I. National Institute for Fusion Science
April 2007 - March 2008

This annual report summarizes research activities at the National Institute for Fusion Science (NIFS) between April 2007 and March 2008. The main objective of NIFS is symbolically expressed as the realization of a sun on the earth, generating a new, futuristic source of energy. Human beings face a serious crisis concerning the change of the global environment. It is obvious that the highest priority for us is to reduce the output of carbon dioxide by developing a new energy source before a climate crisis occurs.

Fusion research has been realizing rapid progress due to world wide integration of successful science and technology and has been recognized as a major big science. This means that fusion energy is accessible, with a clearly defined critical path i.e., systematization of plasma physics, development of low activation materials, understanding of plasma-wall interaction, etc. These are urgent issues requiring solutions and arousing scientific interest and innovation. NIFS carries out fundamental as well as cutting edge studies to achieve these goals. 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 abroad as well as in Japan. More than 400 collaborating studies have been implemented during the covered period.

Experiments on the Large Helical Device (LHD) and large scale simulations are intensively conducted in ways that they both extend the frontiers of plasma physics and related device technology. The Fusion Engineering Research Center (FERC) carries out R&D for an advanced blanket, low activation materials and superconducting magnets. The Coordination Research Center (CRC) promotes coordinated research with domestic and foreign institutes as well as industry.

The LHD is a heliotron type device with an intrinsic divertor. It employs the largest superconducting magnets in the world which have been operated successfully for 10 years. 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 11th experimental campaign in FY2007. Diversified and intensive studies in LHD have elucidated the broad scope of high performance 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 6.8keV at the electron density of $2\times10^{19}m^{-3}$. Although remarkable impurity exhaust in the high- T_i plasma prevented the T_i measurement by charge exchange spectroscopy, bundling the optical fibers for signal enhancement from the core region overcomes the difficulty in measuring T_i even with “impurity hole” and this fine measurement indicates improvement in ion heat transport and spontaneous toroidal rotation. The high density regime by an *Internal Diffusion Barrier* (IDB) has been explored over a wide range of physical parameters. The maximum density and pressure have reached $1.1\times10^{21}m^{-3}$ and 1.5 atm. at the moderate magnetic field of 2.57T. In the IDB region, particle diffusivity is kept at a low level (~ $0.04m^2/s$) in spite of an extremely large density gradient. These high density plasmas do not suffer from the impurity contamination and impurity screening effect in the ergodic layer has been suggested as a potential key mechanism. With regard to steady state operation, 1-MW heating by a combination of ICH (0.9MW) and ECH (0.1MW) sustained the plasma for 800 s, which motivates PWI research in order to suppress an abrupt impurity influx. To enhance cryogenic stability of the helical coil by lowering temperatures at the inlet (3.2K), a subcooling system was installed before the cool-down in 2006 and its routine operation has been established in the 11th experimental campaign. Excitation tests with the field up to 2.96 T at the R = 3.6 m have been carried out successfully. The availability of the higher magnetic field has contributed to the central heating experiment by ECH and achievement of the largest plasma stored energy of 1.62 MJ. Also the propagation length of a normal zone under subcooling is shorter than that under saturated helium (4.4K), which has verified the improvement of cryogenic stability. Studies of these highlighted topics in detail and many additional important results are covered in this annual report.

Analytical and numerical research, and pioneering theories to obtain a comprehensive understanding of the physics mechanisms which determine confinement in LHD are also reported. Numerical codes to cope with 3-D geometry, even including magnetic islands and stochastic fields have been being developed and validated by LHD experiments. MHD equilibrium (HINT2) and stability, MHD simulation, neoclassical transport and gyro-kinetic Vlasov simulation (GKV) are highlighted. Turbulent transport affected by zonal flows and radial electric field attracts wide interest in structure formation and is investigated analytically as well as numerically.

In order to clarify physical mechanisms that underlie many different classes in the experimental results, large-scale simulation research is promoted utilizing fully the capacity of the super computer. Various computer simulation research topics have been accelerated in the Department of Simulation Science which was established on April 1st in 2007. The Department consists of the Division of LHD and Magnetic Field Confinement Simulation, the Division of Fusion Frontiers Simulation, and Rokkasho Research Center. In addition, technical activities by the computer working group, the network working group, and the virtual reality taskforce are organized. Three projects are conducted in the Department, which are LHD and magnetic field confinement simulation, laser fusion simulation, and plasma complexity simulation. Through collaborative research with universities, the department is developing a model for the "hierarchical renormalization simulation" that self-consistently renormalizes hierarchical interactions. This methodology promises to lead to an understanding of the whole structure of natural phenomena. The Department, together with collaborative researchers, will develop the LHD Numerical Test Reactor on the basis of the knowledge and information obtained through this simulation research and development.

The research of the FERC is categorized into (1) basic research for a liquid blanket, (2) R&D for low activation materials and (3) fusion-relevant research for superconducting magnets with emphasis on radiation effects. A major subject of the liquid blanket research is the compatibility of Reduced Activation Ferritic/Martensitic Steels (RAFM) as structural materials with molten-salt Flibe and liquid Li. Radiation shielding to protect a superconducting magnet system is an important issue in fusion blanket designs. Investigations of the shielding performance of a liquid Flibe cooled and Li cooled blanket proposed for the FFHR2 reactor design have been conducted by neutron and gamma-ray transport calculations.

Three divisions in the CRC; the academic research coordination laboratory, the industry-academia research coordination division, and the science communication section are active. The division of atomic and molecular data research division has been reorganized as the A&M and PWI data research section under the academic research coordination laboratory. A variety of coordinated research topics 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 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, and collaborations under the IEA implementing agreements for Stellarator/Heliotron Concept, Spherical Tori and PWI in TEXTOR. NIFS plays an important role as a COE in fusion science on a worldwide scale.

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