I. National Institute for Fusion Science
April 2009 – March 2010

This annual report summarizes research activities at the National Institute for Fusion Science (NIFS) between April 2009 and March 2010. NIFS is an inter-university research organization and conducts collaboration research under three frameworks which are General Collaboration Research, Large Helical Device (LHD) Collaboration Research and Bilateral Collaboration Research. About 500 collaborating studies have been implemented during the covered period. 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. International collaboration also has been promoted steadily under the auspices of agreements and memoranda of understanding. Diversified but intensively advanced results in fusion science and related fields have been obtained from these studies. External collaborators with a total of more than 10,000 man-days have contributed to these achievements together with 140 scientists in NIFS.

NIFS is now promoting 4 projects, which are the LHD Project, the Numerical Simulation Research Project, the Fusion Engineering Research Project and the Coordination Research Project. Together with these organized projects, an extended array of collaborations covered by the above mentioned frameworks promotes new initiatives.

The primary objective of NIFS is defined as the realization of a sun on the earth, generating a new source of energy to resolve the serious crisis which human beings are now facing. It is urgently demanded that we suppress the output of carbon dioxide by developing a new energy source before a climate crisis occurs. 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 research has been realizing rapid progress due to the world wide integration of science and technology, a further intensive and comprehensive approach with innovation is required to resolve the existing critical issues. This is the goal of NIFS and this approach also attracts and arouses diversified scientific interests. For example, physics and engineering for steady-state operation will not be explored sufficiently even by ITER. The LHD has full capability for steady-state operation and, therefore, a complementary and bilateral role for LHD is essentially critical in fusion research. The advantages of a steady-state, stable plasma provide a variety of opportunities for innovative and interdisciplinary studies.

The LHD is a heliotron-type device which employs superconducting magnets. The scale merits of large volume ($30m^3$) and strong magnetic field (3T) enable us to investigate the physics of net-current free plasmas very accurately. The primary heating source is neutral bema injection with a heating power of 23 MW, and Electron Cyclotron Heating (ECH) with 3.5 MW plays an important role in local heating and power modulation in transport studies. In parallel with parameter improvement, the important physics processes of transport and MHD have been identified and assessed by analyses based on profile diagnostics with fine spatial resolution and numerical computation to cope with a real 3-D geometry. The highlighted achievements in plasma parameters are the quasi-steady-state maintenance of a Super-Dense-Core due to an Internal Diffusion Barrier (IDB) for 3 s by the feedback control of pellet fueling, a high electron temperature of 15 keV and a steady-state high-temperature discharge with a central electron temperature of 3 keV for 400 s by ECH, and a central β of 10 % at the moderate magnetic field of 1.5 T by means of the IDB.

The plasma with a central ion temperature reaching 5.6 keV exhibits the formation of an Internal Transport Barrier (ITB) in LHD. The ion thermal diffusivity decreases to the level predicted by neoclassical transport. The ion ITB is accompanied by spontaneous toroidal rotation and an Impurity Hole which generates an impurity-free core. An Impurity Hole is derived from an extremely hollow profile of impurities which develops with the increase of the ion temperature gradient. This phenomenon is due to a large outward convection of carbon impurities in spite of the negative radial electric field which has been confirmed by the heavy ion beam probe. The magnitude of the Impurity Hole is enhanced in the magnetic configuration with larger helical ripples and for higher Z impurities. Another mechanism to suppress impurity contamination has been identified as impurity screening at the plasma edge with a stochastic magnetic field. The 3-D simulation of the edge plasma has reproduced experimental observations and clarified the friction-force role in driving impurities downstream towards the divertor. These features are favorable to further performance improvement in ion temperature and high density operation and clarification of their physical mechanism will provide a critical perspective for a fusion reactor.

The demand for 3-D modeling is becoming inevitable for accurate and detailed studies in tokamaks as well as in helical systems. Both toroidal systems share common 3-D related physics issues such as documentation of 3-D equilibria, transport in a stochastic magnetic field, plasma response to a Resonant Magnetic Perturbation (RMP) and divertor physics. An RMP with $m/n=1/1$, which has resonance in the plasma periphery, has demonstrated the radial expansion of a super-dense-core surrounded by an IDB through the density reduction in the mantle outside the IDB. Detachment physics also has been investigated by applying an RMP to high density plasmas. The study of magnetic-island dynamics with an RMP has clarified that a poloidal flow develops prior to the transition from growth to healing of the magnetic island.

The activity of simulation science in NIFS aims at understanding the complex fusion plasma which is characterized by multi-hierarchy, nonlinearity, non-equilibrium, and openness. It consists of multi physics and multi time/space nonlinear processes, from macroscopic process, such as, plasma transport, all the way through to microscopic electron dynamics. A holistic viewpoint is very important in addition to the investigation of each fundamental physical process. Two tasks in our simulation science are defined to evolve a new paradigm which enables us to comprehend a multi-hierarchy system holistically. One is to construct the simulation methodology and simulation environment that enables us to deal with the complex multi-hierarchy system consisting of multi time/space nonlinear processes and multi physics. The second task is to understand and systemize physical mechanisms in fusion plasmas and explore the science of complexity in plasma as basic research supporting fusion plasma studies by utilizing the developed methodology and simulation environment. Three simulation projects, i.e., the LHD and Magnetic Confinement Simulation Project, the Laser Fusion Simulation Project and the Plasma Complexity Simulation Project have been promoted for these tasks. Multiple physical processes and their mutual interactions occurring in core and edge plasmas are being studied by a combination of fluid and kinetic simulations aimed at the ultimate realization of a helical numerical test reactor. The gyrokinetic Vlasov (GKV) simulations reveal new features in effective regulation of ITG turbulence by zonal flows in the neoclassically-optimized LHD configuration. A new GKV simulation codes, GKV-X, has been developed for direct comparison with the LHD experiment with regard to microinstabilities and turbulent transport. The Rokkasho Research Center of NIFS plays an important role in collaborating with the International Fusion Energy Research Center in Rokkasho. In parallel, the computer working group and the virtual reality taskforce are organized to support collaborating activities.

Fusion engineering research has been implemented as several programs integrated towards the development of a fusion reactor. The experience of reliable operation of a large superconducting system has been accumulated in LHD, and research to examine the properties of the superconducting coils is continued through optimization studies of the subcooling system. Basic research for liquid blankets, R&D for low activation materials and fusion-relevant research for superconducting magnets with emphasis on radiation effects are fundamental elements for development of an attractive reactor concept. Major efforts of the liquid blanket research are in the development of a coating for corrosion resistance, electrical insulation and hydrogen permeation suppression, and on compatibility of structural materials with liquid breeders. In the series of reactor designs for the Force-Free Helical Reactor, the coil pitch parameter of the continuous helical winding and the positions of the poloidal coils have been optimized to reduce the magnetic stored energy below 150 GJ while expanding the blanket space, and a self-cooled Flibe blanket has been proposed as a long-life blanket under neutron wall loading less than 2 MW/m^2. Recent establishment of an innovative high density operation mode in LHD has stimulated a new operational regime, where the divertor heat load can be reduced drastically. While a large-size superconducting helical coil has been shown to be conceptually feasible, divertor design, external heating design and unscheduled blanket replacement are being assessed in terms of the system integration for a reactor.

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. The above mentioned highlighted topics and many other important results are covered in detail 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.

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Director-General
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