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Efficiency transfer method applied to surface beta contamination measurements

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HIGHLIGHTS

- Efficiency transfer method is applied to surface beta contamination measurements.
- Efficiency transfer factors are computed by Monte Carlo method.
- Efficiency transfer factors are computed using the available information on sources.
- Calibration factor of contamination monitors is corrected using transfer factors.

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ABSTRACT

In this paper, the application of the efficiency transfer method to the evaluation of the surface beta contamination is described. Using efficiency transfer factors, the reference calibration factor of contamination monitors is corrected, to obtain the calibration factor for an actual contamination source. The experimental part of the paper illustrates the applicability of the method to the direct measurement of the surface beta contamination.

1. Introduction

Surface contamination measurements are extensively used for radiation protection and for clearing potentially contaminated waste items (ISO, 1996; EU, 1998). Surface contamination is quantified in terms of activity per unit area, the quantity that is used to specify “derived limits”, i.e. maximum limits of surface contamination (ISO 8769, 2016). The new edition of the standard ISO 7503 provides a methodology for calibrating contamination monitors using a set of basic radionuclide reference sources (ISO 7503-1, 2016; ISO 7503-2, 2016; ISO 7503-3, 2016). In practice, the reference calibration factor determined by means of reference sources may be largely different from the calibration factor corresponding to the measurement of an actual contamination source. It is therefore necessary to develop a methodology for estimating the calibration factor for contamination sources.

In this paper, the efficiency transfer method, mostly used in gamma spectrometry measurements, is applied to the measurement of the surface beta contamination, making use of previous results obtained in numerical modeling of electron transport in planar geometry (Stanga et al., 2016). It is shown that the reference calibration factor must be corrected to obtain the calibration factor corresponding to the actual contamination source that can be determined using efficiency transfer factors. The efficiency transfer factor for beta radiation and electrons is computed by Monte Carlo method. Our results show that the efficiency transfer method can be applied to surface beta contamination measurements using the available information concerning the component materials of the source and its main parameters.

The joint research project “Metrology for Decommissioning Nuclear Facilities” of the European Metrology Research Programme (MetroDecom, 2017) includes within its research topics the improvement of the accuracy and traceability of surface beta contamination measurements. The efficiency transfer method described in this paper is a contribution to the improvement of surface beta contamination measurements and is especially useful for clearing potentially contaminated waste items arising from the decommissioning of nuclear facilities.

2. Theoretical basis

2.1. Efficiency of large-area beta sources

Contamination sources are composed of the substrate material and

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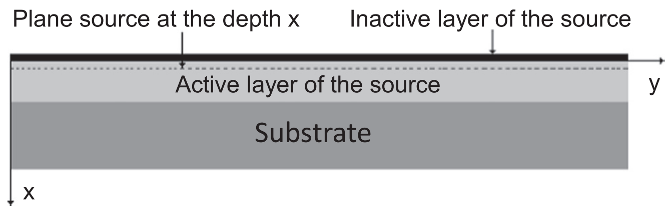

Fig. 1. Schematic view of a large-area contamination source.

the active layer of the source having the atomic numbers Z_s and Z_{la}. An inactive material with atomic number Z_{li} may cover them. A model of contamination source is schematically shown in Fig. 1 (ISO 7503-3, 2016). Assuming that the contamination source contains only one beta emitter, the efficiency of contamination sources for beta radiation and electrons, ε_{be}, is given by

$$\varepsilon_{be} = \frac{E_{be}}{\eta_{be}\Lambda} = \frac{E_b + E_e}{\eta_{be}\Lambda} = \frac{\eta_b\varepsilon_b + \eta_e\varepsilon_e}{\eta_{be}} \tag{1}$$

where $E_{be} = E_b + E_e$ and Λ are, respectively, the surface beta emission rate and the activity of the contamination source, E_b and E_e are surface emission rates due to beta radiation and electrons, η_b and η_e are, respectively, the total probability of beta transitions and the total probability of electron emissions, ε_b and ε_e are the source efficiencies for beta radiation and electrons, respectively and $\eta_{be} = \eta_b + \eta_e$ (η_{be} may be higher than one). Using the efficiency of plane sources, the efficiency of contamination sources for beta radiation and electrons can be expressed as (Stanga et al., 2016)

$$\varepsilon_{be} = \int_0^{x_M} \varepsilon_p(x, s) f(x) dx \tag{2}$$

where $\varepsilon_p(x, s)$ is the efficiency of the plane source at the depth x, $f(x) = \Lambda_p(x)/\Lambda$ is the activity depth distribution of the contamination source, ($\Lambda_p(x)dx$ is the activity of the plane source at the depth x), x_M and s stand for the thickness of active and inactive layers, respectively.

Considering a contamination source covered by a layer of thickness s_l, the transmission coefficient t_l of beta radiation and electrons emitted by the source through the layer is given by

$$t_l = \frac{E_{be,l}}{E_{be}} = \frac{1}{\varepsilon_{be}} \int_0^{x_M} \varepsilon_p(x, s, s_l) f(x) dx \tag{3}$$

where $E_{be,l}$ is the emission rate in 2π of beta particles emerging from the front face of the layer.

The efficiency of contamination sources for photons (gamma radiation and X-rays), ε_{ph}, is given by

$$\varepsilon_{ph} = \frac{E_{ph}}{\eta_{ph}\Lambda} \tag{4}$$

where E_{ph} is the surface photon emission rate, η_{ph} is the total probability of photon emissions. The value of ε_{ph} is usually equal to 0.5 (ISO 7503-3, 2016). If the corrections for the photon attenuation in the source material and the photon backscattering in the substrate of the source are significant then this value must be corrected (Nahle and Kossert, 2012).

2.2. *Detection efficiency of large-area detectors for beta and gamma radiations*

The direct evaluation of the surface beta contamination by means of beta contamination monitors is based on the detection and gross counting of beta particles, electrons, gamma radiation and X- rays using thin-window large-area detectors. Radioactive decay typically yields nearly simultaneous emissions of particles and photons that cannot be counted separately (coincidence summing effect). The standard ISO 7503-3 in Annex A shows that the correction due to the coincidence summing effect is small (it does not exceed 7%) and can be neglected.

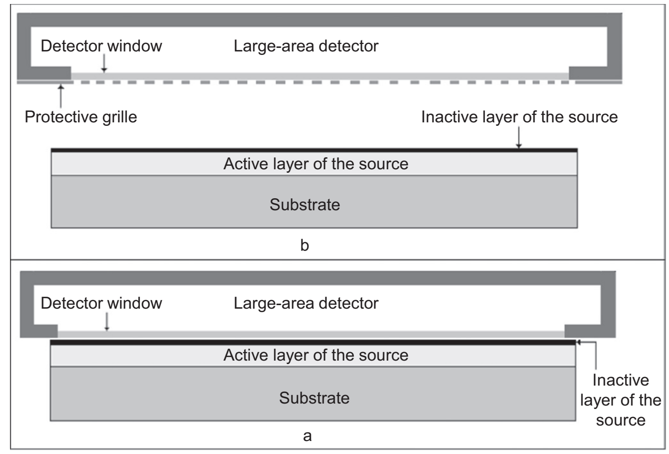

Fig. 2. Schematic view of two planar geometries used for contamination measurements.

As a result, counting efficiency of decays, ε_d, for beta contamination monitors can be expressed as

$$\varepsilon_d = \frac{R_{net}}{\Lambda} = \frac{R_{be} + R_{ph}}{\Lambda} = \eta_{be}\varepsilon_{dbe} + \eta_{ph}\varepsilon_{dph} \tag{5}$$

where $R_{net} = R_{be} + R_{ph}$ is the count rate recorded by the monitor and corrected for background, dead time losses and decay, R_{be} and R_{ph} are the count rates due, respectively, to beta particles (including electrons) and photons, ε_{dbe} and ε_{dph} are the detection efficiencies for beta radiation (including electrons) and photons, respectively.

To evaluate ε_{dbe} and ε_{dph}, we consider firstly the planar geometry shown in Fig. 2a, where the thin-window large-area detector is laid on the surface of the source. The detection efficiency for beta particles and electrons, ε_{dbe}, is defined as the probability of detecting and recording these particles by the counting system for a given counting geometry and detector (ICRU, 1994). Thus, we have

$$\varepsilon_{dbe} = \frac{R_{be}}{\eta_{be}\Lambda} = \frac{p_{be}E_w}{\eta_{be}\Lambda} = \frac{p_{be}t_w E_{be}}{\eta_{be}\Lambda} = p_{be}t_w\varepsilon_{be} \tag{6}$$

where p_{be} is the probability of detecting and recording the beta particles and the electrons that penetrated into the sensible volume of the detector, E_w is the rate of these particles, t_w is the transmission coefficient of beta particle and electrons through the detector window of thickness s_w. Considering Eq. (3), it follows that

$$\varepsilon_{dbe} = p_{be}\varepsilon_{be}t_w = e_{I,be}\varepsilon_{be} = p_{be}\int_0^{x_M} \varepsilon_p(x, s, s_w) f(x) dx \tag{7}$$

where $e_{I,be} = p_{be}t_w$ is the instrument efficiency (defined by ISO 7503-1) for beta radiation and electrons corresponding to the counting geometry from Fig. 2a.

In the second step, we consider the planar geometry shown in Fig. 2b, where the detector is provided with a protective grille, and there is an air gap of thickness s_{air} between the source and the detector. In this case, we have

$$\varepsilon_{dbe} = f_s f_g p_{be} t_{air,w}\varepsilon_{be} = f_s f_g e_{I,be}^{air}\varepsilon_{be} = f_s f_g p_{be}\int_0^{x_M} \varepsilon_p(x, s, s_{air}, s_w) f(x) dx \tag{8}$$

where f_s is the correction factor due to beta particles and electrons that are scattered outside the source-detector solid angle, f_g is the correction factor due to the attenuation of beta radiation and electrons in the material of the grille, $e_{I,be}^{air} = p_{be}t_{air,w}$ is the instrument efficiency for beta radiation and electrons corresponding to the counting geometry from Fig. 2b and $t_{air,w}$ is the transmission coefficient of beta radiation and electrons through the air gap and the detector window.

The detection efficiency for photons (gamma radiation and X-rays), ε_{dph}, is given by