10. International Collaboration

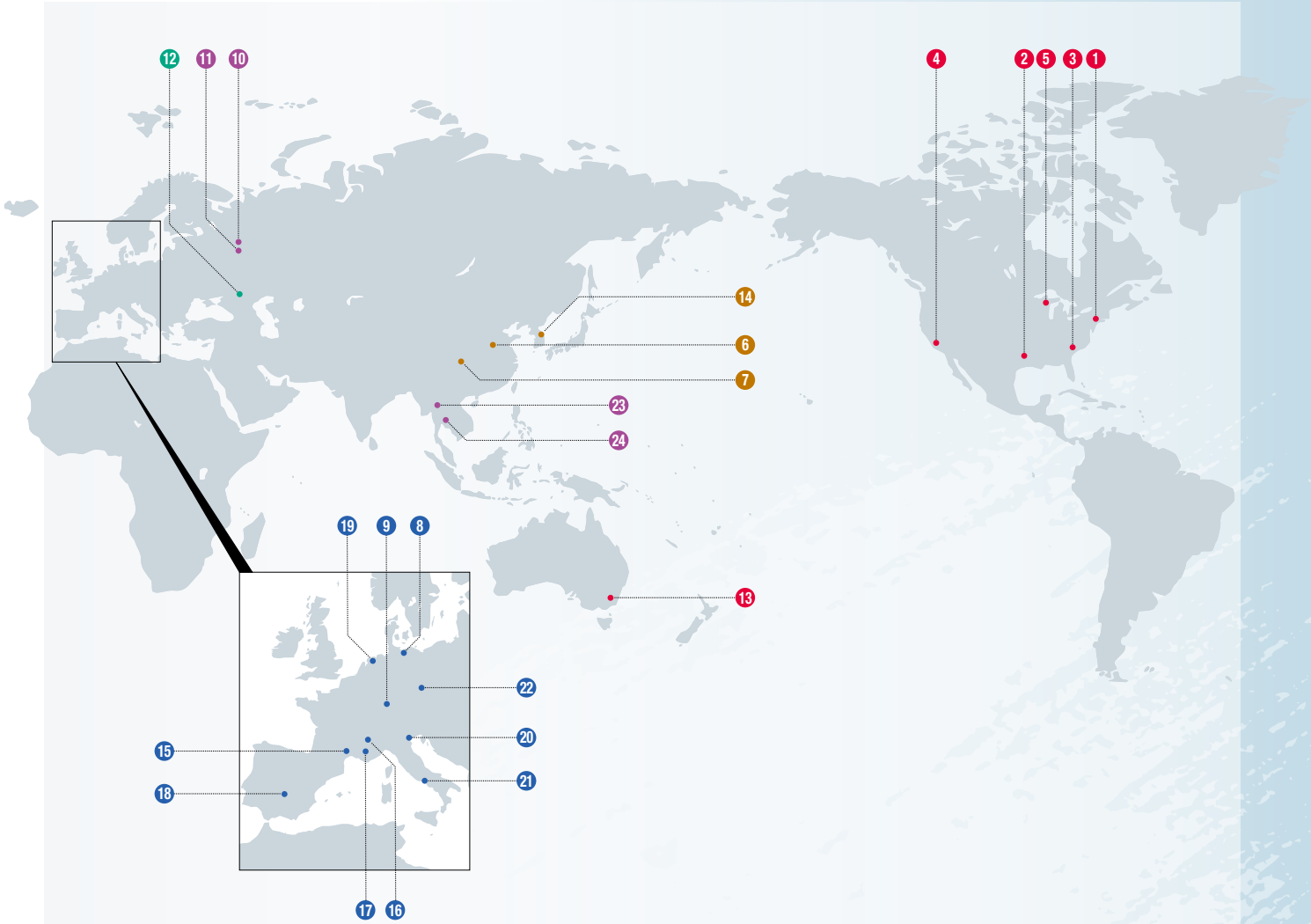
Many research activities in NIFS are strongly linked with the international collaborations with institutes and universities around the world. These collaborations are carried out in various frameworks, such as 1) coordination with foreign institutes, 2) bilateral coordination with intergovernmental agreements, 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.
1. Princeton Plasma Physics Labolatory
2. Institute for Fusion Studies, The University of Texas at Austin
3. Oak Ridge National Laboratory
4. Center for Energy Science and Technology Advanced
5. Research, University of California, Los Angeles University of Wisconsin, Madison

China
6. Institute of Plasma Physics, Chinese Academy of Sciences
7. Southwestern Institute of Physics

Germany
8. Max Planck Institute for Plasma Physics
9. Karlsruhe Institute of Technology

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

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

Australia
13. Australian National University

South Korea
14. National Fusion Research Institute

France
15. Aix-Marseille University
16. Associated International Laboratory (LIA336)
17. Commissariat à l'énergie atomique et aux énergies alternatives

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

Netherland
19. Dutch Institute for Fundamental Energy Research (FOM)

Italy
20. 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)

10. International Collaboration

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.

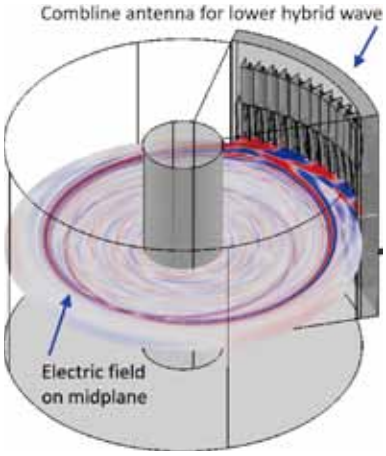


Fig. 1 Electric field distribution on midplane of TST-2. Lower hybrid wave is launched from the combline antenna.

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.

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

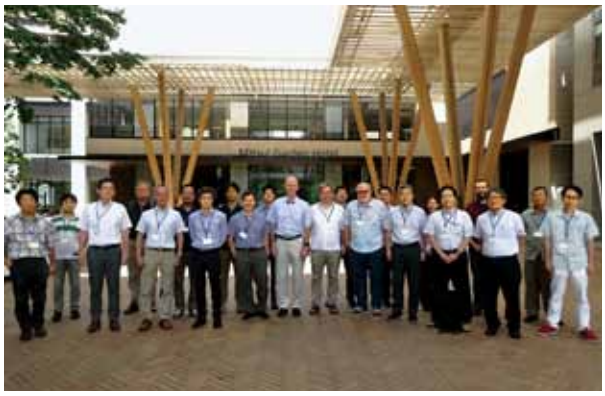


Fig. 2 Workshop on "US-Japan collaborations on co-designs of fusion simulations for extreme scale computing" held in Kashiwa during August 7-9, 2017.

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.

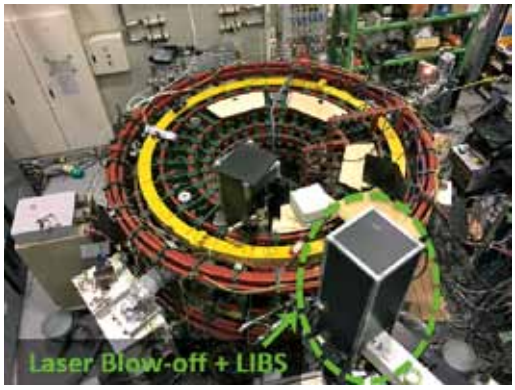


Fig. 3 Heliotron-DR device at Kanazawa University equipped with the laser blow-off and LIBS measurement system.

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.

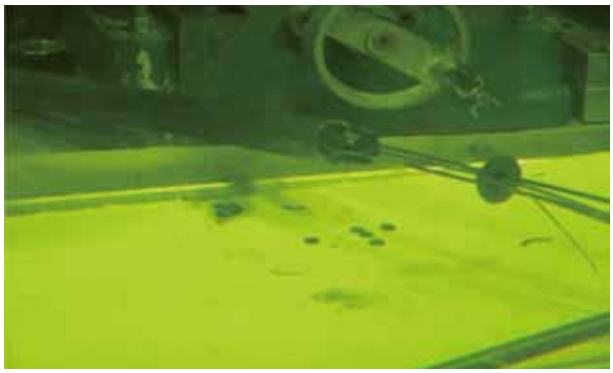


Fig. 4 Disassembly of RB19J capsule

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 ℃ 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 ℃, 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 tungsten	Heun Tae Lee (Osaka Univ.)	12 – 18 Nov. 2017	Thomas Schwarz-Selinger (IPP Garching)
Thermo-mechanical properties of radiation 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;

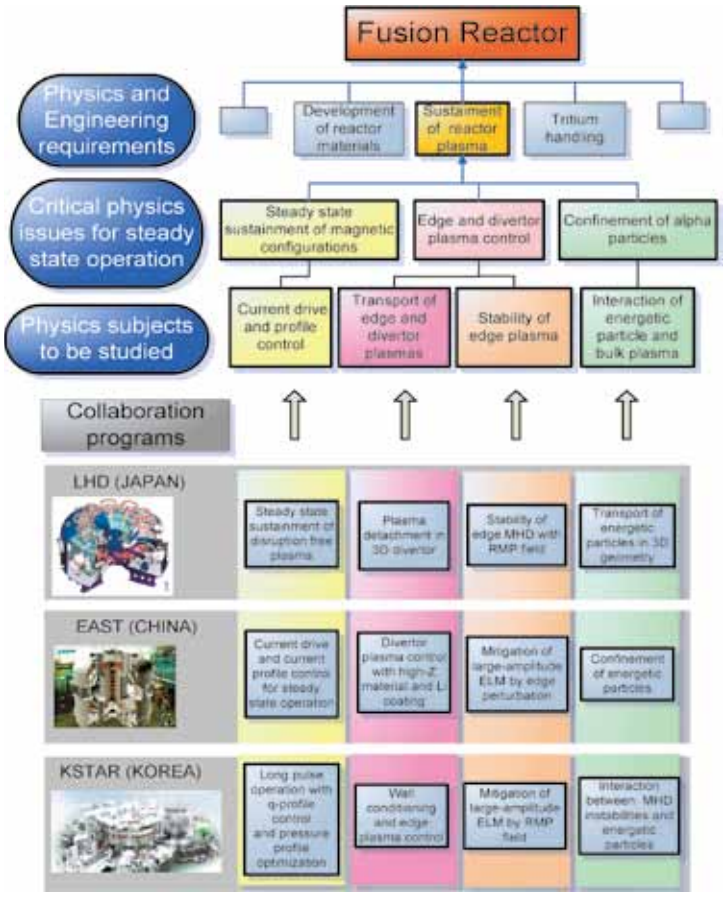


Fig. 1 Schematic drawing on Joint Research Project among LHD (NIFS: Japan), EAST (ASIPP: China) and KSTAR (NFRI: Korea). This Joint Research Project quests three 'Critical physics issues' for the steady state operation and these issues consist of four key 'Physics subjects' to be studied. The collaborative 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 $\rho \sim 0.85$. 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

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[2] L. Zhang, S. Morita, Z. Xu P.F. Zhang, Q. Zang, *et al.*, Nucl. Mater. Energy **12** (2017) 774.
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[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 Δn=1, 2 and Δn=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 $0.3 \leq \Gamma w^{7+} \leq 5.0\times10^{14}cm^{-2}s^{-1}$.

[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.

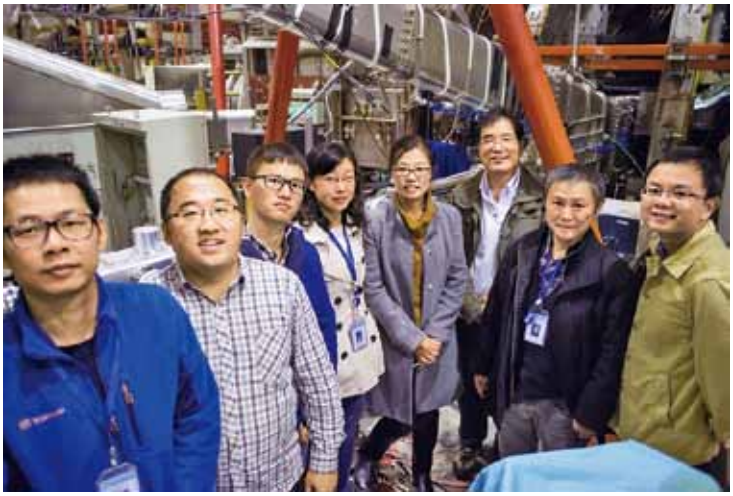
[2] Z.Y. Cui, K. Zhang, S. Morita, X.Q. Ji, X.T. Ding, Y. Xu, P. Sun, *et al.*, Nucl. Fusion **58** (2018) 056012.

[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.)