§5. Effect of Nuclear Elastic Scattering on Burning Plasmas and Its Verification Scenario

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It is well known that for energetic ions, nuclear elastic scattering (NES) contributes to their slowing-down process. The energetic ions contribute to the knock-on tail formation in fuel-ion velocity distribution functions via NES. 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 NES. 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 NES effect. Now we focused our attention on a verification scenario of knock-on tail formation using 0.48-MeV γ-rays by ^{6}Li(d,p)^{7}Li*, ^{7}Li* →^{7}Li+γ reaction in a deuterium plasma. The ^{6}Li(d,pγ)^{7}Li cross section rapidly increases with increasing relative energy between ^{6}Li and deuteron, and owing to the existence of small fraction of knock-on tail component, the (velocity-averaged) ^{6}Li(d,pγ)^{7}Li reaction rate coefficient, i.e., γ-ray emission rate, would be significantly enhanced. Previously we roughly evaluated the ^{6}Li(d,pγ)^{7}Li reaction rate coefficient assuming a uniform plasma [1]. In this study we develop more precise model heading on the future experiment and re-evaluate the rate coefficient of the γ-ray-generating reaction. We take into account behaviors of beam-injected protons in a magnetic confinement device by means of the ion trajectory analysis. Using the obtained two-dimensional (2D) velocity distribution function of beam-injected protons, velocity distribution of the deuteron knock-on source due to NES by energetic protons is evaluated in 2D velocity space from Boltzmann collision integral at every position in a fusion plasma. From the 2D deuteron velocity distribution function, which is obtained by solving 2D Fokker-Planck (FP) equation, enhancement of the 0.48-MeV γ-rays emission rate due to NES is evaluated. The purpose of this study is to show a possibility of the γ-ray-generation reaction to verify the knock-on tail formation due to NES on the basis of a newly-developed more precise model.

A deuterium plasma in which 200 keV proton beam is tangentially or vertically injected to the toroidal axis is considered. The deuteron density $n_d = 10^{19}$ m^{-3}, and the electron temperature $T_e = 2$ keV are assumed. For simplicity, we assume the protons are born on the toroidal axis as a result of NBI. In this plasma the knock-on tail is created in the deuteron distribution function via NES by injected protons. At first, proton distribution function is evaluated using ORBIT code [2]. As a first step, we assume ITER-like magnetic configuration. In Fig.1 (a) we first show the volume-averaged proton distribution functions for tangential beam injection as a function of both parallel and vertical velocity components to the toroidal magnetic axis. Using the obtained proton distribution function the Boltzmann collision integral is carried out. Assuming the knock-up component as a source term in the 2D Fokker-Planck equation, the deuteron velocity distribution function is obtained (Fig.1(b)).

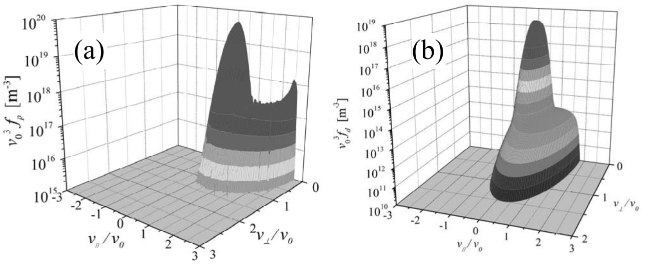

Fig. 1: (a) proton and (b) deuteron velocity distribution functions in proton-beam injected deuterium plasma.

Table 1: ^{6}Li(d,pγ)^{7}Li reaction rate coefficients and the degree of the enhancement η compared with Maxwellian.

Injection	$<\sigma v>_{^6\mathrm{Li+d}}$ [m^3/s]	η
Tangential	5.2×10^{-31}	132
Vertical	5.4×10^{-31}	136

By using the deuteron distribution function obtained, we next evaluate the ^{6}Li(d,pγ)^{7}Li reaction rate coefficient. Here ^{6}Li is assumed to be Maxwellian and ^{6}Li density is assumed as n_{6Li}=0.01n_d. The ^{6}Li(d,pγ)^{7}Li reaction rate coefficient is shown in Table 1 for tangential and vertical injections. When Maxwellian is assumed for both deuteron and ^{6}Li velocity distribution functions, the reaction rate coefficient is evaluated as 3.93×10^{-33} m^3/s in this condition, thus we can find that the reaction rate coefficient is enhanced approximately 2 orders as a result of knock-on tail formation.

The enhancement of the 0.48-MeV γ-ray emission rate via ^{6}Li(d,pγ)^{7}Li reactions due to NES by energetic protons is examined using the newly developed analysis model considering ion behavior in ITER-like device. The results obtained by the present model, i.e., total 0.48-MeV γ-ray emission rate from the plasma, are almost the same as those by previous 1-D Boltzmann-Fokker-Planck model [1]. It is shown that the 0.48-MeV γ-ray emission rate considerably changed according to the magnitude of the knock-on tail in deuteron distribution function, and we can say that the present method can be a useful tool to examine the knock-on tail formation for various plasma conditions. The subsequent investigation for the other useful γ-ray-generation reactions and simulation assuming other types of devices such as LHD are our next issues.

[1] H. Matsuura, et al., Plasma Fusion Res., 2, S1078 (2007).
[2] R. B. White et al., Phys. Fluids, 27, 2455 (1984).