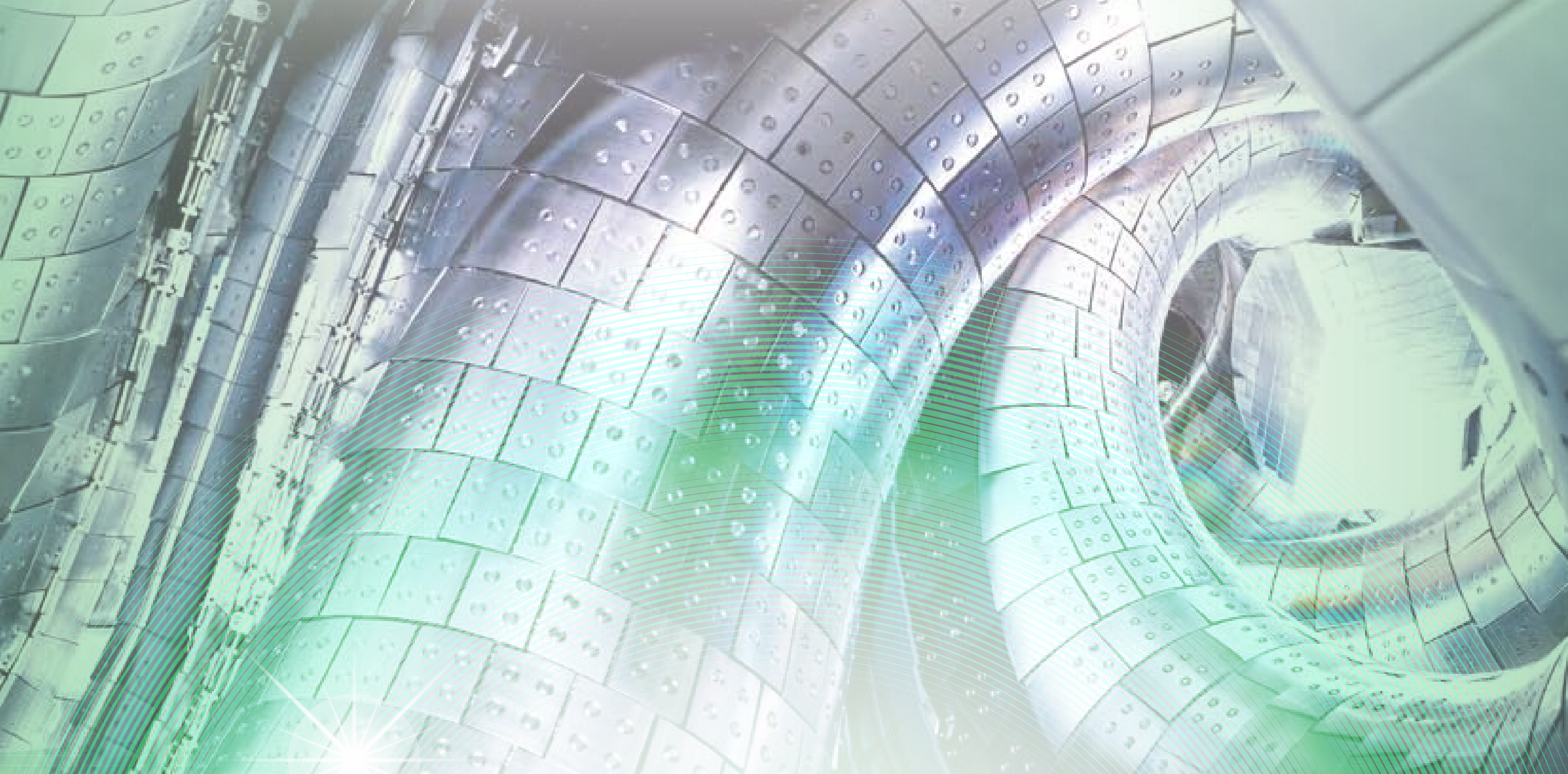

NIFS

NATIONAL INSTITUTE for FUSION SCIENCE

2022 ▸▸▸ 2023

English version
英語版

Inter-University Research Institute Corporation National Institutes of Natural Sciences
NATIONAL INSTITUTE FOR FUSION SCIENCE

NIFS NATIONAL INSTITUTE for FUSION SCIENCE 2022-2023

Inter-University Research Institute Corporation
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NATIONAL INSTITUTE FOR FUSION SCIENCE

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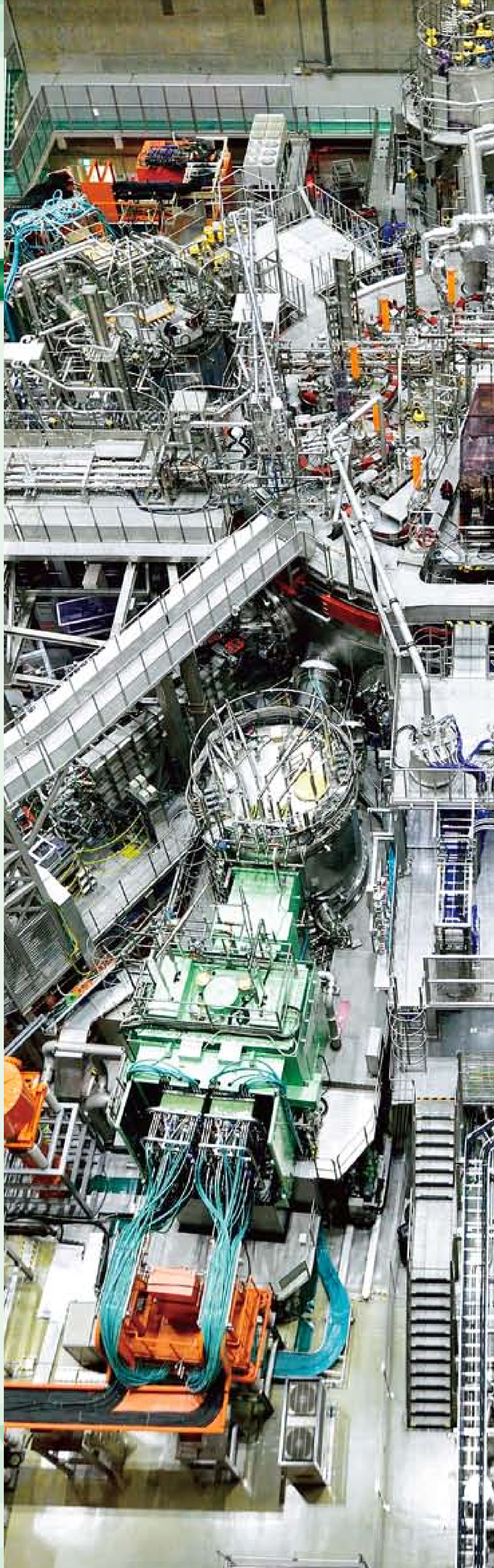
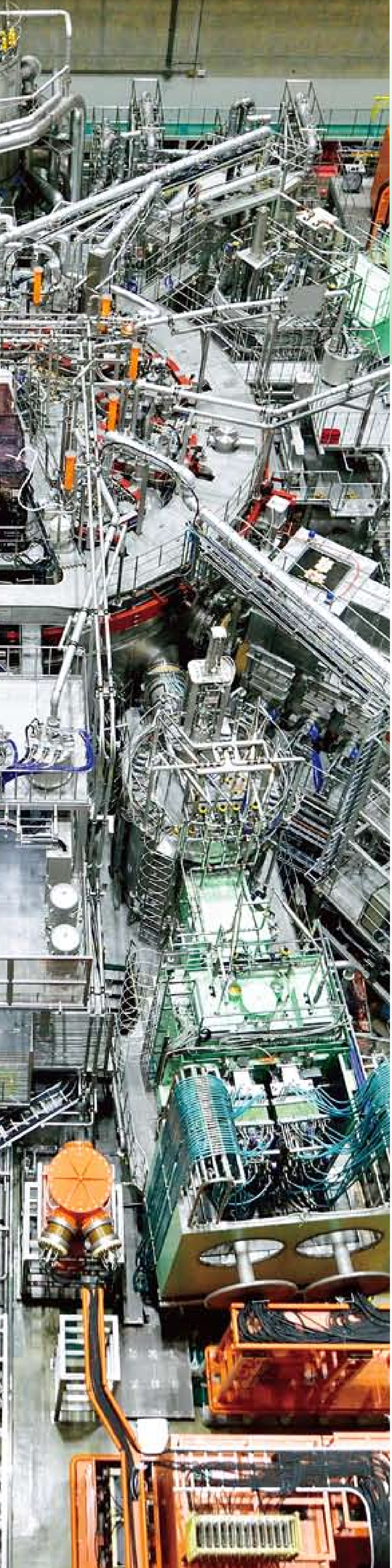




Towards a new era of fusion science

YOSHIDA Zensho
Director General of National Institute for Fusion Science
吉田 善章

Fusion science is a comprehensive area encompassing various disciplines with extremely high potential. Not only the immense merit of fusion energy, but also the possibilities of new discoveries give us the motivation to climb a high mountain - the history of overcoming every challenge has brought academic depth and breadth to fusion science. While the physics of fusion reactions is already well known, we have yet to understand how a “system”, called high-temperature plasma, can maintain a stable condition. It is a macroscopic system producing an internal energy by which autonomous dynamics sustains. The aim of fusion science is to elucidate the mechanism of such a spontaneous process; the fundamental principle must be common to the dynamics of the universe, society, or life. Recognizing the problem in a wide context, we pave the way in a zone of fundamental studies. On the way to fusion, the ultimate energy source, we will encounter many crossroads leading to future science and technology.

As we know, there are three different states of matter, i.e., solid, liquid, and gas. Even if the same molecules constitute matter, its “state” varies as the temperature is changed. At a high temperature, all matter becomes a gas, in which molecules are disconnected and distribute sparsely, moving freely. When the temperature is raised further, molecules are broken into ions (positively charged heavy particles) and electrons (negatively charged light particles) by disconnecting the electrical bonding of ions and electrons; we call such a high temperature state “plasma”. While plasma is not common on Earth, it is the most typical state of matter in the universe. Our sun is a huge mass of plasma, consisting mainly of hydrogen. inside it fusion reactions produce enormous energy. A star is a naturally made sustainable system of high temperature plasma, energized by fusion reactions.

Although the fusion energy is often likened to a “sun on Earth”, we need to think of a system that is completely different from stars. The challenge of fusion science is, indeed, to build a sustainable fusion system, based on a thoroughly new mechanism that we cannot find an example of in nature. A star confines plasma by gravity, but it is a very weak force, only effective against huge masses such as celestial bodies. We have to invoke a much stronger force to create a compact confinement system; magnetic force is the recourse. However, magnetic force acts like “vortex” and its role in creating macroscopic structures is an interesting subject of contemporary physics and mathematics. We also need a much higher temperature than the center of the sun. In a typical star like our sun (the main sequence star), the reaction of synthesizing a helium atom from a hydrogen atom proceeds slowly. This reaction (a so-called p-p chain reaction) is too slow for producing sufficient fusion power in a compact system. We need to apply a faster reaction (a so-called resonant fusion reaction); the easiest is the deuterium-tritium fusion reaction, which produces helium and neutrons, but occurs at temperatures of around 100 million degrees Celsius. On the other hand, several meters away from the plasma, we have to place super-conducting magnets to generate the magnetic field, which are operated at ultra-low temperature. Therefore, fusion on Earth requires an extreme technology, dealing with ultra-high temperatures and ultra-low temperatures, separated only by several meters.

The road to fusion power is purgatory, which is much harder than the prediction made at the beginning (the mid-20th century). However, it is not necessarily unfortunate that we encounter unexpected challenges. As many great researchers say that discovery is born from failure, unknown truths exist outside the range that one can predict. Fusion energy is a steep peak for development researchers to climb, but it is also a treasure trove for academic researchers. The task of the academic researcher is to generate new knowledge from the input of difficult problems.

All members of the National Institute for Fusion Science (NIFS) are working on the construction of a lighthouse that illuminates the direction of fusion science in choppy academic waters ahead. NIFS is a broad avenue for many researchers, through which the scope of “fusion science” will extend in the world of science. We hope that many people will pay attention to our endeavor and participate in these activities.

October 2022

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.

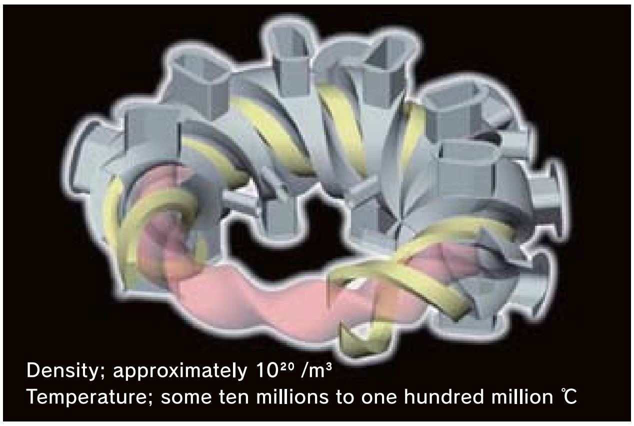
Fossil fuels such as coal, petroleum, and natural gas have powered our industrial society based on highly-advanced modern science and technology. However, our heavy dependence on them has released an immense volume of carbon dioxide and nitrogen oxide into the air, which is having a serious impact on 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 outside 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.

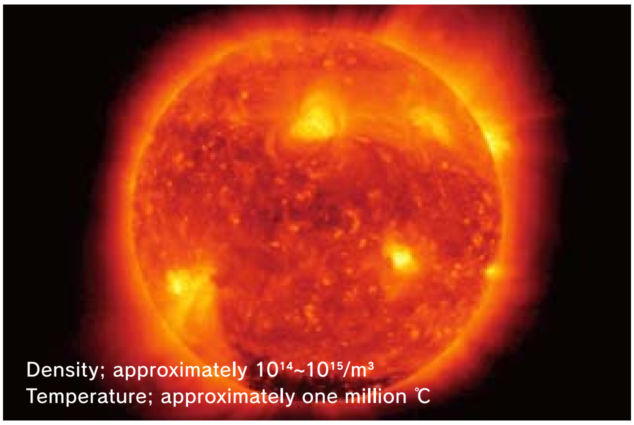
Various Forms of Plasmas

Nuclear fusion plasmas



Schematic picture: Magnetically confined fusion plasma

Solar corona

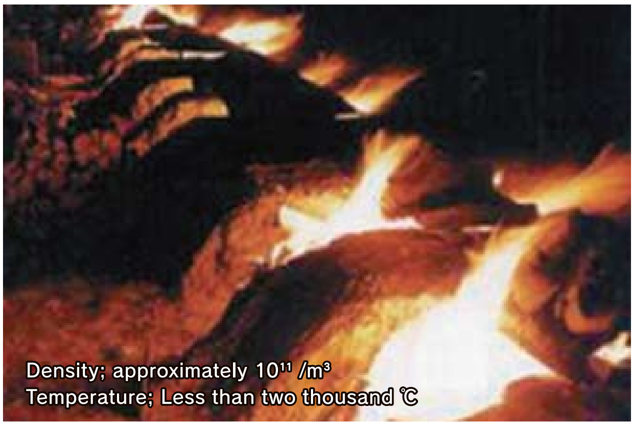


Photograph: provided by NAOJ/JAXA/MSU

Aurora

Photograph: provided by National Institute of Polar Research

Flame (inside the field kiln)

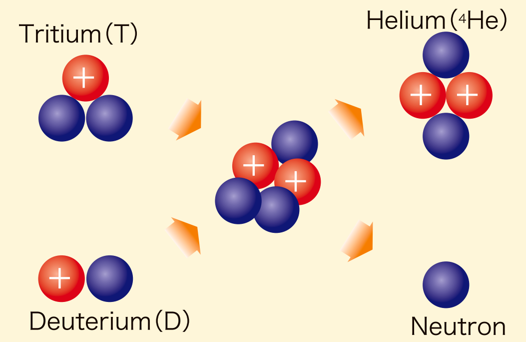


Photograph: provided by the Toki City Junior Chamber

What is FUSION?

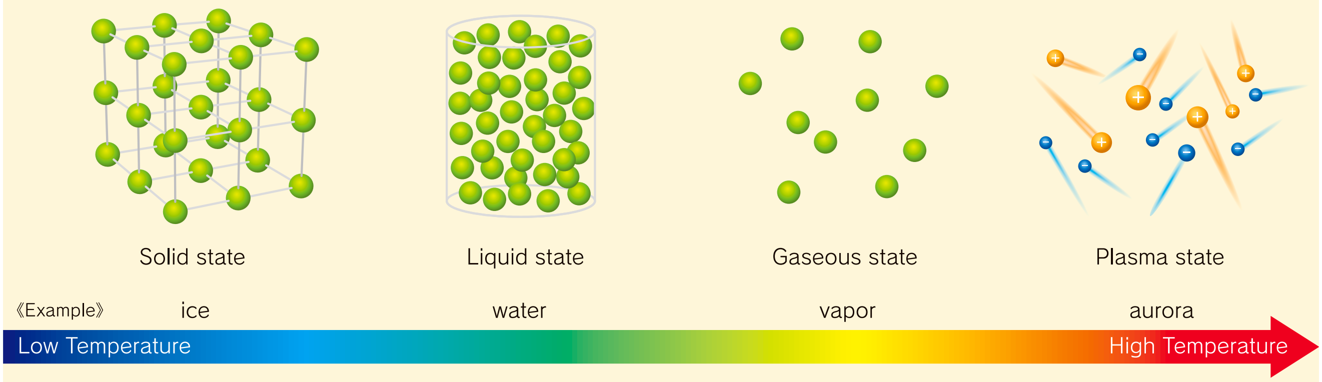
Fusion refers to a nuclear reaction in which lighter nuclei collide with each other to become a heavier nucleus. The total mass of the resulting nuclei is less than that of the original nuclei. Given Einstein's equation ($E=mc^2$), the missing amount of mass is to transform into energy released as a 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.

●D-T (Deuterium-Tritium) reaction

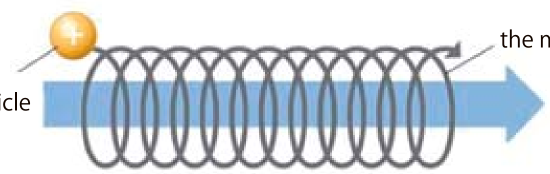


The future fusion power generator is expected to use the reaction between deuterium and tritium at temperatures exceeding 100 million degrees Celsius. When the temperature reaches more than 10,000 degrees Celsius, substances separate into ions and electrons, and reach the status of an ionized gas called "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



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 method 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

April 2022

- Advisory Committee
  - Advisory Board
  - Units Preparation Office
  - Review Team of Academic Experiment Platforms
  - Liaison Meeting of Bilateral Collaboration Research
- Director General
  - 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
  - Project
    - Large Helical Device Project
    - Numerical Simulation Reactor Research Project
    - Fusion Engineering Research Project
  - Department of Helical Plasma Research
    - 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

Staff

Director General	1
Researchers	114
Engineers	44
Administrative Staff	43
Employees on Annual Salary System	15
Research Administrator Staff	3

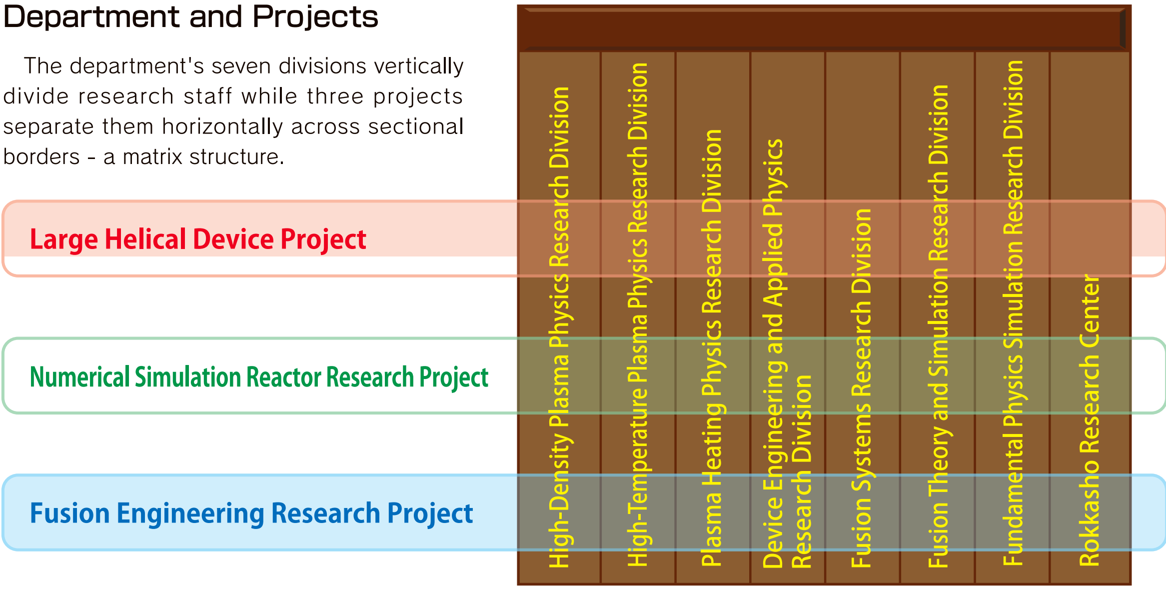
Research Activities

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.

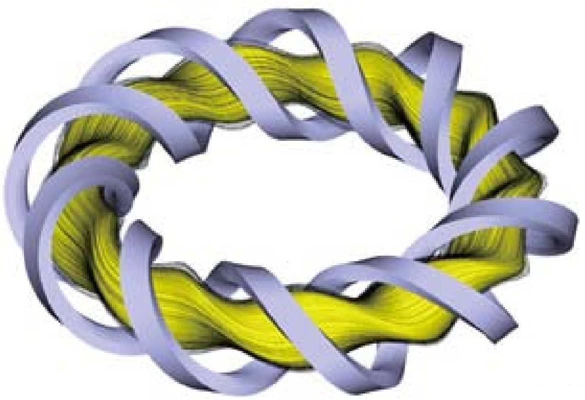


- The High-Density Plasma Physics Research Division conducts comprehensive study of particle fueling/exhausting, heat removal from plasma facing components, to produce and maintain the reactor-relevant plasma. Edge plasma control with the divertor is also investigated to improve the core plasma performance.
- The High-Temperature Plasma Physics Research Division is in charge of investigation of high-temperature plasma physics based on the development of high-accuracy measurement systems.
- The Plasma Heating Physics Research Division performs an important roll for realizing a high-temperature and high-density plasma which satisfies a fusion reactor condition.
- The Device Engineering and Applied Physics Research Division advances broad-based academic research on fusion engineering with a focus on large-scale superconductivity, cryogenics, and radiological safety toward the early realization of a stable and safe fusion reactor.
- The Fusion Systems Research Division promotes reactor system design studies and also carries out the research on low activation materials and materials systems, blankets, reactor structure, plasma-facing components, and the relevant elementary atomic and molecular 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 advances cutting-edge plasma and fusion simulations, interdisciplinary studies, and virtual reality (VR) visualizations.

Large Helical Device (LHD) Project

The Large Helical Device (LHD) Project conducts research on the confinement of high-temperature, high-density plasmas using the LHD, which employs a confinement magnetic field called the heliotron configuration. The LHD is one of the world's largest helical devices with superconducting coils that can generate a strong magnetic field on a regular basis. We are working on research issues related to core plasma physics, steady-state maintenance, and reactor engineering, which are necessary to realize future fusion reactors, by taking advantage of the excellent stability and steady-state characteristics of the LHD.

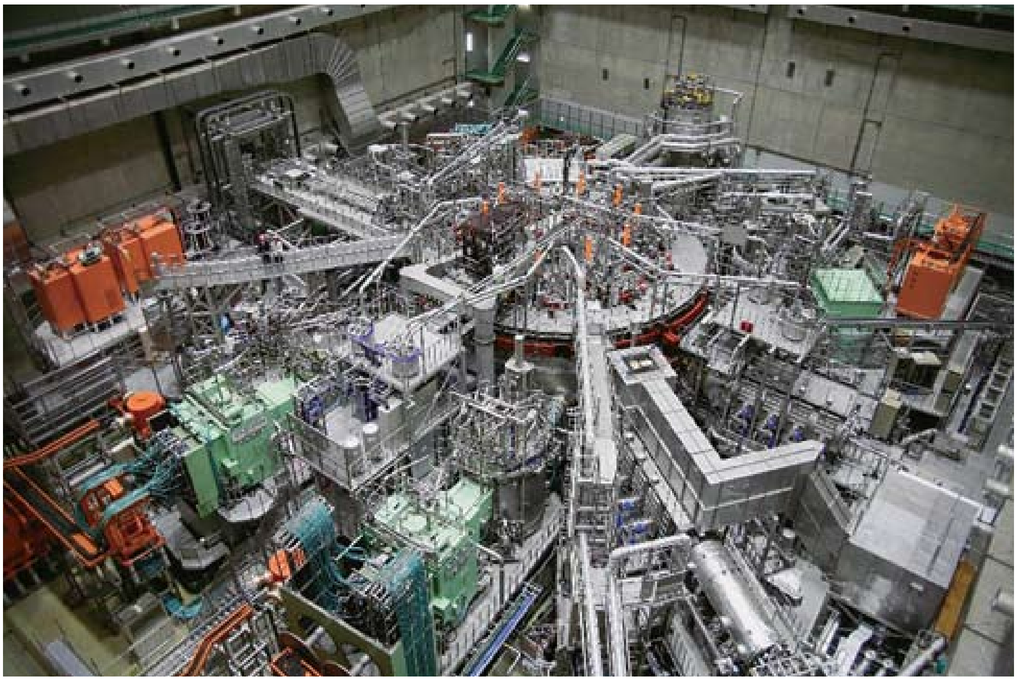
Heliotron Coordination

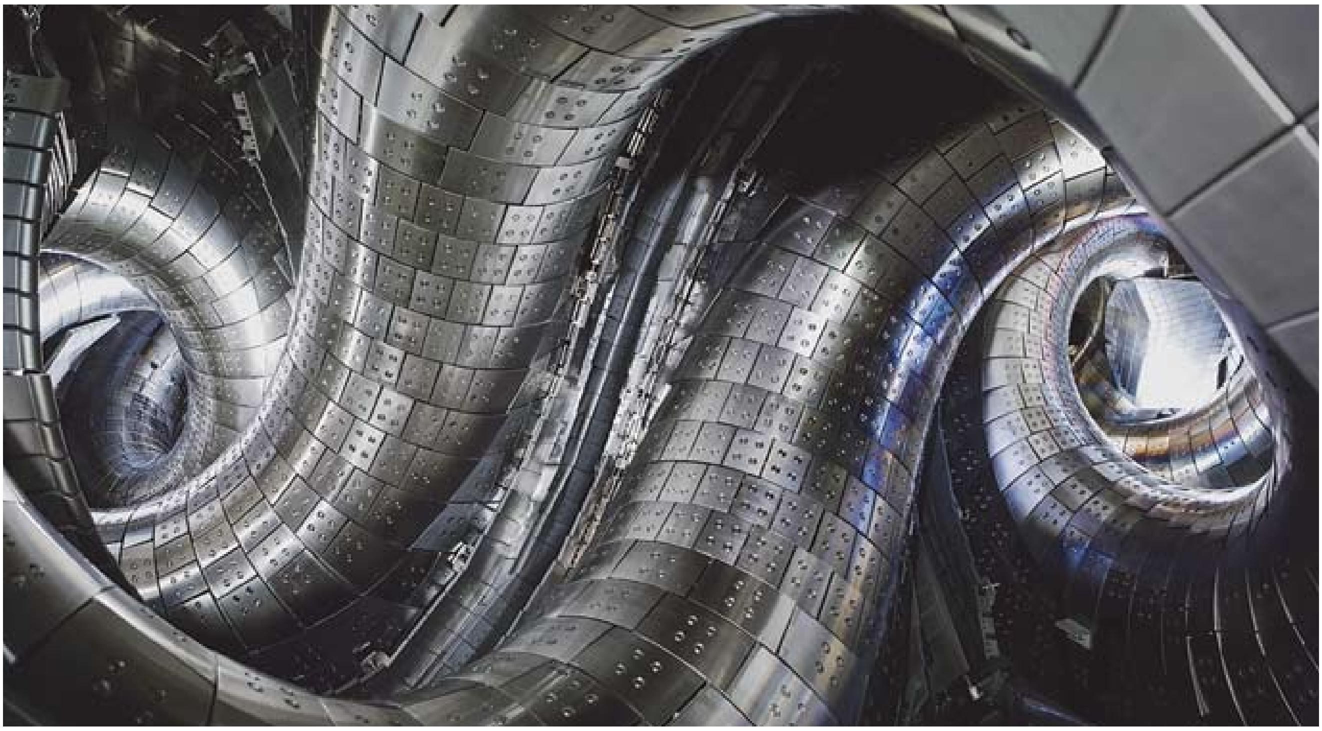


In order to stably confine plasma in a magnetic field container (a basket of magnetic field lines), an infinitely circulating magnetic field line with no end is required to close an escape route for particles. In addition, in order to create a donut-shaped cage with these lines of magnetic force, it is necessary to add a twist to the lines of magnetic field. The LHD is a helical device that employs a magnetic field configuration called a heliotron configuration. The heliotron configuration has excellent steady-state operation capability because the magnetic field configuration necessary for confining the plasma can be formed using only a pair of helical external coils.

Outline of Large Helical Device

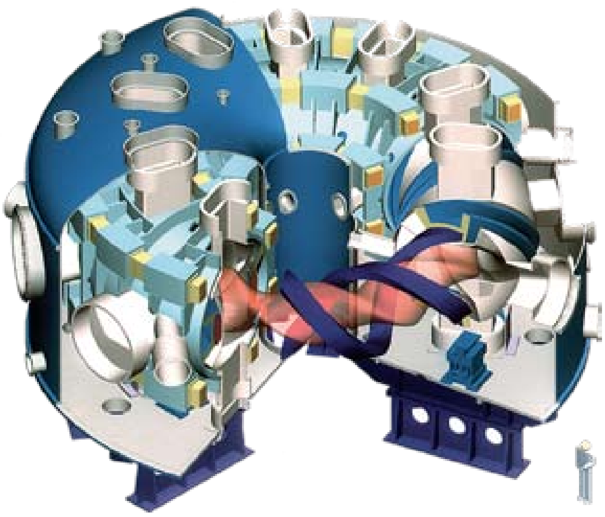
In the LHD project, academic research is being promoted to improve plasma performance and to understand the physics common to torus plasmas, including tokamaks, by using helical plasmas that do not require current flowing in the plasma, leading to the design of helical fusion reactors. The LHD consists of the main body of the device, using superconducting coils, various plasma heating devices, and various instruments to measure various physical quantities such as the temperature and density of the plasma.





Large Helical Device (LHD) Project

Device parameter of LHD	
Outside diameter	13.5 m
Height	9.1 m
Weight	approx.1,500 t
Major radius	3.9 m
Minor radius	0.6 m
Plasma volume	30 m^3
Magnetic field strength	3 Tesla
Total heating power	36 MW



Plasma parameters

The core plasma of a future fusion reactor must have an ion temperature of more than 120 million degrees Celsius and a density of more than 100 trillion ions per cm^3 at the same time, for sustained fusion reactions of deuterium and tritium as fuel. The LHD has been improving its plasma performance for more than 20 years since the first plasma ignition on March 31, 1998, using hydrogen. The ion temperature reached 120 million degrees in the deuterium experiment that started in March 2017, with a central density of 13 trillion ions per cm^3. In terms of density, we achieved a central density of 1200 trillion per cm^3, which is more than 10 times the requirement for fusion, at a low temperature of 3 million degrees. In addition, the β value (the ratio of plasma pressure to magnetic field pressure), which determines the economic efficiency of a fusion reactor, was successfully increased to more than 5 % for the first time in the world, for a helical system. The table below shows the achieved values of the plasma parameters obtained so far in the LHD. Detailed experimental data analysis using advanced plasma measurement devices developed in the LHD and theoretical studies using computer simulations are being conducted in collaboration with universities and research institutes in Japan and overseas.

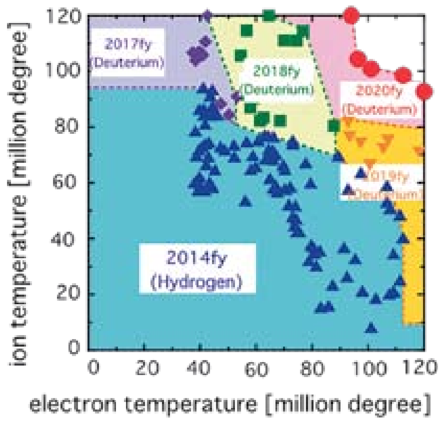
LHD plasma parameters

Plasma parameters	Achievement	Final goal
Ion temperature	120 million degrees (1.3×10^{19} /m^3)	120 million degrees (2.0×10^{19} /m^3)
Electron temperature	230 million degrees (0.2×10^{19} /m^3) 120 million degrees (1.6×10^{19} /m^3)	120 million degrees (2.0×10^{19} /m^3)
Electron density	1.2×10^{21} /m^3 (3 million degrees)	4.0×10^{20} /m^3 (15 million degrees)
β value	5.1 % (0.425 Tesla) 4.1 % (1.00 Tesla)	5 % (1-2 Tesla)
Plasma duration	54 min. (0.5 MW) 48 min. (1.2 MW)	1 hour (3 MW)

Progress in Research

Research on confining high-temperature plasmas with magnetic fields is being conducted around the world with the aim of realizing nuclear fusion power generation. At the Large Helical Device (LHD) of the National Institute for Fusion Science, a "deuterium plasma experiment" has been conducted since 2017 to generate plasma using deuterium gas, and an ion temperature of 120 million degrees Celsius, which is one of the conditions for nuclear fusion, has been achieved. In the LHD, we are also conducting experiments on mixed hydrogen isotope plasmas of "deuterium" and "hydrogen" to simulate the mixed hydrogen isotope plasmas of "deuterium" and "tritium" that will be used in future fusion power generation. This experiment has produced results that will form the basis of future fusion research, such as the world's first observation of mixed hydrogen isotopes.

The realization of fusion power generation requires the stable maintenance of a very high temperature plasma for a long period of time, and there are many issues to be solved to maintain this stability. Plasma confined by a magnetic field must be kept at a high temperature of more than 100 million degrees Celsius in the center where the fusion reaction takes place, while the plasma temperature at the periphery must be kept as low as possible to reduce the heat load on the walls of the device that confines the plasma. This temperature gradient is extremely steep, 100 million degrees in about one meter. When the temperature gradient becomes steep, turbulence with various sizes of vortices is generated in the plasma, and this turbulence stirs the plasma, resulting in a low center temperature. In addition, when the plasma pressure gradient becomes steep, the plasma becomes unstable, and a part of the confined plasma may be lost (this phenomenon is called instability). Therefore, it is necessary to understand turbulence and instability and to establish methods to control them in order to maintain plasma stability.



In the LHD deuterium plasma experiment in FY2020, we developed a scenario to generate a plasma with electron and ion temperatures reaching 100 million degrees and conducted physics experiments using this plasma and achieved many results in 2021. Until now, plasmas with an ion temperature of 100 million degrees or higher have had a low electron temperature, and with this success, we were able to establish a method to produce plasmas that reached 100 million degrees. With this success, LHD research has entered a new stage.

Physics experiments on deuterium and hydrogen isotope mixed plasmas have led to new discoveries about turbulence and instability that interfere with maintaining plasma stability. With regard to turbulence, we found that the central and peripheral regions of the plasma require completely different controls. We found that in the center of the plasma, a steep temperature gradient can be formed by reducing the turbulence, whereas at the edge, increasing the turbulence reduces the heat load on the device. Therefore, it became clear that it is desirable to control the turbulence by suppressing it in the center of the plasma and increasing it at the edge. Experiments have shown that turbulence, which has been emphasized as a negative aspect of fusion, has a positive one. There are two types of plasma instabilities that occur when the pressure gradient becomes steep: those that appear slowly and persist, and those that appear suddenly. Suddenly appearing instabilities are like earthquakes, in that they can occur at any time, but we do not know when. For this sudden type, important experimental results were obtained to clarify the "trigger" and the effect on the plasma.

Physics experiments on plasma turbulence and instability have provided important insights for the development of control methods for turbulence and instability in future fusion plasmas. Turbulence and sudden instabilities are considered to be deeply related not only to fusion plasmas but also to various phenomena occurring in space and on the earth. We are planning to promote such interdisciplinary research in the LHD.

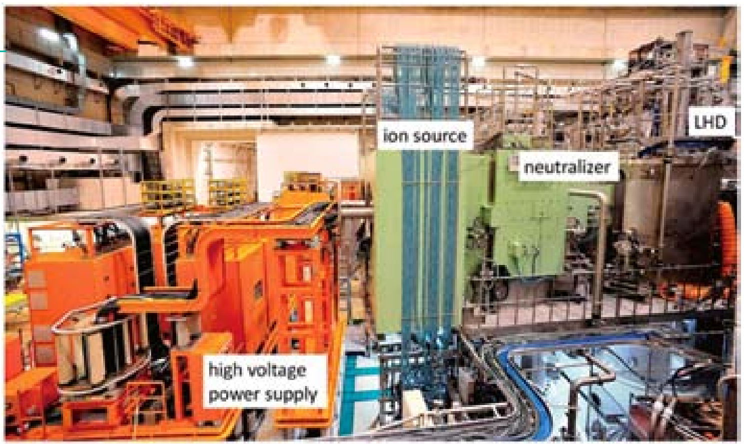
Research results are available at https://www-lhd.nifs.ac.jp/pub/Science_en.html
LHD data is also available at https://www-lhd.nifs.ac.jp/pub/Repository_en.html

High-Performance Peripheral Devices to Realize Efficient LHD Experiments

Neutral Beam Injection System (NBI)

By injecting a beam of high energy hydrogen atoms into the plasma, the ions and electrons are heated. The LHD is equipped with five neutral beam injectors, three of which use negative hydrogen ions having the world's highest performance (beam current). These devices heat ions to 120 million degrees Celsius, which is the required condition for nuclear fusion.

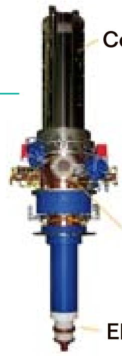
The LHD is the only machine where the Negative-ion based NBI (N-NBI) is in operation. Since the negative-ion based NBI technology is essential for ITER, which is being constructed in Cadarache, France under international collaboration and will demonstrate burning plasmas, the collaboration for N-NBI development was started from fiscal year 2021.



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

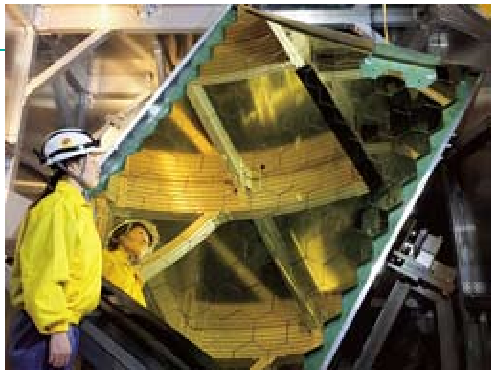
Electron Cyclotron Resonance Heating System (ECH)

The electrons in the plasma are heated by high-frequency electromagnetic waves of 77 and 154 GHz. The high-power electromagnetic waves for heating are produced by a giant vacuum tube called a gyrotron（3 m in length）. The gyrotron generates the world's largest power output of 1,000 kW, which is injected into the plasma. Five gyrotrons in the LHD heat the electrons to 100 million degrees Celsius or higher. These gyrotrons were developed in collaboration research with the university.



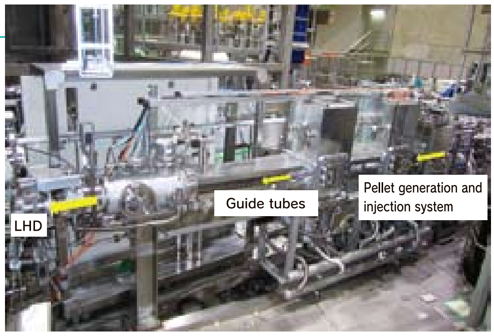
Thomson Scattering System

The measurement of ultra-high temperature plasmas is performed without contact using active laser spectroscopy. An intense infrared laser beam is injected into the plasma. Spectroscopy of the scattered light, called "Thomson scattering", caused by electrons, provides the electron temperature and electron density of the plasma. The LHD's Thomson scattering system, which has the world's highest accuracy, has provided a large amount of data leading to important results. The photo shows a large concave mirror that collects weak scattered light from the plasma and produces an image. It consists of 130 pieces of mirrors, having a gold coating on its surface.



Pellet Injector

This is a device that supplies hydrogen, the "source" of the plasma, into the plasma. To inject as much hydrogen as possible into the center of the plasma, the hydrogen is not injected as gas, but as solid ice. The LHD's pellet injector is designed to inject the pellet at high speed. It is capable of continuously injecting 20 pellets at a speed of 1,300 meters per second.



The pellet injection device for the LHD. The yellow arrows indicate the path of the pellet.

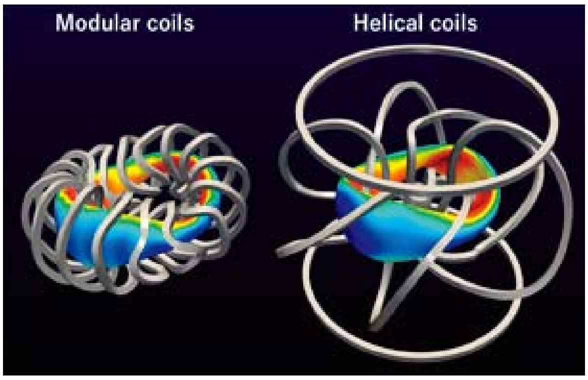
Numerical Simulation Reactor Research Project

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 an integrated system of simulation codes to predict behaviors of fusion plasmas over the whole machine range.

Research Results in 2021

Result 1 A new coil-designing technique using free-form curves and a genetic algorithm

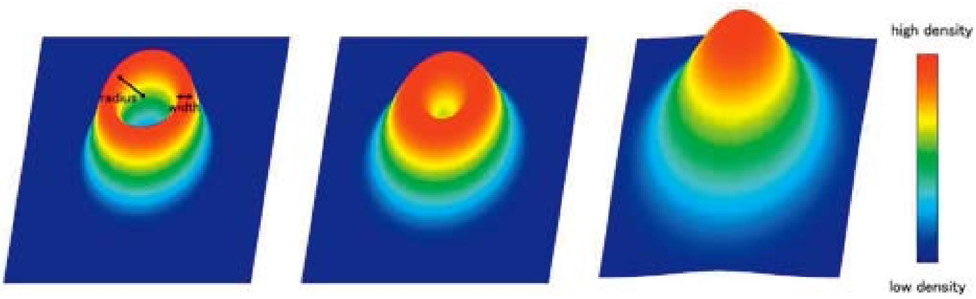
Owing to progress in numerical simulations and computers, the optimized magnetic field configurations that are expected to confine high-temperature plasma efficiently in a steady state have been found. A known method to generate such magnetic fields is to use modular coils. The continuous helical coils, that have also been used for fusion devices such as the Large Helical Device, have unique advantages: the large space between coils enabling easier access into the vacuum vessel and the existence of magnetic field lines guiding the heat and particle fluxes to the exhaust. However, the previous method of designing helical coils could cover only limited types of magnetic configurations. We have developed a new coil-designing technique that is applicable to both the modular and the helical coils, employing free-form curves and a genetic algorithm. By applying this new technique, we have found that a numerically-optimized magnetic field can be reproduced both by the modular coils and the helical ones. We have also found that these helical coils still generate the magnetic field lines that would guide the plasma to the exhaust, as conventional helical coils do. We are working on implementing this technique into a new tool for designing and optimizing a fusion device, taking into account entire magnetic field structures inside the vacuum vessel.



Modular coils (left) and helical coils (right) generating the optimized magnetic field, together with the actual magnetic surface generated by coils are shown. The shape of both types of coil are expressed using free-form curves and have been optimized to reproduce the target magnetic field.

Result 2 Discovery of Pseudo-Maxwellian Velocity Distributions and Clarification of its Formation Mechanism

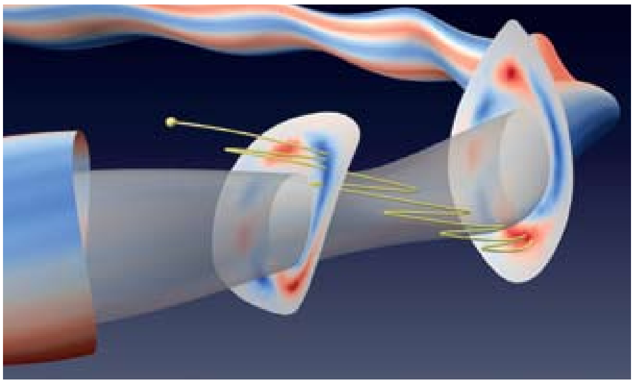
For realization of fusion on earth, plasma heating to extremely high temperature is required. In a different type of device from the LHD, "a spherical tokamak," a heating method via magnetic reconnection is employed, and in this study, we investigate magnetic reconnection physics by means of simulations. In 2021 we found a mountain-shaped ion velocity distribution, which is almost indistinguishable in shape from a Maxwellian one, i.e., a typical velocity distribution under a thermal equilibrium state. We have named it "a pseudo-Maxwellian distribution." In addition, we have shown that the pseudo-Maxwellian distribution belongs to a ring-shaped one with a large width. When the width is much less than the radius, we can clearly see a ring shape, as displayed in the left figure. As the width becomes larger, it is overlapped near the center, and thus the ring's hole is being plugged, as shown in the middle figure. If the width is larger than a criterion, the center is transformed from a hole into the peak of a mountain, that is, a pseudo-Maxwellian distribution is formed, as shown in the right figure. This finding means that although a system is not in a thermal equilibrium state, velocity distributions indistinguishable from a Maxwellian one can exist, and has the potential to significantly affect existing knowledge in experiments and observations.



Bird's eye view of ring-shaped velocity distribution with width. In the left panel, the ring width is much less than the radius, and hence we can clearly see a ring-shaped structure. The middle panel shows that as the ring width becomes larger, the hole in the center is being plugged. In the right panel, the ring width is extremely large, we can see a mountain-shaped, that is, pseudo-Maxwellian distribution, but not a ring-shaped one.

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 (3D) 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.



Fluctuations of electron pressure due to an interchange mode and orbits of trapped ions. We have realized that the trapped ions have a role in lessening the instability.

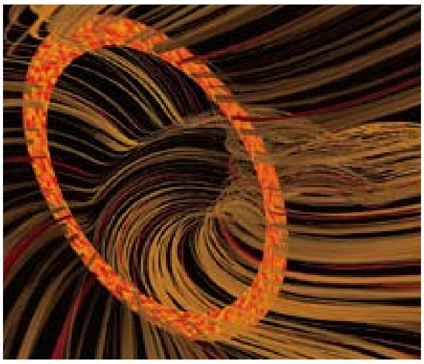
Peripheral Plasma Transport Modeling

Peripheral plasma surrounds core plasma, and interacts with the device walls through an open magnetic field. It balances the confinement of heat and particles in the plasma and the protection of the wall materials, therefore it is an important region for fusion reactor design. We promote research for estimation of physical quantities and for physical understanding of plasma characteristics by modeling transport of the peripheral plasma interacting strongly with hydrogen gas and impurities in three-dimensional devices. We are developing direct comparison methods with measurements of experiments and simulation schemes of realistic discharge conditions. We are working on an application of the transport modeling to helical/stellarator, tokamak, and linear devices through domestic/international collaborations with researchers and the education of students.

A visualization of radiation from a neon-seeded LHD plasma calculated by the EMC3-EIRENE code. The neon radiation shown in blue takes heat from the plasma and reduces its temperature in the peripheral region. This mechanism is utilized to reduce the heat load on the walls.

Kinetic Transport Simulation

In high-temperature plasmas confined in fusion devices, transport of particles, heat and momentum is driven by inhomogeneity of the magnetic field, density and temperature profiles. Using supercomputers, we examine particle motions and their collective properties causing turbulence and/or Coulomb collisions, and investigate more efficient ways to confine the plasma. For the sake of integrated simulations of the whole plasma with extremely different space-time scales, we also grapple with modeling of transport coefficients, for example, heat diffusivity, using analyses of simulation data.



Density fluctuations in the LHD plasma obtained by large-scale simulations of turbulence.

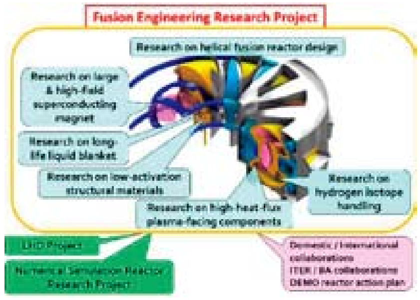
Plasma Simulator Raijin

The Plasma Simulator Raijin is a massive parallel supercomputer system utilized to promote the Numerical Simulation Reactor Research Project. The Plasma Simulator Raijin consists of 540 computers, each of which is equipped with eight "Vector Engine" accelerators. The 540 computers are connected with each other by a high-speed interconnect network. The computational performance of the Plasma Simulator Raijin is 10.5 petaflops. The capacities of the main memory and the external storage system are 202 terabytes and 32.1 petabytes, respectively. The Plasma Simulator Raijin is capable of large-scale simulations of fusion plasmas.

Plasma Simulator Raijin

Fusion Engineering Research Project

The Fusion Engineering Research Project conducts both a conceptual design of a steady-state fusion reactor and various types of engineering research. The project consists of three research groups: Reactor System Design, the Superconducting Magnet, and In-Vessel Components, with 13 task groups. As the center of universities' fusion engineering research, the project carries out domestic and international collaborations utilizing state-of-the-art technologies.



Latest Results

Development of large-current HTS conductors

Large-current high-temperature superconducting (HTS) conductors are being developed for application to next-generation fusion experimental devices. We have designed three types of conductors with different internal structures: STARS, FAIR, and WISE using copper-oxide REBCO wires. Sample conductors were fabricated and tested to examine their characteristics. It has been confirmed that the conductors can energize extremely stably in magnetic fields exceeding 8 Tesla at temperatures 20 degrees higher than -269 degrees Celsius, which is the operating temperature of conventional low-temperature superconducting (LTS) conductors. The current exceeds 20,000 amperes.

Large-current HTS conductors for application in next-generation fusion experimental devices (left: STARS, middle: FAIR, right: WISE)

Development of ultra-high heat removal divertor

The divertor directly receives extremely high heat loading coming from high-temperature plasmas. We have successfully developed a divertor component with ultra-high heat removal efficiency, using a new method, Advanced Multi-Step Brazing (AMSB), to join oxide dispersion strengthened copper alloy (ODS-Cu) to tungsten and other materials. A prototype divertor component fabricated by AMSB has been installed in LHD, which demonstrated excellent heat removal performance. We have also successfully developed a joint technique between a large tungsten sheet and stainless steel, using AMSB.

Prototype divertor heat removal component of W/ODS-Cu, fabricated by AMSB

Joint sample of tungsten sheet and stainless steel, fabricated by AMSB

Structural Design of Fusion Reactor by Topology Optimization

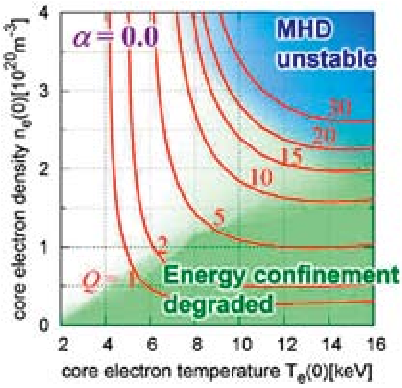
The superconducting coils of a fusion reactor are subject to huge electromagnetic forces of up to 10,000 tons per meter. Therefore, the coils are supported by a structure with sufficient strength. In a conventional design, the total weight of the coils and the structure exceeds 10,000 tons. "Topology optimization" has been applied to reduce this weight, such as by making new apertures in the structure (to change the topology). The figure shows the result of topology optimization. The total weight of the structure is reduced by approximately 25%. A seismic analysis was also conducted on the optimized model, and the soundness of the structure was confirmed.

Conventional design (left) and a topology-optimized one (right) for the coil supporting structure (a part of a doughnut is shown for both).

Research Groups

Reactor System Design Research Group

The Reactor System Design Research Group is responsible for the consistent design of the "plasma," "superconducting magnet," and "blanket" systems. It is also responsible for a system design to determine the specifications of the main components, design of fuel supply to the plasma core, the study of fuel cycle safety treatment systems, calculation of neutron transports, the study of hypothetical operation schedules, and evaluation of power generation costs. Through these studies, we are enhancing the interlinkage between design studies and elemental technology development studies. We are also preparing an academic roadmap in a form that contrasts academic research themes that contribute to solving R&D issues originating in the helical fusion reactor.



The system design code searches for the optimum operation point (within the white area) on the plane of electron and ion temperatures at the plasma center.

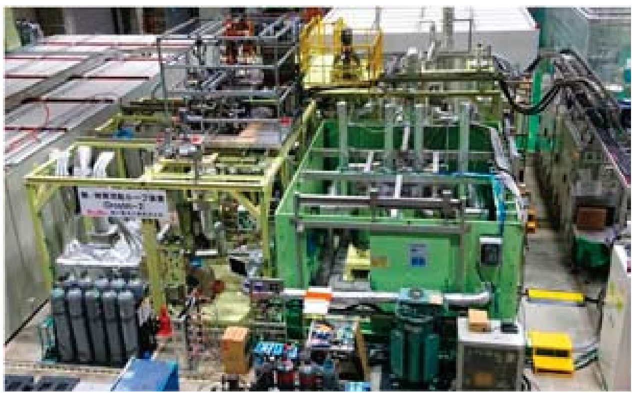
Superconducting Magnet Research Group

Plasma in a fusion reactor is confined by a strong magnetic field. To generate this magnetic field, a superconducting magnet is made by winding superconductors that carry a large current of >10,000 amperes. For the winding conductors, metallic low-temperature superconducting wires and/or copper-oxide high-temperature superconducting tapes are used. We are conducting development research to select the most suitable type of wires and/or tapes and to combine them to stably carry large currents. Since superconducting magnets are subject to large electromagnetic forces, research is also being carried out to find materials and structures that can support these forces. We are also investigating winding and fabrication methods for three-dimensional helical coils.

Large HTS conductor sample and the research team.

In-Vessel Component Research Group

The in-vessel components consist of a "blanket", "first wall", and "divertor". The "blanket" breeds the fuel while receiving thermal energy and neutrons generated by the fusion reaction. Using a molten salt and liquid metal flow loop facility, studies on flow control under high temperatures and high magnetic fields, transport and recovery of thermal energy and hydrogen isotopes, the lifetime of coolant pipes, etc. are being conducted. In addition, we are collaborating with universities to develop advanced materials, such as vanadium alloys for blanket components. The "first wall" is the component closest to the plasma. We are focusing on materials that produce less radioactivity and studying their basic behaviors in the interaction with the plasma at high temperatures and the behavior of hydrogen isotopes in the materials. The "divertor" is a component that receives a heat flux coming from the plasma, which can reach more than 10,000 kW per square meter. Research is being conducted on material selection, cooling technology and design optimization, especially for the unique three-dimensional shape of the helical divertor, including a maintenance scheme.



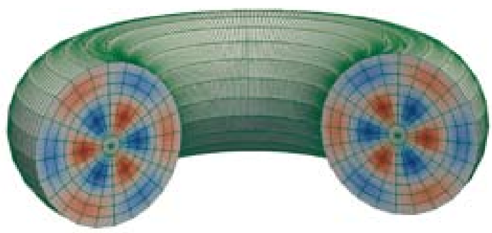
Liquid blanket collaboration platform Oroshhi-2.
Liquid molten salt FLiNaK (temperature: 500° C) and liquid metal LiPb (300° C) are circulated for integrated testing under magnetic fields up to 3 Tesla.

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 diffusing toward a lot of different areas, and are expanding the horizons of fusion science.

Data Science and Plasma Physics

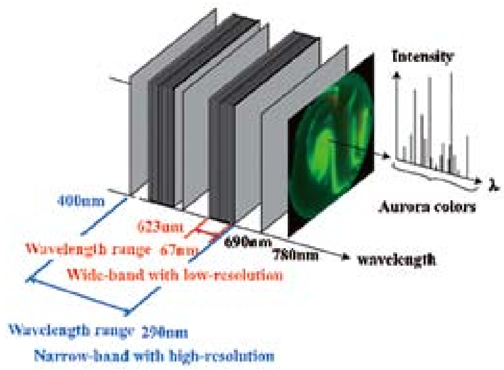
A new approach called data-driven science, using machine learning, is rapidly advancing academic research. Machine learning is a technique that derives the maximum possible relationship from a large amount of numerical data, and is a technology that supports image recognition and machine translation, which have greatly developed in recent years. We are actively introducing this method to the analysis of fusion plasma experiments. It is now possible to identify parameters that predict unexpected disruptive phenomena, which were previously unpredictable, to study how to avoid these phenomena, and to estimate the relationship between experimental data with unprecedented accuracy. We are expressing complicated data as the sum of a small number of orthogonal components. It is possible to analyze experimental data in a way that is understandable to humans, without significantly losing the complexity of fusion plasma. The figure shows an example in which a pattern in the plasma confinement region of the LHD is decomposed by a special pattern, the so-called Saito's Laplacian Eigenfunction. By expressing the physical quantity inside the plasma as the sum of a small number of smooth patterns, it has become possible to perform stable physical quantity estimation that tends to diverge numerically.



Torus-shaped profile expanded by orthogonal patterns.

Aurora spectroscopic observation

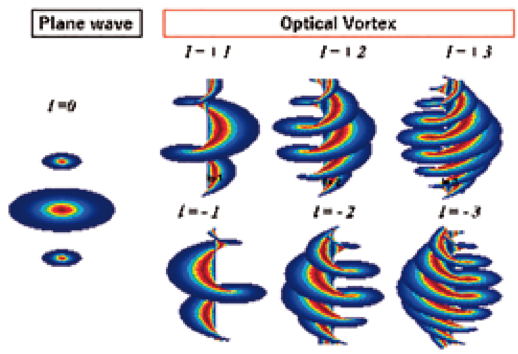
The aurora is an atmospheric luminescence phenomenon, mainly seen in the Antarctic and Arctic circles, in which particles falling from outer space collide with atoms and molecules in the atmosphere and shine. Due to the difference in atoms and molecules, light with wavelengths different from red, green, pink, and light blue is emitted. Although the type of light emitting atom or molecule can be identified from its color, it is necessary to examine the wavelength distribution (spectral distribution) of light by spectroscopy, in order to obtain information on the falling particles. The first spectroscopic view of the aurora was in Angstrom in 1869. However, only the measurement of the narrow part of the aurora was performed, and no image was obtained. Later, a method for obtaining an aurora image (spatial two-dimensional image) using an interference filter that allows only light of a specific wavelength to pass through was developed, but there was a drawback that a spectral distribution could not be obtained. Therefore, in order to obtain an image of the spectral distribution, a two-dimensional spectroscopic system was jointly developed by the National Institute for Fusion Science and the Research Institute for Sustainable Humanosphere, Kyoto University (see figure). This is a system that can observe images and spectral distribution at the same time. This system will be installed at the Poker Flat Research Range Observatory at the University of Alaska, and we plan to observe it for a total of six years, targeting 2025, when the aurora will reach its maximum level.



Data obtained by a two-dimensional spectroscopic system

Optical vortex and plasma

Electrons in a magnetic field move along a helical orbit. This motion excites emissions (electromagnetic waves) called electron cyclotron emissions (ECE). This radiation has long been used as a diagnostic tool and plasma heating in magnetic plasma confinement devices such as the LHD. In 2016, it was reported that such an emission from a rotating electron can have a vortex property (Optical Vortex), as shown in the diagrams. A trial to experimentally demonstrate the vortex property of the ECE has been started, utilizing several components originally developed in NIFS.The demonstration of the vortex feature and the investigation of the propagation characterisitics in the plasma are an important subject from the viewpoint of plasma control in fusion science and are also expected to accelerate the understanding the Optical Vortex and its propagation and interaction properties in various media.



Phase structure of Plane wave and various optical vortex.

Research activities for international standardization of superconducting applied equipment

The International Electrotechnical Commission (IEC), which establishes international standards for electrical equipment, includes the Technical Council (TC90), which discusses international standards for superconducting applied equipment. Each technical council has a secretariat, and since the secretariat of TC90 is in Japan, Japan is expected to play a leading role in establishing international standards for superconducting applied equipment.

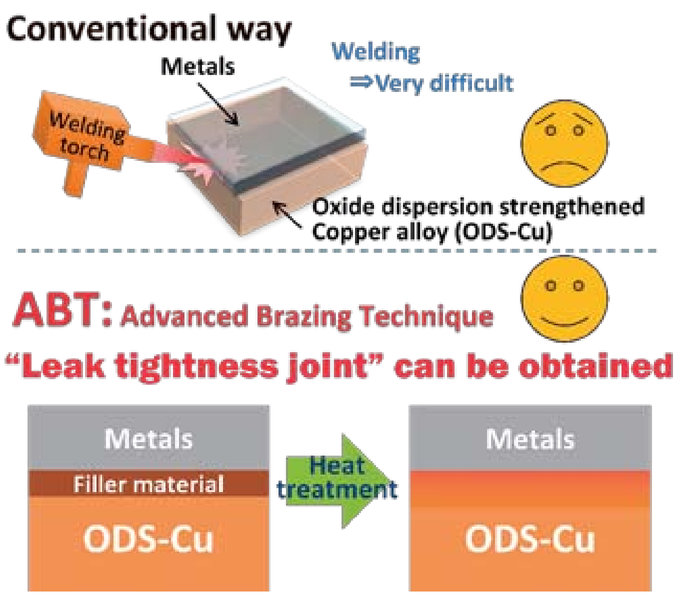
NIFS is making an active contribution to the activities of TC90, such as serving as the chairman of the Domestic Technical Committee and the combined and committee members of each working group.

As a recent activity, considering that the cryogenic system plays a large role in determining the reliability and economic efficiency of superconducting equipment, based on the operation results of the LHD superconducting system, etc. We are proceeding with preparatory activities for this.

LHD superconducting system

Advanced brazing technique (ABT) for joining between ODS-Cu and Metals

Oxide dispersion strengthened copper alloy (ODS-Cu) has strong advantages, such as high temperature strength, high thermal conductivity and erosion resistance. On the other hand, poor weldability is the main drawback of ODS-Cu, whose applicability is sometimes disturbed due to its drawback. A novel method named as the “advanced brazing technique (ABT)” has been developed for joining ODS-Cu to ODS-Cu or ODS-Cu and other metals with higher melting points than ODS-Cu. The ABT includes the following three special features. First : the joint strength is as high as bulk ODS-Cu. Second : the joint ensures a leak tightness condition against any gases and fluids. Third : since the quality of the joint is similar to micro-scale welding, the physical stability of the joint has a strong tolerance against the repetitive brazing heat-cycle. The ABT has possibilities applying to many industrial devices which are simultaneously required for high heat removal capability and high durability.



Differences between the conventional way and ABT.

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 the 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 [https://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.

Ribbon-cutting at the opening ceremony of NIFS Rokkasho Research Center on May 28, 2007. The NIFS Rokkasho Research Center was relocated in the premises of QST Rokkasho Fusion Institute on April 1, 2012.

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 member of Rokkasho research center of NIFS is undertaking work as IFERC project leader, and NIFS has strengthened the cooperation for the BA activities. Since the IFERC project successfully accomplished its purposes in the end of March 2020 and the BA Phase II started in April 2020, the NIFS Rokkasho staff undertook work as the IFERC deputy project leader until March 2022. Also, 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 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.

A scene of the hands-on experiment event held on November 29, 2009: “Interesting Science Experiment Booth”.

A panoramic view of QST Rokkasho Fusion Institute in Dec.2020 where the NIFS Rokkasho Research Center is located.

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 selects 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 five pillars of IR (Institutional Research) / evaluation, public relations enhancement, financial base strengthening, collaborative research enhancement, and young researchers and their career-path 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 : https://reso.nifs.ac.jp/eng/

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・heliotron cooperation
- Subcommittee for laser cooperation
- Subcommittee for ST cooperation
- Subcommittee for academic-industrial cooperation

International Coordination（2022/4/1）

①Multinational Coordination

・The IEA Stellarator・Heliotron 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

②Binational Coordination

(Japan-United States Collaborative Program, Japan-Korea Fusion Collaboration Programs, Japan-China Collaborative Program, Japan-Russia Cooperation, Japan-EU Cooperation, etc.)

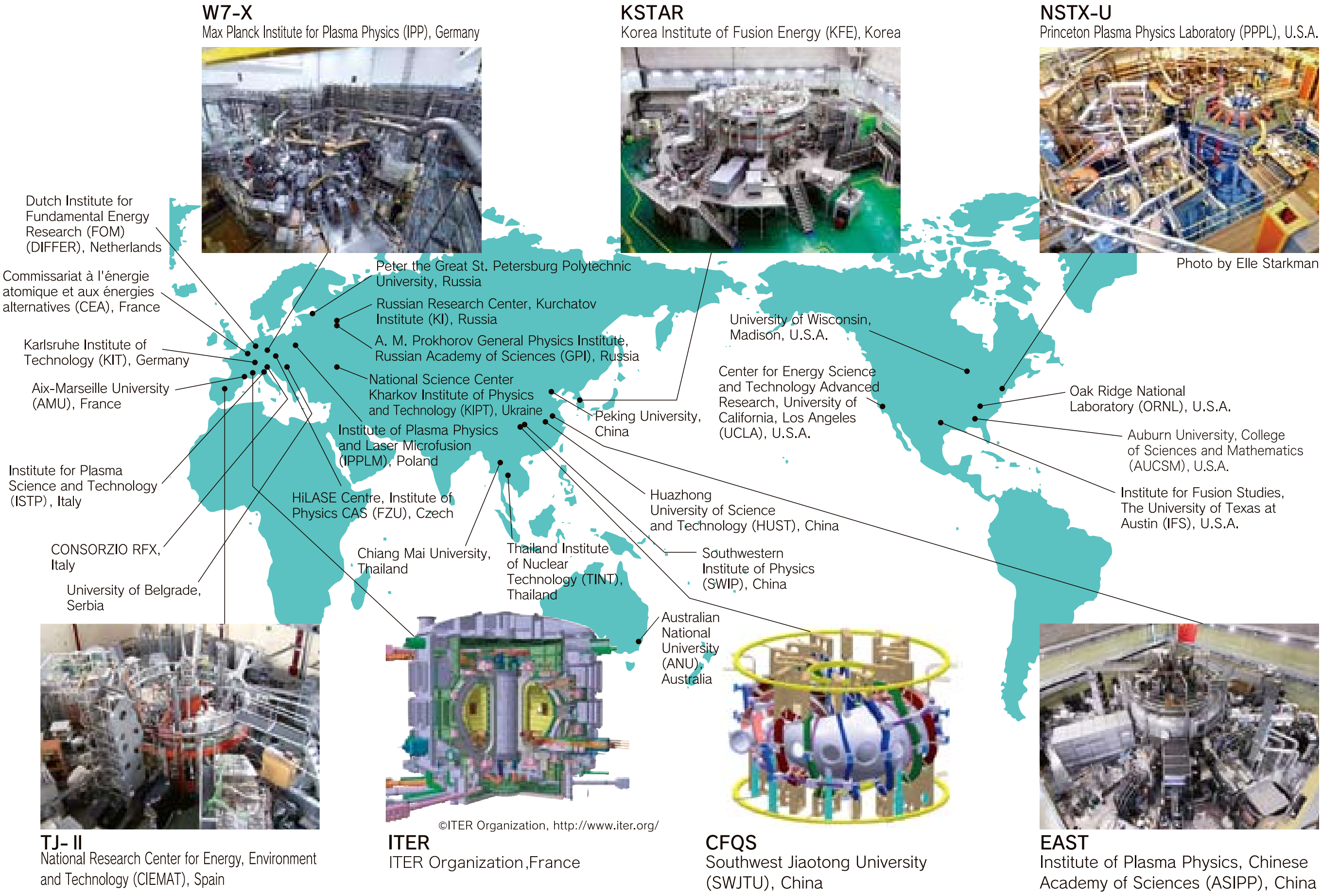
③Coordinaton with Other Institutions (32 International Academic Exchange Agreements)　④Hosting of International Conferences (International Toki Conference, etc.)

Academic Exchange Agreements

country	organization	year	organization	year
China	Institute of Plasma Physics, Chinese Academy of Sciences（ASIPP）	1992	Southwestern Institute of Physics（SWIP）	2012
	Peking University	2017	Southwest Jiaotong University（SWJTU）	2017
	Huazhong University of Science and Technology（HUST）	2018		
Germany	Max Planck Institute for Plasma Physics（IPP）	1993	Karlsruhe Institute of Technology（KIT）	2005
Russia	Russian Research Center, Kurchatov Institute（KI）	1993	A. M. Prokhorov General Physics Institute, Russian Academy of Sciences（GPI）	2007
	Peter the Great St. Petersburg Polytechnic University（SPbPU）	2017		
Ukraine	National Science Center Kharkov Institute of Physics and Technology（KIPT）	1994		
Australia	Australian National University（ANU）	1995		
South Korea	Korea Institute of Fusion Energy（KFE）	1996		
U.S.A.	Princeton Plasma Physics Laboratory（PPPL）	2006	Institute for Fusion Studies, The University of Texas at Austin（IFS）	2006
	Oak Ridge National Laboratory（ORNL）	2006	Center for Energy Science and Technology Advanced Research, University of California, Los Angeles（UCLA）	2006
	University of Wisconsin, Madison	2019	Auburn University, College of Sciences and Mathematics（AUCSM）	2019
France	Aix-Marseille University（AMU）	2007	Commissariat à l'énergie atomique et aux énergies alternatives（CEA）	2015
	International Associated Laboratory(LIA)	2019		
Spain	National Research Center for Energy, Environment and Technology（CIEMAT）	2009		
Netherlands	Dutch Institute for Fundamental Energy Research（FOM）（DIFFER）	2011		
Italy	Institute for Plasma Science and Technology(ISTP)	2019	CONSORZIO RFX	2015
Czech	HiLASE Centre, Institute of Physics CAS（FZU）	2016		
Thailand	Chiang Mai University（CMU）	2016	Thailand Institute of Nuclear Technology（TINT）	2016
Poland	Institute of Plasma Physics and Laser Microfusion（IPPLM）	2017		
Serbia	University of Belgrade	2019		
ITER Organization		2011		

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 brings 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-Heliotron Cooperation

International Stellarator-Heliotron Confinement and Profile Database Activity

Extensive multi-national and multi-institutional coordinated research among Stellarator-Heliotron (S-H) devices has been promoted under the auspices of the IEA (International Energy Agency) Stellarator-Heliotron Technology Cooperation Program Contracting parties are Australia, EURATOM, 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 ISS04, 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

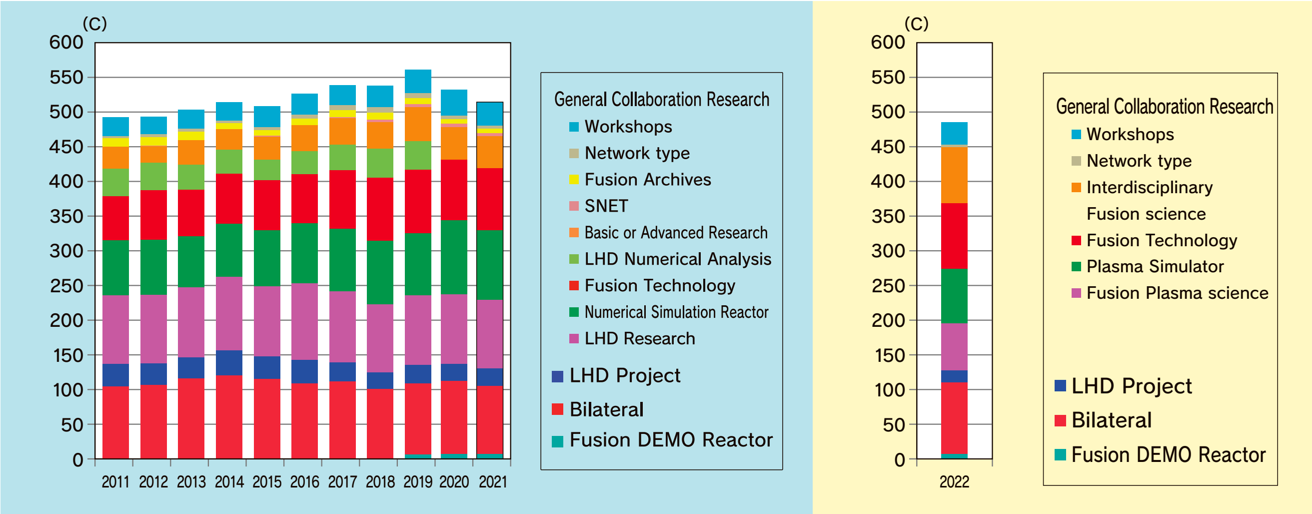
Progress in the Joint Projects

As a Joint Project in the Japan-USA Cooperation Program, FRONTIER (Fusion Research Oriented to Neutron irradiation effects and Tritium behavior at material IntERfaces) Program has been launched for six years from FY2019 to FY2024. In this Program, neutron radiation effects are to be clarified on interactions at the bonding and contact interface for various materials and coolants developed for divertor in fusion power-generation demonstration reactors. Advanced researches are under way utilizing unique devices available only in the United States, such as the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) and Safety and Tritium Applied Research facility (STAR) at Idaho National Laboratory (INL).

High Flux Isotope Reactor (HFIR) (courtesy of ORNL)

Domestic Collaboration Research Programs

In order to satisfy the broad needs for advancing cutting-edge research, NIFS conducts four collaboration research programs. These are Bilateral Collaboration Research, LHD Project Collaboration Research, General Collaboration Research, and Fusion DEMO Reactor Collaboration Research. The joint use and joint research activities are powerfully developed by accepting research proposals from researchers each year.

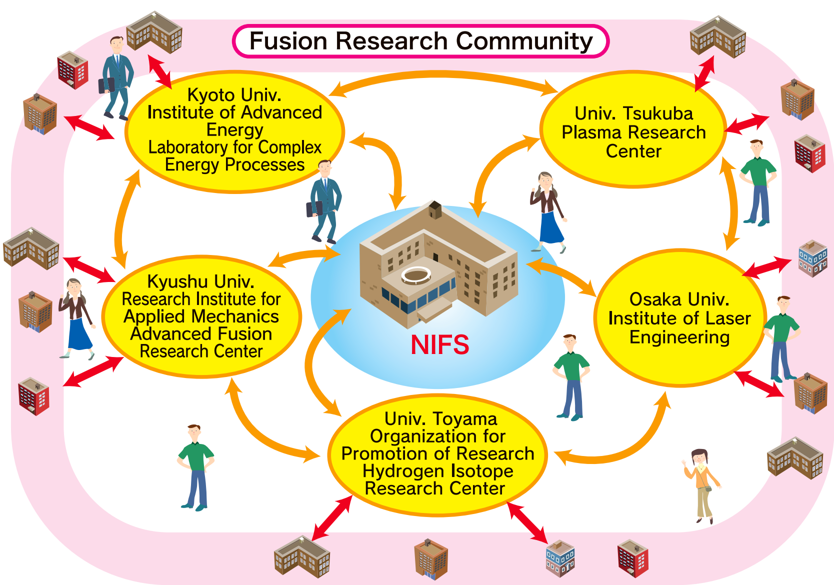


NIFS collaboration research activities are always reviewed and improved so as to be compatible with the latest research trends by changing the categories of collaboration.In FY2022, the categories of General collaboration Research were revised, The figures show the number of accepted collaboration subjects in each category.

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.

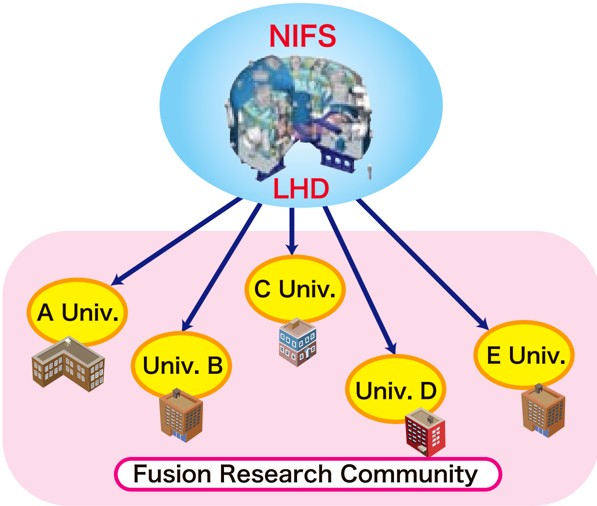


LHD Project Collaboration Research

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. Multi-year proposals are also available. In some cases, NIFS offers the collaborators a specific research category for submitting their application.

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

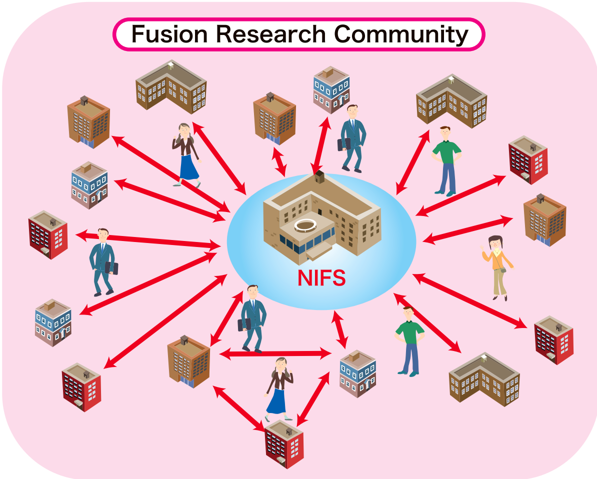


General Collaboration Research

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.

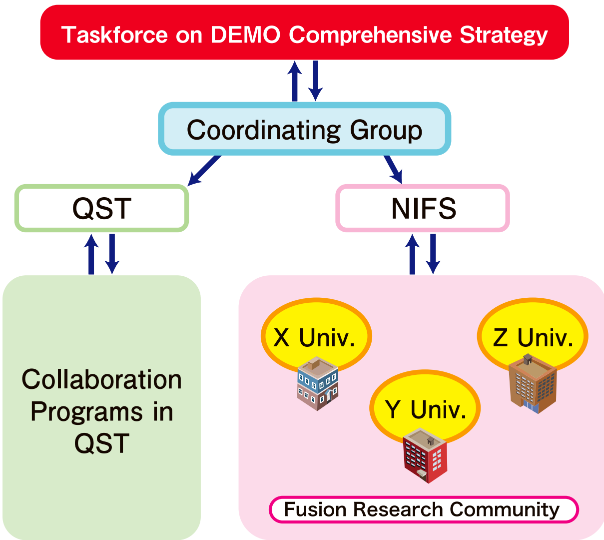
In this collaboration, the collaborators come to NIFS and carry out research at NIFS. However, if it is necessary, NIFS staff can go to the university of a collaborator to perform joint research there. Furthermore, in the "network-type collaboration" category, the collaborators may conduct experiments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



Fusion DEMO Reactor Collaboration Research

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



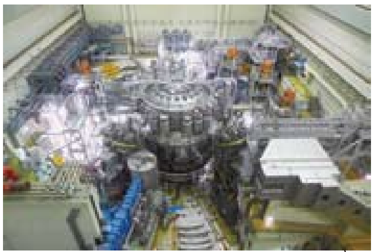
Coordinated Research with Domestic Research Institutions

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 four types of collaboration research programs introduced previously to offer a place for research and interaction 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.

NIFS is also striving for the development of new scientific research fields cooperating with institutions which have excellent specialities through individual academic agreements.

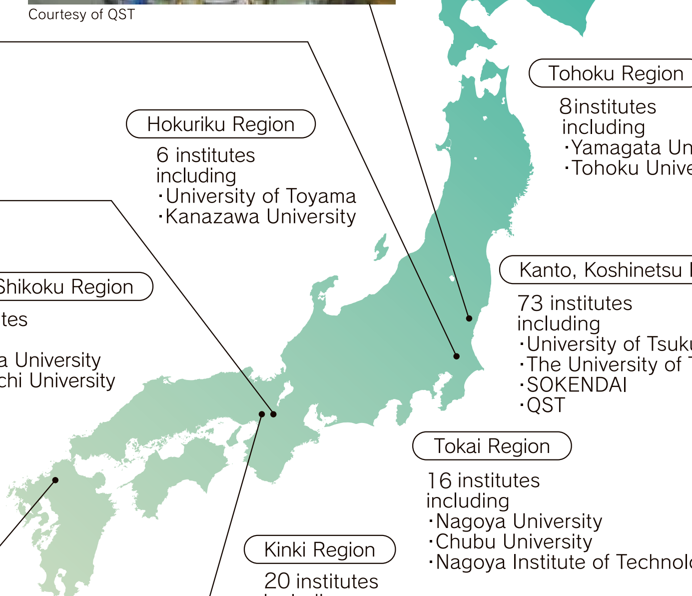
University of Tsukuba
GAMMA 10/PDX

National Institutes for Quantum Science and Technology
JT-60SA



Courtesy of QST

Kyoto University
Heliotron J



Hokkaido Region
8 institutes including
・Hokkaido University
・Kitami Institute of Technology

Tohoku Region
8institutes including
・Yamagata University
・Tohoku University

Hokuriku Region
6 institutes including
・University of Toyama
・Kanazawa University

Chugoku, Shikoku Region
16 institutes including
・Okayama University
・Yamaguchi University

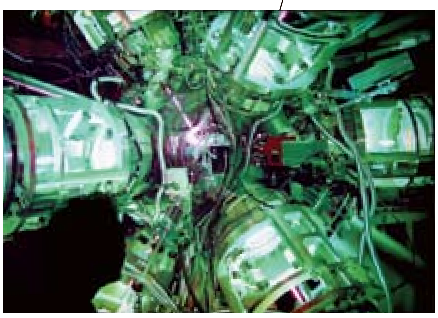
Kanto, Koshinetsu Region
73 institutes including
・University of Tsukuba
・The University of Tokyo
・SOKENDAI
・QST

Tokai Region
16 institutes including
・Nagoya University
・Chubu University
・Nagoya Institute of Technology

Kyushu Region
17 institutes including
・Kyushu University
・University of the Ryukyus

Kinki Region
20 institutes including
・Kyoto University
・Osaka University
・University of Hyogo

Kyushu University
QUEST



Osaka University
GEKKO-XII

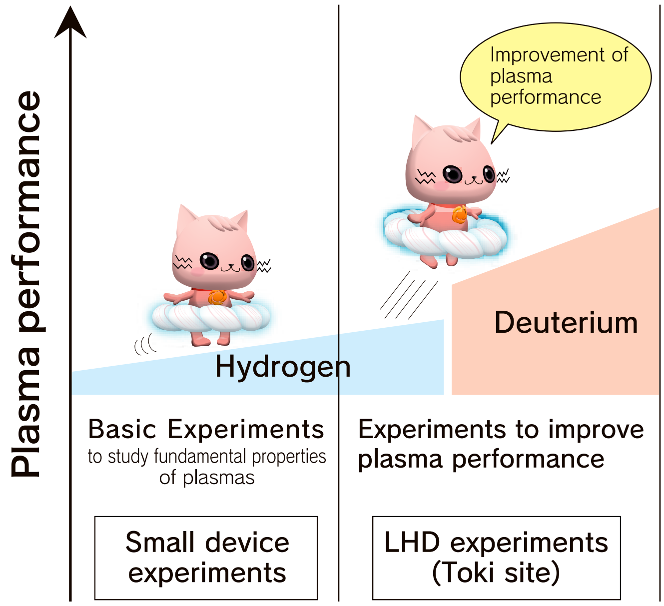
Domestic Academic Agreements 12 institutions

・Hokkaido University
・Tohoku University
・University of Tsukuba
・The University of Tokyo
・University of Toyama
・Shizuoka University
・Nagoya University
・Nagoya Institute of Technology
・Osaka University
・Kyushu University
・National Institutes for Quantum Science and Technology
・Tajimi Technical High School

Division of Deuterium Experiments Management

Experiments using deuterium as a feeding gas started on March 7th, 2017, in the LHD. Because a better confinement property is expected for deuterium plasmas than for hydrogen ones, deuterium experiments enable us to explore high- temperature and high-density plasmas closer to fusion conditions in the LHD, without enlarging the machine size. Indeed, we have succeeded in demonstrating expansion of the high temperature domain of LHD plasmas with deuterium experiments and achieved an ion temperature of 10keV (12 million degrees Celsius), which was difficult to accomplish with hydrogen experiments. The Division of Deuterium Experiments Management was established to manage the safety system and information disclosure related to the experiment on a web-page, especially the results of environmental radiation monitoring and to consolidate experimental apparatuses related to the deuterium experiments.

Deuterium Experiments Project

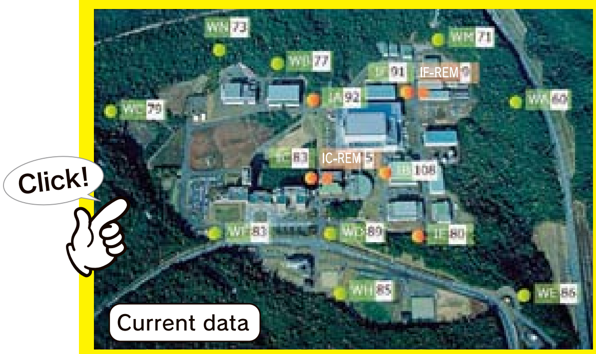


Safety Management

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

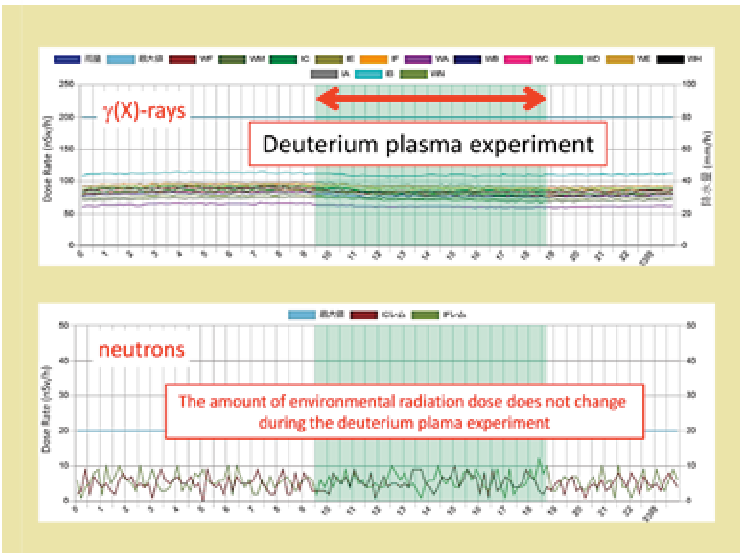
Unit: nSv/h



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 2021/11/17

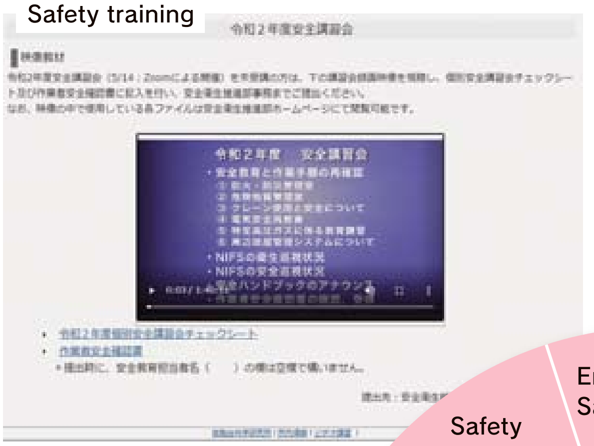


Previous data also can be seen on the NIFS website.

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.

Safety training



Training lecture held by the safety control office leaders and the safety management staff. In 2021, it was held online.

Patrol by health and safety staff

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

Disaster prevention training

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

Radiation monitoring post

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

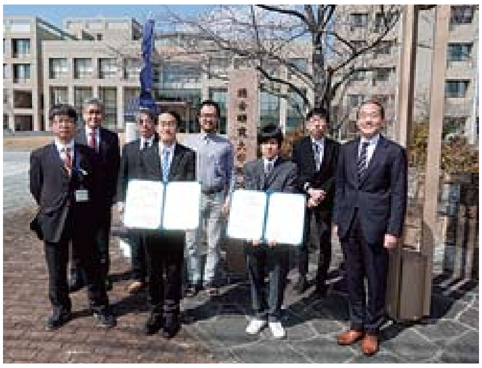
Through these activities, the Division for Health and Safety Promotion conducts environmental safety, which includes radiation safety, safety education, and radiation training. Furthermore, the industrial physician, and health and safety management supervisors also patrol the work areas. The Committee 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. https://www.nifs.ac.jp/en/

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 offers only graduate courses (no undergraduate courses). SOKENDAI consists of six schools in Hayama: the school of Cultural and Social Studies, the school of High Energy Accelerator Science, the school of Physical Sciences, the school of Multidisciplinary Sciences, the school of Life Science and the 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 22 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 fusion engineering, 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 at joint programs with the Graduate School of Frontier Sciences at Tokyo University, the Graduate School of Engineering at Nagoya University, the Graduate School of Science at Nagoya University, the Interdisciplinary Graduate School of Engineering Science at Kyushu University, and elsewhere. At present, 27 graduate students are involved in these programs. NIFS also accepts graduate students (11 in 2022) from other universities by offering special posts.

Library

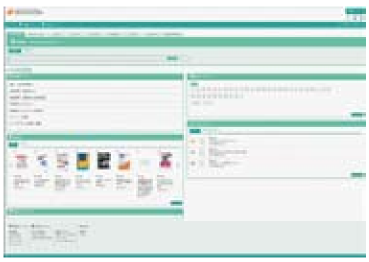
Academic Information Center for Fusion Research

The NIFS Library collects various academic information related to fusion studies and provide academic journals and papers to researchers. The library maintains OPAC, e-journals, e-books, and other online services in an effort to expand its functions as an e-library. We also join the Interlibrary Services (ILL) to obtain materials not stocked in NIFS from other libraries. We are working to provide the collaborators with a photocopy service of the NIFS materials, and strive to provide the same academic information as NIFS staff.

In January 2021, we jointly procured a new library system with Okazaki Library and Information Center within the same organization. We have started a collection search service on the new OPAC system. With the new system, you may research the collections of other institutions such as National Diet Library and CiNii Reaseach without having to re-enter the keywords. (image①)

In recent years, we have set up an exhibition corner near the Library entrance for introducing the collection materials. Exhibitions cover a wide range of themes, not limited to specialized materials. (image②)

In addition, we edit and publish NIFS series and the annual report. Further, we manage the institutional repository by accumulating and disseminating research results.



↑①

↑②

Accumulation and Utilization of Research Activities

Accumulation and Dissemination of Research Activities

NIFS is accumulating information on research activities and in principle, disseminating research results such as academic papers by NIFS staff to the world.

■ 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.

■ NIFS Series

This preprint publication rapidly disseminates research achievements at NIFS within Japan and abroad.

■ Annual Report

The Annual Report summarizes all research achievements and activities at NIFS in each fiscal year. The report is written in English.

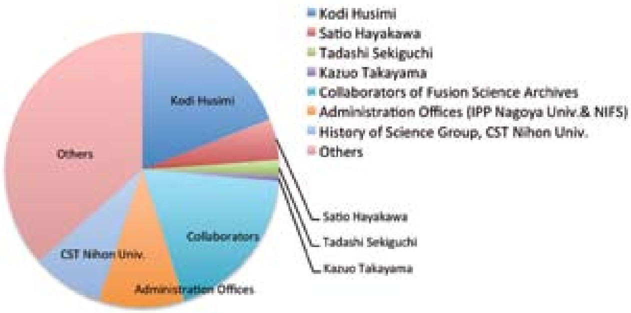
Fusion Science Archives

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 2022 (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.

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

Provenance of registered items(total number ~25,500)



Division of Information and Communication Systems (ICS)

Open science and Network security

NIFS handles a great deal of information, including experimental data. As a center of excellence in fusion science, NIFS is in a position to exchange information both domestically and internationally and is required to open and protect such information. The Division of Information and Communication Systems (ICS) works on open science and network security by centralizing the development and operation of the information and communication systems.

Open science is an initiative that aims "to create new knowledge that transcends fields", "to ensure transparency in research", and "to return the results of the studies to society" by widely open research data and results. And it is becoming a major international trend. NIFS also provides open access to research data and results to researchers worldwide and the public.

Internet communication systems for handling various types of information are increasingly important to support open science. We are working on network security to ensure the safe and appropriate handling of information.

Outreach to Society


↑①


↑②

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 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 cutting edge research. In 2021, due to the impact of the new coronavirus, the event was conducted in an online format in September, with four live broadcasts including an LHD tour (image ①) and a number of videos introducing our research, available on our website (image ②). A total of about 530 people participated in the live broadcast project.

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

Division of External Affairs

The Division of External Affairs, 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 now are the five offices of the Society Cooperation Office, the Content Production Office, the Event Planning Office, the Public Relations and Tour Guide Office, and the 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), publishing public relations magazines (image④), holding academic lectures for local residents (image ⑤), providing tours of the NIFS facilities (image⑥), science classroom activities (image⑦), public relations materials and video production.

Results of Activities held in 2021

- Q&A for Community Meetings posted on the NIFS web page
- Periodic delivery of e-mail newsletters (Research Updates)
- Campus tours (any time)
- Open lectures for the public (online)
- 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 Helica-chan*


↑③

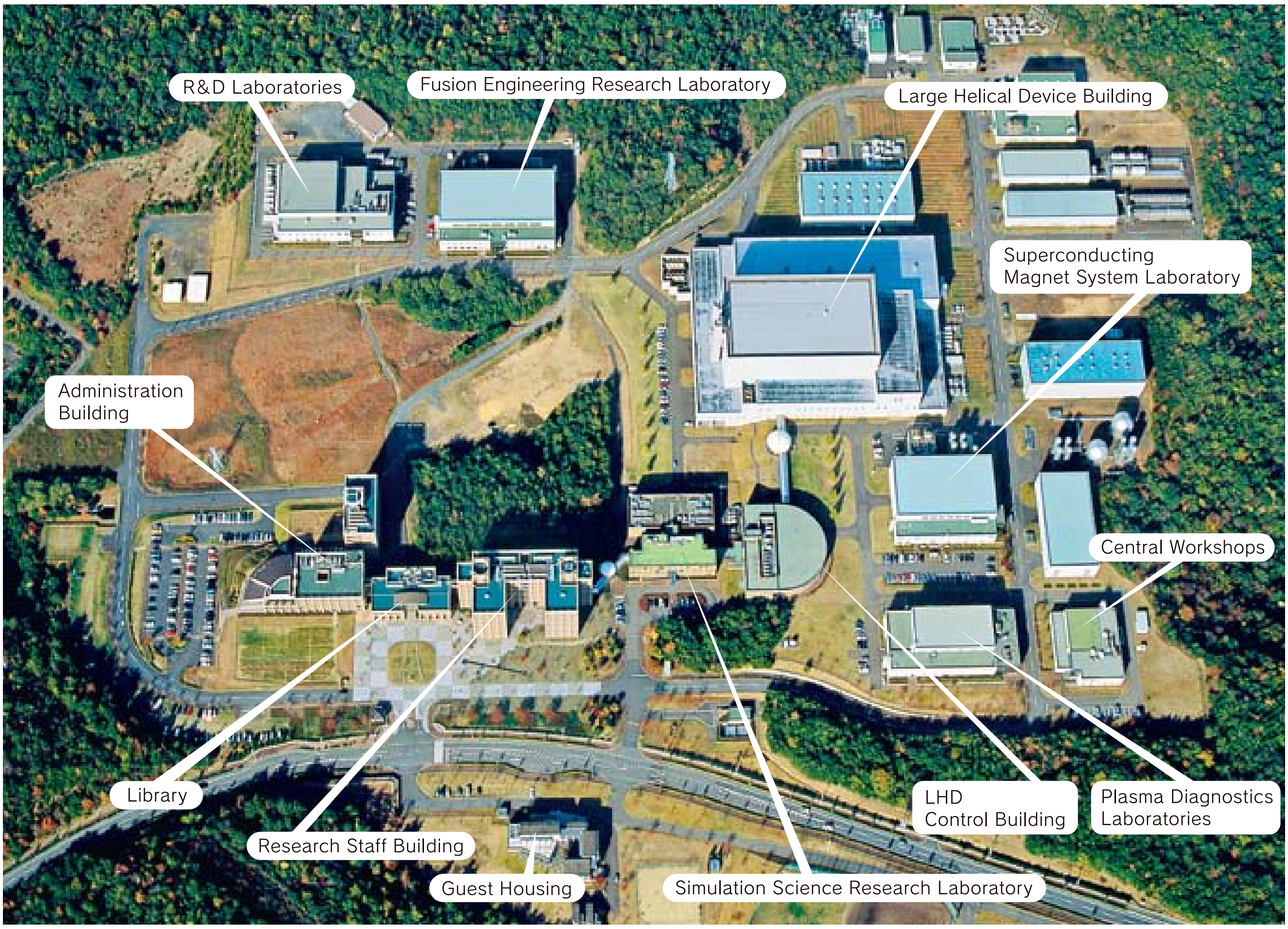
←④

↑⑤


↑⑥


↑⑦

Site Map



Site 464,445㎡ Total Building Area 39,557㎡ Total Floor Space 71,830㎡

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)
May 2004	The 15th year anniversary held
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
May 2019	The 30th year anniversary held

NIFS Location and Access

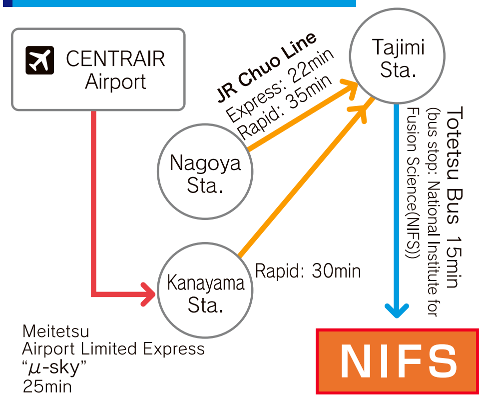
Rokkasho Research Center

Operates inside the building of National Institutes for Quantum Science and Technology's Rokkasho Fusion Institute
2-166 Oaza-Obuchi-Aza-Omotedate, Rokkasho-mura,Kamikita-gun Aomori-ken
039-3212
TEL:0175-73-2151
FAX:0175-73-2199

National Institute for Fusion Science

322-6 Oroshi-cho
Toki-shi, Gifu-ken
509-5292
TEL:0572-58-2222
FAX:0572-58-2601

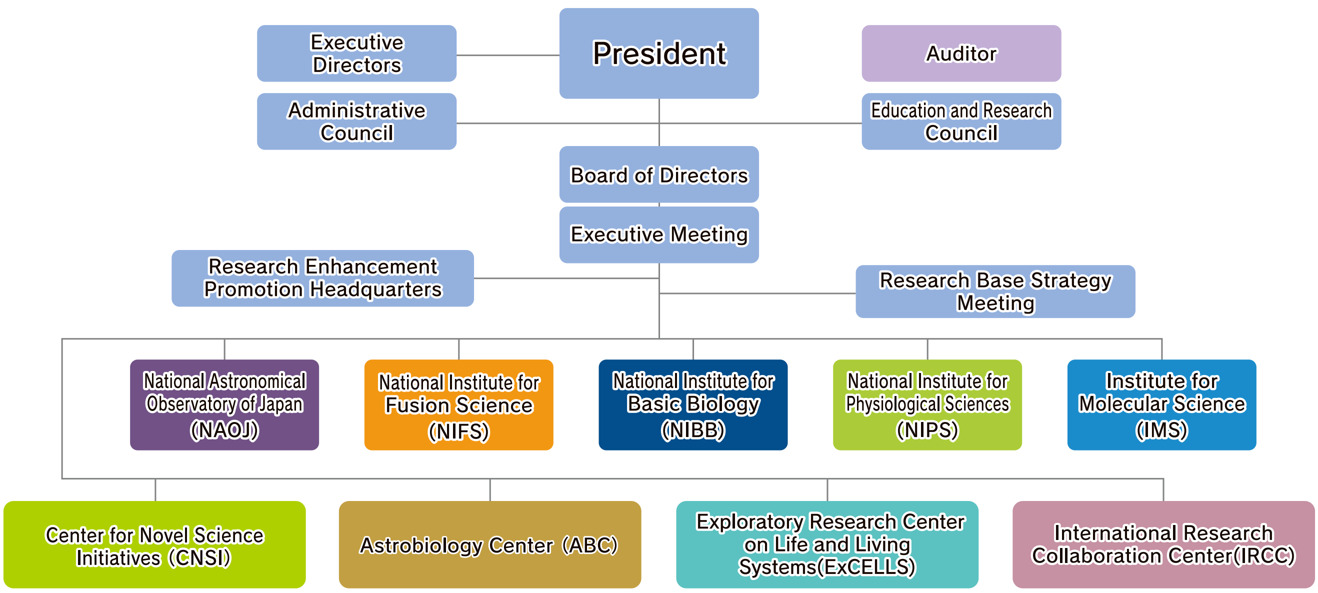
By Public Transportation

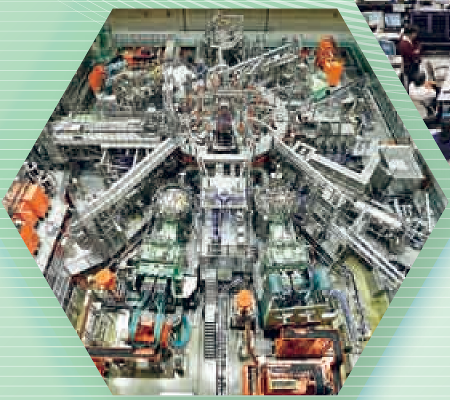


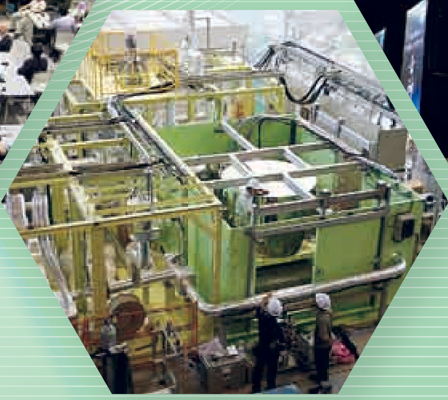
By Automobile

・Toki-Minami Tajimi IC (Tokai-Kanjo Expressway)(5min)
・Tajimi IC/Toki IC (Chuo Expressway)(20min)

NINS National Institutes of Natural Sciences







Inter-University Research Institute Corporation National Institutes of Natural Sciences

NATIONAL INSTITUTE FOR FUSION SCIENCE

322-6, Oroshi-cho, Toki-shi, Gifu-ken 509-5292, Japan
Phone : +81-572-58-2222 FAX : +81-572-58-2601

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