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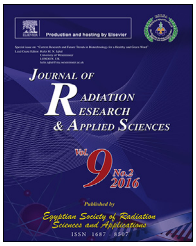

A method of rapid testing of radioactivity of different materials

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ABSTRACT

A new method for the detection of low-level ionising radiation in solid, liquid or loose materials, which is based on the use of the Bayesian approach for the estimation of probabilistic parameters and a special statistical criterion, is offered in the present paper. We describe the algorithm and show the advantages of the method. The approach can be effective even in the case of extremely low signals whose intensity is much less than the background radiation.

1. Introduction

Ionising radiation is one of the major natural and man-made factors affecting human life and health. Due to recent changes in the conceptual approach, the problem of radiation safety does not only apply to the control of a limited number of potentially dangerous objects (plants and laboratories of nuclear fuel cycle, research and defence facilities of the appropriate profile, etc.), but is becoming more global (Marhulys & Bregadze, 2000). In particular, in the case of the building industry, up to 70% of radiation is contributed by natural gamma-emitting radionuclides contained in materials used and, as a result, there is uncontrolled proliferation of these radionuclides in building construction, including walls and ceilings of residences.

The activity concentrations are determined by gamma-ray spectrometry using high-purity germanium detectors (HPGe) and a multichannel analyser. To reach the highest level of accuracy, some researchers (Al-Saleh and Al-Berzan, 2007) conduct the measurement of the samples studied with an accumulating time for about 80,000 s.

Measurements of low-level radioactivity often give results in the order of the detection limit. For many applications it is important to concentrate on multi-isotope analyses of samples with low-level radioactivity. How to measure such kinds of samples? This requires the development of a special analytical approach. To overcome difficulties associated with

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the detection limit, some researchers have appealed to Bayesian statistics, a method that allows statistical inference on nuclide ratios taking into account both prior knowledge and all information collected from the measurements (e.g. Kacker, 2006; Zähringer & Kirchner, 2008; Kirchner, Steiner, & Zähringer, 2009; Dalal & Han, 2010; Qingpeia et al., 2013). Methods based on Bayesian statistics allow quantitative conclusion regarding counts of single isotopes whose activity is low compared to the background radiation. The application of such new approach is illustrated by a number of examples of environmental low-level radioactivity measurements (Kirchner et al., 2009). Qingpeia et al. (2013) note that their sequential Bayesian approach offers the advantages of shorter verification time during the analysis of spectra that contain low total counts, especially in complex radionuclide components.

In particular, Kirchner et al. (2009) disclose details of their method based on the Bayes' theorem. The Bayes theorem is written for the given problem as $f_A(a|X=x) = c(x)f_A(a)f_X(x|A=a)$ where $f_A(a)$ denotes the probability of the unknown A based on information available before the measurement is performed (the prior), $f_A(a|X=x)$ is the conditional probability of A under the condition that event x has been measured (the posterior), $f_X(x|A=a)$ is the conditional probability of measuring x given A, which constitutes the information gained from the measurement (a nuclear disintegration counting), and $c(x)$ is a normalization function. A is conceptualized as a random variable (with realisations a), which is in contrast to the conventional approach. Then the following expression for the probability P(S) of the activities is used, which is originated from a suspected radioactive source S,

$$P(S) = \int D(a_1, a_2, \dots, a_N)^{*} f_A(a_1, a_2, \dots, a_N)|X = (x_1, x_2, \dots, x_N)\, da_1 da_2 \dots da_N \tag{1}$$

where $f_A((a_1, a_2, \dots, a_N)|X = (x_1, x_2, \dots, x_N))$ denotes the joint probability density distribution of the posterior of the N isotopes established after a measurement, and $D(a_1,a_2,\dots,a_N)$ is a decision criterion with $D = 1$ if the activity ratios are consistent with a suspected source S and zero elsewhere.

Thereby for calculation of the probability, the researchers who used the conventional Bayesian approach described above have to utilise a number of trial functions $f_A(a|X=x)$, which are integrands in expression (1). Each next calculation requires a set of new such trial functions.

On the other hand, Zabulonov and Burtniak (2008) argued that measurements of low-level radioactive samples of nonorganic and organic origin can reliably be performed only by special dosimetric and spectrometric instrumentation. They also mentioned that the detection of a low-level radioactive source is complicated by the presence of an existing background radiation, because the intensity of radiation of materials contaminated with radioisotopes is hidden in the natural background and the Compton scattering. These peculiarities make the timely detection of low-intensive radioactive sources unlikely.

Functional capabilities of specialised technical equipment which is now used for radiation monitoring of materials, also do not allow one to realise the problem of detection and control of unauthorized movement of low-level radioactive materials that are characterized by occasional, short and slight excess signals above the background. Therefore the solution of such problems rather requires a conceptually new approach. The new approach to the measurement of low-level radioactivity must appreciate not only technical and functional capabilities of the equipment, but also the algorithmic basis with appropriate software based on Bayesian statistics. Such approach is presented in the given work.

2. Methods

The most significant contribution to the realization of maximum sensitivity of the technical equipment can be reached by using both the efficiency of detectors that record the radiation as well as the algorithm that processes available statistical data.

In practice among the methods of analysis of radiation, most used spectrometric approaches allow the identification of sources of radiation. The spectrometric method is based on the measurement of the energy spectrum of radiation sources. As a result of the measurement one obtains not a true gamma spectrum, but the so-called discrete spectrum of radiation, which is a histogram of the distribution of pulses by energy channels of the analyser in accordance with the channels' amplitudes. Using this spectrometer one can determine both the number of pulses and the energy of each pulse.

In spectrometric devices primary information comes in the form of a random sequence of pulses from the detectors that record radiation. In addition to the registration of useful events, such information contains a number of obstacle signals caused by background radiation, electromagnetic fields, etc. leading to uncertainty. Thus the main task, which must be implemented through the technical facilities, is to detect slight increases in the radiation fields in places of observation and control, as well as the identification of the appropriate sources.

Note we are talking about a multichannel scaling data, which we use in our practice, and not the much more common "differential pulse height" spectrum.

Mathematically, the problem of detection and identification of radiation can be described as follows. Suppose, in a time $t \in [0, T]$ of continuous observation of a source of radiation we record n radioactive particles. The measurement forms a selection $x = (x_1,x_2,\dots,x_n)$ of the general population and the allocation of each x_i are described by the Poisson distribution. The sample x is between fixed values X_0 and H_m. The chance of getting the measured value of x in the interval from X_0 to H_m is described by the distribution function (Janossy, 1965).

Let us denote the frequency of events of "getting radiation" in the bit interval $x_i \in (X_{j-1}, X_j)$ as N_j. A statistical series grouped in such a way is the so-called histogram – a statistical analogue of the distribution curve. If each bit interval is plotted in correspondence with the energy of the registered particle, we obtain the spectral distribution of energy radiation.

While monitoring and controlling the source of radioactivity by the method of spectrometric analysis it is necessary to distinguish the background spectrum from the signal or spectrum that belongs to the radiation source. That is, one should identify the sudden appearance of radiation of a

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