BETA-SPECTROMETRY OF ENVIRONMENTAL OBJECTS

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INTRODUCTION

The modest successes of an applied beta-spectrometry, comparing to lately achievements of alpha- and gamma-spectrometry, are caused, in main, by complexity of processing continuous beta-spectrums and difficulties connected with considering deformation of spectrums in samples with various physical-chemical parameters. By using not-traditional variant of beta-spectrometry proposed in this work, based on synthesis of principles of spectrometry, radiometry and mathematical modelling, it become possible to solve a problem of identification and definition of partial activities in the mixture of beta-emitting radio nuclides and the problem of instrumental determination of ^{90}Sr in food staff and environmental objects, even in presence of significant amounts of ^{137}Cs и ^{40}K.

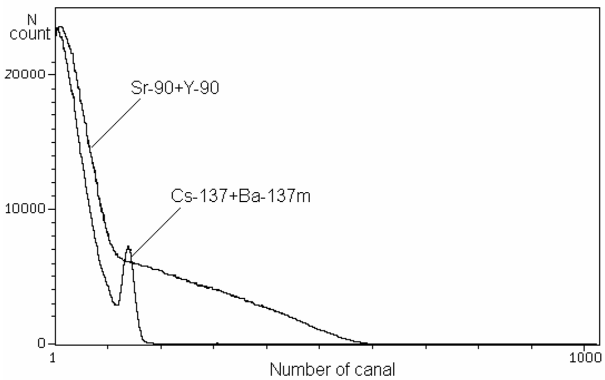

Figure 1. The experimental beta-spectrum of a "thin" sample of ^{137}Cs+^{137m}Ba and ^{90}Sr+^{90}Y

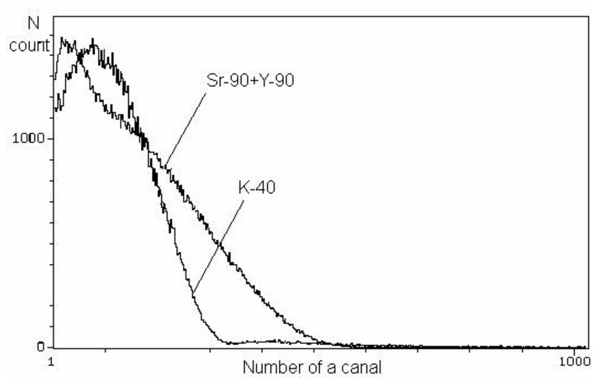

Figure 2. The experimental beta-spectrum of a "thin" sample of ^{90}Sr+^{90}Y и ^{40}K

ACTIVITY DETECTING METHOD

The key points of this method are registration of beta-spectra, distinguished from each other by the form and location on energy scale, with scintillation or semi conductor spectrometer and mathematical proceeding of spectrograms with use of the method of summation in energy range (ER). The typical beta-spectra ^{137}Cs+^{137m}Ba, ^{90}Sr+^{90}Y and ^{40}K, received on scintillation beta-spectrometer SEB-01-70 (manufactured by "Atom Komplex Prylad") are given in a figure 1-3. Spectrum of emanation of mix of **n** expected (a priori) nuclides in the sample is decomposed on spectra of standard mono-sources, which were certified for activity and measured in conditions as much as possible close to those on current measurement. Moreover, standard and samples being researched should have as much as possible common physical-chemical parameters: density, dispersity, effective nuclear number, etc. Mathematically it is approximated by linear combination of **n** given basic numerical functions and represents set of linear algebraic equations (SLAE):

$$\varepsilon_{11}X_1 + \dots\varepsilon_{1j}X_j\dots + \varepsilon_{1n}X_n = b_1 - b_1^{bg}$$

$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$$

$$\varepsilon_{m1}X_1 + \dots\varepsilon_{mj}X_j\dots + \varepsilon_{mn}X_n = b_m - b_m^{bg}$$

where:

ε_{ij} – sensibility (effectiveness) of beta spectrometer to radiation of ***j*** nuclide in ***i*** ER;

X_j – activity of ***j*** nuclide (component of vector X),

b_i, b_i^{bg} -count rates in ***i*** ER during measuring correspondingly of the sample and the background of the device.

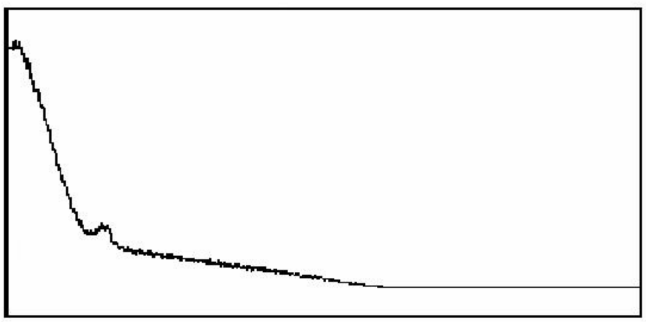

Figure 3. The experimental beta-spectrum of a "hot particle" from Chernobyl

Quantity of ER, their location and width are chosen considering specificity of radionuclides' spectra during concrete problem resolving, and they are optimised considering SLAE solution stability**.** Values of nuclide's activity are found by solving usually over determined set of equations, the quantity of which **m** is determined by the number of ER. This is so called inverse ill-conditioned mathematical problem of least-squares (LS). The method of suspended LS was used, what allowed significantly simplify propagation of uncertainties, shorten volume of calculations and raise the accuracy of solution.

Metrological supplying of the method

Not traditional way of solving the problem condition on new, not standard ways of its metrological maintenance. An original method of experimental search (determination) of real limits of detection of radioactivity on the basis of modelling spectra of mixture of radionuclides with given ratio of their activities was suggested.

In process of search of mentioned limits is used equation for relative statistical uncertainty of single measurement.

$$^{0,95}\delta_c X = \frac{2\sqrt{\sigma_x^2}}{x},$$

where: X – calculated activity of ***j*** radionuclide (vector of SLAE);

σ^2_x – dispersion of value X (diagonal ***j***-element of covariance matrix of solution inaccuracy).

Limits of detection received experimentally are compared to calculate according to known in metrological literature equations.

For characterising the shape of uninterrupted spectra of beta-emitting radionuclides are introduced the notions of spectral ratio and spectral part of radionuclides.

On this basis the method of reductive calibration of spectrometer by sensibility for measuring activity of nonequilibrium blend of $^{90}Sr + ^{90}Y$.

The suggested methods of solving metrological problems allow simplifying and reducing the price of metrology of applied beta-spectrometry.

APPLICATION

The method given above was used for creating scintillation beta-spectrometers SEB-01-70 and SEB-01-150 (photo 1 and 2), which are designed for instrumental detection of activities of ^{137}Cs, ^{90}Sr, ^{40}K and other β-emitting radionuclides in counting samples (prepared from samples of foodstuff and environmental objects) of different configuration: from "thin" after radiochemistry or like aspiration filters AFA RSP to "thick" weighing 160 grams per area of 170 sm^2, including point geometry for analysing "hot" particles.

Photo 1. SEB-01-150

Photo 2. SEB-01-70

Range of measurement of radionuclides' activities embrace 0.1 Bq÷10^4 Bq and allows to control main part of foodstuff instrumentally, and, while using needed conditions of concentration, also environmental objects (air, water, etc.) including contains of ^{90}Sr и ^{90}Y with violation of their radioactive balance.

The spectrometer registers β-radiation in energy ranges 100÷3500 keV, has energy resolution about 10%÷15% for conversion electrons ^{137m}Ba, has integral nonlinearity not less then 1% and temporary instability not more then 2%. As a detector is used scintillation plastic 6 mm÷8 mm thick and 40mm÷150mm in diameter depending on the problem being solved.

The stabilised power units together with programme stabilisation of multiplication factor allow to care out long-time measurements, providing high quality, which allows to use beta-spectrometers not only for controlling contents of radionuclides in the samples, but also for monitoring systems.

Using special methods of processing the results of measurement that are used in software «AKWin», that is supplied together with spectrometer, allowed to solve the problem of express control of not overcoming admissible (controlling) levels (Tab. 1).

Typical parameters of beta-spectrometers for different geometries of counted samples are given in table 2.

Table 1. Time for control for not overcoming admissible (controlling) levels

Spectrometer			SEB-01-70	SEB-01-150
Detector (∅ mm)			70	150
Volume of sample (l)			0.010	0,160
	Controlling levels (Bq/l, Bq/kg)		Time of control, s	
^{137}Cs	Meat	200	2600	55
	Fish	150	4500	100
	Milk	100	9800	180
	Fruit	70	19500	240
	Potatoes	60	26200	450
	Vegetable	40		600
^{90}Sr	Fish	35	11200	1050
	Meat, milk, vegetable	20		3000

Table 2. Some metrological parameters of beta-spectrometers.
**While counting sensibility of $^{90}Sr + ^{90}Y$ activity only one nuclide was taken into account.*

Spectrometer's parameters / Counting sample geometry	Energy range [MeV]	Background activity [imp/s]	Sensitivity (effectiveness) $\left[\frac{imp}{s \cdot Bk}\right]$			MDA ^{90}Sr [Bk] if t_m=5000 s	
			$^{137}Cs+^{137m}Ba$	^{40}K	$^{90}Sr+^{90}Y$	Rated (idealized)	Real on back ground 80Bk/kg ^{40}K and 70Bk/kg ^{137}Cs
filter (disk $60mg/20sm^2$)	0.1 ÷ 2.28	0.6 ÷ 1.0	0.300		0.79	0.08	
disk $\frac{1100mg}{20sm^2}$	0.1 ÷ 2.28	0.6 ÷ 1.0	0.140		0.64		
disk $\frac{5000mg}{30sm^2}$	0.1 ÷ 2.28	0.6 ÷ 1.0	0.085	0.22	0.44	0.13	
disk $\frac{10000mg}{30sm^2}$	0.1 ÷ 2.28	0.6 ÷ 1.0	0.062	0.13	0.29		
disk $\frac{15000мг}{30см^2}$	0.1÷ 2.28 0.2 ÷ 2.28 0.1 ÷ 1.3 0.2 ÷ 1.3	0.6 ÷ 1.0 0.5 ÷ 0.8 0.35 ÷ 0.6 0.3 ÷ 0.5	0.049 0.033 0.049 0.033	0.093 0.081 0.093 0.081	0.263 0.236 0.222 0.195	0.25	0.35
disk $\frac{30000mg}{30sm^2}$	0.1 ÷ 2.28	0.6 ÷ 1.0	0.038	0.049	0.097		
disk $\frac{160g}{170sm^2}$	0.2 ÷ 2.28	1.6 ÷ 2.0	0.025	0.027	0.068		

CONCLUSIONS

The universality of spectrometric method allows using beta-spectrometers for analysing various beta-emitting counting samples including native samples of foodstuff and environmental samples. At that the time of receiving the result shortens, comparing to method of radiochemistry, from 14 days to several hours. Wide applications of beta-spectrometers in the system of radiation control of Ukraine confirm the effectiveness of the proposed method.

Using methods of physical and chemical concentration significantly raise the sensibility of the method. The separate detection of ^{90}Sr и ^{90}Y is also possible, which allows to care out measurement of counting samples just after radiochemical separation of ^{90}Sr, not waiting for the status of equilibrium.