MEASUREMENT OF THE AVERAGE PATH OF GAMMA-RAYS IN THE SAMPLE

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Abstract. *It is shown that the valley-to-peak ratio in gamma-ray spectra bears information about the average path of gamma rays, thansversed in the sample. The measurements of the intrinsic valley-to-peak ratio, due to the response of the detector to gamma rays are presented. The average path in homogeneous sample, estimated from the valley-to peak ration is compared to the path, calculated from the derivative of the efficiency on the attenuation coefficient.*

INTRODUCTION

In gamma-ray spectrometry the activity of gamma-ray emitting nuclides can be evaluated if the probability for the registration of gamma rays in the full energy peaks is known. This probability depends on the characteristics of the detector, the sample and their geometry. For homogeneous samples it can be measured by measuring calibrated sources [1], which resemble the samples in all characteristics. Therefore it is convenient to have a method to justify the supposition about the homogeneity of unknown samples. Hence, methods are sought to determine the inhomogeneity from the measured spectrum itself.

An indication for the presence of inhomogeneity can be obtained from the comparison of the measured average path of detected gamma rays in the sample with the calculated one under the supposition that the sample is homogeneous. When gamma rays pass the material they may by scattered for small angles. The corresponding energy loss is small and they register in the energy interval between the Compton continuum and the full energy peak. However, in this energy interval counts are present even if there is no material between the source and the detector, because of scattering on insensitive layers of the detector and since gamma rays may lose any amount of energy in the sensitive area before escaping. Therefore only the increase of the number of counts in the interval over its intrinsic value bears the information about the thickness of the transversed layer [2]. This information can be then used to assess the distribution of the emitter within the sample or to calculate self-absorption corrections.

METHOD

The relation between the number of gamma rays emitted from the vicinity of the point $\vec{r}$ which are registered in the "valley" between the Compton continuum and the full energy peak and the average path transversed in materials between the sample and the detector has two terms. The first describes the number of counts of the bare detector and the second the increase due to the scattering in the transversed material:

$$dN_v(\vec{r}) = K(\vec{r})\, dN_p(\vec{r}) + \eta'(\vec{r})\, P_1(\mu_a,\vec{r})\, dN(\vec{r}) \quad .$$

Here $dN_v(\vec{r})$ denotes the number of gamma rays emitted in the vicinity of the point $\vec{r}$ and registered in the valley, $dN_p(\vec{r})$ the number of counts registered in the peak, $K(\vec{r})$ the ratio of the number of counts in the valley and the number of counts in the peak for a source placed at the point $\vec{r}$ and in the absence of material between the source and the detector, $P_1(\mu_a,\vec{r})$ the probability for single scattering of gamma rays to the energy interval of the valley, $\eta'(\vec{r})$ the probability for detection of scattered rays with full energy and $dN(\vec{r})$ the number of rays, emitted from the point $\vec{r}$. The constant $K(\vec{r})$ represents an intrinsic property of the detector and must be measured in a similar way as the total-to-peak or peak-to-Compton ratios. The probability for single scattering is given by [2]:

$$P_1(\mu_a,\vec{r}) = K_1\, \mu_a\, \bar{d}(\vec{r})\, e^{-\mu_a \bar{d}(\vec{r})}\, P_\Omega(\vec{r}) \quad ,$$

where K_1 denotes the fraction of the total number of interacted rays, which are scattered into the energy interval of the valley, μ_a the total interaction coefficient, $\bar{d}(\vec{r})$ the average path of gamma rays through the material and $P_\Omega(\vec{r})$ the probability for transversing the space occupied by the scattering material. K_1 is given by the ratio of the integral of the Klein-Nishina cross section over the interval of angles, defined by the energy interval spawning the valley region, and the total interaction cross section. The number of gamma rays detected in the valley region is:

$$dN_v(\vec{r}) = K(\vec{r})\, dN_p(\vec{r}) + K_1'\, \mu_a\, \bar{d}(\vec{r})\, dN_p(\vec{r}) \quad ,$$

where we have used the relation $dN_p(\vec{r}) = \eta(\vec{r})dN$ and $K_1' = K_1 \eta'(\vec{r}) e^{-\mu \bar{d}} P_\Omega(\vec{r}) / \eta(\vec{r}) = K_1 \eta'(\vec{r}) P_\Omega(\vec{r}) / \eta_o(\vec{r})$. In the last expression $\eta_0(\vec{r})$ denotes the efficiency in the absence of the absorbing medium. It can be shown [3], that the dependencies on $\vec{r}$ in the expression on K_1' partially cancel out. The rest can be accommodated to the average path $\bar{d}(\vec{r})$ by its redefinition, so that the valley-to-peak ratio for a volume sample is obtained by integration of the previous equation over the sample volume and division by N_p:

$$\frac{N_v}{N_p} = \frac{\int_{V_s} K(\vec{r})\, dN_p(\vec{r})}{N_p} + K_1'\, \mu_a \frac{\int_{V_s} \bar{d}(\vec{r})\, dN_p(\vec{r})}{N_p} \quad .$$

Since the last factor in the last term represents just the average path in the sample of the scattered and detected rays, it can be expressed as:

$$\bar{d} = \frac{\dfrac{N_v}{N_p} - \dfrac{\int_{V_s} K(\vec{r})\, dN_p(\vec{r})}{N_p}}{K_1'\, \mu_a} \quad .$$

MEASUREMENTS

The valley-to-peak ratio of the detector $K(\vec{r})$ has been measured for a p-type detector of 35% relative efficiency at energies of 320, 661, 835 and 1115 keV on a grid of points within 5 cm in the radial direction and 4 cm in the axial direction from the centre of detector cap with the interval of 1 cm. In order to avoid the contribution of counts from the low-energy tail of the full energy peak the upper limit of the valley region was set to 25 keV below the energy of the gamma rays. The energy interval of the valley region is presented in Fig. 1. The measured energy dependence of $K(\vec{r})$ in the detector axis on the detector surface is presented in Fig 2.

The constant K_1' was measured with a parallel beam of rays, scattered on a layer of material of known thickness. To measure the average path of gamma rays in the sample four sources with aqueous solution of the ^{137}Cs isotope were measured. They were of cylindrical shape with dimensions of Φ60x10, Φ60x36, Φ90x16 and Φ90x39 mm. The comparison between the average path in the sample of the detected rays, calculated from the derivation of the volume-source efficiency on the absorption

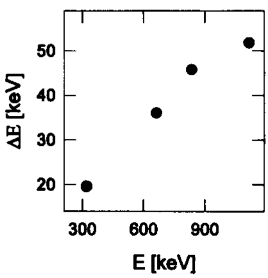

Figure 1. The energy dependence of the valley region.

coefficient [4], and the average path in the sample of scattered and detected rays is presented in Table 1. It may be observed that the path of scattered and detected rays is larger. This is due to the scattering angle, which permits the detection of rays which would not pass the sensitive volume of the detector.

DISCUSSION AND CONCLUSION

The valley-to-peak method was developed for use in in-situ gamma-ray spectrometry, to measure the average depth of the radionuclides deposited in surface layers of the soil. It has been shown that also in laboratory conditions it yields useful results. In laboratory conditions the difference between the paths of scattered and unscattered rays becomes measurable. This difference, since is due to the scattering angle, falls off with increasing energy of gamma rays. The comparison between both average paths offers the opportunity to check the supposition about the homogeneity of the sample on one hand and presents an independent check for the accuracy of the calculation of the influence of self-attenuation on the efficiency on the other. It should be noted also, that in laboratory conditions the spatial dependence $K(\vec{r})$ which reflects the variation of the detector response on the position of the source must be taken into account. Consequently, in measurement of volume samples the integration in Eq. (1) has to be carried out, in order to obtain unbiased results.

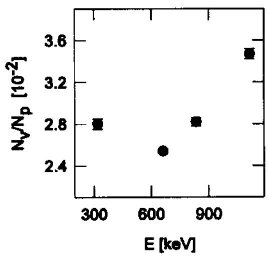

Figure 2. The energy dependence of the valley-to-peak ratio for a point source located on the detector surface on its axis.

TABLE 1. Comparison between the average paths in the sample of the detected and the scattered and detected gamma rays.

Geometry [mm]	Detected [mm]	Sc. & detected [mm]
60 x 10	5.4	4.9 ± 0.9
60 x 36	15.0	17.2 ± 0.9
90 x 16	10.0	11.2 ± 1.0
90 x 39	17.3	20.2 ± 0.7

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