NIFS
NATIONAL INSTITUTE for FUSION SCIENCE
2019 2020
NATIONAL INSTITUTE FOR FUSION SCIENCE

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Solar energy, which is the source of life on Earth, and the energy of the stars glowing in the night sky both are born of nuclear fusion. If we can achieve on Earth the fusion energy that has been produced in space without pause since the Big Bang 13,800,000,000 years ago, human beings will gain never-ending energy. At the National Institute for Fusion Science (NIFS) we aim at achieving fusion energy from the sun on the earth, and we are advancing academic research that extends broadly across science and engineering.

In nuclear fusion, the nuclei of hydrogen isotopes fuse, and we use the immense amount of energy that is generated when the hydrogen nuclei becomes the heavier helium and produces energy. Because the fuels deuterium and lithium are found in seawater in nearly inexhaustible amounts there is no worry of the supply running out. And because the fusion reaction does not emit carbon dioxide there is no strain placed upon the environment. This reaction is excellent in terms of safety. In order to achieve this dream of fusion energy, fuel gas must be converted into the plasma condition in which the ions and the electrons have become separated and raised to a temperature of more than 120,000,000 degrees. Because such a high-temperature plasma cannot be maintained in a conventional container, it is confined by the magnetic field and floats inside the vacuum vessel so that it does not touch the wall. However, confinement is not simple. High-temperature plasma seeks to escape from the magnetic field container, and engages in complicated movements from the central area to the edge. While solving each of these phenomena one by one through scientific methods we raise the plasma’s temperature seeking the conditions for fusion. In order to achieve those conditions we need not only experimental research, but also theoretical research and simulation research derived from utilizing supercomputers. Further, in order to achieve energy using plasma that has met the fusion conditions, development of engineering research and design research for the entire fusion power plant system in fields such as fuel supply, energy conversion, and material development is necessary.

At NIFS, using the world’s largest class superconducting device, the Large Helical Device (LHD), based upon an idea unique to Japan called the heliotron system, we are advancing greatly in a research project through high-temperature plasma experiments using the magnetic field. In addition, we are organically linking the numerical simulation research project utilizing theory and simulation, and the fusion engineering research project for the engineering design leading toward DEMO for conducting fusion power generation. In the LHD Project, in March 2017 we initiated experiments that use deuterium gas, and we expect exceptional improvement in plasma performance. Due to this, still further improvements in research, beginning with achieving the goal of a temperature of 120,000,000 degrees, are anticipated. NIFS is an Inter-University Research Institute, and through joint research with scholars at other research institutes and universities we are advancing in research at the world’s highest level. In addition, we also are actively developing international joint research with scholars in research institutes around the world.

Turning our eyes to the world, we are following the only path for enlarging the energy demand on a global scale due to the explosive population growth and economic development concentrated in developing countries. Further, the increase in carbon dioxide and the depletion of fuel resources due to the continued use of fossil fuels will eventually become serious issues. More than 50 years have passed since the development of fusion energy began, and this energy is also called an energy of one’s “dream.” However, research has advanced such that the generation of fusion energy through ITER (International Thermonuclear Experimental Reactor) is planned for 2035. Actual energy generation through DEMO may be achieved 30 years from now. At NIFS, we also are pouring energy into fostering young researchers who will realize the generation of fusion power in the future through their studies at SOKENDAI (the Graduate University for Advanced Studies) and partner graduate schools.

NIFS celebrates 30th anniversary on May 29, 2019. NIFS keeps to stand at the forefront of the world’s research in fusion energy, and is strongly advancing research aimed at achieving the generation of fusion power. Please visit our research facilities, which are at the world’s leading edge.
Goals of NIFS

Fusion – it is the energy source that keeps the sun and stars shining. In order to replicate the power supply system of the universe on Earth, NIFS has been working on ultra high-temperature plasma - the state of matter to create fusion reactions - for its stable supply. It is expected to help ease humanity’s hunger for energy for years to come.

Fossil fuels such as coal, petroleum, and natural gas have powered our industrial society based on highly-advanced modern science and technology. However, our heavy dependence on them has released an immense volume of carbon dioxide and nitrogen oxide into the air, which is having a serious impact on the global environment. Depletion of resources is a worry, as well. Therefore, one of the world’s top priorities is undoubtedly to obtain an eco-friendly inexhaustible energy source.

NIFS, as an inter-university research institute, is playing an active role in mutual cooperation with universities and research organizations both in and out of Japan. As an educator, NIFS is working with communities to promote basic research as well as educational activities on fusion plasma while developing excellent researchers. Fusion plasma requires the special condition of extremely high density and extremely high temperature (beyond 100 million degrees Celsius) simultaneously. Investigation of such a demanding state, including control of it, is a comprehensive study effort based on leading-edge research across the entire spectrum of modern science and engineering covering both experimental and theoretical approaches. Among those disciplines are physics, electronics, superconductor engineering, material engineering, and simulation science.

NIFS is moving forward in achieving fusion energy as a center of excellence, where national as well as international knowledge gathers and is combined.

Various Forms of Plasmas

Nuclear fusion plasmas

- **Density:** approximately $10^{20}$/m$^3$
- **Temperature:** some ten millions to one hundred million °C

Solar corona

- **Density:** approximately $10^{11}$/m$^3$
- **Temperature:** approximately one million °C

Picture provided by Solar Observatory, NAOJ

Aurora

- **Density:** approximately $10^{14}$/m$^3$
- **Temperature:** One to two thousand °C

Flame (inside the field kiln)

- **Density:** approximately $10^{13}$/m$^3$
- **Temperature:** Less than two thousand °C

Picture provided by the Toki City Junior Chamber
What is FUSION?

Fusion refers to a nuclear reaction in which lighter nuclei collide with each other to become a heavier nucleus. The total mass of the resulting nuclei is less than that of the original nuclei. Given Einstein’s equation \( E=mc^2 \), the missing amount of mass is to transform into energy released as a result of the reaction. It is what has powered the sun and stars for hundreds of millions of years. Once replicating it is successful on Earth, we could be free from concerns over limited energy supplies. Deuterium and tritium are currently expected to be the most favorable fuels for fusion. Deuterium and the lithium that is necessary for tritium production are found in seawater. Three liters of water and 0.3 grams of lithium are equivalent to the amount of annual consumption of electricity per each Japanese person.

The future fusion power generator is expected to use the reaction between deuterium and tritium at temperatures exceeding 100 million degrees Celsius. When the temperature reaches more than 10,000 degrees Celsius, substances separate into ions and electrons, and reach the status of an ionized gas called “plasma.” All the ions are positively charged and repulse each other. To make a collision happen, the ions must gain enough speed to overcome the repulsive force and to come very close to each other. To this end, the ion temperature must be raised to an extremely high level.

Changes in state of matter

<table>
<thead>
<tr>
<th>State</th>
<th>Example</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>ice</td>
<td>Low</td>
</tr>
<tr>
<td>Liquid</td>
<td>water</td>
<td></td>
</tr>
<tr>
<td>Gaseous</td>
<td>vapor</td>
<td>High</td>
</tr>
<tr>
<td>Plasma</td>
<td>aurora</td>
<td></td>
</tr>
</tbody>
</table>

The sun possesses an infinitely strong gravity, and that is how it prevents energetic plasma ions from escaping. However, our planet does not have such a powerful gravity and must use an alternative way to maintain plasma - that is, magnetic force. Charged particles are in the grip of the magnetic power and move around the lines of a magnetic field. This movement is used to confine plasma.
Organization

Apr. 2019

Director General
- Advisory Committee

Research Enhancement Strategy Office
- Division of Health and Safety Promotion
- Division of Deuterium Experiments Management
- Division of Information and Communication Systems
- Division of External Affairs
- Deputy Director General
- Fusion Science Archives

Department of Helical Plasma Research
- Project
  - Large Helical Device Project
  - Numerical Simulation Reactor Research Project
  - Fusion Engineering Research Project
  - Task Force for Next Research Project

  - High-Density Plasma Physics Research Division
  - High-Temperature Plasma Physics Research Division
  - Plasma Heating Physics Research Division
  - Device Engineering and Applied Physics Research Division
  - Fusion Systems Research Division
  - Fusion Theory and Simulation Research Division
  - Fundamental Physics Simulation Research Division
  - Rokkasho Research Center

Department of Engineering and Technical Services
- Fabrication Technology Division
- Device Technology Division
- Plasma Heating Technology Division
- Diagnostics Technology Division
- Control Technology Division

Department of Administration
- General Affairs Division
- Financial Affairs Division
- Research Support Division
- Facilities and Safety Management Division

Library

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- Engineers 46
- Administrative Staff 43
- Employees on Annual Salary System 15
- Research Administrator Staff 2
Research Activities

Projects/Department of Helical Plasma Research

All NIFS researchers are members of the Department of Helical Plasma Research. This department is divided by subject into seven subordinate divisions. Each researcher belongs to one of these divisions according to his or her specialization. The research activities are carried out in the structure below.

Department and Projects

The department’s seven divisions vertically divide research staff while three projects separate them horizontally across sectional borders - a matrix structure.

- Towards the early realization of fusion energy, the High-Density Plasma Physics Research Division promotes research aiming at a comprehensive exact understanding and performance improvement of plasmas with emphasis on “high density.”
- The High-Temperature Plasma Physics Research Division, which is in charge of the high-precision measurements of various physical quantities, is engaged in the clarification of the plasma physics of the LHD.
- The Plasma Heating Physics Research Division performs an important role for realizing a high-temperature and high-density plasma which satisfies a fusion reactor condition.
- Seeking the early realization of a stable and safe fusion reactor, the Device Engineering and Applied Physics Research Division advances with broad-based academic research on fusion engineering that focuses on large-scale superconductivity and cryogenics, and on radiological safety.
- In addition to reactor system design studies, the Fusion Systems Research Division promotes research on low activation materials and materials systems, blankets, reactor structure, plasma-facing components, and the relevant elementary processes for the purpose of developing mainly in-vessel components of fusion reactors.
- The Fusion Theory and Simulation Research Division promotes theory and simulation research on the LHD plasmas and other toroidal fusion plasmas in order to contribute to the realization of fusion energy.
- The Fundamental Physics Simulation Research Division performs cutting-edge simulation studies for physics of open non-equilibrium plasma, simulation methodologies, and virtual reality (VR) visualizations.
Large Helical Device Project

The Large Helical Device (LHD) project involves the operation and maintenance of the world’s largest class of superconducting device, which employs a heliotron magnetic field originally developed in Japan. The objectives are to conduct fusion-grade confinement research in a steady-state machine and to elucidate important research issues in physics and engineering for the helical-type fusion reactor.

Heliotron Configuration

A doughnut-shaped magnetic configuration has the advantage of confining the plasma due to its endless character, but the magnetic field lines need to be twisted. The “helical” type device gives this twist by twisting the external coils themselves. Among several helical configurations, “heliotron” is the Japanese original. The LHD confines plasma with this heliotron configuration using superconducting coils. The necessary magnetic field is formed only by external coils in the heliotron. Helical devices have the advantages of controllability and steady state operation in comparison with the devices which rely on the current inside the plasma, such as a tokamak. Steady state operation is the key issue in a future fusion power plant where more than one year of continuous operation is expected.

Progress of Heliotron Devices

The helical configuration has a longer history than the tokamak, such as the ITER now under construction in France. Mainly due to its required high accuracy in winding the magnetic field coils, helical systems have had to wait for engineering and theoretical progress to demonstrate their real performance. Medium-sized helical devices built in the 1980s showed good confinement properties comparable to the tokamak and scalable to a fusion reactor. The LHD started its design and construction after these experimental results. The LHD is one of the largest class of helical magnetic plasma confinement devices now operating in the world. The other superconducting helical device of similar size is the Wendelstein 7-X in Germany.

Goals of the LHD Plasma Experiments

Fusion research, which is an integrated-system project, has advanced with larger devices that were designed and constructed based on previous achievements, improvement in plasma performance, and advances in theory and engineering technique. One objective of the LHD project is to identify physics and engineering issues in helical-type fusion reactors. Research on steady state operation, which is required for a commercial fusion reactor, is another important challenge for the LHD.

In the figure to the right, the fusion triple products achieved so far in the LHD and tokamaks are shown as a function of discharge duration time. The final target parameter regime of the LHD is shown by a thick red line which is expected to be achieved by using deuterium and increased heating power. The self-ignition condition as well as the expected ITER and commercial reactor operation regions are also shown in this figure.
Overview of the LHD

The LHD is comprised of a plasma confinement device that employs superconducting coils, plasma heating systems, and devices to measure and record plasma properties and phenomena.

- LHD
- Neutral Beam Injectors
- Ion Cyclotron Heating Device (co-axial conduit for power transmission and stub tuner)
- Electron Cyclotron Heating Device (waveguides for microwave power transmission)
- Vacuum Pumps
- Diagnostic Ports
- Superconducting Helical Coils
- Superconducting Poloidal Coils
- Resonant Magnetic Perturbation Coils
- Plasma

 Specifications of LHD

- Outer diameter of the machine: 13.5m
- Height (including ports): 9.1m
- Net weight: approx. 1,500t
- Toroidal plasma diameter: approx. 8m
- Poloidal plasma diameter: 1.0 to 1.2m
- Magnetic field strength: 3T
- Helical pitch number /m: 2/10
- Total power to heat: 36MW
Experimental Results to Date

In the future fusion reactor, in order to achieve the fusion reaction between deuterium and tritium an ion temperature of more than 120 million degrees and an ion density of more than $1.0 \times 10^{20}/m^3$ are to be achieved simultaneously. In the LHD, from the first plasma on March 31, 1998, to today, over more than 20 years, plasma performance has approached the achievement of this condition. In addition, we have achieved the long operation time of 48 minutes for the high temperature plasma of more than 23 million degrees, which is an advantage of the helical system.

Regarding the ion temperature, we have achieved a temperature of 120 million degrees in the deuterium experiment starting from 2017. This is, of course, the world’s highest record for a helical device. Regarding density, though at a low temperature of 3 million degrees, we achieved the density of $12 \times 10^{20}/m^3$ that is 10 times the necessary density for the reactor. Thus, we exploited a new operating scenario of “the approach to self-ignition based upon low temperature high density plasma in helical devices.” Further, we successfully raised the beta value (plasma pressure/ magnetic pressure) above 5% for the first time in the world in the helical device. The beta value controls the economics of the reactor. In the table below, we show the achieved values of the plasma parameters to date in the LHD.

<table>
<thead>
<tr>
<th>Plasma Parameters</th>
<th>LHD Achievements</th>
<th>LHD Targets</th>
<th>Fusion Reactor Expected Regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Temperature</td>
<td>120 million °C</td>
<td>120 million °C</td>
<td>120 million °C (at 0.2×10^{20}/m^3)</td>
</tr>
<tr>
<td></td>
<td>(at 0.13×10^{20}/m^3)</td>
<td>(at 0.2×10^{20}/m^3)</td>
<td>1.0×10^{20}/m^3</td>
</tr>
<tr>
<td>Electron Temperature</td>
<td>230 million °C</td>
<td>120 million °C</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>(at 0.02×10^{20}/m^3)</td>
<td>(at 0.16×10^{20}/m^3)</td>
<td>5T</td>
</tr>
<tr>
<td>Electron Density</td>
<td>$12 \times 10^{20}/m^3$</td>
<td>4.0×10^{20}/m^3</td>
<td>1 year</td>
</tr>
<tr>
<td></td>
<td>(at 3 million °C)</td>
<td>(at 15 million °C)</td>
<td></td>
</tr>
<tr>
<td>Beta</td>
<td>5.1% (at 0.425T)</td>
<td>5% (at 1-2T)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.1% (at 1.000T)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Pulse Operation</td>
<td>54 min. (0.5MW)</td>
<td>1 hour (3MW)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48 min. (1.2MW)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Plasma parameters achieved in the LHD
Research on High-performance Plasma by Using Deuterium

Deuterium has the same chemical properties as protium (common hydrogen, below hydrogen). However, the mass is two times greater than hydrogen, and is called an isotope. In experiments conducted in tokamak devices, deuterium is known to have better performance than hydrogen.

In the first year of LHD deuterium experiment, the ion temperature of 120 million degrees was achieved. In the figure to the right, radial profiles of ion temperature, electron temperature, and electron density are shown in a discharge that reached the ion temperature of 120 million degrees. In this discharge, electron temperature is relatively low compared to the ion temperature, which should be increased in future experiments.

In the LHD deuterium experiment, we are also setting an important target, that is, understanding of accompanying physics phenomena. When we change gas from hydrogen to deuterium, why does the plasma’s performance improve? We still do not understand clearly. Clarifying the mechanism of this phenomenon called the “isotope effect” also has significant academic value.

In the LHD project, together with experimental research to be conducted in LHD, large-scale theory and simulation research using a supercomputer, which are the wheels upon which a car is driven, will propel fusion research forward in a comprehensive way.

Development Research for Instruments and Simulation Codes that Support Plasma Experiments

In order to heighten plasma performance, it is necessary to improve the magnetic field configuration, to devise methods for injecting and evacuating fuel particles, and to improve impurity control methods and steady-state sustainment techniques. Development research relating to these issues is being undertaken together with experimental research in the LHD.

Neutral Beam Injection Heating Device

By injecting a high-energy hydrogen atom (neutral) beam into plasma, the Neutral Beam Injection Heating Device heats ions and electrons. In the LHD, at present there are five beamlines. Among these five beamlines, three are of the high-energy type using negative hydrogen ions, and the negative ion current density is the highest in the world. The two other positive ion beamlines were improved for the deuterium beam injection, and the injection power has been increased by approximately two times. The three negative hydrogen ion beamlines follow in order. We will undertake improvements to optimize the beamlines for deuterium.

Neutral beam injection system in the LHD: Hydrogen ions are accelerated and then neutralized before injection.
Heavy Ion Beam Probe

In the LHD, in order to measure physical quantities of extreme high-temperature plasma we have developed numerous diagnostic devices. The heavy ion beam probe (HIBP) is one of the largest scale devices installed in the LHD.

Gold and copper, as well as other ions with large atomic numbers which are utilized for measurements, are accelerated by using an electrostatic accelerator and injected into plasma. Injected ions escape from the LHD after the trajectory is bent because of the LHD’s magnetic field. By analyzing the energy change of the particles, we can know quantities of the plasma potential and its fluctuations.

Pellet Injectors

To feed fueling particles deep into the core region, a frozen hydrogen pellet is injected into the plasma like a bullet. The photo to the right shows a pellet injector installed in the LHD that can inject 20 pellets repetitively at a velocity of 1300 m/s.
Approach to Steady State Operation
- Long Pulse Sustainment of High Performance Plasma -

Research on steady state plasma sustainment, which is a major advantage of the helical system, is conducted using Radio-Frequency Heating (Ion Cyclotron Heating (ICH) and Electron Cyclotron Heating). The world record of 3.4 gigajoule of injected energy has been accomplished in the LHD. Further, aiming for still longer maintenance of high performance plasmas, we are advancing with preparations for the electron cyclotron resonance heating device. At present, five high-powered microwave oscillators (gyrotrons) are operating.

Development of Numerical Simulation Codes

For the development of nuclear fusion research, numerical studies are as important as experimental studies. In helical systems like the LHD, the three-dimensional effect makes experimental results and understandings complicated. Computer simulations are thus performed to interpolate or extrapolate experimental data for a better understanding of the underlying physics. At NIFS, some simulation codes have been developed matching the progress in the experimental studies.

Manipulator for Plasma Material Interaction Study

To achieve the fusion reactor, it is very important to study plasma-material interactions, as well as the confinement of high temperature core plasma. A large manipulator to introduce samples into the vacuum vessel is equipped on the LHD. This device enables the sample to be examined just after the exposure to the plasma by retracting it without vent. Many collaborators from universities are conducting research using this equipment.
Numerical Simulation Reactor Research Project

A fusion plasma is a typical complex system controlled by multi-physics and multi-time/space nonlinear processes, from macroscopic phenomena, such as plasma transport, to microscopic electron dynamics. In order to understand and systematize physical mechanisms in fusion plasmas, large-scale numerical simulation research has been carried out by utilizing the full capabilities of a supercomputer, Plasma Simulator. Based on this research and development, we promote large-scale simulation science, aiming at the ultimate realization of a helical numerical test reactor, which is based on an integrated predictive model for plasma behavior over the whole machine range.

Research Results in 2018

Result 1
Progress in Validation Study with Turbulence Simulation and LHD Deuterium Plasma Experiment

Turbulence in plasmas causes heat and particle losses due to the turbulent eddy and flows. Clarifying the physical mechanism is one of the most important issues in fusion plasma researches. It has been known that heavier ions in plasma lead to improved confinement. Now, we are conducting cooperative studies with the LHD experiment and the large-scale turbulence simulation GKV, which has been developed in NIFS, to verify the latest theoretical predictions. The GKV simulation clarified a significant difference of the turbulence strength and the heat loss between hydrogen and deuterium plasmas. These results well reproduce the experimental observations in LHD, and contribute to a full understanding of the long-standing issues on the relation between the turbulence and the ion mass.

Result 2
A Novel Simulation Code Has Been Developed toward Whole-Volume Kinetic Modeling of Helical Fusion Devices

We have developed a global gyrokinetic code for whole-volume kinetic modeling of Large Helical Device (LHD) and other helical/stellarator devices in collaboration with the X-point Gyrokinetic Code (XGC) team in the Princeton Plasma Physics Laboratory. Particle-in-cell and finite element methods are employed on unstructured meshes so that the kinetic plasma descriptions are robustly applied not only to the core region but also to the edge region with complicated magnetic field structures. We have demonstrated high-energy particle confinement inside the vacuum vessel and basic core transport phenomena such as linear growth of ion temperature gradient modes, which were previously considered in separate simulation frameworks using different magnetic field equilibria and governing equations. The developed code will be further extended to explore edge turbulent and core-edge coupling phenomena in helical/stellarator devices not fully understood in conventional simulation studies.

Fig: (left) Temperature profiles observed in the LHD experiment, and (right) GKV simulation results indicating the reduction of the heat loss in the deuterium plasma.

The developed simulation code can demonstrate microscopic plasma phenomena (top, green) using unstructured meshes (right, green). The employed numerical scheme can be potentially applied to the entire region inside the vacuum vessel (red).
Magnetohydrodynamics Simulation

We analyze the magnetically confined plasma through the magnetohydrodynamic approach. This approach allows us to treat global phenomena in the plasma. We carry out computer simulations to examine the dynamical change of the plasma and the magnetic field due to the pressure gradient and the current. In particular, we focus on three-dimensional configurations such as Large Helical Device and we investigate the dominant physics to determine the stability boundary. We also extend the model equations by incorporating effects of the particle motions and develop a research scheme based on the new model.

Peripheral Plasma Transport Modeling

Peripheral transport modeling is an important issue for designing the future fusion reactor because high heat and particle fluxes degrade the divertor and the first wall. Sophisticated transport properties in the 3D magnetic field are simulated by the Plasma Simulator.

Plasma-Wall Interaction Simulation

The divertor plate is the inside wall exposed to the plasma most strongly. We estimate the durability of the divertor plate by binary collision approximation (BCA), molecular dynamics (MD), density functional theory (DFT), Monte-Carlo (MC), and their hybrid codes (BCA-MD and MD-MC) in atomic scale. Recently, we revealed the formation process of the tungsten fuzz nano-structure which is generated by helium plasma. The purple and blue spheres indicate tungsten and helium atoms, respectively. As time passes, it is found that the "fuzz" structure is generated.

Plasma Simulator

The Plasma Simulator is a massive parallel supercomputer system utilized to promote the Numerical Simulation Reactor Research Project. The Plasma Simulator was replaced in 2015 by 2,592 computers connected with an extremely high-speed network. The computational performance is 2.62 petaflops, and the capacities of the main memory and the external storage system are 81 terabytes and 10 petabytes, respectively. The Plasma Simulator is capable of large-scale simulation of fusion plasmas.
Fusion Engineering Research Project

The Fusion Engineering Research Project carries out both the conceptual design of a steady-state fusion reactor and various engineering challenges to make it possible to construct the fusion reactor. The LHD-type reactor does not need any plasma current, and this feature gives the great advantage of realizing a steady-state reactor. The project is carrying out research on key components in fusion reactors, such as the superconducting coil system, the high performance blanket, the first wall, and the divertor, while maintaining consistency with the reactor design. Serving as the center of fusion engineering research in Japan, this project enhances domestic and international cooperation in reactor design work and at the same time encourages basic research in the related interdisciplinary areas.

Research Results in 2018

Toughened Joints Can Be Achieved by the Advanced Brazing Technique ~Microstructural Characterization of the Joint Was Performed by Using the Dual Beam Type FIB-SEM (Focused Ion Beam / Scanning Electron Microscope) Device. ~

The divertor heat removal component is exposed to high particle/heat loading from high temperature plasma as shown in Figure (a). The basic concept of a divertor structure is that the refractory metal of tungsten (W) is supposed to be jointed on the copper alloy heat sink. The direct joint has been considered to be difficult because each material property is largely different. On the other hand, the “advanced brazing technique” has been developed, and this technique works well to obtain the very fine and toughened direct joint of the tungsten (W) / Copper alloy. Microstructural characterization of the joint was performed by using the dual beam type FIB-SEM device. Figure (b) shows the cross-sectional image of the vicinity of the joint interface obtained by SEM function. The fine cross-sectional surface was fabricated by FIB function.

A Method to Join HTS Conductors in a Short Time Using a Joint-piece and Low-temperature Heat Treatment

Joint-winding of high-temperature superconducting (HTS) helical coil has been proposed, in which the coil is wound by joining short HTS conductor segments. A new joining method proposed through collaboration with Tohoku University achieved a fabrication time reduction per conductor joint from 18 hours to 3 hours, and a resistance reduction to 1/3 compared to the previous joining method. The method can provide a forecast on one-year fabrication of the FFHR fusion reactor’s helical coil.

A Study about Behavior of He Bubbles in Tungsten

Helium(He) bubbles are formed by He irradiation on Tungsten (W). W is used for plasma facing components and He is generated by fusion reactions. In high temperature, He bubbles can migrate in W and induce surface modification. However, detailed properties are not well understood. We applied thermal pulses with 500 MW/m² heat flux for 0.5 ms on He irradiated W. As the result of the very short time high temperature, hole density observed on the surface were increased. The holes were formed by migrated He bubbles what reached on the surface. These results indicate that the very short time scale is sufficient for the migration of the He bubbles.

The left image is an SEM (scanning electron microscope) image of W surface before applying thermal pulses. The undulation of the surface was formed by surface strain due to He bubble’s pressure. The right image is the SEM image of W surface after thermal pulses. The number of holes in the right image is apparently larger than the number of holes in the left image.
Research Groups

Reactor System Design Research Group

The improvement of a system design code and a neutronics code for selecting primary specifications of the reactor is being conducted. The cost evaluation for power generation and the proposition of an operation schedule are also being conducted. The design optimization for the main components of a fusion power plant (plasma, superconducting magnet, blanket, and shield) is in progress. As part of the fuel system research, fuel supply to the core plasma, safety study of the fuel cycle processing system, and research on the heating and measurement systems with the aim of stable control of burning plasma are being promoted.

Superconducting Magnet System Research Group

The large-scale magnet system for the fusion reactor requires high-performance superconductors with a 100 kA-class current capacity. Research is being conducted for developing such an advanced conductor made of metallic low-temperature superconducting materials and/or copper-oxide high-temperature superconducting materials. Components in magnet systems are subjected to huge electromagnetic forces. Research is ongoing so as to precisely evaluate the expected stress on component materials and to seek the optimum coil supporting structure. The engineering design of the coil winding and fabrication method is also in progress.

In-vessel Component Research Group

In-vessel components include the blanket system, the first wall, and the divertor. Studies on blanket technologies for the coolant flow control, recovery of thermal energy and hydrogen isotope fuel, and material lifetime in a high temperature and high magnetic field environment are being conducted with forced circulation loops of a liquid molten salt and liquid metal. The development of advanced materials, such as a vanadium alloy, is also underway in collaboration with universities. The first wall is required to serve as part of the blanket structure, facing the edge plasma. The plasma-interactions with and hydrogen permeation through selected candidate materials are currently investigated. Divertor heat flux is considered to exceed 10 MW/m². Here, a highly heat-resistant divertor system must be developed. Important research subjects are material selection, bonding technologies, design of the 3D-helical-shape, and maintenance of a helical divertor.

An example of a design window using the system design code. Design parameters including the magnetic field, the reactor size, the blanket thickness, the size of the superconducting magnets, and core plasma parameters are comprehensively optimized. HC: helical coil

Large-current-capacity superconductor sample made of YBCO high-temperature superconducting material (left: the full size view; right: a mockup of the conductor). A 100 kA current has been achieved through collaboration with Tohoku University.

A photo of the FLiNaK/LiPb twin loop system “Oroshi-2.” Integrated tests and demonstrations of blanket functions, properties, and effects of a high magnetic field (max. 4 T) are performed by circulating a FLiNaK coolant (500°C) and LiPb coolant (300°C) in the metal tubes.
The Expansion of Research

In the research section of the Department of Helical Plasma Research, in addition to project-related research, numerous unique research activities are being undertaken. These research activities are important and indispensable for fusion research.

Plasma Biology

It is generally known that plasmas are in fusion devices, the sun, and space, all of which are usually far from our living environment. On the other hand, in recent years, plasmas have been applied to medical treatments, sterilization, agriculture, and other aspects of our daily lives. In agricultural applications, it is reported that radish sprouts pretreated with plasma spray grow faster than those without such pretreatment. NIFS, collaborating with the National Institute for Basic Biology and universities, is conducting the new field of “plasma biology” from the viewpoint of fundamental plasma science and biology at the cellular level. Comprehensive effects of plasma irradiation on fission yeast are studied using sophisticated diagnostics developed for high temperature fusion plasma, and we have accumulated analysis techniques and knowledge for fission yeast.

Technical Verification Tests for Long-distance Ultra-high Speed Data Transfer by Using Fusion “Big Data”

Fusion experiments are equipped with thousands of sensors and daily generate “big data,” which are promptly distributed and analyzed by domestic and foreign research collaborators. It is also expected to realize “remote experiment” in the near future, in which high-speed data transfer will be quite essential technology. Our collaboration with National Institute for Informatics (NII), National Institutes for Quantum and Radiological Science and Technology (QST), and ITER International Fusion Energy Organization in France have performed a high-speed “big data” transfer test between Japan and Europe, and established a new world record of 50 tera-byte per day on inter-continenta long high-speed data transfer. The record has been broken in a few months, however, it has been an epoch-making achievement that demonstrates the fruitful interrelationship between fusion research and the Information Technology.

Demonstration of a New Control Knob for Optimization of Beam Optics

Hydrogen negative ion beams are used for various applications such as cancer therapy and particle physics, as well as fusion research. One of the important factors to determine the beam quality is beam divergence, which is a measure of the increase in the beam diameter. Generally speaking, the small divergence beam is preferable because the divergent beam is easily intercepted by the accelerator and beamline components. We focused on a bias voltage, which was originally introduced to suppress electrons in the beam, as an additional control knob for the beam divergence. Using a neutral beam injector in the LHD, we demonstrated for the first time that the beam divergence can be minimized with the bias voltage control.

Raphanus sativus L. (Radish sprouts) with (lower) and without upper plasma irradiation to seeds.
(By courtesy of Dr. S. Kitazaki, Fukuoka Institute of Technology)

Schematic view and the result of EU-Japan data replication test: The maximum speed was limited under 80 % of the bandwidth not for disturbing other network traffics. It clearly demonstrated that high-speed data transfer had been stably sustained during 50 hours.

(a)Schematic illustration of beam trajectory and (b) dependence of beam width on bias voltage.
Visualization Study of Thermo-fluid Dynamics Under Microgravity Condition

In the microgravity environment we can find some hidden features in thermo-fluid dynamics which are not clear in normal gravity environment. For example, the capillary force becomes a significant role of fluid motion because the deference of weight (i.e., density) is meaningless under microgravity condition. In other words, we can recognize some physical effects under microgravity condition. Our team, NIFS, KEK and Wrocław University of Science and Technology, have tried the visualization experiment of boiling in Superfluid Helium using by the drop tower of ZARM (Center of Applied Space Technology and Microgravity) at University of Bremen, Germany. Through this experiment, we have aimed to reveal some hidden heat transfer mechanisms on the vapor-liquid interface.

Spherical bubble in Superfluid Helium under microgravity condition. The shape of the bubble is very close to perfect sphere because of microgravity.

Development of High Strength and High Magnetic Field Nb$_3$Sn Superconducting Wire by a New Metallurgical Approach

Nb$_3$Sn wires are expected not only for nuclear fusion reactors, but also for nuclear magnetic resonance equipment (NMR) leading the molecular science and the next generation high energy accelerator application. However, it is known that the superconducting properties of Nb$_3$Sn wires are deteriorated by the large electromagnetic force due to the high magnetic field. In general, reinforcement components are placed on the outer side of the wire to increase the strength, we succeeded in increasing of the mechanical strength by a new metallurgical approach. In the ternary bronze alloy (Cu-Sn-X) in which the third element “X” is added to the Cu-Sn ternary bronze alloy, Sn diffuses to Nb filament in order to form Nb$_3$Sn phase. Then the phase transformation occurs on the Cu-X binary alloy due to the solid solution strengthening. Currently, we are advancing optimization of the third element “X” for further improvement of properties.

Nb$_3$Sn phase formation and solid solution strengthening mechanism by NIFS’s new manufacturing method

In the conventional process, Nb filaments are inserted in Cu-Sn binary alloy and the Nb$_3$Sn phase is formed at the Cu-Sn/Nb interface by heat treatment. The Cu-Sn binary alloy after Nb$_3$Sn formation is softened by the Cu transformation. In NIFS’s new approach using a Cu-Sn-X ternary alloy, the Cu-Sn-X alloy after Nb$_3$Sn formation transforms into a Cu-X solid solution strengthened alloy and is relatively strengthened compared with the conventional process.

Simulation Studies on Energy Conversion Process During Magnetic Reconnection

A large solar flare which occurred in 2017 has been a popular topic among people. A solar flare is an explosive phenomenon on the solar surface which emits intense radiations and high-energy plasmas. It occurs as a trigger of magnetic reconnection, in which magnetic field lines are reconnected and stored magnetic energy is rapidly converted to plasma energy. The energy conversion mechanism, however, remains unsolved. In this study, we investigate magnetic reconnection by using the Plasma Simulator. We have found that ion velocity distributions with strange shape, such as a ring and a crescent moon, and thus have elucidated the ion energization mechanism by an electric field produced in magnetic reconnection.

Particle simulation results of magnetic reconnection. The upper figure shows that magnetic field lines are reconnected at the center. As shown in the lower figures, ion velocity distributions with strange shapes such as a ring and a crescent moon are found.
Rokkasho Research Center

History of NIFS Rokkasho Research Center

In parallel with the final process by which Cadarache in France was selected for the ITER construction site, Europe and Japan agreed to implement the Broader Approach (BA) activities from May 2007 in order to complement and support the ITER project and to contribute to the early realization of DEMO reactor as the next step of ITER. The BA activities are composed of three projects, and it was decided that two of them, the International Fusion Materials Irradiation Facility-Engineering Validation Engineering Design Activities (IFMIF/EVEDA) project and the International Fusion Energy Research Center (IFERC) project [http://www.iferc.org], should be implemented in the IFERC site which would be prepared in Rokkasho, Aomori, as a completely new foothold for fusion activities. In order to promote the cooperation and collaboration with the BA activities, Rokkasho Research Center of National Institute for Fusion Science (NIFS) was established in Rokkasho in May 2007, which was synchronized with the start of the BA activities.

Activities in NIFS Rokkasho Research Center

In the beginning, Rokkasho Research Center focused on PR activities such as organizing special exhibitions of fusion researches and hands-on experiment events, broadcasting the NIFS profile video, and distributing NIFS pamphlets. For example, the special exhibitions of nuclear fusion called “Plasma energy to shine the future” were held at the shopping center ReeV exhibition section from October 1 to November 30, 2008 and from November 29 to December 27, 2009. During the exhibition period, the hands-on experiment booth titled “Interesting Science Experiment Booth” was set up, and children and parents enjoyed the train running with superconducting magnets, the vacuum experiments, the plasma ball, and toys with scientific wonder.

From October 2010, a staff of NIFS Rokkasho Research Center is undertaking work as iFERC project leader, and NIFS has strengthened the cooperation for the BA activities. The iFERC project promotes three sub-projects consisting of DEMO Design and R&D Coordination Centre, Computational Simulation Centre, and ITER Remote Experimentation Centre. Other NIFS researchers participate in the BA activities through the application for a call for proposals to the National Institutes for Quantum and Radiological Science and Technology (QST) fusion directorate.

Also, the staff of NIFS Rokkasho Research Center is undertaking the role of the general coordination group leader of the DEMO design joint special team established in 2015. Since the collaboration among many researchers from NIFS and other institutions and technicians from companies is indispensable for the conceptual design investigations of DEMO reactor, which widely spread across instruments, equipment and facilities, the NIFS Rokkasho staff works as a coordinator.

The role of NIFS Rokkasho Research Center is to contribute widely not only to the success of ITER but also to the realization of fusion energy through the continuous efforts mentioned above.
Research Enhancement Strategy Office

The Research Enhancement Strategy Office was established by the Ministry of Education, Culture, Sports, Science and Technology in 2013 as a result of the selection of the National Institutes of Natural Sciences (NINS) for the “Research University Enhancement Promotion Project.” This project selected domestic universities and inter-university research institutes that conduct superlative research, and supports their research enhancement policies. A special feature of this program is the hiring and placement of Research Administrators (URA: university research administration staff) and their performance of related activities.

At NIFS, three Research Administrators focus on the four pillars of IR (Institutional Research): evaluation, public relations enhancement, collaborative research enhancement, and young researcher development. Task groups support the activities of the Research Administrators, and are moving forward with related projects working together with NIFS committees. These projects are linked to the NINS headquarters. In particular, public relations will be widely disseminated in Japan and abroad through the NINS headquarters.

Research Enhancement Strategy Office web page: http://reso.nifs.ac.jp/eng/

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### Division / Research Enhancement and Promotion Meeting

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**Research Enhancement Strategy Office**

Director (1)
Deputy Director (1)
Managers (5)
University Research Administrators (3)
Specially Appointed Senior Specialist (1)
Research Administration Staff (3)

**Director**

**Deputy-Director**

**Research Planning Task Group**

Discusses research planning for NIFS

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**IR/Evaluation Task Group**

1. Investigates and analyzes the research activities
2. Responds to external evaluations
3. Promotes collaboration with industry
4. Formulates research strategy

**Public Relations Enhancement Task Group**

1. Informs scholars in Japan and abroad of research results
2. Enhances awareness of fusion research
3. Produces videos and pamphlets
4. Assists with media relations

**Collaborative Research Enhancement Task Group**

1. Promotes collaborative research
2. Expands the collaborative research database
3. Designs international collaborative research projects

**Young Researchers Development Task Group**

1. Introduces incentives for young researchers
2. Composes guides for submitting research papers
3. Assists with applications for research funding grants
### Coordinated Research Activities

The Coordinated Research aims at a smooth accomplishment of a wide range of coordinated research activities at NIFS. It plans, establishes, supports the framework of coordinated research, and disseminates coordinated research achievements for their effective use. In order to accomplish the above-mentioned purpose, the coordination research committee with the subcommittees as shown in the figure below were established corresponding to a variety of coordinated research.

### Committee for Coordinated Research

- **Subcommittee for cooperation based on agreements**
- **Subcommittee for NINS cooperation**
- **Subcommittee for ITER-BA cooperation**
- **Subcommittee for stellarator-heliacron cooperation**
- **Subcommittee for laser cooperation**
- **Subcommittee for ST cooperation**
- **Subcommittee for academic-industrial cooperation**

### International Coordination(2019/4/1)

1. Multinational Coordination
   - The IEA Stellarator-Heliacron Technology Cooperation Program (SH-TCP) (Japan, Germany, Spain, U.S.A., Australia, Russia, Ukraine)
   - PWI-TCP (Japan, U.S.A., EURATOM, Australia)  
   - Spherical Tori (ST)TCP (Japan, U.S.A., EURATOM, Korea), etc.
2. Bilateral Coordination
   - Japan-United States Collaborative Program, Japan-Korea Fusion Collaboration Programs, Japan-China Collaborative Program, Japan-Russia Cooperation, Japan-EU Cooperation, etc.
3. Cooperation with Other Institutions (29 International Academic Exchange Agreements)  
4. Hosting of International Conferences (International Toki Conference, etc.)

### Academic Exchange Agreements

<table>
<thead>
<tr>
<th>Country</th>
<th>Organization</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>China</strong></td>
<td>Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP)</td>
<td>1992</td>
</tr>
<tr>
<td></td>
<td>Peking University</td>
<td>2017</td>
</tr>
<tr>
<td></td>
<td>Huazhong University of Science and Technology (HUST)</td>
<td>2018</td>
</tr>
<tr>
<td><strong>Germany</strong></td>
<td>Max Planck Institute for Plasma Physics (IPP)</td>
<td>1993</td>
</tr>
<tr>
<td></td>
<td>Karlsruhe Institute of Technology (KIT)</td>
<td>2005</td>
</tr>
<tr>
<td><strong>Russia</strong></td>
<td>Russian Research Center, Kurchatov Institute (KII)</td>
<td>1993</td>
</tr>
<tr>
<td></td>
<td>A. M. Plenkov General Physics Institute, Russian Academy of Sciences (GP)</td>
<td>2007</td>
</tr>
<tr>
<td><strong>Ukraine</strong></td>
<td>National Science Center Kurchatov Institute of Physics and Technology (KIP)</td>
<td>1994</td>
</tr>
<tr>
<td><strong>Australia</strong></td>
<td>Australian National University (ANU)</td>
<td>1995</td>
</tr>
<tr>
<td><strong>South Korea</strong></td>
<td>National Fusion Research Institute (NRF)</td>
<td>1996</td>
</tr>
<tr>
<td><strong>U.S.A.</strong></td>
<td>Princeton Plasma Physics Laboratory (PPPL)</td>
<td>2006</td>
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<tr>
<td></td>
<td>Oak Ridge National Laboratory (ORNL)</td>
<td>2006</td>
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<tr>
<td></td>
<td>College of Engineering, University of Wisconsin, Madison</td>
<td>2016</td>
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<tr>
<td><strong>France</strong></td>
<td>Aix-Marseille University (AMU)</td>
<td>2007</td>
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<tr>
<td></td>
<td>Commissariat à l’Énergie Atomique et aux Énergies Alternatives (CEA)</td>
<td>2015</td>
</tr>
<tr>
<td><strong>Spain</strong></td>
<td>National Research Center for Energy, Environment and Technology (CIEEMAT)</td>
<td>2009</td>
</tr>
<tr>
<td><strong>Netherlands</strong></td>
<td>Dutch Institute for Fundamental Energy Research (FOM) (DIFER)</td>
<td>2011</td>
</tr>
<tr>
<td><strong>Italy</strong></td>
<td>Institute of Ionized Gas (IGI)</td>
<td>2015</td>
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<tr>
<td></td>
<td>CONSORZIO RFX</td>
<td>2015</td>
</tr>
<tr>
<td><strong>Czech</strong></td>
<td>HILASE Centre, Institute of Physics CAS (FZU)</td>
<td>2016</td>
</tr>
<tr>
<td><strong>Thailand</strong></td>
<td>Chiang Mai University</td>
<td>2016</td>
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<tr>
<td></td>
<td>Institute of Plasma Physics and Laser Microfusion (IPLM)</td>
<td>2017</td>
</tr>
<tr>
<td><em>The ITER International Fusion Energy Organization (ITER)</em></td>
<td>2011</td>
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Coordinated International Research

Since its infancy, fusion research has been advanced through peaceful international coordination, and today broad-ranging research is conducted in many countries around the world. Further research and development toward making fusion reactors a reality requires the promotion of joint research programs based on a long-term outlook which bring together the knowledge of researchers not just in Japan, but from around the world. NIFS plays the role of an organization representing Japan in the international coordination of fusion research. Along with this, we are actively advancing joint research and exchange among researchers through international coordination. Regarding the ITER Project and the Broader Approach (BA), global projects that are currently in progress, we are cooperating in various ways, by contributing to the International Tokamak Physics Activity (ITPA), by sending experts, and by providing several technologically-advanced devices conducive to further development.

Examples of International Coordination

● The IEA Stellarator-Heliacon Cooperation
International Stellarator-Heliacon Confinement and Profile Database Activity

Extensive multi-national and multi-institutional coordinated research among Stellarator–Helicon (S–H) devices has been promoted under the auspices of the IEA (International Energy Agency) Stellarator–Helicon Technology Cooperation Program. Contracting parties are Australia, the EU, Japan, Russia, Ukraine, and the USA (in alphabetical order). Among them, Japan, through the Director General of the National Institute for Fusion Science, is performing leadership responsibilities as vice-chair. The scaling law for the energy confinement time, the so-called ISSO4, was successfully derived based on the extended S–H confinement database. Toward deepening physics understanding and increasing the predictive capability, the Profile database activity has been steadily expanded with the participation of multiple institutions.

● Japan–USA Cooperation Program
Progress in the Joint Projects

As a Joint Project in the Japan–USA Cooperation Program, the PHENIX Program (PFC evaluation by tritium Plasma, HEat and Neutron eXperiments) has been carried out in FY2013 to FY2018. In this program, unique studies were carried out that include high heat load and plasma exposure tests for the materials exposed to neutrons in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL).

The photograph below shows the Plasma Arc-Lamp facility, which was used for high heat load tests in divertor–relevant conditions for neutron-irradiated materials. As of April 2019, a new Joint Project, FRONTIER Program (Fusion Research Oriented to Neutron irradiation effects and Tritium behavior at material IntERfaces), was launched as a six-year program.

Photo by Ella Steinman

Plasma Arc-Lamp high heat load test facility (courtesy of ORNL)
Domestic Collaboration Research Programs

In order to satisfy the broad needs for advancing the latest research, NIFS prepares three forms of research collaboration. These are Bilateral Collaboration Research, LHD Project Collaboration Research, and General Collaboration Research. The joint use and joint research activities are powerfully developed by accepting research proposals from researchers each year.

NIFS collaboration research activities are always reviewed and improved so as to be compatible with the latest research trends by changing the categories of collaboration. In FY2011, the categories were revised, and a new category was introduced. The figures to the right above show the number of accepted collaboration subjects in each category after the revision, which indicates a year by year increase.

Bilateral Collaboration Research

Bilateral collaboration research promotes joint research bilaterally between NIFS and a research institute or a university research center which has a unique facility for nuclear fusion research. Under the collaboration, the facility is open for the researchers all over the country as a joint use program of NIFS, an inter-university research institute. This is a unique feature of the system and attracts attention as an example of an advanced network-type joint research system in Japanese academia.

At present, five research centers are participating in the program. They are: the Plasma Research Center at the University of Tsukuba, the Laboratory for Complex Energy Processes at Kyoto University, the Institute of Laser Engineering at Osaka University, the Advanced Fusion Research Center at Kyushu University, and the Hydrogen Isotope Research Center, Organization for Promotion of Research, at the University of Toyama.
Fusion DEMO Reactor Collaboration Research

This collaboration program was initiated in the fiscal year 2019 as the fourth category of the collaboration programs in NIFS to accelerate the "action plan towards the fusion DEMO research and development", which was composed by the Taskforce on DEMO Comprehensive Strategy in Ministry of Education, Culture, Sports, Science and Technology (MEXT). This program will attempt to solve issues of the "action plan" together with the collaboration programs in the National Institutes for Quantum and Radiological Science and Technology (QST).

LHD Project Collaboration Research

LHD Project Collaboration Research is joint research whereby collaborators research and develop, first at their respective universities, various kinds of new devices, technologies, or methods that can be applied to the LHD experiments. Through research and development, LHD Project Collaboration Research also aims at contributing to the progress of research activities at universities.

The opinions and recommendations from the nuclear fusion research community are important. It is a significant feature of this system that the Nuclear Fusion Network, which is composed of university researchers, is involved in the review of research proposals together. That multi-year proposals are available in this system is also a significant feature. In some cases, NIFS offers the collaborators the specific research category for submitting their application.

In principle, the research should be shifted to General Collaboration in order to apply the results to LHD after completing the research and development successfully.

General Collaboration Research

General Collaboration Research is a system for the collaborators to carry out their research by using the facilities or the resources of NIFS, including experimental devices, diagnostics, the supercomputer, databases, and others. Because nuclear fusion includes a wide research area in physics and technology, from fundamental research to application, the system has a variety of categories.

In this collaboration, the collaborators come to NIFS and carry out research at NIFS. However, if it is necessary, NIFS staff can go to the university of a collaborator to perform joint research there. Furthermore, in the "network-type collaboration" category, the collaborators may conduct experiments at other universities involved in a particular project.

Many exploratory research proposals are adopted in the General Collaboration Research, and since a graduate student can be a collaborator, it is useful for training young researchers.
Coordinated Research with Domestic Research Institutions

In many domestic universities and research institutions, the experimental and theoretical research which aims at the realization of nuclear fusion energy is advanced, as shown in the figure below. NIFS is promoting three types of collaborative research programs introduced previously to offer a place of research and interchange among researchers all over the country as a center of excellence of nuclear fusion science aiming at broad development of plasma and nuclear fusion research.

On the other hand, NIFS is striving also for exploitation of new scientific research fields through cooperation with institutions which have distinguished specialties by making individual scientific agreements with them.
Division of Deuterium Experiments Management

Experiments using deuterium as the feeding gas began from March 7, 2017, on the LHD. Because better confinement property is expected for deuterium plasmas than for hydrogen plasmas, deuterium experiments enable us to explore high temperature and high density plasmas closer to fusion conditions in the LHD without enlarging the machine size. We have established the Division of Deuterium Experiments Management in order to introduce the safety management systems and to consolidate experimental apparatuses related to the deuterium experiments. As a provision of the result of environmental radiation monitoring, we are endeavoring to strengthen safety management and information disclosure. These activities will be continued and further enhanced. It must be noted that plasma experiments using tritium as the feeding gas will never be conducted in the LHD.

Deuterium Experiments Project

Safety Management

Sufficient safety facilities, a strict management system, and wide information disclosure will be provided for deuterium experiments. The environmental radiation dose rate can be seen on the NIFS website at any time.

Measurement data with the radiation monitoring system (RMSAFE) at NIFS

Unit: nSv/h

Current data

Radiation data available on NIFS website

The photograph above shows the radiation monitoring points across the NIFS premises. The numbers indicate the latest data, which are updated every 10 minutes. Click an icon and you will see a record of the radiation amount for the day.

The enviroment radiation data 2017/3/21,22

March 21, 2017

March 22, 2017

When rain falls, the dose of α(β) rays changes.

amount of rainfall

Deuterium plasma experiment

Experiments are not performed on maintenance days.

The amount of environmental radiation does not change during the plasma experiment.

Previous data also can be seen on the NIFS website.
Safety Management

The Division for 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 healthy environment for all staff, co-researchers, and students. The division is composed of ten offices, as shown in the figure.

Training lecture held by the safety control office leaders and the safety management staff.

All workers attend the disaster prevention training held every year. They practice evacuation and extinguishing fires.

The leaders of the division for health and safety promotion regularly patrol the work areas.

Nine radiation monitoring posts are placed at the site boundary and five posts are placed near the laboratory buildings.

Through these activities, the Division for Health and Safety Promotion conducts environmental safety, which includes radiation safety, safety education, and radiation training. Furthermore, the industrial physician, and health and safety management supervisors also patrol the work areas. The Committee of Health and Safety discusses and recommends any safety, health, and environmental issues to improve the appropriate safety management. For detailed information, please visit our web-site http://www.nifs.ac.jp/
Education and Training of Young Researchers

An important role of NIFS, as a major institute for fusion research in Japan, is the education and training of young scientists who will support fusion science in the future. At NIFS, we have the Department of Fusion Science in SOKENDAI (The Graduate University for Advanced Studies). We also have several joint programs of graduate courses for fusion science with Japanese universities. In addition, advanced training of young scientists in the research collaboration programs is ongoing.

SOKENDAI (The Graduate University for Advanced Studies)

SOKENDAI (The Graduate University for Advanced Studies) was established in 1988 as the first Japanese university which consists of only a graduate course (no undergraduate course). SOKENDAI consists of six schools in Hayama: School of Cultural and Social Studies, School of High Energy Accelerator Science, School of Physical Sciences, School of Multidisciplinary Sciences, School of Life Science, School of Advanced Sciences. The School of Physical Sciences has five departments in different locations, including NIFS, which is the supporting institute for fusion science education. The Department of Fusion Science provides 14 students with two courses: the fusion systems course and the simulation studies course. The former course provides education in the characteristics of fusion plasmas and related technologies, and the latter provides education in fusion plasma physics using computer simulation. The Department of Fusion Science has a five-year doctoral course which started in 2006, as well as a three-year doctoral course.

Joint Program of Graduate Education and the Special Research Collaboration Program for Education

Graduate course education is given at NIFS apart from SOKENDAI in joint programs with the Division of Quantum Science of the Graduate School of Engineering in Hokkaido University, the Graduate School of Engineering in Tohoku University, the Graduate School of Frontier Sciences in Tokyo University, the Graduate School of Engineering in Nagoya University, the Graduate School of Science in Nagoya University, the Department of Energy Science of the Graduate School of Science and Engineering in University of Toyama, the Interdisciplinary Graduate School of Engineering Science in Kyushu University, and elsewhere. At present, 31 graduate students are involved in these programs. NIFS also accepts graduate students (15 in 2019) from other universities by offering a special post.

Library

Academic Information Center for Fusion Research

The NIFS Library collects various academic materials related to fusion studies and makes them available to NIFS researchers and to those belonging to domestic and international institutions. Users may enter the Library anytime, if they have a valid ID card, so that they can browse, borrow, or return books, or make photocopies.

Further, the Library can be accessed from the NIFS website, enabling users to search NIFS’s archive or tables of contents, to see NIFS’s research reports, and to read electronic journals and books. The Library also accepts requests to other organizations for making photocopies or lending books, requests for new books, questions, and other online services in an effort to expand its functions as an e-Library.

We support researchers through editing for the “Annual Report” and the NIFS series, both published since 2014. We also manage the NIFS Repository making research results and educational activities available to the public.

http://tosho.nifs.ac.jp/
Outreach to Society

The National Institute for Fusion Studies (NIFS) conducts public relations and outreach activities in order for society and the Japanese people to know about fusion research, the research activities, and the research results achieved at NIFS.

Every year we open the Institute and its research facilities to the community so that people may understand our research activities and become interested in our leading edge research. In our Open Campus event held in September 2018, more than 1,500 people, primarily parents and their children, visited NIFS (image ①).

Further, at the Fusion Festa event in Tokyo held in May 2018, to which more than 2,650 people visited, we held open lectures and a science classroom (image ②).

Moreover, we contribute activities to foster future researchers, such as Super Science High-school (SSH) activities (tours of the facilities, practical trainings), internship activities, and other projects.

Division of External Affairs

The Department of Society Cooperation, as the principal office for public relations and outreach activities, promotes conversation with Japanese society including the local community through various activities. Since the reorganization of the department in 2019, there are the five offices of Society Cooperation Office, Content Production Office, Event Planning Office, Public Relations and Tour Guide Office, and Outreach Promotion Office. A summary of the offices is depicted in the following illustration.

Many of the NIFS research staff are active as members of the department. Principal outreach activities include holding public explanatory meetings (image③), holding academic lectures for local residents (image④), providing tours of the NIFS facilities (image⑤), science classroom activities (image⑥), and public relations materials and video production.

Results of Activities held in 2018

- Community Meetings held at 23 places
- Periodic delivery of e-mail newsletters (Research Updates)
- Campus tours (any time) held approximately 330 times; more than 3,500 people participated
- Open lectures for the public
- Science classroom activities

Publications and Videos

- NIFS official pamphlet (in Japanese and in English)
- Public relations magazine: NIFS News
- Pamphlet Energy Creating the Future: Fusion
- NIFS video: For Our Children’s Future
- Public relations magazine: Letters from Plasma-kun

NIFS website
http://www.nifs.ac.jp/

Society Cooperation Office
- Communication with society
- Public explanatory meeting

Event Planning Office
Planning and management of events, such as Open Campus

Outreach Promotion Office
Outreach activities, such as presentations at exhibitions

PR and Tour Guide Office
- Tour guide for visitors
- PR toward visitors

Content Production Office
PR using printed material and home page
Accumulation and Utilization of Research Activities

Accumulation and Dissemination of Research Activities

NIFS is accumulating information related to research activities and is constructing databases useful for promoting improvement of research and education.

NIFS Repository

NIFS Repository releases academic results and intellectual products generated by research or educational activities at NIFS. Anyone can access these files free of charge on the Web. NIFS fulfills social responsibility and makes social contributions by releasing research and educational activities through the NIFS Repository.

Fusion Science Archives

Taking a Lesson from the Past

Fusion Science Archives preserves and maintains collections of historical documents and materials that are related to fusion research in Japan. These activities are important from the viewpoint of the historical evaluation of fusion research and its social accountability. New items are constantly added through domestic and international collaborations. They are stored in acid-free folders and boxes. The total number of registered items is about 25,500 as of December 2018 (See Figure). Part of those catalogues are available to the public through the internet in a hierarchic structure and can be accessed by the use of an electronic retrieval system.

http://www.nifs.ac.jp/archives/

Division of Information and Communication Systems

At NIFS information in various forms is processed in large quantities in each division, including experimental data. Moreover, since NIFS is an inter-university research institute, the exchange of information between outside institutions is also performed frequently, and NIFS is in the position of being asked for disclosure of information and security protection simultaneously.

The Division of Information and Communication Systems (ICS) organizes all the specialists in NIFS and arranges them dynamically in task (groups) and Information Security Office. By performing staff assignments flexibly, maintenance (groups) and Information Security Office management systems are multiplexed and solidified.
Site Map

History of NIFS

- **Nov. 1980** Science Council of the Ministry of Education proposes the “Long Range Plan for Fusion Plasma Research in Universities”
- **Mar. 1988** The structure of the National Institute for Fusion Science (NIFS) and the new project of the Large Helical Device (LHD) outlined
- **Apr. 1988** The preparation committee and preparation office for NIFS established
- **May. 1989** NIFS established
- **Apr. 1992** The Department of Fusion Science established at the School of Mathematical and Physical Science, Graduate University for Advanced Studies
- **Aug. 1995** The LHD building completed
- **July. 1997** Headquarters of NIFS moved from Nagoya to Toki
- **Dec. 1997** Completion of LHD
- **Apr. 1998** The LHD experiments started
- **Apr. 2004** Inter-University Research Institute Corporation, “National Institutes of Natural Sciences (NINS)” inaugurated NIFS becomes one of the research institutes which constitute NINS National University Corporation, “The Graduate University of Advanced Studies (SOKENDAI)” was established; The Department of Fusion Science established in the School of Physical Sciences, The Graduate University of Advanced Studies (SOKENDAI)
- **Apr. 2010** The research section reorganized, and the Department of Helical Plasma Research established
- **Feb. 2014** Research Enhancement Strategy Office established
- **Apr. 2016** Division of External Affairs established
- **Mar. 2017** The LHD deuterium experiments started