Calibration of HPGe detector for in situ measurements of ^{137}Cs in soil by “peak to valley” method

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INTRODUCTION

The contamination of soil with gamma-ray emitters can be measured in two ways: soil sampling method and in situ spectrometry of the ambient gamma-ray radiation.

The conventional soil sampling method has two disadvantages: samples may not be representative for a large areas and determination of the depth distribution of radionuclide requires the measurement of several samples taken from different depths.

In situ measurement of a radionuclide activity in soil is more sensitive and provides more representative data than data obtained by soil sample collection and subsequent laboratory analysis. In emergency situations time to assess the contamination is critical. For rapid assessment of the deposited activity direct measurement of ambient gamma-ray radiation are used.

In order to obtain accurate measurements of radionuclides in the soil, the detector should be placed on relatively even and open terrain

It is our customary practice to place the detector 1 m above the soil surface. At this height, a tripod-mounted detector can be handled easily and still provide a radius of view for gamma emitting sources out to about 10 m.

The “field of view “ actually varies, being somewhat larger for higher sources. Depending upon source energy, the detector effectively sees down to a depth of 15-30 cm.

Commonly used method for field gamma spectrometry is method by Beck (1). The most important disadvantages of in situ spectrometry by Beck are that the accuracy of the analysis depends on a separate knowledge of the radioactivity distribution with soil depth. This information can be obtained by calculations using data from in situ measurements and energy dependence of absorption and scattering of photons in soil and track length distribution of photons in soil (2).

A method of in situ measurements of ^{137}Cs in soil where radionuclide distribution in soil profile is calculated by unfolding of detector responses in the full energy peak net area at 0.662 MeV and in the valley under the peak (peak to valley method) has been developed at IPCM (3). The detector is used with and without collimator in order to achieve more independent responses for unfolding, which result in better resolution in radionuclide distribution.

INSTRUMENTATION

Field gamma measurements are performed using conventional coaxial HPGe detector with a 12.5% relative efficiency (in comparison to 3x3 inch NaI(Tl) full energy peak net area at 1.33 MeV) and resolution of 1.9 keV (FHHM at 1.33 MeV). The useful energy range of the detector is above 40 keV to more than 10 MeV.

A multi-attitude cryostat has been used to allow operation of the detector in any orientation without LN_2 spillage. The cryostat consists of a Dewar with LN_2 capacity of 7.0 liters and a holding time of 5 days. This allows the Dewar to be operated in the horizontal position, pointing vertically upward or downward, without loss of LN_2.

Measurements are made in the field using a computer based spectroscopy system. High voltage, preamplifier and spectroscopy system are supplied to a portable power supply.

A tripod, which supports the detector and its front part, is at high 100 cm above the ground. The orientation of the detector is facing downward.

A cylinder-shaped collimator was used to modify the angular distribution of photons that were impinging of the detector surface. The collimator is made from a lead cylinder with the outer/inner diameter of 19/10 cm and a height of 10 cm.

METHODS

In situ measurements of ^{137}Cs in soil by unfolding method (4) are based on the ratio of the unscattered and forward scattered photons (peak to valley ratio method (5)) and different track length distributions of photons in soil, registered by collimated and uncollimated detector (6).

The detector response N(i) to ith characteristic of gamma ray field above ground with radionuclide distributed homogeneously in horizontal direction is described by integral equation :

$$N(i) = \int \sigma(i,\zeta)\, A(\zeta)\, d\zeta \qquad i=1,2,...,n \qquad (1)$$

where : ζ [kg m^{-2}] - depth in the soil in units mass-per-area,
$\sigma(i,\zeta)$ [Bq^{-1} m^2] - the detector response in gamma-field of plane source of unit activity-per-area in soil,
$A(\zeta)\, d\zeta$ [Bq m^{-2}] - activity of the plane source to be determined.

Quantities presented in terms of soil mass-per-area characterize the related field in air better than the linear depth of the source element in ground.

The unknown activity $A(\zeta)$ in soil profile is obtained by unfolding of the Eqn. (1). The method is based on unfolding of four various responses $\sigma(i,\zeta)$ of in situ measurements at the same place. The responses consist of collimated and uncollimated detector responses in full energy peak net areas of 0.662 MeV primary and 0.62-0.655 MeV forward scattered photons (4). The detector response $\sigma(i,\zeta)$ to ith characteristic of gamma field with flux $\phi(i,\zeta,\theta)$ per-unit-activity of plane radionuclide at the depth ζ in the soil can be described for uncollimated detector:

$$\sigma(1,\zeta)= \int\Phi(1,\zeta,\theta)R(1,\theta)\, d\theta \qquad (2)$$
$$\sigma(2,\zeta)= \int\Phi(2,\zeta,\theta)\, R(1,\theta)\, d\theta + \int\Phi(1,\zeta,\theta)\, R(3,\theta)\, d\theta$$

$\Phi(i,\zeta,\theta)\, d\theta$ - the flux of primary (i=1), or scattered (i=2) photons, that are impinging at angle θ to detector surface.

The photon flux can was determined by a Monte Carlo calculation (4) for the plane soil surface.

$R(1,\theta)$ – angular dependence of response in peak of total absorption of uncollimated detector to a parallel beam of 0.662 MeV photons.
$R(3,\theta)$ – angular dependence of response in channels 0.62-0.655 MeV of uncollimated detector to a parallel beam of 0.662 MeV photons.

In the case of collimated detector the equations for detector response are similar:

$$\sigma(3,\zeta)= \int\Phi(1,\zeta,\theta)\, R(2,\theta)\, d\theta \qquad (2a)$$
$$\sigma(4,\zeta)= \int\Phi(2,\zeta,\theta)\, R(2,\theta)\, d\theta + \int\Phi(1,\zeta,\theta)\, R(4,\theta)\, d\theta$$

$R(2,\theta)$ – the same as $R(1,\theta)$ but for collimated detector.

$R(4,\theta)$ – the same as $R(3,\theta)$ but for collimated detector.

In Eqn. (2) and (2a), the angular dependences of detector were considered to be constant in the energy range of photons from 0.62 up 0.662 MeV (2). Responses of uncollimated and collimated detector to scattered photons of ^{137}Cs with energies 0.62 - 0.655 MeV consist of two components; scattered photons in soil and in housing material of the detector, respectively.

The angular responses $R(i,\theta)$ of the detector have been measured by a point source ^{137}Cs which was positioned at different angles at a fixed distance of 0.7 m from the detector (2).

The background due to natural sources at energy region from 0.62 to 0.655 MeV can be estimated from detector response in channels 0.670-0.705 keV (4).

For unfolding of detector responses the iteration procedure SAND II (7) has been found reliable and capable of calculating distribution of ^{137}Cs in soil profile with adequate accuracy for environmental monitoring purposes (4).

Verification of calibration of the detector for the presented method of in situ measurements of ^{137}Cs in soil was performed during the Intercomparison Measurements on 10th Regular Workshop on Mobile Radiological Laboratories (MORAL10) (8) and on 12th Regular Workshop on Mobile Radiological Laboratories (MORAL12) (9).

RESULTS AND DISCUSSION

MORAL10 was held in Switzerland Alps at Hinterhein. Soil in the site was plane and consisted of mineral fragments and stones. The surface of soil was plane with grass.

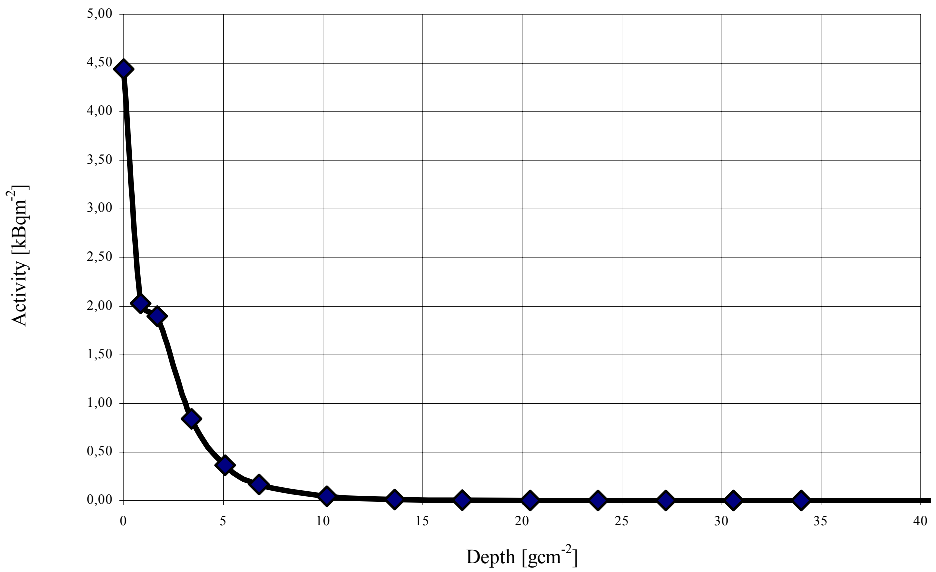

Fig. 1. Depth distribution of ^{137}Cs activity of in soil measured by present in situ method at Hinterhein

The activity of ^{137}Cs is at the surface of soil at Hinterhein. Similar distribution was considered in situ method by Beck, which was used by other 18 teams. Therefore results of both in situ methods, presented peak to valley method with unfolding and method by Beck, could be compared and we performed a correction of calibration of our detector.

The second verification of detector for in situ measurements by presented method was performed on MORAL 12, which was held in Exclusion Zone of the Chernobyl nuclear power plant in locality Kopachi. Soil in Kopachi consists of sand with density of 1.45 g cm^{-3}. The soil surface was covered by grass (with height up to of 40 cm) with dense root system. The terrain had boulders (about 5 pieces per m^2 in average) with height of 10 cm.

The activity distribution of ^{137}Cs with soil depth, measured by presented method peak to valley with unfolding, is shown on Fig. 2.

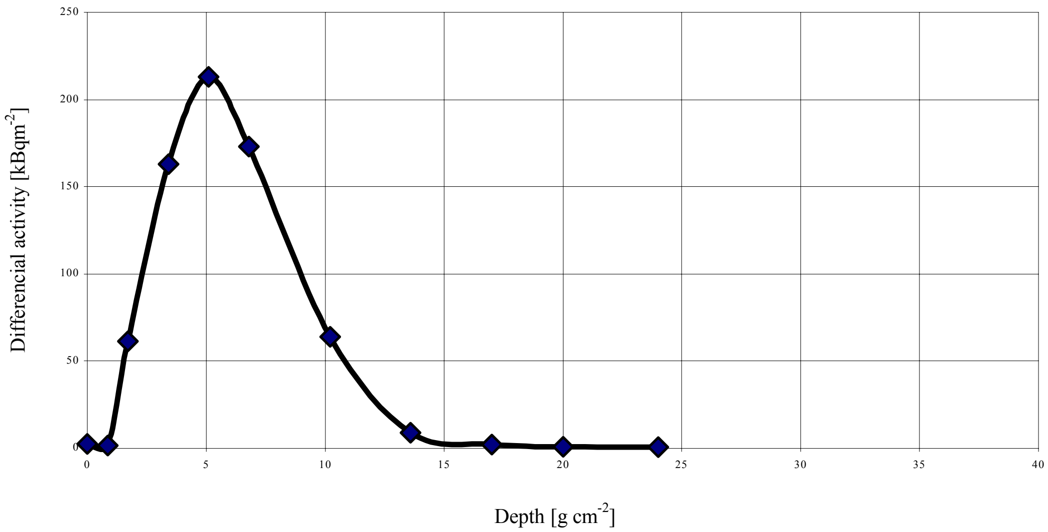

Fig. 2. Depth distribution of the ^{137}Cs activity in soil profile in Exclusion Zone of the Chernobyl nuclear power plant, Kopachi

The ^{137}Cs activity distribution in depth profile of soil, seen by detector for in situ measurements has its maximum at the depth of 5 g cm^{-2}.

The value of ^{137}Cs activity 1600 kBq m^{-2} obtained by presented method has been distinctly different to mean one 415±152 kBq m^{-2}, which was measured by other 6 teams at the same place (9). Our result could not be compared with in situ measurements of other teams, because they used the classical in situ method by Beck with supposition, that the radionuclide ^{137}Cs is concentrated only at the soil surface.

For verification of presented method it was possible to utilize field sampling and measurements in mobile radiological laboratories in MORAL12. The Fig.2 was recalculated into distribution of integral activity of ^{137}Cs with depth of soil in units of cm, Fig.3.

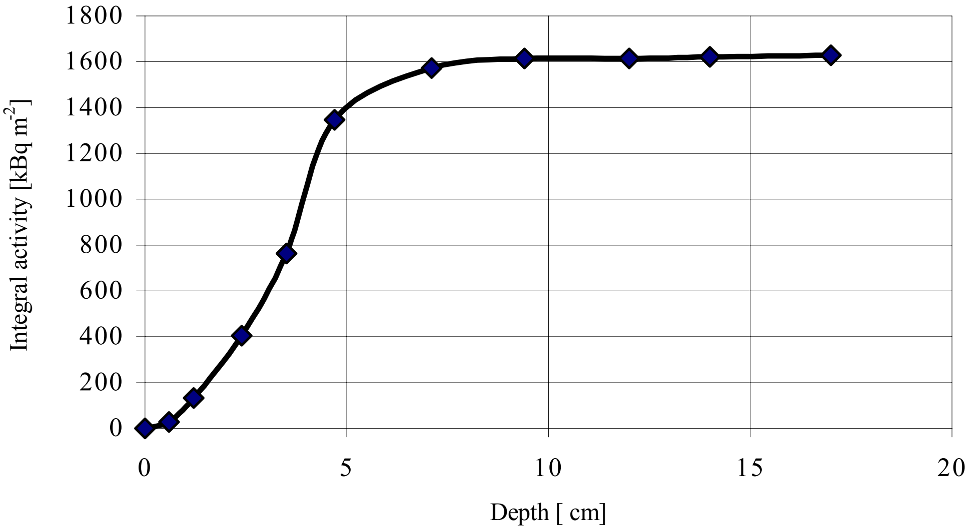

Fig. 3. Integral depth distribution of the ^{137}Cs activity in soil profile in Chernobyl, Kopachi

The activity of ^{137}Cs in soil at Kopachi measured by soil sampling method on MORAL12 is given in Table 1.

Table 1. ^{137}Cs activity in soil measured by field sampling in mobile radiological laboratories at Kopachi [kBqm^{-2}]*

Depth of soil	This work	MORAL 12
0-5 cm	1380	1400
5-10 cm	68	
10-15 cm	6	

* Density of soil at Kopachi was 1.45 g cm^{-3}

The maximum of ^{137}Cs activity in soil seen by in situ detector (Fig. 3) is located deeper in soil than that one measured by soil sampling (Table 1, This work). The reason is photon fluxes Φ used in Eqn. (2) and (2a) that were calculated for plane soil surface and not for soil surface disturbed by boulders with grass, as was at locality Kopachi.

Other teams measured ^{137}Cs activity only in the first 5 cm of soil. In Table 1 (MORAL12) is given an averaged value of 13 soil samples which represents a good mean of ^{137}Cs activity across the whole measured area in the locality Kopachi (9).

From Fig.3 implies that the integral activity of ^{137}Cs at the first 5 cm of soil is 1400 kBq m^{-2}, which is equal to 19.3 kBq kg^{-1} for soil density 1.45 g cm^{-3}.

These values are in good agreement with activity of ^{137}Cs 20.8±7 kBq kg^{-1} or 1400 kBq m^{-2}, which was measured by teams of MORAL12 (9).

CONCLUSION

Calibration of HPGe detector for in situ measurements of ^{137}Cs by peak to valley method with subsequent unfolding of detector responses has been described. An important step in the calibration -

experimental verification was performed during the Intercomparison Measurements on 10th Regular Workshop on Mobile Radiological Laboratories (MORAL10) and on 12th Regular Workshop on Mobile Radiological Laboratories (MORAL12). Results of measurements in Chernobyl (MORAL12) confirm good calibration of the detector and shown the advantages of presented in situ method for measurements of ^{137}Cs in soils with unknown depth distribution.

LITERATURE

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