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Effects of beta-particles attenuation filter of reference sources and contribution in the calibration of surface contamination monitors

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HIGHLIGHTS

- We show how the instrument efficiencies are dependent on filtering.
- We examine the isotropy of β-particle fluences and observe the angular dependence.
- We explain discrepant instrument efficiencies of pure ^{90}Y source and filtered $^{90}Sr/^{90}Y$.

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ABSTRACT

If high-energy beta particles are required for the efficiency determination of surface contamination monitors, wide area filtered $^{90}Sr/^{90}Y$ sources are commonly used instead of short-lived pure ^{90}Y sources. In this work we show how the instrument efficiencies are dependent on filtering. Significant difference in the instrument efficiencies between filtered $^{90}Sr/^{90}Y$ and pure ^{90}Y source was obtained due to spectral degradation of the beta emission spectrum. Changes in the β-particle spectra were investigated by the use of a plastic scintillation spectrometer and the anisotropy of β-particle fluences was examined to clarify the possible reason of such discrepancy.

1. Introduction

Measurement of instrument efficiency of surface contamination monitors is usually made with extended reference sources which are standardized in terms of 2πβ-particle emission rate from the face of the source. Requirements for these reference sources are stated in ISO 8769 (ISO, 2010). In this standard, the recommended radionuclides are chosen for their general availability, suitably long half-lives and reasonably high specific activity. $^{90}Sr/^{90}Y$ is reported as one of the preferred nuclides. In addition, ISO mentions that if only the higher-energy betas from ^{90}Y are required, a filter of 130 mg/cm^2 will be needed for this type of source in order to absorb the ^{90}Sr beta radiation.

However, such an attenuation filter may also result in a significant degradation of the ^{90}Y beta emission spectrum compared with the spectrum obtained from a pure unfiltered ^{90}Y source, and ISO also notes this concern. Indeed, degradation of β-ray spectra after penetrating absorbing materials was studied by Kawada et al. (2008), and significant spectral differences were observed. In addition, considerably large anisotropy of the β-particle fluence caused from the angular dependence of backscattered components and from oblique path in the covering filter was studied by Yamada et al. (2012a). Such differences in the beta spectrum may affect the determination of the instrument efficiency quite directly. Thus, effects of the beta-particle attenuation filter of reference sources on the calibration of surface contamination monitors were studied.

2. Experiments

In a first experiment, both a $^{90}Sr/^{90}Y$ source and a pure ^{90}Y source, having 100 mm × 150 mm active area, were prepared by the use of ink-jet printing technique as described by Sato et al. (2004) and Yamada et al. (2012b). The source was printed on a sheet of thin polyethylene film with a thickness of 0.1 mm which was fixed on an aluminum backing having 4 mm thickness. These sources were covered with an aluminum metalized Mylar film with a mass thickness of 0.9 mg/cm^2. The $^{90}Sr/^{90}Y$ source incorporated an additional acrylic filter with 130 mg/cm^2 mass thickness, as recommended by ISO. Each source was calibrated using a windowless proportional counter installed in JRIA in terms of 2π

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Table 1
Determined instrument efficiencies of portable surface contamination meters using a pure ^{90}Y source and a $^{90}Sr/^{90}Y$ source incorporating an additional 130 mg/cm^2 thickness filter.

	Instrument efficiency	
	(a)*	(b)**
(1) ^{90}Y	0.656 ± 0.006	0.658 ± 0.007
(2) Filtered $^{90}Sr/^{90}Y$	0.765 ± 0.004	0.837 ± 0.003

Uncertainties indicate counting statistcs(1σ).
(a) Model:TCS-R17-54, (Plastic scintillation, sensitive area: 65 cm^2).
(b) Model:TGS-146, (GM tube, sensitive area: 19.6 cm^2).

beta particle emission rate from the source surface, based on the ISO 8769.

Instrument efficiencies, as ratio between the instrument net reading (counts per time after background subtraction) and the surface emission rate of the source (particles emitted per time) in a specified geometry relative to a source, of two commercially available portable surface contamination meters (manufactured by Hitachi Aloka Medical, Ltd) of different models were determined using these prepared sources under the same conditions with respect to source-to-detector geometry in accordance with IEC 60325 (IEC, 2002). In the present study source was set at 4 mm distance from the each detector window. Results are shown in Table 1. Considerable differences between instrument efficiencies obtained with a pure ^{90}Y source and a filtered $^{90}Sr/^{90}Y$ source were found for both instruments.

In order to clarify the possible reason of such discrepancy, a second experiment was made to investigate the $^{90}Sr/^{90}Y$ and ^{90}Y β-particle spectra of after penetrating an absorbing filter. Two additional small size sources consisting in $^{90}Sr/^{90}Y$ and ^{90}Y were prepared on 0.8 mg/cm^2 Mylar films by simple drop deposition technique. In order to decrease self-absorption, a drop of 8000 times diluted solution of Ludox® SM-30 (DuPont™) was added before drying. Both sources were then sandwiched with a 0.9 mg/cm^2 aluminized Mylar film after drying. An additional aluminum filter with various thicknesses (27 mg/cm^2 to 270 mg/cm^2) was incorporated on the $^{90}Sr/^{90}Y$ source.

A special plastic scintillation spectrometer was developed to this aim (Fig. 1). Plastic scintillation spectrometer was equipped with an NE-102A plastic scintillator of 10 mm thickness, corresponding to the range of 2.2 MeV β-particles, and 25 mm diameter with 0.75 mg/cm^2 aluminum metalized Mylar film window. The scintillator was coupled to a Hamamatsu Photonics type R980 photomultiplier. In order to reduce the detection of large angle scattered β-particles, acrylic collimator of 10 mm thickness having a 5 mm diameter through-bore was set in front of the detector window. The thin film source was positioned below the detector. The source stage had a 25 mm diameter through-bore and it also can be blocked up with a changeable backing plate. The backing plate could be brought up directly in contact with the source and then backing and source could be rotated so as to measure the particle fluence at various obliquity angles. An aluminum backing having 4 mm thickness was employed in this study. The source was set at 30 mm distance from the detector window. Angular resolution of the system estimated from the source-to-detector distance and collimator dimension is approximately 10°.

The average energy of the beta spectrum taken with the $^{90}Sr/^{90}Y$ source, at obliquity angle $\theta = 0°$ using the plastic scintillation spectrometer and different aluminum filters is reported in Fig. 2. The mean beta energy of the emitted β-particles first increases with increasing filter thickness up to 75 mg/cm^2, then a plateau in the mean energy can be observed from 75 mg/cm^2 to 140 mg/cm^2. Though the lower-energy component decreases remarkably with increasing thickness of aluminum absorber, the higher-energy component tends to keep nearly constant. As a whole, the mean beta energy does not depend seriously on the filter thickness around the value of 130 mg/cm^2 recommended in ISO 8769.

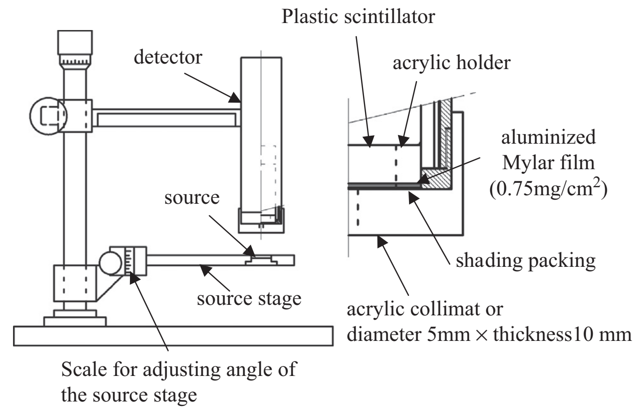

Fig. 1. The special plastic scintillation spectrometer system used in this experiment.

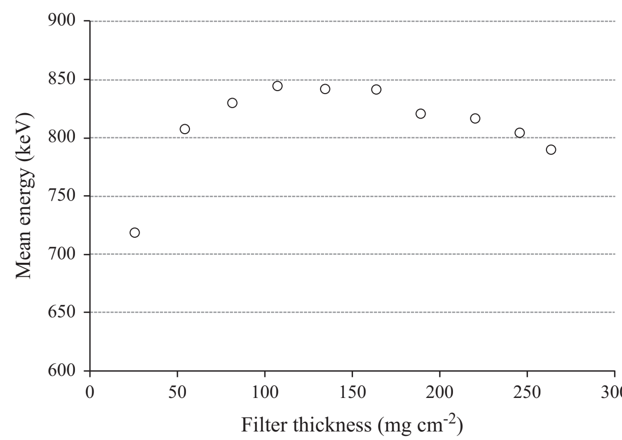

Fig. 2. Mean β-particle energy of $^{90}Sr/^{90}Y$ source obtained with a series of measurement at 0° by use of a plastic scintillation spectrometer after penetrating aluminum filters of various thicknesses.

A comparison of the observed beta spectra for the $^{90}Sr/^{90}Y$ source incorporating an additional 130 mg/cm^2 filter and the ^{90}Y source without additional filter at obliquity angles $\theta = 0°$ and $\theta = 70°$ is reported in Fig. 3. Though the spectrum shapes obtained with the ^{90}Y at both $\theta = 0°$ and $\theta = 70°$ are very similar, significant spectral degradation was found for filtered $^{90}Sr/^{90}Y$ spectrum obtained at $\theta = 0°$ and $\theta = 70°$. As a whole, considerable difference was observed between ^{90}Y and filtered $^{90}Sr/^{90}Y$ spectrum at $\theta = 70°$. Fig. 4 shows the mean energies of β-particles for various obliquity angles θ ranging from 0° to 85° with the two sources and different filtering conditions. The observed mean energy for the filtered $^{90}Sr/^{90}Y$ source was close to the mean energy for ^{90}Y sources with and without filter for θ from 0° to 40°. On the contrary, a significant difference was found for $\theta > 50°$.

In order to look at the discrepancies of beta spectra from pure ^{90}Y and filtered $^{90}Sr/^{90}Y$ sources, we also examined the isotropy of β-particle fluences. We carried out the experiment using the same plastic scintillation spectrometer system in the similar manner as the previous study by Yamada et al. (2012a). Fig. 5 shows relative β-particle fluences for various obliquity angles θ from 0° to 85°. For ^{90}Y sources without filter, β-particle fluence increases slowly with increasing angle up to 70°, and then drastically decreases. On the other hand, for filtered $^{90}Sr/^{90}Y$ and ^{90}Y sources, the β-particle