukiyo S., Morita T., Takabe H., Yamazaki R., Yasuhara R., Habara H., Kuramitsu Y.
Competition of magnetic reconnections in self-generated and external magnetic fields
High Energy Density Physics 52 101132 -2024

78. Sakaki T., Watanabe T., Maeyama S.
Convective growth of auroral arcs through the feedback instability in a dipole geometry
Journal of Geophysical Research: Space Physics 129 12 e2023JA032407 -2024

79. Sangaroon S., Ogawa K., Isobe M.
Neutron emission spectrometer in magnetic confinement fusion
AAPPS Bulletin 34 34 -2024

80. Sangaroon S., Ogawa K., Isobe M., Liao L., Zhong G., Wisitsorasak A., Takada E., Kobayashi M., Poolyarat N., Murakami S., Seki R., Nuga H., Osakabe M.
Neutron Spectroscopy in Perpendicular Neutral Beam Injection Deuterium Plasmas Using Newly Developed Compact Neutron Emission Spectrometers
IEEE Transactions on Instrumentation and Measurement 73 1006911 -2024

81. Sato N.
Quantum-Fluid Correspondence in Relativistic Fluids with Spin: From Madelung Form to Gravitational Coupling
Classical and Quantum Gravity 42 2 25017 -2025

82. Sato N., Morrison P.
A collision operator for describing dissipation in noncanonical phase space
Fundamental Plasma Physics 10 100054 -2024

83. Sato N., Yamada M.
A Reduced Ideal MHD System for Nonlinear Magnetic Field Turbulence in Plasmas with Approximate Flux Surfaces
Journal of Mathematical Physics 65 9 93101 -2024

84. Seki R., Todo Y., Suzuki Y., Spong D., Ogawa K., Isobe M., Osakabe M.
Orbit-following simulations of fast-ion transport and losses due to the Alfvén eigenmode burst in the Large Helical Device
Physics of Plasmas 31 10 102503 -2024

85. Shen J.

Influences of minor Ti addition on microstructure and tensile properties of high-purity V-10Cr alloys
Materials Science and Engineering: A 915 147263 -2024

86. Shoji M., Kawamura G., Smirnov R., Romazanov J., Kirschner A., Tanaka Y., Masuzaki S., Kawate T., Nespoli F., Lunsford R., Gilson E., Brezinsek S., Pablant N.

Full-torus impurity transport simulation in boron powder injection experiments in the Large Helical Device
Nuclear Materials and Energy 41 101803 -2024

87. Shoji M., Kawamura G., Smirnov R., Tanaka Y., Masuzaki S., Nespoli F., Gilson E., Lunsford R.

Self-consistent transport simulation of boron dust particle injection in the peripheral plasma in Large Helical Device
Contributions to Plasma Physics 64 7月8日 e202300105 -2024

88. Su X., Wang X., Xu Y., Okamura S., Shimizu A., Isobe M., Cheng J., Liu H., Huang J., Zhang X., Liu H., Luo Y., Shen J., Hu J., Tang C.

Controlling three-dimensional magnetic island appearance with external current drive in the Chinese first quasi-axisymmetric stellarator
Nuclear Fusion 64 7 76023 -2024

89. Sugama H.

Local momentum balance in electromagnetic gyrokinetic systems
Physics of Plasmas 31 4 42303 -2024

90. Sugiyama T., Masuzaki S., Shoji M., Hayashi Y., Motojima G., Ogawa K., Kawamura G., Kanno R., Ohtani H.

Asymmetry in particle load on divertor tiles in different magnetic field configurations of LHD
Nuclear Materials and Energy 41 101830 -2024

91. Takahata K.

Transition Boiling Heat Transfer on a Horizontal Surface Using Liquid Nitrogen: Observation of Steady-state Boiling Curves in the Transition Boiling Regime and Hysteresis Appearing in the Curves
低温工学 (Journal of the Cryogenic Society of Japan) 60 1 13-20 -2025

92. Tanaka M., Kato H., Suzuki N., Chimura H., Yonezu H., Masuzaki S.

Determination of tritium inventory in carbon divertor tiles used in deuterium plasma experiment by induction heating method
Nuclear Materials and Energy 42 101876 -2025

93. Tanaka M., Kurita S., Akata N.

Impacts of the large fusion test facility on tritium in environmental water and natural radiation levels
Radiation Protection Dosimetry 200 16-18 1802-1806 -2024

94. Tanoue H., Nakagawa S., Nagahara K., Murase T., Shimizu A., Ogawa K., Takahashi H., Shoji M., Okamura S., Isobe M., Osakabe M., Yin D., Liu H., Xu Y.

Engineering design and manufacturing of the modular coil system for the quasi-axisymmetric stellarator CFQS-T
Fusion Engineering and Design 212 114853 -2025

95. Toida M., Kotani T.

Simulation study of energetic-ion mass dependence on nonlinear development of lower hybrid wave instabilities
Physics of Plasmas 31 12 122304 -2024

96. Tokitani M., Miyamoto M., Masuzaki S., Hatano Y., Lee S., Oya Y., Kurotaki H., Asakura N., Nakamura H., Hayashi T., Rubel M., Widdowson A., Likonen J.

Co-deposited layers on gap surfaces of bulk tungsten divertor tiles in JET ITER-like wall: Directional effects and nanostructures
Nuclear Materials and Energy 39 101678 -2024

97. Tokuzawa T., Yoshida M., Imazawa R., Nakagawa S., Inagaki S., Kin F., Chiba S., Suzuki N., Nasu T., Fujisawa A., Ida K.

Preparatory study of feasibility for a vertical viewing electron cyclotron emission diagnostic for the JT-60SA tokamak
Review of Scientific Instruments 95 8 83531 -2024

98. Tsunoda K., Fujita T., Okamoto A., Morizawa S., Kato S., Oshiro T., Nakagawa S., Murase T., Isobe M., Shimizu A.

Three-Dimensional Analysis of Eddy Current in TOKASTAR-2
Plasma and Fusion Research 20 Regular Issue 1402016 -2025

99. Ueda K., Nishiura M.

Nonlinear Gaussian process tomography with imposed non-negativity constraints on physical quantities for plasma diagnostics
Machine Learning: Science and Technology 6 1 15061 -2025

100. Urano T., Takahashi T., Mizuguchi N., Asai T., Okada S.

Hybrid simulation study on ion heating by low-frequency wave excited in a field-reversed configuration
Nuclear Fusion 65 3 36026 -2025

101. Vanthieghem A., Tsiolis V., Spitkovsky A., Todo Y., Sekiguchi K., Fiuza F.

Electron Heating in High Mach Number Collisionless Shocks
Physical Review Letters 132 26 265201 -2024

102. Wang C., Kawaguchi H., Nakamura H., Kubo S.

The study of propagation characteristics of the millimeter-wave vortex in magnetized plasma by using the FDTD method
Japanese Journal of Applied Physics 63 9 09SP08 -2024

103. Wang H., Lauber P., Todo Y., Suzuki Y., Li H., Idouakass M., Wang J., Adulsiriswad P., ASDEX Upgrade T.

Nonlinear excitation of energetic particle driven geodesic acoustic mode by resonance overlap with Alfven instability in ASDEX Upgrade
Scientific Reports 15 1130 -2025

104. Wang H., Lauber P., Todo Y., Suzuki Y., Li H., Wang J., Wei S.

Nonlinear excitation of energetic particle driven geodesic acoustic mode by Alfvén instability in ASDEX-Upgrade Tokamak
Nuclear Fusion 64 7 76015 -2024

105. Wenzel U., Motojima G., Mackel F., Arkhipov A., Jagielski B., Haak V., Meister H., Marquardt M., Fox-widdows E.

Performance of ITER pressure gauges during deuterium operation in the Large Helical Device
Plasma Physics and Controlled Fusion 66 12 125017 -2024

106. Xu M., Zhong G., Zhang Y., Huang L., Hu L., Zhang R., Yang L., Zhang Y., Chen W., Li Y., Sangaroon S., Ogawa K., Isobe M., Liao L., Fan T.

Investigation of Cs27LiYCl6:Ce scintillator energy response for D-D fusion neutron spectrometer
Fusion Engineering and Design 204 114490 -2024

107. Yamagishi O.

Neoclassical transport computations in non-isothermal tokamak plasmas
Physics of Plasmas 31 10 102502 -2024

108. Yamanaka K., Nakanishi H., Tokunaga S., Urushidani S.

A data transfer method for physics data of experimental fusion reactors using virtual disks
Fusion Engineering and Design 211 114743 -2025

109. Yamauchi Y., Tanoue Y., Keta K., Nagasaka T., Shen J., Tomioka S., Matsumoto Y.
Deuterium and helium desorption/retention properties of low-activation vanadium alloys possible for reuse in a short time in fusion reactors
Nuclear Materials and Energy 39 101655 -2024

110. Yang H., Yasuhara R., Noto H., Nagata D., Tokitani M., Kawaguchi H., Suzuki C., Miyagawa R., Uehara H.
Effect of Nanosecond Laser Irradiation on Tungsten Grain Structure
Nuclear Materials and Energy 40 101688 -2024

111. Yoshida Z.
Kinetic Theory with Casimir Invariants–Toward Understanding of Self-Organization by Topological Constraints
Entropy 27 1 5 -2025

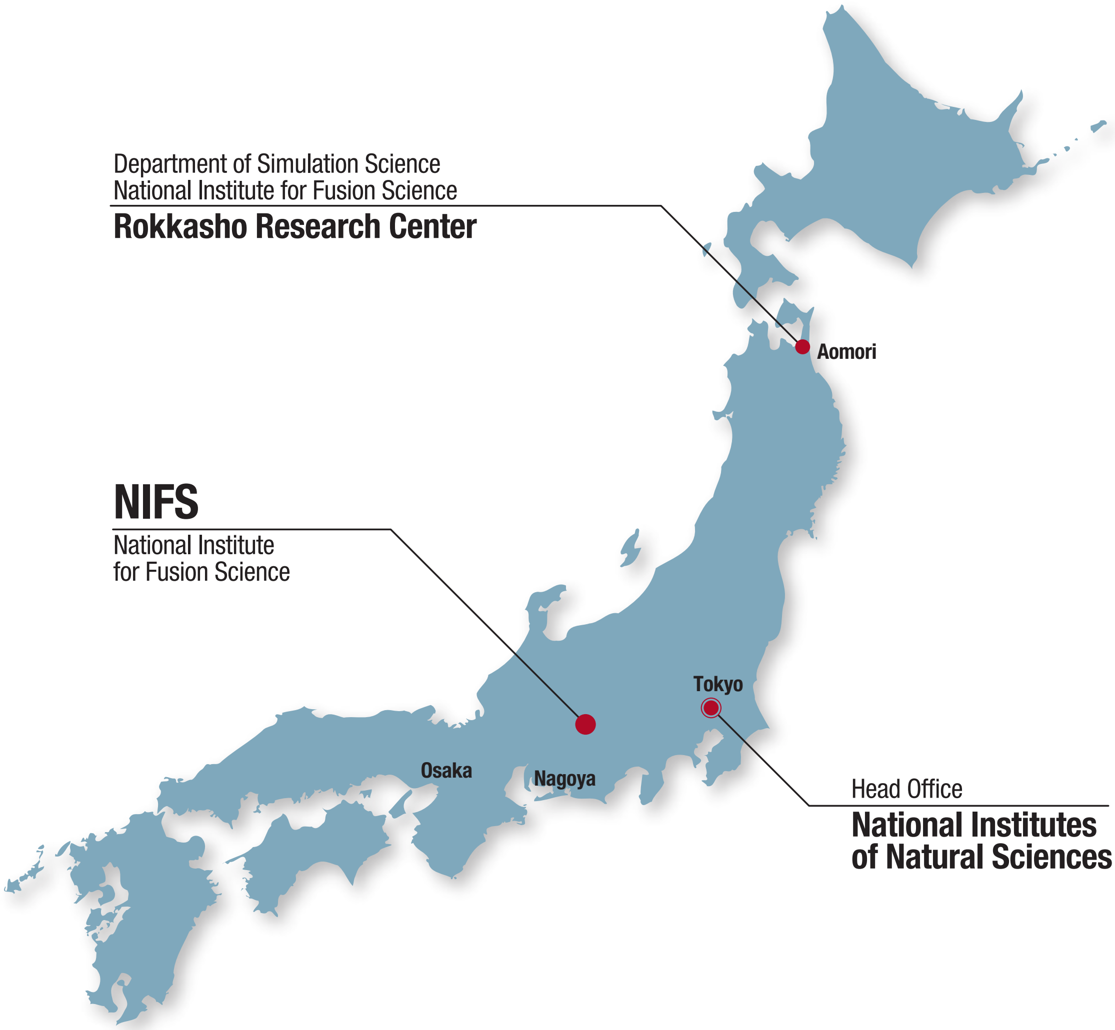
112. Yoshinuma M., Ida K., Ebihara Y.
Development of Hyperspectral Camera for Auroral Imaging (HySCAI)
Earth, Planets and Space 76 96 -2024

113. Yoshinuma M., Ida K., Kobayashi T.
Fast Charge Exchange Spectroscopy for Measurements of Ion-Velocity-Space Distribution Function
Plasma and Fusion Research 19 Regular Issue 1402037 -2024

114. Zhang X., Shimizu A., Nakagawa S., Xu Y., Murase T., Tanoue H., Nagahara K., Shoji M., Cui Z., Hayashi H., Ogawa K., Takahashi H., Isobe M., Okamura S., Liu H., Wang X., Liu H., Hu J., Cheng J., Tang C.
Investigation of modular coil misalignment on magnetic flux surface in the CFQS quasi-axisymmetric stellarator
Fusion Engineering and Design 211 114820 -2025

115. Zhang Y., Zhong G., Huang L., Xu M., Hu L., Huang J., Xu K., Zhang R., Yang L., Mai C., Zhang Y., Chen W., Ogawa K., Isobe M., Fan T., Zhou M.
Study on the contribution matrix for EAST radial neutron camera system
Fusion Engineering and Design 206 114602 -2024

# National Institute for Fusion Science




**National Institute for Fusion Science**
**National Institutes of Natural Sciences**
(TOKI Area)

322-6 Oroshi-cho
Toki-city, GIFU
509-5292

TEL: 0572-58-2222 FAX: 0572-58-2601

**Rokkasho Research Center**
**Department of Helical Plasma Research**
**Located in the Aomori Research and Development Center**
**Japan Atomic Energy Agency**

2-166 Oaza-Obuchi-Aza-Omotedate,
Rokkasho-mura, Kamikita-gun,
AOMORI
039-3212

TEL/FAX: 0175-73-2151

# How to Reach National Institute for Fusion Science


□**ACCESS**

**When you use the public transportation facility**

◇**from Centrair** (Central Japan International Airport)

**Centrair**–(μ-sky)–**Meitetsu Kanayama Sta. (36km)**
about 25min

**JR Kanayama Sta.**–(JR Chuo Line)–**JR Tajimi Sta. (33km)**
about 33min (express)

**JR Tajimi Sta.**–(Totetsu Bus)–**Kenkyuugakuentoshi (7km)**
about 15min

◇**from JR Nagoya Sta.**

**JR Nagoya Sta.**–(JR Chuo Line)–**JR Tajimi Sta. (36km)**
about 22min (limited express) / about 30min (lapid) / about 40min (local)

**JR Tajimi Sta.**–(Totetsu Bus)–**Kenkyuugakuentoshi (7km)**
about 15min

◇**from Nagoya Airport**

(Obihiro•Akita•Yamagata•Niigata•Kouchi• Matsuyama•Fukuoka•Kumamoto•Nagasaki)

**Nagoya Airport**–(Taxi)–**JR Kachigawa Sta. (4km)**
about 10min

**Nagoya Airport**–(Meitetsu Bus)–**JR Kachigawa Sta. (4km)**
about 19min

**JR Kachigawa Sta.**–(JR Chuo Line)–**JR Tajimi Sta. (21km)**
about 20min

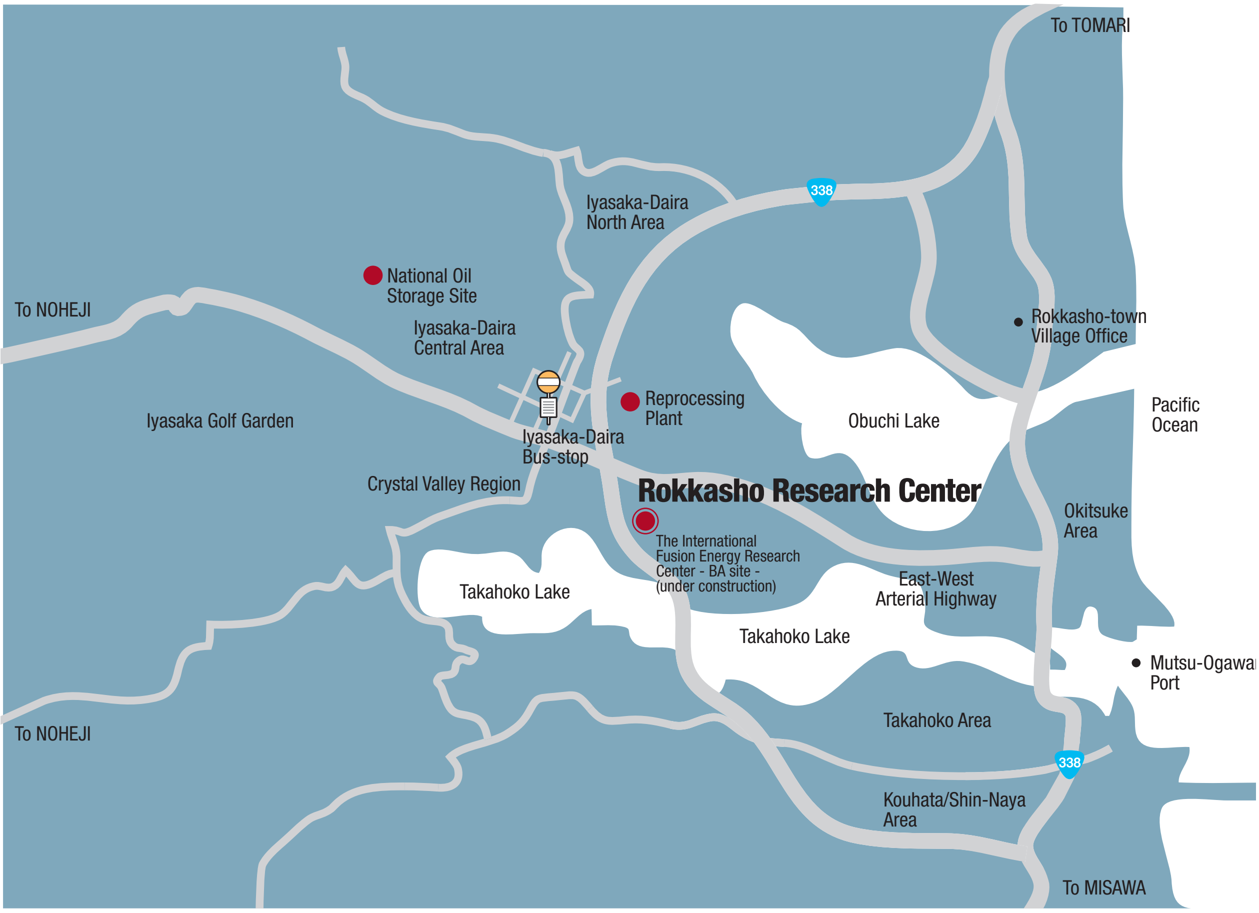
**JR Tajimi Sta.**–(Totetsu Bus)–**Kenkyuugakuentoshi (7km)**
about 15min

**When you use a car**

**from Chuo Expressway Toki I.C. or Tajimi I.C. (8km)**
about 20min

**from Tokai-Kanjo Expressway Tokiminami Tajimi I.C. (2km)**
about 5min

# How to Reach Rokkasho Research Center




☐**ACCESS**
**When you use the public transportation facility**

◇**from Tokyo**

Tokyo–(Tohoku-Shinkansen)–Hachinohe Sta. (630km)
about 3hr

Hachinohe Sta.–(JR Tohoku Limited Express)–Noheji (51km)
about 30min

Noheji–(Shimokita Koutsu Bus)–Iyasaka-Daira (10km)
about 40min

Iyasaka-Daira.....on foot.....Rokkasho Research Center (0.7km)
about 8min

◇**from Misawa Airport**

Misawa Airport–(Bus)–Misawa (2km)
about 13min

Misawa–(JR Tohoku Limited Express)–Noheji (30km)
about 20min

Noheji–(Shimokita Koutsu Bus)–Iyasaka-Daira (10km)
about 40min

Iyasaka-Daira.....on foot.....Rokkasho Research Center (0.7km)
about 8min

◇**from Aomori Airport**

Aomori Airport–(Bus)–Aomori (12km)
about 40min

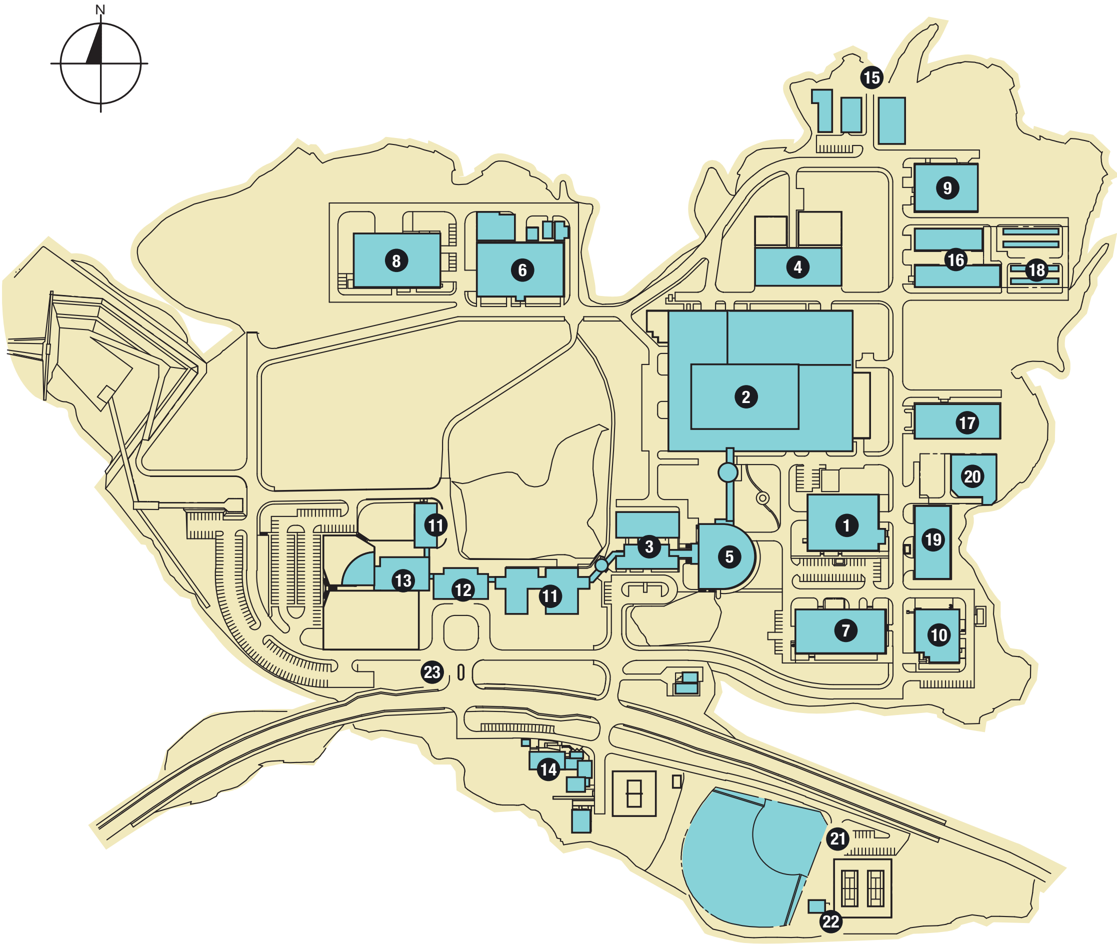
Aomori–(JR Tohoku Limited Express)–Noheji (45km)
about 30min

Noheji–(Shimokita Koutsu Bus)–Iyasaka-Daira (10km)
about 40min

Iyasaka-Daira.....on foot.....Rokkasho Research Center (0.7km)
about 8min

# National Institute for Fusion Science

## Building Arrangement




### NIFS plot plan

1. Superconducting Magnet System Laboratory
2. Large Helical Device Building
3. Simulation Science Research Laboratory
4. Heating and Power Supply Building
5. LHD Control Building
6. Fusion Engineering Research Laboratory
7. Plasma Diagnostics Laboratories
8. R & D Laboratories
9. Motor-Generator Building
10. Central Workshops
11. Research Staff Building
12. Library Building
13. Administration Building
14. Helicon Club (Guest Housing)
15. High-Voltage Transformer Station
16. Cooling Water Pump Building
17. Helium Compressor Building
18. Cooling Tower
19. Equipments Room
20. Helium Tank Yard
21. Recreation Facilities
22. Club House
23. Guard Office