1-2. Research and Development for LHD Upgrade

The LHD project has been executed to establish a physics basis extrapolated to a helical fusion reactor. For completing this goal, the LHD upgrade is projected to explore the high-performance plasmas relevant to the fusion reactor by improving the device capacity. The LHD upgrade is planned based on the deuterium experiments, which is expected to drastically improve the LHD plasma parameters. Including the deuterium experiments, the LHD upgrade program contains power-up of the heating system and improvement of the particle control with the closed helical divertor, together with development of highly precise diagnostics. The safety management research is also conducted for the planned deuterium experiments.

The research and development for the LHD upgrade is categorized as follows;

(1) Study of Deuterium Experiment Program in LHD
(2) Safety Management Research
(3) Diagnostics System
(4) Physics and Engineering of LHD Torus and Heating Systems

For the deuterium experiment, "The Measures for Safety of LHD Deuterium Experiment" was issued in 2007, which summarized the basic concept for the safety management in the LHD deuterium experiment. After the great east-Japan earthquake, the Measures was revised and revalued by the Safety Assessment Committee consisting of only outside experts. The Committee reported in February, 2012 that the revised Measures are appropriate to secure the safety in the LHD deuterium experiment.

Presently, study for the deuterium experiment is restricted to the program development. A workshop was held on March 22 in 2012 in order to discuss the feasibility and the validity of the LHD deuterium experiment. 85 researchers attended the workshop including 35 from universities, and discussed the key issues in the LHD deuterium experiment.

In the safety management research, the radiation safety management and monitoring for the present LHD experiments were carried out, and the results are intended to be applied to the future LHD upgrade program. A monitoring system (RMSAFE) successfully works to discriminate the radiation caused by the plasma experiments from the natural radiation and to accumulate the exposure dose.

For the planned deuterium experiment, the tritium and neutron treatment is a key issue in the radiation safety management. The specific technologies for the tritium monitoring and removing have been developed for an extremely low level of tritium. Also, the present environmental tritium concentration level in water and atmosphere is monitored, and an analysis of the LHD exhaust gas was carried out for the design of the gaseous tritium recovering system.

As non-ionizing radiation monitoring and management, measurement and analysis of the burst electromagnetic fields in LHD has been made in a collaboration work with universities. The monitoring system of the personal RF electromagnetic fields was tested. In an educational activity, potassium chloride is used as a radiation source for a training program on the radiation protection.

For the LHD upgrade, precise measurement of the plasma parameters is required in a three-dimensional helical configuration. Development of the diagnostics system has been performed along the above objectives, as well as improvement of the present diagnostics.

The mapping system was developed for the precise transport analysis, using in-out symmetry of the electron temperature profiles measured with the YAG Thomson. Accurate mapping of the ion and electron temperature and density profiles to the flux coordinate of effective minor radius is possible at each time slices of the Te measurement.

As a part of diagnostics tool that gives perturbation to the plasma, the TESPEL is used for the non-local transport study by combining the temperature measurements with the ECE. For the study on magnetic topology (stochastization), combination diagnostics of the MSE spectroscopy and the ECE were applied in the heat pulse experiments using the modulation ECH.

For the LHD upgrade and the consequent physics and engineering contribution to a fusion reactor, research and development related to the LHD torus and heating systems have been executed. For efficient particle control, the closed helical divertor with the cryo-sorption pumping system was installed at 6 toroidal sections in FY2011. For improvement of the cryo-sorption pumping system, heat load on the system is investigated. Tungsten is a prospective material for the plasma-facing armor in a reactor, and the properties of tungsten coatings on ferrite steel were investigated. Also, transport of the tungsten impurities was analyzed for a reactor with a transport code.

Development of the heating system has been carried out for the LHD upgrade project. In the 15th campaign, the total injection power achieved was 26MW with both negative- and positive-NBIs, which realized 7keV of the ion temperature. The R&D activities for the NBI development have also been continued for the next-step negative-NBI system. Due to the successful development, the total injected power of ECH exceeded 3.7MW with the three 1MW-77GHz gyrotrons, which contributed to the extension of the LHD plasma parameter regime. The ICH-related issues, such as heating efficiency, power density, and arcing in the transmission line and antenna, were discussed in a workshop for future development.

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