I. National Institute for Fusion Science
April 2010 – March 2011

This annual report summarizes achievements from research activities at the National Institute for Fusion Science (NIFS) between April 2010 and March 2011. NIFS is an inter-university research organization and conducts collaboration research under three frameworks which are the General Collaboration Research, the Large Helical Device Collaboration Research and the Bilateral Collaboration Research. In 2010, the International Research Center for Nuclear Materials Science, Tohoku University and the Hydrogen Isotope Research Center, University of Toyama have joined the Bilateral Collaboration Research to promote engineering research in this framework. About 500 collaborating studies have been implemented during the covered period. External collaborators with a total of more than 10,000 man-days have contributed to these achievements together with 140 scientists in NIFS. Diversified but intensively advanced results in plasma physics, fusion science and related fields have been obtained from these studies.

Fusion energy is the ultimate green energy. The fuels for fusion are available from sea-water. Fusion energy is virtually inexhaustible. Fusion energy does not emit greenhouse gases like carbon dioxide. Since energy is a fundamental basis for all human activities, a long-lasting primary energy source alternative to fossil fuel is seriously required to secure a safe and peaceful future. While fusion energy is a promising new energy source which has a large potential as a backbone power source, critical issues which must be resolved in order to put it in our hands still remain.

The primary objective of NIFS is the promotion of scientific research towards the realization of fusion energy, i.e., a sun on the earth, generating a new source of energy to resolve the serious crisis which human beings are now facing. While fusion research has shown rapid progresses due to world-wide efforts, further intensive approaches with innovation are required for the first fusion demo reactor (DEMO). NIFS conducts three major projects which are the Large Helical Device Project, the Numerical Simulation Research Project and the Fusion Engineering Research Project, and these three pillars stimulate each other. NIFS also emphasizes the role as a COE in the development of expertise through a variety of cooperations, which are managed by the Coordination Research Project.

The Large Helical Device (LHD) is the world largest device that confines high temperature plasmas only by external coils. The LHD employs superconducting coils and therefore has full capability for steady-state operation. Due to distinguished stability in both physics and engineering, the LHD has provided more than 100,000 plasma discharges in these 13 years since the initial operation. This large number of research opportunities have driven the progress not only in fusion research but also in innovative and interdisciplinary studies.

In total, 250 experimental proposals have been executed in the 14th experimental campaign from Oct. 14th, 2010 to Jan. 27th, 2011. The primary heating source is Neutral Beam Injection (NBI) with a heating power of 28 MW, and Electron Cyclotron Heating (ECH) with 4 MW plays an important role in local heating and power modulation in transport studies. After a two-year hiatus, Ion Cyclotron Range Frequency (ICRF) heating with 1 MW has been used in the experiment with an improved antenna. Highlighted achievements can be seen in 3 directions, i.e., improvement of plasma parameters, demonstration of new ideas and deepening of understanding of physics processes. Ion and electron temperatures have increased to 6.4 keV and 20 keV, respectively, under the different conditions. Compression of neutral pressure by a factor of 10 has been demonstrated by the baffle-structured helical divertor. A new ICRF antenna has shown efficient heating by phase control. Together with these extensions of plasma parameters and demonstration of new ideas, diversified outcomes on plasma physics have been discussed towards a comprehensive understanding of the underlying physics. For example, the three "non"s, which are non-linear, non-diagonal and non-local, are targets to be documented in terms of transport physics.

The high ion temperature regime has been explored with the extended NBI heating capability. Here it is emphasized that the profile data base with very fine spatial resolution in the measurements has become routinely available and characterization of high-ion temperature plasmas, such as momentum and impurity transports, has progressed based on the obtained database. Although the magnetic configuration of the LHD accommodates a built-in divertor, the present divertor configuration in LHD is open with no facility for active pumping. Studies of this open helical divertor and the local island divertor have matured the concept and scenario of the closed helical divertor. As a provisional approach, a baffle-structured divertor was installed on the inboard side in two sections among 10 toroidal periods before the 14th experimental campaign. Compression of neutral pressure has been demonstrated as the numerical simulation predicts. A helical divertor system with a pump under the dome will be installed after the 15th experimental campaign and will be operational in 2012.

3-D physics is a highlighted issue not only specific to LHD but also shared with tokamaks. Validation of 3-D theoretical and simulation models has progressed through comparison with the experimental observation in LHD. In particular, the evolution of nonlinear MHD instabilities to lead to operational limit, gyrokinetic Vlasov simulation to assess turbulent transports, evaluation of neoclassical transport considering finite orbit width and impurity transport in the scrape-off layer, all of which are based on the real 3-D geometry, illuminate experimental observations and provide prospects for DEMO.

The Numerical Simulation Research Project aims to understand and systemize physical mechanisms in fusion plasmas and to realize the numerical test reactor (NTR) which will have the capability to predict the burning plasma behaviors in a whole machine. All elemental physics in fusion plasmas and innovative numerical technologies are required for NTR. The Plasma Simulator is a high-performance computer platform for studies of confinement physics of fusion plasmas and their theoretical systematization and the exploration of the science of complexity as basic research. The present Plasma Simulator has a total peak performance of 77TFlops and a total main memory of 16TB, and it will be upgraded to a total peak performance of 315TFlops and a total main memory of 32TB in October 2012. Nine research groups have been organized in order to assemble all the obtained results to upgrade the integrated transport model and realize the NTR together with the LHD Projects and Fusion Engineering Research Projects. They are responsible for the development of elements of plasma fluid equilibrium stability, energetic particles, integrated transport simulation, fluid turbulence transport simulation, kinetic transport simulation, peripheral plasma transport, plasma-wall interaction, multi-hierarchy physics and the basis of simulation science .

The Fusion Engineering Research Project has been launched in 2010. This project focuses on both the conceptual design of a steady-state DEMO, and the establishment of the engineering basis required for the next phase of engineering design activities for DEMO. A helical system like LHD does not need any plasma currents and posesses the intrinsic advantage of steady-state operation. The design integration for the helical DEMO (FFHR-d1) has been initiated based on the designs of the Force Free Helical Reactor (FFHR) series for commercial power plants. The latest experimental results from LHD have been incorporated to enhance feasibility and credibility. The developed helical system code analyzes robustness in the design window. Innovative ideas to secure the design such as an optimization of the liquid blanket thickness have been proposed. The project highlights five subjects of engineering R&D, which are a large-scale superconducting magnet system, liquid blanket with long life time, low activation structural materials, plasma facing component exposed to high heat flux and tritium handling. These subjects are key technologies for DEMO and the core-competency of NIFS and our collaborators. The large-scale superconducting magnet system requires high-performance superconductors of 100 kA-class current capacities. R&D has progressed for advanced conductors of not only metallic low-temperature superconducting materials like Nb_3Sn and Nb_3Al but also high-temperature superconducting materials. Vanadium alloy (NIFS-HEAT) is a major candidate low-activation material for DEMO. The integrated feasibility of liquid breeder blankets using molten salts has been studied from the viewpoints of chemical compatibility, fluid dynamics and thermo-mechanical engineering.

Last but not least, NIFS intensively conducts international collaboration programs and plays an important role as a COE in fusion science on a worldwide scale. International collaboration has been promoted steadily under the auspices of agreements and memoranda of understanding. In 2010, NIFS concluded agreements with the ITER Organization and the FOM Institute for Plasma Physics Rijnhuizen in the Netherlands.

Lastly, I am grateful to our technical and administrative staff and contractors for their very strong support of our research activity. All of the achievements are attributed to the tremendous efforts by all collaborators from Japan and abroad.

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Director-General
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