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A novel method for the activity measurement of large-area beta reference sources

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HIGHLIGHTS

- A novel method for determining the activity of large-area sources is described.
- The method makes use of two emission rate measurements.
- It has uncertainties smaller than the limit of 10% required by ISO 8769.

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ABSTRACT

A novel method has been developed for the activity measurement of large-area beta reference sources. It makes use of two emission rate measurements and is based on the weak dependence between the source activity and the activity distribution for a given value of transmission coefficient. The method was checked experimentally by measuring the activity of two (^{60}Co and ^{137}Cs) large-area reference sources constructed from anodized aluminum foils. Measurement results were compared with the activity values measured by gamma spectrometry. For each source, they agree within one standard uncertainty and also agree within the same limits with the certified values of the source activity.

1. Introduction

Large-area reference sources are used for the calibration of contamination monitors and their characteristics are specified by ISO 8769 (ISO, 2010) standard. According to this standard, the surface emission rate of Class 1 large area beta reference sources (end-point energy greater than 150 keV) shall be measured by the national metrology institute with a standard uncertainty not exceeding 3% and the activity shall be derived by the manufacturer and stated with a standard uncertainty smaller than 10%.

There is a general opinion that the calibration of contamination monitors must be performed in terms of surface emission rate but the aim of contamination measurements is the measurement of the activity per unit area (ISO, 2010, 1988). It is possible to obtain a better accuracy of contamination measurements by calibrating the contamination monitors in terms of activity using appropriate large-area reference sources. For this purpose, it is desirable for the national metrology institute to have the capability of independently determining the activity of large-area reference sources. Methods for determining their activity have already been reported by several authors (Janssen and Klein, 1996; Berger, 1998; Stanga, 2014; Javornik and Svec, 2014).

This paper describes a novel method for the activity measurement of large-area beta emitting reference sources constructed according to the standard ISO 8769 requirements (active layer of the source is not too thick). The method was checked experimentally by measuring two certified large-area reference sources (^{60}Co and ^{137}Cs) constructed from anodized aluminum foils. Measurement results were compared with the activity values determined by gamma spectrometry and with the certified values of the activity. For each source, they agree within one standard uncertainty. Uncertainties smaller than the limit of 10% required by ISO 8769 were also obtained.

2. Theoretical basis of the method

We consider the large-area beta source shown in Fig. 1. The surface emission rate, E_S, of the source can be calculated using the plane source concept (Stanga, 2014). Thus, we have

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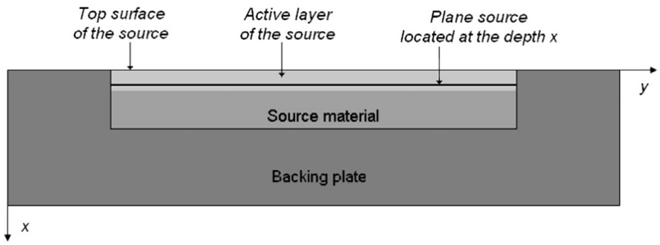

Fig. 1. Schematic view of a large-area source.

$$E_S = f_T \Lambda \int_0^{x_{\max}} \varepsilon_p(x) f(x) \mathrm{d}x \quad (1)$$

where $\varepsilon_p(x)$ is the plane source efficiency, f_T is the total emission probability for beta particles and conversion electrons, Λ is the activity of the source, $x_{\max}$ represents the thickness of the active layer of the source and $f(x) = \Lambda_p(x)/\Lambda$ is the activity depth distribution ($\Lambda_p(x)\mathrm{d}x$ is the activity of the plane source with thickness dx from the depth x).

The efficiency, $\varepsilon_p(x)$, of the plane sources is given by

$$\varepsilon_p(x) = \frac{E_p(x)}{f_T \Lambda_p(x)} = \frac{E_b(x) + E_{ce}(x)}{f_T \Lambda_p(x)} = \frac{f_b \varepsilon_{pb}(x) + f_{ce} \varepsilon_{ce}(x)}{f_T} \quad (2)$$

where $E_b(x)$, f_b and $\varepsilon_{pb}(x)$ are, respectively, the emission rate in 2π, the emission probability and the plane source efficiency corresponding to beta particles, $E_{ce}(x)$, f_{ce} and $\varepsilon_{pce}(x)$ are, respectively, the emission rate in 2π, the total emission probability and the plane source efficiency corresponding to conversion electrons and $f_T = f_b + f_{ce}$.

When the source is covered by an inactive foil of thickness s, the emission rate in 2π of both beta particles and conversion electrons that emerge from the top surface of the covering foil, $E(s)$, is given by

$$E(s) = f_T \Lambda \int_0^{x_{\max}} \varepsilon_p(x, s) f(x) dx \quad (3)$$

where $E(0) = E_S$ and $\varepsilon_p(x, 0) = \varepsilon_p(x)$.

In case that the source and the covering foil are made from the same material, Eq. (3) becomes

$$E(s) = f_T \Lambda \int_0^{x_{\max}} \varepsilon_p(x + s) f(x) dx \quad (4)$$

The transmission coefficient, t, is defined as the fraction of beta particles and conversion electrons emitted by the source and transmitted through a foil of thickness s. As a result, we have

$$t = \frac{E(s)}{E_S} = \frac{\int_0^{x_{\max}} \varepsilon_p(x, s) f(x) dx}{\int_0^{x_{\max}} \varepsilon_p(x) f(x) dx}, \quad (5)$$

where $\varepsilon_p(x, s) = \varepsilon_p(x + s)$ when the source and the covering foil have identical effective atomic numbers.

The efficiency of ^{60}Co and ^{137}Cs plane sources, located at the depth x in aluminum (backing plate is also made from aluminum), was calculated by Monte Carlo method using the PENCYL code from the simulation package PENELOPE (Baro et al., 1995; Salvat et al., 2003). In the case of ^{137}Cs sources, we took into account both beta particles ($f_b = 1$) and conversion electrons ($f_{ce} = 0.094$). Monte Carlo results were fitted by the function $\varepsilon_p(x) = a_0 + a_1 x^{0.5} + a_2 x + a_3 x^{1.5} + a_4 x^2 + a_5 x^{2.5}$ with residuals smaller than 0.5%. In Table 1 the fitting parameters a_0, a_1, a_2, a_3, a_4 and a_5 for ^{60}Co and ^{137}Cs sources are shown.

3. Description of the method

3.1. Dependence of the source activity on the transmission coefficient

From Eq. (4), it follows that

$$\Lambda = E(s)/K, \quad (6)$$

$$\text{where } K = \int_0^{x_{\max}} \varepsilon_p(x + s) f(x) dx. \quad (7)$$

Eq. (6) shows that Λ depends on both x_{max} and $f(x)$ which are usually unknown. Eq. (5) shows that t depends also on x_{max} and $f(x)$. It follows that Λ can be expressed as a function of t and $f(x)$ where t can be determined by measuring $E(s)$ and E_S. To investigate the dependence of Λ on $f(x)$, we used two opposite distributions $f_1(x) = \frac{1+\alpha}{x_{max}}(1 - \frac{x}{x_{max}})^\alpha$ and $f_2(x) = \frac{1+\alpha}{x_{max}}(\frac{x}{x_{max}})^\alpha$ together with the uniform distribution $f_3(x) = 1/x_{max}$. In the case of $f_1(x)$, the activity is concentrated close to the top surface of the source ($\alpha \geq 1$) while for $f_2(x)$ the activity is concentrated close to x_{max} ($\alpha \geq 1$). Fig. 2 shows K as a function of t for ^{60}Co and ^{137}Cs sources constructed from anodized aluminum foils (covered with an aluminum foils of thickness $s = 2.4$ mg/cm^2) and for the distributions mentioned above ($\alpha = 1$ and $\alpha = 5$). As one can see from Fig. 2, K depends weakly on $f(x)$ for a given value of t. It follows that Λ depends weakly on $f(x)$ and this dependence is also weak for other beta emitters such as ^{14}C, ^{147}Pm, ^{36}Cl and ^{90}Sr-^{90}Y. One can also see from Fig. 1 that K takes the maximum value $K_{\max}$ and the minimum value $K_{\min}$ for $f_2(x)$ and $f_1(x)$ for $\alpha = 5$, respectively.

3.2. Basis of the method

The method described here can be applied to different types of large-area beta reference sources constructed according to ISO 8769, namely, the active layer of the source is not too thick. It makes use of two emission rate measurements. Thus, the surface emission rate, E_S, is firstly measured according to ISO 8769 using a windowless gas-flow proportional detector. Secondly, the source is covered with a foil (it is assumed that both the foil and source material have identical effective numbers) of thickness s and the emission, $E(s)$, is measured with the same detector. In this way, the transmission coefficient can be calculated using $t = E(s)/E_S$.

The method makes use of Eq. (6) and is based on the weak dependence of Λ on $f(x)$ for a given value of t. As a result, the source activity Λ can be expressed as

$$\Lambda = f_m \frac{E(s)}{K}, \quad (8)$$

where f_m is a factor which is equal to one and takes into account the uncertainties of the model used for obtaining $\varepsilon_p(x + s)$ and computing K. If the interval $[K_{min}, K_{max}]$ is the only available information regarding K, a rectangular distribution over this interval can be assumed. It follows that

Table 1
Fitting parameters for ^{60}Co and ^{137}Cs plane sources (backing and source are made from aluminum).

	a_0	a_1	a_2	a_3	a_4	a_5
^{60}Co	0.717789557	−0.340266940	0.084607399	−0.020256230	0.003832716	−0.000318940
^{137}Cs	0.714323109	−0.176106937	0.023339380	−0.003506495	0.000442019	−0.000023705