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Radioactivity Measurement of Reactor-produced Radionuclide ^{60}Co using 4πβ(LS)-γ Coincidence System

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1. Introduction

For the standardization of high-demand radioactive isotope (RI) production, reference material production/supply system is under development in Korea Atomic Energy Research Institute (KAERI). Research reactor HANARO in KAERI is used for the production of RI, and the activity of produced RI will be measured using reference material activity measurement system. The produced RI and its information will be provided to customer.

The main technique of reference material activity measurement system is 4πβ(LS)-γ coincidence counting. In this work, the concept and characteristics of reference material measurement system in KAERI are explained, and the result of activity measurement for ^{60}Co produced at HANARO will be presented.

2. Overview of Reference Material Activity Measurement System

2.1 Concept of 4πβ(LS)-γ Coincidence Counting

Emitted βs and γs from the RI are measured by each β and γ detector in certain time, and the number of signals for each detector are N_β and N_γ, respectively. Among the measured signals by β and γ detectors, time-coincident signals are selected, and the number of coincidence signals is $N_{\beta\gamma}$. The relation among these numbers can be written as follows:

$$\frac{N_\beta N_\gamma}{N_{\beta\gamma}} = N_0\left[1 + C\left(\frac{1-\varepsilon_\beta}{\varepsilon_\beta}\right)\right] \qquad (1)$$

where N_0 represents the radioactivity of RI, ε_β is the detection efficiency of β detector, and C is a constant. By changing ε_β, i.e. changing the depth of RI (if it is solid) or the threshold of DAQ, different $N_\beta N_\gamma / N_{\beta\gamma}$ values are obtained. Using these values, extrapolation can be done for $\varepsilon_\beta \to 1$ case, and N_0 is obtained. This method is called "efficiency-extrapolation."

Here, $(1-\varepsilon_\beta)/\,\varepsilon_\beta$ can be rewritten as $(N\_\gamma/N\_\beta\gamma\ -1)$, and Eq. (1) can be changed as follows:

$$\frac{N_\beta N_\gamma}{N_{\beta\gamma}} = N_0\left[1 + C\left(\frac{N_\gamma}{N_{\beta\gamma}} - 1\right)\right] \qquad (2)$$

as shown in Eq. (2), N_0 can be expressed by a constant and measured values, without detection efficiency. Thus, this "efficiency-extrapolation" is very simple and useful method.

2.2 Structure of Reference Material Activity Measurement System

Reference material activity measurement system using 4πβ(LS)-γ coincidence counting is consist of one β detector and two γ detectors. NaI scintillator is used as γ detector, and this material is very commonly used for the γ-detection in 4πβ-γ coincidence counting. [1-[3]

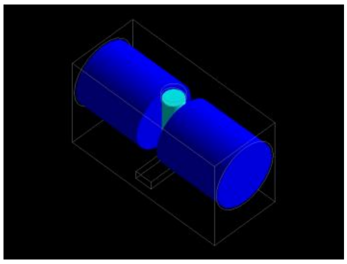


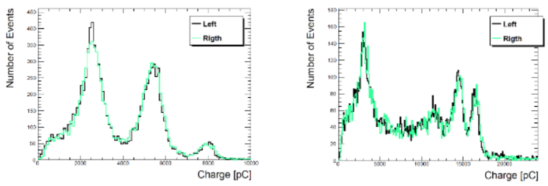
Fig. 1. Schematic of reference material activity measurement system. Cyan colored cylinder is vial in which RI and LS are contained. Blue colored cylinders are NaI scintillators. Diameter of NaI scintillator is 3 inches.

Figure Fig. **1** is schematic of reference material activity measurement system. β detector is a vial containing LS, and RI is also contained in there. SiPM is attached at the bottom of the vial, and measures the scintillation lights from LS. Other sides are covered with reflectors, which helps to collect scintillation light efficiently. The outside of β detector is covered with light shielding materials, to avoid external light. γ detector is cylindrical NaI scintillator. SiPM is attached to the one of plane side, which is relatively far from the β detector. γ detector is also covered with reflectors and light shielding materials.

3. Performances of Detectors

3.1 Performances of γ Detectors

To understand the responses of γ detectors, the γ-sources ^{137}Cs and ^{60}Co are used. Figures Fig. 2 (a) and (b) are the charge distributions of each γ detector, for ^{137}Cs and ^{60}Co. The gain of SiPMs are fitted with allowed supply voltages for SiPMs, and the signal scale is corrected in software level.

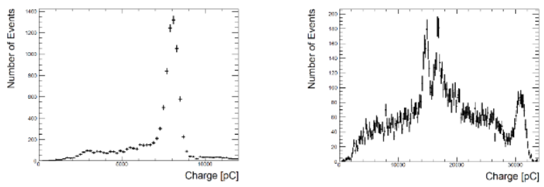


(a) ^{137}Cs (b) ^{60}Co

Fig. 2. Individual charge distributions of NaI scintillators. The charge scales of two γ detectors fit well.

Figures Fig. 3 (a) and (b) are the summed charge distributions for two γ detectors for ^{137}Cs and ^{60}Co. Among the peaks in summed charge distributions, the single γs 0.662, 1.173, and 1.332 MeV are selected, and their signal size values in charge scale are obtained using Gaussian function, by χ^2-fitting method. Using these charge values and Eq. (3), charge-energy curve is obtained.

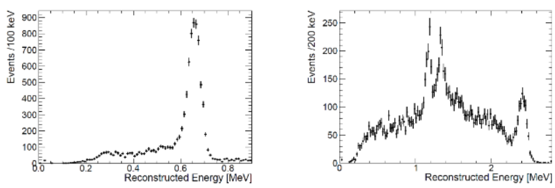
$$\frac{Q}{E} = (p_0 + p_1 E)\left[1 - p_2 e^{(-p_3\sqrt{E})}\right] \qquad (3)$$



(a) ^{137}Cs (b) ^{60}Co

Fig. 3. Summed charge distribution of NaI scintillators. (a) 0.662 MeV γ from ^{137}Cs is presented. (b) 1.173 MeV and 1.332 MeV γs and their combination are presented.

Using the charge-energy curve, the energy values for detected signals are reconstructed from charge scale, as shown in Fig. 4. In Fig. 4 (b), the mean value of peak for 2.505 MeV is not presented as its own energy value, due to the dynamic range of γ detector. As shown in Fig. 5, the dynamic ranges of γ detectors are around 17,000 and 19,000 pC each, and the reconstructed energy value of 17,000 pC is around 1.35 MeV. That means the signal over 1.35 MeV is saturated, and its size is inaccurate.



(a) ^{137}Cs (b) ^{60}Co

Fig. 4. Reconstructed energy spectra of NaI scintillators. While other peaks are well reconstructed, 2.505 MeV peak is not well reconstructed due to the saturation of the high energy signals.

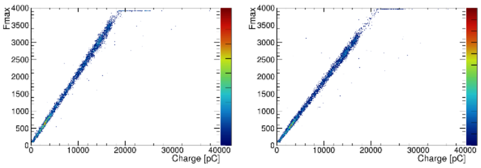
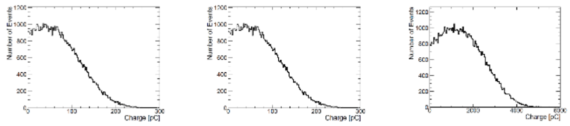


Fig. 5. Signal height (Fmax) versus signal value (charge) for NaI scintillators. Saturation value of left one is relatively low, due to gain difference between two SiPM for NaI scintillators.

3.2 Performance of β Detector

To understand the response of β detector, the β-source ^{3}H is used. The average β energy emitted from ^{3}H is 5.7 keV. The values of supply voltages to SiPM are 53.5, 56, and 58 V, and related charge distributions for β detections are presented in Fig. 6. To evaluate the dynamic ranges for supply voltages, the mean values of charge distributions are calculated and converted as 5.7 keV. The roughly evaluated dynamic ranges are 13.5, 2.4, and 0.5 MeV, respectively.



(a) 53.5 V (b) 56 V (c) 58 V

Fig. 6. Charge distribution of β detector for ^{3}H, for various supply voltages. Averaged values of charge distributions are 74.1, 418, and 1550 pC, respectively.

4. Status and Plan

Each part of reference material activity measurement system is being tested, and the frame is under production. After the construction of the system is completed, the activity measurement for ^{60}Co, the produced RI at research reactor HANARO will be carried out, and the result will be announced.

Acknowledgements

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