§11. Effect of Nuclear Plus Interference Scattering and its Verification Scenario in Burning Plasmas

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It is well known that for energetic ions, nuclear plus interference (NI) scattering contributes to their slowing-down process. The energetic ions contribute to the knock-on tail formation in fuel-ion velocity distribution functions via NI scattering. So far several calculations have predicted that in D^3He plasmas the fraction of transferred power from energetic protons to bulk ions is enhanced almost three times due to the NI scattering. In such a case the required confinement parameter could be reduced. Although the impact of the influence is not so significant, similar effect can also appear even in the DT plasmas. It is important to experimentally verify the NI scattering effect. The knock-on tail causes modification of the neutron emission spectrum from the Gaussian distribution. By detecting the non-Gaussian (energetic) component in the neutron emission spectrum, information for energetic ions and NI scattering effect on plasma heating process can be grasped. We have presented a scenario to experimentally examine the NI-scattering effects which is expected to appear in reactor-grade plasmas by utilizing the currently existing deuterium plasmas. However, the non-Gaussian component is several orders of magnitude less than the peak of the Gaussian distribution function and it is difficult to detect the non-Gaussian component with sufficient accuracy.

In this study, a new verification scenario of knock-on tail formation in the deuteron distribution function due to nuclear plus interference scattering is studied by observing the incident angle distribution of neutrons in a vacuum vessel. A helical deuterium plasma in which ^3He beam is tangentially injected is considered. The deuteron density $n_D = 8 \times 10^{19}$ m^{-3}, and the electron temperature $T_e = 20$ keV are assumed. In this plasma the knock-on tail is created in the deuteron distribution function via NI scattering by fusion produced protons. For simplicity, we focus a mono-energetic 1 MeV deuteron component in the knock-on tail. As shown in Fig.1 the incident angle in the meridional plane as the poloidal incident angle ι_p, and in the equatorial plane as the toroidal incident angle ι_t are defined. The positions and directions of energetic deuteron are calculated by the orbit calculation with the LHD field $B_{ax} = 2.74$ T. The orbit of a 1-MeV deuteron for 200 toroidal turns after it is generated at the magnetic axis with pitch angle 0° is used for this calculation. Neutron emission direction and energy by $D(d,n)^3He$ reaction are calculated using the positions, directions, and energies of the energetic deuterons at the moment when the fusion reaction occurs. Neutron collision points with the first wall and neutron incident angles are calculated using the neutron emission direction and a mathematical expression of the shape of the first wall.

The neutron incident energy spectra due to (a) reactions between thermal deuterons and (b) reactions between 1-MeV and thermal deuterons at the wall position $\theta = 0°$ are shown in Fig.2 as a function of the toroidal incident angles. The neutron incident angle correlates closely with the neutron emission energy and direction. Neutrons emitted in the same direction as the center-of-mass velocity of the reacting deuterons, collide with the first wall at an incident angle $\iota_t = 45°$ with maximum energy. At $\iota_t = 45°$, the largest number of neutrons in the non-Gaussian component is observed. On the other hand, most of the neutrons in the Gaussian component is observed at the incident angles from 50° to 130°. When neutrons are isotropically emitted from a circumference with a radius of 3.6 m, they can collide with the first wall with incident angles within the interval of about $49° \leq \iota_t \leq 131°$. Since detection of the neutrons by reactions of thermal deuterons at $\iota_t = 45°$ is difficult, if we observe the neutron spectrum at $\iota_t = 45°$ point, the difference between the non-Gaussian and 2.5-MeV Gaussian peak is reduced by two orders of magnitude compared with the averaged neutron emission spectrum.

It has been shown that by choosing the wall position and toroidal incident angle adequately, the ratio of the non-Gaussian to Gaussian neutrons can be increased. The accuracy of the non-Gaussian neutron measurement can be improved in the validation of NI scattering effect[1)].

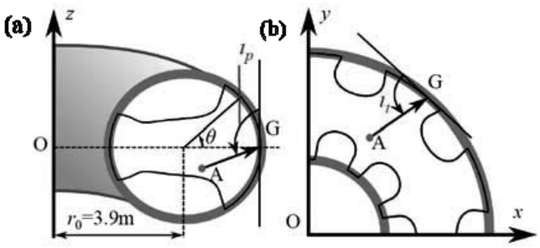

Fig. 1. Relations between the first wall shape and (a) the poloidal incident angle ι_p in the meridional plane, and (b) the toroidal incident angle ι_t in the equatorial plane.

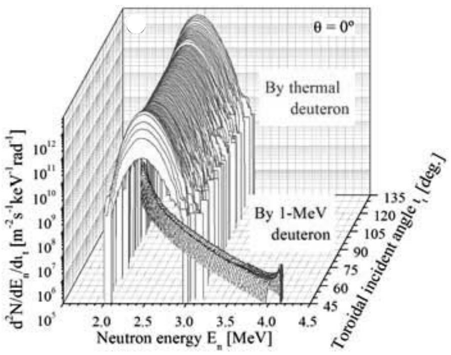

Fig. 2. Incident neutron energy spectra at the wall position $\theta = 0°$ as a function of the toroidal incident angle.

1) Sugiyama, S., et al.: Plasma Fusion Res., **10**, 3403055 (2015).