I. National Institute for Fusion Science
April 2006 – March 2007

This annual report summarizes the research activities at NIFS between April 2006 and March 2007. NIFS is pursuing the integration of science and technology to realize a sun on the earth; a fusion power plant. The systematization of plasma physics, and research and development of reactor relevant engineering are key elements in our strategy. Experiments on the Large Helical Device (LHD) and large scale simulations are intensively conducted in the way they both extend the frontier of plasma physics and related device technology. The Fusion Engineering Research Center (FERC) builds up R&D for a advanced blanket system. The Coordination Research Center (CRC) promotes spin-off of our achievements to industry as well as other academic fields.

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 abroad as well as in Japan.

Three kinds of collaborating frameworks with their own distinguishing features are well arranged to fulfill diverse requirements from collaborators. The general collaboration research covers a wide spectrum of studies on fusion research. The LHD program collaboration research facilitates substantial participation in the LHD project based on the achievements in universities. The bilateral coordinated collaboration research promotes mutual interaction on an equal footing with annexed research institutes of the universities. More than 400 collaborating studies have been implemented during the covered period.

The major programs at NIFS are (i) the experimental study of toroidal plasma confinement using LHD and (ii) theoretical research and computer simulations for the study of the complex state and nonlinear dynamics such as those seen in high temperature plasmas. These major projects are accompanied and followed by unique supporting and applied researches. In particular, advanced engineering and fusion reactor design studies are strongly promoted.

The LHD is a heliotron type device with an intrinsic divertor. It employs the largest superconducting magnets in the world. The major goal of the LHD experiment is to demonstrate the high performance of helical plasmas in a reactor relevant plasma 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. We completed the 10th experimental campaign in FY2006. Diversified studies in LHD have elucidated the broad scope of high performance steady-state plasmas.

The plasma parameters as well as physical understanding have been progressing steadily since the beginning of the LHD experiment in 1998. Three highlighted results, which should be recorded as major milestones, were achieved in the last experimental campaign in FY2006. The first one is the extremely high density plasma with the density up to $1\times10^{21}m^{-3}$ at the moderate magnetic field of 2.54T. The central pressure exceeds atmospheric pressure. An *Internal Diffusion Barrier* (IDB) which was realized only in the *Local Island Divertor* (LID) configuration so far has been reproduced in the open *Helical Divertor* (HD) configuration. The configuration with the outward shift of the magnetic axis (R_{ax}≥3.75m) suppresses neutral build up and recycling. This situation, which is similar to an LID configuration, turned out to be favorable to generation of an IDB. The achievement of extremely high density plasmas with an IDB in HD strongly motivates the upgrade plan of closed HD and a novel scenario of a super-high-density reactor. Characterization and assessment of an IDB proceed greatly by the experimental results in the 10th experimental campaign. The second one is the achievement of the volume averaged beta of 5 %. The beta value, which is the ratio of the plasma kinetic pressure to the pressure of confining magnetic field, is a critical parameter to assess efficiency in a reactor. This achievement demonstrates an attractiveness of a heliotron concept. The beta value of 4.8% has been maintained longer than 10 times the energy confinement time. A hard limit of the beta value has not been observed yet and we still can push the high beta with upgrading the heating power and figuring out means to improve confinement. The third one is the achievements of high ion temperature of 5.2 keV at the density of 1.2×10^{19}m^{-3} in pure hydrogen plasmas. So far, the ion temperature exceeding 10 keV was obtained in the low density (5×10^{18}m^{-3}) Ar discharges. Development of operational schemes to enhance ion heating has produced this result together with good equipment of the perpendicular NBI with 40 keV. An observed large toroidal rotation with several 10 km/s in this high ion temperature plasma suggests confinement improvement and an accompanied observation of impurity evacuation from the core attracts physical interests. LHD produced about 9,600 plasma discharges in FY2006. This high availability of experimental opportunities has indicated a large potential to enable a variety of approaches for scientific research, which is not limited to fusion science in a narrow sense. Many important results other than above mentioned three topics are reported in this annual report.

Based on much effort of R&D to improve the cryogenic stability, the sub-cooling modification has been applied to the helical coil. The temperature has been successfully decreased to 3.2 K from 4.4 K without this system. Available magnetic field for the plasma experiment is raised from 2.75 T to 2.85 T in the case with R_{ax}=3.6m, which enables the central ECH resonance in the magnetic configuration with the inward shifted magnetic axis.

Various computer simulation researches have been pursued with the efforts to explore a new framework of the simulation science, which include simulations related to magnetic fusion plasma physics, more specifically LHD simulations, laser fusion plasma physics, space plasma physics, basic plasma physics, physics of molecular dynamics and so on, and also related area supporting computer simulations such as numerical technique, visualization technique, virtual reality technique, and network technique. With the progress of computer performance, the paradigm shift of methodology is progressing from the classical scheme of reduction to the elements, to the integration of various interconnecting physics with different time-space scales. This methodology promises to lead to an understanding of the whole structure of natural phenomena.

On the way from macro to micro scales, for example, the properties of equilibria with micro-scale effects such as the Hall term, pressure anisotropy, electron inertia, and wave-particle interaction are investigated and a hierarchy-renormalized simulation model is being developed. Some large scale simulations such as a gyro-kinetic simulation code GKV and a 3-D MHD equilibrium code HINT2 are closely connected to the LHD experiments.

In FERC, corrosion of ferritic steels, vanadium alloys in Flibe and Li are mainly studied collaborating with laboratories in universities. One of critical issues is compatibility of the structure materials with the breeding/cooling materials, namely, corrosion behavior in static and flowing conditions of the liquid breeder.

Three divisions; academic research coordination, industry-academia research coordination, and atomic and molecular data research, are acting in CRC. A variety of coordinated researches with other institutions in NINS, ITER, the Institute of Laser Engineering in Osaka Univ., the Gifu Prefecture Institute of Ceramics, Pennsylvania State Univ. and industrial companies are managed.

Lastly, NIFS conducts several 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, JSPS-CAS Core-University Program, TEXTOR Collaboration and International Collaboration on Helical Research based on the IEA agreement. NIFS plays an important role as a COE in fusion science on a worldwide scale.

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