I. National Institute for Fusion Science
April 2008 – March 2009

This annual report summarizes research activities at the National Institute for Fusion Science (NIFS) between April 2008 and March 2009. The primary objective of NIFS is symbolically expressed as the realization of a sun on the earth, generating a new source of energy to resolve a serious crisis which human beings are now facing. It is an urgent demand for us to suppress the output of carbon dioxide by developing a new energy source before a climate crisis occurs. Energy is a fundamental base for all human activities. A long-lasting key energy source alternative to fossil fuel is seriously required to secure safe and peaceful future.

Fusion research has been realizing rapid progress due to the world wide integration of science and technology. Now these efforts convince us that fusion energy is accessible, with clearly defined critical paths. An intensive and comprehensive approach with innovation is required to resolve the critical issues. This is the goal of NIFS and this approach also attracts and arouses diversified scientific interest.

NIFS carries out fundamental as well as cutting edge studies to achieve this goal. It should be emphasized that NIFS has been strengthening its function as an inter-university research organization and executing a variety of excellent collaborating studies together with universities and research institutes in Japan and abroad. More than 400 collaborating studies have been implemented during the covered period.

Experiments on the Large Helical Device (LHD) and large scale simulations are two major leading projects in NIFS and they have been intensively conducted in ways that they both extend the frontiers of plasma physics and related device technology. These two major activities have shown steady progress in the existing research body as well as extended a new horizon by discovery of what was previously unknown. In addition, but not the least, the Fusion Engineering Research Center (FERC) carries out R&D for an advanced blanket, low activation materials and superconducting magnets and the Coordination Research Center (CRC) promotes coordinated research with domestic and foreign institutes as well as industry. The Safety and Environmental Research Center (SERC) has been studying to promote and to implement radiation safety issues in NIFS.

The LHD is the heliotron-type device which employs the largest superconducting magnets in the world. The LHD has been operated quite stably without any serious troubles for 11 years and has provided more than 90,000 plasma discharges for a wide range of collaboration. The major goal of the LHD experiment is to demonstrate helical plasmas in a reactor relevant regime. Thorough exploration should lead to the establishment of not only a prospect for a helical fusion reactor but also to a comprehensive understanding of toroidal plasmas. Productive collaborating research on LHD has led to significant enhancement in plasma parameters of temperature, density, β and pulse length. In addition to this steady progress, new findings such as an *Internal Diffusion Barrier* (IDB) and *Impurity Hole* have brought breakthroughs to improve the prospects of a steady-state helical fusion reactor. Deep understanding and insight into the physical mechanisms attributed to a 3-D magnetic configuration have been built by our thorough study in LHD, which is also now recognized as a critical element in tokamaks. For example, resonant helical perturbation is seriously considered so as to suppress ELMs.

We completed the 12th experimental campaign in FY2008. Diversified and intensive studies in LHD have elucidated the broad scope of high performance stable and steady-state plasmas. In particular, the high ion temperature regime has been further extended with the achievement of the central ion temperature (T_i) of 5.6 keV at the electron density of $1.6\times10^{19}m^{-3}$. Perpendicular NBI with a relatively low accelerating voltage of 40 keV is effective in ion heating and obtained high ion temperature is also associated with confinement improvement. The 2nd perpendicular beam is under construction and will be available in 2010 and the total NBI power including 3 tangential NBI's will be 32 MW. The ion temperature could be scaled up to 8 keV by this new heating source. A remarkable feature accompanying this high ion temperature is the *Impurity Hole*. Even with carbon pellet injection, carbon impurities are expelled from the core as ion temperature increases and eventually the carbon concentration falls below 0.3 %. While heavy ion beam probe diagnostics shows that a negative electric field is generated in the core as the neoclassical transport predicts, this clear outward convection of impurities contradicts the neoclassical transport. Although the mechanism of this anomalous convection has not been clarified yet, this discovery is a welcome development for accelerating the increase in ion temperature and the avoidance of dilution of fuels. The high density regime by an IDB and the high beta regime have been also extended steadily to $1.2\times10^{21}m^{-3}$ and 5.1 %. Systematic data in these frontiers have been accumulated, and new physical understanding and a feasibility of innovative scenarios are derived from this database. Theoretical studies on micro turbulence and its response to zonal flows, MHD equilibrium involving magnetic islands, nonlinear evolution of MHD instability, etc. have progressed and their results have been validated with experimental observation. The extension of an operational regime has been conducted by mission oriented theme groups in the LHD Experiment Group and physics oriented theme groups have promoted keen approaches. Continued efforts to develop the facilities of superconducting magnets, heating and diagnostics have made critical contributions to the progress of the LHD experiment and also their own achievements are of great value in science and technology.

The highlighted topics and many additional important results from the LHD experiment are covered in detail in this annual report.

The Department of Simulation Science, established in 2007, promotes simulation science based on the recent remarkable development of information technology such as supercomputers, networks and visualization systems. The Plasma Simulator, which is the main platform of our simulation study, was renewed on March 3, 2009. Presently the main system has the total peak performance of 77 TFlops and the total main memory of 16 TB and will be upgraded to total peak performance of 315 TFlops and total main memory of 32 TB with a 2.0 PB storage in October 2012. The simulation research is now evolving a new paradigm, which comprehends a multi-hierarchy system holistically, from the conventional reductionism approach. The Department consists of the Division of LHD and Magnetic Field Confinement Simulation, the Division of Fusion Frontiers Simulation, and the Rokkasho Research Center.

In the LHD and Magnetic Confinement Simulation Project, research on multiple physical processes and their mutual interactions occurring in core and edge plasmas is being done based on fluid and kinetic simulations aiming at the realization of the LHD numerical test reactor. Together with highly sophisticated simulation codes like MINOS (MHD instabilities) and GKV (gyrokinetic Vlasov), TASK3D which is an integrated modeling and predictive code for 3-D magnetic configuration is being developed for a direct application to the LHD experiment. The Laser Fusion Simulation Project has been promoted to clarify the physics of *Fast Ignition* by the Fast Ignition Integrated Interconnecting code (FI^3).

The FERC grapples with three major engineering issues, (1) basic research for liquid blankets, (2) R&D for low activation materials and (3) fusion-relevant research on superconducting magnets with an emphasis on radiation effects. Efforts to improve the compatibility of Reduced Activation Ferritic/Martensitic Steels (RAFM) with molten-salt Flibe and liquid Li have been reported. The collaboration network to carry out the study on neutron irradiation effects on materials has been established among NIFS/FERC, the Japan Atomic Energy Agency, the National Institute for Material Science, the High Energy Accelerator Research Organization and universities. On the basis of physics and engineering results established in the LHD project, the LHD-type D-T reactor; the *Force Free Helical Reactor* (FFHR) has been studied through collaborative works in wide research areas on fusion science and engineering.

A variety of interesting research associated with basic plasma physics and fusion science and technology, and also interdisciplinary approaches have been executed through collaboration. Their achievements have formed the fundamental research basis for the above mentioned major activities in which NIFS takes the initiative.

The last but not the least, NIFS intensively conducts international collaboration programs, such as the US-Japan Fusion Cooperation Program, the Korea-Japan Cooperation in the Area of Fusion Energy Research and Related fields, the JSPS-CAS Core-University Program, and collaborations under the IEA implementing agreements for the Stellarator/Heliotron Concept, Spherical Tori and PWI in TEXTOR. NIFS and CIEMAT in Spain signed an agreement on the academic and scientific cooperation in 26th February, 2009, which is the 15th agreement with foreign institutes. NIFS plays an important role as a COE in fusion science on a worldwide scale.

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