I. National Institute for Fusion Science
April 2013 – March 2014

This annual report summarizes achievements from research activities at the National Institute for Fusion Science (NIFS) between April 2013 and March 2014. NIFS is an inter-university research organization and conducts open collaboration research under three frameworks which are the General Collaboration Research, the Large Helical Device Collaboration Research and the Bilateral Collaboration Research. More than 500 collaborating studies were implemented during the covered period. About 2,400 collaborators participated in joint research from 220 external institutions. Many intensively advanced results in plasma physics, fusion science and related fields have been obtained from these studies. Not only NIFS, but also 6 university centers; Plasma Research Center, University of Tsukuba; Laboratory of Complex Energy Process, Institute of Advanced Energy, Kyoto University; Institute of Laser Engineering, Osaka University; Advanced Fusion Research Center, Research Institute for Applied Mechanics, Kyushu University; Hydrogen Isotope Research Center, the University of Toyama and International Research Center for Nuclear Material Science, Institute for Material Research, Tohoku University, serve as joint research laboratories/centers under bilateral collaboration research. NIFS also organizes diversified frameworks for international collaboration through 6 bilateral agreements, 3 multi-lateral agreements and academic exchange agreements with 18 institutes abroad for the global development of the function of inter-university research organization.

Fusion energy, which NIFS aims at, will be able to secure energy stably for the long term in the future and has the potential to resolve a serious crisis in the global environment such as global warming. Fusion energy has advantages from the aspect of safety and can be the ultimate green energy. The realization of fusion energy is a common challenging issue for mankind.

The primary objective of NIFS is the promotion of scientific research towards the realization of fusion energy. NIFS conducts three major projects to achieve this goal. The first is the *Large Helical Device (LHD) Project* which explores high-temperature and high-density steady-state plasmas experimentally by means of a *heliotron* magnetic field originated in Japan. The second is the *Numerical Simulation Research Project* by means of a super computer. The third but not least, is the *Fusion Engineering Research Project* for a helical DEMO reactor. All these studies are promoted as collaborations with the global research community. Consequently, NIFS has being playing a leading role in fusion science as a COE since its establishment in 1989. The recent remarkable progress convinces us of the possibility of the realization of electric power generation by fusion in 3 decades if we can maintain the present growth. NIFS also emphasizes the development of human resources, in particular, education of graduate students to support fusion science and related science/technology in the long term. NIFS also promotes interdisciplinary research to explore new scientific horizons as a constituting institute of the National Institutes of Natural Sciences (NINS). Along with a new initiative of the ministry (MEXT), the NINS established a new organization "Research Enhancement Strategy Headquarters" in the Tokyo office, and NIFS has established a "Research Enhancement Strategy Office (RESO)" in 2013. In RESO, three University Research Administrators were assigned for the purpose of (1) encouraging international collaborative research, (2) supporting young researchers, and (3) enhancing public relations. The strategic approach for these missions is reinforced.

The *LHD Project* enthusiastically pursues the extension of plasma performance and comprehensive understanding of toroidal plasmas by making full use the world's best platform for steady-state operation of high-performance plasmas. The LHD has provided more than 120,000 plasma discharges in these 16 years since the initial operation and engineering experience as well as plasma physics knowledge which has been accumulated. The 17th experimental campaign of the LHD experiment was completed successfully in the Japanese fiscal year 2013. During the 17th experimental campaign from Oct. 2nd to Dec. 25th in 2013, the LHD produced more than 7,000 plasma discharges and this large number of research opportunities has driven the progress not only in fusion research but also in innovative and interdisciplinary studies. Parameter extension, in particular in ion temperature, as well as physics understanding, in particular 3-D physics issues, have been advanced by making full use of the intrinsic physics and technological advantages of LHD. The extension of the high-ion-temperature regime has been emphasized in the recent experimental campaigns and the central ion temperature has exceeded 8.1 keV at the density of $1.0\times10^{19}\text{m}^{-3}$. Steady-state operation also has been extended to a higher heating power regime up to 1.2 MW and consequently the plasma with a density of $1.2\times10^{19}\text{m}^{-3}$ and a temperature of 2 keV has been maintained for 48 minutes. The total injected heating energy during this long-pulse discharge has reached 3.4 GJ which doubles the last record. Plasma dynamics specifically related to the 3-D geometry are a common important physics issue in toroidal plasmas. Beyond the intrinsic 3-D characteristics of heliotron plasmas, LHD has provided diversified cutting-edge physics insight into the plasma response in perturbed 3-D magnetic fields. In particular, topological change including the generation of magnetic islands and stochastization and its impact on plasma flow and radial electric field is highlighted. The effects of magnetic perturbation have been discussed and documented from a variety of aspects such as detachment, ELM mitigation, magnetic island and transport. These experimental observations have been carefully compared with sophisticated 3-D simulations as well as joint experiments of tokamaks in order to clarify the underlying physics. In parallel with these experiments, the preparation for the deuterium experiments has started and this new stage of the *LHD Project* is planned for 2016.

The *Numerical Simulation Research Project* (NSRP) is aiming to understand and systemize physical mechanisms in fusion plasmas and to realize ultimately the *Numerical Test Reactor* (NTR) which will be an integrated predictive model for burning plasmas across the whole machine range. The NSRP covers a wide range of simulation subjects including 3-D equilibrium of core plasmas and its stability, high energy particle physics, plasma heating, plasma transport, micro and macro turbulence, burning plasma physics, fueling, periphery plasmas, plasma-wall interaction, other basic plasma physics supporting fusion science, and simulation methodology such as multi-scale simulation modeling and scientific visualization. In particular, development and improvement of sophsticated simulation codes required for the construction of the NTR, covering fluid, kinetic, hybrid, multi-scale, integral transport codes has been promoted and then they have been applied to magnetic fusion plasmas including the Large Helical Device (LHD) plasmas. Clarification of new physical pictures of three-dimensional equilibria, transport, instabilities, and nonlinear evolutions has progressed in conjunction with verification and validation of physics models. These achievements make the evolution of this project to the *Numerical Simulation Reactor Research Project* in 2014.

The *Fusion Engineering Research Project* (FERP) focuses on both the conceptual design of a steady-state fusion demonstration reactor and various areas of engineering research and development, which are needed before entering into the engineering design activities for DEMO. Therefore, this project consists of three research groups, (1) reactor system design, (2) superconducting magnets, and (3) in-vessel components. The *heliotron* concept does not need plasma current for plasma confinement and has a built-in divertor. These excellent features give a great advantage for realizing a steady-state reactor. Therefore, along with a conceptual design of the helical reactor FFHR-d1 towards DEMO by integrating design bases of the FFHR commercial-power-plant series, the project is carrying out research on key components, such as the superconducting coil system, high performance blanket, first wall and divertor, etc. In this fiscal year, as the second round of design integration, detailed 3-D designs of in-vessel components, mechanical supporting structures, divertor pumping configurations and replacing scenarios have been performed based on the primary design parameters of FFHR-d1. In particular, 3-D neutronics analyses are in progress to enhance the merit of the divertor which can be placed to avoid direct irradiation of fast neutrons. Collaborations for plasma design have been also enhanced with an NSRP on MHD stability and confinement of alpha particles. As the center of fusion engineering research at universities, the FERP enhances domestic and international cooperation to advance reactor design studies and R&D activities.

In addition to the above mentioned 3 major projects which have well-defined missions, NIFS also supports interdisciplinary and basic research, and promotes the coordinated research for ITER-BA cooperation, laser cooperation and academic-industrial cooperation etc.. A cluster of reports of the NIFS collaboration research in basic plasma physics, and plasma physics applications including research into innovating concepts are available in this annual report.

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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