§19. Development of Neutron Diagnostic System for LHD Deuterium Experiment

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LHD has provided good particle confinement and a high β with quasisteady-state operation. Currently, the operation of LHD is performed with hydrogen and/or helium gases. To obtain a higher-performance heliotron plasma and a prospect of reactor based on LHD concept, deuterium experiments are in plan on LHD. One of key physics subjects in the LHD deuterium experiment is to enhance the understanding of fast ion-related physics such as a ripple transport, anomalous transport of fast ions caused by Alfvénic modes or turbulences. Because most of neutrons will be produced by so-called beam-plasma reactions in a neutral beam (NB)-heated LHD plasma, neutron diagnostics will play an important role not only in measuring fusion output but also in assessing global confinement property of beam ions. Deuterium experiments also will provide a new opportunity to investigate confinement of MeV ions isotropic in the velocity space in LHD plasmas. A list intended to satisfy the needs for optimization of fusion output measurement and energetic-ion physics in LHD includes 1) ex-vessel neutron flux monitors (NFMs) and activation foil system, 2) neutron profile monitor, 3) 2.5 MeV neutron energy spectrometer (NES), 4) 14 MeV neutron diagnostic, and 5) prompt γ-ray diagnostic [1]. To work on development of diagnostics mentioned above, the joint fusion neutron team has been organized from 2008 in the framework of NIFS collaboration (see Fig.1) and has performed a feasibility study and a proof of principle (POP) experiment for neutron detection system promising for LHD. An outline of representative results of our activities from FY2008 to 2011 is described below.

The neutron transport calculation is essential in a design stage of NFM. To perform Monte Carlo calculations for LHD, we have been made a great effort so as to model a complicated LHD structure on the MCNP-4C2 code for these four years. As a result of our efforts, in addition to the fluence rate and the energy spectrum of neutron near the LHD, the response function of the candidate neutron flux monitor for the DD neutrons and those from a ^{252}Cf neutron calibration source can be now calculated. We have investigated a) neutron shielding effects by a pair of helical coils, b) neutron energy spectra for a DD and ^{252}Cf neutron sources at the candidate position of NFM, c) the calibration process and the uncertainties associated with measurement of total neutron yield, d) the influence of the liquid helium for cooling the superconducting coils that will not exist during the calibration process, and so on. The obtained results are summarized in Refs. 2 and 3 in detail.

A novel DD NES based on associated-particles coincident counting technique has been developed. Because fuel ions are no longer Maxwellian in NB-heated plasmas, a neutron spectrum mainly reflects velocity distribution of beam ions. Neutron spectrometry can therefore contribute to the study of energetic-ion behavior in deuterium plasmas. The POP experiment indicated that our NES has the energy resolution of ~6% for DD neutrons [4,5] and this value is comparable with that of NES employed in JET.

For a neutron emission profile monitor, we have made an effort to enhance n-γ discrimination performance of stilbene detector by use of digital signal processing technique [1,7,8]. In addition, we have also proposed a neutron pinhole camera with state-of-the-art nuclear emulsion technique for imaging of the emission profile of DD neutron produced by beam ions [6]. Recoiled proton due to elastic scattering of incident neutron passing though the pinhole makes a track in the nuclear emulsion. The incident neutron energy can be estimated by the energy of recoil proton and scattering angle that are derived from the track length and an angle between the track and the incident direction of neutron, respectively. We made preliminary designs on the pinhole collimator size and arrangement. The estimated spatial resolution would be better 100 mm with tungsten alloy collimator for the application to emission profile imaging of DD neutron in LHD plasma.

Development of artificial diamond as a 14 MeV neutron spectrometer has been carried out [9]. To suppress stress resulting from unconformity of lattice spacing between a substrate and a grown layer, an off-axis (001) surface fabricated on HP/HT type IIa diamond single-crystal substrate was adopted. Energy resolution of 0.6% for alpha particles was obtained by one CVD diamond single crystal.

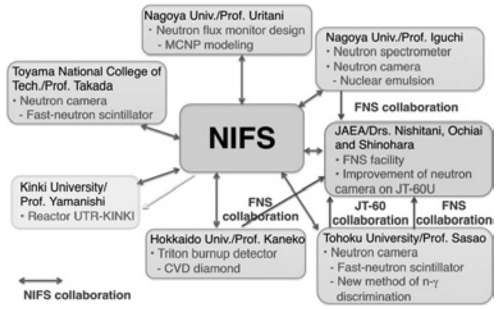

Fig. 1. Structure of the joint team for development of fusion neutron diagnostics in the framework of NIFS collaboration.

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