Construction of a γ–γ and β–γ Coincidence Measurement System for Precise Determination of Nuclear Data

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A γ–γ and β–γ coincidence measurement system was constructed for the precise determination of nuclear data, such as thermal neutron capture cross sections and γ-ray emission probabilities. The validity of the system was tested by a γ–γ coincidence measurement with a ^{60}Co standard source.

1 Introduction

It is of fundamental importance for the nuclear transmutation study of radioactive waste to obtain precise value of nuclear data, such as thermal neutron capture cross sections, $\sigma_{n\gamma}$. From this point of view, we have performed a series of experiments to determine precisely thermal neutron capture cross sections of the FP nuclides by the activation method.

To determine $\sigma_{n\gamma}$ precisely in the conventional activation method, in which γ rays emitted from an activated sample are measured using only one detector, accurate data for γ-ray emission probabilities I_γ are required. For some nuclides, $\sigma_{n\gamma}$ can be determined more precisely if the I_γ of their capture products are obtained with better accuracy.

For the precise determination of $\sigma_{n\gamma}$ and I_γ, a γ–γ and β-γ coincidence measurement system was constructed. In this system, the data is accumulated in list format with singles trigger condition, i.e. singles as well as coincidence data are taken simultaneously. This feature makes dead times of singles and coincidence measurements being canceled out in deducing the activity, so cross sections can be obtained precisely.

In the next section, the feature of the system is described. Section 3 describes an experiment in which γ–γ coincidence measurement was done using standard source, to test the validity of the system. Details of the analysis are also presented in this section, including corrections for sum coincidence and angular correlation. Finally, section 4 summarizes the present work.

2 Feature of the system

A schematic diagram of the system is shown in Figure 1. It consists of two detectors and a fast data acquisition system. Gamma rays are measured by a large Ge detector (relative efficiency 90% of 3"×3" NaI). In β–γ measurements, a thin (0.5–2mm^t) plastic scintillator is used for β detection.

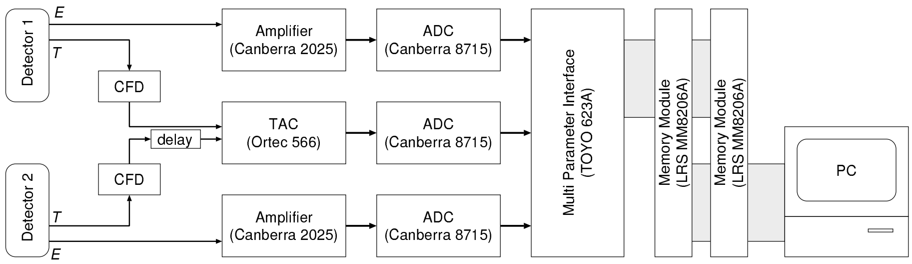

Figure 1: Schematic diagram of the system

The data acquisition system consists of two series of amplifier(Canberra2025)–Fast ADC(Canberra 8715) and a timing circuitry (TAC(ORTEC 566)–ADC(Canberra 8715)) connected to a multi–parameter interface(TOYO 623A). The list data gathered by the interface are temporarily accumulated in one of the two cascade–connected large capacity (64k words) CAMAC memory modules. The data in a memory module are transferred to a PC (NEC PC-9821 Xa16) when the module is not in use, and stored in hard disk of the PC, so the data is accumulated fast and efficiently. The data are accumulated when there's at least one ADC with valid datum. Coincidence events are extracted from the list data in off–line analysis. In γ–ray measurement in singles mode, photo–peak counts N_{i,γ_j} of a γ ray γ_j in a detector i can be expressed as the following:

$$N_{i,\gamma_j} = A \times I_{\gamma_j}\, \epsilon_{i,\gamma_j}\, R_i \times T, \tag{1}$$

where A is activity, I_{γ_j} emission probability of γ_j, ϵ_{i,γ_j} peak efficiency of γ_j in the detector i, T the measurement time, and R_i the ratio of live–time to elapsed time for the measurement. In γ–γ coincidence measurement, the yield is described by the following equation:

$$N_{1,\gamma_1\, 2,\gamma_2} = A \times I_{\gamma_1}\, \epsilon_{1,\gamma_1} \times I_{\gamma_2}\, \epsilon_{2,\gamma_2} \times R_C \times T, \tag{2}$$

where R_C is live–time ratio for coincidence measurement. According to the above relations, the activity A reads

$$A = \frac{1}{T}\, \frac{N_{1,\gamma_1}\, N_{2,\gamma_2}}{N_{1,\gamma_1\, 2,\gamma_2}}\, \frac{R_1\, R_2}{R_C}. \tag{3}$$

In this system, $R_C = R_1\, R_2$, and

$$A = \frac{1}{T}\, \frac{N_{1,\gamma_1}\, N_{2,\gamma_2}}{N_{1,\gamma_1\, 2,\gamma_2}}, \tag{4}$$

i.e. the dead times in singles and coincidence measurements are canceled out.

3 Validity test of the system

To test the validity of the system, a γ–γ coincidence measurement was performed using a ^{60}Co standard source with known activity. Gamma rays emitted from the source were measured with the two Ge detectors. The detectors were placed face–to–face, and the distance between the source and the front surfaces of the detectors were 20cm. Counting rate for a detector was $\sim$ 2k cps. A total of 1.6×10^7 events were accumulated within about an hour.

Shown in Figure 2 are projection spectra of the energy of the two detectors and TAC data. The two γ rays (1173 and 1333 keV) from the source are clearly seen. Also seen in the figures is 1461 keV peak, which is originated from ^{40}K in the room background. From these projection spectra, yields of the 1173(1333)keV γ ray in Ge–1(Ge–0) was

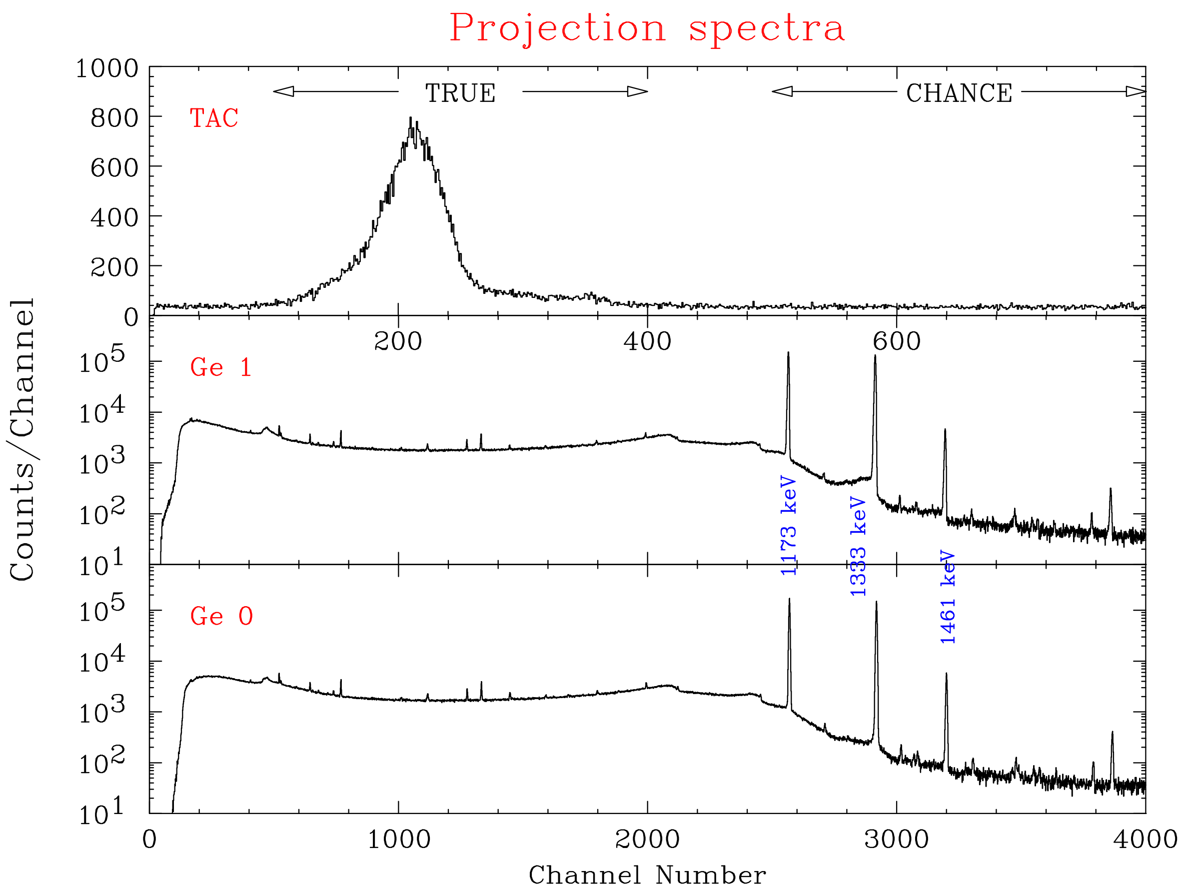

Figure 2: Projection spectra.

obtained.

To extract γ–γ coincidence events, gates were applied to TAC peak ('TRUE' in Figure 2) and Ge–1 1173 keV peak ('G_P' in Figure 3). Spectrum thus obtained is shown in Figure 4.

One of the advantages of list–form data acquisition is that it enables various corrections such as chance coincidence and background contributions, without relying on empirical formula. To estimate contributions from chance coincidence and background component in the coincidence events, separate gates were applied, and the resultant yields were subtracted from the number of coincidence events. Chance coincidence

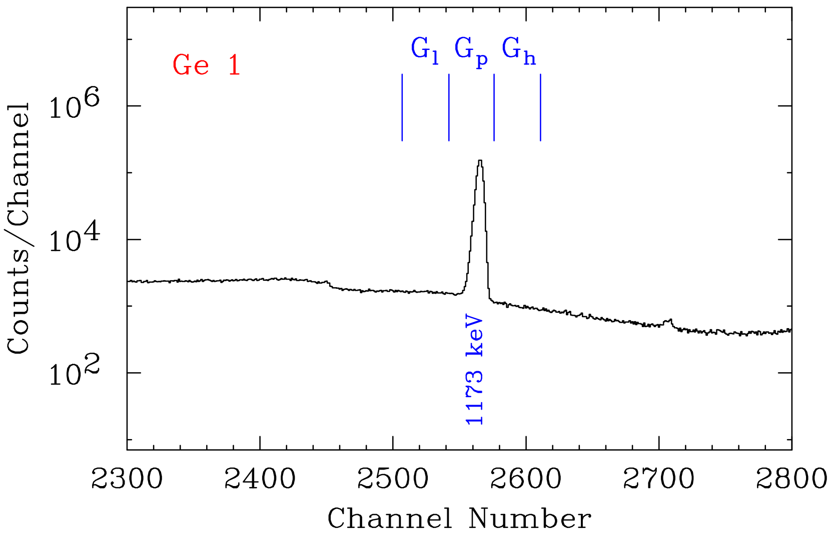

Figure 3: The gates applied to the Ge–1 data.

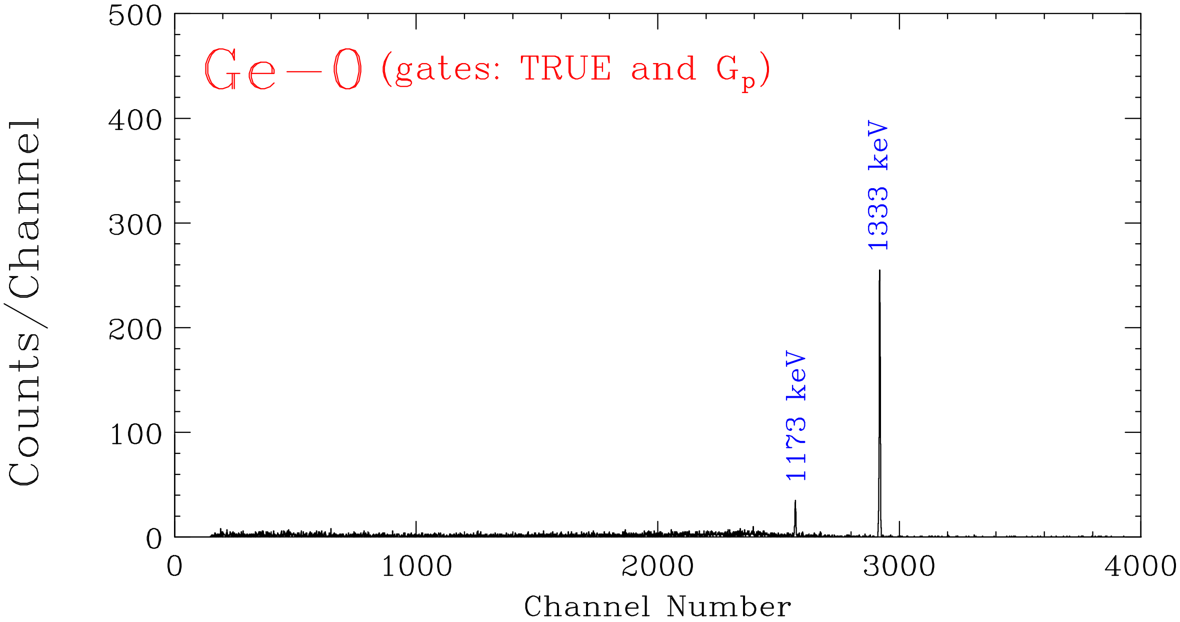

Figure 4: Spectrum obtained by gating Ge–1 1173 keV peak and TAC peak.

contribution was estimated by gating '$\mathrm{G_p}$' and off–peak portion of TAC data. For background estimation, two gates with the same width were applied on both sides of the peak ('$\mathrm{G_l}$' and '$\mathrm{G_h}$' in Figure 3), and an average of the resultant counts was regarded as the background.

In addition to the corrections described above, corrections for angular correlation and sum coincidences were made. The correction of coincidence counts, $N_{1,\gamma_1\,2,\gamma_2}$, for the angular correlation was done using the following well-known angular correlation function of the two γ rays,

$$W(\theta) = 1 + 0.102 \times P_2(\cos\theta) + 0.0091 \times P_4(\cos\theta), \quad (5)$$

where θ is the opening angle between the two γ rays. The correction factor amounted to 1.112. In sum coincidence events, the two cascade γ rays are detected in the same detector, and therefore singles photo-peak counts are reduced. The correction factors, F_{SC}, of the sum coincidence were calculated for the two cascading γ rays to be

$$F_{SC,1173} = (1.0 - \epsilon_{T,1333} \times f_W)^{-1} \quad (6)$$

and

$$F_{SC,1333} = \left(1.0 - \frac{I_{\gamma,1173}}{I_{\gamma,1333}} \times \epsilon_{T,1173} \times f_W\right)^{-1}, \quad (7)$$

where $\epsilon_{T,1173}(\epsilon_{T,1333})$ is the total detection efficiency of 1173(1333) keV γ ray, $I_{\gamma,1173}(I_{\gamma,1333})$ emission probability of the 1173(1333) keV γ ray, and f_W is the average value of angular correlation function over the detector solid angle weighted by the γ–ray attenuation probability in the Ge crystal. f_W was calculated using the relation (5) above. The factors for the present setup are $F_{SC,1173} = 1.00517$ and $F_{SC,1333} = 1.00531$.

Taking into account all of the above corrections, the activity of the source was obtained as 135.4 ± 5.8 kBq, which agreed to the catalog value with decay correction, 132.5 ± 2.5 kBq. Thus, validity of the system was confirmed in the γ–γ coincidence experiment. The error of the obtained value was mainly (99.6%) originated from the statistical error of the number of coincidence events, and can be reduced with long–time measurements.

4 Conclusion

For precise determination of source activities and γ-ray emission probabilities, a γ–γ and β–γ coincidence measurement system was constructed. Using this system, in which the data are accumulated in essentially singles mode, the dead times for singles and coincidence measurements are canceled out, and the activity can be determined accurately.

To check the validity of the system, the activity of the ^{60}Co standard source was measured with the system using γ–γ coincidence method. The obtained value was agreed to the catalog value within the error, and the validity of the system was confirmed.