I. National Institute for Fusion Science
April 2011 – March 2012

This annual report summarizes achievements from research activities at the National Institute for Fusion Science (NIFS) between April 2011 and March 2012. 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. About 500 collaborating studies were implemented during the covered period. More than 2,400 collaborators including 150 graduate students participated in joint research from 170 external affiliations. Diversified but intensively advanced results in plasma physics, fusion science and related fields have been obtained from these studies.

The most inevitable issue for mankind in this century is energy security. Energy resources alternative to fossil fuels are indispensable for a sustainable society. The realization of fusion energy, i.e., a sun on the earth, can resolve the serious environmental/energy crisis which human beings are now facing. The fuels for fusion are available from sea-water, therefore fusion energy is virtually inexhaustible. Fusion energy does not emit greenhouse gases like carbon dioxide, thus fusion energy can be the ultimate green energy. On the other hand, critical scientific and technological issues which must be resolved in order to put this energy resource in our hands still remain.

The primary objective of NIFS is the promotion of scientific research towards the realization of fusion energy. NIFS conducts three major projects, which are the Large Helical Device Project, the Numerical Simulation Research Project and the Fusion Engineering Research Project, in order to establish the scientific and engineering basis required for a fusion reactor. These three pillars stimulate each other and accelerate development of the first fusion demo reactor (DEMO) before 2040.

NIFS emphasizes its roles as an inter-university organization as well as a COE in the development of human resources, in particular, in the education of graduate students and in the development of expertise through a variety of cooperations, which are managed by the Coordination Research Project. NIFS also promotes interdisciplinary research to develop new scientific horizons as a constituting institute of the National Institutes of Natural Sciences. NIFS intensively conducts international collaboration programs and plays an important role as a COE in fusion science on a worldwide scale.

The Large Helical Device (LHD) is the world's largest device that confines high temperature plasmas only by external coils. The LHD employs superconducting coils which form a *heliotron* magnetic configuration and therefore has full capability for steady-state operation. Due to distinguished stability in both physics and engineering, the LHD has provided more than 110,000 plasma discharges in these 14 years since initial operation. This large number of research opportunities has driven the progress not only in fusion research but also in innovative and interdisciplinary studies. The 15th experimental campaign of the LHD experiment was completed successfully in the Japanese fiscal year 2011. In total, about 260 experimental proposals were executed from Jul. 28th, 2010 to Oct. 20th in 2011.

The extension of the high-ion-temperature regime has been emphasized in the recent experimental campaigns and the central ion temperature has exceeded 7 keV at the density of $1.5\times10^{19}m^{-3}$. The provisional experiment of a closed divertor has been advanced to where 20% of the inboard side divertor was modified to a baffled structure. After completion of the 15th experimental campaign, this modification has expanded to include 80% of the inboard divertor, also with a cryo-pump. Therefore, reduced recycling, which is preferable for the high-ion-temperature approach as well as for high-density and steady-state scenarios, is foreseen in the 16th experimental campaign in 2012. The LHD has already demonstrated a volume averaged beta value of 5.1% at the low magnetic field of 0.425T. Since the plasma lies in the collisional regime due to low temperature, extension of high beta plasma to higher magnetic field has been promoted. Consequently, 4.1 % and 3.4 % have been achieved at 0.75 T and 1 T, respectively, and in this way the database of high beta plasmas has been extended to the collisionless regime.

Assessments of 3-D effects based on diagnostics with fine spatial resolution and numerical models to cope with a real 3-D geometry have remarkably progressed. In particular, a Resonant Magnetic Perturbation has been applied to the experiments of divertor detachment, ELM mitigation, and magnetic island dynamics. Novel wave heating schemes have been advanced. A new dipole antenna for ICH can control the toroidal phase. It shows better heating efficiency at higher density than the conventional monopole antenna as expected. With regard to the physics of energetic particles, an interesting phenomenon which suggests bulk-ion heating by the energetic particle drive mode has been observed. The non-diffusive nature attracts interest in new conceptions of thermal and momentum transport. The dynamic response of micro-turbulence to ECH modulation has been studied in terms of the long distance radial correlation of the turbulence and suggests a significant contribution of non-locality to the heat transport.

The Numerical Simulation Research Project aims to systemize physical mechanisms in fusion plasmas and to realize the numerical test reactor (NTR) which will enable an integrated predictive model of burning plasmas over the entire machine range. NTR requires integration of all elemental physics models which are validated with experiments. The project is organized by 9 research groups which are responsible for their own subjects including 3-D MHD equilibrium and stability, high-energy particle physics, integrated transport simulation, fluid turbulence transport simulation, kinetic transport simulation, edge plasma physics, plasma-wall interaction, multi-hierarchy physics and scientific visualization. Nine research groups have been managed 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. The core transport code in a 3-D configuration; TASK-3D has been developed by packing modules for neoclassical transport in 3-D, 3-D MHD equilibrium and a time-dependent 1-D diffusive process, etc. Interactive analyses of heat transport and time-dependent simulation of temperature profiles have been examined for the LHD experiment. The gyrokinetic Vlasov code GKV-X has been applied to the LHD experiment and this non-linear ITG turbulent transport simulation has reproduced the ion heat flux and poloidal wavenumber spectra of density fluctuations observed in experiment. Dynamic processes on plasma facing materials, such as a chemical sputtering of a carbon divetor plate, have been investigated by a molecular dynamics simulation. The Plasma Simulator is a high-performance computer platform for these studies and for the exploration of the science of complexity as basic research. The Plasma Simulator will be upgraded to a total peak performance of 315TFlops and a total main memory of 40TB in October 2012.

The Fusion Engineering Research Project has advanced a conceptual design of the helical DEMO reactor FFHR(Force-Free Helical Reactor)-d1 by utilizing design bases established so far on the conceptual designs of the FFHR series for commercial power plants and by integrating wide-ranging engineering R&D through cooperative research. Based on these activities on the FFHR series, "re-design" studies for the DEMO reactor FFHR-d1 have been initiated. In the first round of design integration, the primary design parameters of FFHR-d1 have been selected by introducing a core plasma design with the Direct Profile Extrapolation from LHD experiment data and by reducing blanket thickness with advanced shielding materials, resulting in a reactor size optimization for blanket space and magnetic stored energy < 160GJ. The detailed 3-D design of in-vessel components, mechanical supporting structures, divertor pumping configurations and component replacement scenarios are in progress as a second round. There was much progress in the development of a helical system code, advancing new ideas using high-temperature superconductors as a counter option to conventional superconductors, performing a poloidal optimization of radial-build calculations with the neutron wall loading < 2 MW/m^2, etc. R&D for applied superconductivity systems, low-activation vanadium alloy, long-life-time liquid blanket and high-heat flux components have been highlighted as key subjects in fusion engineering.

In addition to the above mentioned 3 major projects which have well-defined missions, the Coordinated Research Project aims at the promotion of a wide range of coordinated research activities in NIFS. The Coordinated Research Committee manages 7 sectional meetings which promote specific coordinated research topics, such as university cooperation, ITER-BA cooperation, academic-industrial cooperation, etc.

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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National Institute for Fusion Science