§25. R&D of Alpha Particle Induced Gamma-ray Imaging System with Tandem Accelerator

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It is important to study plasma physics on the confinement of the energetic particles, which are produced by DT and/or DD reaction in a burning plasma. The diagnostics of the distribution of energetic particle loss site have been proposed. The fundamental principle is the detection of 4.44-MeV gamma rays produced by the interaction between the energetic particles come from the plasma and the first wall. To study the loss of the high energy alpha particles, it is need to obtain an image of the gamma-ray production points on the first wall. The aim of this study is a development of the imaging system for high energy gamma rays.

The HP-Ge detector was set at the end of beam line on the 1.7 MV tandem accelerator at Kobe University. Gamma rays were produced by some reactions such as Be(α, nγ), Be(p, γ), Be(d, γ), C(d, γ) reactions. Be(α, nγ) reaction has been typically used for recent experiments and the incident ion is 4.5-MeV helium. The energy of the gamma ray is 4.44 MeV. Some polyethylene blocks including boron was used for neutron shielding and some lead blocks were used to shield the environmental gamma rays and the spectrum was measured with a HP-Ge detector.

After a compound nucleus, $^{13}C^*$, of the Be(α, nγ) reaction emits a neutron, the nucleus becomes $^{12}C^*$. A gamma ray emission occurs rapidly during the nucleus still moving. The spectrum of the gamma rays is affected with Doppler effects, such as the peak shift and the broadening.

A photo peak shape is affected by a detector resolution, the energy of helium in collision, a neutron emission process and the Doppler effects. The resolution of the HP-Ge detector was measured with some standard radiation sources for calibration. These gamma energy was up to 1.33-MeV (^{60}Co). A resolution at the energy of 4.44 MeV was obtained from extrapolating these resolutions, and the value was 14.6 keV. These value were confirmed with PHITS [1] calculations.

Gamma ray spectra was measured with HP-Ge detector at various detection angles. The direction of the incident beam is $\theta = 0$. Fig. 1 shows some examples of the photo peak spectra at some detection angles. Those solid angle of detector and the number of the incident ions are same.

Doppler shift are not observed at $\theta = 90°$, because the velocity component toward 90° is almost nothing. The broadening of the peak at $\theta = 90°$ was caused by a neutron emission process, the difference of incident helium kinetic velocity and a lifetime of exited nucleus of $^{12}C^*$. The shape was the same as the experimental result with Am-Be standard source. The high energy region of the peaks in forward direction broadened by Doppler broadening. Otherwise the lower energy of the peaks in backward direction broadened.

Moreover, the Doppler shifts of the peaks are seen in Fig. 1. The dependence of the shift on detection angles are shown in Fig. 2. The shift is almost proportional to cos θ. This result is agrees with theoretical energy shift.
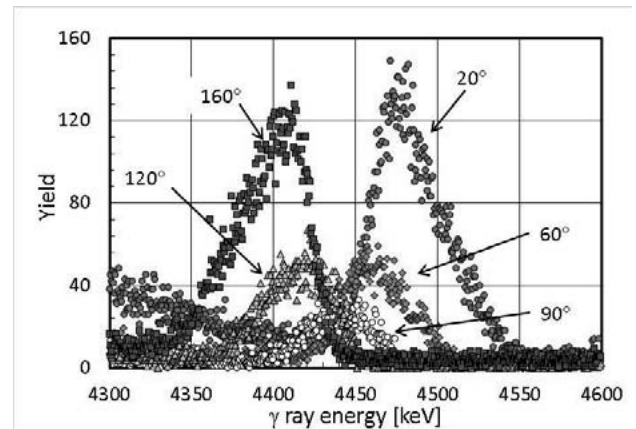

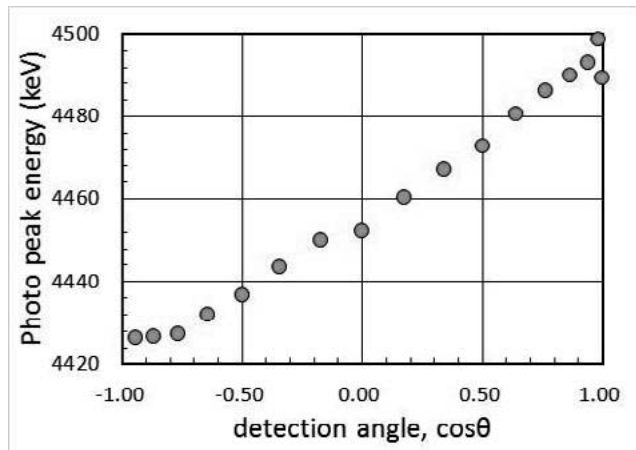Fig. 1. Examples of photo peak spectra for detection angle $\theta = 20°, 60°, 90°, 120°, 160°$.

Fig. 2. Doppler shift of the photo peaks as a function of a cosine of the detection angle θ.

We have been developed the multi-channel detector for the gamma ray imaging. To count the gamma rays in each channel, the energy range in the spectrum must be selected, of cause including the photo peak. The spectrum is affected by the Doppler effects obtained in this study, and the selection have to take it into accounting.

[1] T. Sato et al., J. Nucl. Sci. Technol. 50:9, 913-923 (2013)