

GAMMA SPECTRUM ANALYSIS FOR ENVIRONMENTAL NUCLIDES

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Abstract: This paper is related to problems concerning thermoluminescence (TL) dating procedures. In our TL dating laboratory the annual dose rates are determined from the high-resolution gamma spectrometry measurements. For spectral investigations a Canberra spectrometer with the HPGe detector and Marinelli geometry (0.5 l capacity) with a shield is used. The method for spectral analysis of radioactivity is based on the Sampo90 computer program. The results of deconvolution of composite gamma-emission lines with strongly overlapping peaks are presented in detail. The typical peak table of environmental samples, which is used as a reference table in our dating procedure, is shown with the respective gamma-ray intensities. Identification procedure is discussed in the context of the natural nuclide and series activity calculation.

1. INTRODUCTION

The duration of the natural radiation exposure, i.e. the „age” of an object t , can be derived from the general equation

$$t = D_{TL} / D', \quad (1.1)$$

where D' is the dose rate of the radiation (usually annual dose) and the symbol D_{TL} denotes the total dose, as recorded by the thermoluminescence (TL) phenomenon. The evaluation of paleodose D_{TL} is possible if the relationship between TL signal strength and absorbed radiation dose from an artificial source is established (Aitken, 1985). The age determined this way is measured from the time of the last erasure of the accumulated natural TL. The major sources of radiation, exciting natural TL, originate from naturally occurring radioactive decay chains and elements: ^{232}Th , ^{238}U , ^{235}U series, ^{40}K , ^{87}Rb , and from cosmic radiation. For TL dating applications, the annual dose rate of radiation is divided into at least three contributions related to varying efficiency and absorption of alpha, beta and gamma radiation in a luminous mineral. In our laboratory the dose rate is determined from radioisotope concentration measurements performed by gamma spectroscopy (Oczkowski *et al.*, 1998 and 2000). The main advantage of this method is that partial matrix doses for alpha, beta and gamma radiation are determined directly and simultaneously from high-resolution gamma spectrum.

2. EXPERIMENTAL SET-UP

The gamma spectrometer, Canberra System 100, used in our laboratory consists of a comparatively low sensitivity HPGe detector (XtRa-GX1520 with 0.5 mm Al window). The resolution and the relative efficiency of the detector for 1332 keV (^{60}Co) are 1.82 keV and 19.4%, respectively. Standard Marinelli beakers (of 0.5 l capacity) are used as sample containers. The detector and preamplifier are placed inside the shield and cooled by liquid nitrogen from a vertical dipstick cryostat (7500SL). The integrated signal processor (model 1510) consists of a pulse height analysis system (Wilkinson ADC) to transform pulses, which are finally collected by a computer-based MCA with 2 MeV corresponding to 4096 channels.

The signal processor contains high-resolution spectroscopy amplifier with a pile-up rejector and a live-time corrector, which allows spectrum analysis nearly independent of system count rate. In our measurements the input pulse shaping is set to 4 μs . The dead time of a Wilkinson type AD converter with a clock rate of 100 MHz equals a fixed time of 1.5 μs (for peak detection) plus 0.01 μs multiplied by the channel number. Automatic correction for dead time is obtained by collecting data for a given live time. In general, the gross count rates for our samples are low; therefore the random summing corrections are neglected. Operating parameters of the system are governed and controlled by the computer program – Canberra System MCA 100. The spectral analysis is performed by widely used gamma analysis software – SAMPO90.

To minimise the amount of laboratory background in the measurement of environmental samples they should be measured in a shield. Lead is the shielding material of choice for this application. The lead X-ray fluorescence is minimised with a shield lining of tin and copper (Canberra 747 shield). The reduction of tin and copper and detector distance improves the counting efficiency. By combining higher efficiency, larger detector and a larger sample the highest count rate is achieved (Debertin and Helmer, 1988).

3. SPECTRUM ANALYSIS PROCEDURE AND NUCLIDE ACTIVITY CALCULATION

Sampo90 is a significantly improved commercial version of the original program developed by Routti and Prussin (Routti and Prussin, 1969 and Koskela *et al.*, 1981 and Aarnio *et al.*, 1988). As is usual in spectrum analysis, a peak table is initiated by a peak search procedure. The search algorithm applied by Sampo calculates peak channels and their uncertainties using a generalised second difference expression. The peak table may be then modified using the insert and drop option. Next, a peak fitting procedure is initiated. The use of a precalibrated shape for peak area determination is the basic feature of fitting algorithms. The shape parameters are determined at suitable intervals from some well-defined peaks. The algorithms for peak search and peak fitting allow resolving of complex multiplets in fully automatic or interactive modes of work.

The mathematical representation of a photopeak is a modified Gaussian with exponential tails on both sides superimposed on background continuum. The border between the background and the peak is assumed to be linear or parabolic. The area of the peak is defined as the sum of the counts above the peak background continuum. As a result, the following values are calculated and stored in the peak table: peak count area, parameters characterising the quality of fitting and respective uncertainties. Data from the detector efficiency file, time of measurements and peak areas allow one to calculate the intensity of the respective gamma line.

Since the laboratory background also contains the same photopeaks as the measured spectrum of the natural sample, an independent procedure, called peaked background subtraction, is also applied. A "pure background" spectrum resulting from prolonged measurement is collected. This spectrum is analysed normally and results are saved in the laboratory background file. In the nuclide identification procedure performed by Sampo90 those peaks are subtracted from the respective sample peaks and the resulting net areas are used in the activity calculations.

The nuclide identification procedure (Sampo 90 User's Manual, 1993) associates spectral lines with particular nuclides. It is performed by comparing the energy of each peak from the peak table with the energies of gamma lines of all nuclides in the library. The user specifies tolerance parameters and a gamma reference library name, which contains energies, gamma yield information and the

names of nuclides of interest. The identification library should be modified for specialised application, in particular for environmental radioactivity analysis. The selection algorithm gives a set of candidate nuclides. In this analysis, a working matrix is formed. Rows correspond to gamma peak energies and a column corresponds to a nuclide which is accepted if its value of total confidence index is higher than certain user definable threshold. The elements of the working matrix are the fractions of gamma emission per decay for the accepted nuclide, or otherwise zero.

The working matrix is repeatedly rearranged into determined or possibly overdetermined subsets. Each subset may contain multiple peaks of a single nuclide as well as gamma peaks from interfering nuclides (interference matrix). In any case the activities of nuclides are solved using the weighted linear squares method by minimising the following expression

$$\chi^2 = \sum_{i=1}^n \frac{(Y_i - \sum_{j=1}^m a_{ij} X_j)^2}{s_i^2}, \quad (3.1)$$

where n – the number of photopeaks (rows) in the subset, m – the number of nuclides (columns in interference matrix), a_{ij} – the fraction of j -th nuclide decays yielding i -th gamma peak, Y_i – the respective intensity of i -th peak from the peak table, X_j – the activity of j -th nuclide and s_i – the variance of i -th peak intensity.

Those nuclides whose standard deviations of the solution (X_j) are larger than the threshold or are negative are deleted from the working matrix. The respective peaks are moved to the list of unidentified peaks and activities are solved again. The nuclides corresponding to undetermined interference matrix are specially marked, since the solution is not unique.

This method of activity analysis takes all lines associated with a particular nuclide into consideration, and the interfering lines of different nuclides. It allows one to determine the percentage of the peak area used for the calculation of the particular nuclide activity. This information is included in the peak association report. For each identified nuclide the associated peak energy and the so-called peak usage are calculated. For a particular peak the total peak usage should be roughly 100%. Therefore, this value additionally tests the multiplet deconvolution.

The additional concept that underlines the spectroscopy application to activity measurement is the specific behaviour of radioactivity series and concerns the relationship between the activities of different members of the chain. In secular equilibrium the daughter activity is equal to that of the parent. Due to numerous geochemical and geophysical processes occurring continuously in nature, any nuclide with a long enough half-life may be separated from its parent. However, secular equilibrium is still likely to apply among certain subsets of nuclides in the natural chain, because of the absence of long half-lives within the subset. For this reason Murray and Aitken (1982 and 1988) introduced to TL dating subsets of series

reflecting the presumed potential for disequilibria. The measurement of the activity of any subset member gives the group activity. The activity calculated this way is assigned to the subset parent.

These subsets, along with the parent names and individual gamma-emitters and some remarks (see column Rem) concerning reasons for the build up of disequilibria (s-water soluble complexes, c-deposition, v- gaseous state) are shown in **Table 1**. Additional data taken from Browne and Firestone (1986) relate to the gamma spectrum, namely: the total number of stronger gamma rays (Lin Tot), the range of emission in keV, the energy and gamma emission probability of the main gamma emission line (keV and γ Eff%). Increasing number of spectral lines used in Eq. (3.1) supports an accurate calculation of the subset activity in comparison with the calculation for an individual nuclide. It improves the precision of activity calculation especially in the case of nuclides with minor peaks (e.g. from I and VII group) and low activity (actinium series).

Since, for an increasing number of nuclides in the library the probability for incorrect identification also increases, our libraries were optimised many times and selected to provide the spectrum analysis for natural nuclides. At present, in the library NAT20.ilf for 23 nuclides 186 entries are extracted. The library MUR8 includes 11 nuclide subsets with 169 lines.

4. UNWANTED EFFECTS AND COMPONENTS OF THE GAMMA-SPECTRUM

Several lines are usually deleted from the peak table after the spectral peaks have been fitted. In particular, the narrow region near 511 keV is excluded from our next analysis. Hence, the 510.7 keV γ -rays of Tl-208Th and 509.0 keV (Bi-214U) are not considered. Also the single- and double escape lines (SE and DE) related to the full-energy peaks are removed from the peak fit table (e.g. DE 1593 keV and SE 2104 keV from the generic 2615 keV emission of Tl-208Th). Moreover, in the lowest energy region of the spectrum a strong peak (24 keV) of X-ray fluorescence in the shielding material is also observed, but not analysed.

In the sample holder, such as Marinelli beaker, the matrix absorption has to be considered since, especially for γ -ray energies below 100 keV, there are appreciable absorption effects. However, no corrections have to be applied if a sample is measured relative to the standard of the same matrix and geometry. In such a case the self-attenuation effects are fully described by the spectral dependence of detector efficiency.

In the natural decay chain spectrum there are peaks originating from gamma transitions in cascade. For nuclides emitting two or more photons in sequence, within the spectrometer resolving time, coincidence summing

Table 1. Simplified decay schemes, nuclide groups and selected data.

(Parent Group)	Z	Nuclide	Lin Tot	Rem	Range [keV]	Main Line [keV]	γ Eff [%]
Uranium (37.3Bq/kg)							
I	92	U-238U	2	s	13, 16	16.2	4.2
	90	Th-234U	6		13 - 113	92.6	5.4
	91	Pa-234mU	2		766, 1001	1001.0	0.7
II	92	U-234U	0	s	-	-	-
III	90	Th-230U	1	c	68	67.7	0.4
IV	88	Ra-226U	2		83, 186	186.1	3.3
(Rn-222)	82	Pb-214U	18	v (Rn)	13 - 840	351.8	37.2
V	83	Bi-214U	40		79 - 2119	1764.0	15.9
VI	82	Pb-210U	3	c	13-47	46.5	4.1
Thorium (41Bq/kg)							
(Th-232)	88	Ra-228Th	4		12 - 19	12.7	4.4
VII	89	Ac-228Th	30		13 - 1630	911.2	29.3
	90	Th-228Th	4		12 - 84	84.3	1.2
	88	Ra-224Th	1		241	240.8	3.9
(Rn-220)	82	Pb-212Th	9	v (Rn)	13 - 300	238.5	43.6
VIII	83	Bi-212Th	5		12 - 1621	727.2	6.7
	81	Tl-208Th	7	br 36%	73 - 860	583.0	86.3
Actinium (1.7Bq/kg)							
IX	92	U-235Ac	6	s	13 - 205	185.7	53.7
	90	Th-231Ac	7		13 - 89	16.6	37.1
X	91	Pa-231Ac	8	c	13 - 330	300.0	2.4
	90	Th-227Ac	12		12 - 330	235.9	11.3
XI	88	Ra-223Ac	12		14 - 338	269.4	13.6
	86	Rn-219Ac	2	v	271, 402	271.1	9.9
	82	Pb-211Ac	4		404 - 832	404.8	3.8
Potassium (310Bq/kg)							
XII	19	K-40	1		1461	1460.8	10.7

Table 2. Peak fit table for typical quartz sample with nuclide and multiplet analysis.

No Ln Mltp	[keV] (exp)	ArCo x.01	Gps (exp)	Nat20 Nuclide	[%] Us (exp)	Mur8 Subset Parent	[%] Us (exp)
4 Md	19.42	29	2.1	Ac-228Th	13.29	Th-232Th	13.91
				Th-234U	2.67	U-238U	2.89
				(Th-231Ac)	-	U-235Ac	1.23
7	27.35	22	0.3	Pa-231Ac	28.76	Pa-231Ac	13.65
8	39.89	15	<.1	Bi-212Th	109.00	Rn-220Th	94.44
9	46.58	158	0.5	Pb-210U	99.99	Pb-210U	100.02
*10	50.11	13	<.1	Th-227Ac	80.08	Pa-231Ac	92.05
11	53.26	35	0.1	Pb-214U	72.47	Rn-222U	68.99
12	63.34	161	0.4	Th-234U	87.16	U-238U	94.59
13	72.90	54	0.1	Tl-208Th	48.34	Rn-220Th	50.11
14 MA	74.89	497	1.2	Pb-212Th	61.01	Rn-220Th	69.57
				Tl-208Th	7.33		
				Pb-214U	41.68	Rn-222U	39.68
15 MB	77.15	723	1.7	Pb-212Th	68.29	Rn-220Th	69.39
				Pb-214U	46.87	Rn-222U	44.62
16	81.13	7	<.1	(Th-231Ac)	-	U-235Ac	19.42
17 MC	84.25	91	0.2	Ra-223Ac	123.72	Ra-223Ac	122.70
				Th-228Th	52.65	Th-232Th	44.76
				Tl-208Th	17.48	Rn-220Th	18.12
				Ra-226U	9.25	Ra-226U	11.39
				Ra-223Ac	20.51	Ra-223Ac	20.34
18 MD	87.26	245	0.5	(Th-231Ac)	-	U-235Ac	14.25
				Pb-212Th	74.06	Rn-220Th	75.25
19 ME	89.99	142	0.3	Pb-214U	50.60	Rn-222U	48.17
				Ac-228Th	67.44	Th-232Th	67.55
				Pb-212Th	38.21	Rn-220Th	38.82
				Pb-214U	26.08	Rn-222U	32.27
				Bi-214U	7.28		
MF1 20	92.59	194	0.4	(Th-231Ac)	-	U-235Ac	1.07
MF2 21	93.34	129	0.3	Th-234U	128.11	U-238U	139.03
*22	94.68	21	<.1	Ac-228Th	111.89	Th-232Th	112.07
23	99.49	26	<.1	Ra-223Ac	24.05	Ra-223Ac	23.86
MG 24	105.42	26	<.1	Ac-228Th	135.41	Th-232Th	135.63
MH *25	108.99	10	<.1	Ac-228Th	199.11	Th-232Th	199.44
*26	112.90	8	<.1	Ac-228Th	175.20	Th-232Th	175.48
27	115.25	12	<.1	Th-234U	63.50	U-238U	68.91
28	129.11	57	0.1	Pb-212Th	128.60	Rn-220Th	130.65
29	143.95	28	<.1	Ac-228Th	121.83	Th-232Th	122.03
MI				U-235Ac	92.00	U-235Ac	75.70
				Ra-223Ac	8.83	Ra-223Ac	8.76
30 MJ	154.09	25	<.1	Ac-228Th	69.31	Th-232Th	69.42
				Ra-223Ac	10.13	Ra-223Ac	10.05
*31	163.47	7	<.1	U-235Ac	92.71	U-235Ac	76.28
32 MK	186.00	166	0.5	Ra-226U	42.61	Ra-226U	52.49
				U-235Ac	57.40	U-235Ac	47.23
*33	205.26	11	<.1	U-235Ac	52.90	U-235Ac	43.53
34	209.32	74	0.2	Ac-228Th	92.51	Th-232Th	92.66
*35	235.95	17	<.1	Th-227Ac	66.42	Pa-231Ac	76.34
36	238.69	794	3.3	Pb-212Th	86.72	Rn-220Th	88.10
ML1 *37	241.09	79	0.3	Ra-224Th	100.00	Th-232Th	71.75
ML2 38	242.07	135	0.5	Pb-214U	92.90	Rn-222U	88.44
*39	256.09	4	<.1	Th-227Ac	143.00	Pa-231Ac	164.36
*40	258.90	9	<.1	Pb-214U	99.26	Rn-222U	94.50
MM1 *41	269.36	10	<.1	Ra-223Ac	38.46	Ra-223Ac	38.15
MM2 42	270.30	54	0.2	Ac-228Th	92.02	Th-232Th	92.17
MM3 *43	271.35	8	<.1	Rn-219Ac	109.70	Ra-223Ac	35.80
44	277.44	31	0.1	Tl-208Th	103.91	Rn-220Th	107.72
45	295.28	287	1.4	Pb-214U	96.03	Rn-222U	91.42
46 MN	300.19	51	0.2	Pb-212Th	81.90	Rn-220Th	83.21
				Pa-231Ac	9.19	Pa-231Ac	8.21
				Th-227Ac	3.35		
*47	302.49	4	<.1	Pa-231Ac	111.17	Pa-231Ac	51.45
48	328.06	38	0.2	Ac-228Th	99.19	Th-232Th	99.35
*49	330.23	2	<.1	Pa-231Ac	117.56	Pa-231Ac	171.09
MO				Th-227Ac	100.40		
*50	332.24	6	<.1	(Ac-228Th)	lff	(Th-232Th)	lff
51 MP	338.37	146	0.8	Ac-228Th	89.90	Th-232Th	90.04
				Ra-223Ac	0.44	Ra-223Ac	0.44
52	351.97	467	2.8	Pb-214U	96.74	Rn-222U	92.10
53	389.12	7	<.1	Bi-214U	63.98	Rn-222U	65.26
*54	401.69	5	<.1	Rn-219Ac	88.21	Ra-223Ac	28.79
*55	405.07	4	<.1	(Pb-211Ac)	-	Ra-223Ac	20.96
56	409.53	20	0.1	Ac-228Th	95.83	Th-232Th	95.99
57	463.06	39	0.3	Ac-228Th	94.53	Th-232Th	94.68
58	480.39	4	<.1	Pb-214U	80.35	Rn-222U	76.50
59	562.49	6	<.1	Ac-228Th	104.18	Th-232Th	104.35
60	583.25	215	2.0	Tl-208Th	99.73	Rn-220Th	103.38

61	609.38	329	3.2	Bi-214U	98.13	Rn-222U	100.10
62	665.64	10	0.1	Bi-214U	99.80	Rn-222U	101.80
63	727.36	46	0.5	Bi-212Th	96.62	Rn-220Th	83.72
64	755.38	6	<.1	Ac-228Th	117.42	Th-232Th	117.61
*65	763.39	4	<.1	Tl-208Th	81.11	Rn-220Th	84.08
*66	766.44	5	<.1	Pa-234mU	48.03	U-238U	20.52
MQ				Pb-214U	9.68	Rn-222U	9.22
				(Pb-211Ac)	-	Ra-223Ac	1.64
67	768.44	28	0.3	Bi-214U	98.15	Rn-222U	100.13
68	772.29	9	0.1	Ac-228Th	61.82	Th-232Th	61.92
69	785.82	11	0.1	Bi-212Th	61.66	Rn-220Th	53.42
MR				Pb-214U	57.30	Rn-222U	69.88
70	795.02	24	0.2	Ac-228Th	96.61	Th-232Th	96.77
71	806.32	6	<.1	Bi-214U	104.81	Rn-222U	106.92
72	835.82	7	<.1	Ac-228Th	120.88	Th-232Th	121.08
*73	840.03	6	<.1	Ac-228Th	79.67	Th-232Th	79.80
74	860.67	25	0.3	Tl-208Th	83.77	Rn-220Th	86.84
75	904.32	4	<.1	Ac-228Th	106.73	Th-232Th	106.90
76	911.32	136	1.8	Ac-228Th	101.00	Th-232Th	101.16
77	934.21	15	0.2	Bi-214U	104.67	Rn-222U	106.77
MS				Ac-228Th	96.78	Th-232Th	96.94
79	969.09	79	1.1	Ac-228Th	98.05	Th-232Th	98.21
80	1001.20	7	0.1	Pa-234mU	143.40	U-238U	61.28
81	1120.47	62	1.0	Bi-214U	108.23	Rn-222U	110.41
82	1155.27	7	0.1	Bi-214U	105.05	Rn-222U	107.16
83	1238.32	23	0.4	Bi-214U	98.80	Rn-222U	100.79
84	1281.20	7	0.1	Bi-214U	77.74	Rn-222U	79.30
85	1377.83	16	0.2	Bi-214U	91.16	Rn-222U	92.99
86	1385.77	3	<.1	Bi-214U	90.99	Rn-222U	92.82
87	1401.54	5	0.1	Bi-214U	91.87	Rn-222U	93.72
88	1408.21	8	0.1	Bi-214U	110.45	Rn-222U	112.67
89	1460.99	1380	28	K-40	100.00	K-40	100.00
90	1496.14	4	<.1	Ac-228Th	90.88	Th-232Th	91.03
91	1509.42	7	0.1	Bi-214U	104.55	Rn-222U	106.65
92	1538.89	2	<.1	Bi-214U	68.56	Rn-222U	69.94
93	1543.70	2	<.1	Bi-214U	63.59	Rn-222U	64.87
94	1588.34	10	0.2	Ac-228Th	111.01	Th-232Th	111.20
95	1620.98	4	<.1	Bi-212Th	123.14	Rn-220Th	106.69
96	1630.82	6	0.1	Ac-228Th	100.77	Th-232Th	100.93
97	1661.57	4	<.1	Bi-214U	93.36	Rn-222U	95.24
98	1729.75	10	0.2	Bi-214U	98.62	Rn-222U	100.60
99	1764.68	51	1.1	Bi-214U	100.63	Rn-222U	102.65
100	1847.63	7	0.1	Bi-214U	88.12	Rn-222U	89.89
101	2118.99	3	<.1	Bi-214U	86.58	Rn-222U	88.32

Notes:

* = inserted peak; if = data not present in the library; (Th-231Ac) = unidentified nuclide (brackets)

will occur. In particular, many cascade photons are emitted in the decay of ^{214}Pb , ^{214}Bi from uranium and ^{208}Tl from thorium series, i.e. for multienergy gamma ray emitters, which are very convenient for spectral analysis. The most important result of cascade is the loss of counts from the full energy peak (sum loss). The sum gain effect is strong mainly because of crossover transitions. Procedures developed to correct the spectrum for this effect require considerable experimental and numerical effort (e.g.: Debertain and Schötzig, 1979; Arnold *et al.*, 2000 and Piton *et al.*, 2000), despite the simplified procedures (de Felice *et al.*, 2000).

However, if any count is lost from one peak area due to the summing effect of another in coincidence, then it is likely that this process enriches the number of counts in over-crossing line which belongs to the same nuclide. Since the identification procedure calculates the isotope activity using the least-squares best fit to all spectral data corresponding to a particular nuclide therefore, at least to some extent, the coincidence effects are averaged by this routine procedure. Of course the above discussion assumes that one analyses all of the contributing gamma lines, not only the main peak.

In fact, the best solution to the problem of coincidence summing corrections is to calibrate the detector with a standard source of the nuclide dispersed in a matrix under study. In that case, coincidence-summing effects need not be considered (Debertain and Schötzig, 1979 and Debertain and Helmer, 1988). For reasons mentioned above, in what follows, we confine ourselves strictly to the efficiency calibration procedure performed with a radioactive ore diluted in quartz.

5. SPECTRAL COMPLEXITY. COMPOSED LINES

Spectra taken from environmental samples are very complex. The low energy range of spectrum (15 - 100 keV) shows the greatest complexity. In this region there are spectral multiplets with a large height ratio among many interfering components. Moreover, the low energy photons are of different origin, related to the X or gamma isomeric transitions. The shape of an X-ray peak is different from that of a gamma due to different natural widths. For these reasons the low energy spectral multiplets are especially difficult to resolve. However, the mixed fitting mode allows some peaks to be inserted, shaped and

fixed while other ones are floating during fit calculations. Despite the automated methods included in Sampo90 the user should verify the peak table for each multiplet region and frequently adjust it manually before accepting results to a permanent record.

In order to specify multiplets, which are characteristic for gamma spectra of natural radioactivity, the gamma spectra for three types of samples (called Nat, Rad and Thor) were measured and analysed. Because of different activity the observed shapes of the composed peaks are also different, therefore the deconvolution procedure is substantially simplified. To test the isotope composition related to the multiple peaks in a numerical way, fundamental data concerning gamma energy and efficiency emission of natural nuclides were extracted from the literature. Data were taken mainly from the Table of Radioactive Isotopes (Brown and Firestone, 1986). Using the detector efficiency and nuclide activity it was possible to simulate a count rates for different composed peaks to confirm experimentally registered spectra (Oczkowski, 2001).

Table 2 shows the results of analysis performed for gamma spectrum measured in our laboratory for a typical quartz sample (Ka13) from Kępa Kujawska (this sample is used as a reference sample to test the spectrometer system stability. The multiplets (not “pure” lines) are denoted here as: Md for the lowest energy region and MA, MB,... MS for the remainder. In the experimental part of the table the line numbers (NoLn), taken from the peak fit report, are given together with the experimental peak energy (keV) and total number of counts (ArCo – full peak area). The measured gamma intensity (Gps) is the result of dividing the peak area by the absolute detector efficiency. The last columns show the nuclide and peak usage values (in per cent) taken from the identification and activity analysis report performed by Nat20 and Mur8 library, respectively. Three initial peaks are omitted since the lowest region of spectrum is exceptionally sensitive to the matrix and the radionuclide composition.

Despite the fact that the observed shapes and location of composite peak depend on the concentration of nuclides in a particular sample, the measured peak energies shown in **Table 2**, within less than 0.5 keV, are in agreement with the known value for the reported nuclide. This table is used as a comparative table in our routine analysis of gamma spectrum of natural samples.

6. FINAL REMARKS

In routine spectral analysis some of the complex lines are decomposed not only by the fitting algorithm but also by the activity calculation procedure when the peak area has contribution to more than one nuclide. In this case one needs all of the emission probabilities of the gamma rays associated with each nuclide that might contribute to this line. Hence the peak table and nuclide library have to be complete and consistent. Otherwise activity analysis may be erroneous and sometimes it is even more effective to delete the composed peak from the table than try to interpret it.

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