I. 1. Low Background Beta-ray Spectroscopy Based on a Counter Telescope with Plastic Scintillation Detectors

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Beta-ray spectrometer, consisting of two pieces of plastic scintillator forming a counter-telescope, has been developed for the purpose of compliance with the clearance level for solid materials generated from the decommissioning and operation of the reactors at electric power plants. Due to coincidence measurements, background-free counting for low-level emission of the beta-ray is available. Compliance with the clearance level for solid materials is in the order of 0.01 Bq/gr with the present beta-ray spectrometer.

In the case of clearance compliance, judgment is carried out by measuring specific gamma-rays such as these from $^{59}$Co etc, mainly due to the conveniences to detect gamma-ray compare to these to analyze beta-rays. However, counting of gamma ray is not straightforward for judgment of the density of activity in the unit of Bq/g, while that of beta ray is directly connected to the activity in the unit of Bq/g in the clearance object. As such, a compact system to detect beta-ray with low background and high-efficiency specifications is strongly awaited for.

One of the most important points in the system specification is “low-background”, since the radiations, concerning clearance level, are more than ten times smaller in magnitudes comparing to those of surrounding natural radiations. For this purpose, the counter telescope type detector has been tested\(^1\). In Ref. 1, beta energies were measured via a 5 cm diameter ~ 2 cm thick BC-404 plastic scintillator preceded by a single, 100 mm thick, totally depleted, silicon DE detector. Photon events in the $E$ detector were rejected by requiring a coincidence between the $E$ and DE detectors. Photon rejection ratios vary from 225:1 at 1.25 MeV ($^{60}$Co) to 360:1 at 0.36 MeV ($^{133}$Ba).

Beta-ray Detector and Measuring System

In this report, we discuss another beta-ray detector for clearance level inspection,
where much more simple composition is essentially requested. As such, we used a thin plastic detector, in stead of silicon semi-conductor, for $\Delta E$ counter.

Figure 1 illustrates the counter-telescope type beta-ray detector tested in the present experiments.

As shown in Fig. 1, the counter telescope is consists of two detectors. The $\Delta E$ counter is made of 50 mm-thick NE-102A plastic scintillator, the size for which are 20×20 mm$^2$. The counterpart $E$-counter is made of the same NE-102 plastic scintillator, the size for which are 20×20 mm$^2$ and 30 mm in its length.

From the technical points of view, light shield was difficult, since a beta ray passes through three times the light-shield losing its energy significantly. In the present detector, 30 mm-thick black-tapes shut out completely lights from outside. These arrangements makes a particle identification system. The several hundred keV-energetic electrons are able to go through three by 30 mm-thick black-tapes and one 50 mm thick plastic scintillator, and produce two electric signals, while gamma ray gives us only one signals produced in thicker 20 mm scintillator. Figure 2 shows the electric diagram for beta-ray counting. The system is nothing but ordinary one. Two signals formed by linear amplifiers are analyzed by two-dimensional analog to digital converter (2D-ADC) and (512×512) list data are stored in the computer memories.

**Performance Test and Results**

Performance tests have been carried out by measuring beta-rays from radioisotopes of $^{90}$Sr with the beta-rays ($Q_b = 2.28$ MeV), $^{137}$Cs with a beta-ray ($Q_b = 0.51$ MeV) and monochromatic electrons with $E_c=0.625$ MeV, and RaD($^{210}$Pb) with a beta-ray ($Q_b =1.18$ MeV). Figure shows pulse-height spectrum projected to the axis of thick detector. The single peak due to internal conversion electron is clearly seen.

Further measurements have been carried out for $^{90}$Sr and RaD($^{210}$Pb). Continuum spectra are illustrated in Fig. 5 together with fitting by phase space calculation: with

$$\frac{dn}{dE_0} = \frac{dv}{2\pi\hbar} \frac{dv}{E_c^2 \sqrt{E_0^2 - m_e^2 c^4}} \cdot EdE$$

, where $E_0$ is Q-value of beta decay.

Line shapes of continuum electron spectra have been reproduced successfully by calculations. The energy resolution for the monochromatic 625-keV electrons from $^{137}$Cs source is 13.6%. The detection efficiency for the 625-keV electrons from $^{137}$Cs source is 53.0%.
Conclusion

A low-background, compact and high-resolution beta ray spectrometer has been constructed. Compliance with the clearance level for solid materials is now in the order of 0.007 Bq/gr in the energy range of ~625 keV with the present beta-ray spectrometer. The size of the spectrometer is 20 mm×20 mm. Further development for larger detector is needed for practical use.

Reference


![Figure 1](image1.png)  
Figure 1. Counter telescope beta-ray spectrometer.

![Figure 2](image2.png)  
Figure 2. Electric diagram for beta-ray counting.
Figure 3. Two dimensional display of two signals from counter telescope system.

Figure 4. Projected energy spectrum of beta ray from $^{137}$Cs projected. Monochromatic peak corresponds to events of 625-keV conversion electrons.

Figure 5. Projected spectra of beta rays from $^{90}$Sr, $^{137}$Cs and RaD. Lines are fitting by phase space distribution.