TO: Executive Secretaries of the US-Japan Fusion Research Collaboration

FROM: Steering Committee, US-Japan Joint Institute for Fusion Theory (JIFT)

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SUBJECT: JIFT Annual Report of Activities for 2022-2023

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Annual Report of JIFT Activities

François Louis Waelbroeck
US Chairman, JIFT Steering Committee
Director, Institute for Fusion Studies
The University of Texas at Austin
Austin, Texas 78712, USA

Hideo Sugama
JA Chairman, JIFT Steering Committee
Director, Numerical Simulation Reactor Research Project
National Institute for Fusion Science
Oroshi 322-6, Toki, Gifu 509-5292, Japan

Annual Report of Activities

US-Japan Joint Institute for Fusion Theory

April 1, 2022–March 31, 2023

JIFT Steering Committee

Co-Chairmen: H. Sugama and F. L. Waelbroeck

Co-Executive Secretaries: Y. Todo and A. Arefiev

March 10, 2023

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1. *INTRODUCTION*

The Joint Institute for Fusion Theory (JIFT) is one of the four programs through which the US-Japan Fusion Research Collaboration is organized. The other three programs are the Fusion Physics Planning Committee (FPPC), the Fusion Technology Planning Committee (FTPC), and the US-Japan Joint Project (FRONTIER).

The distinctive objectives of the JIFT program are (1) to advance the theoretical understanding of plasmas, with special emphasis on stability, equilibrium, heating, and transport in magnetic fusion systems; and (2) to develop fundamental theoretical and computational tools and concepts for understanding nonlinear plasma phenomena. Both objectives are pursued through collaborations between U.S. and Japanese scientists by means of two types of exchange program activities—namely, workshops and exchange visitors.

Each year the JIFT program usually consists of four topical workshops (two in each country), six exchange scientists (three from each country). So far, during its 42 years of successful operation, JIFT has sponsored 248 long-term visits by exchange scientists and 140 topical workshops.

- The *workshops* typically have an attendance of 15–30 participants, of whom usually three to seven scientists (depending on the particular workshop) travel to the workshop from the non-host country. Scientists from countries other than the U.S. and Japan are also often invited to participate in JIFT workshops, either as observers or multi-laterals.
- Of the approximately three *exchange visitors* in each direction every year, one (called the "JIFT Visiting Professor") is supported by the host country, while the others (called "Exchange Scientists") are supported by the sending country. The visits of the Exchange Scientists usually last from one to several weeks in duration, whereas the Visiting Professors normally stay for one month.

The topics and also the participating scientists for the JIFT exchange visits, and workshops are selected so as to have a balanced representation of critical issues in magnetic fusion research, including both fundamental problems as well as questions of near-term significance, and also to take into account the specific capabilities and interests of both countries. The Japanese and US members of the JIFT Steering Committee agree together on the appropriateness of proposed topics before recommending them.

2. *SUMMARY OF COMPLETED ACTIVITIES (2022-2023 PROGRAM)*

Some of the activities in personal exchanges—that had been scheduled for the 2022-2023 JIFT program were done in remote collaborations because of the COVID-19. The JIFT Steering Committee meeting was held by email for discussing schedules for the 2022-2023 and 2023-2024 JIFT programs.

Summary reports about JIFT activities for 2022-2023 are given below.

A 2022-2023 Workshops

Japan to US:

JF-1 Theory and simulation on the high field and high energy density physics
Organizers: Yasuhiko Sentoku (Osaka U) and Alexey Arefiev (UCSD)
Location: Spokane, WA, USA
Dates: October 16, 2022

The purpose of this workshop is to promote activities on the high field and high energy density physics. The workshop was held at Spokane, WA on Oct. 16, right before the APS-DPP meeting. We have 4 participants from Japan and 5 from USA. Due to the COVID-19 situation, the number of Japanese participants was limited, so that we have a compact workshop, just for a half of day, to discuss the research update and promote our friendship. The topics discussed are the energy transport in dense plasmas, high field interaction including QED processes, and mesoscale laser plasma modeling.

B. 2022-2023 Exchange Visits

Japan to US:

JF-2 Modeling of gamma-ray emission and BW pair creation driven by ultra-intense laser light
Visiting Scientist: Kaoru Sugimoto (Osaka Univ., ILE)
Location: Online meeting
Dates: April (7,13,27), May (19,24), June (7), July (12,26), August (24,31), November (16), 2022
Summary:

The purpose of this research fellowship is to develop a modeling of the positron production process by the gamma-ray-driven linear Breit-Wheeler(BW) process in intense laser-plasma interactions and to incorporate it into the PIC code. The linear BW process is a fundamental phenomenon in which an electron-positron pair are produced by the collision of two photons, but it has not been experimentally verified. This study will enable us to analyze the dynamics of the generated positrons and provide important information for the experimental demonstration of the linear BW process. We had planned to visit our collaborator, Associate Professor Alexey Arefiev at the University of California, San Diego, in FY2022, but due to the coronavirus, we had to cancel the trip. Instead, we held discussions through online meetings via Zoom. As a result of our research, we constructed an algorithm to generate positrons by a linear BW process in the PIC code, PICLS. Using this code, we performed simulations of the interaction between a carbon target of near-critical density and an intense laser field. The simulations revealed that positrons generated by the linear BW process are accelerated to energies up to GeV or higher and form beams with divergence angles within 10 degrees. Information on the dynamics of these positrons is important for the experimental demonstration of the linear BW process. We have also submitted these research results as an academic paper.

JF-3 Collaboration on Tokamak boundary plasma turbulence simulations for divertor heat flux width
Visiting Scientist: Haruki SETO (QST)
Location: Lawrence Livermore National Laboratory, California, USA
Dates: Jan. 8-22, 2023
Summary:

The purpose of this collaboration is to improve the numerical treatment of BOUT++ code [1] used for study on the extrapolation of the experimental scale law of the divertor heat flux width [2,3] to the ITER-class device [4], which has been conducted at LLNL, by introducing a numerical scheme developed at QST to treat the interaction between turbulent and zonal flows [5]. A reliable prediction of divetor heat loads in ITER-class devices is important for the design and lifetime prediction of divertors in ITER and Japanese DEMO. Both parties will benefit from this collaboration, since QST can get the six-field reduced Braginskii module [6,7] developed at LLNL and LLNL can also get the extension to handle the interaction between turbulence and zonal flows developed at QST.

Although we had originally planned to do personnel exchange in FY2021, we decided to postpone it to FY2022 due to the pandemic of COVID-19. Therefore, in FY2021, we developed a numerical method for calculating edge MHD and turbulence in the full annular torus domain based on the method to handle the interaction between turbulence and zonal flows [5] through the remote collaboration via TV meetings. The developed scheme resolves the numerical instabilities in the low-toroidal mode components in the conventional BOUT++, which was published in Computer Physics Communications in Oct. 2022 [8].

In consideration of the situation of COVID19, we decided to do personnel exchange from QST to LLNL in FY2022 on 9-20 January. Dr. Seto participated in 2023 BOUT++ workshop (hybrid format, local venue: Hertz Hall, LLNL Open Campus) hosted by LLNL on January 9-12, 2023, and visited LLNL on January 13-20 to discuss the extension of the BOUT++ code for the divertor heat load simulation in the full annular torus domain including interaction of turbulence and zonal flow.

In the workshop, there were 34 presentations which are mainly focused on BOUT++ code, and there were animated discussions. For talks related to this collaboration, Dr. Seto gave a talk on numerical methods for edge MHD turbulence simulations in the full annular torus domain [8] and Dr. Li of LLNL gave a talk on mechanism of the SOL heat flux width broadening in the grassy ELM in EAST [9,10].

At the research meeting, QST provided LLNL with a set of BOUT++ source codes (QST version of BOUT++), including extensions to calculate edge MHD and turbulence in the full annular torus domain. Dr. Seto ported the QST version of BOUT++ to Cori supercomputer at NERSC, confirmed that the linear growth rate of the linear ballooning mode instability reported in Ref. [8] could be calculated correctly at Cori. He also explained how to compile the QST version of BOUT++ at Cori and the input file for calculation of the linear ballooning mode instability. On the other hand, LLNL provided Dr. Seto with a set of source codes for the BOUT++ code (LLNL version of BOUT++) including the six-field reduced Braginskii module, and the magnetic field equilibrium data set for the ITER divertor heat load simulation [4]. The instruction on the BOUT++ grid file generator using experimental data was also provided.

Through discussion between Dr. Seto and experts in LLNL on a code development strategy for divertor heat load simulation in full annular torus domain, we agreed to port the LLNL's six-field reduced Braginskii module to the QST version of BOUT++ code. In addition, for the research collaboration in FY2023, Dr. Seto and Dr. Li discussed the possible impact of interplay between zonal flow and turbulence on the SOL heat flux width broadening in small ELMs in EAST.

[1] B.D. Dudson et al., Comput Phys. Commun. 180 (2009) 1467
[2] T. Eich et al., Nucl. Fusion 53 (2013) 093031
[3] T. Eich et al., Nucl. Fusion 60 (2020) 056016
[4] X.Q. Xu et al., Nucl. Fusion 59 (2019) 126039
[5] H. Seto et al., Phys. Plasmas 26 (2019) 052507
[6] T.Y. Xia et al., Nucl. Fusion 53 (2013) 073009
[7] B. Zhu et al., Comput. Phys. Commun. 267 (2021) 108079
[8] H. Seto et al., Comput. Phys. Commun. 283 (2023) 108568
[9] N. Li et al., Nucl. Fusion 62 (2022) 096030
[10] N. Li et al., Phys. Plasmas 29 (2022) 12230

JF-4 Development of radiation ray tracing code system for implosion core diagnosis and its application

Visiting Scientist: Tomoyuki JOHZAKI (Hiroshima University)
Location: CMUXE, Purdue University, West Lafayette, Indiana (US)
Dates: Feb. 16-Feb. 24, 2019
(This collaboration was done online.)
Summary:

This exchange activity was Japan pending as a US-Japan fusion program. In order to prevent COVID-19 virus infection, the collaborative research has been conducted online.

Prof. Johzaki has been collaborating for a number of years with Prof. A.Sunahara at Center for Materials Under eXtreme Environment (CMUXE), Purdue University on the simulation study for implosion and fusion burning related to the fast ignition laser fusion. Prof. Johzaki has developed hybrid-type code "FIBMET" for calculating core heating and fusion burning of fast ignition laser fusion. In this code, laser-produced electron and ion beams are treated by particle model, bulk plasma is treated by radiation-hydro model and fusion-produced alpha-particle is treated by multi-group transport model. Prof. Sunahara has developed radiation-hydro code "STAR-1D and -2D" for fuel implosion process. This code includes laser heating by ray-tracing method and detailed atomic data (EOS and radiation Opacity tables). Using both codes, we evaluated core heating properties and proposed the fast electron beam guiding scheme using external magnetic field and self-generated magnetic field for enhancing core heating efficiency.

The present collaboration program started in 2018. The purpose of the program is to integrate the two codes for simulating the whole process from implosion to fusion burning excepting heating beam generation. (The generation of heating beam is calculated by PIC code since the kinetic effect should be considered.) In previous fiscal year, we have modified FIBMET to solve the magnetic field evolution with MHD scheme. Using the resultant code, we started to evaluate the magnetic field effects on fusion ignition and burning.

In this fiscal year, we have developed the X-ray ray-tracing code. In the experiment, the fuel implosion characteristics such are evaluated by spontaneous X-ray emission images and X-ray backlight images. However, in the experiment, the true profiles of density and temperature of imploded fuel cannot be obtained. On the other hand, in the numerical simulation, we can get the spatial and temporal profiles of imploded fuel. To evaluate the accuracy of imploded core measurement scheme using X-ray, and also to analyze the experimentally observed X-ray images, we have developed X-ray ray-tracing code. We applied the developed code to analyze the X-ray backlight image measurement for the implosion simulation of a CD solid ball target. First, we performed the implosion simulation to obtained temporal evolution of the imploded target plasma. And then, for the plasma profile at the different timing, we carried out the X-ray ray-tracing simulation to obtain two-dimensional X-ray transmission images, where Ti K□ line emission was assumed as the backlight source. Then, the obtained transmission images are converted into the absorption coefficient profile using Able inversion, and into density profile using Opacity table data. The simulation results indicate that photon energy of Ti K□ emission (4.5 keV) is too low to measure the density profile around the maximum compression. After this collaborative research period, we also will evaluate the requirement of spatial resolution of measurement system, the noise effect, candidate of alternative X-ray source in collaboration with the experimental group at institute of laser engineering, Osaka University.

JF-5 Theoretical study on high energy density plasma creation and ion acceleration by kJ-class intense lasers
Visiting Scientist: Hiroyuki YAMAGUCHI (NIFS)
Location: Online
Dates: June 2022
Summary:

This exchange activity was originally planed to be done in 2020. Dr. Yamaguchi been developing a coil-shaping-based optimization code for stellarator and heliotrons. In 2019, Dr. Yamaguchi attended US-JP Workshop on stellarator optimization held at Wisconsin University, which triggered this exchange activity . The original plan was to improve the helical coil configurations aiming at reduced neoclassical transport by realizing quasi-symmetry of magnetic field strength. The activity was conducted remote in 2022. Dr. Yamaguchi discussed online with Dr. A. Bader of Wisconsin University, and they agreed to begin with comparing the modular coil configuration and helical coil configuration for quasi-helically symmetric magnetic configuration. By applying the coil-shaping optimization, quasi-helically symmetric configuration has been found using helical coils. From the field-line tracing and connection length analysis, it has been found that the divertor leg structure is created in the region between the helical coils and the last-closed flux surface, which does not appear in conventional modular coil configurations.

Related publications

[1] H. Yamaguchi, "Development of coil-shaping-based optimization code and its application to helical coil stellarator", 23rd International Stellarator-Heliotron Workshop, June 20-24, 2022, Warsaw.

US to Japan:

JF-6 Theoretical model of WDM regime driven by intense laser
Visiting Scientist: Frank Graziani (LLNL)
Location: Institute of Laser Engineering, Osaka University
Dates: online 4/6, 4/23, 6/15, 9/21,10/21
Summary:

Yasuhiko Sentoku (Osaka U) and Dr. Graziani have been collaborating on the high energy density physics, especially, about modeling of a warm dense matter with a pressure over megabars. This year, due to the COVID-19 situation, Dr. Graziani could not travel to Japan, however, we have a monthly meeting to keep the collaborations from April to October.

JF-7 Modeling of pair-creation in intense laser-plasma interaction
Visiting Scientist: Alexey Arefiev (UCSD)
Location: Institute of Laser Engineering, Osaka University
Dates: online 4/7, 4/13, 4/27, 5/19, 5/24, 6/7, 7/12, 7/26, 8/24, 8/31, 11/16, 2022
Summary:

Yasuhiko Sentoku (Osaka U) has been collaborating with Prof. Arefiev on a research of electron positron pair creation in high field laser-plasma interaction. This year, due to the COVID-19, Prof. Arefiev could not make a visit to Japan, however, we have online meetings every two weeks for the collaborations. In the online meeting, we invited graduate students in each group and discuss the physics and modeling related to the QED processes which are important for the laser plasma interaction with intensities > 1022 W/cm2. The discussions are fruitful and we could write a joint paper, which is under review at this moment.

JF-8 Collaboration on Tokamak boundary plasma turbulence simulations for divertor heat flux width
Visiting Scientist: Xue-Qiao Xu (LLNL)
Location: National Institutes for Quantum Science and Technology, Rokkasho, Japan
Dates: Apr. 26, May 16, May 23. Jun. 21, Jul 25, Sep 12, Nov 22, 2022
(Remote collaboration via TV meetings)
Summary:

The purpose of this collaboration is to improve the numerical treatment of BOUT++ code [1] used for study on the extrapolation of the experimental scale law of the divertor heat flux width [2,3] to the ITER-class device [4], which has been conducted at LLNL, by introducing a numerical scheme developed at QST to treat the interaction between turbulent and zonal flows [5]. A reliable prediction of divetor heat loads in ITER-class devices is important for the design and lifetime prediction of divertors in ITER and Japanese DEMO. Both parties will benefit from this collaboration, since QST can get the six-field reduced Braginskii module [6,7] developed at LLNL and LLNL can also get the extension to handle the interaction between turbulence and zonal flows developed at QST.

In this collaboration, we have two personnel exchanges, one is JF-3 (Japan to US) and the other is JF-8 (US to Japan). Here, JF-8 is mainly focused on the possibility of research collaborations conducted mainly in LLNL. Due to COVID-19 pandemic, JF-8 was conducted remotely in preparation meetings for JF-3 (done in person in 8th -23rd Jan in 2023) in FY2022 and will be conducted in person in FY2023.

Through discussion between Dr. Seto and experts in LLNL on a code development strategy for divertor heat load simulation in full annular torus domain, we agreed to port the LLNL's six-field reduced Braginskii module to the QST version of BOUT++ code [8]. Dr. Seto and Dr. Li discussed the possible impact of interplay between zonal flow and turbulence on the SOL heat flux width broadening in small ELMs in EAST [9,10], which is expected to be studied mainly by LLNL through JIFT collaboration after FY2023.

[1] B.D. Dudson et al., Comput Phys. Commun. 180 (2009) 1467
[2] T. Eich et al., Nucl. Fusion 53 (2013) 093031
[3] T. Eich et al., Nucl. Fusion 60 (2020) 056016
[4] X.Q. Xu et al., Nucl. Fusion 59 (2019) 126039
[5] H. Seto et al., Phys. Plasmas 26 (2019) 052507
[6] T.Y. Xia et al., Nucl. Fusion 53 (2013) 073009
[7] B. Zhu et al., Comput. Phys. Commun. 267 (2021) 108079
[8] H. Seto et al., Comput. Phys. Commun. 283 (2023) 108568
[9] N. Li et al., Nucl. Fusion 62 (2022) 096030
[10] N. Li et al., Phys. Plasmas 29 (2022) 12230

JF-9 Kinetic-MHD hybrid simulations of energetic-particle driven instabilities
Visiting Scientist: Chang Liu (PPPL)
Location: NIFS
Dates: August 29 – September 29, 2022 (32 days); paid by Japan
Summary:

Dr. Chang Liu visited NIFS to collaborate with Dr. Yasushi Todo on kinetic-MHD hybrid simulation research of energetic-particle driven instabilities in toroidal plasmas. Kinetic-MHD hybrid simulation codes MEGA and M3D-C1 are developed at NIFS and PPPL, respectively. Dr. Liu is a developer of the M3D-C1 code for kinetic-MHD hybrid simulations. He learned and ran the MEGA code during his visit. He is also interested in kinetic-MHD phenomena in stellarators/heliotrons. He started MEGA simulations in a 3-dimensional equilibrium. He also started a collaboration with Dr. Wang Hao (NIFS) and Dr. Yasuhiro Suzuki (Hiroshima University) on the 3-dimensional equilibrium code HINT. Dr. Liu gave an excellent online seminar on "Kinetic-MHD simulation with both fast and thermal ions using M3D-C1" to NIFS scientists on September 9, 2022.

3. *PROGRAM ADMINISTRATION*

JIFT has a Steering Committee consisting of eight members, four from each country. Two of these members are the Japanese and US co-chairmen. Two other members of the Steering Committee, the US and Japanese co-executive secretaries, are responsible for the ongoing daily oversight of the progress of JIFT activities. The co-chairman and co-executive secretary on the US side are, respectively, the director and a research scientist at the Institute for Fusion Studies (IFS) of The University of Texas at Austin. The Japanese co-chairman is the Leader of the Numerical Simulation Reactor Research Project at the National Institute for Fusion Science, and the Japanese co-executive secretary is the director of the Fundamental Physics Simulation Research Division in the Department of Helical Plasma Research at the National Institute for Fusion Science. Furthermore, on the Japanese side there is an Advisory Committee comprised of five members representing a spectrum of Japanese universities and the National Institutes for Quantum and Radiological Science and Technology; and on the US side there is an Advisory Committee comprised of five members representing a spectrum of US universities and national laboratories. The names of the persons on the Steering Committee and the names of the Advisors are listed below.

JIFT Steering Committee

US Members	*Japanese Members*
F. Waelbroeck (IFS)—Co-Chairman	H. Sugama (NIFS)—Co-Chairman
A. Arefiev (UCSD)—Co-Exec. Secretary	Y. Todo (NIFS)—Co-Exec. Secretary
D. Spong (ORNL)	S. Murakami (Kyoto)
J. Mandrekas (DOE)	Y. Sentoku (Osaka)

JIFT Advisors

Japanese Advisory Committee: Y. Kishimoto (Kyoto), T.-H. Watanabe (Nagoya), M. Yagi (QST)

US Advisory Committee: J. Palastro (LLE/Univ. of Rochester), F. Graziani (LLNL), C. S. Chang (PPPL), and P. Terry (UWM)

The JIFT Steering Committee attempts to schedule workshops in such a way as to dovetail with other meetings. It also encourages participation at workshops by interested experimentalists and invites relevant available scientists from other countries to attend workshops.

As the principal program for fundamental theoretical exchanges in the US-Japan Fusion Research Collaboration, JIFT operates alongside the Fusion Physics Planning Committee (FPPC), the Fusion Technology Planning Committee (FTPC), and the US-Japan Joint Project (FRONTIER). In particular, the JIFT activities are coordinated with the four FPPC areas of activity, viz., core plasma phenomena, edge behavior and control, heating and current drive, and new approaches and diagnostics.

4. *PLANS FOR FUTURE ACTIVITIES (PROPOSED 2023-2024 PROGRAM)*

The topics and themes of the exchange activities that have been proposed for the next year (April 1, 2023–March 31, 2024) are consistent with the traditional emphasis of JIFT on fundamental theoretical plasma physics issues. At the same time the proposed activities have direct relevance to the fusion science programmatic interests of both countries. The schedule of proposed activities for the coming year (2023-2024) is listed below.

A. 2023-2024 Proposed Workshops

US to Japan:

JWJ1 Theory and simulation on the high field and high energy density physics
Organizers: Y. Sentoku (Osaka) and Alexey Arefiev (UCSD)
Proposed Place/Time: Apr. 17, 2023 at Yokohama (Japan)

JWJ2 Progress of fusion research with extreme-scale computing and data science
Organizers: T. Moritaka (NIFS) and C.S. Chang (PPPL)
Proposed Place/Time: Oct. 23-24, 2023 at NIFS (Japan)

B. 2023-2024 Proposed Exchange Visits

Japan to US:

JPU1 Collaboration on Tokamak boundary plasma turbulence simulations for divertor heat flux width
Visiting Scientist: H. Seto (QST)
Location: Lawrence Livermore National Laboratory
Dates: Aug. 6-13, 2023

JPU2 Neutron transport in fast ignition laser fusion fuel
Visiting Scientist: T. Johzaki (Hiroshima Univ)
Location: Purdue Univ.
Dates: Mar. 2-15, 2024

US to Japan:

JPJ1 Collaboration on Tokamak boundary plasma turbulence simulations for divertor heat flux width
Visiting Scientist: Xueqiao Xu (LLNL)
Location: QST
Dates: Nov. 12-25, 2023