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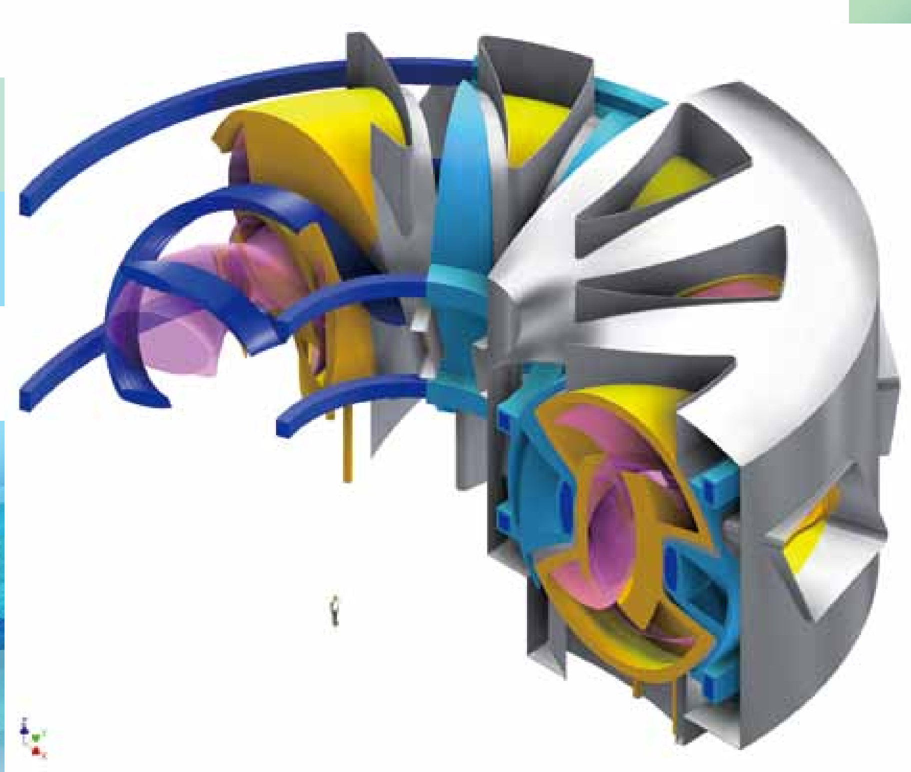
ANNUAL REPORT OF NATIONAL INSTITUTE FOR FUSION SCIENCE

April 2017 – March 2018



NATIONAL INSTITUTE FOR FUSION SCIENCE

TOKI CITY, JAPAN

Front cover picture : Schematic of the helical fusion reactor FFHR-d1

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ANNUAL REPORT OF NATIONAL INSTITUTE FOR FUSION SCIENCE

April 2017 – March 2018

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Inter-University Research Institute Corporation
National Institutes of Natural Sciences

NATIONAL INSTITUTE FOR FUSION SCIENCE

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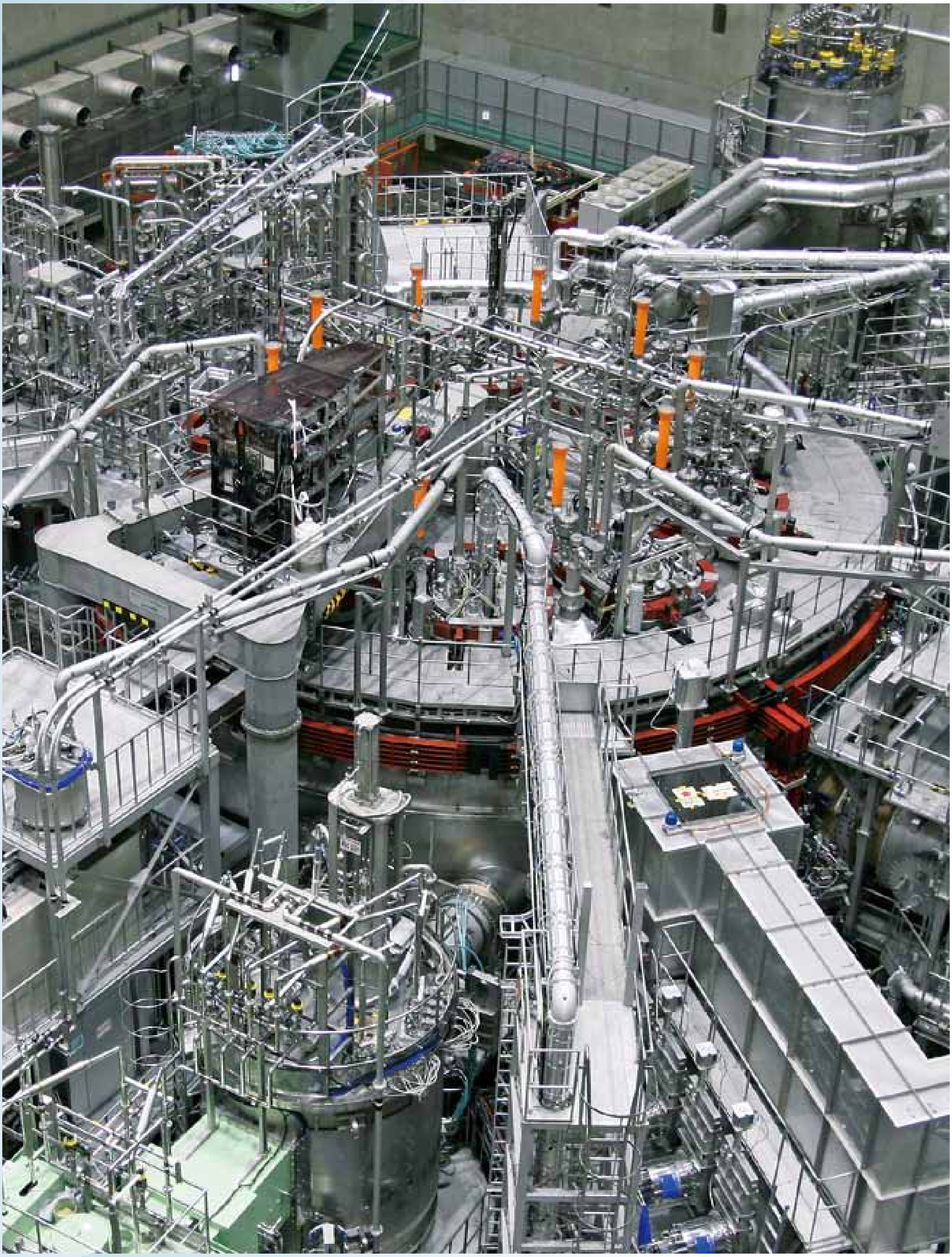
National Institute for Fusion Science
April 2017 – March 2018



Energy resource alternatives to fossil fuels are indispensable for a sustainable society because there is expanding demand for energy on a global scale due to the explosive population growth and economic development concentrated in developing countries. In addition, the increase in greenhouse gases such as carbon dioxide due to continuous use of fossil fuels and the depletion of fuel resources will become serious issues. The realization of nuclear fusion energy can resolve the serious environmental and energy crisis which human beings are now facing. The fuels for fusion can be obtained from seawater, therefore fusion energy is virtually inexhaustible. Furthermore, the fusion reaction does not emit carbon dioxide, thus fusion energy can be the ultimate clean energy. Fusion research around the world has progressed year by year based on the steady progress of basic science and advanced technology. On the other hand, to place this energy resource in our hands, critical scientific and technological issues which must be resolved still remain.

In order to promote the scientific and engineering research towards the realization of fusion energy, National Institute for Fusion Science (NIFS) conducts three major projects, the Large Helical Device (LHD) Project, the Numerical Simulation Reactor Research Project and the Fusion Engineering Research Project. These three pillars collaborate and stimulate each other to contribute the progress of the comprehensive fusion science. In addition to the above mentioned three major projects, NIFS also supports interdisciplinary and basic research, and promotes the coordinated research for ITER-BA cooperation, laser cooperation and academic-industrial cooperation.

This annual report summarizes achievements of research activities concerning the fusion research at NIFS from April 2017 to March 2018. NIFS is an inter-university research organization, which conducts collaboration research programs under three frameworks, i.e., General Collaboration Research, LHD Collaboration Research and Bilateral Collaboration Research. More than 500 collaborating research topics were proposed by collaborators in universities or institutes across the country. Proposals from abroad were also included.

Finally, I would like to emphasize one more important role of NIFS, the development of human resources. NIFS is pouring energy into education for graduate students who will realize the fusion power generation and society. For this purpose, NIFS provides the advanced education system through the Graduate University for Advanced Studies (Sokendai). Educational collaboration with partner universities across the nation is also conducted, by accepting their graduate students to NIFS.

Yasuhiko Takeiri
Director-General
National Institute for Fusion Science

1. Large Helical Device (LHD) Project

The Large Helical Device (LHD) project conducts fusion-grade confinement research in a steady-state machine to elucidate important research issues in physics and engineering for the helical-type fusion reactor. The LHD is one of the largest helical devices, with poloidal/toroidal period numbers of 2/10, and major and averaged plasma minor radius of 3.6 – 4.0 m and 0.6 m, respectively. A double helical coil and three pairs of poloidal coils are all superconducting, by which maximum magnetic field strength at the plasma center is 3 T. Twenty small normal conducting loop coils are equipped outside the cryostat to apply resonant magnetic perturbations to the plasma. For plasma heating, three negative-ion-based 180 – 190 keV neutral beams with total heating power of 8 – 16 MW are injected tangentially to the plasma. Two positive-ion-based 40 – 80 keV neutral beams with total heating power of 6 – 18 MW are also injected perpendicular to the plasma. In addition, electron cyclotron resonance heating with total heating power of ~ 5.5 MW is also available. For fuelling, LHD is equipped with four gas puff valves and two pellet injectors.

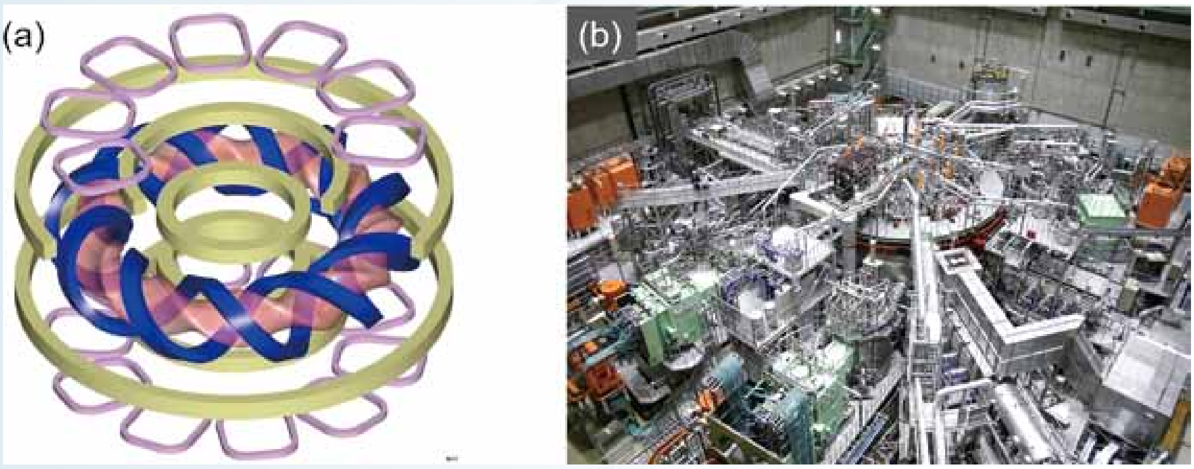


Fig. 1 (a) Coil configuration of LHD. Superconducting helical coils (blue), poloidal coils (yellow) and normal conducting RMP coils, together with plasma. (b) LHD torus hall.

In experiments conducted to date in tokamak devices, we have learned that plasma confinement performance is better in deuterium than in hydrogen, which is called the "isotope effect." However, we do not yet understand clearly why plasma performance increases when we change the gas from hydrogen to deuterium. Clarifying the mechanism of this phenomenon is of great academic significance.
On March 7, 2017, LHD started the deuterium experiment, which successfully ended in August. The first experimental campaign with deuterium plasma produced a significant result. The ion temperature of 10 keV (120 million °C) was achieved.

Finally, achieved plasma parameters with hydrogen (before the deuterium experiment) are summarized in Table 1 with the targets of the LHD project.

Table 1 Achieved plasma parameters (1998 – 2017).

Parameters	Achieved	Key physics	Target
Ion temperature T_i	10 keV (n_e = 1.2×10^{19} m^{-3})	Ion ITB Impurity hole	10 keV (n_e = 2×10^{19}m^{-3})
Electron temperature T_e	20 keV (2×10^{18} m^{-3}) 10 keV (1.6×10^{19} m^{-3})	Electron ITB	10 keV (2×10^{19}m^{-3})
Electron density n_e	1.2×10^{21}m^{-3} (T_e = 0.25 keV)	Super dense core	4×10^{20} m^{-3} (T_e = 1.3 keV)
Beta	5.1 % (B_T = 0.425 T) 4.1 % (1 T)	MHD in current-free plasmas	5 % (B_T = 1 - 2 T)
Duration time	54min. 28sec (0.5MW, 1keV, 4×10^{18}m^{-3}) 47min. 39sec. (1.2MW, 2keV, 1×10^{19}m^{-3})	Dynamic wall retention	1 hour (3 MW)

1. Large Helical Device (LHD) Project

Highlight

The ion temperature of 10 keV achieved, and the study on energetic particles progressed in the first LHD deuterium plasma experiment campaign

The deuterium plasma experiment was initiated in the LHD in March 2017. In its very first deuterium campaign, we successfully extended the high temperature regime in the LHD. The new record of the ion temperature (Ti) of 10 keV, which is the landmark achievement of helical systems research worldwide to satisfy one of fusion conditions. It was achieved with the ion internal transport barrier (ITB) formation, and several operational optimization [1]. The confinement characteristics of ITB plasmas were compared between hydrogen and deuterium discharges. The ion thermal diffusivity was reduced in the ion-ITB plasmas with deuterium compared with the plasmas without deuterium. It was also found that the electron thermal confinement of the electron-ITB plasmas was clearly improved in the deuterium case.

The study on energetic particles behaviour has been also extensively progressed in the first deuterium experiment campaign through the neutron measurement and consolidations of relevant simulation codes.

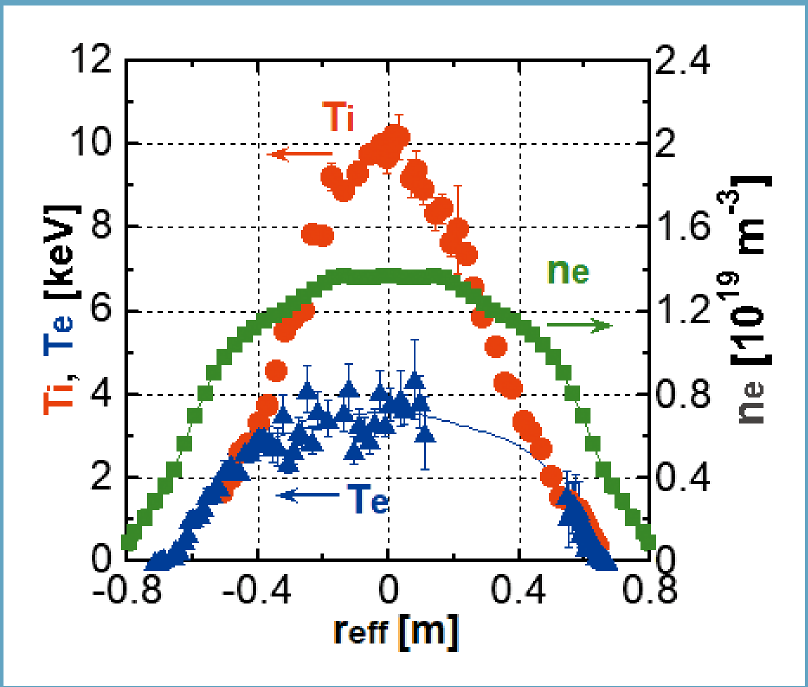


Fig. 1 The radial profiles of T_i, T_e, and n_e of the highest-T_i plasma in the LHD [reproduced from Y. Takeiri, Atoms 2018, 6(4), 69].

Extension of High-Temperature regime

During the first deuterium plasma experiment campaign, we achieved the highest T_i of 10 keV in the LHD due to the several operational optimizations such as the wall condition, the impurity quantity, and the magnetic configuration, with the increased NBI power [1]. Figure 1 shows radial profiles of T_i, T_e (electron temperature) and n_e (electron density) at the timing of the maximum T_i. The T_e and n_e data in 0.13 m < r_{eff} < 0.53 m were scattered due to the stray light from the in-vessel components, thus the data are omitted in Fig. 1. Slightly inward-shifted configuration of R_{ax} = 3.58 m / B_t = 2.87 T (counter clockwise direction) was chosen for the experiment. Also, the intensive wall conditioning using high power ECRH was conducted before the discharge. The plasma was sustained using high power NBI and the optimized-size carbon pellet was injected at t ~4.57 s. The central T_i was gradually increased after the additional NBI from t = 4.6 s and reached the maximum value at t = 4.85 s. The peaked T_i profile with the central value of 10 keV was successfully achieved. The achievement of the T_i of 10 keV is a milestone toward realizing a helical reactor, which has an intrinsic advantage for steady state operation, because the T_i value is one of the important ignition conditions.

The bursty MHD event, which is so-called energetic ion driven resistive interchange modes (EICs), was observed during the discharge. The EICs are driven by the increased pressure gradient of helically trapped energetic ions, which are mainly generated by the perpendicular NBI [2]. The neutron emission rate dropped associated with the EIC event. This indicates the loss of the energetic ions from the plasma. Consequently, the plasma stored energy and the ion temperature were degraded. Thus, the suppression of EICs is one of key issues for realizing higher-T_i plasmas in LHD. One of the control knobs of the EIC is ECRH. In the previous study, the EICs were found to be suppressed by an ECRH superposition [2]. On the other hand, the increase in the ion thermal diffusivity χ_i with increase in the T_e/T_i during the stepwise ECRH superposition was also observed in the LHD [3]. Higher T_i plasmas are possibly realized by suppressing EICs with a small increase in T_e/T_i using an optimized ECRH injection with moderate power and/or choosing the appropriate location of the ECRH power deposition with the off-axis ECRH injection.

Higher energy confinement in the high-T_e plasma with the strong e-ITB was also realized in the first deuterium experiment campaign in the LHD [1]. Figure 2 shows the radial profiles of (a) n_e, (b) T_e, and (c) the electron thermal diffusivity χ_e for H and D with approximately the same n_{e_fir} ~2.4×10^{19} m^{-3}. The magnetic configuration was R_{ax} = 3.6 m / B_t = 2.705 T (clockwise direction) both for the H and D plasmas. The purity of the target ions, $n_H/(n_H+n_D+n_{He})$, is 0.94 for the H-dominant plasma and 0.81 for the D plasma, respectively. Unfortunately, one gyrotron had trouble in the D experiment phase and thus that gyrotron was not available in this comparative experiment. Thus, the total ECRH injection power became smaller in the D-dominant experiments. Despite the decreased ECRH power for the D plasma, almost the same T_e profile with H plasma was realized. Although the n_{e_fir} was fixed as ~2.4×10^{19} m^{-3}, the n_e profile was slightly different between H and D plasma. The χ_e was evaluated from the power balance analysis and was decreased in r_{eff} < 0.3 m both for the H and the D plasma due to the formation of the e-ITB. From the comparison between these two cases, χ_e clearly reduced in the D plasma except for the plasma edge. The systematic data for the comparison of the global energy confinement of the e-ITB plasmas between H and D were also obtained with the n_{e_fir} of 1.5-4.7×10^{19} m^{-3} and the injection ECRH power of 1-3 MW. The energy confinement in D plasmas was found to be statistically 10-20% higher than H plasmas [5].

Progress of study on energetic particles behaviour

Global confinement property of beam ions is studied by means of the neutron flux monitor (NFM) since neutrons are primarily created by beam-plasma reaction in neutral beam (NB)-heated plasmas. An NB with the short pulse length, which is much shorter than Spitzer slowing down time, is injected into the magnetohydrodynamic (MHD)-quiescent electron-cyclotron-resonance-heated plasma in order to study whether or not beam ions slow down classically without beam ion loss. A rapid increase of total neutron emission rate (S_n) during NB injection and the slow decay of S_n following NB turn-off are observed. Numerical simulation using the 5D drift kinetic equation solver based on the Boozer coordinates, the Global NEoclassical Transport (GNET) code [6] shows that not only the decay time of S_n (τ_n) but also the absolute value of S_n agrees well with those obtained by experiment (Fig. 3). Hence, global beam-ion transport in LHD can be described in the neoclassical model in the MHD-quiescent regime.

As predicted by calculation based on Fokker-Planck equation [7], S_n increases with electron density (n_e) rapidly, then has a peak around n_e of around 2.5×10^{19} m^{-3}, and then decreases gently with n_e. Higher S_n in inward-shifted configuration are obtained and the maximum S_n reaches 3.3×10^{15} n/s in the first deuterium cycle. The line-integrated neutron profile is measured in co-injected NB-heated plasma with different magnetic axis (R_{ax}) with the vertical neutron camera (VNC). The neutron counts (C_n) become larger in the inward-shifted configuration, which is consistent with S_n. The radial peak position of C_n changes according to R_{ax} shows that the VNC works successfully as designed. Significant drop of C_n in central cords synchronized with a perpendicularly-injected-NB-excited MHD instability called helically-trapped EP driven resistive interchange mode (EIC) is observed. Note that S_n noticeably drops up to 50 % due to the EIC burst. By comparing the beam ion density predicted by the GNET code, the significant drop of C_n in central cords indicates

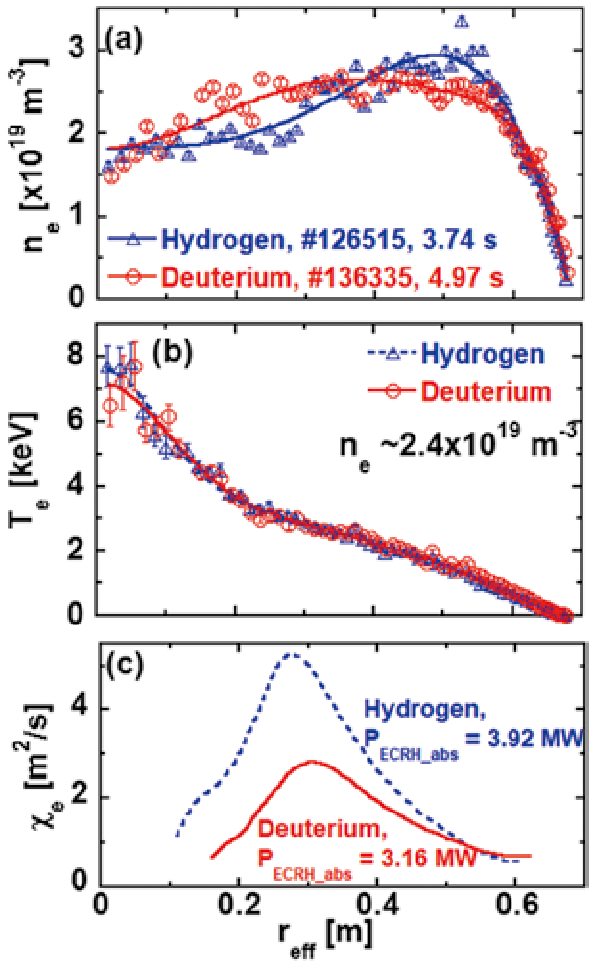


Fig. 2 The radial profiles of (a) n_e, (b) T_e, and (c) χ_e for H and D with approximately the same n_{e_fir} and the different ECRH power [1].

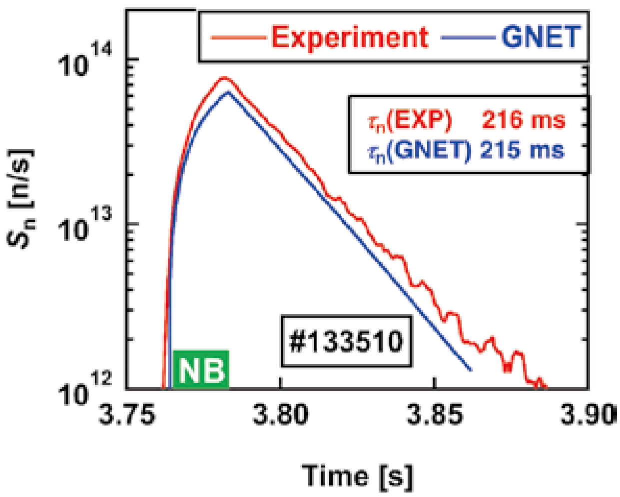


Fig. 3 Time evolution of S_n in a beam blip experiment. The time trend of S_n agrees with that calculated by the GNET simulation.

that helically-trapped beam ions are substantially lost due to the EIC.

Alpha particle simulation experiment is conducted by measuring 14 MeV neutron generated by secondary DT reactions in the deuterium plasma. Note that 1 MeV triton can be regarded as simulation particles of DT-produced alphas since kinematic parameters such as Larmor radius and processional drift frequency are quite similar. Time-resolved 14 MeV neutron flux is measured for the first time in stellarator/heliotron to study the confinement of 1 MeV triton produced by DD reaction using scintillating-fiber detectors calibrated with neutron activation systems. A build-up rate of 14 MeV neutron flux is slower than that of S_n as predicted according to the cross-section curves for DD and DT reactions. A significant increase of triton burnup ratio defined as a ratio of secondary DT neutron yield to primary DD neutron yield can be seen in the inward-shifted configuration (Fig. 4). The triton burnup simulation performed by the GNET code shows that the confinement of the helically-trapped tritons is improved by inward shift of R_{ax}.

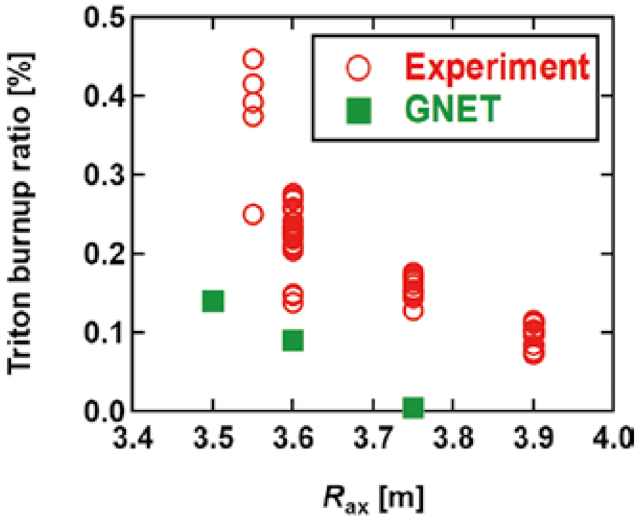


Fig. 4 Triton burnup ratio as a function of R_{ax}. The tendency is reproduced by the GNET simulation.

[1] H. Takahashi *et al.*, Nucl. Fusion **58** (2018) 106028.
[2] X.D. Du *et al.*, Phys. Rev. Lett. **118** (2017) 125001.
[3] H. Takahashi *et al.*, Nucl. Fusion **57** (2017) 086029.
[4] M. Nakata *et al.*, Comput. Phys. Commun. **197** (2015) 61.
[5] F. Warmer *et al.*, Nucl. Fusion **58** (2018) 106025.
[6] S. Murakami *et al.*, 2004 Fusion Sci. Technol. **46** (2004) 241.
[7] M. Osakabe *et al.*, 2017 Fusion Sci. Technol. **72** (2017) 199.

Highlight

Measurements of hydrogen-deuterium ratio in the core plasma with bulk charge exchange spectroscopy

Bulk charge exchange spectroscopy system has been installed in LHD to measure the radial profiles of $n_H/(n_H+n_D)$ and $n_D/(n_H+n_D)$ in the plasma from H_α and D_α lines emitted by the charge exchange reaction between the bulk ions and the neutral beam injected. The hot component due to the active charge exchange reaction with the neutral beam is smaller than the cold component emitted in the edge by one order of magnitude. In order to subtract the cold component of the H_α and D_α charge exchange lines, beam modulation technique is applied. Figure 1 shows the Spectrum of H_α and D_α lines after subtracting the spectrum at beam-off timing from the spectrum at beam-on timing for the discharge with H and D pellet injection. Although most of the cold components of the charge exchange lines are subtracted by the beam modulation, there still remain cold components comparable to the hot components, as seen in the spectra of bulk charge exchange lines.

The charge exchange lines are fitted by 4 Gaussian of H and D cold components and H and D hot components (I_H^{cold}, V_H^{cold} T_H^{cold}, I_D^{cold}, V_D^{cold} T_D^{cold}, I_H^{hot}, V_H^{hot} T_H^{hot}, I_D^{hot}, V_D^{hot}, T_D^{hot}, 12 free parameters). Here I, T, and V are intensity, flow velocity, and ion temperature, respectively. In order to reduce the number of the free parameters, the flow velocity, ion temperature, and D/H ratio of cold component ($V_H^{cold}=V_D^{cold}$, $T_D^{cold}=T_H^{cold}$, I_D^{cold}/I_H^{cold}, 5 parameters) are given by fitting the spectrum at beam off timing. The flow velocity of hot component is derived from the rotation velocity measurements of carbon impurity ($V_H^{hot}=V_D^{hot}=V_C^{hot}$, 3 parameters) and equal ion temperature between hydrogen and deuterium is assumed ($T_H^{hot}=T_D^{hot}$, 1 parameter). The amplitudes of hot and cold components, ion temperature, and D/H ratio of the hot components (I_D^{hot}/I_H^{hot}, $T_H^{hot}=T_D^{hot}$, $I_D^{hot}+I_H^{hot}$, $I_D^{cold}+I_H^{cold}$, 4 parameters) are selected as the free parameters to be fitted.

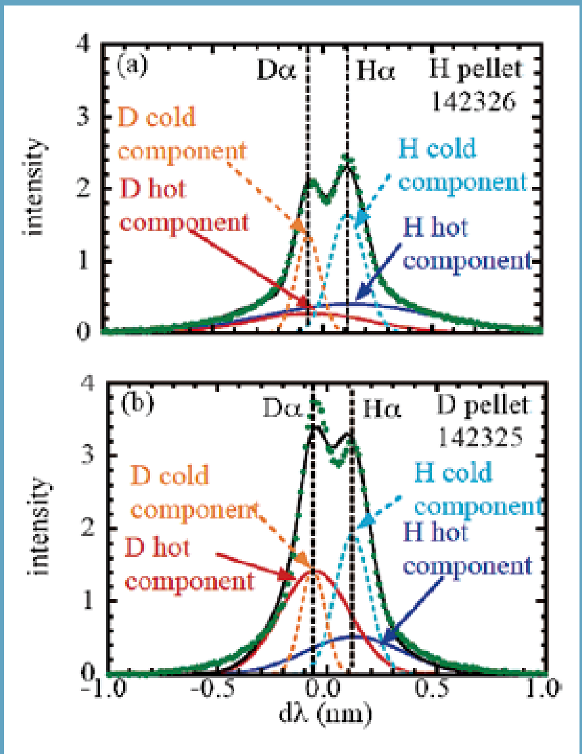


Fig. 1 Spectrum of H_α and D_α lines after H pellet and D pellet. The charge exchange lines are fitted by 4 Gaussian of H and D cold components (dotted lines) and H and D hot components (solid lines). Intensity (H hot component) > Intensity (D hot component) in the discharge with H pellet and Intensity (D hot component) > Intensity (H hot component) in the discharge with D pellet. There is almost no difference in cold components between the discharges with H pellet and D pellet, respectively.

Spectroscopic study of tungsten ions and hydrogen pellet ablation cloud

A spectroscopic study of tungsten ions has been carried out, for which the impurity pellet injection system is used to provide tungsten ions for the plasma. The measurement focuses on the pseudo-continuum radiation, the so-called UTA (unresolved transition array), of the tungsten ions, in particular. EUV (extreme ultra-violet) spectra including UTA in the wavelength range between λ = 15 Å and 70 Å are measured. From the temporal developments and spatial profiles of the UTA intensities, the charge states of ions responsible for several wavelength intervals in a UTA are identified as shown in Figure 2; λ = 49.24 Å to 49.46 Å by W^{27+}, λ = 48.81 Å to 49.03 Å by W^{26+}, and λ = 47.94 Å to 48.15 Å by W^{24+}.

A spatially resolved spectroscopic measurement inside the hydrogen pellet ablation cloud, which is elongated along the magnetic field line, has been conducted [2]. For that purpose, a band-shaped field-of-view is devised with optics composed of an optical fiber and a cylindrical lens. Spectra are continuously recorded when the ablation cloud crosses the field view so that the time series of spectra can be regarded as the spatial profile. The electron density n_e is evaluated from the Stark broadening of the H_β line for each spectrum (Figure 3) and the n_e profile in the ablation cloud along its elongation direction is derived. The obtained n_e profile is found to be peaked and have a dip at the center that is consistent with a simulation result [3].

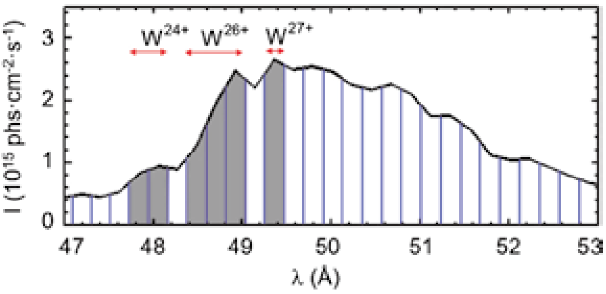


Fig. 2 Tungsten spectrum with UTA lines between λ = 47 Å and 53 Å. The three wavelength intervals indicated by the grey color are identified to be the UTA from W^{24+}, W^{26+}, and W^{27+} ions, respectively (cited from [1]).

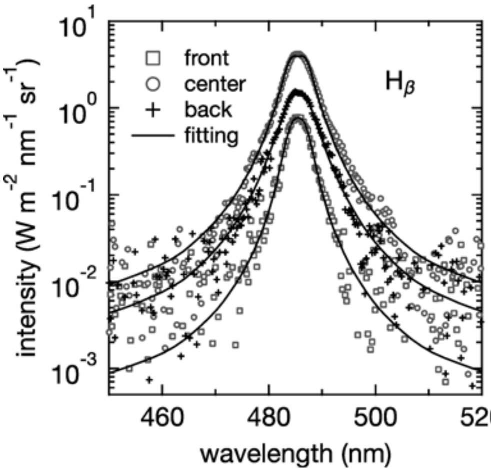


Fig. 3 Fitting results of the observed H_β line at different locations in the ablation cloud. The n_e at the front edge, center, and back edge are determined to be 1.2×10^{23} m^{-3}, 1.5×10^{23} m^{-3}, and 1.3×10^{23} m^{-3}, respectively (cited from [2]).

[1] Y. Liu *et al.*, J. Appl. Phys. **122**, 233301 (2017).
[2] G. Seguineaud *et al.*, Atoms **6**, 34 (2018).
[3] G. Cseh *el at.*, Nucl. Fusion **57**, 016022 (2017).

Study of nonlinear neutral beam-beam interaction effect in deuterium discharges

In the 19th experimental campaign, experiments in the plasma heating physics category such as feedback control of EC-wave polarization, 3rd harmonic ECH, effect of ECCD and NBCD on ion temperature, thermal equipartition between electrons and ions, nonlinear neutral beam-beam interaction effect, fundamental X-mode and EBW heatings, RF measurement using magnetic probe, ECE measurement using ECH antenna for optimum ECH and EBWH, collective Thomson scattering measurement, and others, were performed.

Here, we report the study of nonlinear neutral beam-beam interaction effect in deuterium (D) discharges. When two NBIs are operated with D and hydrogen (H) gasses with the same acceleration voltage, TASK/FP Fokker-Planck code predicts that the decay-time-constant of neutron yield, τ_D, after the stop of D-beam injection becomes longer when co-D-NBI and co-H-NBI are operated than τ_D in the case of co-D-NBI and counter-H-NBI. This prediction was experimentally confirmed. The agreement indicates that the slow D-ions are accelerated due to collision by faster H-ions in the case of both co-injection (Fig. 4).

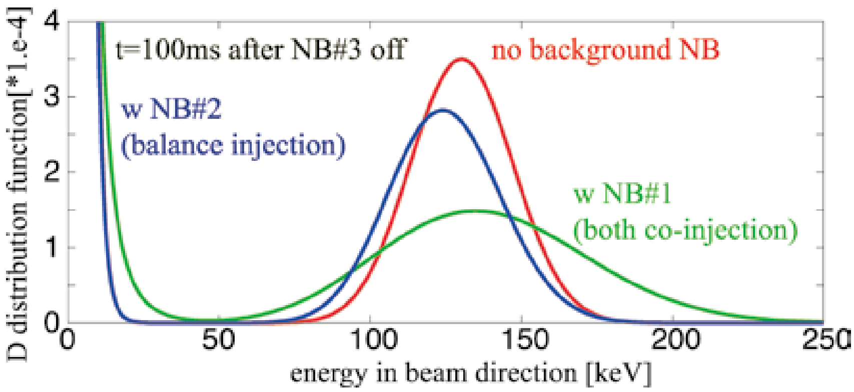


Fig. 4　Energy distribution functions of deuterium injected by NB#3 (co, D) in the cases of with NB#2 (counter, H), with NB#1 (co, H), and without other NBs.

Analysis of the tritium distribution on the wall

To confirm the overall tritium distribution on the wall surface, a tritium imaging plate (IP) technique was applied on the extracted first wall samples and divertor plate. Fig. 5 shows the representative IP images from the analyzed divertor tiles. The colored regions of the green and orange areas correspond to the density of the tritium distribution. The divertor strike point is often located on the bottom series of the tiles. On the other hand, the upper series of tiles, which perform the role of the baffle plate, shows a higher tritium level than that on the lower series. The standard tritium samples were placed on the IP together with the divertor tiles to estimate the relative density of the tritium on the tiles. The maximum tritium density can be roughly estimated in the near future. The mixed-material deposition layer mainly composed by carbon seems to be formed on the tile surfaces. Such a deposition layer might have acted as the possible tritium sink.

In the case of the first wall sample, the carbon based mixed-material deposition layers were clearly identified on the samples located at the outer side of the torus. Thick deposition layers were mainly found near the divertor tile arrays, and a high tritium level was detected on the deposition dominant region.

The carbon based mixed-material deposition layer seems to act as the main trapping site of the tritium. If the divertor tiles are replaced by metal materials, tritium inventory would be expected to be suppressed.

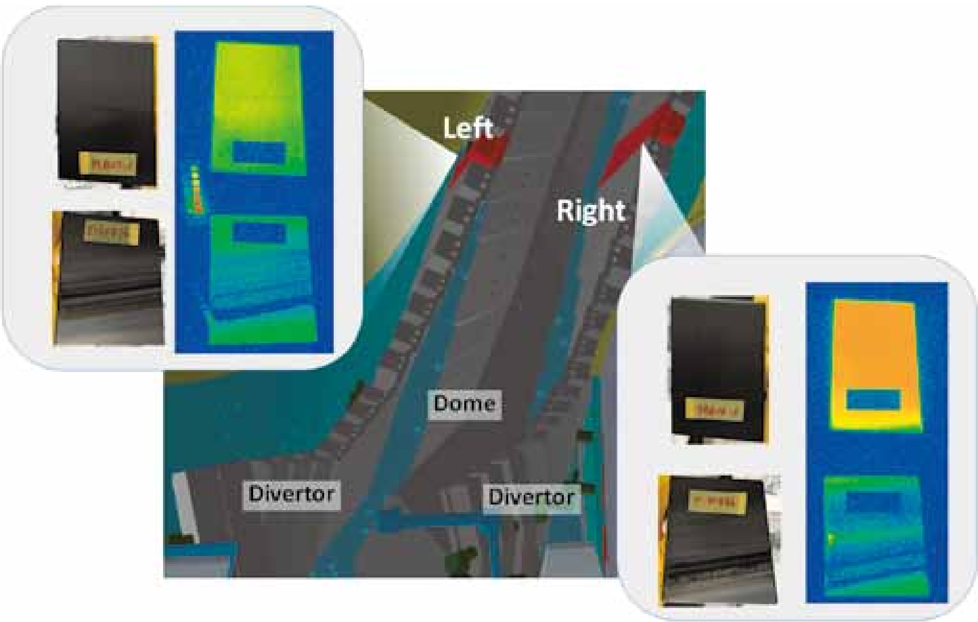


Fig. 5 The extracted divertor tiles and corresponding IP images from the left and the right hand side of the helical divertor array. The red colored tiles in the CAD image indicate the position of each tile.

Highlight

Isotope effects on confinement in ECRH plasma of LHD

The transport of different hydrogen isotopes is an important issue for predicting the performance of ITER and the future reactor operation. In a tokamak, improved transport character and lower H mode threshold power in D plasma than in H plasma were reported. Both tokamak scaling (ITER98y2) and helical scaling (ISS04) follow gyro-Bohm (GB) scaling with the exception of ion mass and ion charge number. While GB scaling predicts enhanced transport in D plasma, many experiments show better confinement (in tokamak) in D or comparable confinement (in medium-sized helical devices). In the 19th LHD experimental campaign, we performed the systematic study of the isotope effects in ECRH plasma of LHD.

In the dataset obtained in 19th LHD experimental campaign, the contamination of helium is less than 5% and the purity of the H and D are higher than 80%, respectively. The injection power was 0.6-3.9MW in D, 0.8-3.8MW in H, and $n_{e\ bar}$ was 0.6-3.7×$10^{19}m^{-3}$ in D, 0.3-3.8×$10^{19}m^{-3}$ in H. The one path absorption power was 92+-4% of injection power both for H and D plasma. Only one path absorption power was used for the τ_E estimation. The magnetic axis was 3.6m and Bt was 2.75T. Figure 1 shows comparison of predicted global energy confinement time (τ_E) by ISS04 scaling and experimental τ_E. The experimental τ_E was estimated from diamagnetic stored energy and power deposition calculated by LHDGAUSS [1]. As shown in Fig.1, τ_E in D plasma is systematically higher than τ_E in H plasma. The enhancement factors are τ_E / τ_E.

$_{ISS04}$=1.27+-0.12 in D and 1.09+-0.02 in H plasma. Thus, improvement of τ_E in D to H is 17%. The regression analysis was performed, then, the scaling $\tau_{E\ ECH} \propto A^{0.24\pm0.01} n_{e\ bar}^{0.58\pm0.01} P_{abs}^{-0.52\pm0.01}$were obtained, where A is ion mass (1 for H, 2 for D), $n_{e\ bar}$ is the line averaged density, and P_{abs} is absorption power. The power exponent of A, which is 0.24, is a similar value to tokamak L mode scaling.

The contribution of the neoclassical heat flux is around one-half of the total heat flux. The improvement is due to the reduced turbulence driven transport [2]. The clear improvement of core electron transport was found in electron ITB plasma [3]. The detail investigations of the turbulence characteristics are now underway from the turbulence measurements and gyrokinetic analysis.

[1] T. Tsujimura *et al.*, Nucl. Fusion **55** (2015) 123019.
[2] F. Warmer *et al.*, Nucl. Fusion **58** (2018) 106025.
[3] H. Takahashi *et al.*, Nucl. Fusion **58** (2018) 106028.
[4] H. Yamada *et al.*, Nucl. Fusion **45** (2005) 1684.

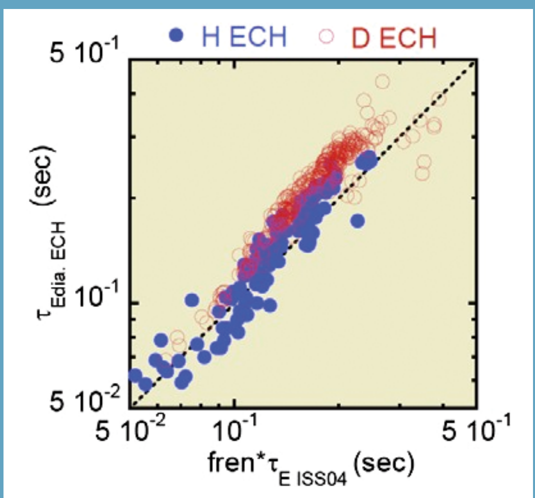


Fig. 1 Comparison of ISS04 prediction and experimental global energy confinement time. fen is the normalization factor of ISS04 scaling [4].

Observations of rapidly varying radial structure of flow velocity around spontaneously rotating magnetic island

The radial profile of flow velocity can be observed by newly installed microwave frequency comb Doppler reflectometer when the spontaneous rotation of magnetic island occurs. Because the spontaneous large sized magnetic island sometimes leads the plasma collapse in the LHD, the understanding of the physical mechanism is one of the important issues.

Doppler reflectometer gives the temporal behavior of perpendicular flow velocity $V_\perp$. This flow velocity and also the radial electric field are well known to affect the growth and decay of the magnetic island. In the experiment, it is clearly observed when the m/n=1/1 magnetic island is rotating, $V_\perp$ is oscillating at the same frequency as the magnetic fluctuation, as shown in Fig. 1. The value of $V_\perp$ changes back and forth from around -10 to 0 km/s until t=5.185 s. The observed change of the two values could be explained as follows from the knowledge of the past LHD experiments which showed that the poloidal velocity in the static magnetic island is almost 0 km/s. The observation of $V_\perp$ ~ 0 km/s means that the O-point of the rotating magnetic island comes to the observation region. On the other hand, when the O-point of the magnetic island is absent in the observation point, the value of $V_\perp$ equals the background flow velocity. Then, the signal oscillates between two values. This suggests that the Doppler reflectometer can measure the structure of fast varying magnetic island. Figure 2 shows the temporal change of the radial profile of the $V_\perp$. Periodically, $V_\perp$~ 0 (green color) appears widely in the plasma edge region. Although the center position of the magnetic island is the core region (r_{eff}/a_{99}~0.7), the observation results clearly show that the effect of the island structure extends over a wide range. These results are quite meaningful to understand the spontaneous rotating magnetic island affecting the confinement.

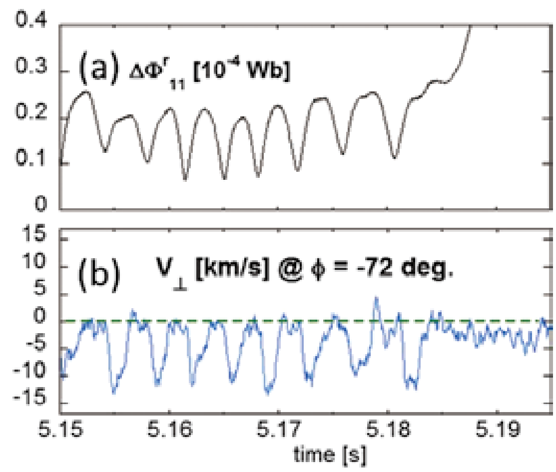


Fig. 1 Temporal change of (a) m/n=1/1 component of the radial magnetic flux and (b) the perpendicular velocity around r_{eff}/a_{99}=0.96. Cited from Fig. 3 in [1].

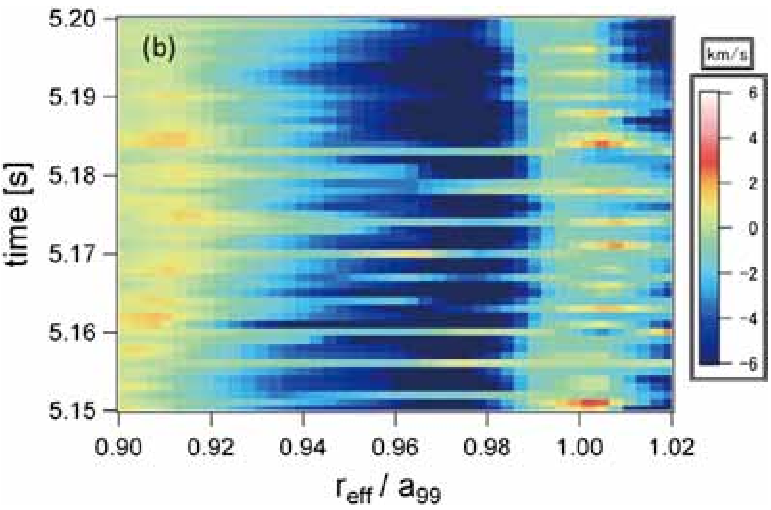


Fig. 2 Spatio-temporal behavior of $V_\perp$ in the plasma edge region. Here, r_{eff} is the effective minor radius and a_{99} is the effective minor radius of which encloses 99% of the total electron pressure. Cited from Fig. 4 in [1].

[1] T. Tokuzawa *et al.*, Nucl. Fusion **57** (2017) 076003.

Helically trapped energetic particle driven resistive interchange mode (EIC)

Repeated bursts of the magnetic fluctuations were observed in the hydrogen campaign of LHD in the low electron density regime [1]. This activity is called helically trapped Energetic particle driven resistive InterChange modes (EIC), since the pressure gradient of helically trapped energetic particles (EP), shown in Fig. 4, drives this mode. Helically trapped EPs are mainly produced by the perpendicularly injected beams. Two perpendicular neutral beam injection (PERP-NBI) systems are upgraded for the deuterium plasma campaign, and the injected power increases from 6+6 MW to 9+9 MW, respectively. As results, the beta value of helically trapped EPs, $\beta_\perp$ has increased up to $\beta_\perp$~0.35 %. And it is found that the amplitude of the EIC bursts becomes larger in the deuterium campaign as shown in Fig. 2 [2].

Excitation of the EIC requires resonance of the precession motion of the helically trapped EP and the MHD mode. In the deuterium experiments with higher beam energy, the effect of the EP becomes smaller because the orbit width of EPs (Fig. 1(b)) is wider and the EPs stay a shorter time inside the eigenfunction of the resistive interchange mode. Therefore, since the EIC mode is more stable with D beam, the energetic particle pressure becomes larger before each EIC burst. That is the reason why the EICs are excited less frequently and with a larger amplitude.

The effects of the EIC on the performance of the plasma is not negligible (Fig. 2(b)). Therefore, several controlling methods, based on the physical mechanism of the EIC, are being tested. One promising candidate is the EC heating. When the electron temperature around the rational surface increases, the width of the eignenfunction narrows. The interaction between EPs and the MHD mode is thereby reduced. Disappearance of the EICs and the performance enhancement are observed with EC heating.

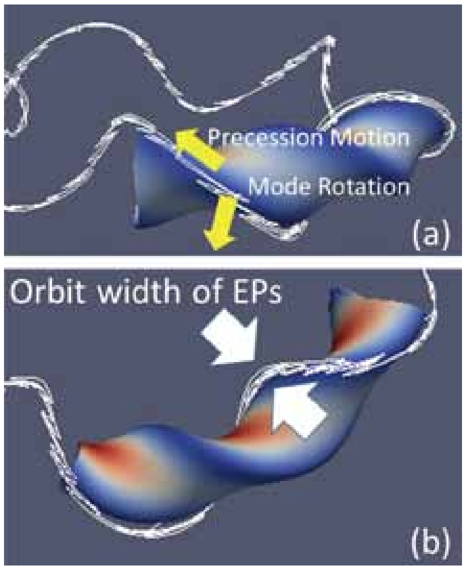


Fig. 1 Orbit of the helically trapped particle. The surface color indicates the magnetic field strength.

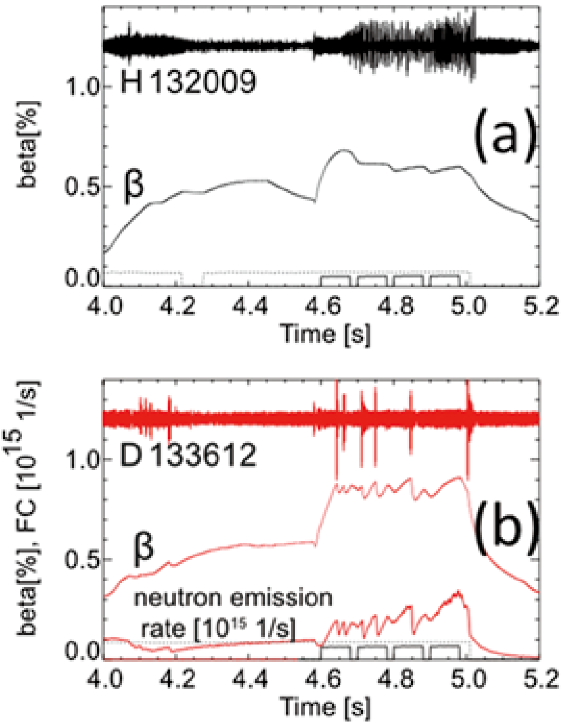


Fig. 2 Time evolution of the magnetic fluctuations with H beam (a) and D beam (b). Time evolution of the diamagnetic beta value and the neutron emission rate (only with D- beam) are shown together.

[1] X. D. Du, *et al.*, Phys. Rev. Lett, **114** (2015), 155003.
[2] T. Bando, *et al.*, Nucl. Fusion, in press.

Dependence of RMP penetration threshold on ion species in helical plasmas

The intrinsic RMP (error field) is thought to be a cause of tokamak disruption induced by the locked mode instability, and the RMP by external coils is applied as an effective control knob to improve the confinement performance in the torus plasmas. However, it is reported that the RMP is sometimes shielded by plasmas, and it penetrates plasmas when the amplitude of the RMP is larger than a value, which is called the penetration threshold. The phenomena are observed in both tokamaks and in helicals, including the LHD.

The most popular model on the shielding mechanism of the external RMP is a balance between the electro-magnetic and the viscous torque [1]. According to a model [2] in helical plasmas without an external torque, the poloidal neoclassical viscosity is considered dominant, and the viscous torque is expressed by the product of a poloidal rotation speed and a viscosity coefficient, and the electro-magnetic one is roughly proportional to the square of the RMP coil current.

Since it is expected that the plasma rotation speed depends on the ion species, we compare the m/n=1/1 RMP penetration threshold in the hydrogen and the deuterium plasmas. Figure 1 shows the threshold dependence on the collisionality in the hydrogen and the deuterium of the LHD with A_p=5.7 and β_{local}~0.3%. Here A_p is the plasma aspect ratio. From Fig. 1, the penetration threshold in the deuterium is smaller than that in the hydrogen, which means that we can affect the plasmas by the smaller RMP in the deuterium than in the hydrogen. In Fig. 2, we plot the penetration thresholds of theVarious aspect ratio, beta, and ion species plasmas (A_p=7.1; ◇, A_p=5.7; ○ and H; ●, D; ■) as the function of the plasma poloidal rotation ($\omega_{pol@\iota=1}$) at the rational surface just before the penetration. In all of the cases, the RMP penetration thresholds are higher as the poloidal rotation is faster, which is qualitatively consistent with the torque balance model between the electro-magnetic and the poloidal neoclassical viscous torque [2]. Then the main reason why the penetration threshold in the deuterium is lower than that in the hydrogen is considered to be because the poloidal rotation in the deuterium is slower than that in the hydrogen.

[1] R. Fitzpatrick, Nuclear Fusion **39** (1993) 1049.
[2] S. Nishimura *et al.*, Phys. Plasmas **19** (2012) 122510.

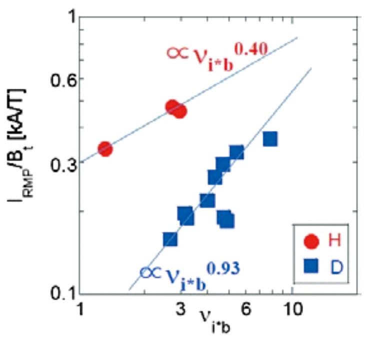


Fig. 1 RMP penetration threshold as the function of the collisionality in the LHD with A_p=5.7 and β_{local}~0.3%.

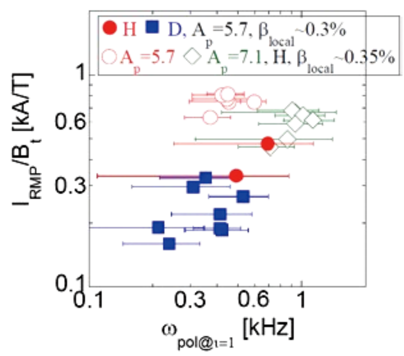


Fig. 2 RMP penetration threshold as the function of $\omega_{pol@\iota=1}$ in the LHD with A_p=5.7~7.1 and β_{local}=0.3~0.35%.

(T. Morisaki)

Research and Development collaboration program for LHD-project

A special collaboration program, which is aimed to support the research and development activities in domestic universities for advanced diagnostics or heating scenarios, is founded for the future application on LHD. Two examples of such activities are shown in this section.

a) Development and Installation of Electron Cyclotron Emission Imaging Diagnostics

Imaging diagnostics using microwave has been made remarkable contribution to the research on MHD instabilities and turbulence studies in large devices [1]. Over the past few years, we have been proactively developed the microwave imaging devices under the collaboration between NIFS and the Tokyo University of Agriculture and Technology. Based on these activities, a new electron cyclotron emission imaging (ECEI) system was successfully developed for LHD and started its operation during the LHD experiment campaign in 2017. The observation frequency of this ECEI system is 50~57 GHz (2nd harmonic), and this system has 8 channels in each of poloidal and radial directions (frequency domain). One of the key device in this ECEI system is a new antenna array, which is named as Local oscillator Integrated Antenna array (LIA) as shown in Fig. 1 [2,3].

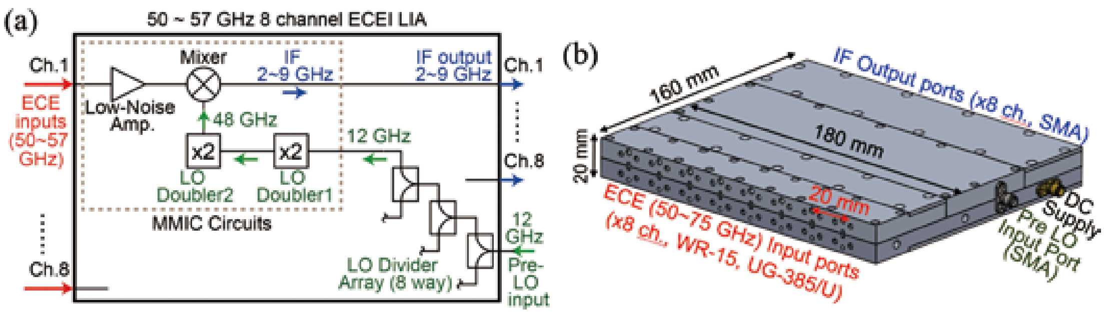


Fig. 1 (a) Schematic diagram of LIA circuit, and (b) outside drawing of LIA.

The role of this antenna array is to convert very high frequency ECE signals (need to be treated as light) to cable-transmittable low Intermediate Frequency (IF) signals using a mixer and Local Oscillation frequency (LO). A conventional ECE antenna array requires special LO optics, where the uniform LO power feeding to each antenna element is difficult. It also requires an expensive high-power LO source. Our new LIA has successfully solved these problems using a microwave monolithic integrated circuit (MMIC) as LO supply unit, which is installed at each antenna element. Using compact and inexpensive MMIC frequency multipliers, it became possible to supply the low frequency Pre-LO signal to the LIA via a coaxial cable.

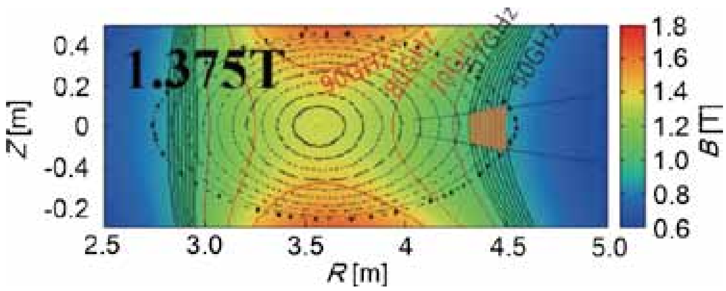


Fig. 2 The observation area of 50~57 GHz ECEI system at B_t = 1.375 T [4].

The observation area of our new ECEI system, which is installed at the 4-O port of LHD, is shown in Fig. 2, where the magnetic field strength on axis is set to 1.375 T. The focal point of the optics is located near the outer half radius of the LHD-plasma to detect the oscillation on the ι = 1 (m/n = 1/1) surface.

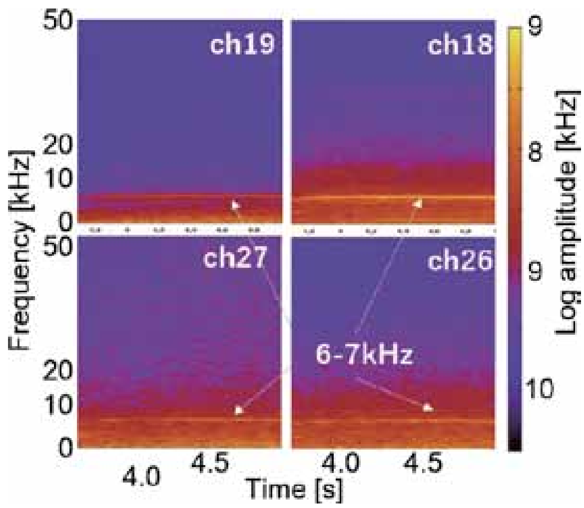


Fig. 3 Time evolutions of frequency spectrograms of ECE signals for Ch19 (52GHz), ch27(52 GHz), ch18(51GHz) and ch26(51 GHz), respectively [4].

Figure 3 shows the time evolutions of frequency spectrograms of the ECE signals from selected channels from this ECEI system. The fluctuation between 6 and 7 kHz was observed in each channel. It was evaluated from the toroidal and poloidal mode analysis by a magnetic probe array that the fluctuation was due to the MHD instability around ι = 1 surface, The phase difference between each ECEI channel was also evaluated, and the propagation direction and the correlation length can be estimated.

[1] H. Park *et al.*, Rev. Sci. Instrum. **75** (2004) 3875.
[2] D. Kuwahara *et al.*, Rev. Sci. Instrum. **85** (2014) 11D805.
[3] Y. Nagayama *et al.*, Rev. Sci. Instrum. **88** (2017) 044703.
[4] H. Tsuchiya *et al.*, Plasma Fusion Res. **13** (2018) 3402063

b) Development of plasma diagnostics for detached plasmas

To improve the core plasma performance, it is inevitable to understand the physics in divertor region as well as core plasmas. Plasma detachment is thought of as a method to control particle/heat loads on divertor materials; the measurement of the low temperature recombining plasmas is not so simple. Anomaly is identified in the current voltage characteristics of electrostatic probes, and a special care is required for Thomson scattering, since the temperature is much lower than 1 eV. In this study, based on developments of measurements systems in linear divertor simulators, the understanding in the physics of plasma detachment was progressed. A Tunable Diode Laser Absorption Spectroscopy (TDLAS) and a Laser Thomson Scattering (LTS) system have been developed to measure the atomic temperature and the electron density and temperature in the divertor simulator NAGDIS-II.

A TDLAS system was developed using a distributed feedback (DFB) laser. TDLAS of helium metastable (23S1) has been carried out using a lab-made DFB laser system in the detached plasma 1.4 m downstream from the discharge region [5]. Figure 4 shows the non-averaged absorption spectra of metastable helium atoms in a detached plasma. The Gaussian fitted lines were obtained using the spectra averaged over repeated measurements. The temperature and density of the metastable helium atom were derived as 0.04 eV and 1.6×10^{17} m^{-3} from the width and area of the absorption coefficient spectra, respectively.

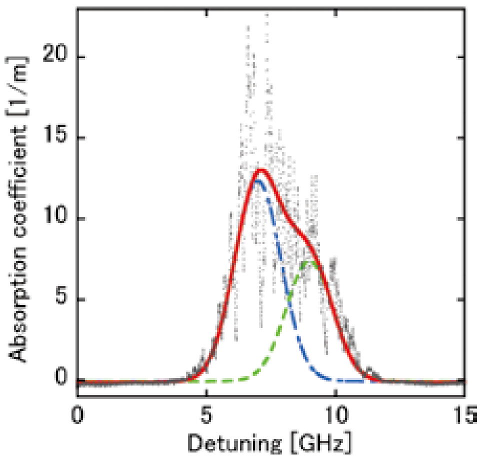


Fig. 4 Non-averaged absorption spectra in NAGDIS-II (from [1]).

An LTS system was developed for the NAGDIS-II using an Nd:YAG laser (Continuum: SLII-10) at the wavelength of 532 nm with the pulse width of 5-6 ns. The spectrometer is composed of a volume phase holographic grating (2600 l/mm) and two camera lenses [6]. The high etendue spectrometer was developed based on prototypes for MAGNUM-PSI [7]. Figures 5(a) and (b) show typical Thomson scattering (TS) spectrum in an attached ionizing plasma and a detached recombining plasma, respectively. To obtain the spectrum, TS signals were averaged 300 times (30 s). The plasma parameters were successfully deduced from the spectrum. The deduced temperature in the detached plasma was 0.29 eV, which was one order of magnitude lower than the attached plasma.

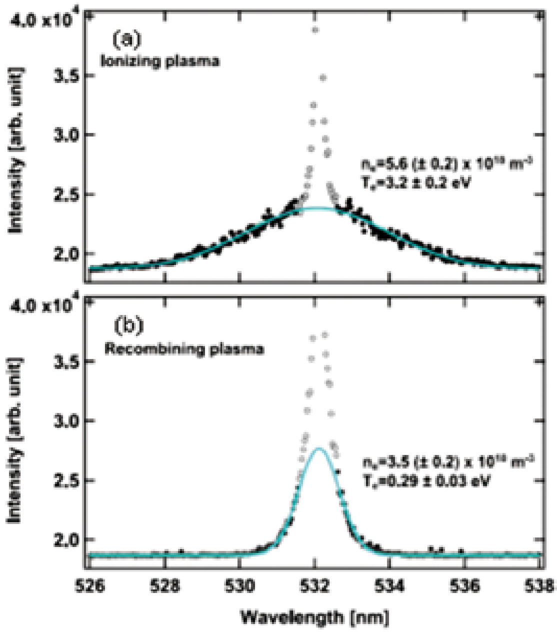


Fig. 5 Typical TS spectrum in (a) an attached ionizing plasma and (b) a detached recombining plasma, respectively (from [6]).

From the TDLAS and LTS measurements, it was found that metastable state atoms were produced in the peripheral region of the plasma and transported toward the wall radially. It was also revealed from the detailed LTS spectrum analysis that the plasma had two electron temperature components, and the values were consistent with those obtained from the helium line intensity ratios method [8]. Those results suggested the importance of future investigation in the influences of transport of metastable state atoms and fluctuations on line emission in recombining plasmas.

[5] M. Aramaki, T. Tsujihara, S. Kajita, H. Tanaka, and N. Ohno, AIP Advances, **8** 015308 (2018).
[6] S. Kajita, T. Tsujihara, M. Aramaki, *et al.*, Phys. Plasmas **24**, 073301 (2017).
[7] H. J. van der Meiden, A. R. Lof, M. A. van den Berg, *et al.*, Rev. Sci. Instrum. **83**, 123505 (2012).
[8] S. Kajita, K. Suzuki, H. Tanaka, N. Ohno, Phys. Plasmas **25**, 063303 (2018).

(M. Osakabe)

2. Fusion Engineering Research Project

Fusion Engineering Research Project (FERP) started in FY2010 at NIFS. Along with the conceptual design studies for the helical fusion reactor FFHR, the project has been conducting development on the technology of key components, such as the superconducting magnet, the blanket and the divertor. The research is also focused on the materials for blankets and divertors, the interaction between plasma and the first wall including the atomic processes, handling of tritium, plasma control, heating and diagnostics. The project has 13 tasks and 44 sub-tasks with domestic and international collaborations.

Reactor Design Studies

The conceptual design studies on the helical fusion reactor have been intensively conducted by FERP. In FY2016, the present design was summarized as FFHR-d1. The major radius of FFHR-d1 is 15.6 m, which is four times that of LHD (3.9 m). The heliotron magnetic configuration is similar to that of LHD, having a pair of helical coils with a toroidal pitch number of 10. The toroidal magnetic field has two options at 4.7 T (for FFHR-d1A) and 5.6 T (for FFHR-d1B). The operation point is explored using a design integration code, HELIOSCOPE, incorporating the “Direct Profile Extrapolation” (DPE) method based on the LHD plasma parameters. A self-consistently obtained operation scenario secures the energy multiplication factor $Q \sim 10$. The confinement improvement in the ongoing deuterium plasma experiments in LHD, when confirmed, should lead ultimately to the self-ignition ($Q = \infty$). From FY2017, the design activity has been shifted to a smaller version of FFHR-d1, which is FFHR-c1. The major radius is presently set at 10.92 m (2.8 times LHD).

For both the engineering design of FFHR-d1 and c1, a number of innovative ideas have been proposed from the following three purposes: (1) to overcome the difficulties related with the construction and maintenance of three-dimensionally complicated large structures, (2) to enhance the passive safety, and (3) to improve the plant efficiency. The details are described below associated with the development of each component.

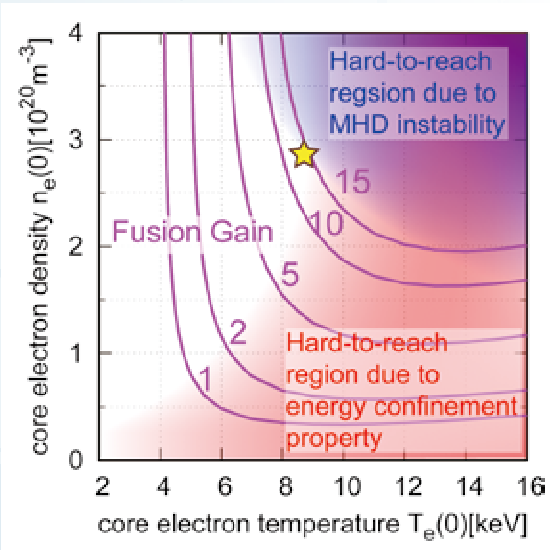


Fig. 1　POPCON plot for the helical fusion reactor FFHR-c1.

Highlight

Innovations for making the helical fusion reactor compact

As is described above, the conceptual design study for the LHD-type helical fusion reactor is now being shifted from the previous design of FFHR-d1 (major radius R = 15.6 m) to a more compact design of FFHR-c1 (R = 10.92 m). There are two innovative factors that have made this shift possible.

(1) One is the employment of the NITA (Newly Installed Twist Adjustment) coils. The NITA coils are the sub-helical coils located outside the main helical coils. The minor radius of the NITA coils is about two times that of the main helical coils. The current is applied in the opposite direction from that of the main helical coils and its amplitude is about 5-10%. By having these NITA coils, it is found that the distance between the helical coils and the plasma (or the ergodic layers outside the last closed magnetic surface) can be increased. A comparison of vacuum magnetic surfaces with and without the NITA coils is shown in Fig. 2. Owing to this innovation, the new design point can be explored as shown in Fig. 3.

(2) The other factor is the employment of the high-temperature superconductors (HTS). For the present FFHR-c1 design, the maximum magnetic field on the helical coils is about 19 T, which is beyond the limit of the low-temperature superconductors (LTS), such as Nb_3Sn. The HTS has been considered also for FFHR-d1, but this was for the purpose of employing the “joint-winding” method. This could be the primary choice also for FFHR-c1.

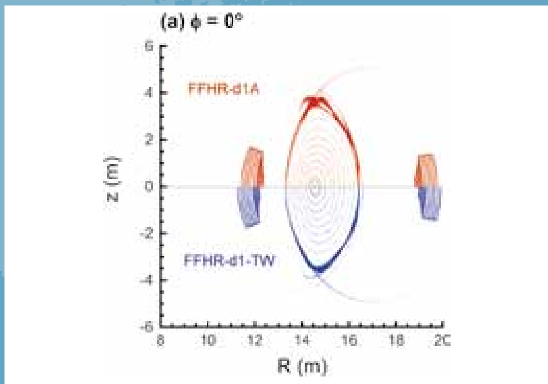


Fig. 2 Comparison of the vacuum magnetic surfaces with and without the NITA coils. The plasma is not very different, but the helical coils are located farther from the plasma with the NITA coils.

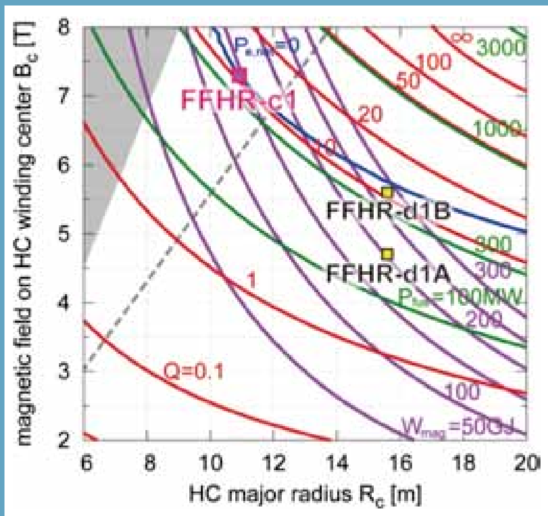


Fig. 3 The design window analysis showing the design points for the FFHR devices. The FFHR-c1 has been selected by considering the core plasma performance and positive net electric power. The shaded region corresponds to where the nuclear heating on the superconducting magnets is too high. The design limit by this nuclear heat moves to the region shown by the broken line if the NITA coils are not used for the blanket space enlargement.

Research and Development on the Superconducting Magnet

The large-scale superconducting magnet system to be applied to the helical fusion reactor has been developed both for the low-temperature superconductor (LTS) and high-temperature superconductor (HTS) options in collaboration with universities and research institutes, domestic and international. For this purpose, the new testing facility equipped with a 13 T magnetic field and a large ϕ0.7 m bore superconducting magnet has started its operation. The facility supplies 4.2-50 K temperature controlled helium and 50 kA sample current. The first cooling test of the 13-T magnet was successfully conducted and the excitation test was carried out up to the magnetic field of ~1.7 T. A full excitation test is planned to be carried out in summer FY2018.

For the LTS conductors, the degradation of the transport current property by mechanical strains on the practical Nb_3Sn wires is a serious problem to be applied to the future fusion magnets operated under higher electromagnetic forces. A development of an internal-matrix-strengthened Nb3Sn multi-filamentary wire is being carried out utilizing the solid solution strengthening mechanism. We successfully developed an Nb3Sn multi-filamentary wire using Zinc (Zn) solid solution ternary Cu-Sn alloy (Cu-Sn-Zn) matrix through the conventional bronze process. The cross-sectional image is shown in Fig. 4. The internally strengthened matrix due to the (Cu, Zn) solid solution is a simpler method than other reinforcement methods, and it has become one of the attractive high strengthening method.

For the HTS conductor, a 100 kA-class STARS (Stacked Tape Assembled in Rigid Structure) conductor has been developed to be applied to the helical fusion reactor FFHR-d1. In the earlier test, a 3-m sample successfully achieved 100 kA at 5.3 T and 20 K. One of the issues associated with this conductor is the non-uniform current distribution among the stacked REBCO tapes. In order to focus on this problem, a down-scaled conductor sample using five tapes was fabricated and tested in liquid nitrogen (Fig. 5). The sample current was supplied from one side of the stacked tapes, and a non-uniform current distribution was formed, which was confirmed by Hall probes measurement. Despite this fact, the transport current reached the expected critical current determined for the whole five tapes. A detailed numerical analysis is being conducted to explain this observation.

Another type of HTS conductor, named TSTC (Twist Stack Tape Cable) has been developed at Massachusetts Institute of Technology (MIT) in US. A 2-m TSTC sample is being prepared to be tested in the 13-T magnet facility in summer 2018.

Fig. 4 Typical cross-sectional image of the internal-matrix-strengthened Nb_3Sn multi-filamentary wire using the solid-solution strengthening mechanism.

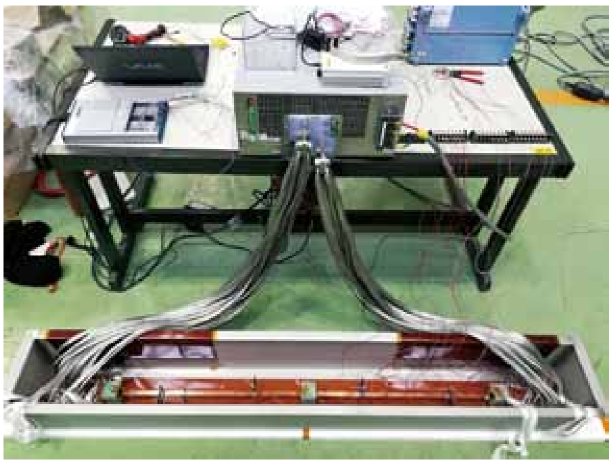


Fig. 5 Experimental setup of a down-sized HTS conductor for the measurement of current distribution among simply-stacked REBCO tapes.

Research and Development on the Blanket

The blanket is a crucial component for a fusion reactor that converts kinetic energy of neutrons to heat and also produces the fuel, tritium, using lithium. This part of the blanket is called the breeder blanket. Behind the breeder blanket, the shielding blanket is situated for the purpose of stopping the residual neutrons so that the superconducting magnet outside the blanket is effectively shielded.

For the helical fusion reactor, FFHR, the liquid-type breeder blanket is considered and designed. For the purpose of developing the blanket, a large-scale forced-convection twin-loop facility of heat and hydrogen, “Oroshhi-2”, was constructed equipped with a superconducting magnet to apply uniform perpendicular magnetic field of 3 T to the flow of either molten salt (Flinak) or liquid metal (LiPb). Using this facility, various researches have been conducted, such as the measurement of the MHD pressure drop in a flow of liquid LiPb through a two-sectioned bending tube in collaboration with Kyoto University. In FY2017, the corrosion characteristics on various materials have been investigated with a molten salt (Flinak) flow at a temperature of higher than 600 centigrade under the magnetic field of 1 T applied in the perpendicular direction to the flow. The experimental setup is depicted in Fig. 6.

For the tritium breeding blanket design, we have chosen the liquid blanket option with molten salt from the viewpoint of passive safety. The present selection of molten salt is FLiNaBe, which has the melting point at 580 K. In order to increase the hydrogen solubility, an innovative idea was proposed to include metal powders, such as titanium. An increase of hydrogen solubility over five orders of magnitude has been confirmed in an experiment, which makes tritium permeation barrier less necessary for the coating on the walls of cooling pipes. Various R&D’s related to this idea are ongoing.

Maintenance is one of the important and difficult issues to realize the helical fusion reactor. For the blanket, a toroidally-segmented system, T-SHELL, was proposed, by dividing the toroidal blanket into every 3 degrees. Another innovative idea is the cartridge-type blanket concept, CARDISTRY-B. The discussion about the maintenance concepts both for the blanket and the divertor is ongoing.

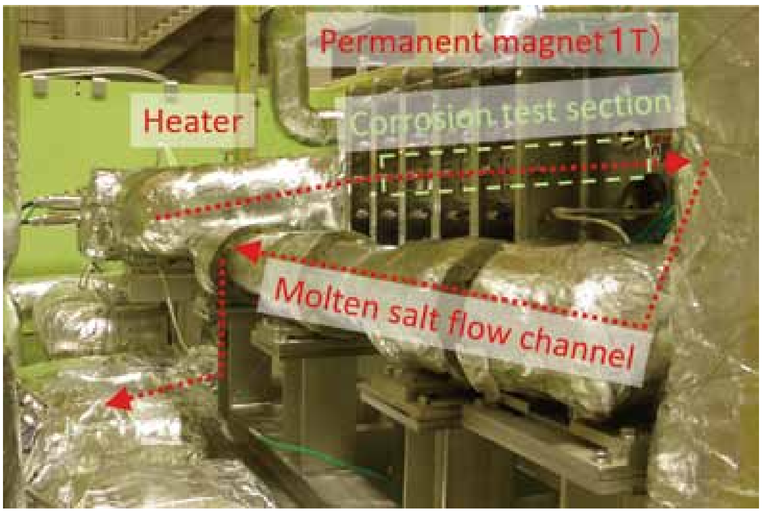


Fig. 6 The corrosion experiment part in the molten salt loop in the Oroshhi-2 twin-loop facility.

Research and Development on the Divertor

The divertor heat flux in fusion reactors is considered to become higher than 10 MW/m^2 in steady state. Important subjects in the engineering research and development for coping with this high heat flux are the material selection, bonding technology between armor tiles and coolant pipes. The design studies on the three-dimensional shape for the helical fusion reactor FFHR is especially important by including the precise neutronics analysis. For FFHR, the water-cooled tungsten monoblocks is considered to be the primary choice. It is expected that a copper-alloy could be applied by placing diverter tiles at the backside of blankets where the incident neutron flux is sufficiently reduced. The peak divertor heat load on the divertor is expected to exceed > 20 MW/m^2 because of the non-uniform divertor heat load profile.

Improvement of copper alloys is being examined in respect to high temperature mechanical properties and radiation resistance. Fabrication process using mechanical alloying and hot isostatic pressing (HIP) is being investigated. Characterization of welding and HIP joints are also carried out for ODS steels and ferritic steels.

An in-situ fabrication process designed to fabricate dispersion strengthened (DS) copper (Cu) alloy with yttria (Y_2O_3) dispersed particles is being proposed, which is an advanced in-situ process combining Mechanical Alloying (MA) and Hot Isostatic Pressing (HIP). For the optimization of the process control, the effects of MA time and Y amounts were investigated. Detailed inspections using XRD, TG-DTA, and SEM confirmed that Cu, Y and CuO powders were mechanically alloyed successfully after MA of 32 hrs. The XRD of these samples also confirmed the formation of Y_2O_3 particles. In addition, the higher Y amounts helps the densification process and enhances the strength of materials. However, it deteriorates the thermal conductivity. Because of the strength-conductivity trade-off, the selection of Y_2O_3 amount should be determined.

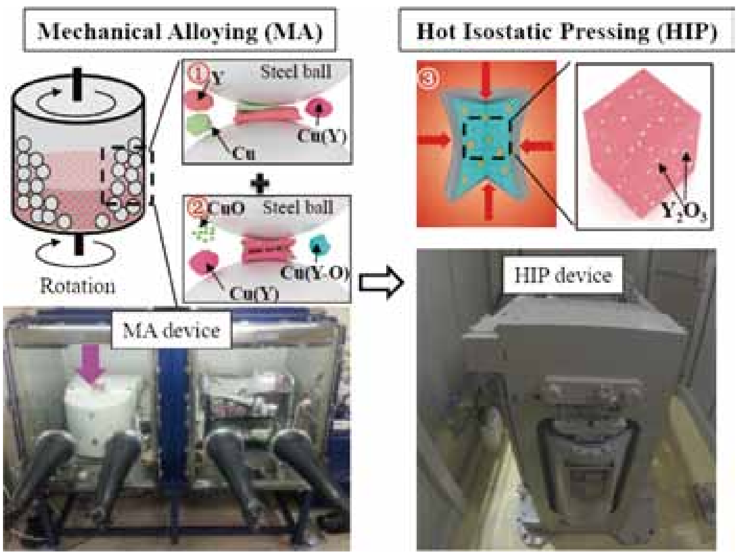


Fig. 7 Fabrication method of Y_2O_3-dispersed copper alloys using an advanced in-situ process combining Mechanical Alloying (MA) and Hot Isostatic Pressing (HIP).

The ACT-2 electron beam facility (maximum power: 300 kW) has been used to apply >10 MW/m^2 of steady-state heat flux to various samples, such as a tungsten block brazed with a copper alloy. This facility is also used to promote collaborations with universities as well as the industry to develop heat removal techniques from water channels. During the last fiscal year, the control system of the electron beam has been upgraded and so that this facility now has a capability of applying also a short pulse (< 1 ms) high power heat flux. The experiment shows that the surface structure on tungsten samples with high power heat flux is significantly varied before and after irradiation by helium ions.

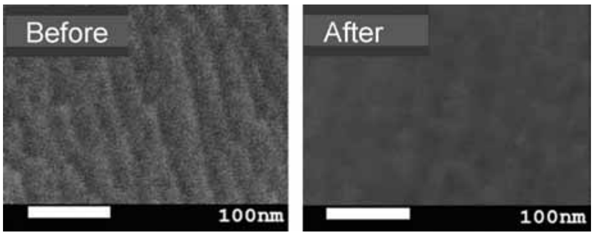


Fig. 8 Surface images of tungsten samples with high heat flux electron beams before (left) and after (right) irradiation by helium ions in the ACT-2 electron-beam facility.

An advanced brazing method for bonding tungsten and Oxide Dispersion Strengthened copper (ODS-Cu) is being developed. The small-sized bonding specimens show that the strength of the bonding interface is higher than that of the bulk tungsten. On the basis of this result, a large-scale divertor mock-up was fabricated using 28 tungsten plates bonded to an ODS-Cu block. A reliable bonding technique was established by maintaining a constant gap of 0.5 mm between each tungsten plate.

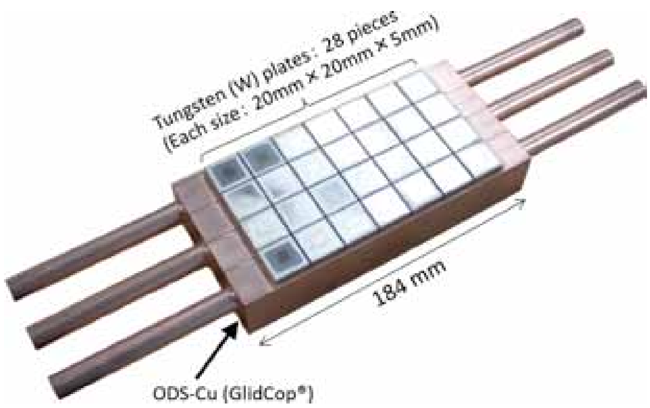


Fig. 9 A large-scale divertor mock-up fabricated using 28 tungsten plates bonded to an ODS-Cu block.

In order to solve the difficult issues on divertors associated especially with the intense heat flux, another possibility is to use liquid metal instead of solid tungsten. A new concept of liquid metal limiter/divertor, REVOLVER-D, has been proposed, having ten units of molten tin shower jets (falls) installed on the inboard side of the torus of FFHR to intersect the ergodic layer. It is proposed that the vertical flow of Tin jets could be stabilized using metal chains embedded in the jets. This system works as an ergodic limiter, and the conventional full-helical divertor becomes less necessary, although they could, or should, be still situated at the backside of the liquid divertor. Neutral particles are expected to be efficiently evacuated through the gaps between liquid metal showers. There are also some other merits of applying liquid divertors, which are that the maintenance scheme could become revolutionary easy compared to the situation for the full-helical three-dimensional divertors and the total volume of waste would be much smaller than the case of all those tungsten plates and copper alloys. The R&D for developing the REVOLVER-D system has begun having a free fall of liquid metal through a channel with an external magnetic field provided by an array of permanent magnets.

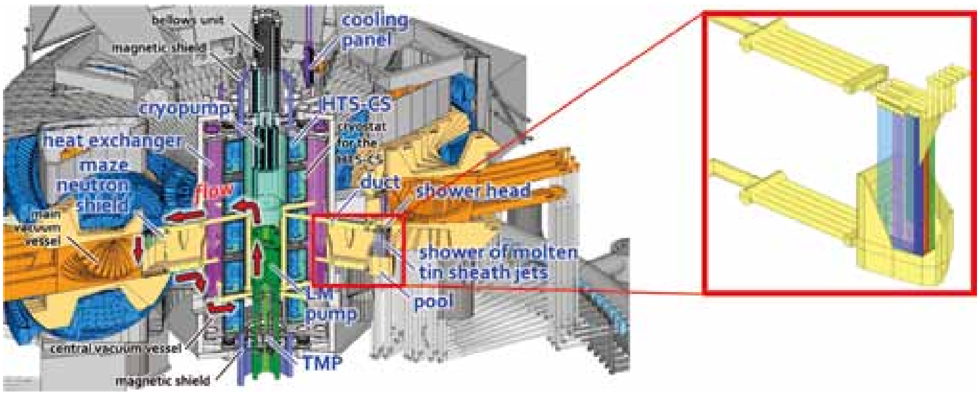


Fig. 10 Schematic illustration of the liquid divertor system REVOLVER-D.


Fig. 11 Experimental setup for investigating the free fall characteristics of liquid metals. Magnetic field is applied to the liquid metal flow using an array of permanent magnets.

Highlight

Innovations for the blanket material

The low-activation vanadium alloys of V-4Cr-4Ti, with a chemical composition of 92 (mass)% Vanadium, 4 (mass)% of Cromium and 4 (mass)% of Titanium can be promising candidates for the structural materials of fusion reactor blankets. However, previous alloys exhibited technical problems, such as brittle fracture at weld joint and cracking during tubing process. The embrittlement is induced by ductility loss due to contamination with gaseous impurities, such as C, N and O, in the fabrication processes. National Institute for Fusion Science (NIFS) has been leading the scale-up and purification of vanadium alloys under collaboration with Japanese universities, and developed NIFS-HEAT-2 alloy. The purification has successfully enhanced workability, weldability and also low-activation property. Fig. 12 shows the improvement of weldabilty, indicating much high absorbed energy in impact fracture tests on the weld joint, compared with the previous V-4Cr-4Ti alloy US832665 made by US-DOE (United States of America, Department of Energy) program. No degradation of impact energy was revealed for the weld metal of NIFS-HEAT-2 alloy, while it was under the acceptable level as structural materials for US alloy.

Although many properties were improved by the purification, possible degradation of high-temperature strength due to purification softening was a concern. Therefore, the NIFS fusion energy research project has recently focused on the high-temperature creep property of NIFS-HEAT-2, which limits the operation condition for fusion reactor blanket. Constant load was applied at elevated temperature, and induced deformation and finally rupture of NIFS-HEAT-2 in the creep tests. Fig. 13 plots the loading stress versus creep rupture time at 800°C. It was successfully confirmed that creep strength of NIFS-HEAT-2 in the lower loading condition was comparable to those of US, whereas in the higher loading condition, it was degraded compared with the dashed trend line for US data. Since the loading is expected as 100 MPa or less in the fusion blanket, the purification of NIFS-HEAT-2 does not require any change in design loading condition for vanadium alloy blanket. In conclusion, the purification for NIFS-HEAT-2 improved many properties, such as weldability, workability and low-activation properties, and raised no negative effect on high-temperature creep properties under the blanket loading conditions.

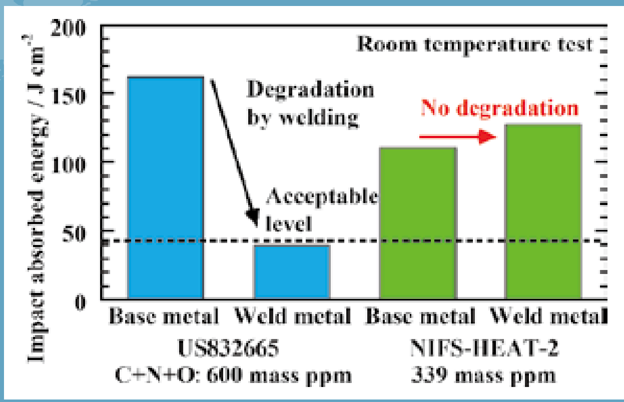


Fig. 12 Impact absorbed energy of the weld metal after welding and the base metal before welding.

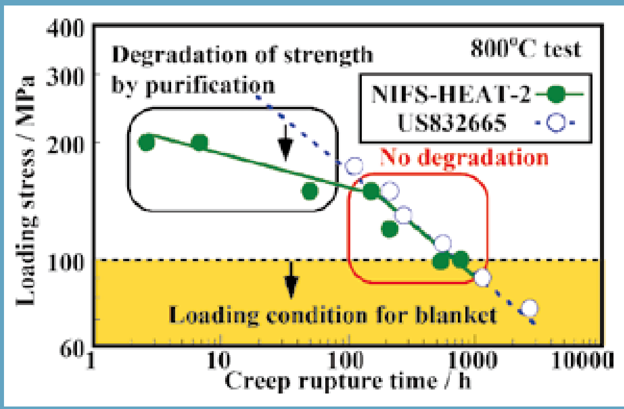


Fig. 13 Creep rupture time under the constant loading stress at 800°C.

LHD-Project Research Collaboration

The LHD Project Research Collaboration program has been contributing to enhancing both the scientific and technological foundations for the research related with LHD as well as the future helical fusion reactors. The characteristics of this collaboration program is that the researches are performed at universities and/or institutions outside NIFS.

It has been twelve years since the LHD Project Research Collaboration started to invite external reviewers from universities and institutions within Japan to form three committees and one advisory council in the selection process of collaboration subjects on fusion engineering, fusion science and plasma physics. Close collaboration among these areas is getting more and more essential for the further progress of fusion research. It is required for NIFS to develop a sound network of fusion research among universities and government institutions, by enhancing information exchange, planning, international collaboration, and education of graduate students. An important criterion for choosing a new collaboration subject is that the proposal is new and innovative, which is useful for the LHD project but is not directly planned at NIFS.

In the research area on the fusion engineering, the following twelve subjects were approved and conducted in FY2017.

1. In-situ LIBS measurements of hydrogen isotope retention and material mixing
2. Development of plasma-spray technique and evaluation of coating properties for LHD tungsten divertor
3. Tritium accumulation and its decontamination of deposition layer
4. Study on development of environmental tritium behavior model incorporating organic bonded tritium
5. Investigation of helical winding application of Nb3Sn cable-in-conduit conductor after heat treatment
6. H, D and T quantitative analyses for plasma facing walls exposed during deuterium experiment
7. Knowledge and technology transfer from IFMIF-EVEDA accomplishment to systemization of liquid blanket research
8. Development of irradiation-resistant NDS-Cu alloys for helical reactor divertor
9. Development of effective heat removal method from liquid metal free-surface with local heating under strong magnetic field and its demonstration by Oroshhi-2
10. Engineering approach to lithium isotope separation using cation exchange resin
11. Behavior of tritium in a secondary cooling loop of a fusion reactor
12. Establishment of molecular biology response and investigation of the biological effects of low level tritium radiation

From the above ten research items, two of them (6 and 10) are briefly described below:

<u>H, D and T quantitative analyses for plasma facing walls exposed during deuterium experiment</u>

A new thermal desorption spectroscopy (TDS) measurement system was designed and installed in LHD to evaluate all the hydrogen isotope desorption behaviors in materials, simultaneously. Using this HI-TDS system, D and T desorption behaviors in implanted or DT gas exposed tungsten samples installed in LHD were examined. It was found that the major hydrogen desorption stages consisted of two temperature regions, i.e., 700 and 900 K. This is consistent with the result obtained in the previous hydrogen plasma campaign, which showed that most of the hydrogen atoms were trapped by the carbon-dominated mixed-material layers. By energetic ion implantation, the major D desorption was found at ~900 K with a narrow peak. For gas exposure, H was preferentially replaced by D and T with a lower trapping energy. In addition, T replacement rate by additional H_2 gas exposure was evaluated. This observation indicates that the hydrogen replacement mechanism might be clearly varied by exposure methods.

Fig. 14 The HI-TDS system installed in the LHD building at NIFS.

<u>Engineering approach to lithium isotope separation using cation exchange resind</u>

The lithium isotope separation by the displacement chromatography using cation exchange resin has been studied. We made cation exchange resins with 50% and 90% cross-linkage, and the SEM photo of the latter one is shown in Fig. 15. The isotope separation coefficient depends on the cross-linkage. The separation coefficients of the synthesized resins are much higher than that of commercially available resins.

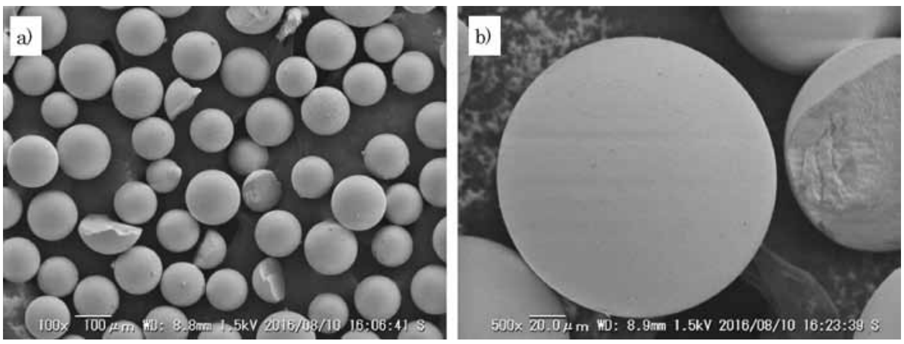


Fig. 15 SEM photo of the cation exchange resin with 90% cross-linkage with two magnifications.

(T. Muroga)

Numerical Simulations of MHD properties in LHD plasmas

Highlight

Numerical scheme for 3D global flow consistent with 1D experimental data and effects on MHD dynamics of interchange mode

We study the nonlinear interaction between the global flow and the interchange modes using three-dimensional (3D) numerical simulations. In the Large Helical Device (LHD) experiments, partial collapses of the electron temperature profile due to the interchange modes are observed in some discharges. In the collapses, the mode rotation stops during the mode growth and the nonlinear collapse [1]. The mode frequency is dominated by the background flow frequency [2]. Thus, we numerically analyze the effects of the flow on the nonlinear evolution of the interchange mode. For this purpose, we have developed a numerical scheme to calculate the flow profile consistent with the experimental data firstly. In LHD, one-dimensional radial profiles of the poloidal and toroidal components of the flow are observed only in the outer side of the torus [3]. By applying the scheme to the data, we can obtain the 3D profile of the global flow in the entire plasma region. Figure 1 shows the 3D profile of the stream lines corresponding to the experimental data. This figure indicates that the flow value in the inner side that is not observed experimentally is larger than that observed in the outer side. Then, the stabilizing effects of the flow on the MHD dynamics is studied with the MIPS code [5]. In the present study we utilize a static and strongly unstable equilibrium calculated by the HINT code [6]. The global flow is incorporated in the initial perturbation. As the results, in the change of the absolute value of the flow, the flow stabilizes the interchange mode weakly up to a certain value, while destabilizes the plasma beyond the value through the excitation of the Kelvin-Helmholtz instability. This tendency is similar to the electro-static g-mode theory [7].

[1] S. Sakakibara, *et al.*, 2015 Nuclear Fusion, **55** 083020.
[2] Y. Takemura, *et al.*, 2013, Plasma and Fusion Res. **8**, 1402123.
[3] M. Yoshinuma, *et al.*, Fusion Sci. Tech., **58** (2010), 103.
[4] K. Ichiguchi *et al.*, Proc. IAEA FEC 2016 Kyoto, TH/P1-4.
[5] Y. Suzuki, *et al.*, 2006 Nucl. Fusion, **46** L19.
[6] Y. Todo, *et al.*, 2010 Plasma and Fusion Res. **5** S2062.
[7] H. Sugama, *et al.*, Phys. Fluids, **B3**, 1110 (1991).

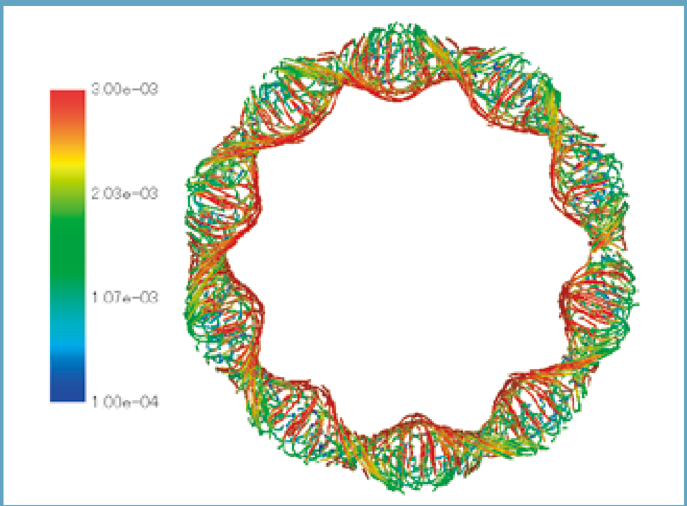


Fig. 1 3D profile of the stream lines of the global flow corresponding to the 1D experimental data.

Magnetic island generation mechanism in a resistive interchange mode

The magnetic island generation mechanism in a resistive interchange mode has been numerically investigated based on a two-fluid model [1]. It is found that one of the mechanisms is the nonlinear generation of a tearing parity mode due to a modulational parity instability. The formation of magnetic islands can be linked to the parity of the mode. The interchange mode has two types of parity modes, interchange and tearing parity modes. The electrostatic potential of the former and the latter modes are even and odd functions of the local radial coordinate around the mode resonance surface, respectively. The formation of the magnetic islands is represented by the appearance of the tearing parity mode. Figure 2(a) shows the time evolution of the kinetic energy of both parities of the n=1 mode where n is the mode number. Since the nonlinear mode coupling is weak at the beginning, the amplitude of the interchange parity mode with n=1 is significantly larger than that of the tearing parity mode in the initial nonlinear saturated state. However, the initial saturated state is unstable against the modulational parity instability. Then, the amplitude of the tearing parity mode with n =1 grows and becomes comparable to that of the interchange parity mode and a large magnetic island is formed as shown in Fig. 2(b).

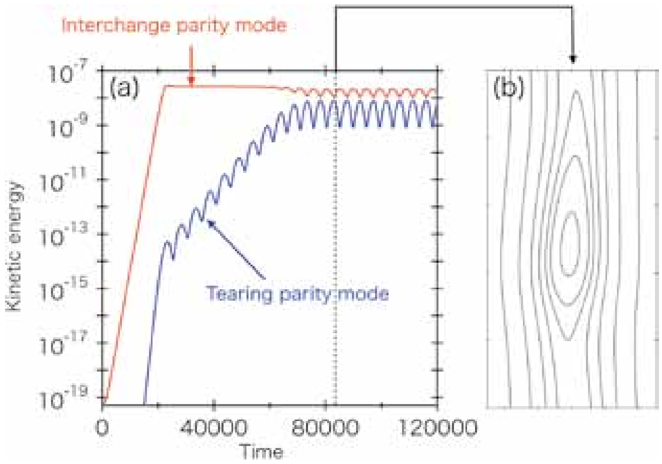


Fig. 2 (a) Time evolution of kinetic energies of both parities of the n=1 mode and (b) magnetic flux surfaces at the final saturated state.

[1] M. Sato and A. Ishizawa, 2017 Phys. Plasmas, **24** 082501.

MHD simulation on pellet injection in the LHD plasma with an m/n=1/1 island

In order to investigate the behaviors of the pellet plasmoids in the LHD plasmas with and without an m/ n=1/1 island, we have performed MHD simulations with the extended CAP code [1]. As shown in Fig. 3, it is found that the peak position of the plasmoid density in the plasma with the island is located at more outboard side than that in the plasma without islands. The maximum density of the plasmoid within the island is greater than that without islands. On the other hand, the plasmoid density in the plasma with the island in the region between the magnetic axis and the island is less than that in the plasma without islands in the corresponding region. These results qualitatively agree with the rapid increments of the density in the experimental data [2]. The elongation of the plasmoid along the field line in the plasma with the island is also found to be inhibited as compared with that in the plasma without islands.

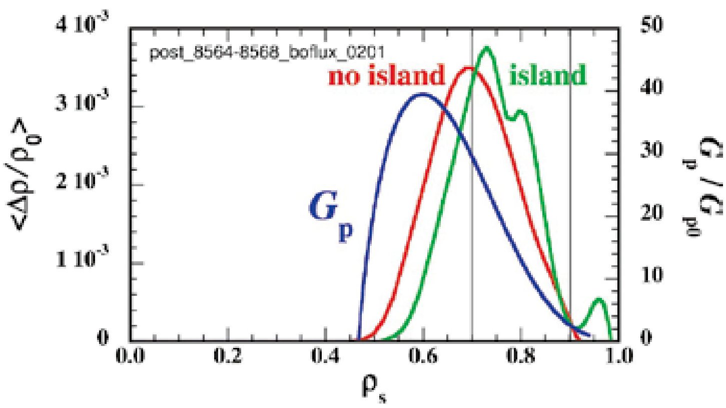


Fig. 3 Normalized plasmoid densities averaged on the flux surface $\langle \Delta\rho/\rho0 \rangle$ as a function of the minor radius ρs with the Boozer coordinate. The red and the green lines indicate those plasmoid densities in the plasmas without and with the islands, respectively. The blue line indicates the normalized ablation rate Gp/Gp0.

[1] R. Ishizaki, *et al.*, Plasma Phys. Control. Fusion **53**, 054009 (2011).
[2] T. E. Evans, *et al.*, EX/1-3, 25th IAEA Fusion Energy Conference (2014).

3D upgrade of global full-f kinetic simulations for 3D plasmas

Highlight

A global gyrokinetic toroidal 5D full-f Eulerian code, GT5D, is now upgraded to incorporate general 3D helical plasmas

The world's first global full-f kinetic simulations for helical plasmas

Predicting and improving the confinement performance determined by the particle/energy transport in magnetically confined plasmas has been a central issue for the fusion research activities. To this end, much effort has been devoted to understand the physical mechanisms on the transport processes and profile formations. A global full-f gyrokinetic simulation based on the first principle is regarded as one of the most promising tools for the whole plasma modeling, since it can predict a steady state of a plasma which is realized as a consequence of the self-consistent interaction among the turbulent/collisional transport, the time-developing plasma profile, and heat/particle sources. Despite the great advantages, however, the global full-f gyrokinetic simulations have been exclusively applied to axisymmetric tokamak plasmas, and no applications to three-dimensional helical/stellarator plasmas have been reported due to their complicated magnetic field structures.

Recently, a global full-f gyrokinetic simulation code, GT5D, which was originally developed for the transport studies of tokamak plasmas, has been upgraded to incorporate general three-dimensional magnetic field equilibria. To guarantee the numerical conservation of the particle and energy is essentially important. In addition, the pole singularity at the magnetic axis should be avoided. To overcome the issue, a novel coordinate system, in which the poloidal symmetry with respect to the axis holds, is proposed and the conservative non-dissipative finite difference scheme is applied on this coordinate system. For the numerical verification of the 3D extension of GT5D, a series of benchmarks on the neoclassical transport, the ambipolar radial electric field and the zonal flow damping in a typical LHD plasma are performed; good agreements with an existing simulation and a theory are confirmed, respectively.

GT5D for 3D helical plasmas have been developed based on a collaboration with Japan Atomic Energy Agency. Detailed descriptions of GT5D can be found in [1]. Further development of the code for the turbulence, impurity transport, and so on is being actively continued. Experimental analyses have been also initiated.

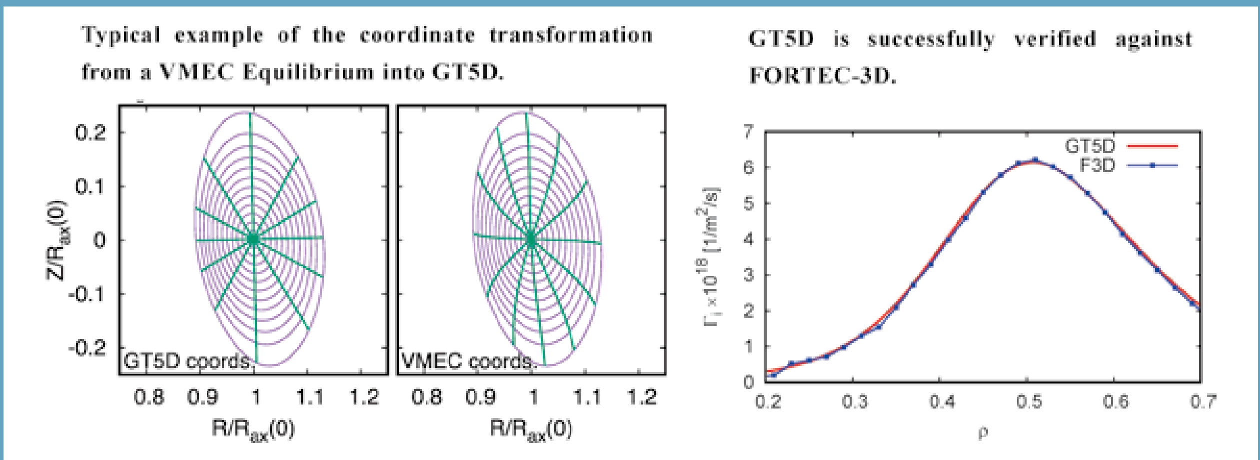


Fig. 1 Coordinate system and the numerical verification of the neoclassical transport in GT5D [1].

Multiple time-scale global transport simulations based on direct-coupling approach with gyrokinetic and transport solvers

Time-dependent global transport simulation is a powerful approach to predict the dynamic evolution of plasma profiles, the confinement performance, and the fusion power in future burning plasmas. To this end, a new global transport solver TRESS+GKV [2] has been developed by the collaborations with National Institutes for Quantum and Radiological Science and Technology. The dynamical transport problems with both the neoclassical and turbulent transport processes are solved by the direct coupling between the multiple fluxtube gyrokinetic simulations by GKV and macroscopic 1-D radial heat transport simulation by TRESS/GOTRESS (the left figure). The effects of realistic tokamak magnetic geometry, kinetic electrons, and multiple ion species are incorporated. Currently, the neoclassical and turbulent heat fluxes are calculated by using the matrix inversion method and the quasilinear approximation, respectively. Under the realistic heating conditions, the time evolutions of the ion and electron temperature profiles towards a power balanced steady state are simultaneously solved. Several acceleration methods, e.g., the adaptive source/sink and the Newton iteration, and the genetic algorithm [3] are implemented to perform global ITG-TEM driven turbulent transport simulations with less numerical costs.

Reduced transport model for ion heat diffusivity by gyro-kinetic analysis with kinetic electron response

A high ion temperature plasma in the Large Helical Device is examined in the case in which the ion temperature gradient mode is unstable. The nonlinear gyro-kinetic simulation is performed to evaluate the turbulent ion heat diffusivity with the kinetic electron response. To reduce the computational cost for applying to the dynamical transport simulation, an extended transport model for the ion heat diffusivity in terms of the mixing length estimate and the characteristic quantity for the linear response of zonal flows is proposed. The values for the ion heat diffusivity of the nonlinear gyro-kinetic results are compared with those for the reduced model by the linear simulation with the circles in the right figure [4]. The use of the linear simulation results enables us to reproduce the nonlinear simulation results by the reduced model. The decay of zonal flows with the kinetic electron becomes faster. The decay time of zonal flows is found to decrease radially outward and the ion energy transport increases outward due to the trapped electron.

[1] S. Matsuoka, Y. Idomura, and S. Satake, Phys. Plasmas **25** (2018) 022510.
[2] M. Nakata, M. Honda, and M. Nunami, Plasma Conference 2017, Himeji (2017).
[3] M. Honda, Comput. Phys. Commun., in press (2018).
[4] S. Toda, M. Nakata, M. Nunami, A. Ishizawa, T.-H. Watanabe, and H. Sugama, Plasma Fusion Res., **12** (2017) 1303035.

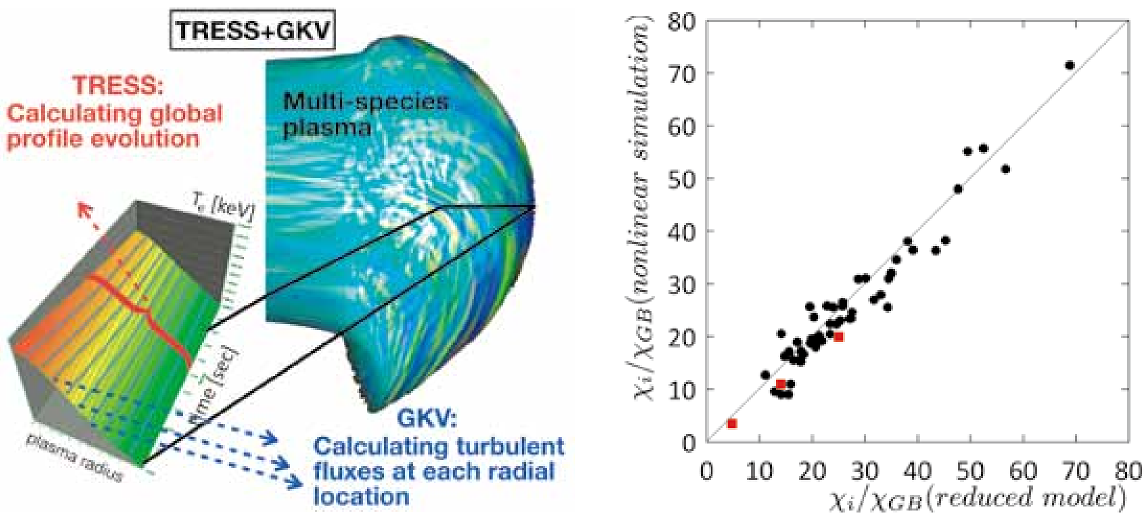


Fig. 2 Left: Joint framework in TRESS+GKV. Multiple local turbulent transport calculations by GKV directly couple to the 1-D global transport solver TRESS.
Right: The comparison of the nonlinear simulation results for the ion heat diffusivity with the reduced model.

3. Numerical Simulation Reactor Research Project

Impurity transport in peripheral plasma

Highlight

Three-dimensional impurity transport modeling of neon-seeded and nitrogen-seeded LHD plasmas

Understanding the impurity transport in the peripheral plasma is an important issue to design the future fusion reactor, because the plasma is detached from the divertor by the radiation of the impurity. In this group, the transport in the peripheral plasma, which includes the impurity and neutral, is studied by three-dimensional kinetic and fluid codes on the supercomputer “Plasma Simulator”.

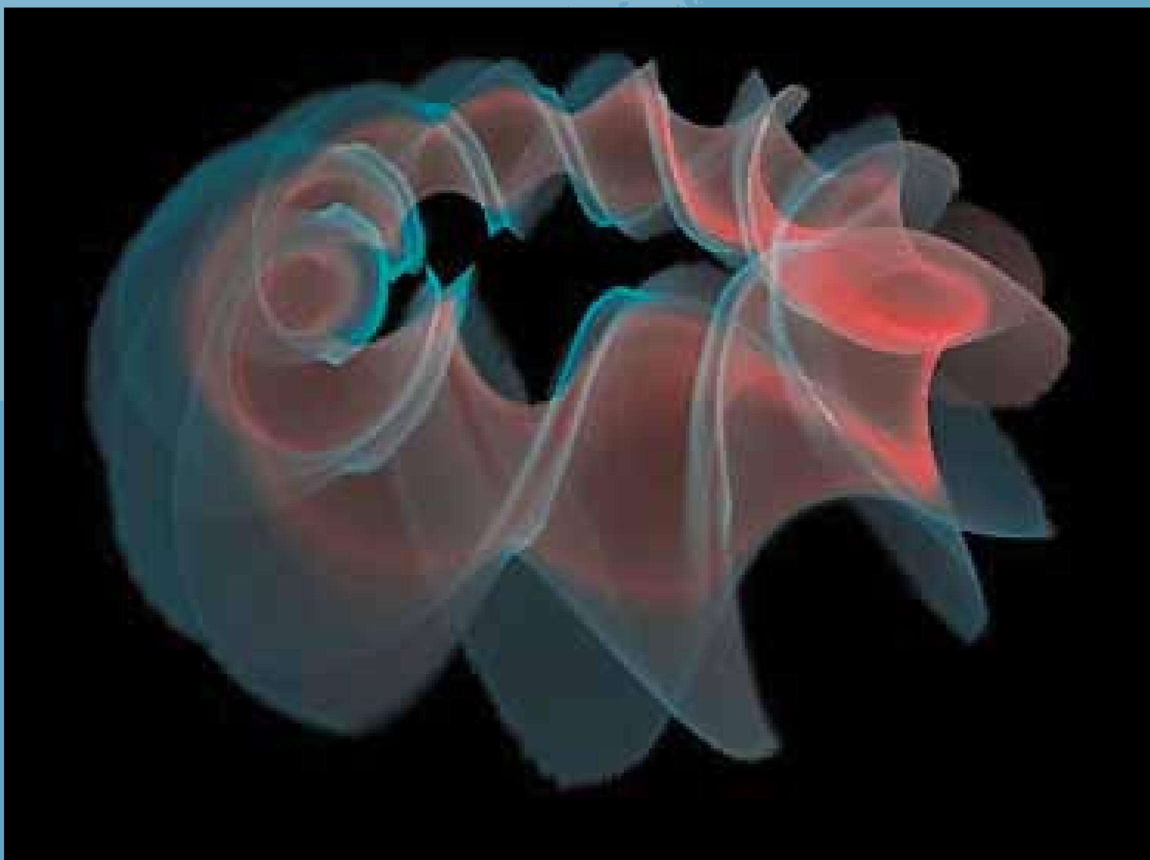


Fig. 1 Impurity radiation simulated by EMC3-EIRENE code.

Prediction of a plasma is essential for a reactor design to ensure safety margins to engineering limits and good controllability of discharges. Increase of core performance, enlargement of device size, and extension of discharge time lead to severe engineering issues such as high heat load on the plasma facing components statically or dynamically and accumulation of impurities and hydrogen isotopes on wall surfaces. These issues are closely linked to divertor plasma transport and, therefore, its modeling is strongly required to estimate the plasma parameters and the influence upon components surrounding the plasma. In particular, for the heat load issue, application of impurity radiation, optimization of divertor structure, and plasma detachment are the major topics.

Divertor plasma modeling of fusion devices is studied with calculation codes solving fluid equations of plasma along magnetic field lines with cross-field diffusive terms and kinetic equations of neutral particles. Codes for tokamak devices assume axisymmetry but plasmas with Resonant Magnetic Perturbations (RMP) in tokamak devices and plasmas in helical devices require a three dimensional calculation code. EMC3-EIRENE code is a three dimensional Monte Carlo code extensively applied to fusion devices with non-axisymmetric components. Fluid transport equations along magnetic field with perpendicular diffusive transport are solved by EMC3 code, and kinetic equations with atomic and molecular processes are solved by EIRENE code. Recently, impurity seeding experiments with gas puffing have been conducted with different gas species, such as neon, argon, krypton, xenon, and nitrogen. From an experimental analysis, toroidally symmetric/asymmetric distributions of particle flux on divertor plates and differences of transport characteristics of neon and nitrogen were revealed in LHD. A helical plasma intrinsically has a toroidal asymmetry, however usually it has a toroidal periodicity due to repeated toroidal structures of magnetic field coils. A toroidal symmetry in this work represents the periodicity, and a toroidal asymmetry represents violation of the periodicity. In this work, we present a modeling study of impurity-seeded plasma with EMC3-EIRENE code to reproduce the toroidal symmetric/asymmetric characteristics. Also, validation of the model with experimental measurements and open questions suggested from differences between model results and experimental measurements are addressed.

Figure 2 shows toroidal distributions of the particle flux on divertor plates. Bold lines indicate predicted results by EMC-EIRENE code and symbols of cross and circle indicate measured results in experiments. For the neo seeding case, the distribution is toroidally symmetric but for the nitrogen seeding case, the distribution is toroidally asymmetric. EMC3-EIRENE results well reproduce experimental observations. That means the prediction of EMC3-EIRENE code is well validated by the LHD experiment.

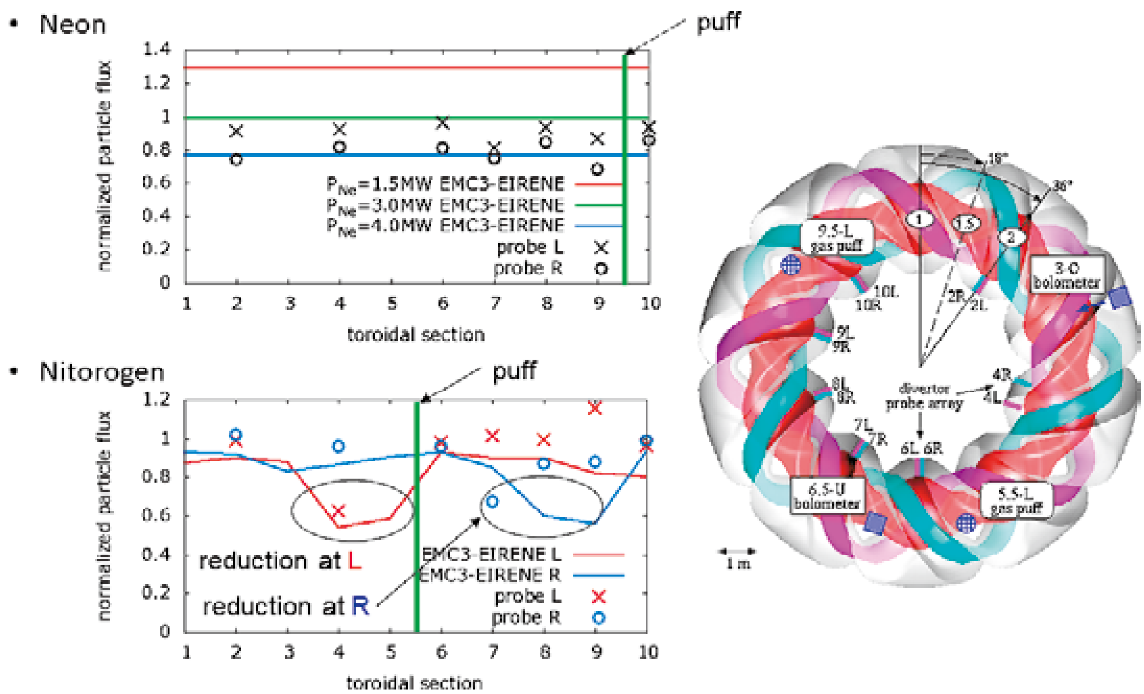


Fig. 2 Configurations of the puffing nozzles, the bolometer systems, and the divertor probe arrays in the LHD and the toroidal flux distribution of hydrogen ions for neon and nitrogen seeding cases.

Ion heating mechanism in magnetic reconnection

Highlight

Ion heating mechanism in magnetic reconnection is clarified by using our particle simulation model "PASMO"

For realization of fusion devices, high-temperature plasmas need to be produced. In a different type of device from the Large Helical Device (LHD), a spherical tokamak, two plasmas with low temperature are merged into a single plasma with high temperature. In this process, magnetic reconnection occurs, through which plasmas are heated. The comprehension of the heating mechanism can lead to the production of higher-temperature plasmas.

We investigate plasma heating processes during magnetic reconnection by using our particle simulation code "PASMO." Figure 1 (a) shows the spatial profile of the ion temperature in the simulation region. The ion temperature is high in the downstream of the magnetic reconnection point, and this result is consistent with results of plasma merging experiments in spherical tokamaks. Our simulations further demonstrate ion velocity distributions by assembling velocities of individual ion particles. Figure 1 (b) is an ion velocity distribution in the low-temperature region, where a mountain shape, i.e., a Maxwellian distribution is seen. Figure 1 (c) is an ion velocity distribution in the high-temperature region, where we can see that a caldera-shape structure is formed. By investigating the formation process of the caldera-shape structure, we successfully clarify the detailed mechanism of the ion heating.

This work has been published in Physics of Plasmas [1].

[1] S. Usami, R. Horiuchi, and H. Ohtani, Phys. Plasmas **24**, 092101 (2017).

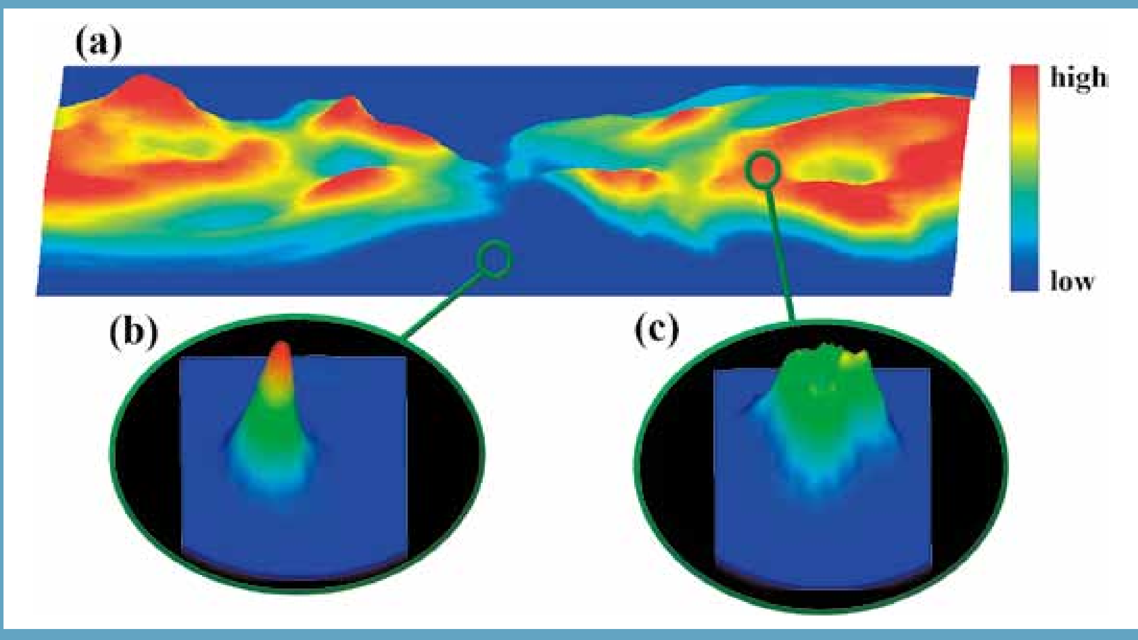


Fig. 1 PASMO simulation of magnetic reconnection. (a) Ion temperature in the magnetic reconnection surface. (b) Ion velocity distribution in the low-temperature region. (c) Ion velocity distribution in the high-temperature region.

Blob/hole dynamics study by the p3bd code

In the Multi-Hierarchy Physics Research Group, the three-dimensional (3D) electrostatic particle-in-cell (PIC) simulation code, called “p3bd” (**p**article-in-cell **3**-dimensional simulation code for **b**oun**d**ary layer plasma dynamics), for the study of blob and hole propagation dynamics has been developed, where the blob and the hole are the intermittent filamentary coherent structures observed in the boundary layer plasmas of various magnetic confinement devices. In order to verify the p3bd code, the relations between the radial propagation speed of coherent structures and the structure poloidal size, which are observed in the p3bd simulations, have been compared with the theoretical relations. As a result, it has been shown that the observed relations are in good agreement with the theoretical relations. Furthermore, the code has reproduced a larger distortion of a hole shape than that of a blob shape (Fig. 2), which arises from the larger propagation velocity shear, and has shown that the propagation of a blob or a hole becomes faster in the situation without end plates, which is similar to the detached state.

This work has been published in Plasma and Fusion Research [2].

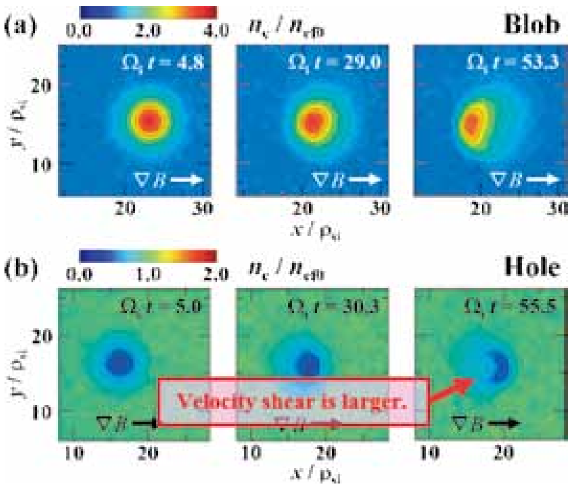


Fig. 2 Time evolutions of the electron density distribution on the poloidal cross-section in the blob (a) and hole (b) propagations. This figure appeared on the front cover of Journal of Plasma and Fusion Research Vol. 93, No. 12 and the top page of the Plasma and Fusion Research website.

[2] H. Hasegawa and S. Ishiguro, Plasma and Fusion Research **12**, 1401044 (2017).

Two-fluid tearing mode instability in cylindrical geometry

The two-fluid resistive tearing mode instability in a periodic plasma cylinder of finite aspect ratio was investigated analytically and numerically [3, 4]. The cylindrical dispersion relation was derived for general cases of the cylindrical aspect ratio and two-fluid effects. It shows that the non-zero real frequency of the mode arises due to the combination of two-fluid and cylindrical effects. Scaling laws for the growth rate and the real frequency of the mode with respect to the resistivity and ion skin depth, scale length of the two-fluid effect, were derived from the analytic dispersion relation in both limits of small and large ion skin depths. The real and imaginary parts of the mode growth rate become comparable for parameters such that the cylindrical aspect ratio and two-fluid effects are of order unity (Fig. 3). The numerically obtained eigenvalues agree very well with the analytic dispersion relation and the agreement improves the smaller the resistivity and the larger the ion skin depth are. Comparison between the numerical eigenfunctions and the inner solutions of the boundary layer theory shows that the eigenfunctions develop imaginary parts within the resonant layer, also due to the combination of two-fluid and cylindrical effects.

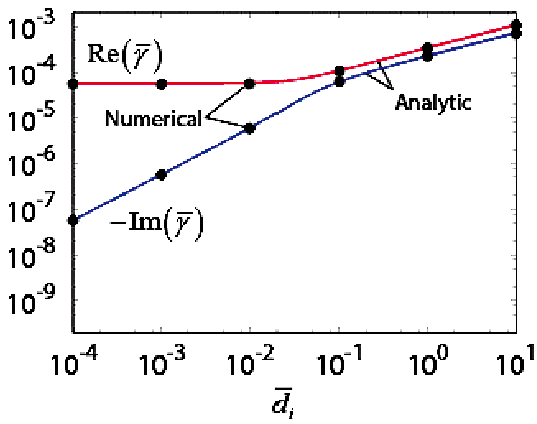


Fig. 3 Growth rates and real frequencies as functions of the ion skin depth obtained numerically from the eigenmode equations (points) compared with the analytic dispersion relation (lines).

[3] A. Ito and J. J. Ramos, Phys. Plasmas **24**, 072102 (2017).
[4] A. Ito and J. J. Ramos, Phys. Plasmas **25**, 012117 (2018).

Construction of helical model reactor in virtual-reality space

Highlight

Virtual-reality technology is applied to the reactor design research: reactor design CAD data with robot arm system is visualized, the movement of the system can be confirmed, and the virtual hand grasps the component of the reactor.

It is important to design a reactor while considering previously how to assemble the components, because it will be possible to build up the reactor efficiently. Additionally, it is also significant to consider how to detach the components, such as blanket structure and divertor plate, in the reactor, how to move them through the reactor along toroidal direction, and how to pass them through the small port by moving and rotating them without collisions with the other components. The fusion reactor is designed to replace the components periodically in the fusion operation, and it is necessary to give consideration to the replacement process in advance. In the ITER project, the processes of assembling and exchanging the components are investigated by using CAD software, and the robotics system is studied for remote manipulation. However, it is expected that the handling will become difficult. Presently, NIFS is researching and designing the new concept reactor, that is, a cartridge-type reactor which does not require such complex movement of the components in the reactor in the replacement process. In this cartridge-type reactor, the robotics system for assembling and detaching the components from outside the reactor is investigated by using CAD software. However, it is not easy to determine how to move and rotate the components on the 2D monitor by using CAD software because the information regarding depth is lost. By motion parallax, a human being can also perceive the depth, for example, when the object is rotating. But it would be difficult to confirm the collision between the components and the movement of the component by the robot arm during their rotation.

Because the virtual-reality (VR) system gives a viewer deep immersiveness into the three-dimensional (3D) space by the stereo-viewer system, tracking system, and other methods, the viewer can watch the visual objectives before the viewer's very eyes in the real-scale VR world.

Our CAVE-type VR system "CompleXcope" visualizes the CAD data by VirDSE of Asahi Electronics. In this system, the viewer can come into the reactor and confirm the design [1]. It is also possible to measure the distance between the positions which the viewer indicates by Wand. The viewer can watch the movement of the components as animated graphics in the VR space. The viewer can also grasp the component by his virtual hand in the VR space, which moves corresponding to the real hand movement. In Fig. 1, the viewer watches the robot arm system, and grasps one component by his virtual hand. By using this system, the viewer can also perform collision detection when assembling. When the components collide with each other, the component struck is highlighted.

VR technology is also powerful for design of the reactor, and examination of the maintenance operation. We believe that the progress shown in this paper will enhance research in fusion plasmas and fusion engineering.

Fig. 1 Virtual-reality visualization of cartridge-type helical reactor CAD data. Left figure shows the reactor design data with robot-arm system, and right figure displays that one component is grasped by the virtual hand.

Analysis of periodic nanostructure formation mechanism by particle simulation

It was found in many experiments that repeated irradiations of short pulse lasers could form periodic nanostructures on metal surfaces, but its formation mechanism is not fully understood yet. We use 2D PIC simulations to investigate the formation mechanism. If the laser is relativistic intensity, the Weibel instability plays an important role to form the periodic nanostructure [2]. On the other hand, standing wave of surface plasma waves and oscillating two-stream instability can form the periodic nanostructure in the case of non-relativistic laser intensity [3]. Typical simulation results are shown in Fig. 2.

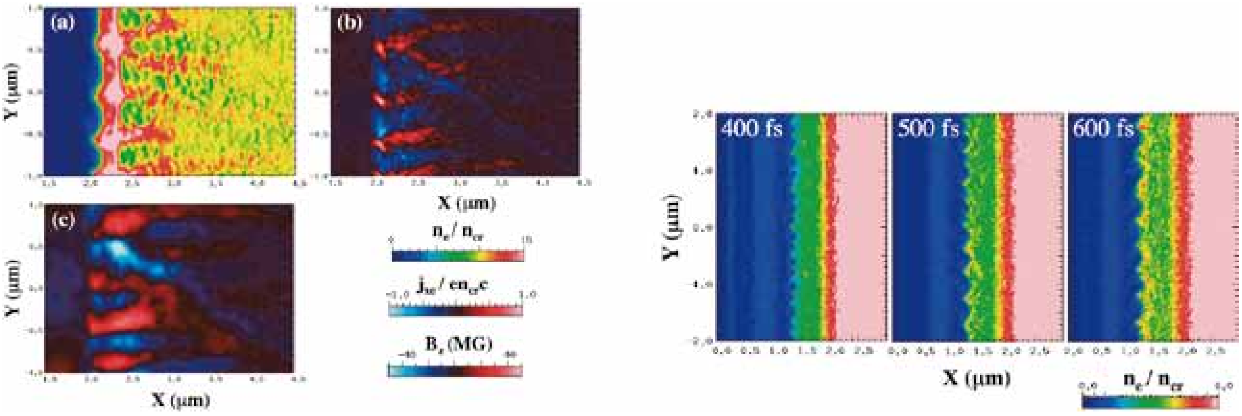


Fig. 2 Left: Weibel structure in the case of relativistic laser intensity at t = 250 fs. (a) electron density, (b) electron current density in X direction and (c) magnetic field in Z direction.
Right: Time evolution of electron density profile in the case of non-relativistic laser intensity.

Performance evaluation of three-dimensional fluid code written by XcalableMP

In order to adapt the parallel computer from a special kind of machines to general convenient tools for computational scientists, a high-level and easy-to-use portable parallel programming paradigm is mandatory. XcalableMP (XMP) [4], which is proposed by the XMP Specification Working Group, is directive-based language extensions to easily describe parallelization in programs for distributed memory parallel computers. IMPACT-3D is a three-dimensional Eulerian fluid code which performs compressible and inviscid fluid computation. We used XMP to parallelize the code, and measured its performance on the K computer. We found that programs converted by the XMP/F compiler prevent some optimizations by the native Fortran compiler and show lower performance than that by hand-coded MPI programs. Finally, almost the same performance is obtained by using specific compiler options for the native Fortran compiler [5].

In addition to the studies mentioned above, (1) application of dynamical load balancing library “OhHelp” to electromagnetic particle simulation code “PASMO” by H. Ohtani *et al.*, and (2) coding method for advancing of SIMD and pipeline in particle simulation code by S. Satake *et al.*

[1] H. Ohtani and S. Ishiguro, Proc. 36th JSST Annual International Conference on Simulation and Technology, 194 (2017).
[2] A. M. Gouda, H. Sakagami, T. Ogata, M. Hashida, and S. Sakabe, Appl. Phys. A, **122**, 454 (2016).
[3] A. M. Gouda, H. Sakagami, T. Ogata, M. Hashida, and S. Sakabe, Plasma Fusion Res., **11**, 2401071 (2016).
[4] XcalableMP, http://www.xcalablemp.org/.
[5] H. Sakagami and H. Murai, Proc. of the 30th International Supercomputing Conference, Frankfurt, Germany, July 12-16, (2015).

(S. Sugama)

As an inter-university research institute, NIFS activates collaborations with researchers in universities as well as conducting world-wide top level researches. The collaboration programs in basic, applied, and innovative research support research projects motivated by collaboration researchers in universities. It is also important to establish the academic research base for various scientific fields related to fusion science and to maintain a powerful scientific community to support the research. Programmatic and financial support to researchers in universities who work for small projects are important. As an inter-university research institute in fusion science, NIFS performs such an important role and the programs in basic, applied, and innovative research are prepared for this purpose.

For basic plasma science, NIFS operates several experimental devices and offers opportunities to utilize them in the collaboration program for university researchers. A middle-size plasma experimental device HYPER-I is prepared for basic plasma research. In addition to the collaboration support with experimental facilities in NIFS, various small experiments conducted in universities for basic and applied plasma science are supported by NIFS for its operational cost and most importantly for providing the community network relationship for research information exchange and personnel exchange.

Measurements of velocity distribution function using the HYPER-I device

The experiments in the HYPER-I device [1] have been carried out to understand transport phenomena and structure formation in inhomogeneous plasma, in which these issues are significant for the plasma confinement in fusion devices and for various plasma applications. Focusing on the effect of neutral particle flow on plasma structure formation, we have directly measured the velocity distribution function of neutral particles in plasma using high accuracy laser-induced fluorescence spectroscopy. Recently, the asymmetry of velocity distribution function has been observed in the neutral depletion structure as shown in Fig. 1 (a). It is interesting that a simple relation between the skewness and the inhomogeneity-induced flow holds as shown in Fig. 1 (b). The result indicates that the higher order geometric form factor has physical meaning in an inhomogeneous system, and this simple method using the skewness may be effective to investigate the transport phenomena [2].

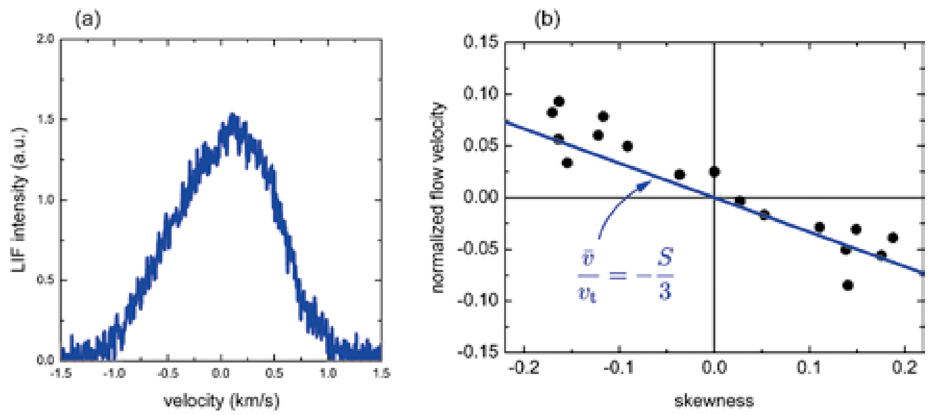


Fig. 1 (a) Asymmetry velocity distribution function in an argon plasma and (b) normalized flow velocity as a function of skewness. The data in (a) and (b) are the same with that in Fig. 4 (d) and Fig. 7 of Ref. [2].

Plasma window for novel vacuum interface

Plasma window has been expected as a virtual interface to separate vacuum (10 Pa) from atmospheric condition (100 kPa) without a large pumping system. This novel vacuum interface is realized by thermal arc discharges, by which charged particles and x-ray are transmitted into the atmospheric side, while the air cannot flow into the vacuum chamber. For application of plasma windows, we constructed a compact TPD (Test plasma by Direct current) apparatus (FIG.2). The discharge source generated high-density Ar plasmas in an opening of 3 mm (T_e~1 eV, n_e~10^{17} cm^{-3}). We demonstrated the pressure gradient between the vacuum chamber (100 Pa) and atmosphere (100 kPa) at 50-A discharge through 100-mm plasma channel. Therefore, the plasma window developed can be applied to an electron beam welding under air atmosphere, which is usually performed in vacuum environment [3].

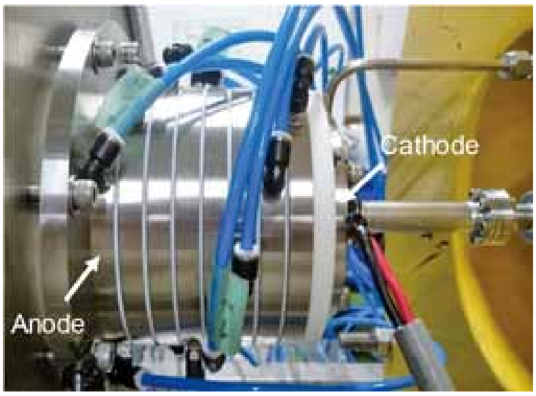


Fig. 2 TPD plasma source for plasma window.

Development of Faraday material for the advanced plasma diagnostics

A laser-aided diagnostics method is one of the reliable methods for measuring the plasma parameters in fusion research. In this method, a laser light source is the most important factor for the performance of measurement results. In this study, we have developed the new material of the transparent Ho_2O_3 ceramics for a Faraday rotator, which is the key optics for high power lasers. This report for fabrication and evaluation in this material is the first, to the best of our knowledge [4]. The transparent Ho2O3 ceramics have the excellent magneto-optic properties which are the most important propriety for a Faraday rotator. The value of the Verdet constant representing the magneto-optic propriety at 1064 nm is 46.3 rad/Tm which is about 1.3 times higher than that of the standard material of terbium gallium garnet (TGG) (Fig.3). From the result, this material has potential as a new Faraday rotator for high-average power lasers.

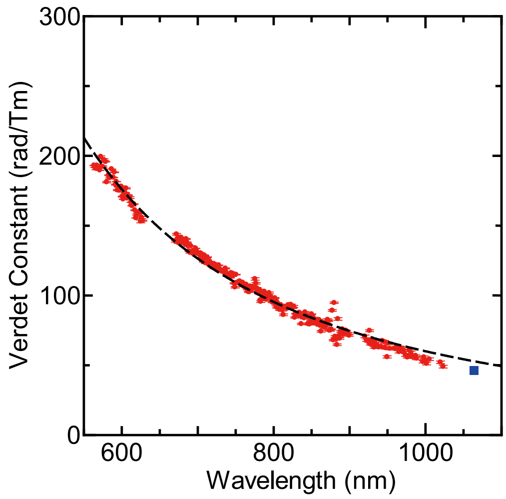


Fig. 3 Verdet constant of Ho_2O_3 ceramics as a function of wavelength. Cited from Ref. [4].

[1] S. Yoshimura *et al.*, J. Plasma Phys. **81**, 345810204 (2014).
[2] K. Terasaka *et al.*, Phys. Plasmas **23**, 112120 (2016).
[3] S. Namba *et al.*, Rev. Sci. Instrum. **87**, 083503 (2016).
[4] H. Furuse and R. Yasuhara, Opt. Mater. Express 7, 827-833 (2017)

(I. Murakami)

5. Network-Type Collaboration Research

The NIFS General Collaboration has been basically based on a one-to-one (especially, NIFS-to-University) collaborative system. Some collaborations, however, require the use of more than one experimental facility in different universities and institutes to achieve their objectives. In the network-type collaboration, this type of collaboration becomes practicable by admitting travel expenses for moving between universities, which have not been admitted as a rule in the general collaboration projects.

Since FY 2011, NIFS has employed this network-type collaboration. Three projects of the different fields were accepted in FY 2011 for the first time. Challenges in these collaborations spread over various fields. Before starting the collaborations, a collaboration plan for the year should be submitted. The plans include the items how the collaborations between research institutes are planned, that is, who goes when and where by what purpose.

In this fiscal year, seven proposals were submitted and six were accepted. One proposal was joined to another similar proposal. Two proposals are continuing subjects, and five proposals are new subjects in FY2017. The titles of the research items are listed below.

(1) "Estimation of regional and seasonal variations for environmental tritium and radon concentrations in Japan" M. Furukawa (University of the Ryukyus).

(2) "Self-organization via fast electrons in spherical tokamaks" Y. Takase (The University of Tokyo).

(3) "Effect of the resonant magnetic perturbation on MHD phenomena of toroidally magnetized plasmas" M. Okamoto (National Institute of Technology, Ishikawa College)

(4) "Self-organization in high-beta torus plasmas under active control"
N. Fukumoto (University of Hyogo)

(5) "Hydrogen isotope retention of plasma facing materials damaged by neutron irradiation" N. Ohno (Nagoya University).

(6) "Interdisciplinary study of plasma heating at O-point and X-point using laboratory experiments, numerical simulations and solar observations" M. Ono (The University of Tokyo).

The item (1) requires the movement of researchers and students over wide areas to collect samples in different places. The items (2), (3), (4) and (6) are related to the intercommunication of researchers and students, and are the comparative researches of the results obtained in the different devices in universities, institutes, and NIFS. Item (5) is related to the inspection of neutron-irradiated materials by utilizing the compact divertor plasma simulator (CDPS) installed at the Oarai Center of Tohoku Univ. And all proposals take advantage of the merit of the network-type collaboration.

The major achievements of two representative projects are briefly outlined below.

"Hydrogen isotope retention of plasma facing materials damaged by neutron irradiation"

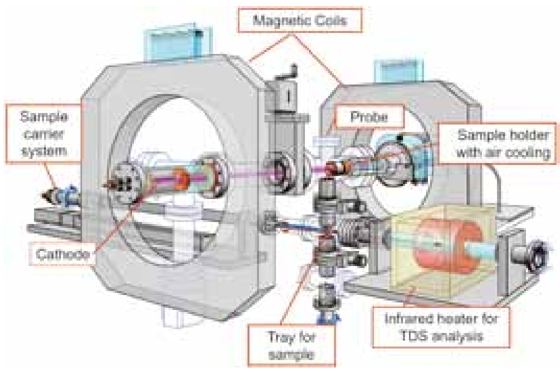
N. Ohno (Nagoya University)

The purpose of this study is to establish the researchers' network of plasma-wall interaction study focusing on neutron-irradiated materials by utilizing the compact divertor plasma simulator (CDPS shown in the figures below) installed at the Oarai Center of Tohoku Univ. The collaboration is also intended to hold seminars where graduate students learn the principles and usage of instruments of other research institutes.

At the collaborative researchers' meeting, we discussed the research topics and plans to be carried out at each institution to clarify the hydrogen retention characteristics of neutron irradiated tungsten (W); (a) the effects of defect distribution (Shizuoka Univ.), (b) hydrogen retention characteristics in neutron irradiated W-Re and W-K

(Osaka Univ., Kyushu Univ.), (c) Effects of adding other impurities (Toyama Univ.) , (d) Evaluation of effective diffusion coefficient of neutron irradiated W and verification of effect of annealing (NIFS), (e) helium plasma irradiation effect (Hokkaido Univ.).

The seminar for graduate students was held in NIFS. 14 students from universities participated in the tour and the briefing of surface analysis equipment.



Schematics of compact divertor plasma simulator (CDPS)

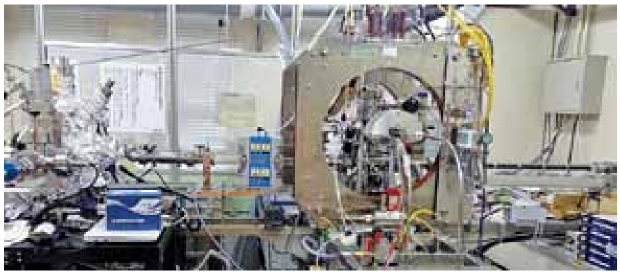


Photo of CDPS

"Self-organization via fast electrons in spherical tokamaks"

Y. Takase (Graduate School of Frontier Sciences, The University of Tokyo)

Experiments on self-formation of the spherical tokamak (ST) configuration and plasma current (I_p) ramp-up by various RF waves (LHW/ECW/EBW) were performed. The purpose of this research is to clarify the physical mechanism of self-organization via fast electrons created by RF waves, and is carried out collaboratively among the University of Tokyo (TST-2), Kyoto University (LATE), Kyushu University (QUEST), and NIFS. The ST plasma is formed and maintained by LHW (TST-2), EBW (LATE), or ECW (QUEST), respectively. Characteristics of these plasmas are determined by RF-accelerated energetic electrons through their pressure and current.

Ion Doppler measurements were performed on LATE with the Univ. of Tokyo visible spectrometer using a total of 33 sightlines. Emission of carbon, CV, and oxygen, OV, lines imply much higher T_e (> 100 eV) than TST-2 and QUEST. T_i had negative, positive, positive correlations with n_e, B_t, and I_p, respectively. Large excursions in T_i (up to 200 eV) were observed under some conditions. The mechanism of this unusual ion heating is under investigation. The particle-fluid hybrid code, MEGA, was modified to treat energetic electrons, and was used to obtain a self-consistent equilibrium with wave/Fokker-Planck codes successfully for the first time.

(T. Shimozuma)

6. Fusion Science Archives (FSA)

The following collaborative works are performed this fiscal year:

- **History of Establishment and Evolution of Inter-University Collaboration System**
  (NIFS16KVX009) H. Iguchi *et al.*
  The "Inter-University Research Institute Corporation System" has been developed by research centers established in individual universities. The history of such "Inter-University Research Institute Corporation System" can be divided into three generations. **1951 to 1975:** The Yukawa Institute of Theoretical Physics as the beginning, many "Joint Usage/Research Centers of Japanese National Universities", have been established based on the advice of the "Science Council of Japan". The Ministry of Education started to govern Japanese science policy. **1976 to 2000:** Many "Inter-University Research Institute Corporations under the direct control of the Ministry of Education" were established after KEK (High Energy Physics Institute, established in 1971). NIFS was established in 1989, and was almost the last in this trend. These institutes organized the "Graduate School of Advanced Study" to give a specialized education and the degree of doctor. **2000 to present:** National universities and inter-university research institutes became independent corporation in 2004. The joint research system was reorganized to introduce the "Joint Usage/Research Center of Excellence" system.

- **History of Institute of Plasma Physics Nagoya University**
  (NIFS16KVXV010) K. Matsuoka *et al.*
  Following last year's investigation, it was investigated how the research was performed in the Institute of Plasma Physics, Nagoya University (IPPJ) developed or affected the present researches. These were roughly divided into three fields, "Fusion Science", "Reactor Technology" and "Plasma Science". In the field of "Fusion Science", it was found that the Akihiro MOHRI had built a SPAC-I (l=2, m=21 Torsatron) in 1970. This configuration that forms flux surfaces by external winding coils is now a standard "Heliotron" configuration adapted in Heliotron-E, CHS, and LHD. In the "Reactor Technology" area, the Council for Science and Technology issued the statement in 1980 to promote R-project in terms of the long term policy of fusion science in the universities. The development of the negative ion-based neutral beam injector (N-NBI) was initiated in IPPJ. In the "Plasma Science" area, many pioneering researches, including quiet high density plasma production by TPD-I and II were started and subsequently developed into new area of sciences and technology or were applied to industry.

- **Historical investigation of collaborative research meeting on plasma spectroscopy**
  (NIFS17KVXV011) N. Yamaguchi *et al.*
  Plasma spectroscopy is a cross sectional research area which covers plasma physics, atomic and molecular physics, spectroscopy and diagnostic technics. The plasma spectroscopy research in Japan was started and developed along with the plasma physics research in Institute of Plasma Physics, Nagoya University (IPP). This fiscal year, data of the workshop on "Plasma elementary process" were collected from "KAKUYUGO KENKYU" and its suppliments (1962-1984), "IPPJ Letter" (1983-1987), "IPPJ monthly" (1987-1989), "Annual NIFS research achievement reports" (1990-2017), "IPPJ steering committee records", "IPPJ experts committee under steering committee records", and "IPPJ 25th annals". The first workshop on "Plasma elementary process" was held in 1969 under the support of KAKENHI SOUGOU (B) "Research on plasma elementary process". The workshop in 2017 was 50-th anniversary.

- **Studies on History of Activities of Researchers at the dawn stage of Fusion Research in Japan**
  (NIFS17KVXV012) T. Amemiya (College of Science and Technology (CST), Nihon Univ.), *et al.*
  The investigation of the laboratory of the history of science of CST, Nihon University captured the general trend of fusion science picked up from the international collaborations, conferences or dawn of the history of fusion science from 1950's to 1960's. The focus is placed more on the individual researchers or the organizations that have led fusion science development in the dawn of fusion science in Japan from this fiscal year utilizing the archives in the FSA and the KEK archives office. Featured researchers and organizations are Mitsuo TAKETANI, Koji HUSHIMI and KAKUYUGO Kondankai.

- **Development of a Cooperating System of Archives Finding Aids and Technical Terms Databases**
  (NIFS17KVXV013) Y.Takaiwa (KEK) *et al.*
  Technical terms often appear in the historical materials related to the science and technology areas such as those in KEK or in FSA. It is desirable to provide a proper dictionary of such technical terms in order to utilize those historical materials efficiently. Furthermore, the incorporation of such a dictionary for the search systems greatly increases the availability of the database. At present, the historical databases in KEK and FSA are accumulated by both general purpose software (FileMaker Pro) and commercial cloud database system (Infolib). Utilizing Wikipedia or something similar would be one of the solutions, but the maintenance of its quality and responsibility are issues. Possible candidates among free or open license softwares are noted. The next task will be to link such a dictionary database to the historical database.

- **Making name authority data about persons, groups, and organizations appearing in FSAD, related to fusion science in Japan**
  (NIFS17KVXV014) H. Goto (Kyoto University Museum) *et al.*
  FSA accepts various materials related to the fusion science history and necessary informations of them are picked up, categorized, and registered in the database. The catalog created in such a way is provided to the users of interest. Researchers or research groups committed to fusion science and their mutual relations are not clear to the user only from the catalog. The purpose of this research is to clarify the method of accumulating and sorting the directories of those who have committed to fusion science. This fiscal year we have confirmed the difficulty in retrieving necessary relations between researchers or research groups. We have started this activity by digitizing the 15 annuals of NIFS or the 25 annuals of IPPJ, or registering the information of a few famous researchers using the *ArchivesSpace*. As for the NIFS related researchers, records of the collaboration program of NIFS can be a useful source if they are used with the existing academic database such as CiNii, KAKEN or Scopus.

- **Archival Studies on Heliotron Studies at Kyoto University**
  (NIFS17KVXV015) T. Mizuuchi (IAE, Kyoto Univ.) *et al.*
  This archival study is focused on the fusion oriented high temperature plasma experiments performed in the series of Heliotron devices at Kyoto University. Comprehensive and systematic collection of the research materials on each heliotron device are pursued under the collaboration program. In addition to collecting these documents, finding image video records in the very early phase of the Heliotron E experiment and making a digital library of photographic slides of experimental devices and presentations in the Heliotron E era. Restoring the raw data of Heliotron E experiments (including some program files for data analyses) into a set of hard-disks (HD) have been performed. Due to the limited room for preserving materials and, furthermore, the recent strict requirement for efficient usage of the university facilities, the space is the main issue, in particular, for relatively large fusion experiment devices, or related hardware. This issue should be jointly discussed with FSA in NIFS.

- **Study and analysis of documents in the start up phase of the fusion technology research**
  (NIFS17KVXV016) H. Yoshida *et al.*
  The start up phase of the fusion technology research in Japan was investigated from the view point of Japan Atomic Energy Agency (JAEA) and the Institute of Plasma Physics, Nagoya University (IPPJ) under the collaboration with FSA. The origin of the systematic investigation toward the fusion reactor is found to be the workshop organized by Shigeru MORI in 1969 gathering the fission reactor specialists as well as fusion scientist from the historical materials of Kenzo YAMAMOTO and Shigeru MORI. Shigeru MORI organized research group on reactor design (1972), heating technology (1973), blanket (1975), super-conducting coil (1976), surface and vacuum technology (1976), materials development (1978), neutron technology, neutron source (1979), and tritium handling facility (1985) inside JAEA. From the interview with Shigeru MORI, a direct links of these facilities with similar facilities established in the 1980's in IPPJ or in universities was not found.

- **History of the early days of Nuclear Fusion Research Group in Japan**
  (NIFS17KVXV017) C. Namba *et al.*
  The organization "Informal Gathering of Fusion Science" (KAKUYUGO KONDANKAI) was established in 1958 and continued to perform an important role in the research and development in fusion science in Japan as a voluntary organization for researchers until it became "The Japan Society of Plasma Science and Nuclear Fusion Research" in 1983. Based on the interview with Dr. I. Kawakami who worked as a principal editor of "KAKUYUGO KENKYU", the journal of the "KAKUYUGO KONDANKAI", the environment at the establishment of "KAKUYUGO KONDANKAI" was clarified. "KAKUYUGO KONDANKAI" was formally established on February 10, 1958, at its inaugural meeting held in Tokyo. The first advisory chairman was Hideki YUKAWA. In October 1959, H. YUKAWA formally expressed his wish to retire since the research system was almost established. It was proposed and discussed at the gathering in February 1960 to ask H. YUKAWA to be an advisory chairman emeritus and to organize a standing committee.

- **Accountability of Research Activity and Archives**
  (NIFS16KKGV002) E. Kikutani *et al.*
  In the archives activity during this one decade, we have analyzed a history of the inter-university research institutes and discussed the value of their existence. The importance of the knowledge of archives themselves and the method of operating archives activities have been re-recognized. In this trend, we have held two meetings every year, one at KEK and the other at NIFS over these several years. "Archives and historical analysis" was set as a theme of the meeting at NIFS in 2017. The invited speaker was Dr. Tadashi NISHITANI. He gave a talk titled "Shoichi SAKATA and his laboratory (E-lab)". Related talks were given and discussed the common issues regarding archives and their historical analysis.

(S. Kubo)

SNET is a cluster of logical network circuits dedicated for the Japanese fusion research collaborations, *i.e.*, Fusion Virtual Laboratory (FVL) in Japan. It consists of layer-2 and layer-3 virtual private networks (L2/L3-VPN) which directly connect the collaborative universities and institutes via the national academic network backbone SINET5 of National Institute of Informatics (NII). NIFS started the SNET operation for the "remote participation for LHD experiment" in March 2002. Since 2005 fiscal year (FY), "remote use of supercomputer" and "bilateral collaboration" categories have been added. SNET had 17 participating nodes in 2017 FY.

On the other hand, a new technology of on-demand point-to-point connection, secure socket layer (SSL) VPN, has come into wide use with drastically improved network throughputs than before. Therefore, NIFS has decided that the above-mentioned three SNET categories be unified into one "bilateral collaboration for remote data acquisition and archiving," and the other categories should move onto the NIFS SSL-VPN service. The existing VPN circuits have been operating for the service continuity. However, the invitation for new applications has been stopped for those two SNET categories since the 2018 FY collaboration.

As for the bilateral collaboration, a new experimental site, TST-2 of the University of Tokyo, has been joined to SNET and successfully started the operation of remote data acquisition since March 2018.

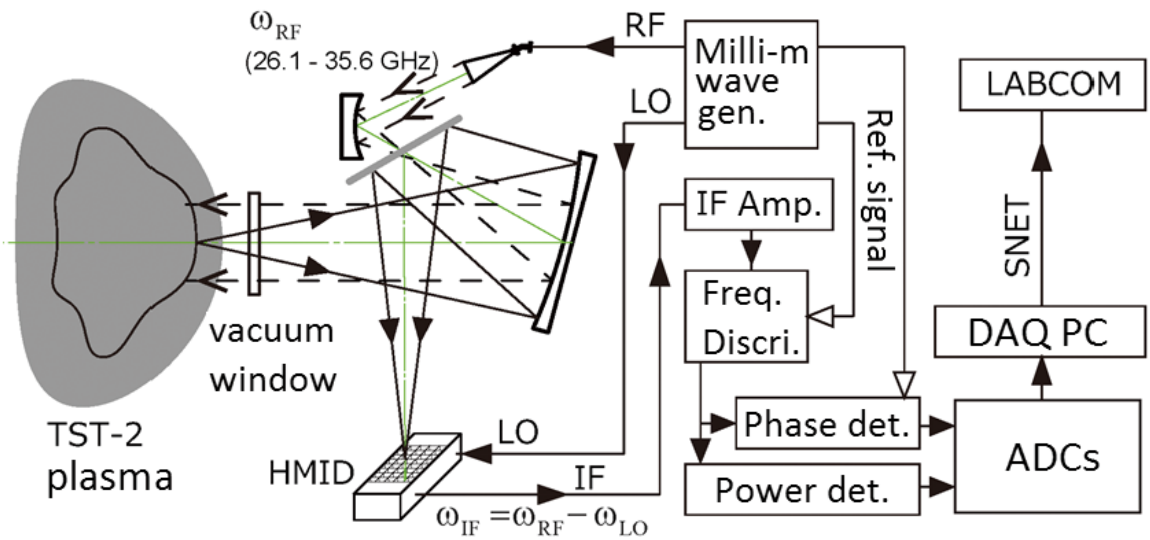


Fig. 1 Schematic diagram of TST-2 MIR remote data acquisition

Research highlights

Large volumes of the whole LHD data were successfully replicated to the ITER Remote Experimentation Centre (REC) in Rokkasho at unprecedented speeds. Major advances in the technical groundwork have been made for remote data archiving, under the collaboration with the National Institutes for Quantum and Radiological Science and Technology (QST) and the National Institute of Informatics (NII). The data traffic passed through Toki – Gifu DC – Hirosaki DC – Rokkasho L2VPN on SNET. Since SINET5 connects every prefectural DC each other with 100 Gbps, it can make full use of 10 Gbps bandwidth of both sites' uplinks.

From 1 to August 3, 2017, in the final week of the 19th experimental campaign of LHD, the technical verification tests of on-sequence full data replication have been performed from the LHD data storage at the NIFS Toki site to the SSD-based data receiver installed at the REC site, almost 1 000 km away from NIFS LHD. All the plasma pulse data of each shot was successfully replicated to the REC receiver storage within 2 minutes in every 3 minute repetitive sequences of real LHD operations.

Another massive data transfer test was carried out in which more than 400 TB of the whole LHD plasma data were to be replicated into 500 TB magnetic tape library of REC at once. To absorb the speed differences between fast network and data reading/storing, the intermediate sender/receiver PCs had been reinforced with three of 1.2 TB PCI Express 3.0 × 4 lanes SSDs for fast data buffers providing about 3 GB/s throughput.

By optimizing the throughput on each stage of pipelined data streaming, the total throughput of about 400 MB/s (= 3.2 Gbps) was successfully sustained during the entire data replication. The performance bottleneck exists in the staging HDD array of the REC tape library because such the intermediate buffer devices require double I/O performance of the actual data stream for processing reads and writes concurrently.

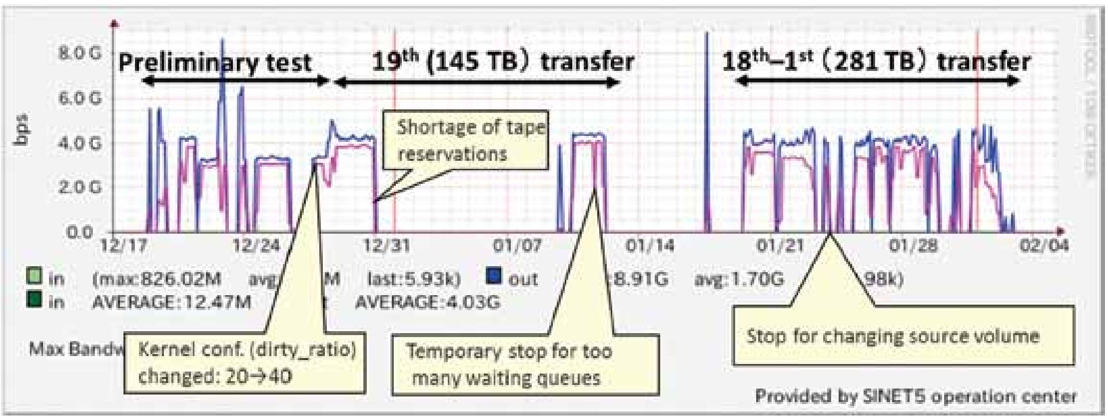


Fig. 2 Network traffic during the LHD ➔ REC full data replication test.

(H. Nakanishi)

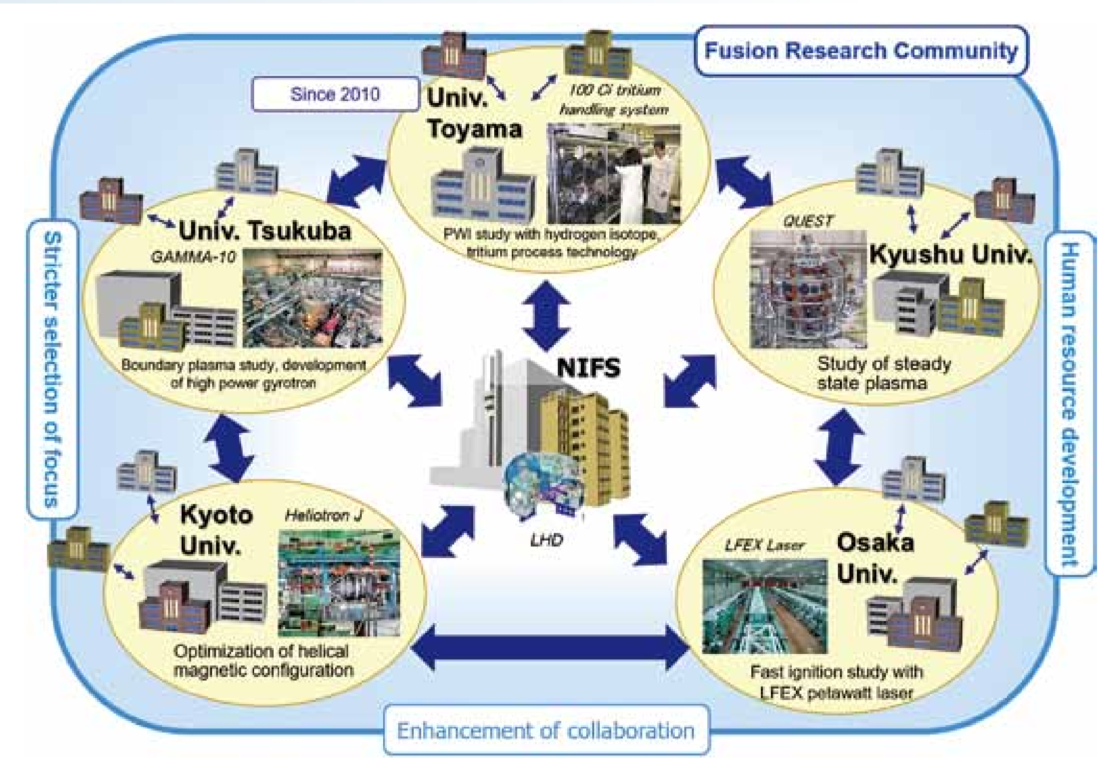
8. Bilateral Collaboration Research Program

The purpose of the Bilateral Collaboration Research Program (BCRP) is to enforce the activities of nuclear fusion research in the universities by using their middle-size experimental facilities of the specific university research centers as the joint-use facilities for all university researchers in Japan. The current program involves 5 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

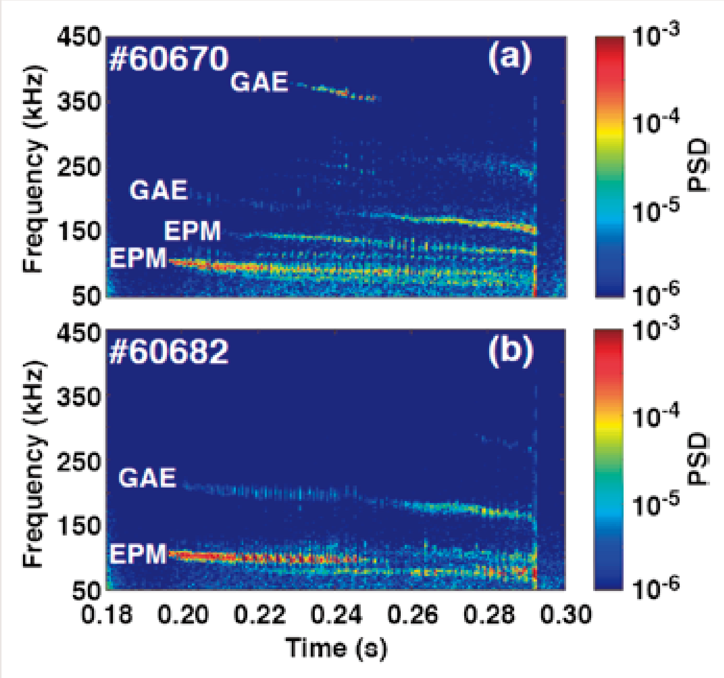
In BCRP, each research center can have its own collaboration programs using its main facility. Researchers at other universities can visit the research center and carry out their own collaboration research there, as if the facility belongs to NIFS. That is, all these activities are supported financially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

(T. Morisaki)



Schematic of the Bilateral Collaboration Research Program

Kyoto University



Suppression of MHD instabilities by ECCD in Heliotron J: (a) without ECCD and (b) with ECCD

Highlight

Suppression of MHD instabilities by ECCD in Heliotron J

Fast-ion-driven MHD instabilities are suppressed by using ECCD in Heliotron J for an NBI+ECH plasma. The upper figure shows global Alfvén eigenmode (GAE) and energetic particle mode (EPM) for no ECCD case. By applying ECCD (0.6 kA), the GAE is strongly suppressed as shown in the lower figure.

Study of suppression of fast-ion-driven MHD instabilities by ECH/ECCD [1]:

ECH and ECCD are utilized to control MHD instabilities in toroidal plasma confinement devices. In Heliotron J having almost zero magnetic shear in a whole plasma region in vacuum, both negative and positive magnetic shear induced by co- and counter- EC-driven plasma current suppress the observed fast-ion-driven MHD instabilities such as EPMs shown in Fig. 1(a) and (b), and GAEs. Regarding the ECCD effect on fast-ion-driven MHD instabilities, continuum damping whose rate is related to magnetic shear regardless of its sign is a key physical mechanism to suppress the observed fast-ion-driven MHD instabilities.

We also observed the ECH effect on fast-ion-driven MHD instabilities in Heliotron J. Some fast-ion-driven MHD instabilities are stabilized and the others are destabilized by ECH depending on ECH power, deposition location and magnetic configuration in Heliotron J. The GAE amplitude decreases with increasing ECH power for on-axis ECH (Fig. 1(c)). When ECH deposition is close to the GAE location $r/a \sim 0.6$, the GAE amplitude is larger than that for on-axis ECH (Fig. 1(d)). These dependences indicate that both the change of fast ion profile by ECH through the change of electron density and temperature, and/or the collisional damping due to trapped fast electrons may affect the Alfvén eigenmode stability.

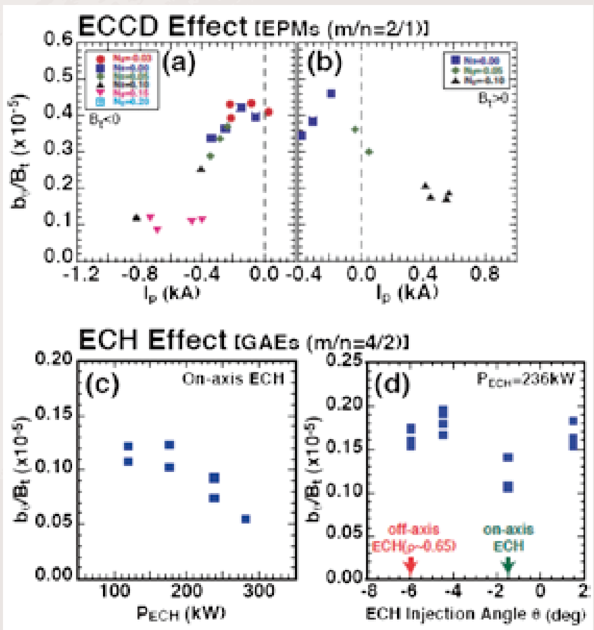


Fig. 1 (a) and (b): Dependence of EPM on EC-driven plasma current. Dependence of GAE on (c) ECH power and (d) ECH deposition location in Heliotron J.

Research Topics from Bilateral Collaboration Program in Heliotron J

The common objectives of the researches in Heliotron J under this Bilateral Collaboration Program are to investigate experimentally/theoretically the transport and stability of fusion plasma in advanced helical-field, and to improve the plasma performance through advanced helical-field control. Picked up in FY2017 are the following seven key topics; (1) experimental observation of rational-surface effect on e-ITB formation, (2) relationship of density fluctuation to H-mode transition in high density plasmas, (3) comprehensive study of fast ion behavior in ICRF+NBI heating, (4) long-range correlation and hydrogen-isotope effect in edge turbulence, (5) suppression of fast-ion-driven MHD instabilities using ECH/ECCD, (6) measurement of fast-ion loss accompanied with MHD fluctuations and (7) development of ice-pellet injector for steady and stable operation.

Poloidal flow measurement using charge-exchange recombination spectroscopy (CXRS) [2]: The radial electric field in helical devices is a key parameter for the transport in the low collisional region. The improvement of poloidal-flow velocity measurement by CXRS for the estimation of radial electric field is necessary although the parallel-flow velocity has been measured successfully in Heliotron J. The main issue is to determine the wave length of the measured spectrum and the stability of the calibration of the absolute wave length. A new spectrometer and a new CCD camera are installed to get stronger signals. Using the new camera, the signal becomes four times as large as the previous one. The wave-length calibration is also changed to use the line spectrum of Sm ramp. The resultant error of wave length is reduced from 2.8×10^{-3} nm to 9.1×10^{-4} nm, corresponding to 1.7 km/s and 0.51 km/s in velocity, respectively. The poloidal velocity is now measurable within this error, which is considered to be sufficient for the determination of poloidal velocity. A result from the CXRS measurement is shown in Fig. 2, where the poloidal flow is in the electron diamagnetic direction in an NBI plasma and the ion diamagnetic flow is observed in the central region for additional ECH injection.

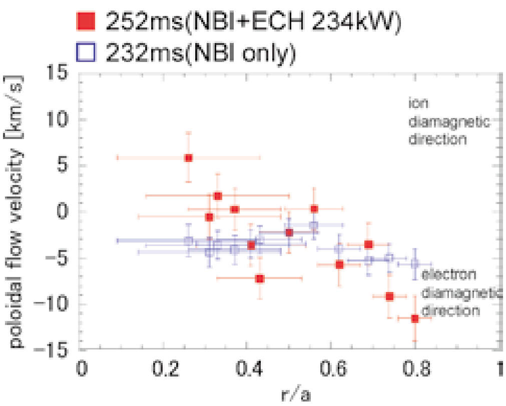


Fig. 2 Poloidal flow velocity profile for NBI+ECH and NBI only plasmas. Balanced injection is made using two opposite tangential beam lines for NBI heating.

Interaction of fast ions and MHD instabilities [3]: The confinement of alpha particles generated in fusion reactions, is important since alpha particles are utilized as heat source. MHD instabilities sometimes affect fast-ion confinement via resonant or non-resonant interactions. In Heliotron J, fast-ion-driven MHD instabilities, such as GAE and EPM, are observed. A lost-ion probe of Faraday-cup type has been used for the measurement of fast-ion confinement, however, the high noise level prevents from the correct calibration of the detector. For the reduction of noise, a scintillator type detector is introduced. The fluorescent light on the scintillator are divided into two, then they are detected by PMTs and CCD camera. For the fluctuation measurement, 9-channel PMT signals are used, of which frequency response is up to 200 kHz. The EPMs are observed in a counter-NBI plasma with this detector in Heliotron J. The observation grid map on the scintillator surface for energy and pitch angle is illustrated in Fig. 3. The energy range is indicated by proton Larmor radius. In Fig. 4, (a) magnetic fluctuation, (b) SLIP (PMT) signal in ch. 5, (c) line-averaged electron density, (d) heating timing are shown. The EPMs are observed in (a) and (b).

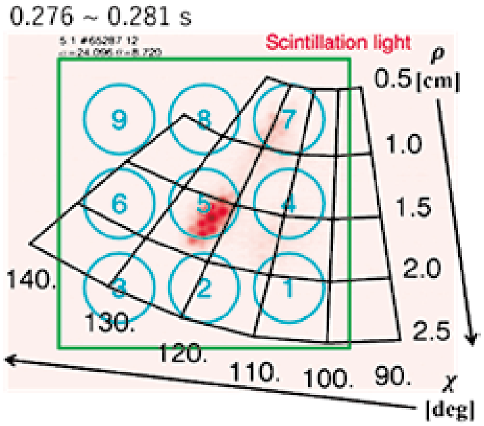


Fig. 3 The observation grid map on the scintillator surface for energy and pitch angle. Blue circles indicate the observation area of each PMT channel. The red part indicate CCD scintillating area observed by a CCD camera.

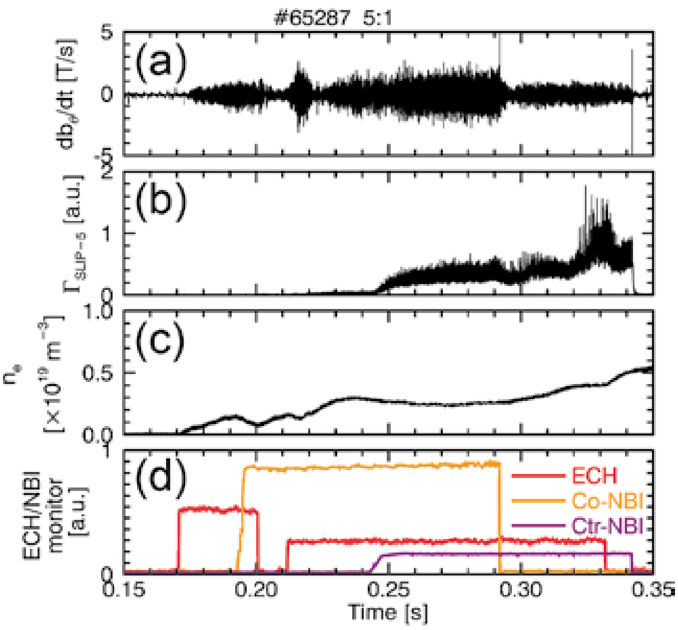


Fig. 4 Time traces of fluctuations, density, and heating timing for the combination heating of NBI and EC heating. (a) Mirnov coil signal, (b) SLIP (PMT) signal of channel 5, (c) line-averaged electron density, and (d) timing chart of heating devices.

[1] S. Yamamoto, *et al.*, “Suppression of fast-ion-driven MHD instabilities by ECH/ECCD on Heliotron J”, Nucl. Fusion **57** (2017) 126065.

[2] S. Tanohira, *et al.*, “Poloidal Flow Measurement with Charge-Exchange Recombination Spectroscopy in Heliotron J (2)”, Plasma Conf. 2017 (20-24 Nov. 2017, Himeji), 23P-12.

[3] S. Yamamoto, *et al.*, “Study of interplay between fast-ions and MHD instabilities in Heliotron J”, Plasma Conf. 2017 (20-24 Nov. 2017, Himeji), 22Cp-05.

(K. Nagasaki)

University of Tsukuba

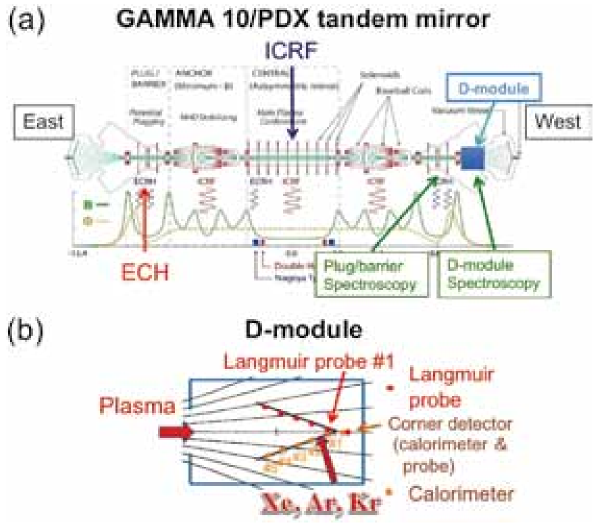


Fig. 1 Schematic view of GAMMA 10/PDX (a) and D-module (b).

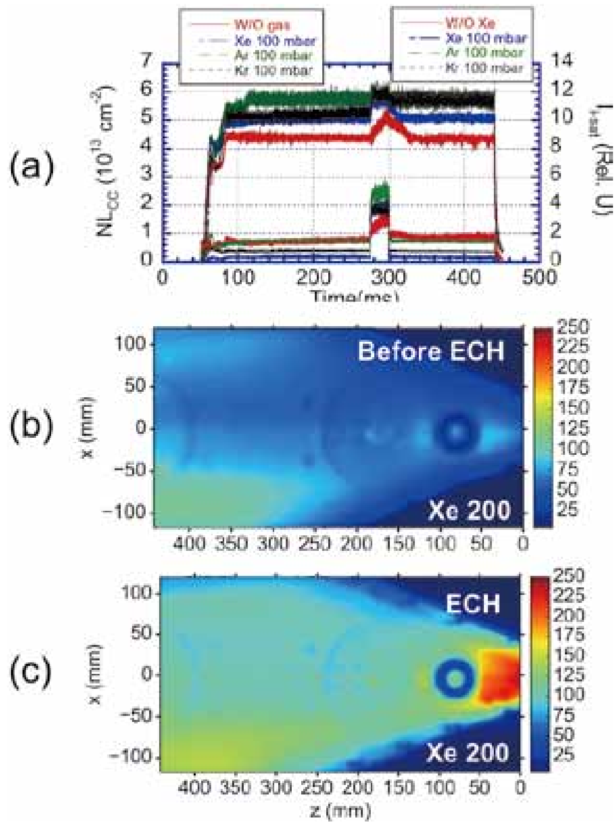


Fig. 2 Results of detached to attached transition experiments: Time evolution of line-density in the upstream plasma (central-cell) and ion flux measured at the corner of the V-shaped target in the D-module (a). Two-dimensional visible image in front of the V-shaped target before ECH (b) and during ECH (c).

Highlight

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

Divertor simulation experiments in the large tandem mirror device (GAMMA 10/PDX) have been extensively performed using plasma flow with high ion energy. By using divertor simulation experimental module (D-module) installed at the east end-mirror exit of GAMMA 10/PDX, characterization of detached plasmas was performed. In the gas injection experiments for detached plasma formation, additional heating pulses of ECH were applied in the upstream region and the effect of plasma heating on the detached plasma was investigated. It was found that ion flux and heat flux were abruptly increased during ECH and the detached to attached transition phenomena were clearly observed. Puff and pump experiments were also successfully performed in the D-module and the effect of the exit door of the module was precisely evaluated.

A test of a new 28/35 GHz dual-frequency gyrotron (2 MW for 3 s and 0.4 MW CW) was carried out and the cooling characteristics of a double-disk sapphire window were evaluated. It was confirmed that the operation of 0.4MW with CW at 28 GHz is possible at with a coolant flow rate of more than 30 L/min. For the development of diagnostics, we developed the new multi-pass Thomson scattering (MPTS) system with the laser amplification system to increase the pass number of the MPTS signals. The laser amplification system can improve the degraded laser power after six passed in the multi-pass system to the initial laser power.

In the Plasma Research Center, University of Tsukuba, studies on boundary plasmas by making best use of the large tandem mirror GAMMA 10/PDX have been performed together with the development of high-power gyrotrons under the bilateral collaboration research program. Since FY2010 the number of the research subjects of the program in PRC continues to increase and in FY2017 a total of 31 subjects were accepted including the base subject. Figure 1(a) shows the schematic view of GAMMA 10/PDX which has open magnetic field configuration. By using the high heat plasma flow produced with high-power ICRF and ECH systems, divertor-simulation experiments have been performed at the end-cell region.

In ICRF heating studies, initial experiments were performed to reveal the excitation efficiency of a slow Alfvén wave in a high-density regime, and to develop a novel heating method applicable to a high-density regime. The target high-density plasma, the maximum of ~1×10^{19} m^{-3}, was produced by ECH in the central-cell. Under the standard slow wave heating, the axial variation of the phase fluctuation intensities of the 6.36 MHz slow wave was measured by a microwave reflectometer with fast antenna switching capability.

A number of divertor simulation experiments were performed using the divertor simulation experimental module (D-module) installed on the west end as shown in Fig. 1 (b). This module consists of a rectangle box made of stainless steel and V-shaped tungsten target plates in closed divertor structure. Hydrogen and several kinds of radiator gasses (N_2, Ne, Ar, Kr, and Xe) are injected into D-module. In the gas injection experiments for detached plasma formation, additional heating pulses (ECH 150 kW) were applied in the east plug/barrier-cell and the effect of plasma heating on the detached plasma was investigated. It was found that the ion flux and heat flux were abruptly increased during ECH and the detached to attached transition phenomena were clearly observed. In order to evaluate the effect of leakage of neutral gas on plasma detachment, we conducted an experiment of gas puff and pump. Hydrogen gas was supplied to the divertor simulation plasma when the exhaust door, which was attached on the backside of the D-module, was closed and opened. In both cases, the electron temperature near the corner of the V-shaped target is observed to be from ~20 eV to ~2 eV. The electron density near the corner first increased and then decreased, indicating a rollover. After the rollover, the decrease in the electron density with the door open was smaller than that with the door closed. When the electron temperature was ~2 eV, the vibrational and rotational temperature of hydrogen molecule with the door open were almost the same as those with the door closed. The total neutral pressure in the D-module was about one-third of that with the door closed, suggesting hydrogen molecule density near the target was smaller than that with the door closed.

In addition to the divertor simulation experiments, the development of high power gyrotrons has also progressed. In FY2017, the cooling characteristics of a double-disk sapphire window were evaluated in an experimental test of the new 28/35 GHz dual-frequency gyrotron (2 MW for 3 s and 0.4 MW CW) for QUEST, NSTX-U, Heliotron J, and GAMMA 10/PDX. Temperature evolution at the center of the output window was measured by an infrared (IR) camera during and after the oscillation of 2 s for 0.45 MW and the heat transfer coefficient versus the flow rate of the double disk window coolant was estimated. The calculated window temperature is saturated to about 80 °C with an output power of 0.4 MW and a heat transfer coefficient of 0.15 W/cm^2K. It was confirmed that the operation of 0.4MW with CW at 28 GHz is possible at a coolant flow rate of more than 30 L/min. A long pulse operation test was conducted up to 2.8 s with 0.46 MW. Detailed designs of a 14 GHz 1 MW gyrotron have been started for actual fabrication.

The optical collection system for Thomson scattering (TS) light consists of three spherical mirrors and nine bundled optical fibers. The measurable radial positions of TS system are normally 5 cm intervals in the region of ±20 cm. By using the lab jack system, we can change the bundled optical fibers position, which enable to measure radial profiles of electron temperature and density in more detail. We developed the new multi-pass Thomson scattering (MPTS) system with the laser amplification system to increase the pass number of the MPTS signals. The laser amplification system can improve the degraded laser power with six-times-passed in the multi-pass system to the initial laser power. We successfully obtained the continued multi-pass signals after the laser amplification system in the gas scattering experiments.

(Y. Nakashima)

8. Bilateral Collaboration Research Program

University of Toyama

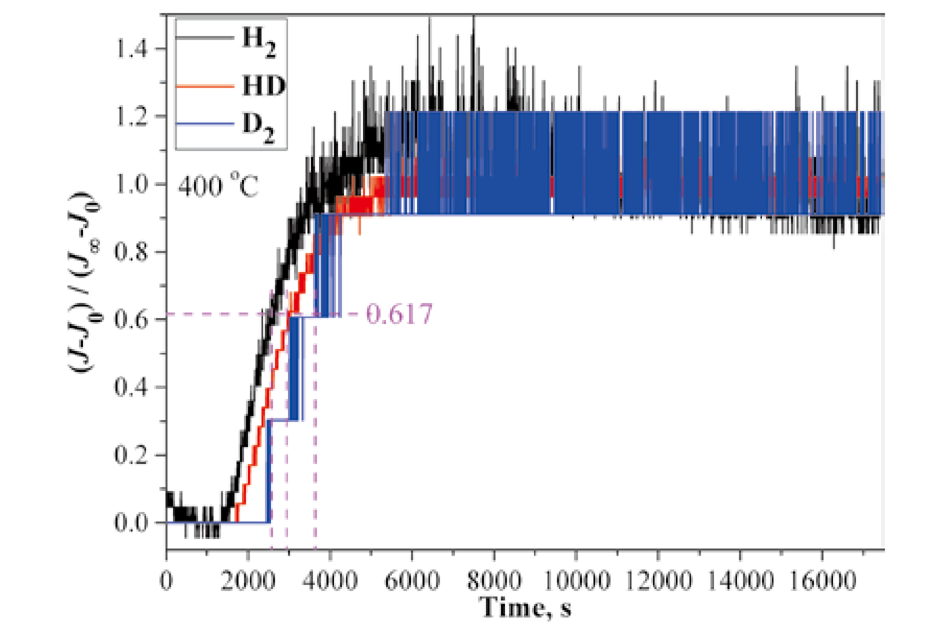


Fig. Permeation curves of H_2, HD and D_2 under exposure to H_2-D_2 mixture gas, showing faster diffusion of H than D.

Highlight

CuCrZr alloy and oxide dispersion strengthened Cu alloy are candidates of heat sink materials of fusion reactors. Evaluation of tritium permeation to coolant through these alloys is important for assessment of safety and tritium self-sustenance. From these viewpoints, permeability, diffusivity and solubility of hydrogen and deuterium were examined by permeation tests using H_2, D_2, and H_2-D_2 mixture gases. Clear isotope effects were observed on permeability and diffusivity; the values obtained for hydrogen were larger than those for deuterium by a factor of $\sqrt{2}$. Namely, the difference between H and D corresponded to ratio of square root of mass.

The titles and principal investigators of research projects performed in U. Toyama in 2017 are listed below.

(1) Isotope effects on trapping and release of hydrogen isotopes in fusion reactor materials (Y. Hatano, U. Toyama)
(2) Hydrogen isotope transport through plasma modified fusion reactor materials (H. T. Lee, Osaka U.)
(3) Hydrogen isotope behavior for W with controlled damage profile (Y. Oya, Shizuoka U.)
(4) Tritium removal from tungsten by isotope exchange (Y. Nobuta, Hokkaido U.)
(5) Tritium removal on deposited layers by glow discharge cleanings (N. Ashikawa, NIFS.)
(6) Evaluation of diffusion, retention and desorption of hydrogen isotopes implanted (N. Yoshida, Kyushu U.)
(7) Tritium retention on facing materials modified by plasma wall interactions (K. Tokunaga, Kyushu U.)
(8) Helium and deuterium retention behavior in simultaneous implanted tungsten (Q. Zhou)
(9) A study of synthesis of high-concentration tritium water (Y. Arikawa, Osaka U.)
(10) Evaluation of the refractive index of solid DT fuel for inertial confinement fusion targets (K. Yamanoi, Osaka U.)
(11) Evaluation of hydrogen isotope retention and release of SiC/SiC composite for fusion reactor (H. Kishimoto, Muroran Inst. Technol.)
(12) Double-strand breaks in a genome-sized DNA caused by β-ray using fluorescence microscopy (T. Kenmotsu, Doshisha U.)

For the evaluation of hydrogen isotope transport and retention in plasma-facing components, tritium penetration profiles in W samples with various microstructures were investigated at 300 and 573 K. The samples were pre-implanted by 1 keV D ion irradiation and then loaded with T from the gas phase. Samples were sectioned by etching and the radioactivity of the residual T was measured by imaging plate technique. Penetration distance was calculated from sample mass loss measurements following successive etching steps. The penetration profiles can be fitted well with an error function - indicating the inward transport of T is diffusion limited. Very little dependence on W microstructure was observed. Comparing the values at 300 and 573 K, an activation energy of ~0.2 eV was estimated, which is lower than the range of reported activation energy for diffusion of solute hydrogen in W (0.2~0.4 eV). This suggests that T transport by D-T exchange is governed by a characteristic rate constant that is very weakly dependent on temperature.

Tungsten specimens with various depth profiles of radiation-induced defects were prepared and deuterium retention was studied. The total D retentions in the specimen decreased with increasing concentration of damages induced near the surface region.

To develop efficient tritium removal technique from plasma-facing components, tritium release from polycrystalline tungsten in D_2 gas atmosphere was examined at elevated temperatures. Clear enhancement of tritium release was observed under the presence of D.

Tritium removal from deposited carbon and tungsten layers by glow discharge cleaning technique was also investigated. Comparable tritium removal efficiency was observed for H and He glow discharges in the case of W, though H discharge was far more effective in the case of carbon.

A model to evaluate transportation of tritium, radiation-induced defects, and heat in solid materials was developed. The concentration of radiation-induced defects under heavy ion implantation was successfully estimated by considering annihilation, diffusion, accumulation, and recombination.

A new laser fusion target using a 200-μm diameter CH capsule filled with 0.1-1% tritium containing deuterium oxide water liquid was designed. Tritium is used as a tracer material to measure the fusion plasma ion temperature diagnostics.

To examine performances of SiC as a constituent material of plasma-facing components and tritium breeding blankets, specimens of three types of SiC/SiC composites were prepared: monolithic SiC plates of α-SiC and β-SiC and a NITE SiC/SiC composite plate consisted of β-SiC. Retention of hydrogen isotopes including tritium will be examined.

Quantitative evaluation on the double-strand breaks of genome-sized giant DNA (T4 DNA; 166 kbp) caused by photon irradiation was performed at difference concentrations of PEG, Polyethylene Glycol, to compare with the effects of tritium β-ray irradiation. It has become clear that PEG decreases the probability of double-strand breaks.

(Y. Hatano)

Osaka University

Fast Ignition of Super High-Dense Plasmas

Laser-driven inertial confinement fusion by the Fast Ignition (FI) scheme has been intensively studied as the FIREX-1 project at the Institute of Laser Engineering, Osaka University. The researches consist of target fabrication, laser development, fundamental and integrated implosion experiments, simulation technology and reactor target design, and reactor technology development. In FY2017, following progress was made through Bilateral Collaboration Research Program with NIFS and other collaborators from universities and institutes (2016NIFS12KUGK057 as the base project and 18 other individual programs).

Fundamental and Integrated Plasma Experiments

In FY 2016, heating experiment of Cu-doped target was performed and the temperature of the heated plasma was found to be as high as 1.7 keV by x-ray spectroscopy. However, the ion temperature measurement by neutron time-of flight method was not performed. Recently, a new scheme to produce a target in which Cu-doped D_2O fuel liquid is filled has been developed. Both Cu for x-ray spectroscopic measurement and D for neutron measurement were simultaneously contained in a capsule. Electron temperature of the heated plasma was measured to be about 1.2 keV from the Cu x-ray spectrum. The neutron signal was obtained at the same time, and the ion temperature was estimated to be 1-1.5 keV from the total neutron yield. These results indicate that the ions were heated by thermal relaxation from the electrons. The heating efficiency from the heating laser energy to the fuel thermal energy was estimated to be about 5%.

High-density implosion of solid sphere target by using a tailored laser pulse has been proposed as a high-performance FI scheme. An experimental program has been started by introducing an arbitrary pulse-shape modulator after a fiber oscillator. Required pulse contrast of the foot pulse to the main pulse is 1:300. Achieved main beam energy balance was as good as 6%. In FY 2018, more precise control of both the pulse shape and the energy balance will be established.

Theory and Simulation, Target Design

Integrated simulations for implosion and fast-heating experiments with applied magnetic field for collimation of the electron flow have been performed by using the integrated simulation code, "FI^3." Calculated ion temperature and the heating efficiency were 1.7 keV and 6%, respectively, which are in good agreement with the experimental results. For further improvement of the heated plasma performance, target design activities have been continued taking into account of laser pulse tailoring, cone geometry, and control of electron flow with laser-plasma interaction and applied magnetic field.

Target Fabrication and Reactor Technology

Solid sphere target with doped Cu as tracer atoms for x-ray spectroscopic diagnostics was developed. Solid spheres made of Cupper Oleate ($Cu(C_{18}H_{33}O_2)_2$) were successfully produced with recently developed micro-fluid device. The target has a diameter of 200 microns, sphericity of better than 97%, and 10wt% of Cu content, which all meet the requirements for experiments. Cu x-ray spectrum emitted from the imploded core plasma gives detailed information on spatial distribution of the fast electrons generated by irradiation of the heating laser beams

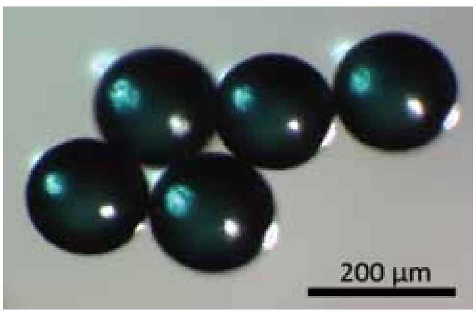


Fig. 1 Solid sphere target made of Cupper Oleate (Cu(C18H33O2)2).

as well as the core plasma temperature and heating efficiency.

Preparation for target injection experiment has been made in FY2017. A tracking system of the injected target that has been developed in Ibaraki University was installed in the target injection system. The position of the injected target can be accurately monitored by using Arago's spot technique with probing laser beams. The shape of the dummy targets for this injection experiment will be improved in FY2018 in order to generate a brighter Arago's spot.

Operation and improvement of LFEX Laser system

LFEX laser (Fig. 2, left) for plasma heating in fast ignition experiments was operated stably in FY2017. Four beams of LFEX delivered a total output energy of 2 kJ in a 1-ps pulse. Spatial uniformity of the amplifier gain was improved by installing trigger meshes around the flash lamps in the amplifier case to straighten the discharge path. This also contributes to long-life operation of the flash lamps.

Fig. 2 View of amplifier chains of LFEX and GEKKO-XII lasers.

Individual Collaborations

In parallel to the main project described above, 18 other collaborations by individual researchers including two from abroad have been performed. Those were on electron-driven fast ignition (8 collaborations), ion-driven fast ignition (4), alternative scheme of laser-driven inertial fusion (1), diagnostics of high-temperature and high-density plasmas (3), and reactor technology (2). Nine collaborations were ones continued from the previous year(s) and 9 were newly accepted in FY2017.

(R. Kodama)

8. Bilateral Collaboration Research Program

Kyushu University

Research activities on QUEST in FY2017.

We will summarize the activities on advanced fusion research center, research institute for applied mechanics in Kyushu University during April 2016-March 2017. The QUEST experiments were executed during 12th May-5th Aug. (2017 Spring/ Summer; shotno 34700-35819) and 30th Nov.-9th Mar. (2017 Autumn/Winter; shotno 35820-36662). Main topics of the QUEST experiments in FY2017 are listed below.

1) The highest plasma current discharge of 85kA in non-inductive current drive was obtained by 28 GHz microwave injection which developed with Tsukuba University (Gyrotron) and NIFS (polarizer) (shotno 35682). The plasma current was tentatively obtained.
2) The polarized and focused microwave of 28GHz was injected and high density plasmas up to 8×10^{18} m^{-3} measured with Thomson scattering system which has been developed by the University of Tokyo. The density is close to plasma cutoff of 28GHz (9.7×10^{18} m^{-3}). The plasma will be good for a target of electron Bernstein wave heating/current drive.
3) A Thomson scattering system was used to measure electron temperature and density profiles for various discharges. Typical parameters are about 5 eV and about 3.0×10^{18} m^{-3} for a discharge sustained by the ECH with a frequency of 28 GHz, and about 1 eV and about 8.0×10^{18} m^{-3} for a CHI discharge. Note that the CHI plasma stayed at the lower region of the vacuum vessel, and these values seem to represent the edge parameters.
4) In the fiscal year of 2017, several important facilities have been transported from the National Institute for Fusion Science for the sake of off-line evaluation of the possible implementation of the liquid metal divertor concept in QUEST. These include the following: 1. a liquid metal circulation loop driven by an electric magnetic pump; 2. a TDS (thermal desorption spectrometry) facility for the evaluation of hydrogen isotopes uptake by liquid metals. It is expected that these facilities will be in operation in the fiscal year of 2018.
5) New design of permeation probe system has been proposed in order to evaluate membrane contamination due to impurity deposition that can affect calibration factor of the probe. Installation of the system is under preparation for the next QUEST experiments.
6) To examine the drift compensation of the in-vessl Mirnov type sensors by using ex-vessel hall sensors and the reconstruction of magnetic surface with both sensors, the installing hall sensors addition to exist eight sensors and providing relevant data acquisition system have been launched.
7) For successful operation of CHI in QUEST, the poloidal coil operation scenario of NSTX have been analyzed numerically on shot number #118346, which shows the successful CHI plasma current start-up. Tracing of 3D magnetic field line shows that careful choice of the PF coil current is important and the lower diverter coil should be reduced during the CHI operation in QUEST.
8) Grad-Shafranov equation with anisotropic pressure profile was investigated by COMSOL starting from a Solov'ev analytical solution and the current density profile tends to shift outward qualitatively.
9) The W samples were installed in the plasma facing wallsQUEST and exposed more than 4000 shots of hydrogen plasma in each 2015AW, 2016SS and 2016AW campaign. After plasma operation, the additional D2+ implantation and thereafter TDS experiment were performed. Major D desorption temperature for 2015AW Top sample was found at 400 K, but that for 2016SS and 2016AW Top sample was located at around 600 K, indicating that D trapping by vacancies would be the major trapping states.
10) A visible spectroscopy system installed at MH16 port was upgraded to observe the entire radial distribution in the midplane and vertical distribution in the poloidal section. A 28 GHz discharge (#35788) was measured and the distributions of the ion emissivity, temperature, and velocity were obtained.
11) In a tokamak plasma of ~40 kA produced by 28 GHz microwaves, about 20 % of total current extracted from the upper divertor plates by divertor biasing reached the grounded lower divertor plate. The ratio of electron saturation current to the ion one in the biased plate was about 7 to 13, of which ratio is about 1/4 of the square root of proton to electron mass ratio.
12) TDS measurements after post-irradiation with deuterium ions for the samples exposed to the QUEST plasma revealed that a large amount of hydrogen isotope was trapped by the carbon-dominated mixed-material layer. In addition, the reduction of the carbon concentration in the deposition layer suppressed a large D desorption.
13) New in-vessel 3-rod antenna for ion cyclotron emission measurement in QUEST has been designed.
Heat resistant property of the antenna is improved compared to the previous design by using Zirconium copper as material of rods.
14) Samples of vacuum plasma spray (VPS) and atmospheric plasma spray (APS) tungsten were exposed to plasma in QUEST

in 2016 autumn-winter experimental campaign. Thermal desorption measurements showed the hydrogen retention in APS-W was smaller than that in VPS-W by an order of magnitude.

15) A low energy ion source (10 kev) for QUEST NBI was studied with beam trajectory simulations [1]. Low divergence angle of around 0.5 degree was obtained at 100 mA/cm^2 H+ beam current density with optimization of extraction aperture diameter and gap length between grids. It will enable generation of 20 A, 200 kW ion beams with multi-aperture grid extraction area of 200 cm^2. NBI power above 100 kW will be possible supposing beam transport efficiency of 80 % and neutralization of 85 %.

16) The central control system and peripheral sub-control systems are modified by using recent advance in technology actively topromote experiments effectively. Especially, in 2017, the pumping control system of main vacuum vessel is modified. The information such as vacuum gages is shared between sub-systems by Ethernet and the user interfaces are provided not in hardware but in software.

17) High-performance date replication tests have been carried out between the LHD data repository (Toki) and the ITER remote experimentation center (REC, Rokkasho): (i) Shot-by-shot 30 GB data replication synchronously on LHD sequence, and (ii) bulk replication of the whole 430 TB repository. Both were successfully achieved with (i) 6 Gbps and (ii) 4 Gbps speeds, which have revealed that not only the networking technology but also the storage optimization should be mandatory for exchanging big data.

18) The equilibrium and flow reversal of the simple magnetized plasma are examined with respect to the pitch angle of the applied vertical filed. The peak of the density decay time at a certain pitch angle is experimentally found and is modeled by the global equilibrium equations (EXB drift and parallel flow).

19) The CT drift tube in between the CT injector and QUEST was newly designed and made to avert the deterioration of CT plasma parameters. The CT guiding tube made of oxygen-free high-conductivity copper, is installed inside the 316 SS drift tube for conservation of CT magnetic flux. The new drift tube would lead to improve CT fueling efficiency.

20) Last year, the magnetic fluctuation signals were able to acquire by installing magnetic probes with outer diameter 22φ, 500 turn.

This year the modified hybrid probe (including triple probes) will be installed.

21) Temperature dependence of tritium retention behavior in stainless steel type 316L under irradiation of tritium ions has been examined using β-ray induced X-ray spectrometry. The amount of surface tritium decreased with temperature rise, while it contrarily increased above 523 K, indicating that tritium retention strongly depends on material temperature as well as ion energy.

22) Electron cyclotron non-inductive plasma start-up of an 80 kA level has been achieved with a polarized 28 GHz focusing beam. The obtained electron density was one order of magnitude higher, compared to the previous experiments with no polarized focusing-beam. The electron temperature decreased with the increasing density beyond the cutoff, then the hard X-ray (HX) count started to increase. The HXs with 60 keV energy range were measured at the forward tangential viewing resonant radius for current- carrying electrons.

23) By modifying capacitor bank power supply to allow the injector current to be reduced to zero more rapidly, and by using the upper center stack coil to pull the evolving CHI plasma closer to the center stack, transient Coaxial Helicity Injection (CHI) plasma evolved into a configuration that is more favorable for the formation of closed flux surfaces. Under these conditions, 46kA of toroidal current was generated. This also resulted in the first observation of some toroidal current persistence after the injector current was decreased to zero. This is a significant improvement for transient CHI on QUEST.

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Kazuo Toi (NIFS) 11)
Mitsutaka Miyamoto (Shimane University) 12)
Shigeru Inagaki (Kyushu University) 13)
Yuji Hatano (University of Toyama) 14)
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(K. Hanada)

9. Activities of Rokkasho Research Center

At Rokkasho village in Aomori Prefecture, the International Fusion Energy Research Centre (IFERC) project and International Fusion Materials Irradiation Facility/Engineering Validation and Engineering Design Activities (IFMIF/EVEDA) project have been conducted under the Broader Approach (BA) agreement between the EU and Japan from June 2007. The roles of the NIFS Rokkasho Research Center (RCE) established on May 2007 are to assist NIFS and universities to cooperate with those activities, and to prepare the environment for promoting various collaborative research including technology between activities at Rokkasho and at universities. As cooperation activities, the head of the NIFS RCE is undertaking tasks as the IFERC Project Leader (PL) from September 2009, and the NIFS RCE has been placed inside the Rokkasho Fusion Institute of QST, where IFERC and IFMIF/EVEDA projects are located. Also, a staff member of the NIFS RCE is working as the leader of the general coordination group of the Joint Special Team for a Demonstration Fusion Reactor (DEMO) design, which is the organization set in May 2015 for establishing technological bases required for the development of DEMO as an all-Japan collaboration. In addition, the NIFS RCE performs communication work with the organizations related to ITER-BA, the Aomori prefectural office, and the Rokkasho village office, and also publicity work in order to have local residents understand nuclear fusion research.

In order to complement ITER and to contribute to an early realization of the DEMO reactor, the IFERC project implements the three sub-projects under the coordination by IFERC PL: DEMO Design and R&D Coordination Centre composed of DEMO Design Activities (DDA) and DMEO R&D activities, the Computational Simulation Centre (CSC), and the ITER Remote Experimentation Centre (REC). The IFERC project itself was and is implemented on schedule as originally planned. However, update of the IFERC project plan with the extension until the end of March 2020 was approved in order to ensure the smooth transition to BA phase II planned from April 2020 to March 2025.

In 2017, the DEMO design work was primarily focused on the design integration of baseline DEMO plant concepts, which work as a proxy for more detailed design integration work, and mainly concentrated on five tasks; (1) compilation of the 2nd intermediate report, (2) design integration for DEMO pre-conceptual design, (3) DEMO physics design integration, (4) component design and system engineering, and (5) material database activities.

The DEMO R&D activity in 2017 was dedicated to draft the final reports of JA Procurement Arrangements (PAs), and the final report of DEMO R&D Activity was compiled in December 2017. Research activity such as structural material R&D is continued under DDA. In addition, the EU/JA joint work for analysis of JET dust and tiles is continued until the end of 2019, based on the mutual understanding that this joint work is quite important for the ITER regulatory aspects as it provides the only experimental evidence in a tokamak of tritium retention in first wall materials.

CSC Activity was successfully completed and all the deliverables related to PAs were submitted and approved in 2017. After the complete shutdown of the CSC took place on December 31, 2016, the activity on CSC consisted in dismantling the IT equipment, organising the final CSC review meeting, and preparing the CSC closing ceremony and the CSC final report. The final report on the CSC consists of a main part and two annexes – one for the IT equipment, and the other for the scientific results. An "IFERC HPC follow-up working group" was set-up in 2017 for continuously sharing experience and practices and for preparing propositions for future joint activities in HPC for the BA extended period.

The main objectives of REC in 2017 were to complete 1) preparation of remote facility: the environmental preparation of the REC room and network at Rokkasho IFERC site, 2) the development of remote participation tools: the software for the remote experimentation system, experimental data analysis and simulation for interdischarge analysis for JT-60SA, and 3) the development of the software for the RDA and analysis. Those objectives were successfully completed, verified through various verification tests, and summarized in the provisional final report of REC activity as of December 2017.

Another staff member of NIFS Rokkasho Research Center is undertaking the role of the leader of the general coordination group of the Joint Special Team for a DEMO design. Since collaboration among many researchers from NIFS and other institutions and technicians from companies is indispensable for the conceptual design investigations of the DEMO reactor, which is widely spread across instruments, equipment, and facilities, the NIFS Rokkasho staff works as a coordinator and provides advice on various design activities.

In summary, the NIFS RCE contributes widely not only to the success of ITER but also to the realization of fusion energy through the continuous efforts mentioned above.

(N. Nakajima)

10. International Collaboration

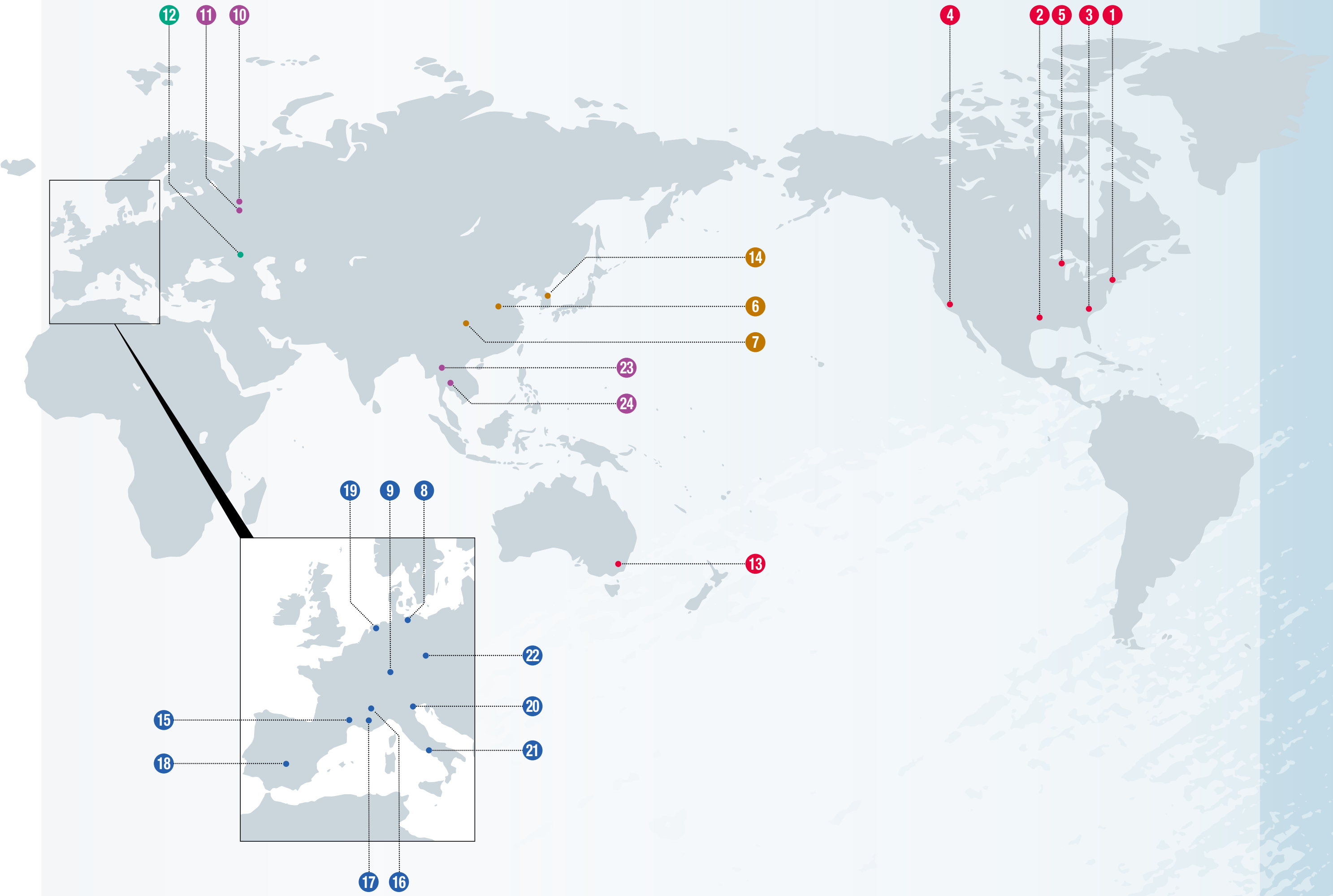
Many research activities in NIFS are strongly linked with the international collaborations with institutes and universities around the world. These collaborations are carried out in various frameworks, such as 1) coordination with foreign institutes, 2) bilateral coordination with intergovernmental agreements,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

The coordination with foreign institutes is important as the basis of collaborative research. From 1991, NIFS concluded 24 coordination through FY2016. In FY2017, 5 coordination were concluded between NIFS and Peking University, Southwest Jiaotong University, Huazhong University of Science and Technology (China), Institute of Plasma Physics and Laser Microfusion (Poland), and Peter the Great St. Petersburg Polytechnic University (Russia).

NIFS is the representative institute for the three bilateral coordination with intergovernmental agreements (J-US, J-Korea, and J-China), and for the four multilateral coordination under the IEA (Plasma Wall Interactions (PWI), Stellarator-Heliotron concept, Spherical Tori, and Steady State Operation). For the bilateral coordination, and the multilateral coordination PWI Technology Collaboration Program (TCP), NIFS coordinate the collaborative research not only for NIFS researchers, but also for researchers in universities. The activities of the bilateral and multilateral coordination activities are reported in the following subsections, respectively.

In 2017, the Joint meeting of the 26th International Toki Conference and the 11th Asia Plasma and Fusion Association Conference was held on 5 – 8 December in Toki, Japan, and NIFS hosted the meeting. More than 300 researchers from 14 countries participated.

(S. Masuzaki)



U.S.A. ❶ Princeton Plasma Physics Labolatory
❷ Institute for Fusion Studies, The University of Texas at Austin
❸ Oak Ridge National Laboratory
❹ Center for Energy Science and Technology Advanced
❺ Research, University of California, Los Angeles University of Wisconsin, Madison

China ❻ Institute of Plasma Physics, Chinese Academy of Sciences
❼ Southwestern Institute of Physics

Germany ❽ Max Planck Institute for Plasma Physics
❾ Karlsruhe Institute of Technology

Russia ❿ Russian Research Center, Kurchatov Institute
⓫ A. M. Prokhorov General Physics Institute, Russian Academy of Sciences

Ukraine ⓬ National Sciense Center of the Ukraine Khar'kov Institute of Physics and Technology Institute of Plasma Physics

Australia ⓭ Australian National University

South Korea ⓮ National Fusion Research Institute

France ⓯ Aix-Marseille University
⓰ Associated International Laboratory (LIA336)
⓱ Commissariat à l'énergie atomique et aux énergies alternatives

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

Netherland ⓳ Dutch Institute for Fundamental Energy Research (FOM)

Italy ⓴ CONSORZIO RFX
㉑ Institute of Ionized Gas

Czech ㉒ HiLASE Centre, Institute of Physics CAS (FZU)

Thailand ㉓ Chiang Mai University
㉔ Thailand Institute of Nuclear Technology (TINT)

US – Japan (Universities) Fusion Cooperation Program

The US-Japan Joint Activity has continued since 1977. The 38th CCFE (Coordinating Committee for Fusion Energy) meeting was held on March 7, 2018, via televideo conference system. The representatives from the MEXT, the DOE, universities, and research institutes from both Japan and the US participated. At the meeting, current research status of both countries were reported together with bilateral technical highlights of the collaborations. The FY 2017 cooperative activities were reviewed, and the FY 2018 proposals were approved. It was noted that both sides have developed significant and mutually valuable collaborations involving a wide range of technical elements of nuclear fusion. Also carried out was the discussion on the bilateral programs and multi-lateral activities. Both sides agreed on the usefulness and necessity of the continuation of the Joint Activity.

Fusion Physics Planning Committee (FPPC)

In the area of fusion physics, 8 workshops (4 from JA to US, 4 from US to JA) and 21 personnel exchanges (15 from JA to US, 6 from US to JA) were carried out. Due to funding limitations and schedule conflicts, 6 personal exchanges (3 from JA to US, 3 from US to JA) were cancelled or postponed.

Each personal exchange was performed successfully in the research fields of steady-state operation, high-beta physics, confinement and transport, diagnostics, and the high density physics related to the inertial fusion and its application. Fruitful discussions were held in the workshops with many participants from both sides. These programs were productive and beneficial for the progress of fusion physics, and were recommended to continue.

A new full-wave cold plasma simulation code developed in MIT was transported to the University of Tokyo to investigate the lower hybrid wave propagation in the TST-2 spherical tokamak device. Using measured density profiles and EFIT equilibrium data for TST-2, the lower hybrid current drive experiments were modelled and analyzed by the code coupled with a Python-based interface named "piScope" developed in MIT. Detailed electric field profiles on the midplane of the TST-2 were obtained, as shown in Figure 1.

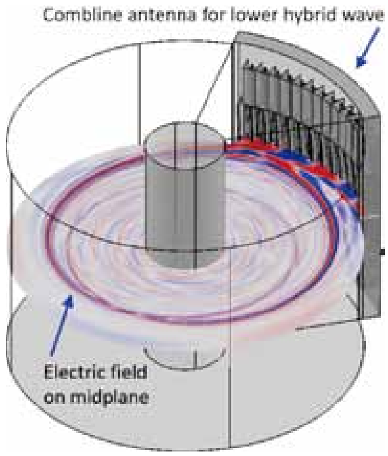


Fig. 1 Electric field distribution on midplane of TST-2. Lower hybrid wave is launched from the combline antenna.

Joint Institute for Fusion Theory (JIFT)

Most of the activities in the two categories, workshops and personnel exchanges, that had been scheduled for the 2017-2018 JIFT program were carried out during the past year. Four workshops were successfully held, in addition to the JIFT Steering Committee meeting. In the workshops, multiscale methods in plasma physics, co-designs of fusion simulations for extreme scale computing, advanced optimization concept in stellarator-heliotrons, and high energy density physics were discussed as main topics (Figure 2). In the category of personnel exchanges, two Visiting Professors and seven Visiting Scientists made exchange visits for the purpose of collaboration on theoretical modeling and simulation of magnetic and inertial confinement fusion plasmas. At the JIFT Steering Committee meeting that was held at NIFS on December 1, 2017, the status of JIFT activities for 2017-2018 was reviewed and

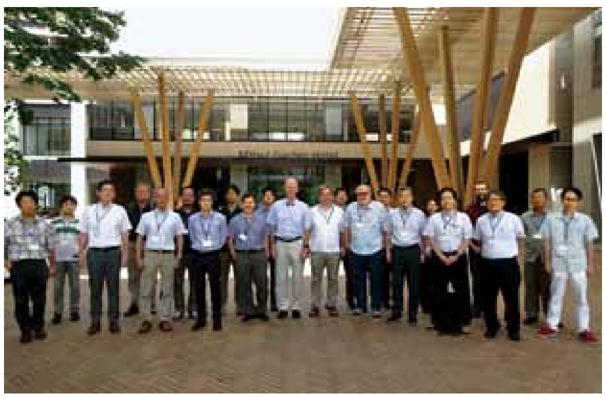


Fig. 2 Workshop on "US-Japan collaborations on co-designs of fusion simulations for extreme scale computing" held in Kashiwa during August 7-9, 2017.

the recommendation plans for 2018-2019 were discussed. The JIFT discussion meeting was held at Toki on September 8, 2017, in the Plasma Simulator Symposium.

Fusion Technology Planning Committee (FTPC)

In this category of the US-Japan Collaboration, personnel exchange programs were continued in six research fields, i.e., superconducting magnets, low-activation structural materials, plasma heating technology, blanket engineering, high heat flux components, and reactor design. Of the 10 originally planned items, 7 were completed including 2 workshops/technical meetings and 5 personnel exchanges.

One of the highlights was the in-situ LIBS measurement (laser-induced breakdown spectroscopy) carried out by Dr. Daisuke Nishijima of University of California San Diego (UCSD) in the Heliotron-DR device at Kanazawa University for examining the LHD-like metal deposition layers (with Fe and W) produced by a laser blow-off system (Figure 3). The LIBS system successfully detected the deuterium ratio deposited in tungsten.

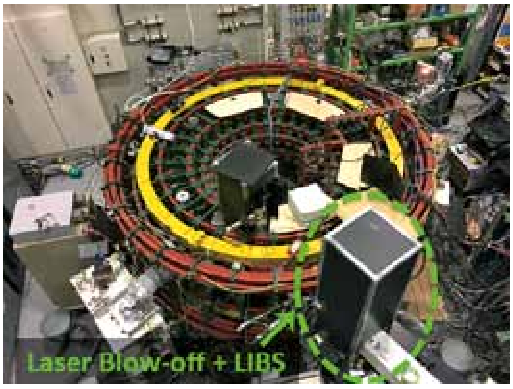


Fig. 3 Heliotron-DR device at Kanazawa University equipped with the laser blow-off and LIBS measurement system.

US-Japan Joint Project : PHENIX

FY2017 was the fifth year of the six-year project of PHENIX. A number of experiments were successfully carried out during the year.

For Task 1, the He-cooled divertor with multi-jets cooling (HEMJ) was tested at higher temperatures than previous years using He loop at the Georgia Institute of Technology (GIT). The new results for the HEMJ at He inlet temperatures T_i = 300 °C~425 °C were consistent with their previous data at lower T_i. Extrapolation to prototypical conditions suggested that the HEMJ can withstand a heat flux of 9.9 MW/m^2 over a hexagonal tile at even a higher T_i.

For Task 2, PXW-2 and PXW-5 rabbit capsules and the RB19J capsule, which were irradiated with neutrons in FY 2015 and FY2016, respectively, in High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL), were disassembled in a hot cell facility (Figure 4). The specimens retrieved from the capsules were safely shipped to Low Activation Materials Development and Analysis Laboratory (LAMDA) at ORNL and to Safety and Tritium Applied Research (STAR) Facility at Idaho National Laboratory (INL). The post-irradiation examination commenced, and hardness and thermal diffusivity testing was completed.


Fig. 4 Disassembly of RB19J capsule

For Task 3, the W specimens irradiated with neutrons in PXW-2 and PXW-5 rabbit capsules were successfully exposed to high flux deuterium plasma at 400 °C in Tritium Plasma Experiment at STAR Facility, INL. Deuterium retention was evaluated using thermal desorption spectrometry. Diffusion analysis codes developed in Japan and the US showed the presence of strong radiation-induced traps with trapping energy ranging from 1.8 to 2.6 eV.

(T. Muroga)

10. International Collaboration

Plasma Wall Interaction (PWI) Collaboration

This collaboration is based on the IEA Technical Collaboration Programme (TCP) of the "Development and Research on Plasma Wall Interaction Facilities for Fusion Reactors" (in short, PWI TCP). The objective of this TCP is to advance physics and technologies of the 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 the first wall materials and components for fusion reactor. In this fiscal year, collaborations on PWI experiment, tritium retention analysis, plasma diagnostics, detachment plasma experiment, thermo-mechanical examination of tungsten alloys, and edge plasma simulation were conducted. All the collaborations are listed in Table I. Highlight of each activity is described in this report.

Analysis of the mirror effect of simple mirror magnetic configurations with B2 code

In a scrape-off layer (SOL) region of a torus device, the spatial variation of the magnetic field strength B can be as large as a factor of ~ 2 even with a typical aspect ratio of R/a ~ 3. In this research, the effect of inhomogeneity of B on plasma proles and atomic and molecular processes were investigated by applying a SOL-divertor plasma code package B2-EIRENE to simple mirror configurations.

Impact of impurity on surface erosion in helium plasma exposed tungsten

Impact of impurity on surface erosion in helium plasma exposed tungsten has been investigated on the linear device, PSI-2. High-purity recrystallized tungsten specimens, which was mechanically polished and annealed at 1773 K under vacuum conditions for 2 hours, have been exposed to helium plasma at ~800 K. The incident helium energy has been controlled within the range of 33 eV and 220 eV by changing bias voltage at the target. Surface structure morphology with helium plasma exposure has been observed using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Focused ion beam (FIB) method has been employed to make cross-sectional samples for the depth profile observation of damage structure. The effective erosion rate has been measured by comparing mass difference between before and after plasma exposure.

Collaboration of plasma diagnostic study on MAGNUM-PSI

In the detachment plasma condition, the strong density fluctuations have been observed in the linear plasma devices. To study the fluctuation, the 3-channel frequency multiplied microwave interferometer system, which was constructed in GAMMA 10/PDX, was installed in MAGNUM-PSI. In the detached plasma condition, the coherent fluctuations were observed in the line densities at three radial positions measured by the interferometer system, and the fluctuations were also observed in the Hα emission, the 2D image of plasma taken with the high speed camera, and the target plate potential.

Tritium distribution on W-coated divertor tiles and selected Be tiles used in the 3rd JET ITER-Like Wall campaign

Integrated tests of ITER reference materials (Be and W) have been performed in JET ITER-like wall campaigns. The authors have measured tritium distributions on the W-coated CFC divertor tiles used in the first ILW campaign (2011–2012) and the second campaign (2013–2014) using an imaging plate (IP) technique. The IP images showed significant enrichment of tritium on the horizontal parts of the upper inner diver tiles and the shadowed region of the floor tiles due to co-deposition with Be and other impurities. In this study, tritium distributions on the divertor tiles and selected Be tiles used in the third ILW campaign (2015–2016) were examined using the IP technique.

Dynamic response of detached plasma due to plasma heat pulse injection and ion temperature measurement in MAGNUM-PSI device

The interaction between plasma heat pulse and detached hydrogen plasmas was investigated in MAGNUM-PSI by using the fast reciprocating probe system designed and fabricated in Nagoya University. Pulsed high heat flux plasma was produced by modulating discharge current using capacitor bank after generating detached hydrogen plasma. Dynamic response of the detached hydrogen plasma to the pulsed plasma was measured using the floating potential of the target plate and the ion saturation current measured by the probe system.

Hydrogen de-trapping dynamics in tungsten

D-H isotope exchange experiments were performed in Tungsten using the dual beam experiment located at IPP, Garching to understand the physics behind D-H isotope exchange in hydrogen trap sites in tungsten. The device is equipped with a mass-analyzed D/H ion implantation source and is capable of in-vacuo nuclear reaction analysis to quantify hydrogen concentrations. The main advantage of such a system is that the D-H isotope exchange can be measured as a function of implanted fluence for a single specimen in vacuum. Comparing the experimental data with a simple combinatorial model that calculates the probability of exchange based on hydrogen release temperatures from a single vacancy shows good qualitative agreement.

Thermo-mechanical properties of radiation tolerant tungsten alloys

To clarify the thermo-mechanical properties of radiation-tolerant tungsten alloys, which have been developed by Tohoku university, thermal shock tests were carried out at Forschungszentrum Juelich GmbH. Materials evaluated in this research were 1) pure tungsten as a reference, 2) potassium-doped tungsten, 3) 3% rhenium added tungsten alloy, and 4) potassium-doped and 3% rhenium added tungsten alloy. These materials consisted of hot-rolled plates and swaged rods. Part of specimens were annealed at 2300 ºC for evaluating the recrystallization effect on thermal shock resistance. The thermal shock tests simulating edge localized mode (ELM) were conducted using JUDITH 1 electron beam irradiation devise. Pulse duration, number of pulses, absorbed power density, and base temperature were 1 ms, 1000 cycles, 0.19 GW/m2 and 0.38 GW/m2, 1000 ºC, respectively. The pure tungsten plate showed good resistance to the thermal shock. In contrast, doped and alloyed plates showed particular surface modifications and cracks. Alloying by rhenium seemed to improve the resistance in potassium-doped material. These tendencies are opposite to the mechanical properties.

Table I. List of collaborations

Subject	Participants	Term	Key persons
Analysis of the mirror effect of simple mirror magnetic configurations with the plasma fluid code B2	Satoshi Togo (Univ. Tsukuba)	2 – 30 July 2017	D. Reiser, P. Börner (UCSD)
Impact of impurity on surface erosion in helium plasma exposed tungsten	Ryuichi Sakamoto (NIFS)	1 - 11 Sep. 2017	A. Kreter (FZJ)
Collaboration of plasma diagnostic study on Magnum-PSI	Masayuki Yoshikawa (Univ. Tsukuba)	24 Sep. - 1 Oct. 2017	H. V. Meiden (DIFFER)
Tritium distribution on W-coated divertor tiles and selected Be tiles used in the third JET ITER-like wall campaign	Yuji Hatano (Univ. Toyama)	7 – 14 Oct. 2017	J. Likonen (VTT)
Dynamic response of detached plasma due to plasma heat pulse injection and ion temperature measurement in MAGNUM-PSI device	Noriyasu Ohno (Nagoya Univ.)	21 – 29 Octc. 2017	H. V. Meiden (DIFFER)
Hydrogen de-trapping dynamics in tung-sten	Heun Tae Lee (Osaka Univ.)	12 – 18 Nov. 2017	Thomas Schwarz-Selinger (IPP Garching)
Thermo-mechanical properties of radia-tion tolerant tungsten alloys	Shuhei Nogami (Tohoku Univ.)	26 Nov. – 1 Dec. 2017	Gerald Pintsuk, Marius Wirtz, Thorsten Loewenhoff (FZJ)

(S. Masuzaki)

10. International Collaboration

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

Programmatic collaborations have been further extended in the new era of SH research

The SH TCP’s objective is to improve the physics base of the Stellarator-Heliotron concept and to enhance the effectiveness and productivity of research by strengthening cooperation among member countries. All collaborative activities of the worldwide stellarator and heliotron research are combined under the umbrella of this programme, which promotes the exchange of information among the partners, the assignment of specialists to facilities and research groups of the contracting parties, joint planning and coordination of experimental programmes in selected areas, joint experiments, workshops, seminars and symposia, joint theoretical and design and system studies, and the exchange of computer codes. The bi-annual “International Stellarator-Heliotron Workshop (ISHW)” has served as an important forum for the scientific exchange within the scientific community. The research activities have been organized mainly through the Coordinated Working Group Meetings (CWGM).

Fig. The group photo at 21th International Stellarator-Heliotron Workshop, Shiran-Kaikan, Kyoto, Oct. 2017, Courtesy of Heliotron J group at Kyoto University

● Major achievements in 2017

In 2017, major achievements were the deuterium plasma campaign in the Large Helical Device (LHD) and start of the second experimental campaign of the Wendelstein 7-X (W7-X). First results of LHD deuterium campaigns were reported in many presentations at the International Stellarator-Heliotron Workshop (ISHW) in Kyoto including the ion temperature exceeding 10 keV. This is the landmark achievement in the world-wide helical research, which realizes one of fusion conditions. The first half of the second experimental campaign of W7-X (so called OP1.2a) was completed. With an uncooled divertor the injected energy was extended from 4 MJ to 80 MJ - a major milestone on the way to a steady state plasma.

● 21st International Stellarator-Heliotron Workshop (ISHW)

The 21st ISHW was hosted by the Institute of Advanced Energy at Kyoto University from Oct. 2 to Oct. 6, 2017 in Kyoto and included a special session on the physics of decoupling transport channels to promote synergies between tokamaks and stellarator-heliotrons. The workshop attracted nearly 200 delegates coming from the whole Stellarator-Heliotron community as well as invited speakers from the tokamak community.

Web: http://www.center.iae.kyoto-u.ac.jp/ishw2017/

● **46th Executive Committee (ExCo) Meeting**

The Executive Committee met on October 3, 2017, at the venue of the ISHW in Kyoto. The meeting was attended by nine representatives from five out of six contracting parties, as well as an observer from Costa Rica. Two presentations were given by contenders for the 18th ISHW, and the ExCo voted for Madison, Wisconsin as the venue for 2018. The ExCo also voted unanimously to invite Costa Rica as a participant to the TCP and to seek discussions with Chinese entities with the prospect of joining. (**Related remarks:** China has been extending its fusion activities towards SH research. This includes the start of the joint project to construct Chinese First Quasi-axisymmetric Stellarator (CFQS) by the joint project between NIFS and Southwest Jiaotong University (SWJTU), and the move of the Heliac H1 from the Australian National University to the University of South China. In preparation, the International Workshop was held on March 26-28, 2018 in Hangzhou, China.)

● **17th Coordinated Working Group Meetings (CWGM)**

The 17th CWGM was held, with about 40 participants, on Oct. 6, 2017, in Kyoto, on the occasion of the 21st ISHW. Due to the time constraint after the adjournment of the ISHW (~2 hours), the main purpose of this meeting was the follow-up of the previous 16th CWGM.

The agenda was as follows:

- Brief report from 16th CWGM
- EUROfusion supported activities in NIFS
- Discussion on a couple of sessions with ON-GOING intensive collaborations:
  - ✓ Transport modelling (chaired by Shinsuke Satake)
  - ✓ Energetic particles/AEs control (Satoshi Yamamoto)
  - ✓ Impurity transport (mainly on TESPEL injection) (Naoki Tamura)
  - ✓ Core Electron-root Confinement (Felix Warmer)
  - ✓ Turbulence/isotope effect (Motoki Nakata)
- Setting up milestones: joint actions, joint papers etc.

The materials presented in this meeting are available at http://ishcdb.nifs.ac.jp/ and http://fusionwiki.ciemat.es/wiki/Coordinated_Working_Group_Meeting. The brief report was published at Web: https://stelnews.info//sites/default/files/pdf/sn159.pdf).

Fig. Scene of the venue of 17th Coordinated Working Group Meeting, Shiran-Kaikan, Kyoto, Oct. 2017, Courtesy of Dr. S. Yamamoto (Kyoto Univrsity)

(Y. Takeiri)

10. International Collaboration

JSPS A3 (China, Japan and Korea) Foresight Program

I. Project title

Study on critical physics issues specific to steady state sustainment of high-performance plasmas

II. Period of cooperation

August 2012 - July 2017

III. A3 foresight program in the field of plasma physics

The three countries, China, Japan and Korea (C-J-K), have built large toroidal devices called EAST, LHD and KSTAR having superconducting magnetic coils, respectively, and have successfully started the academic research aimed at the steady-state operation of high-performance plasmas. By conducting a joint research among three superconducting devices with entirely unique features, various advanced studies on critical physics issues to be resolved for early realization of the fusion reactor are possible based on the long-pulse sustainment of high-performance plasmas.

IV. Significant cooperative activities

When the discharge is longer, the handling of high heat load on the divertor and the first wall becomes a vital issue and a challenging subject among the three devices. The study of critical physics for the steady state operation of high-performance plasmas is made possible only by superconducting devices. The following three critical physics issues are then listed up for the joint research among C-J-K as shown in Fig.1. The category IV covers three experimental categories of I-III;

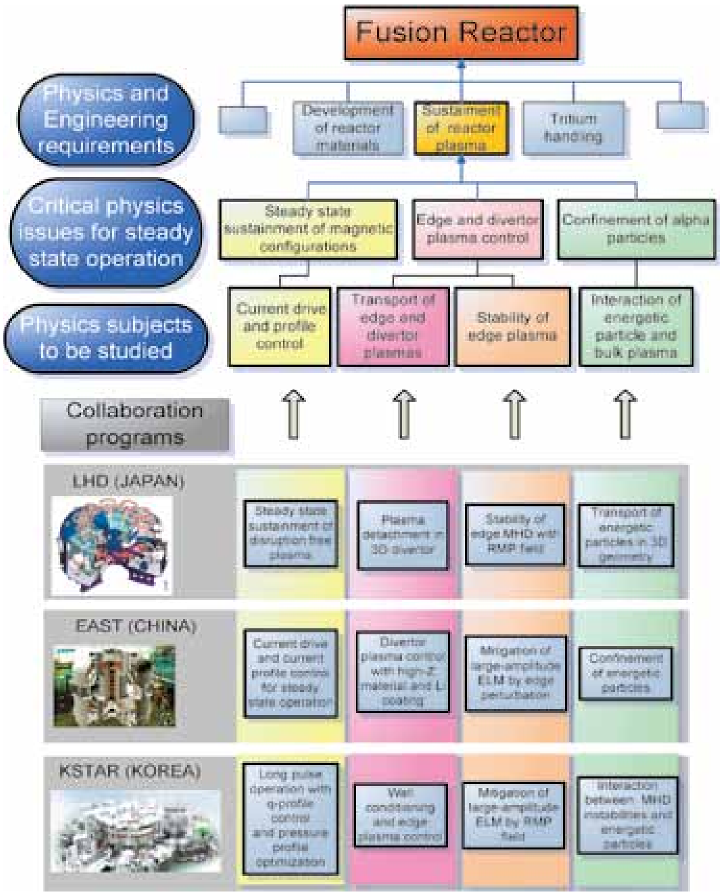


Fig. 1 Schematic drawing on Joint Research Project among LHD (NIFS: Japan), EAST (ASIPP: China) and KSTAR (NFRI: Korea). This Joint Research Project quests three 'Critical physics issues' for the steady state operation and these issues consist of four key 'Physics subjects' to be studied. The collaborative research is coordinated among 'Collaboration programs' by considering the characteristics and capability of three devices.

(I) Steady state sustainment of magnetic configuration
(II) Edge and divertor plasma control
(III) Confinement of alpha particles
(IV) Theory and simulation

V. Activities in FY 2017

The 11th scientific seminar on A3 Foresight Program was held in Sapporo of Japan during 11 - 14 July 2017 with totally 58 participants. The 12th scientific seminar on A3 Foresight Program was also held in Chongqing of China during 12 - 15 December 2017 with totally 60 participants, while the official period of A3 Program had already ended at 31th July 2017. In the seminars the collaborative results were presented with their check and review and future directions for the collaboration after A3 program are discussed. Many young scientists and graduate students were also invited at the oral presentation.

Main results of scientific collaboration in the last year of A3 program are listed in the following.

[LHD]
1. Education of Chinese young scientists
2. EUV spectroscopy on tungsten UTA spectra
3. MHD turbulence in edge plasmas

4. Neutron and high-energy ion diagnostics
5. Simulations of energetic particle-induced MHD and edge plasma transport

[EAST]
1. EUV spectroscopy for vertical profile measurement
2. Orbit analysis of energetic ions
3. Signal check for SX camera system
4. PWI study on hydrogen and deuterium retention
5. Simulation of tungsten divertor plasmas
6. Simulation of high-energy ions in LHCD

[KSTAR]
1 Effect of mode structure for ELM mitigation
2. Data analysis on neutron and fast ion behaviors
3. High-temperature wall discharges
4. Behavior of tungsten dust
5. Simulation study on core transport and MHD turbulence

Based on the collaboration totally 16 papers were published with A3 program acknowledgement in international journals after peer review by referees and 4 presentations were made in international conferences in addition to 118 presentations in the A3 seminars. Results of A3 Foresight Program were presented as a plenary talk in 11th Asian Plasma and Fusion Association Conference (APFA) & 26th International Toki Conference (ITC) [1]. Scientific activities on the A3 Foresight Program during past five years were reported with recent fusion research activities in the Asian region. A method for controlling the tungsten accumulation was investigated in EAST tokamak with tungsten divertor. It is found that LHW heating can suppress the tungsten accumulation in discharges at H-mode phase [2]. It is also found that in NBI heating discharges the power ratio of PLHW to PNBI is important for the tungsten suppression. The impurity transport for Fe ions in core plasmas was studied in LHD [3]. It is found that a positive density gradient appeared in hollow density profiles can suppress the inward impurity transport creating an impurity transport barrier at ρ~0.85. A lithium beam experiment was carried out and distributions of the lithium neutral and ions are analyzed with Monte Carlo codes [4]. Atomic level structures of tungsten ions were theoretically studied and possible transitions were also calculated for plasma diagnostics [6-8]. An effect of polycrystalline structure on helium plasma irradiation of tungsten materials was investigated based on a binary-collision-approximation-based simulation [9].

A statistical summary on personal exchange between J-C and between J-K is listed in Table 1.

Table 1 A3 collaboration in FY2017 (April - July)

J→C person (person-day)	18 (90)*
C→J person (person-day)	30 (238)*
J→K person (person-day)	0 (0)
K→J person (person-day)	15 (63)

* includes 2 month stay in NIFS by Chinese USTC student

[1] S. Morita, L.Q. Hu, Y.K. Oh, N. Ashikawa, M. Isobe, D. Kato, Y. Kishimoto, S. Ohdachi, S. Sakakibara, Y. Todo *et al.*, PFR **13** (2018) 3502046.
[2] L. Zhang, S. Morita, Z. Xu P.F. Zhang, Q. Zang, *et al.*, Nucl. Mater. Energy **12** (2017) 774.
[3] X.L. Huang, S. Morita, T. Oishi, I. Murakami, M. Goto, H.M. Zhang and Y. Liu Nucl. Fusion **57** (2017) 086031.
[4] Y. Liu, S. Morita, X.L. Huang, T. Oishi, M. Goto, H.M. Zhang J. Appl. Phys. **122** (2017) 233301.
[5] K.S. Chung, Y. Hirooka, N. Ashikawa, S.G. Cho, H.G. Choi, *et al.*, Fus. Eng. Des. **119** (2017) 61.
[6] X.-B. Ding, R. Sun, F. Koike, I. Murakami, D. Kato *et al.*, At. Data Nucl. Data Tables **119** (2017) 354.
[7] X.-B. Ding, R. Sun, J.-X. Liu, F. Koike, I. Murakami, D. Kato *et al.*, J. Phys.B **50** (2017) 045004.
[8] X.-B. Ding, J.X. Yang, F. Koike, I. Murakami, D. Kato *et al.*, J. Quant. Spectr. Radiat. Trans. **204** (2018) 7.
[9] S. Saito, H. Nakamura, S. Yooyen, N. Ashikawa and K. Katayama Jpn. J. Appl. Phys. **57** (2018) 01AB06.

(S. Morita)

10. International Collaboration

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

I. Post-CUP collaboration

The post-CUP collaboration is motivated by collaboration on fusion research with institutes and universities in China including Southwestern Institute of Physics (SWIP). Collaborations with Institute of Plasma Physics Chinese Academy of Science (ASIPP), University of Science and Technology of China (USTC) and Huazhong University of Science and Technology (HUST) are basically included in the A3 Foresight Program financed by the Japan Society for the Promotion of Science (JSPS). The Post-CUP collaboration is carried out for both studies on plasma physics and fusion engineering, while the A3 program is carried out only for the plasma physics.

II. Activities of collaboration in FY 2017

In 2017 FY 18 scientists who belong to NIFS and Universities visited SWIP including young scientists and graduate students. Two scientists visited Fudan University and Beijing University individually. Necessary expenses for the collaboration are prepared by NIFS, Grants-in-Aid and counterpart spending. 13 scientists visited NIFS from SWIP including young scientists and graduate students.

Some of results on the Post-CUP collaboration in 2017 FY are described in the following.

In HL-2A the lower hybrid current drive was successfully carried out with high coupling efficiency using a passive–active multi-junction antenna [1]. An ELM mitigation technique has been studied using supersonic molecular beam injection, impurity seeding, resonant magnetic perturbation and lower hybrid wave. The ion internal transport barrier was observed in NBI-heated plasmas. In a long-lasting runaway electron plateau achieved after argon injection, it is found that low-*n* Alfven ion temperature gradient modes can be destabilized in ohmic plasmas with weak magnetic shear and low-pressure gradients. A result on the impurity transport study shows that the radial transport of Al ions is strongly enhanced during the an inverse sawtooth oscillation with the long lasting m/n=1/1 mode at ECRH phase. Modification of impurity transport was discussed in the presence of long-lasting m/n=1/1 MHD mode [2].

In the field of atomic physics the electron correlation effect and Breit interaction were studied for the energy level and transition properties of Ne-like ions of W^{54+}. It is found that the correlation from 3s and 3p orbits have an important contribution to the energy level and transition wavelength and probability [3].

Extreme-ultra violet (EUV) spectra of tungsten unresolved transition array were observed in LHD by injecting a coaxial tungsten pellet at the wavelength range of 15Å–70Å and analyzed at two different wavelength intervals of 15–45Å and 45–70Å, which mainly consist of $\Delta n=1$, 2 and $\Delta n=0$ transitions for n=4 partially ionized tungsten ions, respectively [4]. It is found that the wavelength intervals of 49.24Å≤λ≤49.46Å, 48.81Å≤λ≤49.03Å and 47.94Å≤λ≤48.15Å, which are identified as W^{27+}, W^{26+}, and W^{24+}, respectively, are applicable to the tungsten diagnostics. The tungsten spectra have been also observed in LHD to identify the emission lines in EUV range of 10 - 500Å [5]. As a result, a lot of tungsten lines from low-ionized ions of W^{4+}, W^{6+} and W^{7+} were observed for the first time in toroidal devices in addition to tungsten lines from highly ionized ions of W^{41+}-W^{45+}.

The tungsten spectrum in EUV wavelength range has been also investigated in HL-2A tokamak to find line emissions from low-ionized tungsten ions which can be used for tungsten transport study in plasma edge [6]. Analyzing carefully the observed tungsten spectrum, two isolated line emissions of WVII (5p-5d: 216.219Å) and WVII (5p-5d: 261.387Å) from W^{6+} ions were successfully identified for the first time in tokamaks. Based on the WVII emission observed during the re-entry event of tungsten ions, an influx of the W^{7+} ion, Γw^{7+}, to the edge plasma is evaluated using the inverse photon efficiency calculated with the CR model. As a result, it is found that the Γw^{7+} typically ranges in $0.3 \le \Gamma w^{7+} \le 5.0 \times 10^{14} cm^{-2} s^{-1}$.

[1] X.R. Duan, Y. Liu, M. Xu, L.W. Yan, Y. Xu, X.M. Song, M. Isobe, S. Morita *et al.*, Nucl. Fusion **57** (2017) 102013.

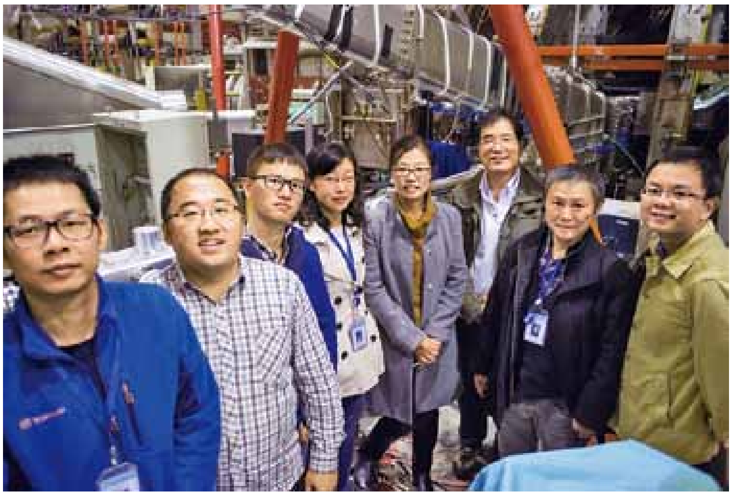
[2] Z.Y. Cui, K. Zhang, S. Morita, X.Q. Ji, X.T. Ding, Y. Xu, P. Sun, *et al.*, Nucl. Fusion **58** (2018) 056012.

[3] X.-B. Ding, R. Sun, F. Koike, D. Kato, I. Murakami, H.A. Sakaue, C.-Z. Dong, European Physical Journal D **71** (2017) 73.

[4] Y. Liu, S. Morita, X.L. Huang, T. Oishi, M. Goto, H.M. Zhang, J. Appl. Phys. **122** (2017) 233301.

[5] Y. Liu, S. Morita, T. Oishi, M. Goto, X.L. Huang Plasma Fus. Res. **13** (2018) 3402020.

[6] C.F. Dong, S. Morita, Z.Y. Cui, P. Sun, K. Zhang, I. Murakami, *et al.*, "Evaluation of tungsten influx rate based on observation of EUV line emissions from W^{6+} ions in HL-2A", submitted to Nucl. Fusion.



2017/Oct. Collaboration on EUV spectroscopy in HL-2A tokamak at SWIP in Chengdu, China. Discussions are made on spatial distribution measurement with EUV spectrometer and Al and W injection using laser blow-off technique.

2017/Oct. Faculty building for cultural affairs in Fudan University in Shanghai, China. Shanghai-EBIT device is installed in Fudan University and collaborations are made on atomic physics with Tokyo-EBIT in University of Electro Communications, and on fusion research with ASIPP at Hefei, China and NIFS at Toki, Japan.

(S. Morita)

10. International Collaboration

Collaboration under implementation agreement between MEXT of Japan and the MOST of China for cooperation in the area of magnetic fusion energy research and development and related fields (JWG)

The China-Japan collaboration under the collaboration agreement between the MEXT of Japan and the MOST of China has been performed following the result of the 10th JWG (Joint Working Group) held in Tokyo, Japan on July 19-20, 2017.

In the meeting, in total 46 collaborative programs (7 programs from NIFS and other institutes to China and 21 programs from China to NIFS and other institutes) are proposed and approved for the fiscal year of 2017. Ten proposals during JWG-10 and 2 proposals after JWG-10 were approved. Among them 7 were preformed, 3 were canceled and 2 were postponed.

- JC140 (Canceled) Tetsuo SEKI, Kenji SAITO, Hiroshi KASAHARA, Ryosuke SEKI, Shuji KAMIO (NIFS) to ASIPP
  - *ICRF heating experiment and relevant RF technology in EAST*
- JC141 (Canceled) Katsuyoshi TSUMORI to ASIPP
  - *Diagnostics and Optimization for ASIPP and NIFS NBI Systems*
- JC142 (Performed) Shin KUBO, Yasuo YOSHIMURA to SWIP March 26-29, 2018
  - *ECRH System Optimization and ECRH Experiment in HL-2A, and HL-2M*
- JC143 (Performed) Katsunori IKEDA, Katsuyoshi TSUMORI, Haruhisa NAKANO, Yutaka FUJIWARA to ASIPP Jan. 22-28, 2018
  - *Diagnostics and Optimization for ASIPP and NIFS NBI Systems*
- JC144 (Performed) Shigeru MORITA to ASIPP/SWIP Mar. 4-17, 2018
  - *Study of tungsten transport in EAST, HL-2A and LHD*
- JC145 (Performed) Mitsutaka ISOBE, Kunihiro OGAWA to SWIP Mar. 26-28, 2018
  - *Study on high-energy particles in EAST and HL-2A/2M*
- JC146 (Performed) Naoko ASHIKAWA to ASIPP Jan. 2-6, 2018
  - *Study on divertor cassette replacement*
- JC147 (Canceled) Nagato YANAGI, Shinji HAMAGUCHI to ASIPP TBD, one week
  - *Superconducting magnet and cryogenics systems*
- JC148 (Performed, added after JWG-10) Katsuyoshi TSUMORI to SWIP Jan. 20-24, 2018
  - *Development of Cs-Seeded Negative Ion Source for NBI*
- JC149 (Performed, added after JWG-10) Hisamichi FUNABA, Ichihiro YAMADA to SWIP Jan. 23-Feb. 1, 2018
  - *Development of the HL-2A/M Thomson scattering system*
- JC150 (Postponed) Yoshiteru SAKAMOTO, Ryoji HIWATARI to SWIP
  - *Discussion of Fusion DEMO Design and R&D in SWIP*
- JC151 (Postponed) Yoshiteru SAKAMOTO, Ryoji HIWATARI to ASIPP
  - *Discussion of Fusion DEMO Design and R&D in ASIPP*

Each program has been performed as a substantial collaboration in each field and has benefitted the research progress of both sides as well as making mutual understanding stronger for future collaborations.

The following 14 collaborations were executed, 2 were postponed, and 5 were cancelled out of 21 approved programs from China to NIFS.

- CJ168 (Postponed) Yongjin Feng (SWIP) with Yasuhisa OYA (Shizuoka Univ.), June 11-15, 2018
  - *Study on the tritium release behavior of neutron irradiated breeders*
- CJ169 (Performed) Pengfei ZHENG, Haihong WEI (SWIP) with Noriyasu OHNO (Nagoya U.) and Takuya NAGASAKA / Nagato YANAGI (NIFS), May 14-18, 2018
  - *Nuclear reaction analysis on D permeation in novel plasma facing materials and exchange in materials related study progress*
- CJ171 (Performed) Xiaoyan LIU, Zhicai SHENG (ASIPP) with TBD (NIFS), Dec. 6-14, 2017
  - *High voltage power supply*
- 2 (Canceled) Xiaochuan LIU and Qiangwang Hao (ASIPP) with Yoshihiko NUNOYA
  - *Jacket and conduct in superconducting magnet*

- CJ172 (Performed) Zhongshi YANG and Guojian NIU (ASIPP) with Gakushi KAWAMURA (NIFS), Oct. 16-Nov. 9
  - *Heat and particle simulation in the edge plasma*
- CJ173 (Postponed) Hai-Shan ZHOU and Yu-Ping XU (ASIPP) with Naoko ASHIKAWA (NIFS), Jan. 2019, 1 week
  - *Plasma and wall interaction*
- CJ174 (Canceled) Songlin LIU (ASIPP) with Yoshiteru SAKAMOTO (QST),
  - *Blanket technology and analyses*
- CJ175 (Performed) Hongming ZHANG and Yingying LI (ASIPP) with Shigeru MORITA and Katsumi IDA (NIFS), Dec. 24-30, 2017
  - *Spectroscopy and application*
- CJ176 (Postponed) Ling ZHANG (ASIPP) with Shigeru MORITA (NIFS), Jan. 2019
  - *Impurity radiation and transport*
- CJ177 (Performed) Juan HUANG (ASIPP) with Masahiro KOBAYASHI (NIFS), Jun. 29-Jul. 16, 2018
  - *3D Visualization*
- CJ178 (Performed) Zhiyong ZOU, Shouxin WANG (ASIPP) with Masaki OSAKABE (NIFS), July 23-July 27 and July 30-Aug. 3, 2017
  - *Dispersion interfeometer*
- CJ179 (Performed) Ruijie ZHOU, Guoqiang ZHONG (ASIPP) with Mitsutaka ISOBE (NIFS), Jul. 23-31, 2018
  - *Energetic particle detection*
- CJ180 (Performed) Caichao JIANG, YAHONG (ASIPP) with Mieko KASHIWAGI (QST), Nov. 5-21, 2017
  - *NBI injector technology*
- CJ181 (Performed) Chundong HU, Yuanlai XIE, and Ling LIU (ASIPP) with Masaki OSAKABE (NIFS), Nov. 6-17, 2017
  - *NBI injector technology*
- CJ182 (Postponed) Jiang MIN, Deliang YU (SWIP) with Katsumi IDA (NIFS)
  - *Comparative study of turbulence and ITB formation on HL-2A and LHD*
- CJ183 (Postponed) Yi LIU, Yipo ZHANG (SWIP) with Mitsutaka ISOBE (NIFS)
  - *Joint design and numerical simulation for TOF Neutron emission spectrometers on HL-2A and LHD*
- CJ184 (Postponed) Dong CHUNFENG (SWIP) with Shigeru MORITA (NIFS)
  - *Collaborative study of two-dimensional visible imaging system on HL-2A and LHD*
- CJ185 (Postponed) Haiying FU, Shuang YANG (SWIP) with Takuya NAGASAKA (NIFS), July 2018, 1 week
  - *Development of dissimilar-metal bondings for fusion blanket*
- CJ186 (Postponed) Mei HUANG, Zhang FENG (SWIP) with Shin KUBO (NIFS), June 2018, 1 week
  - *Comparative study of ECRH transmission line, antenna and system commissioning on HL-2A and LHD*
- CJ187 (Postponed) Cao JIANYONG, *et al.* (SWIP) with Masaki OSAKABE (NIFS), June 2018, 1 week
  - *Discuss the design and control on neutral beam line based on negative ion source*
- CJ188 (Postponed) Lei GUANGJIU, *et al.* (SWIP) with Akira ANDO (Tohoku Univ.), Oct. 17, 1 week
  - *Characteristics of RF negative ion source for NBI and negative ion production problems and discussion on RF driver conceptual design for CFETR N-NBI*

Next JWG meeting (JWG-12) will be held in Nagoya, Japan near the end of July 2019 to discuss fiscal year 2019 programs.

(S. Kubo)

10. International Collaboration

Japan-Korea Fusion Collaboration Programs

Closer and deeper cooperation in the areas of plasma heating systems, diagnostic systems, and SC toroidal device experiments was essential for physics research. Another important aspect of this collaboration is human resource development for future fusion research.

I. KSTAR collaboration

1 Plasma Heating Systems

1.1 Radio Frequency Systems

The collaboration and exchange of personnel and technical knowledge for the development of radio frequency technologies in fusion plasmas has been continued.

2 Diagnostic Systems

2.1 Bolometer Systems

The electrical shielding of the IR camera. has been improved. The absence of operational problems with the IR camera during experiments after the shielding improvements indicated that the shielding is suffcient. Therefore, it is concluded that no further improvements are deemed necessary. The two dimensional tomography system for the newly acquired IR camera was developed.[1)]

2.2 Edge Thomson Scattering System

LHD and KSTAR groups collaborated regarding the high repetition rate sampling (5 GS/s) DAQ system.[2, 3, 4, 5)] The collaboration on the alignment and calibration technique on Thomson scattering system in KSTAR and LHD has been also performed.[6, 7)] The improvements of the KSTAR and LHD Thomson scattering systems has been discussed. The collaboration on the 10 Hz YAG Laser has been continued.

2.3 Electron Cyclotron Emission (ECE) and Imaging (ECEI) System

The discussion on the ECE imaging systems was started. The operation technique and interpretation of imaging data were discussed.

2.4 Fast RF spectrometer system

The collaborated on improving time resolution of fast RF spectrometer using Digital Storage Oscilloscope (DSO) and fast digitizer started as a new proposal between NIFS and POSTECH. The fast RF data from LHD has been analyzed to discuss ion cyclotron emission (ICE) mechanism for diagnostics. Mini ICE workshop was held at NIFS in March 2018. Experimental data from KSTAR and LHD were discussed with theoretical/simulation study on RF radiation.

2.5 Charge Exchange Recombination Spectroscopy

The collaboration on the three types of Charge Exchange Recombination Spectroscopy (CES) spectrometers for the advanced KSTAR transport physics research has been continued.

2.6 Neutron and Energetic-ion Diagnostics

The cooperatively development on a scintillating-fiber detector to measure time-resolved fast-neutron flux for a study of triton burnup in KSTAR deuterium plasmas has been performed between NIFS, National Institute of Technology, Toyama College (NIT, Toyama College), NFRI and Seoul National University (SNU) developed.[8, 9, 10, 11, 12, 13)]

2.7 Soft X-ray CCD Camera (SXCCD) and VUV Telescope System

The design of the new support structure of SXCCD to share the space with the VUV camera and the GEM detector was finalized and the fabrication has started.

2.8 SC Toroidal Device Experiments

Collaborative research on intrinsic rotation reversal, non-local transport, and turbulence transition in KSTAR has been performed.[14)] The LHD - KSTAR joint experiment has been done to study rotation transport dynamics under the non-axisymmetric magnetic perturbation field.[15)] The post data-analysis system, EMA, which consists of data server (EG-server), data viewer (Myview) and automatic analysis (Autoana), into the KSTAR data acquisition system has been installed to KSTAR data acquisition as a post-analysis system.

II. Human Resource Development

The total number of researchers that were exchanged between Japan and Korea in JFY 2017 were 44 from Japan to Korea and 61 from Korea to Japan. 13 Workshops in various fields were held in each country (8 in Japan and 5 in Korea).

- Workshop on Physics validation and control of turbulent transport and MHD in fusion plasmas, Kyoto Univ., Japan, 8-10 May 2017.
- Workshop on ITER tritium system, Toyama Univ. Japan, 18-19 July 2017.
- Recovery of tritium in fusion reactor and its safety technology (II), Toyama Univ., Japan, 18-19 July 2017.
- Modeling and Simulation of Magnetic Fusion Plasmas, Inuyama, Japan, 20-21 July 2017.
- 3rd Japan-Korea Joint Workshop for Fusion Material Technology Integration and Engineering, Busan, Korea, 17-19 August 2017.
- Japan - Korea Blanket Workshop, OST, Japan, 16-17 October 2017.
- Technical discussion about NBI, QST, Japan 31 October - 1st November 2017.
- 11th Workshop on ITER Diagnostics, NFRI, Korea, 18-19 December 2017.
- Physics of fine plasma particles, Hanyang Univ., Korea 21-23 December 2017.
- KSTAR Conference, Muju Resort, Korea, 21-23 February 2018.
- Fusion Material and Engineering Toward Next Fusion Devices, NIFS, Japan, 26-27 February 2018.
- Workshop on Physics and Technology of Heating and Current Drive, Kyoto Univ. Japan, 27-28 February 2018.
- Korea - Japan Blanket Workshop, Haeundae, Korea, 14-15 March 2018.

1) J. Jang, W. Choe, B.J. Peterson, D.C. Seo, K. Mukai, R. Sano, S. Oh, S.H. Hong, J. Hong, H.Y. Lee, 'Tomographic reconstruction of two-dimensional radiated power distribution during impurity injection in KSTAR plasmas using an infrared imaging video bolometer', to be published in Current Applied Physics **18** (2018).
2) J. Lee, *et al.*, "Research of Fast DAQ system in KSTAR Thomson scattering diagnostic", JINST., 12, C12035 (2017).
3) J. Lee, *et al.*, "Research of Fast DAQ system in KSTAR Thomson scattering diagnostic", 18th LAPD, Czech republic (2017).
4) I. Yamada *et al.*, "Application of fast ADC system in Thomson scattering diagnostic", 26th A3 workshop, China (2017).
5) H. Funaba *et al.*, "Development of Fast-signal Processing for Thomson Scattering Measurement on LHD", KSTAR conference 2017, Korea (2017).
6) J. Lee, *et al.*, "Progress of KSTAR Thomson Scattering Diagnostic System in 2017 and system upgrade plan", 26th ITC, Japan (2017).
7) I. Yamada, *et al.*, "Application of the Neural Network Technique in the LHD Thomson Scattering System", KSTAR conference 2017, Korea (2017).
8) M. Isobe, J. Kim, Y. Zhang, J. Chang, Kunihiro Ogawa, J.Y. Kim, Y. Liu and L. Hu, "Recent Advances of Scintillator-based Escaping Fast Ion Diagnostics in Toroidal Fusion Plasmas in Japan, Korea, and China", Fusion Science and Technology 73 60 (2017).
9) M. Isobe, *et al.*, "Summary of energetic-particle diagnostics and physics collaborations in Japan, Korea, and China for the last five years", 11th A3 Foresight Program Workshop on Critical Physics Issues Specific to Steady State Sustainment of High-Performance Plasmas, 11-14 July, 2017, Sapporo, Japan.
10) J. Kim, *et al.*, "Research Status of Energetic Particle Physics & Diagnostics in KSTAR", 11th A3 Foresight Program Workshop on Critical Physics Issues Specific to Steady State Sustainment of High-Performance Plasmas, 11-14 July, 2017, Sapporo, Japan.
11) J. Kim, *et al.*, "Current status of neutron & energetic-ion diagnostics on KSTAR", Japan-Korea KSTAR Diagnostics Collaboration Meeting, 22nd August 2017.
12) T. Nishitani, *et al.*, "Neutron Calibration Experiment and the Neutronics Analyses for the Deuterium Plasma Experiments on LHD", The 13th International Symposium on Fusion Nuclear Technology (ISFNT-13), 25-29 September 2017, Kyoto, Japan.
13) J. Jo, *et al.*, "Neutron measurement experiment in KSTAR", The 11th Japan-Korea ITER diagnostics workshop, 18-19 December, 2017, Daejeon, Korea.
14) Y.J. Shi, J.M. Kwon, P.H. Diamond, W.H. Ko, M.J. Choi, S.H. Ko, S.H. Hahn, D.H. Na, J.E. Leem, J.A. Lee, S.M. Yang, K.D. Lee, M. Joung, J.H. Jeong, J.W. Yoo, W.C. Lee, J.H. Lee, Y.S. Bae, S.G. Lee, S.W. Yoon, K. Ida and Y-S. Na, 'Intrinsic rotation reversal, non-local transport, and turbulence transition in KSTAR L-mode plasmas', Nucl. Fusion **57** (2017) 066040.
15) K. Ida, *et al.*, "Modulation method as a tool to measure three dimensional magnetic field structures in toroidal plasmas (oral)", 59th Annual Meeting of the APS Division of Plasma Physics, October 23-27, 2017, Milwaukee, Wisconsin U.S.A.

(Ida, K.)

11. Research Enhancement Strategy Office

The Research Enhancement Strategy Office (RESO) was founded in October 2013, and three University Research Administrators (URAs) were assigned. Under the Research Planning Task Group, the following four Task Groups were organized.

(1) IR(Institutional Research)/Evaluation Task Group
(2) Public Relations Enhancement Task Group
(3) Collaboration Research Enhancement Task Group
(4) Young Researchers Development Task Group

The IR/Evaluation Task Group was newly established in FY2017 as a new emphasis.

(1) The collaborative research activities

1) Enhancing international collaborative research in the stellarator-heliotron (S-H) plasma, and steady-state operation (SSO) toward a fusion reactor

The second helical plasma experiment (OP1.2a) for Wendelstein 7-X (W7-X), which is promoted by Max Planck Institute of Plasma Physics (IPP) in Greifswald, Germany, was carried out from Aug. to Dec. 2017. Several scientists in NIFS were assigned to IPP to initiate collaboration. In order to accelerate the collaborations, the Annexes to the NIFS-IPP Agreements were modified.

Collaborative research was also enhanced with PPPL and the University of Wisconsin in the United States, CIEMAT in Spain, CEA in France, CONSORZIO RFX in Italy, Culham Centre in the United Kingdom, and Southwest Jiaotong University (SWJTU) in China.

2) International research network for integrated plasma physics

NINS promotes the international research networks with Princeton University and Max-Planck Research Institutes for the integrated plasma physics. Following the Memorandum of Understanding (MoU) with Princeton University made in 2017, three MoUs for the international collaborations within the integrated plasma physics framework were made with three Max-Planck institutes, namely, Max-Planck Institute for Plasma Physics (IPP), Astrophysics (MPA), and Solar System Research (MPS).

A postdoctoral fellow was employed for a term of two years and was involved in the international collaborations between NINS and Princeton University.

3) Promoting establishment of Agreements with institutes in East Asia to accelerate collaborative research

In order to enhance helical and stellarator research in East Asian countries, NIFS concluded a new general agreement with SWJTU in 2017, under which a joint-experimental project was started. Young researchers of SWJTU visited NIFS to obtain experience for designing magnetic coils. The target parameters of the joint-experiments were determined through several headquarter meetings.

(2) Supporting young researchers

In the activities for supporting young researchers, international collaboration activities of young researchers were encouraged, enhancing their basic research skills. RESO supported the international collaboration plans proposed by young researchers in NIFS. Applications were reviewed by the Young Researchers Development Task Group. Two programs were supported in FY2017 as follows.

1. Development of flow monitoring of multi-isotopes in the atmosphere for establishing precise monitoring method of tritium diffusion.
2. Simulation code benchmark study for the energetic particle driven instabilities of EGAM and TAE in the ASDEX-U and LHD devices.

In addition, RESO supported the basic research plans of young scientists for the purpose of enhancing their fundamental scientific skills. Two programs were supported in FY2017 as follows.

1. Experimental study of the effect of double sheath structure of plasma-wall surface on negative ion beam production.

2. Improvement of automatic physics modeling analysis system of LHD experimental data by enforcing the magnetic surface database.

RESO also assisted the applications of young scientists to the “Grants-in-aid Scientific Research” program. Approximately 70 application documents were reviewed and suggestions were given to the authors for improvement.

(3) Enhancing public relations

1) Dissemination of research achievements through EurekAlert!

Five topics were released : i) “Clarifying the Mechanism for Suppressing Turbulence through Ion Mass: Theoretical Research Develops Significantly towards Improved Performance in Fusion Plasmas,” ii) “How Do Impurities Move in Tungsten?: Automatic and High-speed Search on Migration Paths by Using a Supercomputer,” iii) “Ion Temperature of One Hundred Million Degrees Achieved: Important Progress toward Feasibility of Helical Plasma Fusion,” iv) “Success in Enhancing Performance of the Cryogenic Adsorption Pump Used in the Divertor: Making Possible the Effective Evacuation by Installing in the Vacuum Vessel,” and v) “A New Discovery that Makes Possible Prediction Immediately Before Plasma Loss: Contributions to the Prediction of Volcanic Eruptions and Other Sudden Phenomena.” These topics were released to the media in Japan, too. Some topics attracted attention from international media.

2) Improvement of Web page for foreign researchers

The Web page in English was enriched by uploading “Research Update” for dissemination of research activities to readers overseas. English translation of guides for recruiting collaborative research was upgraded.

3) Outreach activities based on the fusion community

One of the outreach activities is to join the organization of ITER/BA Projects annual report meeting. RESO exhibited panels showing NIFS research activities at the meeting.

4) Others

RESO introduced interesting science topics to citizens on the occasion of the science café at the Open House of NIFS shown in Figure 1.

The NINS symposium entitled “Infinite Possibilities to be Developed by Plasma – Energy, Medical, Industry and Space” was held by NIFS at Sakata-Hirata Hall in Nagoya University on March 11, 2018. RESO was the core of the host organization. Figure 2 shows a photo of an exhibition of NINS activities, held jointly with the Symposium.

Fig. 1 The science café at the Open House of NIFS.

(4) IR/Evaluation activities

A new task group for the IR (Institutional Research) and evaluation was started in 2017 in order to make systematic analyses of the present research activities of the institute and for giving proposals to improve the research management of the institute. A systematic review was undertaken for recognizing what are important issues in managing efficient research collaborations of NIFS and in enhancing high level research. Two reports were given to the director general of NIFS.

(T. Muroga)

Fig. 2 Exhibition of NINS activity jointly held with NINS Symposium at Nagoya University.

12. The Division of Health and Safety Promotion

The Division of Health and Safety Promotion is devoted to preventing work-related accidents, to ensuring safe and sound operation of machinery and equipment, and to maintaining a safe and healthful environment for researchers, technical staff, co-researchers, and students. Each division cooperates with each other to ensure health and safety.

As a nationwide activity, we hold an information exchange meeting on health and safety each year, calling on those involved in the health and safety of university related organizations. About 60 people from 18 organizations participated this fiscal year.

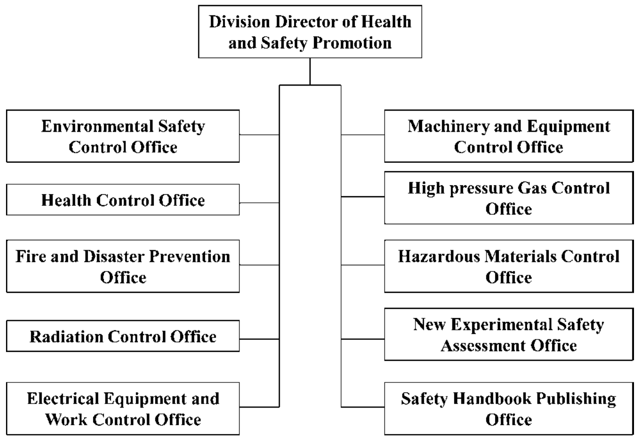


Fig. 1 Division of Health and Safety Promotion

1. Environmental Safety Control Office

This office has the responsibility to maintain a safe work space and environment. Although the other nine offices of the division of health and safety promotion cover most of the risks that exist in the institute, some problems fall wide of them. The role of this office is to cope with such problems. Therefore, this office has a broad range of tasks.

(i) Management to solve the problems pointed out by the safety and health committee.
(ii) Maintenance of the card-key system for the gateways of controlled area.
(iii) Maintenance of the fluorescent signs of the evacuation routes and the caution marks.

2. Health Control Office

The main role of this office is to keep the workers in the institute healthy, including co-researchers and students. The tasks of this office are summarized as follows.

(i) Medical checkups both for general and special purposes and immunization for influenza.
(ii) Mental health care services and health consultation.
(iii) Accompany the inspections of the health administrator and the occupational physician.
(iv) Maintenance of AEDs.

Various lectures were held for physical and mental health. And, an on-line stress-check was held in October.

3. Fire and Disaster Prevention Office

The main role of this office is to prevent or minimize damage caused by various disasters. The tasks of this office are summarized as follows.

(i) Making self-defense plans for fires and disasters, and implementation of various training.
(ii) Promotion of first-aid workshops and the AED class.
(iii) Maintenance of fire-defense facilities and attending on-site inspections by a local fire department.
(iv) Review and update disaster prevention rules and disaster prevention manuals.

All workers have to attend the disaster prevention training held every year.

4. Radiation Control Office

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

(i) Maintain the radiation safety for the workers
(ii) Registration and dose control of radiation area workers.
(iii) Observation of radiation in the radiation controlled area and the peripheral area.
(iv) Maintenance of the radiation monitor.
(v) Application for radiation equipment to the agencies and the local government.
(vi) Revise official regulations and establish new rules.

Two educational lectures were held on February 3 and March 17, 2018 for the radiation area workers. Non-

Japanese workers can be educated and trained in English.

5. Electrical Equipment and Work Control Office

The main role of this office is to maintain electrical safety for researchers, technical staff, and students. The tasks of this office are summarized as follows.

(i) Check and control the electric facilities according to the technical standards.
(ii) Safety lecture for to the researchers and workers.
(iii) Annual check of the electric equipment with the blackout.

Annual inspection in this site was carried out from September 30 – October 1, 2017.

6. Machinery and Equipment Control Office

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

(i) Inspection and maintenance of cranes.
(ii) Management of the crane license holders and safety lectures to the crane users.
(iii) Schedule management of crane operations.

7. High Pressure Gas Control Office

This office has a very important role in NIFS, because the main experimental machine LHD is the superconducting machine which requires cooling by liquid helium and many other machines have cryogenic pumping systems, which also require cooling down. The tasks of this office are summarized as follows.

(i) Safety operation and maintenance of high pressure gas handling facilities in NIFS.
(ii) Daily operation, maintenance, system improvement, and safety education according to the low.
(iii) Safety lectures for researchers and workers.

8. Hazardous Materials Control Office

The main role of this office is the management of the safe treatment of hazardous materials and maintaining safety for researchers against hazardous events. The tasks of this office are as follows.

(i) Research the request for hazardous materials and the storage status.
(ii) Management to ensure safe storage of the waste.
(iii) Monitoring of discharging water to prevent water pollution.
(iv) Implementation of chemical substance risk assessment.

9. New Experimental Safety Assessment Office

The main role of this office is to check the safety of experimental devices other than LHD. For this purpose, researchers who want to setup new experimental apparatus must apply for the safety review. Two reviewers are assigned from members of this office and other specialists and they check the safety of these devices. The tasks of this office are summarized as follows.

(i) Examine new experiments for safety problems and advise on safety measures. (New experiments in LHD are reviewed by the LHD Experiment Group)
(ii) Improve safety in each experiment and reinforce the safety culture at NIFS by annual reviews by NIFS employees.

10. Safety Handbook Publishing Office

The tasks of this office are publication of the Safety Handbook in Japanese and in English, and to update them as necessary. The regular safety lectures were held on May 12, August 8, and September 5, 2017. All workers including the co-researchers and students must attend this safety lecture every year.

Detailed information is opened in our web-site:
http://www.nifs.ac.jp/

(Nishimura, K.)

13. Division of Deuterium Experiments Management

Division of Deuterium Experiments Management

The deuterium experiment has been carried out on LHD since March 7, 2017. Objectives of the deuterium experiments are (1) to realize of high-performance plasmas by confinement improvement and by the improved heating devices and other facilities, (2) to explore the isotope effect study, (3) to demonstrate the confinement capability of energetic particles (EPs) in helical system and to explore their confinement studies in toroidal plasmas, and (4) to proceed with the extended studies on Plasma-Material Interactions (PMI) with longer time scales.

The agreement for the environmental conservation and the LHD deuterium experiment was concluded between NIFS and the local government bodies of Toki-city, Tajimi-city, Mizunami-city, and Gifu-Prefecture in March 2013. After that, the preparation for the deuterium experiment has been carried out.

The Divison of Deuterium experiments management was founded to establish the safety management system and to consolidate experimental apparatus related to the deuterium experiments. To accelerate the preparation for the deuterium experiments, a taskforce named “Deuterium Experiment Preparation Taskforce” was established under this division and was renamed to “Deuterium experiment management assistance taskforce” after the start of the deuterium experiment. The main jobs of this taskforce were (1) the establishment and modification of manuals to operate LHD and peripheral devices safely during deuterium experiments, (2) check and modification of the regulations related to proceeding with the deuterium experiments safely, (3) the upgrade of LHD itself, its peripheral devices, and the interlock systems for the safe operation during the deuterium experiments, (4) upgrade and optimization of heating devices and diagnostic systems for the deuterium experiments, (5) remodeling the LHD building and related facilities, and so on. These jobs proceed with the cooperation of the LHD board meeting and the division of health and safety promotion. In addition, the necessary tasks related to the safety evaluation committee founded by NIFS and those related to the safety inspection committee for the National Institute for Fusion Science (NIFS) founded by local government bodies are discussed in this division.

The cooperation with the safety inspection committee of NIFS is an important task to the divisions of the deuterium experiments management. The environmental neutron dose monitoring at NIFS and the tritium concentration monitoring in the environmental water around NIFS has been performed by the committee since 2015. In FY 2016, these monitoring activities were performed twice as scheduled under the cooperation with the division of the deuterium experiment management.

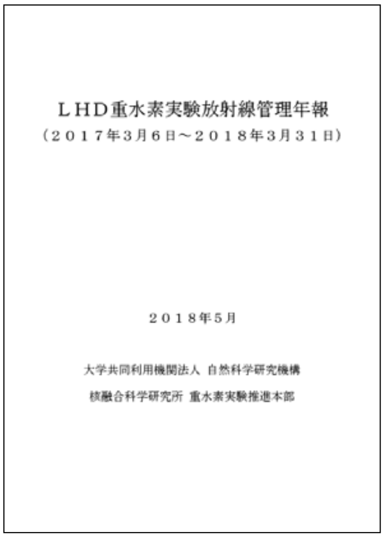
The publication of an annual report for the radiation management at the LHD deuterium experiment is another important task of this division.

a)

b)

c)

d)



ＬＨＤ重水素実験放射線管理年報

（２０１７年３月６日～２０１８年３月３１日）

２０１８年５月

大学共同利用機関法人 自然科学研究機構

核融合科学研究所 重水素実験推進本部

(a) The photographs at the environmental water sampling with the secretariat of the safety inspection committee. (b) The real-time radiation monitoring post where the cooperative environmental neutron monitoring is performed with the secretariat. (c) Additional neutron dosimeters placed by the secretariat of the safety inspection committee (left) and by the division of deuterium experiment management (right) near the radiation monitoring post at the cooperative environmental neutron monitoring with the secretariat. (d) The front cover of the annual report for the radiation management at the first LHD deuterium experiment (written in Japanese).

(M. Osakabe)

14. Division of Information and Communication Systems

The Department of Information and Communication System (ICS) was founded in 2014 in order to develop and maintain the information and network systems of NIFS efficiently. All of the information system experts in NIFS belong to the ICS. There are five TASK groups which correspond to the classifications in NIFS. The Network Operation task group manages and maintains the communication systems in NIFS, such as the E-mail system including security issues. The Experimental Data System task group performs operation and development of data acquisition systems for the LHD experiment. The institution's Information Systems task group carries out the maintenance and development of the management systems for collaboration research and its outputs. The Atomic and Molecule Database task group maintains the atom and molecule database which is open to researchers around the world. The integrated ID management and authentication system task group manages integrated ID and authentication systems.

The ICS works as follows: the request for the maintenance, improvement, and development of the information and communication system from each section has is submitted to the ICS. The deputy division directors of ICS check all the requests, establish the priority among them, and assign them to the appropriate Task Group. Because all the experts belong to the Technical Service Section of ICS, each Task Group Leader asks the Section Leader to allot the required number of experts for a prescribed period of time so as to finish the job.

In NIFS, three research projects run across the research divisions. It can be said that the ICS is another "project" which lies across all the divisions in the institute for keeping the information and communication systems stable, secure, and up-to-date.

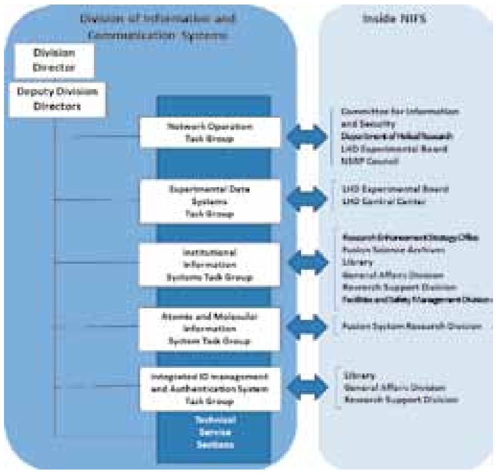


Fig. 1 Structure of Division for Information and Communication Systems

Information Network Task Group

The information network is a foundation for research activity. The Information Network Task Group operates the advanced NIFS campus information network named "NIFS-LAN," which contributes to the development of nuclear fusion research, with strong security systems.

Notable activities in FY 2017 by the Information Network Task Group:

- The Access line that connects the NIFS campus network and the SINET node has been upgraded from a single 10 GbE line to four 10GbE lines. A storage system for the virtual foundation system of the Research Information Cluster has been upgraded. UTP cables in the Administrative and Welfare Building have been replaced with category-6 cables to ensure the GbE connections.

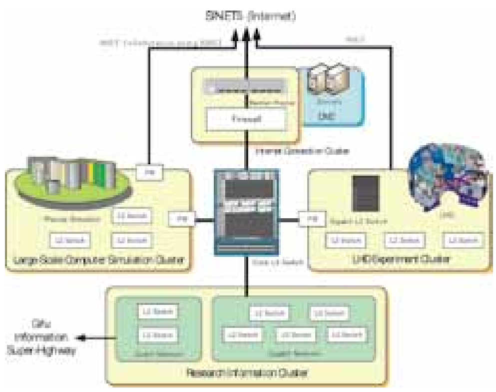


Fig. 2 Block diagram of the NIFS campus information network, which consists of three autonomous clusters that have their own purposes and usages.

- Isolation racks have been installed for the network equipment and servers of the LHD Experiment Cluster. Before the LHD experiment campaign, the security condition of each PC was checked in order to keep the safety network free of malware.
- Security incidents were treated with a malware detection system and lectures were held regarding the information network and its security. URL filtering has been activated on the firewall to avoid malicious connections. An informational system audit held by NINS was also accomplished.

Experimental and Institutional Information Systems Task Groups

The objective of these Task Groups (TGs) is to promote the research activities in both the LHD experiment and the NIFS institutional aspects by providing better computational services for research and official work.

Regarding the experimental information systems (EIS), a number of LHD subsystems were successfully operating until August 2017, the end of the 19th LHD campaign. This was the longest period with the largest number (> 13 000) of plasma experiments ever. Accordingly, the acquired data amount of 382 TB was also the largest record in LHD, even though the number of data acquisition nodes had been decreased by more than 15 % (105 → 88). The accumulated amount of archived data are 1.29 PB, exceeding 1 PB for the first time.

One of the most innovative achievements in the institutional information systems (IIS) was the functional extension of the conference organizer assisting system (Icarus), which has enabled organizers to provide the online proceedings to the participants' mobile terminals according to the conference timetable in real time. The new function has been used at the 26th International Toki Conference (ITC-26) successfully and obtained a high evaluation from not only the participants but also the organizers. Not only for research collaboration purposes, the IIS has extended its online services to some institutional administrative affairs and public services, such as sports ground lending. Since October 2017, the NIFS collaboration database system (Nicollas) has been renewed as the NINS open use system (NOUS) in which most of the Nicollas codes have been ported with the original functionalities.

(S. Ishiguro)

Fig. 3 Conference program view of the Icarus mobile service: Every participant can check not only the presentation abstracts according to the timetable, but also other conference logistics information.

15. Division of External Affairs

The Division of External Affairs has been focusing on the following six activities with a view to increasing social recognition of the necessity of nuclear fusion research and also NIFS's scientific achievements.

- Planning and conducting NIFS Tour
- Participation in local events and festivals
- Publication of the PR magazine "NIFS NEWS"
- Creation of showpieces and booklets to make PR efforts more attractive and effective
- Update of the NIFS website
- Educational tie-ups with national high schools / Educational programs for local communities (e.g., work experience, scientific demonstrations, and workshops)

Fig. 1 A photo at the Tajimi Festival in Tajimi city

Below are details of the PR efforts made by the Division of External Affairs.

- NIFS Tour
  - Handling requests, coordinating schedules, and conducting tours of the institute: A total of 4,280 visitors enjoyed the NIFS Tour.
  - Development of various materials and devices for scientific demonstrations/attractions during the tour
  - Upgrading of the scientific exhibit space "Kids Corner"

- Publications
  - Design, publication, and distribution of the PR magazine "NIFS NEWS"
  - Design, publication, and distribution of the PR booklets: "NIFS 2017-2018," "Fusion – Energy to Pave the Way for Future," "NIFS Does Research Aimed at Extracting Energy from Sea Water," and "Introduction to NIFS and the NIFS Tour"
  - Design, publication, and distribution of the PR leaflet "Plasma-kun Dayori"

- Web
  - Release of information through Web pages, mailing lists, and SNS (Twitter and Facebook)
  - Design of signs and other advertisement materials
  - Creation of special website featuring scientific events, symposia, and conferences
  - Creation of frames for research divisions' pages
  - Upgrading of various on-line application forms
  - Expansion of in-house contents

- Educational contributions
  - Educational partnership activities of Super Science High School (SSH): Thirteen high schools and 441 students participated.
  - Special alumnus lectures and other visiting lectures: Twelve high schools were visited.
  - Internship and working experiment programs for junior and high school students: Four schools were accepted.
  - Internship programs for college and technical college students: Fourteen students were accepted.
  - Science handicraft workshops for local communities: Thirty-six workshops were organized and a total of 1,367 participants attended.

Fig. 2 Working experiment for junior high school students

Fig. 3 Science handicraft activity at kindergarten

(K. Takahata)

16. Department of Engineering and Technical Services

The Department of Engineering and Technical Services covers a wide range of work in the design, fabrication, construction, and operation of experimental devices in the fields of software and hardware.

The department consists of the following five divisions. The Fabrication Technology Division oversees the construction of small devices and the quality control of parts for all divisions. The Device Technology Division works on the Large Helical Device (LHD) and its peripheral devices except for heating devices and diagnostic devices. The Plasma Heating Technology Division supports the ECH system, the ICRF system, and the NBI system. The Diagnostic Technology Division develops, operates, and maintains all diagnostic devices. Finally, the Control Technology Division concentrates on the central control system, the cryogenic system, the current control system, and the NIFS network.

The total number of staff is 54 (2017). We are in charge of the development, the operation, and the maintenance of the LHD and its peripheral devices together with approximately 58 operators.

1. Fabrication Technology Division

The main work of this division is the fabrication of experimental equipment. We also take care of technical consultation and experimental parts supplies related to the LHD experiment. In addition, we manage the administrative procedures of the department.

The number of machined requests was 50, and the production parts total number was 233 in this fiscal year (FY). The total number of electronic engineering requests and articles were 8 and 22, respectively. Details of some of this division's activities follow below.

(1) Phase detection circuit

The circuit shown in Fig. 1 is to use the CO2 laser dispersion interferometer. It is constructed of ADC (5Ms/s, 16bit, AD7625), FPGA board (EDX-301, Spartan6), and DAC (DA9754). The FPGA calculates the arctangent of the output IQ complex signals from the interferometer in real time.

(2) Corrugated Resonator

We have fabricated a grating mirror (as shown in Fig. 2) to divide a microwave at the frequency of 82.7 GHz and 165.4 GHz. The mirror has 70 gratings. The parameter of the grating is line spacing 1.878 mm and 30 degree blaze angle.

Fig. 1 Phase detection circuit

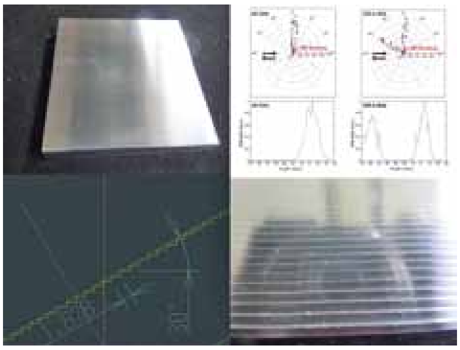


Fig. 2 Grating mirror

2. Device Technology Division

The Division supports the operation, the improvement, and the maintenance of LHD.

(1) Operation of LHD

The LHD 19th plasma experimental campaign began on February 8, 2017, and continued through August 3, 2017. In this experimental cycle, we generated plasma using deuterium gas.

We started to evacuate the air from the cryostat vessel for cryogenic components on December 15, 2016, and the plasma vacuum vessel on December 16. During this experimental campaign, our vacuum pumping systems were able to evacuate the air from both of the vessels without trouble. The LHD operation was completed on September 26, 2017. The number of days of the plasma experimental period was 92 days in total.

(2) Operation of the exhaust detritiation system

In fiscal 2017, the exhaust detritiation system (EDS) was operated continuously except for the inspection period.

The EDS consists of two systems. One is the vacuum gas detritiation system (MS type system) and the other is the purge gas detritiation system (PM type system). After the LHD 19th plasma experimental campaign, the tritium contained in the purge gas from the vacuum vessel was removed by PM type system for workers to enter the vacuum vessel. After the removal operation for 4 weeks, the concentration of the tritium decreased below the specified value and workers could enter the vacuum vessel.

(3) Access control system of vacuum vessel

After the Deuterium Experiment, only permitted people can enter the vacuum vessel. To strictly manage entrance into the vacuum vessel, an electric lock was installed in the door of the entrance of the vacuum vessel. This door is unlocked by a card key, FeliCa.

When an admitted person holds the card key over a card reader, the lock is unlocked if the key has already been registered. The card reader is connected to a small computer named Raspberry Pi. An administrator can register and delete the information of the card keys through the Raspberry Pi from the remote control room. By watching monitors (Fig. 3) which are in the entrance of the vacuum vessel and the control room, workers are able to know who is in the vacuum vessel.

In the vacuum vessel, the state of the oxygen concentration and the ventilation are very important for workers. A monitoring system (Fig. 4) monitors the values of oxygen concentration and ventilation, and bans entrance when the values become out of range.

Fig. 3 Access display monitor

Fig. 4 Monitoring system

(4) Thermal analysis of the newly designed pumping system using NEG pumps in the closed helical divertor (CHD) in LHD

For the effective divertor function, the Saes getters NEG (Non-Evaporable Getter) pump module, HV400 module, was selected as a hopeful candidate for the vacuum pump in the CHD on the basis of experimental results in the test facility.

In the CHD configuration, the vacuum pumping system is installed behind the dome structure on the inboard side of the torus as shown in Fig. 5. The super-conducting magnet coils are located on the back side of the vacuum vessel (VV). In the operational aspect, for the activation of the HV400 module, the getter material in the module requires heating process by passing a suitable AC current. Therefore, one of the thermal issues in designing the pumping system is the evaluation of heat load by radiation due to the activation process of the HV400 modules in order to ensure the heat insulation reliability to the super-conducting magnet coils.

To evaluate the temperature rise of the VV against the radiation heat flux, the heat load was analyzed using a finite element method based software for multi-physics analysis (ANSYS). The model geometry is shown in Fig. 6. For reducing the heat intrusion due to plasma radiation, the VV is covered with protection plates 10 mm in thickness, and it is cooled by the cooling channels attached on the inner surface of the VV. Regarding thermal boundary conditions, the surface temperature of an HV400 module during an activation process reaches 400 °C according to an actual measurement value. The water temperature in the cooling channel is assumed to be 22 °C in a normal temperature. We can approximate the value for the heat transfer coefficient between the inner surface of the cooling channel and the coolant water with a constant value of 1000 W/m2K because the coolant velocity is close to constant. Fig. 7 shows calculated temperature distributions of protection plates and the VV. The maximum local temperature of the VV is less than 70 °C at the location far from cooling channels, even though the maximum temperature of the protection plates is approximately 160 °C. As a result, it is shown that the maximum local temperature of the VV can be kept below 95 °C, which is an allowable temperature of the VV from the viewpoint of heat insulation properties.

Regarding the above results, the thermal shielding performance of protection plates is adequate for protecting the VV from the heat flux from HV400 modules. Lessons learned from this work can be included in the operation plan.

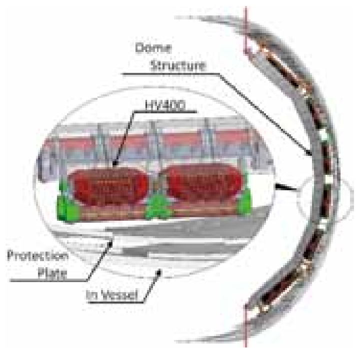


Fig. 5 Geometry of the pumping system using Saes getter NEG pump modules. These modules are connected to the cooling pipe of the dome structure by the support structure.

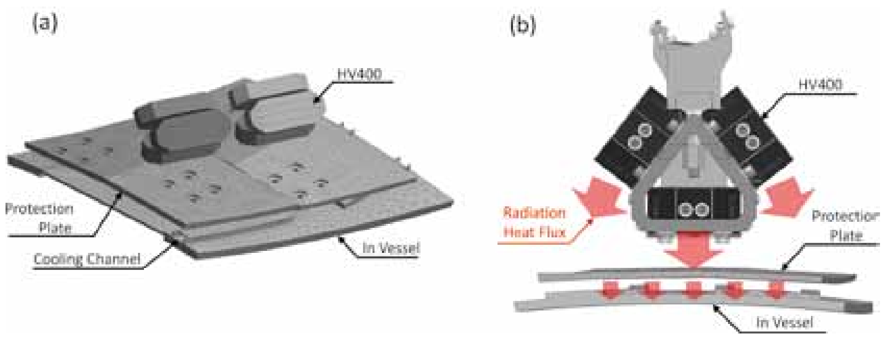


Fig. 6 (a) Model geometry and (b) schematic view of heat flux due to the radiation heating

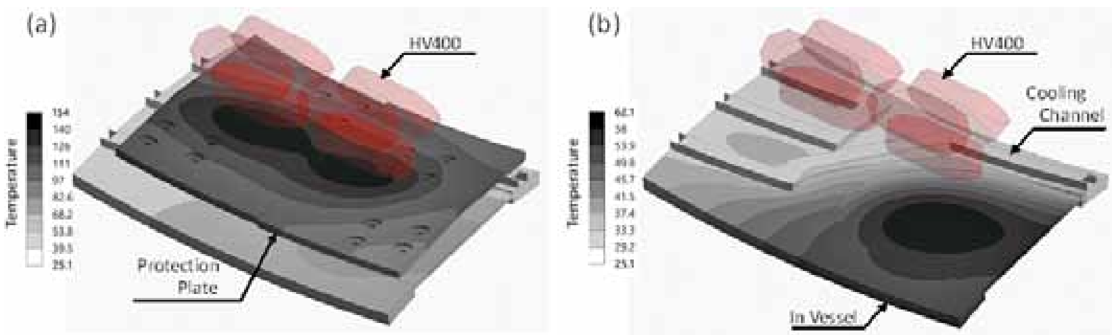


Fig. 7 Temperature profiles of (a) protection plates and (b) in vessel

3. Plasma Heating Technology Division

The main tasks of this division are the operation and the maintenance of the three different individual types of plasma heating devices and their common facilities. We have also performed technical support for improving, developing, and newly installing these devices.

In this fiscal year, we mainly carried out device improvement and modifications that enable the deuterium plasma experiment and plasma injection. The details of these activities are as follows.

(1) ECH

(a) Gyrotron Operation and LHD Experiment

During the 19th experimental campaign, we injected the power of 5.3MW to assist deuterium plasma experiments continued from last year. That injected power contributed to accomplishing the plasma with 10keV of high ion temperature with that power, and before that, operated by long pulse discharge to clean the wall of the vacuum vessel with low power. Some trouble halted operation of the gyrotrons. However, ECH technical staff of the LHD experimental group contributed to the plasma heating of all experiments.

(b) Support of cooperative research

ECH group started cooperative research study of optical vortex generation experiments using our gyrotron and related devices. We supported installation of these devices, operated the gyrotron, and acquired the data that shows the vortex radiation generated by interaction with electron accelerated by microwave from gyrotron and external magnetic field.

(2) ICH

ICRF antennas removed from LHD were stored in the Heating Power Equipment Room. Among the antennas, we planned to modify the inner conductor of HAS antennas to adapt impedance transformers which were designed to reduce the voltage along the transmission line such as that of the FAIT antennas (Fig. 8). As the preparation for this modification, we disassembled the HAS antennas in order to divide the inner conductors into the parts for reuse, such as a pivot section, and other parts.

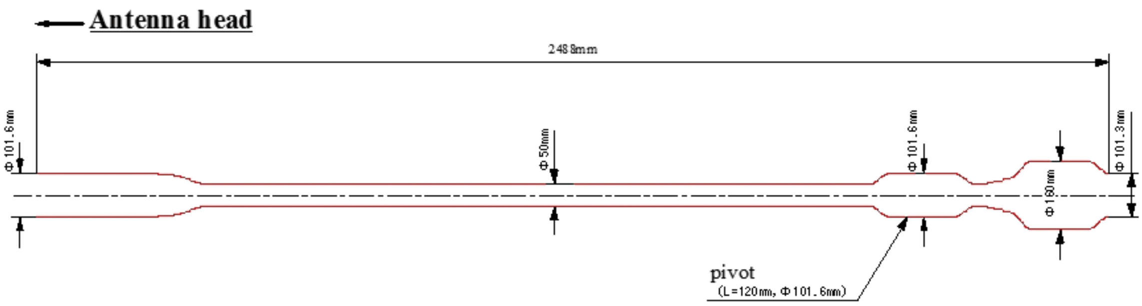


Fig. 8 The design of impedance transformer for HAS antenna

(3) NBI

(a) Maintenance of ion sources in maintenance room

The 19th experimental campaign of LHD was finished in August 2018. Every year, ion sources of NBI are maintained by manufacturers in their factories after the campaign. However, after the deuterium experiments, we cannot take ion sources outside of the radiation controlled area. Thus, we installed a maintenance room in the radiation controlled area in 2016.

We started maintenance of ion sources in September 2017. The maintenance includes polishing grid and insulating tube. Dust comes out in the polishing work, thus we perform this work in the greenhouse installed in the maintenance room. The greenhouse has a dust collector. The maintenance of ion sources of NBI by NIFS was finished in May 2018. Fig. 9 shows the polishing work on the insulation tube.

Fig. 9 The polishing work in the greenhouse

(b) Maintenance for the facility of liquid nitrogen in LHD-NBIs

The transfer tube for liquid nitrogen consumed in the cryopumps of LHD-NBIs has a double-layered structure composed of an inner tube and an outer tube. The space between the layers is evacuated in order to thermally insulate the inner tube from the outer tube. During the 19th plasma experimental campaign, the vacuum insulation of the transfer tubes of NBI #3 was reduced. Thus, after this campaign, the vacuum insulation layer in the transfer tubes of NBI #3 was evacuated up to 1×10^{-3} Pa by the turbo-molecular pump.

(4) Motor-Generator (MG)

The MG supplies the pulsed power to the NBI and the ECH for LHD. The MG has supplied power for 17,135 shots in this fiscal year and 614,015 shots since its construction. The operation time was 975 hours. The MG was overhauled, and lower oil-cooling pipe unit was exchanged (Fig. 10, Fig. 11). Peeling was found on thrust metals, and replaced with a spare (Fig. 12).

Fig. 10 Motor disassembly (A motor is on the stay. There is a generator under the stay)

Fig. 11 The lower oil-cooling pipe unit (Removed from a generator)

Fig. 12 Penetrant test for thrust metal

4. Diagnostics Technology Division

The main tasks of this division are radiation control and support of the diagnostic devices. There was no serious trouble in our managed equipment during the 19th LHD experiment. After the experiment campaign, we made an annual inspection of the integrated radiation monitoring system, the access control system, ITV system, the NFM (Neutron Flux Monitor), and the RMSAFE (Radiation Monitoring System Applicable to Fusion Experiments).

(1) Radiation control

This fiscal year is the first year after the deuteron experiment. Thus, necessary procedures of radiation control have been considered and established. For example, the way of collecting RI waste from maintenance work has been considered and started. RI waste was delivered to JRIA (Japan Radioisotope Association) on January 23, 2018, for the first time. The Fig. 13 shows the collection of RI waste by the JRIA.

(2) Installing a multichannel collimator for the radial profile measurement

The second multichannel collimator unit was installed to measure the emission profiles of neutrons and neutral particles in the open mouth with 2 m depth on the floor of the torus hall. Fig. 14 shows the collimator unit with apertures of 13 channels with 1.5 m length and inner diameter of 50 mm. The collimator unit was made by a hematite-doped heavy concrete whose specific gravity is above 3.5 to block off neutrons and weighs more than 6 tons.

Fig. 13 The collection of RI waste by the JRIA

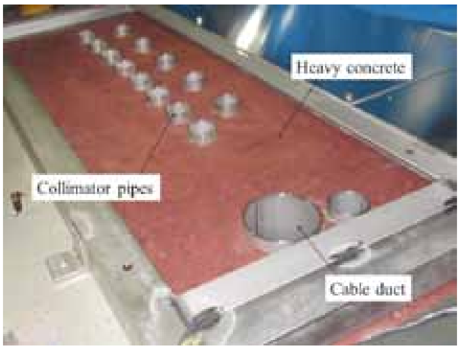


Fig. 14 Multichannel collimator unit made by heavy concrete

(3) Electric lock installation for a laser room

FIR laser interferometer and YAG Thomson scattering system each have a laser room, respectively. In order to improve personnel safety and to control persons entering into the laser rooms, we installed electric locks and emergency stop buttons on the laser room doors. Only listed persons can enter these rooms. The construction of this control system is given in an account of the Control Technology Division section.

(4) Data processing of diagnostic devices

For the LHD Data Acquisition (DAQ) System, we released the new version of the LHD data management library "Retrieve+dbStore ver.19.2.0" which can manage new data of the two additional digitizers. And we have been developing the new FPGA modulator instead of the old VME modulator for the DAQ timing system.

(5) The radioisotope (RI) samples management system

For the D-D experiments, we developed the radioisotope (RI) samples management system that can manage locations, status, etc. of RI samples using secured QR code (SQRC) on the WWW browser.

5. Control Technology Division

The Control Technology Division is in charge of the important engineering tasks in the LHD project, such as operation, management, and development, which are mainly targeted upon the central control system, cryogenic system, coil power supply, and super-conducting coils.

We are also responsible for the IT infrastructures, for example, the LHD experiment network, NIFS campus information network, and internet servers, in every phase of the project including requirements analysis, design, implementation, operation, and user support.

Described below are the essential topics of activities in the last year.

(1) LHD cryogenic control system

The cryogenic system relaunched its operation after replacement of temperature sensors, which were damaged by the fire accident in 2015, in the cold box. The cooling and warming operation periods were 27 days and 22 days, respectively. These periods were the same as the previous operation (18th cycle of operation). Fig. 15 shows cooling operation results. The steady operation was conducted for 179 days (4297 hours), which was the longest period in the past 18 cycles of operation. In the 19th cycle of operation, the first deuterium plasma experiment was performed. No accidents occurred in the 19th cycle of operation with the control system. The total system operating period was 362 days (8688 hours).

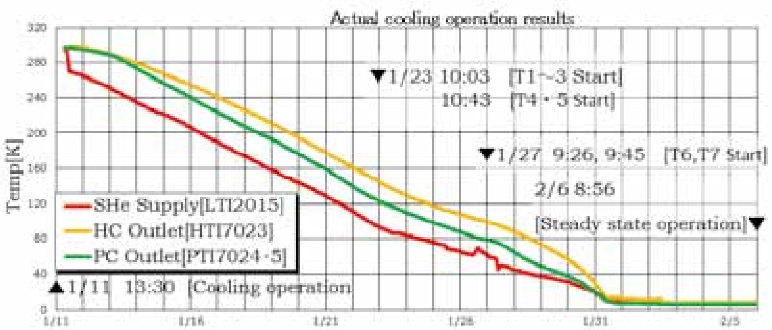


Fig. 15 Actual results of the cooling operation

(2) Laser room interlock system development

We designed and implemented interlock systems in the rooms where laser injection systems, YAG Thomson Scattering System, and Far-infrared Laser Interferometer are equipped in order to improve safety. The system stops laser injection when it detects entry and exit.

We placed FeliCa card readers inside and outside the doors. We then connected them to Windows tablets. To handle our staff ID cards, which are NFC standards, we used WinSCard library. This choice enabled the interlock systems to read FeliCa ID from the staff ID cards to control laser injection by communicating with PLC (Programmable Logic Controller). Fig. 16 shows the entrance of a room where both a monitor and a FeliCa card reader are installed.

(3) Network management

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

New contributions in FY 2017 are as follows:

(a) Renewal of the virtual server system

The virtual storage for the virtual server system was replaced with the HPE MSA 2050. The virtualization software, VMWare vSphere, was upgraded from version 5.5 to version 6.5 update 1.

(b) Renewal of the LHD Access Gateway

A firewall was installed to limit the connection between NIFS-LAN and LHD-LAN, and its authentication server was renewed from MAG 4610 manufactured by Juniper Network Corporation to PSA 300 manufactured by Pulse Secure (Fig. 17). Since the usage is the same, there were no inquiries from the users. The number of new registrants to the LHD access gateway was 29 people in FY 2017.

Fig. 16 Laser room interlock system in operational check

Fig. 17 Renewed LHD Access Gateway

6. Symposium on Technology

The Symposium on Technology was held March 1-2, 2018, at the Industrial and Cultural Center in Tajimi city, Gifu Prefecture, Japan. The National Institute for Fusion Science (NIFS) hosted this event. There were 170 participants from many Japanese universities, national laboratories, and technical colleges. In this symposium, 32 oral reports and 39 posters were presented in five technical groups. At the same time, we held a technology exchange meeting on the theme of thermal analysis simulation. The 38 participants visited NIFS to see the Large Helical Device. Fig. 18 shows the opening ceremony.

Fig. 18 A photograph of the opening ceremony

(S. Kobayashi)

17. 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 (※ This list was compiled as of March 31, 2018.)

Director General	1
Professors	36
Associate Professors	39
Assistant Professors	47
Administrative Staff	43
Technical and Engineering Staff	47
Employee on Annual Salary System	14
Center of Excellence Researcher	3
Research Administrator Staff	2
Visiting Scientists	23
Total	255

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.

(JFY 2017)

Settlement (in million of Yen)

Salaried Wages	2,097
Operating Costs	7,054
Equipment	0
Site and Buildings	150
Grant-in-Aid for Scientific Research	149
Total	9,450

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 (since Feb. 2014), 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 (JFY 2017)

	Applications Applied	Applications Accepted	Researchers Accepted
LHD Project Collaboration Research	35	34	296
Joint Research	274	271	1,854
Joint Research Using Computers	112	111	373
Workshops	31	31	643
Bilateral Collaboration Research	101	101	1,304
Total	553	548	4,470

Number of Graduate School Students
(SOKENDAI: The Graduate University for Advanced Studies) (As of March 31, 2018)

Doctoral Course					
Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Total
3	3	1	6	3	16

(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, 19graduate students are involved in the programs as of March 31, 2018.

The Special Research Collaboration Program for Education (As of March 31, 2018)

Affiliation \ Degree	Master's Course	Doctoral Course	Total
National Graduate School	8	1	9
Public Graduate School	0	0	0
Private Graduate School	1	0	1
Total	9	1	10

Foreign Researchers to NIFS (JFY 2017)

P.R. China	Rep. of Korea	Thailand	Germany	Philippines	Italy	U.S.A	France	Others	Total
72	25	24	20	20	12	9	8	30	148

NIFS Researchers to Foreign Countries (JFY 2017)

U.S.A.	P.R. China	Rep. of Korea	Germany	France	Italy	Taiwan	Czech Rep.	Spain	Others	Total
62	54	41	37	18	16	15	15	11	45	314

Books and Journals (JFY 2017)

Books in Japanese	18,375
Books in Other Languages	50,023
Total (volumes)	68,398
Journals in Japanese	287
Journals in Other Languages	783
Total (titles)	1,070

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.

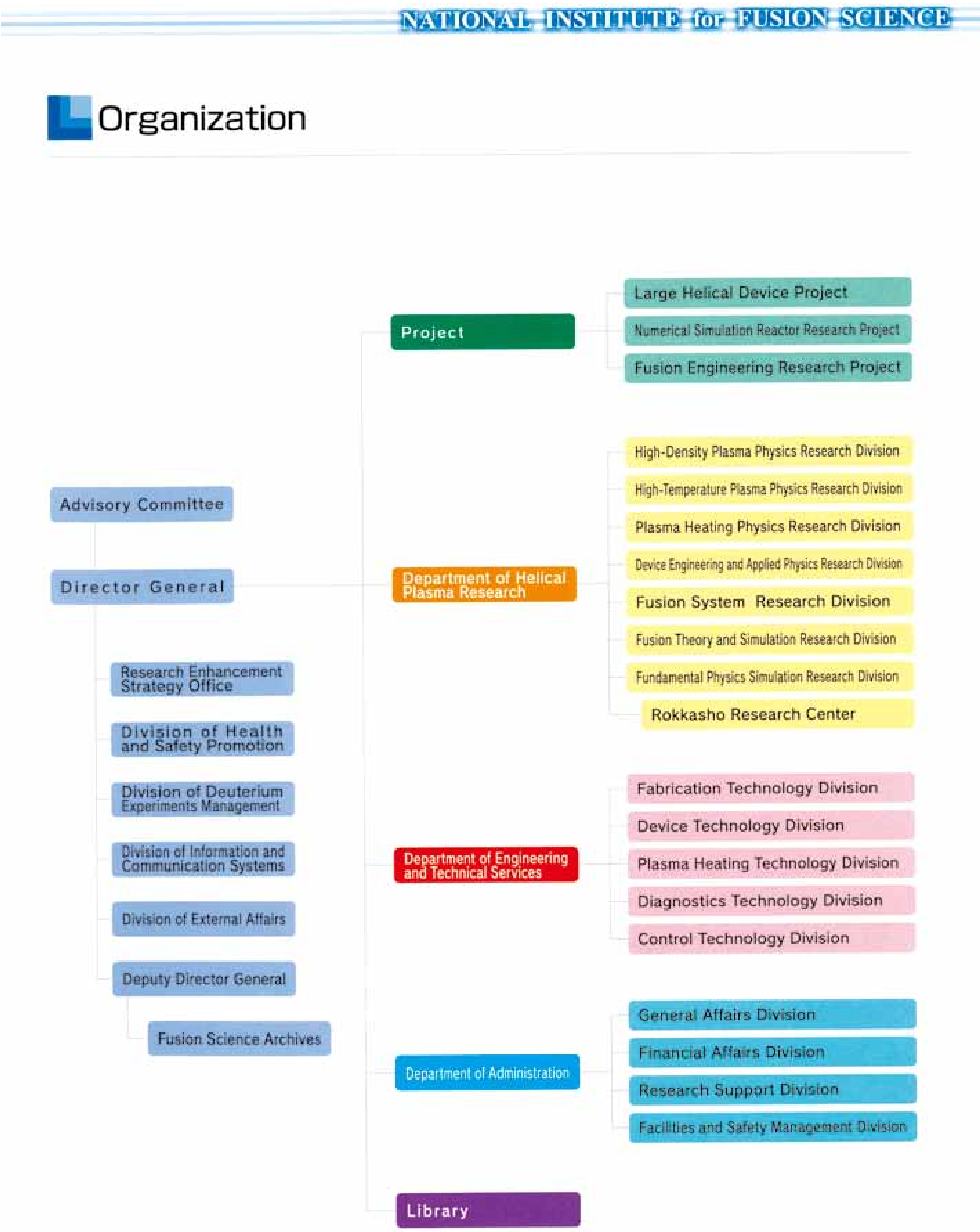
The Safety and Health Management Section also arranges medical examination and disaster drills. These three sections promote facilities' environment better for all staff.

Site and Buildings (JFY 2017)

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

APPENDIX

APPENDIX 1. Organization of the Institute



APPENDIX 2. Members of Committees

Advisory Committee

KODAMA, Ryousuke	Director, Institute of Laser Engineering, Osaka University
ANDO, Akira	Professor, Graduate School of Engineering, Tohoku University
OHNO, Noriyasu	Professor, Graduate School of Engineering, Nagoya University
OGAWA, Yuichi	Professor, Graduate School of Frontier Science, The University of Tokyo
NAKASHIMA,Yousuke	Director, Plasma Research Center University of Tsukuba
HANADA, Kazuaki	Professor, Research Institute for Applied Mechanics, Kyushu University
MIZUUCHI, Tohru	Director, Institute of Advenced Energy, Kyoto University
MORI, Masahiro	Managing Director, Fusion Energy Research and Development Directorate, National Institutes for Quantum and Radiological Science and Technology
WADA, Motoi	Professor, Faculty of Science and Engineering, Doshisha University
WATANABE, Tomohiko	Professor, Department of Physics, Nagoya University
MUROGA, Takeo	Deputy Director General, NIFS and Executive Director of Fusion Engineering Research Project, NIFS
MORISAKI, Tomohiro	Executive Director of Large Helical Device Project (on Science), NIFS
OSAKABE, Masaki	Executive Director of Large Helical Device Project (on Device), NIFS
SUGAMA, Hideo	Executive Director of Numerical Simulation Research Project, NIFS
YANAGI, Nagato	Executive Director of Fusion Engineering Research Project, NIFS
KUBO, Shin	Director of Plasma Heating Research Division, NIFS
MITO, Toshiyuki	Director of Device Engineering and Applied Physics Research Division, NIFS
IZUMI, Murakami	Director of Fusion Systems Research Division, NIFS
TODO, Yasushi	Director of Fusion Theory and Simulation Research Division, NIFS
ISHIGURO, Seiji	Director of Fundamental Physics Simulation Research Division, NIFS
NISHIMURA, Kiyohiko	Division Director for Health and Safety Promotion, NIFS

※ This list was compiled as of March 31, 2018

APPENDIX 3. Advisors, Fellows, and Professors Emeritus

Advisors

Michael Tendler	Professor Royal Institute of Technology Alfvèn Laboratory

Fellows

YAMADA, Hiroshi

Professors Emeritus

ICHIKAWA, Yoshihiko (1993)
MIZUNO, Yukio (1994)
OBAYASHI, Haruo (1995)
FUJITA, Junji (1996)
KURODA, Tsutomu (1997)
AMANO, Tsuneo (1998)
MOMOTA, Hiromu (1998)
IIYOSHI, Atsuo (1999)
HATORI, Tadatsugu (1999)
TANAHASHI, Shugo (2000)
KAWAMURA, Takaichi (2000)
SATO, Tetsuya (2001)
FUJIWARA, Masami (2002)
TODOROKI, Jiro (2003)
KAMIMURA, Tetsuo (2003)
OHKUBO, Kunizo (2005)
HAMADA, Yasuji (2007)
KATO, Takako (2007)
NODA, Nobuaki (2008)
WATARI, Tetsuo (2008)
MOTOJIMA, Osamu (2009)
SATOH, Kohnosuke (2010)
OHYABU, Nobuyoshi (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)
Hirooka, Yoshihiko (2018)

※ This list was compiled as of March 31, 2018

APPENDIX 4. List of Staff

Director General

TAKEIRI, Yasuhiko

Deputy Director General

MUROGA, Takeo

Department of Helical Plasma Research

Prof. MUROGA, Takeo (Director)

High-Density Plasma Physics Research Division

Prof. MORISAKI, Tomohiro (Director)
Prof. YAMADA, Hiroshi
Prof. WATANABE, Kiyomasa
Prof. MORITA, Shigeru
Prof. SAKAMOTO, Ryuichi
Assoc. Prof. YOHIMURA, Shinji
Assoc. Prof. OHDACHI, Satoshi
Assoc. Prof. SHOJI, Mamoru
Assoc. Prof. TOKUZAWA, Tokihiko
Assoc. Prof. KOBAYASHI, Masahiro
Assoc. Prof. MOTOJIMA, Gen
Asst. Prof. NARUSHIMA,Yoshiro
Asst. Prof. TAKEMURA, Yuki
Asst. Prof. TSUCHIYA, Hayato
Asst. Prof. OHISHI, Tetsutaro
Asst. Prof. NISHIMURA, Shin

High-Temperature Plasma Physics Research Division

Prof. SAKAKIBARA, Satoru (Director)
Prof. TANAKA, Kenji
Prof. ISOBE, Mitsutaka
Prof. IDA, Katsumi
Prof. PETERSON, Byron Jay
Assoc. Prof. GOTO, Motoshi
Assoc. Prof. AKIYAMA, Tsuyoshi
Assoc. Prof. YAMADA, Ichihiro
Assoc. Prof. OZAKI, Tetsuo
Assoc. Prof. IDO, Takeshi
Assoc. Prof. NAKANISHI, Hideya
Asst. Prof.OGAWA, Kunihiro
Asst. Prof. KOBAYASHI, Tatsuya
Asst. Prof. MUTO, Sadatsugu
Asst. Prof. TAMURA, Naoki
Asst. Prof. FUNABA, Hisamichi
Asst. Prof. YASUHARA, Ryo
Asst. Prof. YOSHINUMA, Mikirou
Asst. Prof. SUZUKI, Chihiro
Asst. Prof. SHIMIZU, Akihiro
Asst. Prof. EMOTO, Masahiko
Asst. Prof. MUKAI, Kiyofumi
Specially Appointed Prof. NISHITANI, Takeo

Plasma Heating Physics Research Division

Prof. KUBO, Shin (Director)
Prof. SIMOZUMA, Takashi
Prof. OSAKABE, Masaki
Prof. TSUMORI, Katsuyoshi
Assoc. Prof. YOSHIMURA, Yasuo
Assoc. Prof. IGAMI, Hiroe
Assoc. Prof. SAITO, Kenji
Assoc. Prof. SEKI, Tetsuo
Assoc. Prof. NAGAOKA, Ken-ichi
Asst. Prof. TSUJIMURA, Toru
Asst. Prof. NAKANO, Haruhisa
Asst. Prof. MAKINO, Ryohhei
Asst. Prof. KAMIO, Shuji
Asst. Prof. IKEDA, Katsunori
Asst. Prof. KISAKI, Masashi
Asst. Prof. TAKAHASHI, Hiromi
Asst. Prof. SEKI, Ryosuke
Asst. Prof. FUJIWARA, Yutaka
Asst. Prof. NUGA, Hideo

Device Engineering and Applied Physics Research Division

Prof. MITO, Toshiyuki (Director)
Prof. TAKAHATA, Kazuya
Prof. IMAGAWA, Shinsaku
Prof. YANAGI, Nagato
Prof. NISHIMURA, Kiyohiko
Assoc. Prof. IWAMOTO, Akifumi
Assoc. Prof. HAMAGUCHI, Shinji
Assoc. Prof. CHIKARAISHI, Hirotaka
Assoc. Prof. TAKAYAMA, Sadatsugu
Assoc. Prof. TANAKA, Masahiro
Assoc. Prof. AKATA, Naofumi
Assoc. Prof. SAZE, Takuya
Asst. Prof. TAKADA, Suguru
Asst. Prof. OBANA, Tetsuhiro
Asst. Prof. KOBAYASHI, Makoto

Fusion Systems Research Division

Prof. MURAKAMI, Izumi (Director)
Prof. MUROGA, Takeo
Prof. MIYAZAWA, Jun-ichi
Prof. HIROOKA, Yoshihiko
Prof. NISHIMURA, Arata
Prof. MASUZAKI.Suguru
Assoc. Prof. TANAKA, Teruya
Assoc. Prof. NAGASAKA, Takuya
Assoc. Prof. TAMURA, Hitoshi
Assoc. Prof. HISHINUMA, Yoshimitsu
Assoc. Prof. KATO, Daiji
Asst. Prof. GOTO, Takuya
Asst. Prof. YAGI, Juro
Asst. Prof. ASHIKAWA, Naoko
Asst. Prof. NOTO, Hiroyuki
Asst. Prof. SAKAUE, Hiroyuki
Asst. Prof. TOKITANI, Masayuki
Asst. Prof. HAMAJI.Yukinori
Specially Asst. Prof. YAJIMA, Miyuki

Fusion Theory and Simulation Research Division

Prof. TODO, Yasushi (Director)
Prof. SUGAMA, Hideo
Prof. NAKAJIMA, Noriyoshi
Prof. ICHIGUCHI, Katsuji
Prof. ITOH, Kimitaka
Prof. YOKOYAMA, Masayuki
Assoc. Prof. MIZUGUCHI, Naoki
Assoc. Prof. TODA, Shin-ichiro
Assoc. Prof. SATAKE, Shinsuke
Assoc. Prof. KANNO, Ryutaro
Assoc. Prof. SUZUKI, Yasuhiro
Assoc. Prof. NUNAMI, Masanori
Asst. Prof. YAMAGISHI, Osamu
Asst. Prof. NAKATA, Motoki
Asst. Prof. WANG, Hao
Asst. Prof. KAWAMURA, Gakushi
Asst. Prof. SATO, Masahiko
Asst. Prof. YAMAGUCHI, Hiroyuki

Fundamental Physics Simulation Research Division

Prof. ISHIGURO, Seiji (Director)
Prof. HORIUCHI, Ritoku
Prof. MIURA, Hideaki
Prof. NAKAMURA, Hiroaki
Prof. SAKAGAMI, Hitoshi
Assoc. Prof. OHTANI, Hiroaki
Assoc. Prof. ITO, Atsushi M.
Assoc. Prof. TOIDA, Mieko
Assoc. Prof. USAMI, Shunsuke
Asst. Prof. HASEGAWA, Hiroki
Asst. Prof. ITO, Atsushi
Asst. Prof. TAKAYAMA, Arimichi
Asst. Prof. YAMAMOTO, Takashi
Asst. Prof. MORITAKA, Toseo

Rokkasho Research Center

Prof. NAKAJIMA, Noriyoshi (Director, Additional Post)
Prof. NISHIMURA, Arata (Additional Post)
Asst. Prof. SATO, Masahiko (Additional Post)

Project

Large Helical Device Project

Prof. MORISAKI, Tomohiro (Executive Director (on Science))
Prof. OSAKABE, Masaki (Executive Director (on Device))

Numerical Simulation Reactor Research Project

Prof. SUGAMA, Hideo (Executive Director)

Fusion Engineering Research Project

Prof. MUROGA, Takeo (Executive Director)
Prof. YANAGI, Nagato (Executive Director)

Research Enhancement Strategy Office

Prof. MUROGA, Takeo (Director)
Specially Appointed Prof. MATSUOKA, Keisuke
Specially Appointed Prof. OKAMURA, Shoichi
Assoc. Prof. KASAHARA.Hiroshi

Division of Health and Safety Promotion

Prof. NISHIMURA, Kiyohiko (Division Director)

Division for Deuterium Experiments Management

Prof. OSAKABE, Masaki (Division Director)

Division of Information and Communication Systems

Prof. ISHIGURO, Seiji (Division Director)

Division of External Affairs

Prof. TAKAHATA, Kazuya (Division Director)

Fusion Science Archives

Prof. KUBO, Shin (Director)

Library

Prof. MURAKAMI, Izumi (Director)

※ This list was compiled as of March 31, 2018

Guest Professor

Prof. ONO, Yasushi	Tokyo University	Apr. 1, 2017-Mar. 31, 2018
Prof. MORIYAMA, Shinichi	Japan Atomic Energy Agency (JAEA)	Apr. 1, 2017-Mar. 31, 2018
Prof. TOKITA, Keiichiro	Nagoya University	Apr. 1, 2017-Mar. 31, 2018
Prof. HOUCHIN, Teruhisa	Nagoya University	Apr. 1, 2017-Mar. 31, 2018
Prof. FUCHINO, Shuichiro	National Institutes for Quantum and Radiological Science and Technology	Apr. 1, 2017-Mar. 31, 2018
Prof. NAGATA, Masayoshi	University of Hyogo	Apr. 1, 2017-Mar. 31, 2018
Prof. MURATA, Isao	Osaka University	Apr. 1, 2017-Mar. 31, 2018
Prof. SENTOKU, Yasuhiko	Osaka Univeristy	Apr. 1, 2017-Mar. 31, 2018
Assoc. Prof. YAMAGUCHI, Soichiro	Kansai University	Apr. 1, 2017-Mar. 31, 2018
Assoc. Prof. EJIRI, Akira	Tokyo University	Apr. 1, 2017-Mar. 31, 2018
Assoc. Prof. WATANABE, Takashi	Thorium Tech Solution Inc.	Apr. 1, 2017-Mar. 31, 2018
Assoc. Prof. YUSA, Noritaka	Tohoku University	Apr. 1, 2017-Mar. 31, 2018
Assoc. Prof. ISHIZAWA, Akihiro	Kyoto University	Apr. 1, 2017-Mar. 31, 2018
Assoc. Prof. YONEMURA, Shigeru	Tohoku University	Apr. 1, 2017-Mar. 31, 2018
Assoc. KOSUGA, Yusuke	Kyushu University	Apr. 1, 2017-Mar. 31, 2018
Assoc. AKIYAMA, Youko	Osaka University	Apr. 1, 2017-Mar. 31, 2018
Assoc. YOGO, Akifumi	Osaka University	Apr. 1, 2017-Mar. 31, 2018
Assoc. OTSUKA, Teppei	KINDAI University	Apr. 1, 2017-Mar. 31, 2018
Assoc. HONDA, Mitsuru	National Institutes for Quantum and Radiological Science and Technology	Apr. 1, 2017-Mar. 31, 2018
Prof. Lucianetti, Antonio	HiLASE Centrum	Jul. 1, 2017-Aug. 31, 2017
Assoc. Prof. Dodin, Ilya	Princeton Plasma Physics Laboratory	Apr. 1, 2017-May 1, 2017
Assoc. Prof. McCollam, Kardten	University of Wisconsin-Madison	Sep. 3, 2017-Oct. 14, 2017
Assoc. Prof. Velasco, Jose Luis	CIEMAT	Jan. 15, 2018-Feb. 15, 2018

COE Research Fellows

HUANG, Xianli	Apr. 1, 2017-Sep. 30, 2017
Nuga, Hideo	Apr. 1, 2017-Dec. 28, 2017
BO, Huang	Apr. 1, 2017-Sep. 30, 2018
KUZMIN, Arseniy	Apr. 1. 2017-Mar. 31, 2018
TERASAKI, Yoshiro	Apr. 1, 2017-Mar. 31, 2018
SIMON, Patrick	Dec. 1, 2017-Mar. 31, 2018

Research Fellow (Science research)

(none)

Research Fellow (Industrial-Academic coordination)

(none)

JSPS Research Fellow

(*Postdoctoral Fellowships for Foreign Researchers*)

(none)

(*Invitation Fellowship Programs for Research in Japan*)

(none)

Depertment of Administration

NISHIYAMA, Kazunori	Department Director

General Affairs Division

TAKEUCHI, Shohji	Director
ICHIOKA, Akihiro	Deputy Director
ARAI, Masanori	Chief/General Affairs Section
SHIMIZU, Kazuma	Chief/Planning and Evaluation Section
URUSHIHARA, Satona	Chief/Employ Section
SUGIMOTO, Michiyasu	Chief/Personnel and Payroll Section
ICHIOKA, Akihiro	Leader/External Affairs Office (Additional Post)
TAKAHASHI, Nobuhiro	Chief/Communications and Public Affairs Section

Financial Affairs Division

NISHIYAMA, Kazunori	Acting Director
TSUZUKI Tatsuko	Deputy Director
IKEDA, Katsumi	Specialist
KAWAI, Sanae	Chief/Financial Planning Section
Iwashima, Itsuki	Chief/Accounts and Properties Administration Section
FUJII, Kazuki	Chief/Audit Section
FUKUOKA, Miwa	Chief/Contracts Section
MATSUBARA, Tomohisa	Chief/Procurement Section
TSUZUKI, Tatsuko	Leader/Purchase Validation Section (Additional Post)

Research Support Division

KUWABARA, Hiroaki	Director
TERUMOTO, Naoki	Deputy Director
FUKAYA, Yosuke	Chief/Research Support Section
SAKO, Chihiro	Chief/International Collaboration Section
OHKAWA, Jun	Chief/Graduate Student Affairs Section

OHTA, Masako	Chief/Academic Information Section
TERUMOTO, Naoki	Leader/Visitor Center (Additional Post)
HOSOKAWA, Hideo	Chief/Visitor Center

Facilities and Safety Management Division

OHHASHI, Masaya	Director
NITTA, Haruki	Senior Specialist. Chief/Facilities Section (Additional Post)
MIYATA, Kazuaki	Chief/Equipment Section

Department of Engineering and Technical Services

IIMA, Masashi	Department Director
TANIGUCHI, Yoshiyuki	Deputy Department Director

Fabrication Technology Division

BABA, Tomosumi	Director
KATOH, Akemi	Chief/Parts and Material Section
ITO, Yasuhiko	Electronic Engineering Section
OKADA, Kohji	Mechanical Engineering Section
KATO, Shinji	Device Maintenance Engineering Section

Device Technology Division

YONEZU, Hiroaki	Director
HAYASHI, Hiromi	Chief/Device System Engineering Section
TSUCHIBUSHI, Yasuyuki	Chief/Vacuum Engineering Section
YASUI, Koji	Chief/Power Supply Engineering Section
SUZUKI, Naoyuki	Chief/Experimental Application Engineering Section

Plasma Heating Technology Division

KOBAYASHI, Sakuji	Director
KONDO, Tomoki	Chief/Heating System Engineering Section
SEKIGUCHI, Haruo	Chief/Particle Heating Engineering Section
ITO, Satoshi	Chief/Electron Heating Engineering Section
NOMURA, Goro	Chief/Ion Heating Engineering Section

Diagnostics Technology Division

MIYAKE, Hitoshi	Director
HAYASHI, Hiroshi	Chief/Radiation Measurement System Engineering Section
KOBUCHI, Takashi	Chief/Experimental Radiation Measurement Engineering Section
YOKOTA, Mitsuhiro	Chief/Environmental Radiation Measurement Engineering Section
OHSUNA, Masaki	Chief/Radiation Measurement Device Control Engineering Section

Control Technology Division

TANIGUCHI, Yoshiyuki	Director
MORIUCHI, Sadatomo	Chief/Control System Engineering Section
INOUE, Tomoyuki	Chief/Information Infrastructure Engineering Section
OBA, Koki	Chief/Low Temperature Control Engineering Section
OGAWA, Hideki	Chief/Control Information Engineering Section

※ This list was compiled as of March 31, 2018

APPENDIX 5. List of Publications I (NIFS Reports)

NIFS-PROC-110 Edited by Jun Hasegawa and Tetsuo Ozaki
Resent Developments of Pulsed Power Technology and Plasma Application Research
Jan. 12, 2018

NIFS-PROC-109 Edited by Shigeru MORITA, Liqun HU and Yeong-Kook OH
"Proceeding of A3 Foresight Program Seminar on Critical Physics Issues Specific to Steady State Sustainment of High-Performance Plasmas 11-14 July, 2017, Sapporo, Japan"
Jan. 12, 2018

NIFS-PROC-108 Edited by Yeong-Kook OH, Shigeru MORITA and Liqun HU
"Proceeding of A3 Foresight Program Seminar on Critical Physics Issues Specific to Steady State Sustainment of High-Performance Plasmas November 22-25, 2016, Jeju, Korea"
Jan. 11, 2018

NIFS-PROC-107 Edited by Hiroaki Ito and Tetsuo Ozaki
Recent Progress of Pulsed Power Technology and its Application to High Energy Density Plasma
Nov. 27, 2017

NIFS-PROC-106 Edited by Keiichi Kamada and Tetsuo Ozaki
Evolution of Pulse Power and its Peripheral Technology
Nov. 01, 2017

NIFS-PROC-105 Edited by Weihua Jiang
Frontiers of Applied Pulse Power Technology
Aug. 28, 2017

NIFS-MEMO-81 Report on Administrative Work for Radiation Safty From April 2016 to March 2017
Radiation Control Office / Division of Health and Safty Promotion National Institute for Fusion Science
Jan. 22, 2018

NIFS-MEMO-80 Program Committee of Technical Study on the Operation and Control of the Fusion DEMO Reactors
Report on the Operation and Contro; of the Fusion DEMO Reactors
Nov. 30, 2017

NIFS-MEMO-79 A. Sagara, T. Goto, J. Miyazawa, N. Yanagi, H. Tamura, T. Tanaka, R. Sakamoto, S. Imagawa, T. Mito, T. Muroga, A. Iwamoto, H. Chikaraishi, M. Tanaka, O. Mitarai, K. Tsumori, M. Isobe, G. Kawamura, S. Okamura, X. Ji, S. Hamaguchi, K. Takahata, S. Ito, S. Yamada, S. Masuzaki, N. Ashikawa, S. Kubo, H. Kasahara, K. Ogawa, T. Nishitani, M. Goto, I. Yamada, R. Yasuhara, T. Akiyama, T. Tokuzawa, S. Ishiyama, T. Obana, Y. Hishinuma, S. Takada, T. Nagasaka, H. Fu, Y. Hirooka, J. Yagi, S. Takayama, D. Kato, M. Tokitani, Y. Hamaji, H. Noto, I. Murakami, H. Sakaue, and NIFS Fusion Engineering Research Project
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Production of intense, pulsed, and point-like neutron source from deuterated plastic cavity by mono-directional kilo-joule laser irradiation
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Concentrations of chemical components, including ^{210}Pb, present in aerosols collected at Naha, Okinawa Prefecture, a subtropical region of Japan
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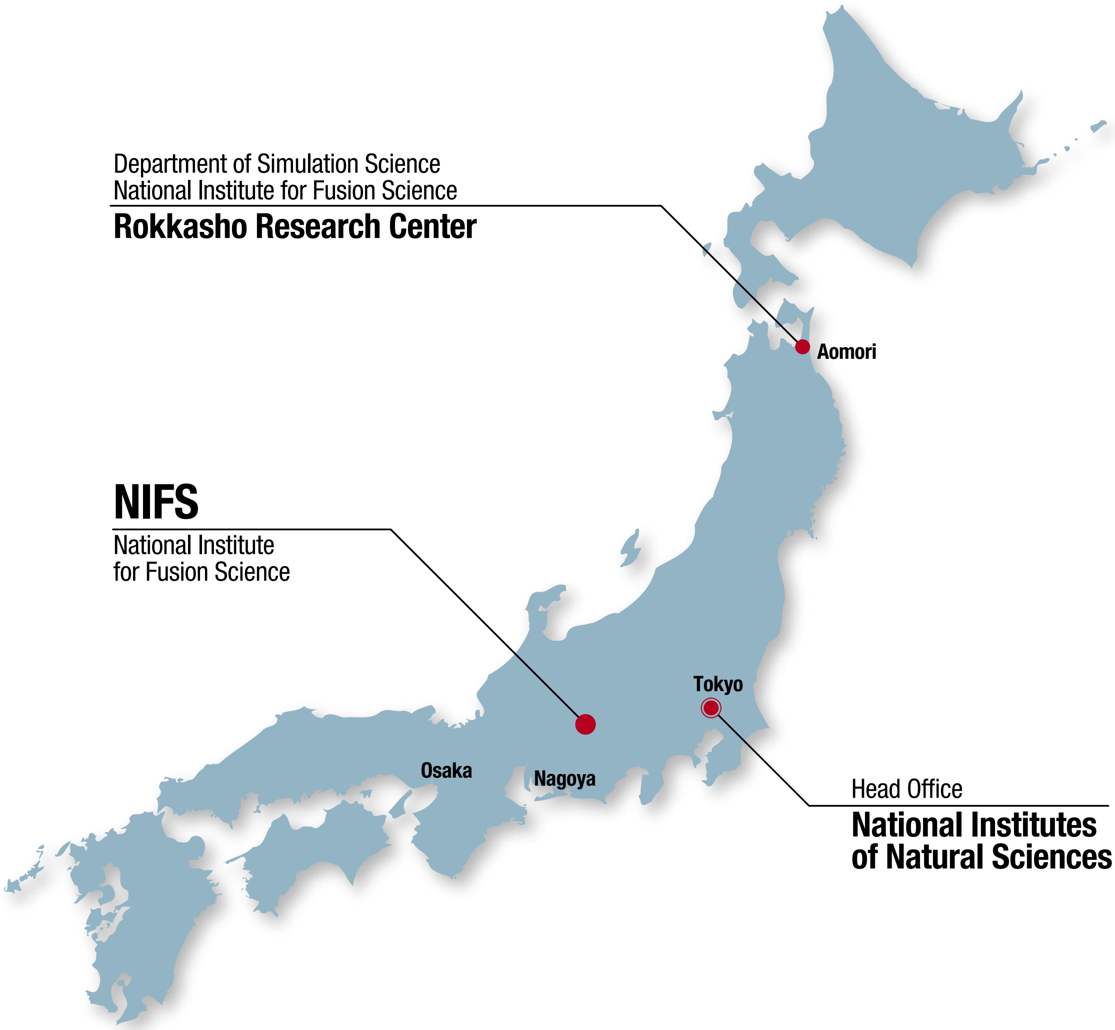

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How to Reach National Institute for Fusion Science

□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

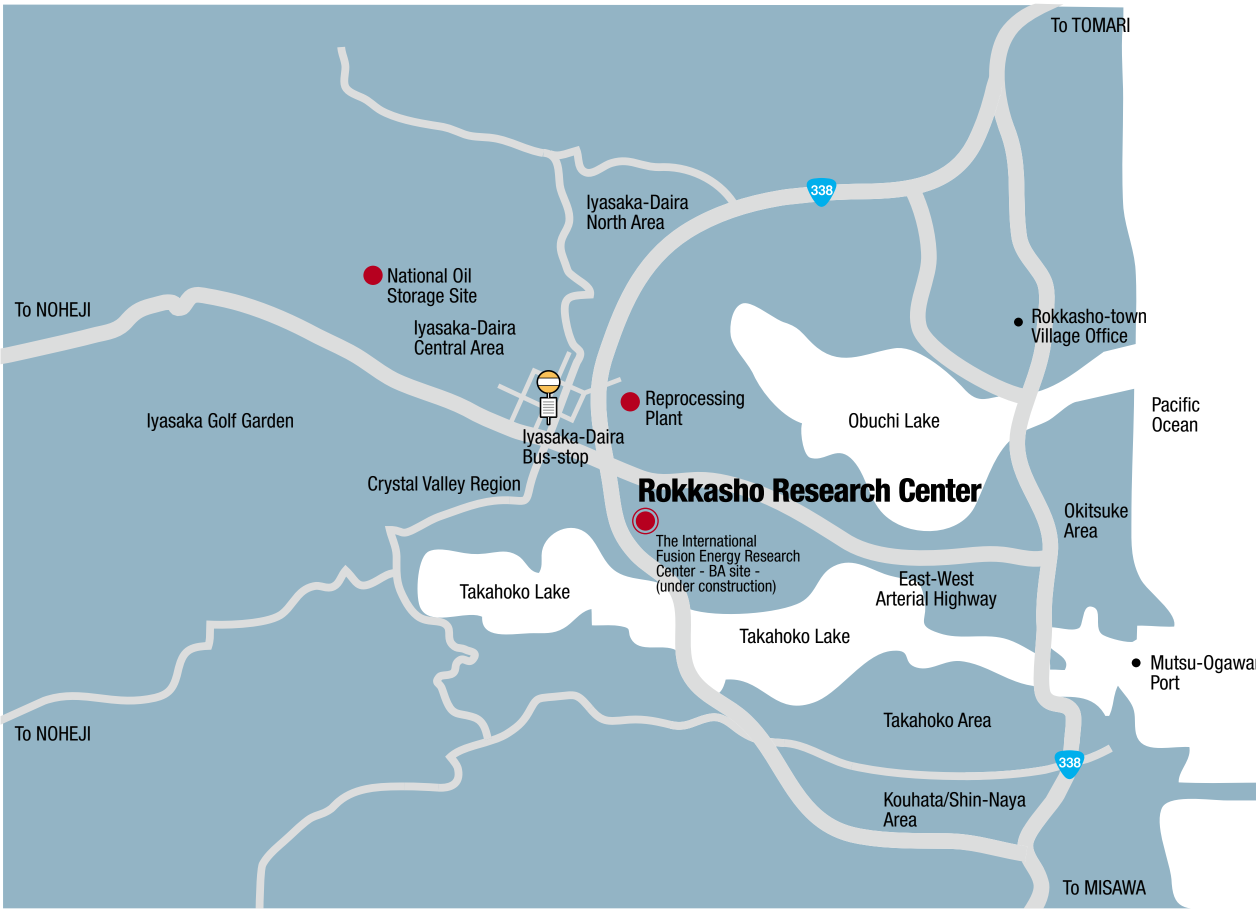
JR Tajimi Sta. –(Totetsu Bus)– Kenkyuugakuentoshi (7km)
about 15min

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

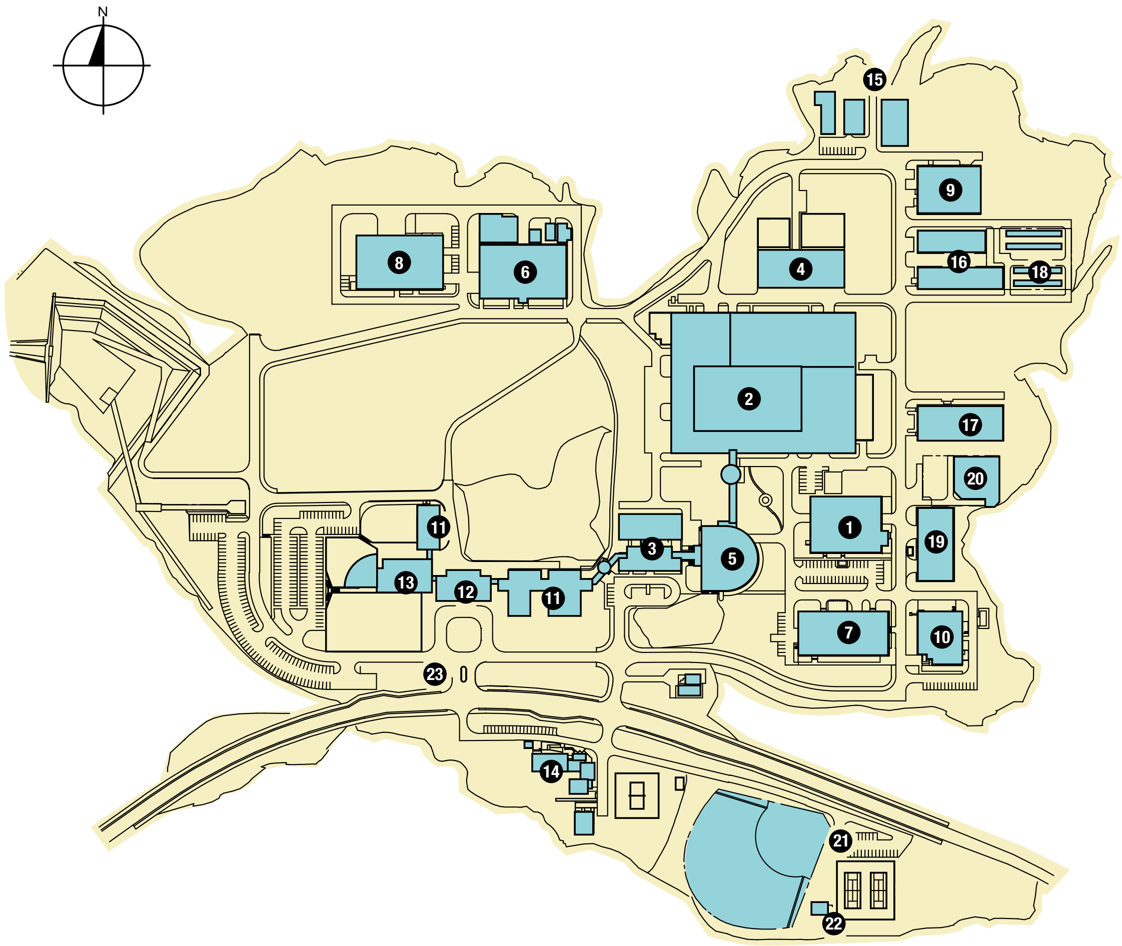
Aomori–(JR Tohoku Limited Express)–Noheji (45km)
about 30min

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