1-2. Device Engineering and Cooperative Development Research

(1) Physics and Engineering of LHD Torus System

Research and development of the LHD torus system have been conducted for a future upgrade of LHD and a reactor design. In particular, efficient fueling and pumping schemes and exploration of plasma wall interaction are emphasized since it is directly related to confinement improvement in the present and future experiment on LHD and also particle control is a major critical issue in a fusion energy reactor.

Progress in an LHD experiment has motivated the upgrade where the installation of closed divertor system, the use of deuterium as a working gas and enhancement of heating capability are planned. The results of research and development related to the first two subjects are reported here.

The closed Helical Divertor (HD) in LHD is planned to accomplish an active neutral control. Conversion from the present open HD configuration will show promise to improve plasma confinement and to sustain high performance long pulse discharges. The torus-inboard side divertor is considered for the first step to the full closed HD,. The analysis of neutral density distribution by a fully three-dimensional neutral particle transport simulation code (EIRENE) and experimental observation by a Hα emission detector array show that the neutral particle density is relatively high in the inboard side of the torus for R_{ax}=3.60m in which good energy confinement has been achieved. For this reason, the installation of closed divertor structure in the inboard side is favorable for efficient particle control. To exhaust 10 Pa · m^3/s of H_2 flux corresponding to fueling flux by repetitive hydrogen ice-pellet injection is a target value of the divertor pumping. To achieve the target exhaust flux using a realistic pump system, such as in-vessel cryogenic pumps, the neutral pressure in the HD has to be enhanced by more than one order of magnitude compared to that under the present open divertor condition. The design of the closed divertor structure (slanted divertor and baffle plates, a dome) to fulfill this requirement has been presented. It indicates that installation of additional vacuum pumping systems in the closed chambers can be effective for efficient particle control in the plasma periphery. Based on these analyses and design, a proto-type closed HD will be installed at one toroidal section in the nearest experimental campaign.

Many precedent experiments with deuterium D as a working gas have reported significant improvement of plasma performance. Conversion of fuel gas from hydrogen to deuterium, which provides opportunity to investigate isotope effect, will enhance a variety of experimental approaches. It should be noted that many preparatory studies are required to execute a deuterium experiment. In this category, plasma wall interaction has been investigated in the framework of collaboration with universities. Retention of deuterium in stainless steel (SUS) under deuterium plasma exposure and release of deuterium from SUS under He plasma exposure have been investigated by using a linear-divertor-plasma simulator (NAGDIS-II) in Nagoya University.

When all circumstance to conduct a deuterium experiment is arranged, the use of ^{3}He will be also possible. Protons with 14.67 MeV are produced by a fusion reaction of D and ^{3}He. Discrimination and acquisition of these high energy protons have been investigated by a numerical computation to examine possibility to demonstrate electric power generation. The present study shows that if an appropriate acquisition system is installed outside the chaotic field line region, the acquisition rate of 14.67MeV protons in LHD is estimated roughly up to 30 %. Direct power generation project from D-^{3}He experiment in LHD is under way.

Supersonic cluster beam and compact torus (CT) injection are being developed to establish efficient fueling. Properties of gas flow have been investigated in a test stand, which suggests expected behavior of supersonic cluster beam. Development of innovative fueling using a compact torus (CT) has been continued in the experimental facility, SPICA (SPeromak Injector using Conical Accelerator). Performance of the SPICA injector has been improved recently by optimization of the conical accelerator length and CT plasma production. The CTs with the density of $10^{21}m^{-3}$ can travel through a 1.8 m long drift tube. In addition to a direct fueling by CT injection, production of extremely super-high speed neutral particle flow is explored as a new approach to effective fuelling. In the experimental scenario, an accelerated CT penetrates into a long drift tube as a neutralizer cell, which is filled with H_2 up to the order of 1 to 10 Pa, then super-high speed neutral particle flow is produced through charge-exchange between CT plasma and neutral gas in the neutralizer cell. The neutral particle flow is expected to have a high speed of 300 km/s (equivalent to about 1 keV) and a high density of 10^{21} m^{-3}.

New experimental findings in LHD and these technological achievements in development programs stimulate each other and form a basis towards an attractive fusion energy reactor

(Yamada, H.)