8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

# Fusion neutron spectroscopy using the newly developed CLYC7 scintillation detector-based neutron spectrometer


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Understanding the transport of fast ions, produced by auxiliary systems such as neutral beam injection (NBI) and ion cyclotron range of frequencies (ICRF) waves, is crucial for achieving high-performance plasmas and advancing the development of fusion power reactors. Comprehensive neutron diagnostics are employed to study fast ions by measuring neutron emissions from fusion plasma. Among these diagnostics, the neutron emission spectrometer is particularly notable for its effectiveness. Traditionally, neutron spectroscopy in thermonuclear fusion has been used to determine fuel ion temperature through the Maxwellian distribution of neutron energies from Maxwellian plasmas. However, with intense NBI heating of deuterium plasma in fusion devices like the Large Helical Device (LHD), the role of neutron spectroscopy has changed. During the NBI heating phase, the neutron spectrum is no longer Maxwellian. As a result, the Doppler shift in neutron energy offers valuable insights into the energy distribution of fast ions produced by NBI and ICRF waves. In the LHD, the confinement of passing and helically-trapped fast ions generated by NBI and ICRF waves has been extensively studied [1] using a comprehensive set of neutron diagnostics [2].

To enhance our comprehension of the slowing-down process of fast ions and the mechanisms behind fast-ion-driven MHD instabilities in the LHD, fast-ion energy distribution measurements were conducted using the compact neutron emission spectrometer (CNES). The CNES, featuring a liquid (EJ-301) scintillation detector and a $Cs_2LiYCl_6$:Ce with $^7$Li enrichment (CLYC7) scintillation detector, capable of tangential and perpendicular sightline measurements, has been in operation at LHD from 2020 to 2022. The CNES based on EJ-301 has a capability in a wide neutron emission rate region due to the fast decay time of its signal [3]. Deuterium-deuterium neutron is measured through the recoiled proton created by the elastic collision, thus the unfolding is needed [4], [5]. Unlike the EJ-301, the CLYC7 detects the deuterium-deuterium neutron through the $^{35}$Cl(n,p)$^{35}$S reactions, therefore the unfolding is not fully required. Nevertheless, CLYC7 produces a relatively long decay time signal, therefore, the operation of the CNES based on CLYC7 is limited in a relatively low neutron emission rate region [6].

The CLYC7 scintillation detector has been characterized across a wide range of neutron energies in the neutron sources facilities before its installation in the LHD, showing its potential in the field of fusion neutron spectroscopy [7]. In the LHD, three CLYC7 scintillation detectors with tangential and perpendicular line-of-sight configurations have been utilized for the CNES system. These detectors successfully measured the deuterium-deuterium neutron spectrometer during negative-ion-source-based NB (N-NB) injected fast ions and perpendicular positive-ion-source-based NB (P-NB). Figure 1 shows the results of neutron energy spectra during N-NBs heated plasma shot #164277 measured by CNES based on CLYC7.

References


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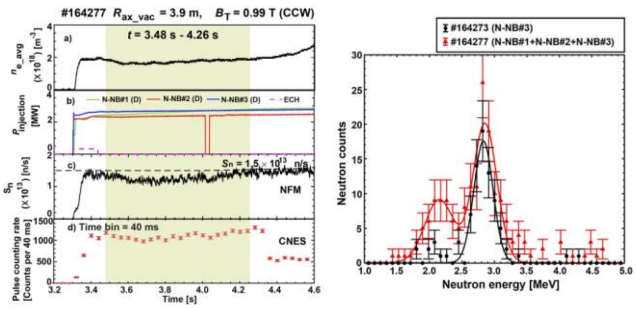


**Figure 1**. Left: time evolution of deuterium plasma shot #164277. Right: neutron energy spectra during N-NBs heating of LHD deuterium plasma measured by CNES based on CLYC7 [6].