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Minimum Detectable Activity in gamma spectrometry and its use in low level activity measurements

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HIGHLIGHTS

- Three different MDA algorithms were applied to gamma spectrometry measurements.
- The measurements were performed using two HPGe detectors.
- MDA performances of the two spectrometric systems were compared.
- The measured samples had different geometries and contained a mixture of radionuclides.
- MDA was studied also as a function of measuring time.

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ABSTRACT

In this paper there are described three different algorithms of Minimum Detectable Activity (*MDA*) calculus, and its use in high resolution gamma spectrometry. In the first part, few introductive theoretical aspects related to the *MDA* are presented. Further, the theory was applied to real gamma rays spectrometry measurements and the results were compared with the activities reference values. Two different gamma spectrometry systems, both of them using High Purity Germanium (HPGe) detectors, but having different efficiencies, were used. Samples having different geometries and radionuclides content were measured. The measured samples were made by dissolving of some acids containing anthropogenic radionuclides in water, obtaining a density of 1 g/cm^3. Choosing this type of matrix was done because of its high homogeneity.

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1. Introduction

The *MDA* is a very important parameter when we speak about the capabilities of gamma rays spectrometers involved in low level activity measurements. To be more accurate, we start by defining of some involved quantities ("characteristic limits") (ISO 11929, 2010):

"- decision threshold (L_C) gives a decision on whether or not the physical effect quantified by the measurand is present;

- detection limit (L_D) indicates the smallest true value of the measurand which can still be detected with the applied measurement procedures; this gives a decision on whether or not the measurement procedure satisfies the requirements and it is therefore suitable for the intended measurement purpose;

- limits of the confidence intervals enclose, in the case of the physical effect recognized as present, a confidence interval containing the true value of the measurand with a specified probability".

The Minimum Detectable Activity is defined by Gilmore, (2008) as being the smallest quantity of activity that we are sure we can detect with a system, in specific measurement conditions. This quantity is very important for the Spectrometric Analyses Laboratory (LAS) from the Management of Radioactive Wastes Department (DMDR), Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), Romania, since here, beside the qualitative measurements, it is decided if a sample is contaminated or not. The laboratory is working under the Romanian National Commission of Nuclear Activities Control (CNCAN) (CNCAN, 2008), which define *MDA* as the smallest activity of a radionuclide which can be detected in a sample, with a predefined probability of 95% (approximatively k=2), taking into account of 5% probability of making type I errors (assumption that a radionuclide is present, but actually it is not) and making type II errors

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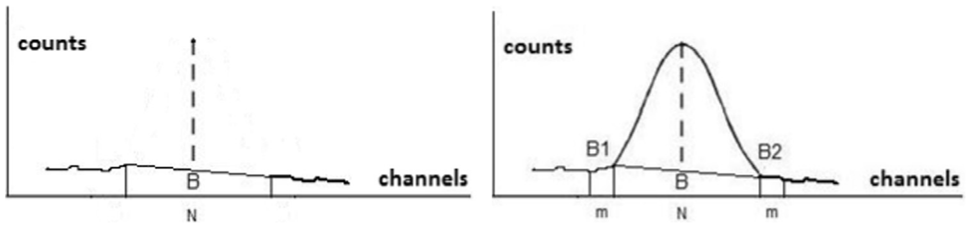

Fig. 1. Theoretical representations of no-peaked and peaked backgrounds.

(assumption that the radionuclide is not present, but actually it is).

In present, three *MDA* calculus methods are widely used: "Currie", KTA (German Nuclear Authority) and ISO11929. In addition to "Currie", the KTA method takes into account a supplementary safety factor and the ISO11929 one takes into account the systematic uncertainties of all involved parameters. Unlike integral measurements, in spectrometric measurements there are some incoherences related to the background determining algorithms. The two main cases studied in this paper are the ones when a peak is present, respectively not present, in the region of interest (ROI), as it can be seen in Fig. 1.

When the peak is not located, the background number of counts may be assessed as the number of counts in the ROI. Consequently, if a peak is present but not located it is included into the continuous background. However, if the peak is located, the background number of counts is calculated by interpolating the continuous background under the peak from the adjacent regions *B1* and *B2*.

The three *MDA* formulas used in this paper (Currie, 1968; Debertin and Helmer, 1988; Kirkpatrick et al., 2015; KTA 1503.1, 2013; Trnková and Rulik, 2009), used in the case of no-peaked backgrounds, are:

$$MDA_{Currie} = \frac{k^2+2k\sqrt{2\bullet B}}{\varepsilon\bullet i\bullet t} \tag{1}$$

$$MDA_{ISO11929} = w\bullet\frac{k^2+2k\sqrt{2\bullet B}}{1-k^2\bullet var(w)} \tag{2}$$

$$MDA_{KTA} = \frac{0.5\bullet(2k^2) + 2k\sqrt{B' + B'\frac{N}{2m}}}{\varepsilon\bullet i\bullet t} \tag{3}$$

where B, B' is the background, ε is the detection efficiency, i is the emission intensity, t is the measurement time and w is the weighting factor ($w=\frac{1}{\varepsilon\bullet i\bullet t}$), N is the number of channels of the ROI and m is the number of channels to the left and to the right of the ROI, used for background subtraction. The confidence level (k) used was 1.645. The ROIs used for calculating B and B' are the one where gamma-rays from for a certain radionuclide is expected to be registered, taking into account the energy and resolution calibrations. The ROI used for calculating B is four times the *FWHM* plus 2 channels to the left and 2 channels to the right of an expected centroid. The ROI limits assigned for calculating B' (KTA case) take into account 1.25 times the expected *FWHM* to the left and to the right of the expected peak region (ISOCS/LabSOCS, 2002).

In the case of the peaked backgrounds, the background determination algorithm is changing. This change causes an incoherence which is obvious when the dependence of the *MDA* as a function of measuring time is plotted. In the case of a low activity sample being measured, after a certain aquisition time, an activity value will be reported and the *MDA* value will have a significant decrease.

In the case of the peaked backgrounds, the *MDA* $_{Currie}$ (1) and *MDA* $_{ISO11929}$ (2) formulas will become then:

$$MDA_{Currie} = \frac{k^2+2k\sqrt{B + B\frac{N}{2m}}}{\varepsilon\bullet i\bullet t} \tag{4}$$

$$MDA_{ISO11929} = w\bullet\frac{k^2+2k\sqrt{B + B\frac{N}{2m}}}{1-k^2\bullet var(w)}. \tag{5}$$

The decrease does not occur in the *MDA* $_{KTA}$, which is always the smallest, due to the fact that B' is calculated by interpolating the continuous background from *B1* and *B2* (Fig. 1) regardless if the peak is identified or not.

In gamma rays spectrometry, the *MDA* value depends to a variety of parameters such are: detector intrinsic efficiency for *E* energy photons, emission intensity, spectrum acquisition time, detector resolution, geometric efficiency, the activity of other radionuclides found in spectrum, cosmic and telluric radiation background and electronic noise background which affects the resolution.

2. Experimental

There were made two sets of spectrometric measurements. Both of them were made using aqueous solutions obtained at DMDR (Management of Radioactive Wastes Department, Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering – Romania), by pipetting from an initial solution prepared at the Institute of Nuclear Research Pitesti (SCN). The solution was sent to DRMR in the frame of a national comparison between laboratories and the reference value of the activity was calculated by taking into account the values submitted to the organizer by all participant laboratories. Samples activities were chosen to be very low, maximum 2 Bq, to fulfill their goal. The samples were measured in a close contact to the detector surface geometry.

2.1. First set of measurements

The first set of gamma spectrometric measurements was made on Sample 1, 0.9 kg 130 G type Marinelli geometry, which contained the radionuclides presented in Table 1.

Activities reference dates were those when the spectrometry measurements were made.

To be able comparing MDA values obtained for two different

Table 1
The radionuclides content of Sample 1.

Radionuclide	Activity [Bq]	Uncertainty [Bq]
Co-60	0.07	0.02
Ba-133	0.15	0.04
Cs-137	0.17	0.04
Am-241	0.25	0.06

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