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A simple method for determining the activity of large-area beta sources constructed from anodized aluminum foils

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HIGHLIGHTS

- A method for determining the activity of large-area beta sources is presented.
- The method is based on a model of electron transport in planar geometry.
- The method makes use of linear programming for determining the activity.
- The uncertainty of the method is smaller than 10%.

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ABSTRACT

A simple method has been developed for determining the activity of large-area beta reference sources in anodized aluminum foils. It is based on the modeling of the transmission of beta rays through thin foils in planar geometry using Monte Carlo simulation. The method was checked experimentally and measurement results show that the activity of large-area beta reference sources in anodized aluminum foils can be measured with standard uncertainties smaller than the limit of 10% required by ISO 8769.

1. Introduction

Large-area reference sources constructed from anodized aluminum foils are widely used for the calibration of contamination monitors. Their characteristics are specified by the international standard ISO 8769 (ISO, 2010). According to this standard, the surface emission rate of Class 1 beta-sources (end-point energy greater than 150 keV) shall be measured by the national metrology institute with a standard uncertainty not exceeding 3%. The activity shall be derived by the manufacturer and stated with a standard uncertainty smaller than 10%. However, 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; Svec et al., 2006).

This paper describes a simple method for determining the activity of large-area beta reference sources constructed from anodized-aluminum foils. The method was checked experimentally by measuring two certified (^{14}C and ^{36}Cl) large-area sources. The measured values of the activity for both sources agreed within the uncertainty limits with the certified values and the relative standard uncertainty of measurement results is smaller than the limit of 10% required by ISO 8769.

2. Theoretical basis of the method

2.1. A general relationship between surface emission rate and activity

A general relationship between the surface emission rate, E_t, and the activity, Λ_t, of large-area beta sources can be obtained using the plane source concept (Berger et al., 1996; Stanga et al., 2011). Thus, we have

$$E_t = \Lambda_t \int_0^{x_{\max}} \varepsilon_p(x) f(x) dx \tag{1}$$

where $\varepsilon_p(x) = E_p(x)/\Lambda_p(x)$ is the efficiency of a plane source located at the depth x ($E_p(x)dx$ is the emission rate in 2π of the plane source with thickness dx from the depth x), $f(x) = \Lambda_p(x)/\Lambda_t$ is the activity depth distribution of the large-area source ($\Lambda_p(x)dx$ is the activity of the plane source with thickness dx from the depth x) and $x_{\max}$ is the maximum depth of the active layer of the source.

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It is evident that

$$\int_0^{x_{\max}} f(x)dx = 1 \qquad (2)$$

$$\varepsilon = \frac{E_t}{\Lambda_t} = \int_0^{x_{\max}} \varepsilon_p(x) f(x)dx \qquad (3)$$

where ε is the source efficiency. When the source is covered by an inactive aluminum foil of thickness s, the emission rate of beta particles that emerge from the top surface of the covering foil, $E_t^s(s)$, is given by

$$E_t^s(s) = \Lambda_t \int_0^{x_{\max}} \varepsilon_p^s(x) f(x)dx = \Lambda_t \varepsilon^s(s) \qquad (4)$$

where $E_t^s(0) = E_t$.

2.2. *Efficiency of plane sources*

The efficiency of plane sources, located at the depth x in aluminum, was previously calculated (Stanga et al., 2011) using the program PENCYL from the simulation package PENELOPE (Baro et al., 1995; Salvat et al., 2003). Here we used the same program to calculate more accurately the efficiency of plane sources for ^{14}C and ^{36}Cl beta emitters over large intervals of x values. Monte Carlo results were fitted with residuals smaller than 0.5% by the function $\varepsilon_p(x) = a + bx^{0.5} + cx^{1.0} + dx^{1.5} + ex^{2.0} + fx^{2.5}$. In Table 1 both Monte Carlo results and fitting parameters a, b, c, d, e and f are shown.

2.3. *Activity depth distribution of large-area beta sources in anodized-aluminum foils*

The activity of large-area sources in anodized-aluminum foils is incorporated in the top surface of an aluminum foil resulting in a source which has an active layer composed of aluminum and aluminum oxide and extends to approximately 1–4 mg/cm^2 below the surface. It should be noted that the efficiency of plane sources calculated above remains valid for the mixture composed of aluminum and aluminum oxide because the effective atomic number of the aluminum oxide is close to the atomic number of aluminum.

The activity depth distributions of large-area beta reference sources are not known but a model was elaborated using data from literature (Janssen and Thieme, 2000; Stanga et al., 2011). According to this model, the activity depth distribution is a unimodal function with the maximum located approximately at the depth $x_0 = 0.09$ mg/cm^2 and $f(0) = f(x_{\max}) = 0$. For a given nuclide, $f(x)$ has a typical shape and $x_{\max}$ takes a typical value both corresponding to the typical value of the source efficiency given by the manufacturer (Nuclitec-Isotrak Catalog, 2009). Due to the variability of the manufacturing process the source efficiency has deviations from typical values. These deviations can be estimated by taking into account theoretical bounds of the source efficiency previously calculated (Stanga, 2012), the fact that the anodizing process can be controlled and the experience in the measurement of these sources. Thus, for low-energy beta emitters such as ^{14}C, the relative deviation of the source efficiency from its typical values is smaller than about 10%. For high-energy beta emitters such as ^{36}Cl, the relative deviation is smaller than 5%.

The family of beta distributions can be used for approximating $f(x)$. This distribution depends on two parameters and is flexible enough to model a large variety of activity depth distributions. Taking into account that the maximum of $f(x)$ is located at the depth x_0 (mode $f(x) = x_0$) and $x \in (0.0,\ x_{\max})$, $f(x)$ can be approximated by the following beta distribution

$$f(x) = A(\alpha) x^{p\alpha} (x_{\max} - x)^{\alpha} \qquad (5)$$

where $p = x_0/(x_{\max} - x_0)$, $A(\alpha) = 1/[x_{\max}^{1+(1+p)\alpha} B(1+p\alpha,\ 1+\alpha)]$ and $\alpha > 0$ ($B(1+p\alpha,\ 1+\alpha)$ is a beta function).

Using the beta distribution, Eqs. (3) and (5), intervals of possible values of $x_{\max}$ were determined for ^{14}C and ^{36}C sources taking $\alpha \in (1,\ 4)$, knowing that $x_{\max} \in (1,\ 4)$ mg/cm^2 and considering relative deviations of the source efficiency from typical values of about 10%. It was obtained, $x_{\max} \in (2.2,\ 3.0)$ mg/cm^2 and $x_{\max} \in (1.4,\ 3.0)$ mg/cm^2 for ^{14}C and ^{36}Cl sources.

3. Description of the method

The method of activity measurement described in this paper is based on two emission rate measurements. Thus, the surface emission rate, E_t, is firstly measured according to ISO 8769 using a windowless gas-flow proportional detector. Secondly, the source is covered with an aluminum foil of thickness s and the emission, $E_t^s(s)$, is measured with the same detector.

The method is based on the mathematical model above which describes the transmission of beta-rays through aluminum foils in planar geometry. Thus, using Eq. (4) we get

$$\Lambda_t = \frac{E_t^s(s)}{\varepsilon^s(s)} = \frac{E_t^s(s)}{\varepsilon_p(s) - \Delta(s)} = F(s)\frac{E_t^s(s)}{\varepsilon_p(s)} \qquad (6)$$

Table 1
The efficiency of plane sources, $\varepsilon_p(x)$, for different x values and fitting parameters for ^{14}C and ^{36}Cl.

^{14}C				^{36}Cl			
x (mg/cm^2)	$\varepsilon_p(x)$	x (mg/cm^2)	$\varepsilon_p(x)$	x (mg/cm^2)	$\varepsilon_p(x)$	x (mg/cm^2)	$\varepsilon_p(x)$
0.000	0.7205	1.080	0.2843	0.000	0.7147	5.400	0.4595
0.027	0.6345	1.620	0.2222	0.135	0.6732	7.560	0.4165
0.054	0.5993	2.160	0.1781	0.270	0.6553	9.180	0.3899
0.081	0.5735	2.700	0.1456	0.540	0.6320	10.800	0.3661
0.135	0.5342	3.240	0.1199	1.080	0.5960	13.500	0.3317
0.216	0.4906	3.780	0.0994	1.620	0.5710	16.200	0.3020
0.270	0.4669	4.320	0.0831	2.160	0.5478	21.600	0.2528
0.405	0.4202	4.860	0.0696	2.700	0.5298	27.000	0.2136
0.540	0.3830	5.400	0.0585	3.510	0.5055	35.100	0.1680
0.810	0.3270	6.750	0.0382	4.320	0.4840	43.200	0.1327

	Fitting parameters					
	a	b	c	d	e	f
^{14}C	0.72109541	−0.55450869	0.12130888	0.01986002	−0.01440111	0.00208587
^{36}Cl	0.71499833	−0.11446412	−0.00092954	0.00156359	−0.00018706	0.00000941