

§37. Neutron Spectrometer for Deuterium Plasma Diagnostics

Iguchi, T., Kawarabayashi, J., Tomita, H. (Nagoya Univ.),
Isobe, M., Yamanishi, H.

We are developing a neutron spectrometer for deuterium plasma diagnostics in helical magnetic confinement system¹⁾. The spectrometer is based on coincident detection of the scattered neutron and recoiled proton from a plastic scintillator as the incident neutron target, or a radiator. In the case of elastic scattering of neutron in the radiator, the neutron energy is derived from sum of the deposit energies in the radiator and the recoiled proton detector and the scattered neutron energy measured by a time-of-flight technique. To investigate the neutron spectra emitted from DD reaction in deuterium plasma on LHD, we considered a first approximation model described as follow²⁾. Neutron spectra at position of the spectrometer $\phi(E_n)$ is obtained as

$$\phi(E_n) = \int \left(\int \int F_1(v_1) \cdot F_2(v_2) \cdot \sigma(v_r) \cdot v_r \cdot P_{Labo}(\Omega) dv_1 dv_2 \right) n_1 \cdot n_2 dV_p \quad (1)$$

where $F_{1,2}(v)$ is the velocity distribution of ion, $\sigma(v_r)$ is the cross section of fusion reaction, v_r is the relative velocity of ion, $P_{Labo}(\Omega)$ is the solid angle in the laboratory system, $v_{1,2}$ is the ion velocity, $n_{1,2}$ is the number density of ion, and V_p is the plasma volume within the field of view of the spectrometer. In this model, we neglect neutron interactions with the constructional material of LHD (e.g. plasma vacuum vessel, superconducting coils, cryostat vessel, and coil support structure) during neutron transport to the spectrometer. Assuming that time constant τ_{loss} corresponding to loss of the fast ion due to NBI heating in plasma, the velocity distribution of the fast ion in the steady state is given as

$$F_{fast}(v) = 4\pi v^2 \cdot \frac{S_0 \tau_{se}}{v^3 + v_c^3} \left(\frac{v_0^3 + v_c^3}{v^3 + v_c^3} \right)^{\frac{\tau_{se}}{\tau_{loss}}} \quad (2),$$

where τ_{se} is the ion slowing-down time due to collisions with electrons, v_c is the critical velocity, and v_0 is the initial velocity of fast ion. Here, $x \equiv \tau_{se}/\tau_{loss}$ is a dimensionless parameter related to confinement of fast ion in plasma. As the velocity distribution of thermal ion, we used Maxwellian distribution. We considered the deuterium plasma to be available on LHD, which is $n = 2 \times 10^{19} \text{ 1/m}^3$, $V_p = 3 \text{ m}^3$, ion/electron temperature of 5 keV with NBI heating with injection energy of 180 keV and power of 6.4 MW. Note that the plasma has no spatial distribution of density/temperature of thermal ion, or spatially uniform in this model. Assuming that the spectrometer is installed at distance of 7 m from the center of plasma along the tangent line, expected neutron spectrum was calculated as Figure 1 (a). In the case of $x > 1$, there was just a little difference in the spectra due to DD reaction between the fast ion and the thermal ion. On the other hand, the calculated neutron spectrum due to DD reaction between fast ion and thermal ion had a difference in these shapes and intensities for each

x at 0.01 – 1.0 as shown in Figure 1 (b). Figure 2 shows the dependence of the neutron intensity on x . To evaluate the fast ion confinement by the intensity of DD neutron, DD neutrons without scattering before incident into the spectrometer should be separated from a background of scattered neutrons. Since an energy broadening of the spectrum was estimated to be about 7% in FWHM, an energy resolution of less than 7% is required for the spectrometer. In addition, the detection efficiency of 10^{-6} counts/neutron is required to keep the statistical uncertainty of the detected neutron intensity less than 10%. As a next step, we will consider the detailed design of the prototype spectrometer to satisfy the requirements.

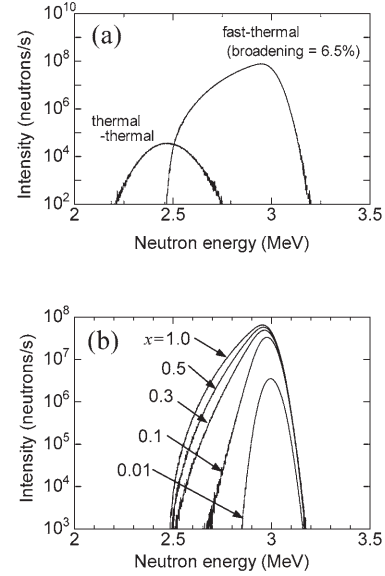


FIG. 1. Calculated neutron spectrum at distance of 7 m from the center of plasma along the tangent line (a), and calculated neutron spectrum due to DD reaction between the fast ion and the thermal ion for $x = 0.01 - 1.0$ (b).

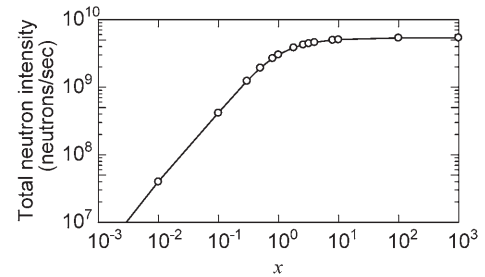


FIG. 2. Dependence of the neutron intensity on x .

- 1) H. Iwai, T. Iguchi, H. Tomita, J. Kawarabayashi, M. Isobe, and C. Konno, 2009 IEEE Nuclear Science Symposium Conference Record (NSS/MIC), 1356 – 1359, (2009).
- 2) H. Tomita, H. Iwai, T. Iguchi, M. Isobe, J. Kawarabayashi, and C. Konno, “Development of neutron spectrometer toward deuterium plasma diagnostics in LHD” Rev. Sci. Instrum. (*submitted*).