Available online at www.sciencedirect.com
ScienceDirect
Journal of Environmental Radioactivity 99 (2008) 1520–1524
JOURNAL OF ENVIRONMENTAL RADIOACTIVITY
www.elsevier.com/locate/jenvrad

Calibration of a portable HPGe detector using MCNP code for the determination of ^{137}Cs in soils

J.L. Gutiérrez-Villanueva [a,b,*], A. Martín-Martín [a,b], V. Peña [a,b], M.P. Iniguez [b], B. de Celis [c]

[a] Laboratorio LIBRA, Edificio I+D, Paseo Belén 3, 47011 Valladolid, Spain
[b] Departamento de Física Teórica, Atómica y Óptica, Facultad de Ciencias, P° Prado de la Magdalena, s/n 47005 Valladolid, Spain
[c] University of León, Escuela de Ingeniería Industrial, León 24071, Spain

Available online 20 February 2008

Abstract

In situ gamma spectrometry provides a fast method to determine ^{137}Cs inventories in soils. To improve the accuracy of the estimates, one can use not only the information on the photopeak count rates but also on the peak to forward-scatter ratios. Before applying this procedure to field measurements, a calibration including several experimental simulations must be carried out in the laboratory. In this paper it is shown that Monte Carlo methods are a valuable tool to minimize the number of experimental measurements needed for the calibration.
© 2007 Elsevier Ltd. All rights reserved.

Keywords: Germanium detector; Monte Carlo; MCNP; Portable

1. Introduction

In situ γ-ray spectrometry is increasingly used in many applications, such as geophysical exploration, assessment of doses to the population due to radioactive fallout and determination of soil erosion rates employing the ^{137}Cs technique (Nouira et al., 2003; Tyler, 2004; Li et al., 2005; Perrin et al., 2006). Traditionally, erosion studies relied on the collection of several soil cores from the area of interest. The cores were then transported to the laboratory and, once divided into sections, measured by γ-ray spectrometry in order to quantify ^{137}Cs inventories at each sampling site. Portable γ-spectrometry can be used instead of the conventional method or combined with it, allowing measurements to be performed more rapidly and thereby wider areas to be surveyed.

The main shortcoming of in situ spectrometry is that, because the radionuclide depth distribution in the soil is unknown, the calculated ^{137}Cs inventories are uncertain. A solution proposed to overcome this drawback consists in considering not only the 661.7 keV photopeak count rate but also the peak to forward-scatter ratio, Q (Zombori et al., 1992; Tyler et al., 1996). In order to apply this procedure to in situ measurements, a series of experiments must be carried out in advance in the laboratory aimed at obtaining a calibration which relates Q to some parameter characterizing the ^{137}Cs distribution in the soil.

In this work the Monte Carlo code MCNP is used to estimate ^{137}Cs inventories considering typical depth distributions corresponding to uncultivated and cultivated soils. It is shown that the laboratory calibration can be practically replaced by Monte Carlo simulations, requiring one to perform only a minimal number of experimental measurements. Our results are validated by comparing field measurements taken with a Canberra portable HPGe detector to the results derived from soil cores measured in the laboratory.

2. The full-energy peak to forward-scatter ratio method

A field γ-ray spectrum can provide an estimate of the amount of activity per unit area of soil surface for fallout nuclides such as ^{137}Cs. For a given detector and measuring setup,

* Corresponding author. Laboratorio LIBRA, Edificio I+D, Paseo Belén 3, 47011 Valladolid, Spain. Tel.: +34 983 183807; fax: +34 983 183806.
E-mail addresses: joselg@libra.uva.es (J.L. Gutiérrez-Villanueva), alonsomm@libra.uva.es (A. Martín-Martín), victorp@libra.uva.es (V. Peña), piluca@fta.uva.es (M.P. Iniguez).

0265-931X/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvrad.2007.12.016

the relation between the count rate in the 661.7 keV photopeak from ^{137}Cs and its inventory in the soil largely depends on the depth activity distribution which is unknown.

In order to gain information on the activity profile, the full-energy peak to forward-scattered ratio (Q) can be used. The valley region between the ^{137}Cs full-energy peak and the corresponding Compton edge in the spectrum have contributions from several sources: ^{137}Cs photons suffering multiple Compton scattering prior to escape, multiple Compton scattering events from photons with higher primary energy, cosmic radiation and forward-scattering interactions. The contribution of forward-scattering is related to the interaction probability of the photon in its trajectory between the source and the detector. The deeper the activity is distributed in the soil, the more forward-scattered radiation per unit primary fluence is generated. Once the spectrum has been stripped out of the partial absorption and cosmic ray events, the quantity to compute is:

$$Q = \frac{N}{B_T}, \tag{1}$$

N being the net count rate in the 661.7 keV photopeak and B_T the average count rate in the range 609–662 keV.

3. Monte Carlo simulation of the detector's response

The portable HPGe detector used in the study is an *n*-type Canberra GC4019 model with a relative efficiency of 40.3% at 1332 keV. It was simulated using the Monte Carlo code MCNP v.4C (Briesmesiter et al., 1992). To verify the accuracy of the simulation, several point-like sources were prepared using a multi-gamma cocktail from Framatome, containing ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{60}Co and ^{88}Y. A series of measurements were carried out placing the sources corresponding to single-line emitters at different distances along the detector axis and perpendicular to it. Various detector parameters were modified in order to obtain a better agreement between experimental and calculated efficiencies following the procedure described in García-Talavera et al. (2000). In Table 1 the results obtained for the ^{137}Cs efficiencies are presented.

Table 1
Comparison of experimental ($\text{Efficiency}_{\text{Ex}}$) and Monte Carlo ($\text{Efficiency}_{\text{MC}}$) photopeak efficiencies for ^{137}Cs point-like sources in different positions along the detector axis (P1–P5) and perpendicular to it (P6–P9)

Position	$\text{Efficiency}_{\text{Ex}}$ (%)	$\text{Efficiency}_{\text{MC}}$ (%)	Deviation (%)
P1	6.228 (0.018)	6.617 (0.008)	5.891
P2	1.053 (0.009)	1.098 (0.002)	4.051
P3	0.385 (0.004)	0.407 (0.002)	5.402
P4	0.210 (0.003)	0.218 (0.001)	3.810
P5	0.127 (0.002)	0.135 (0.001)	5.9
P6	4.143 (0.030)	4.407 (0.002)	6.002
P7	4.115 (0.030)	4.372 (0.002)	5.870
P8	3.096 (0.030)	2.931 (0.001)	5.630
P9	3.224 (0.030)	3.041 (0.001)	6.025

Quantities in the parentheses are the associated uncertainties.

Furthermore, it is necessary to verify that not only the photopeak efficiencies are correct, but also that the code is able to reproduce peak to forward-scattered ratios. To test it, the following geometrical setup was used: a point-like source was placed at 10-cm distance from the detector window and a vessel containing variable amounts of water was interposed between the detector and the source. A comparison of the experimental and Monte Carlo efficiency and Q values for this configuration is given in Table 2. The agreement is always better than 7%.

4. Simulation of in situ measurements

The shape of ^{137}Cs activity profiles in soils is highly variable due to a number of factors, including soil properties, time since radiocaesium deposition and tillage practices. Generally, the activity depth distribution conforms to one of the three following shapes: *uniform*, typical of cultivated soils; *exponential*, characteristic of fresh fallout in undisturbed soils; *pseudo-gaussian*, which exhibits a maximum several centimetres below the surface and is common for older fallout. By means of the Monte Carlo code it was obtained the variation of the net count rate and Q with different parameters characterizing each of the three distributions.

4.1. Uniform activity distribution

Tillage practices mix the soil and the associated ^{137}Cs within the ploughing layer. Cultivated soils usually present a constant activity concentration A_0, down to the mass depth of the ploughing layer D, and zero below it. It was simulated by Monte Carlo spectra that such ^{137}Cs distribution in the soil would produce in the detector pointing downwards, at 1 m above the ground. In Fig. 1, the variation of Q with D for two different soil densities is showed. The same was done for the 661.7 keV peak net count rate referred to unit ^{137}Cs inventory in the soil. The Monte Carlo data have been fitted by a least-squares analysis to the following equations (Tyler et al., 1996):

$$Q = Q_0\, e^{-aD}, \tag{2}$$

Table 2
Comparison of experimental ($\text{Efficiency}_{\text{Ex}}$, Q_{Ex}) and Monte Carlo ($\text{Efficiency}_{\text{MC}}$, Q_{MC}) efficiencies and peak to forward-scatter ratios for a ^{137}Cs point-like source separated from the detector by a container full with varying amounts of water

Water thickness	0 cm	5 cm	10 cm
$\text{Efficiency}_{\text{Ex}}$	0.4096 (0.0032)	0.3172 (0.0025)	0.2423 (0.0025)
$\text{Efficiency}_{\text{MC}}$	0.3969 (0.0002)	0.3041 (0.0002)	0.2289 (0.0005)
Deviation (%)	3.20	4.30	5.87
Q_{Ex}	18.21	12.04	8.91
Q_{MC}	19.55	12.41	8.96
Deviation (%)	6.87	3.01	0.60

Quantities in the parentheses are the associated uncertainties.

Download English Version:

https://daneshyari.com/en/article/1739197

Download Persian Version:

https://daneshyari.com/article/1739197

Daneshyari.com