I. National Institute for Fusion Science
April 2012 – March 2013

This annual report summarizes achievements from research activities at the National Institute for Fusion Science (NIFS) between April 2012 and March 2013. 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. About 600 collaborating studies were implemented during the covered period. More than 2,400 collaborators participated in joint research from 170 external affiliations. 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, are involved in the bilateral collaboration research.

Fusion energy, which NIFS aims at, will be able to secure energy stably in 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 issue of mankind.

The primary objective of NIFS is the promotion of scientific research towards the realization of fusion energy. NIFS conducts three major projects to accelerate this process. The first is experimental studies of high-temperature and high-density plasmas in the Large Helical Device (LHD) which employs a *heliotron* magnetic field originated in Japan. The second is the analysis of the LHD experiment and diversified theory and simulation studies by means of a super computer. The third but not least is fusion engineering for DEMO. 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 realization of electric power generation by fusion in 25 to 30 years if we can keep the present growth. NIFS also emphasizes the development of human resources, in particular, education of graduate students to support fusion science and related technology in the long term. NIFS also promotes interdisciplinary research to explore new scientific horizon as a constituting institute of the National Institutes of Natural Sciences (NINS).

The *LHD Project* enthusiastically pursues the extension of plasma performance and comprehensive understanding of toroidal plasmas by making full use the world best capability for steady-state operation of high-performance plasmas. The LHD has provided more than 110,000 plasma discharges in these 15 years since the initial operation and engineering experience as well as plasma physics knowledge has been accumulated. The 16th experimental campaign of the LHD experiment was completed successfully in the Japanese fiscal year 2012. During the 16th experimental campaign from Oct. 17th to Dec. 6th in 2012, the LHD produced more than 5,000 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 advantage 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 7.3 keV at the density of $1.2\times10^{19}m^{-3}$. A new gyrotron with 154 GHz has extended the high-electron temperature regime and 13.5 keV of electron temperature has been achieved at the moderate density of $1.4\times10^{19}m^{-3}$. Steady-state operation also has been extended to a higher heating power regime up to 1 MW and consequently to a higher density ($1\times10^{19}m^{-3}$) and temperature (2.5 keV) regime than before. It should be emphasized that the steady-state-operation (SSO) theme group and the plasma-wall-interaction (PWI) theme group have been combined and worked together closely since the 16th experimental campaign, and consequently synergy between SSO and PWI has been reinforced. The conversion from an open helical divertor configuration to a closed helical divertor configuration has proceeded step by step. Prior to the 16th experimental campaign, a baffle-dome structure had been installed on 8 of the inboard sides among a total of 10 toroidal field periods. Provisional operation of a divertor cryo-pump has also started at one toroidal section. 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 3-D magnetic fields. In particular, topological change including the generation of magnetic islands and stochastization and its impact on plasma flow is highlighted. The effects of magnetic perturbation have been discussed and documented from a variety of aspects such as ELM mitigation, magnetic island and transport. These experimental observations have been compared with sophisticated 3-D simulations carefully in order to clarify the underlying physics. Advanced understandings of plasma physics in width and depth make critical contribution to resolve emergent issues in tokamaks and will lead to comprehensive understanding of toroidal plasmas.

The *Numerical Simulation Research Project* 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. For the realization of the NTR, all elemental physics model to describe fusion plasmas should be validated by comparison with experiments, and innovative numerical technologies to interlock them, together with powerful supercomputing resources at the peta-scale level are needed. The *Plasma Simulator*, which is the major platform of the NSRP, was upgraded in Phase 2 to a HITACHI SR16000 model M1 on October 1, 2012. The total peak performance jumped up from 77 TFlops to 315 TFlops. The new Plasma Simulator was ranked as the 95th in the world on the TOP500 List of the high-performance computers. Then assembly of all obtained results in synergy with the LHD Project and the Fusion Engineering Research Project enables an integrated approach to the final NTR. In order to make this approach effective, nine research groups responsible for each task in the NSRP have been set up, which cover a wide range of simulation subjects including the 3D 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.

The *Fusion Engineering Research Project* focuses on both the conceptual design of a steady-state fusion demonstration reactor and various 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. In this fiscal year, as the second round of design integration of the helical DEMO reactor, 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, 3D neutronics analyses are in progress to enhance the merit of the divertor, which can be placed to avoid direct irradiation of fast neutrons. There is much progress in a helical system code with the Direct Profile Extrapolation method from the LHD experiment and assessment of core plasma in terms of neo-classical transport, MHD stability and confinement capability of alpha particles by means of 3-D numerical codes. New elements such as high-temperature superconductors, optimization of radial-build calculations with the neutron wall loading < 2 MW/m^2, liquid blankets, improvement of nuclear shielding efficiency, divertor design of cooling and pumping, modeling of steady-state tritium efficiency, etc have been incorporated into a conceptual integrated design. In parallel with these design studies, NIFS has promoted R&D programs of applied superconducting technology, cryogenic engineering and low-activation structural materials.

In addition to the above mentioned 3 major projects which have well-defined missions, NIFS promotes interdisciplinary approach and also supports basic research. The coordination research project manages a cross-sectional wide range of coordinated research activities such as university cooperation, international cooperation, NINS cooperation, ITER-BA cooperation, laser cooperation and academic-industrial cooperation. 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
National Institute for Fusion Science