AN IMPROVED METHOD OF IN-SITU MEASUREMENT OF ^{137}Cs CONCENTRATION IN SOIL TEN YEARS AFTER CHERNOBYL.

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Introduction

This contribution is aimed to the possibility of improving the in-situ gamma spectrometry to be independent on a priori knowledge about a depth distribution of ^{137}Cs in soil and sufficiently sensitive for the measurement of the post-Chernobyl ^{137}Cs at present, as well. The depth distribution of ^{137}Cs averaged over a large area of soil is obtained by unfolding of the detector responses to primary and in soil forward scattered photons. The proposed method employs detector with and without collimator.

Methods

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

The responses of collimated and uncollimated detector $\sigma(i,\zeta)$ to primary 0.662 MeV and to 0.62-0.655 MeV photons scattered in the soil are considered in the proposed method. The detector responses are obtained by calculations in combination with experimental calibration.

Calculational procedures

The detector response $\sigma(i,\zeta)$ to ith characteristic of gamma field with flux $\phi(i,\zeta,\theta,E)$ per-unit-activity of plane source at the depth ζ in the soil can be described as follows:

$$\sigma(i,\zeta) = \iint \phi(i,\zeta,\theta,E).R(i,\theta,E)d\theta.dE \qquad (2)$$

where R(i,θ,E) - detector response in peak of total absorption for a parallel photon beam of energy E impinging at angle θ to the detector axis.

The Equation (2) can be simplified by assumption that the dependences R(i,θ,E) are in the energy range of photons from 0.62 up to 0.662 MeV constant:

$$\sigma(i,\zeta) = \int \Phi(i,\zeta,\theta).R(i,\theta)d\theta \qquad (3)$$

where $\Phi(i,\zeta,\theta)\, d\theta$ - photon flux at angle θ integrated over energy, R(i,θ) - angular dependence of detector response for a parallel photon beam of energy 0.662 MeV.

The photon flux Φ has been calculated by our Monte Carlo code SOILSC. Homogeneous and isotropic plane source of thickness 0.5 $g.cm^{-2}$ was simulated up to 85 $g.cm^{-2}$ of depths in the soil, starting with the plane source on the ground. The plane source radii were chosen 100 m to represent an infinitive plane soil contamination with radionuclide ^{137}Cs.

Experimental procedures

A portable N-type high purity germanium HPGe detector with relative efficiency of 12,5% and resolution of 1,7 keV for 1,33 MeV gamma rays has been used. The detector was supported by a tripod and the front of the detector was at the height 100 cm above the ground. The orientation of the detector is facing downward.

A cylinder-shaped collimator has been used to modify the angle distribution of photons impinging to the detector surface. The collimator is made from lead cylinder with the outer/inner diameter 19/10 cm and height 10 cm laying on aluminium cylinder with the outer/inner diameter 30/10 cm and height 2 cm. The bottom of aluminium disk was located at height of 100 cm above the ground.

The experimental calibrations were aimed to determine the responses $R(i,\theta)$ (in Equation 3) of collimated and uncollimated detector in the energy region 0.62-0.655 MeV and in peak of total absorption of the 0.662 MeV photons, as well, and to asses the background in the energy region 0.62-0.655 MeV due to photons from the natural sources.

Application to post-Chernobyl ^{137}Cs

The photon spectra were recorded over lawns in Southern Slovakia. In-situ gamma spectrometry was performed with and without collimation of the detector, which was located above the centre of the area used for soil sampling.

Figure 1 shows the pulse height distribution measured by the unshielded detector at the location No.2 in the energy interval 0.55 - 1.0 MeV. Exponential approximation of the spectrum in the interval 0.67 - 1.0 MeV, bold line in the figure, is used for assessment of background for 0.62-0.655 MeV photons scattered in the soil.

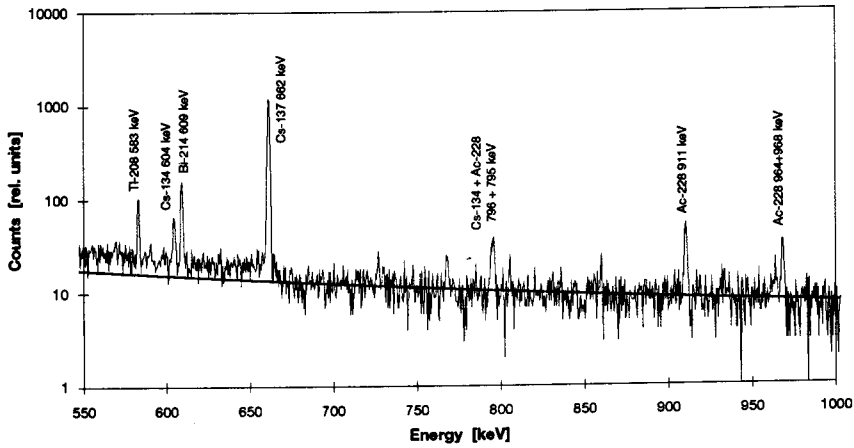

Figure 1. The pulse height distribution measured by the HPGe detector at the location No.2.

Figure 2 shows depth distributions of the ^{137}Cs activity in soil measured in surrounding of Bratislava, the places were in distance 20 km. The results obtained by presented method are compared to results by soil sampling. The relative standard deviation of the ^{137}Cs activity in soil samples were <10% for each depth of soil.

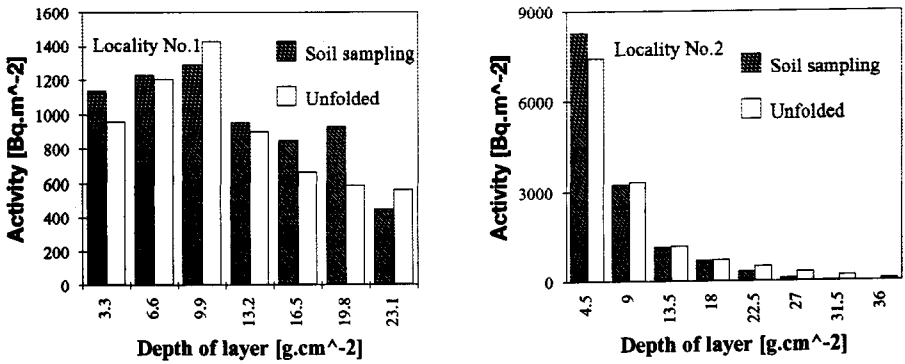

Figure 2. Distributions of the ^{137}Cs activity in soil profile of lawn in the locality No.1 and 2 determined by presented method and by soil sampling, as well.

The downward transport of ^{137}Cs have occurred to a peak concentration that lies below the surface of lawns. The differences between presented method and soil sampling of the distributions in Figure 2 are within 20%, except of distributions at the deeper depths where resolution of unfolding method is worse.

The ^{137}Cs activity-per-mass and/or activity-per-area in soil determined by presented method of deconvolution, by sampling method and by standard in-situ spectrometry using the exponential depth distribution in the soil (1), that has been determined by exponential least squares fit of results of soil sampling, are given in Table 1.

Table 1. ^{137}Cs activities in soil of lawns in Southern Slovakia determined by various methods.

No. of	Presented method		Soil sampling		Standard method	
locality	[kBq.m^{-2}]	[Bq.kg^{-1}]	[kBq.m^{-2}]	[Bq.kg^{-1}]	[kBq.m^{-2}]	[Bq.kg^{-1}]
1	6.3±1.6	274±68	6.8±0.7	258±26	-	307
2	13.2±3.5	-	13.8±1.5	-	12.5	-
3	1.2±0.5	39±16	1.1±0.2	36±7	-	33

Conclusion

In the presented method a fairly accurate concentration estimate for the top layer of the soil, down to a depth of about 30 g cm^{-2}, is obtained. The analysis of the spectra collected with the detector, used in this study indicates that ^{137}Cs concentration in soil, in time of 10 years after the Chernobyl accident, would be measurable using a middle HPGe detector (about 30% of relative efficiency) and a counting time of the order 1 hour or less. Even with smaller detectors, ^{137}Cs concentrations of 5 kBq m^{-2} are measurable and the depth distribution of ^{137}Cs of activities above 10 kBq m^{-2} in soil can be estimated by presented method when counting time of the order 3 hours is used.

REFERENCES

1 H. L. Beck, J. DeCampo, C. Gogolak, In situ Ge(Li) and NaI(Tl) gamma-ray spectrometry; Health and Safety, TID-4500 (1972)