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Potassium compounds for gamma spectrometer efficiency verification

E. Eren Belgin*, G.A. Aycik

Mugla Sitki Kocman University, Faculty of Science, Department of Chemistry, Mugla 48000, Turkey

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ABSTRACT

Now-a-days several standard and well calibrated radioactive sources are available for gamma spectrometer efficiency calibration but at some situations, like lack of standard calibrators, in need of verification of standards or preparation a standard with the same properties with the interested sample, ^{40}K is a cheap and easily available radioisotope that could be used. In this study, eighteen different inorganic potassium compounds that have different potassium abundances, types of elements, densities and particle sizes were studied as efficiency verification sources. Gamma spectrometric measurements were performed and it was dawn on the compounds which have low density, low molecular weight and high potassium abundance showed higher ^{40}K activity concentration. It was also indicated that potassium abundance of the compound was the dominant property in these parameters. The activity concentrations were also calculated theoretically and results were in good agreement with the experimental results. Thus it was reported that the ^{40}K compounds with these properties are much suitable for to use as verifying sources or gamma calibrators.

1. Introduction

Gama spectrometry is the most widely used technique for measurement and analysis of radioactivity of environmental samples. High purity germanium (HPGe) detectors are preferred for gamma spectrometers due to its high resolution in spite of their low count efficiencies changing due to crystal volume. Thus the efficiency calibration associated with many parameters like sample mass, density, particle size, chemical composition, counting angle, detector-sample positioning etc. becomes significant for accuration of the results. Experimental efficiency calibration is in need of large number of primary standard sources at numerous energies of very similar geometrical dimensions, source configurations and chemical-physical specifications of the sample of interest. This method is based on comparison of sample peak area of interested energy and standard source peak area at the same energy. But the primary standard sources, if available, are costly and would need to be renewed, especially when the included radionuclides have short half-lives. Availability of a standard source for all possible samples with different properties (density, geometry etc.) is also very costly even if impossible in some situations. Thus when primary standards are not available, needed to verified or in the case of preparing a sample proprietary standard some potassium containing chemical compounds that are cheap and easily available could be used as radioactive sources due to their radioactive ^{40}K radioisotope content.

Potassium is the most common naturally occurring radioactive element on earth, with average abundance of 2.58% (Israel Science and Technology (2014)). There are three naturally occurring potassium isotopes as ^{39}K, ^{41}K and ^{40}K with abundance of 93.26%, 6.73% and 0.0118%, respectively. Only ^{40}K is radioactive in these isotopes with a half-life of 1.277×10^9 years and has two types of disintegrations. One is beta (β^-) decay that ^{40}K disintegrates to ^{40}Ca and other is electron capture (EC) that ^{40}K disintegrates to ^{40}Ar, Fig. 1. In β^- decay of ^{40}K the maximum energy is 1.311 MeV with 89.3% decay constant while the EC decay gives rise to the well-known 1460.8 keV gamma ray that is seen ubiquitously in all background gamma spectra with decay constant of 10.55% (Handbook of Chemistry and Physics (1980)). Thus, ^{40}K is an important radioisotope to be used as verifying source for efficiency calibration of gamma spectrometer due to its easy provision, cheapness and having a clear photo peak at 1460.8 keV.

The activity concentration of ^{40}K in natural potassium varies between 27.33 and 31.31 Bqg^{-1}(Samat et al. (1997)). Thus potassium compounds could be used to prepare sample compatible standards for efficiency calibration of gamma spectrometer in the default of primary standards. In this situation, calculated activity from the ^{40}K isotope can account for the observed activity in the sample. In order to determine accuration of the measured gamma activity for a sample containing potassium, the comparison of measured and calculated activities across a range of potassium concentrations for some inorganic potassium compounds have to be done.

Aim of this study was to measure ^{40}K activities of several chemical compounds having different potassium abundances, compositions, densities and to investigate effect of these parameters on the measured

* Corresponding author.
E-mail address: ebelgin@mu.edu.tr (E. Eren Belgin).

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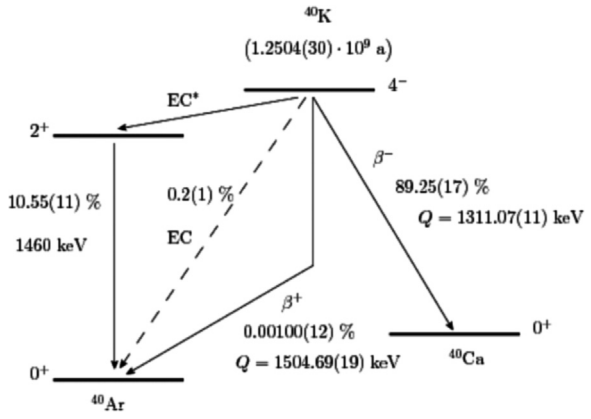

Fig. 1. Decay scheme of ^{40}K (INSPIRE (2016)).

activity concentration of ^{40}K. The theoretical and experimental activity concentrations of the compounds were compared at the end of the measurements and the most suitable potassium containing compounds for usage as standard/verifying sources and for preparation of a sample proprietary standard sources were reported.

2. Experimental

2.1. Sampling

In this work, eighteen different potassium containing chemical compounds with different physical properties were analysed, Table 1. All samples were sieved to < 37 μm particle size to eliminate particle size effect on the results. The mass of the dry potassium salts was measured by the use of a five-digit analytical balance (Sartorius CPA 2250) and the uncertainty in the mass was determined as the standard error on the mean of five readings.

Polypropylene sample tubes with 10 mm diameter and 70 mm height were used for measurements. Compounds were filled to sample tubes up to 25 mm sample height that is equal to the height of the standard calibration sources used in the study. Thus the geometrical arrangement differences between the samples and standard sources that could affect efficiency of the detector were eliminated for experimental activity concentration calculations.

2.2. Radiometric parameters and procedure

In the study an ORTEC HPGe well-type detector with a crystal volume of 110 cm^3 was used for experimental measurements. The detector had nominal FWHM resolutions of 0.90 keV at 122.07 keV and 1.92 keV at 1332.5 keV, and the resolution of ^{60}Co at 1.33 MeV was 3.78 keV. The detector was connected to conventional electronic components with an amplifier gain of 21.25 and a shaping time of 6 μs. The detector had a crystal height and diameter of 50 mm and 75 mm, respectively. The well depth was 54 mm and the diameter was 33 mm. The detector was shielded with electrolytic copper of 0.5 cm and lead of 10 cm. The determination of potassium compounds' performances on efficiency was based on comparison of gamma measured activity concentrations with theoretically calculated values.

2.2.1. Determination of experimental activity concentrations

The measurements were done for both sample and the background matrix (sample-like matter) to avoid extraneous background counts in the experimental activity spectra of ^{40}K. Commercial powdered potassium-free glucose ($C_6H_{12}O_6$) was used as the background matrix and it was provided in the same specifications as the samples and measured in the same geometry. The tubes were placed into the detector well and all measurements were conducted for a sufficiently long period of time that the statistical uncertainties in the peak areas were below < 2% (40,000 s for samples, 213,000 s for background matrix). Measurements were performed for three consecutive data acquisition. After the individual manual selection of the data points, the photo peak of interest (1460.8 keV) were processed by the ORTEC Omnigam B30 data acquisition analysis software for net peak area of the photo peaks (total counts). After evaluation of the total counts recorded activity concentrations of the samples were calculated via Eq. (1).

$$A_i = \frac{cps}{\varepsilon \times f_\gamma \times m_s} \quad (1)$$

where cps is the background subtracted net counting rate (counts per second) of the prominent peak at 1460.8 keV, ε is the full energy peak efficiency at 1460.8 keV, f_γ is the absolute photon emission probability of gamma-decay of ^{40}K at 1460.8 keV energy and m_s (kg) is the mass of the sample.

The cps values of the samples were calculated after determination of net total counts of samples and background as it is mentioned above. Then the total counts determined were divided to measurement time and background counts were subtracted from sample counts thus cps value of the samples were determined. The f_γ value in Eq. (1) was

Table 1
Properties of used potassium compound samples.

Sample Number	Compound Name	Formula	Origin	Purity (%)	Molecular weight (gmol^{-1}) Israel Science and Technology, 2014	%Potassium (w/w)	Density (gml^{-1})
1	Potassium iodide	KI	Kimetsan	99.6	166.0028	23.5528	1.81
2	Potassium carbonate	K_2CO_3	Horasan	98	138.206	56.5798	1.08
3	Potassium oxalate mono hydrate	$K_2C_2O_4{\cdot}H_2O$	Horasan	99.5	184.231	42.4448	1.21
4	Potassium thiocyanate	KSCN	Kimetsan	97.18	97.18	40.23	0.90
5	Potassium cyanide	KCN	Horasan	97	65.116	60.044	0.79
6	Potassium acetate	CH_3COOK	Panreac	99	98.143	39.838	0.67
7	Dipotassium hydrogenphospate	K_2HPO_4	Riedel-de-Haen	99	174.1759	44.8952	0.96
8	Potassium chromate	K_2CrO_4	Merck	99.5	194.190	40.2680	1.61
9	Potassium chloride	KCl	Kimetsan	100	74.551	52.445	1.07
10	Potassium fluoride	KF	Labosi	100	58.0967	67.2987	1.24
11	Potassium metabisulfide	$K_2S_2O_5$	Riedel-de-Haen	96	222.31	35.174	1.24
12	Potassium bromide	KBr	Riedel-de-Haen	100	119.002	32.8551	1.58
13	Potassium periodate	KIO_4	Fluka	98	230.0004	16.9992	1.54
14	Potassium sulphate	K_2SO_4	Horasan	99.5	174.25	44.875	1.32
15	Potassium dichromate	$K_2Cr_2O_7$	Iron	99.5	294.184	26.5808	1.56
16	Potassium permanganate	$KMnO_4$	Kimetsan	99	158.0339	24.7405	1.37
17	Potassium iodate	KIO_3	Merck	99.5	214.0010	18.2701	2.26
18	Potassium bromate	$KBrO_3$	Merck	99.6	167.001	23.4121	1.42