

Joint Institute for Fusion Theory¹

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The Joint Institute for Fusion Theory (JIFT) is one of the three programs through which the US-Japan Fusion Research Collaboration is organized. For twenty years JIFT has contributed to the development of productive working relationships between Japanese and US scientists in carrying out theoretical and computational research on fusion plasmas and related scientific issues.

History

Cooperation with Japan has become an significant element in the US magnetic fusion program during the last two decades. In 1979, the US Secretary of Energy and the Japanese Minister of Foreign Affairs signed a ten-year agreement to cooperate in energy research and development. Shortly thereafter, the first US-Japan cooperative activity in fusion was begun with a diplomatic Exchange of Notes. At the same time, a joint US-Japan Coordinating Committee on Fusion Energy was created to oversee all such cooperative efforts.

An important component of the fusion collaboration with Japan is the theory and basic research exchange program. This program is coordinated through JIFT, which was formed in 1980 by the co-signing of the "Statement of Governance and Operation of the Joint Institute for Fusion Theory" by DOE and MOE representatives. Its purpose is to organize an annual exchange program consisting of visits by scientists and workshops on topics of mutual interest in the fusion programs of the two countries.

After the expiration of the original ten-year (1980-90) fusion exchange agreement between the US and Japan, a new framework was developed that reorganized the exchange activities under the three categories of Fusion Physics Planning Committee (FPPC), Fusion Technology Planning Committee (FTPC), and JIFT. In this scheme, JIFT operates alongside the other two committees as the central vehicle for fundamental theoretical and computational exchanges. 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).

On the US side, the IFS plays a lead role in organizing JIFT activities, because the Department of Energy delegated this responsibility to the IFS as part of its original charter when it was established in 1980.

Objectives

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.

Activities

The JIFT objectives are pursued through collaborations between U.S. and Japanese scientists, by means of three types of exchange program activities: workshops, exchange visitors, and joint computational projects. The JIFT program each year usually has four topical workshops (two in each country), approximately six exchange scientists (three from each country), and a fluctuating number of joint computational projects (on the order of a dozen). So far, during its 20 years of successful operation, JIFT has sponsored 75 topical workshops, 40 visiting professors, 85 exchange scientists, and 122 joint computational projects.

The workshops typically have an attendance of 25-35 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.

¹ Adapted from Chapter 1 written by M. Okamoto and J. W. Van Dam of *Twenty Year Report for Activities regarding U.S.-Japan Fusion Research Collaboration [Expert Summary for 1980 (Nov. 1979)—2000]*, published by U.S.-Japan Coordinating Committee on Fusion Energy (June 22, 2000).

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 several weeks to a month or two in duration, whereas the Visiting Professors normally stay for three months.

The third category of JIFT exchange activities consists of joint computational projects. In general these are continuing collaborations on various problems of current interest, which initially develop out of interactions at workshops and through individual exchange visits.

Administration

JIFT has a Steering Committee of eight members, four from each country, with two co-chairmen. The co-chairman on the Japanese side is the director of the Theory and Computer Simulation Center at the National Institute for Fusion Science. The co-chairman on the US side is the director of the Institute for Fusion Studies of The University of Texas at Austin. Two other members of the Steering Committee, called co-executive secretaries, are responsible for the ongoing daily oversight of the progress of JIFT activities. Also, on the Japanese side there is an official advisor, who is from the Japan Atomic Energy Research Institute; and on the US side there is an advisory committee whose membership is drawn from universities and national laboratories.

The Japanese and US members of the Steering Committee select the topics and also the participating scientists for the JIFT exchange visits, workshops, and joint computational project. Annual meetings are held by the Steering Committee to plan future activities in these three areas. Selection criteria include having a balanced representation of critical issues in magnetic fusion research, which includes both fundamental problems as well as questions of near-term significance, and also taking into account the specific capabilities and interests of both countries. Every year the Steering Committee submits a report concerning JIFT activities to the US-Japan Executive Secretaries Meeting.

Accomplishments

A number of general benefits have resulted over the years from the JIFT program. In particular, the following may be cited: JIFT has provided efficient communication channels for the latest theoretical research results, techniques, and directions; JIFT activities have attracted serious participation from allied fields such as fluid turbulence, statistical physics, computational science, and space plasma physics, which brings new scientific tools into the fusion program and enhances the stature of fusion physics; JIFT exchanges have contributed to efficient utilization of international research facilities; and JIFT emphasis on large-scale computational studies has reaped significant mutual benefits from the supercomputer resources and code-building expertise of both countries.

JIFT activities have led to the publication of numerous scientific papers, as well as review articles and books. JIFT research has also been featured in a number of invited talks at major international meetings (e.g., the biennial IAEA Conference on Plasma Physics and Controlled Nuclear Fusion).

Through JIFT, close and long-lasting scientific connections have been established between the US and Japanese fusion theory communities. Not only have senior scientists profited from these collaborations, but also young scientists—and even, on occasion, two advanced graduate students—have had many opportunities to enhance their research careers. The lectures given by JIFT visiting professors during the first decade of the program were published in a book for the benefit of scientists and students.

Themes

Indicative of scientific themes that JIFT has pursued are the topics of the 35 workshops held during the past nine years. These topics can be partially categorized as: (1) MHD equilibrium, stability, sawteeth oscillations, and disruptions; (2) High-beta plasmas and beta limits; (3) Highly energetic particles and their effects on stability; (4) Turbulent transport, transport barriers, and confinement; (5) Theory and new concepts for helical confinement configurations; (6) Bootstrap current; (7) Edge physics; (8) Dense plasmas; (9) Interactions of intense electromagnetic waves with plasma and matter; (10) Dynamo phenomena; (11) Reconnection; (12) Self-organization; (13) Numerical simulation codes, visualization techniques, and virtual reality; (14) Innovative

concepts. The workshops were organized so as not to focus on only one specific fusion device, but instead to aim at general scientific understanding of fusion plasmas and of basic plasma physics and the development of tools for large-scale computer simulations. Rapid progress in numerical simulation methodology has especially marked the past decade of JIFT activities.

Selected Highlights

Through the years, a number of JIFT workshops and scientific exchanges have made significant theoretical contributions to the design and data analysis of helical confinement configurations and stellarators (e.g., Heliotron E, CHS, and LHD in Japan and ATF in the US). New concepts for improved configurations have also been considered, relevant to the current US stellarator design effort and to future plans for Japanese helical systems. For example, a JIFT visiting professor invented a new topology (so-called “wavy” vertical field coils) for a quasi-axisymmetric stellarator that simplifies coil complexity, has improved access, and may allow the design of a divertor. Two well-known books on the physics and numerical simulation of helical plasmas have been written as the result of JIFT activities.

A longstanding JIFT effort was the benchmarking of stability predictions from various different MHD numerical codes that were applied to a common three-dimensional stellarator equilibrium configuration. The results of this important work, pursued over several years among Japanese, US, and Russian scientists, were finally published in a detailed paper. Three-dimensional plasma equilibria including magnetic islands were extensively studied with the HINT code. Progress was made in analyzing whether island formation is a global effect due to the Pfirsch-Schluter current or a local effect due to resistive interchange. The phenomenon of “self-healing” was discovered, and its physics mechanism compared to that for the neoclassical tearing mode. These studies suggested that the bootstrap current can play an important role in suppressing islands, which is interesting for recent LHD experiments.

Several workshops focused on understanding the universal properties of high-beta plasmas, not limited to any specific device. Stability beta limits and the bootstrap current fraction have been explored. Other problems considered were neoclassical tearing modes, resistive wall modes, equilibrium and stability for the field-reversed configuration, stability for the spheromak and the reversed-field pinch, and liquid lithium walls.

Another area of continuing interest in workshops and scientific exchanges has been the physics of high energetic particles. Fruitful results have been obtained in theoretically understanding the burst modes observed in CHS experiments, in interpreting observations of toroidal Alfvén instabilities in JT-60U and during the TFTR deuterium-tritium discharges, in modeling ripple loss of fast particles, and in developing theory and simulations for the nonlinear behavior of fast particle instabilities.

Many published papers and invited talks at various conferences have resulted from collaborations on plasma turbulence and anomalous transport. A recent book written on this subject is now a standard reference in the field. Other books were published as proceedings of JIFT transport workshops. A particular result was new understanding of how the Hasegawa-Mima equation and Hasegawa-Wakatani equation, as well as Waltz model, contribute to plasma turbulence. Also, insight has been gained concerning the formation of sheared plasma flow due to Reynolds stress.

A long-standing JIFT collaboration on the physics of spheromak plasma and magnetic reconnection resulted in MHD code simulations of internal reconnection events in a spherical torus device, which reproduced experimental results extremely well. Also, a simulation of collisionless reconnection with a particle code revealed physics of interest to the reconnection experiment at Princeton. The comparison of theoretical predictions and simulation results of collisionless reconnection has been very fruitful for both countries.

Dynamo simulations for the generation of the earth’s magnetic field attracted attention from the general physics community. These simulations showed the importance of self-consistent nonlinear dynamic processes.

Over several years, macro-scale particle simulations and gyro-kinetic particle simulations were compared and discussed. This led to a new direction to develop hybrid MHD-Vlasov simulation methods.

A JIFT exchange scientist made a breakthrough in object-oriented simulation techniques, viz., expression templates, and applied it to develop high-performance particle simulation capabilities that were then utilized for efficiently running a large Monte-Carlo type of code on a parallel processor computer.

Visualization methods, including virtual reality, have been recognized as critically useful for present and future large-scale simulations. JIFT research activities have made use of the NIFS CompleXcope and the Virtual Reality Simulation Laboratory. At a JIFT workshop on Nonlinear Plasma Simulation and Visualization held jointly with the 1998 International Conference on Numerical Simulation of of Plasmas, two Japanese fusion scientists won Buneman awards for their work in this field.

Another continuing JIFT research area has been plasma complexity in systems that are nonlinear, non-equilibrium, and open. Simulations of plasma self-organization, both on macro-scales and on micro-scales, excited considerable interest in order and structure formation. Also, recently the self-organization of plasmas with flow is being jointly studied in several areas—the stability of non-Hermitian plasmas with flow, the interpretation of the H-mode as self-organization of a shear-flow plasma at the edge, and double curl Beltrami flow–diamagnetic structures.

A well-attended annual series of workshops on the interaction of high-intensity electromagnetic waves with plasma and matter have attracted scientists from research areas such as ultrashort pulse laser-plasma interactions, laser acceleration, laser Compton scattering, nonlinear plasma dynamics, fast ignitor concept, energy research, X-rays, and laser astrophysics. This has stimulated opportunities for cross-field synthesis. The proceedings of the most recent of these workshops will shortly be published in a book.