

⁴⁰K measurement to determine the total potassium content

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Total potassium concentration has been determined measuring the 1461 keV gamma-rays emitted during the ⁴⁰K decay. Using KCl salt set of ⁴⁰K sources were prepared as standards and were used to characterize a NaI(Tl) γ -ray spectrometer. To test the procedure two unknown sources were used, for these ⁴⁰K mass were determined as well as the specific activity. The rate of change between the mass of K and the net count rate under the 1461 keV photopeak is constant, allowing determining the mass of K measuring the γ -ray emitted during ⁴⁰K decay. Specific activity was approximately 31 Bq/g being consistent with values reported in literature.

Keywords: ⁴⁰K standards; γ -ray spectrometry; K content.

Se determinó la concentración de potasio total a través de la medición de los rayos gamma de 1461 keV emitidos en la desintegración del ⁴⁰K. Un conjunto de estándares se prepararon con sal de KCl y se usaron para caracterizar un sistema espectrométrico para rayos gamma que usa un centellador de NaI(Tl). Para probar el procedimiento se usaron dos fuentes para las que se determinó la masa de ⁴⁰K y la actividad específica. La razón de cambio de la masa de K y las cuentas netas bajo el fotopico de 1461 keV es constante, esto permite determinar el total de K a través de medir los rayos gamma emitidos durante el decaimiento del ⁴⁰K. Se encontró que la actividad específica del ⁴⁰K es aproximadamente 31 Bq/g que es consistente con el valor reportado en la literatura.

Descriptores: ⁴⁰K; espectrometría rayos γ ; K total.

PACS: 07.85.-m; 07.85.Nc; 06.60.-c

1. Introduction

Background radiation has two sources, one produced by the planet and another from cosmic radiation. On Earth radiation is originated naturally and from anthropogenic activities [1].

In the environment radiation is produced during ²³⁸U, and ²³²Th decay series, and the simple decay series of ⁴⁰K [1]. Worldwide the average values of soil activity are: 32 Bq/kg for ²²⁶Ra, 45 Bq/kg for ²³²Th and 420 Bq/kg for ⁴⁰K [2].

Gamma radiation from radionuclides on the ground can be an important source of exposure to radiation. Its assessment is very complex due to a large number of environmental factors affecting the flow of gamma photons in the air from soil [3-5].

The radionuclides in the food chain are a source of internal exposure [6, 7]. There are 17 elements that are indispensable for growth and reproduction of living beings, one of these is the potassium [8], particularly K⁺ is one of the 5 essential ions of all species in addition to Ca⁺², Na⁺, Mg⁺², and Cl⁻ [9]. However, low or excessive potassium intake has an adverse effect on the body's metabolism [6].

The K exists abundantly at the earth's crust being present in materials used in construction [1], and in sand [10]. K has three isotopes, 0.0117% is ⁴⁰K which is radioactive contributing to background radiation interfering with measurement process. ⁴⁰K is incorporated to the body through consumption of food and water [10] being the most abundant radioactive substance in human body [11]. ⁴⁰K half-life

is 1.3×10^9 years; the biological and effective half-life is 58 days [12]. Once in the body the ⁴⁰K contributes to internal dose, therefore it is important to determine the amount of K in food and liquids that are ingested [8], however due to its presence in the environment its measurement is challenging.

⁴⁰K decays to ⁴⁰Ca in 89.3% through β -emission, 10.3% decays by electron capture and the emission of 1.456 MeV γ -ray. Due to secular equilibrium between ⁴⁰K and ⁴⁰Ca the gamma-ray emission rate is proportional to the amount of ⁴⁰K present in a sample, thus the total amount of K can be estimated measuring the γ -rays produced in the decay of ⁴⁰K [13].

The aim of this work is to prepare and characterize a set of ⁴⁰K standards to be used with a γ -ray spectrometer, with a NaI(Tl) scintillator, to determine total amount of K.

2. Materials and Methods

2.1. Preparation of standards

One of the problems associated with the measurement of ⁴⁰K by measuring the γ -ray emitted during the ⁴⁰K decay is the efficiency calibration of the spectrometer, because there is not standards with pure ⁴⁰K, normally a compound with ⁴⁰K is used. In this study, a set of standards were prepared using potassium chloride. The salt used was 99.3% pure from J.T. Baker®.

TABLE I. Mass of KCl in each standard.

Standard	Mass _{KCl} [g]
STD-0	0.0000
STD-1	0.5444 ± 0.0001
STD-2	1.0817 ± 0.0001
STD-3	3.0073 ± 0.0001
STD-4	6.1850 ± 0.0001
STD-5	10.0166 ± 0.0001



FIGURE 1. Aluminum container and final ⁴⁰K standard

Six cylindrical ⁴⁰K sources were manufactured using KCl salt, each source was prepared using different mass of KCl, in Table I is shown the KCl mass in each source.

The KCl salt was weighed on an analytical balance Ohaus® Model Analytical Plus. The KCl salt was placed on the bottom of the aluminum container; the cylinders were filled up to the top with boric acid. To avoid the loss of salt during sources handling and to keep the source volume constant, each container was pressed using 2800 kg/cm². The six ⁴⁰K sources are 3 Ø × 0.5 cm²; in figure 1 is shown an image including the aluminum container and one of the sources used as ⁴⁰K standard.

2.2. Spectrometric system

Standards were measured with a gamma spectrometer system with a 7.62 Ø × 7.62 cm² NaI(Tl) located inside a lead shield, to reduce the background radiation. The γ-ray spectrometer was characterized using ⁶⁰Co, ¹³⁷Cs and ²²Na calibrated sources. Weighted least-squares regression [14] was used to obtain fitted functions for energy and efficiency calibration.

The pulse-height spectrum for each source was measured during 1800 s, for each source the net count rate under the ⁴⁰K photopeak, N, was related to KCl, K and ⁴⁰K mass. For

the mass of K, m_K, it was assumed that the rate of change between the K mass and the net count rate in the photopeak is constant, α, as shown in Equation (1).

$$\frac{d m_K}{d N} = \alpha \tag{1}$$

Equation (1) general solution is shown in equation (2).

$$m_K(N) = \alpha N + \beta \tag{2}$$

Once the mass of K is determined, ⁴⁰K mass and activity were calculated.

To test the procedure a double-blind experiment was carried out, where two sources containing KCl were used to determine the mass of KCl, K as well as the mass and activity of ⁴⁰K.

3. Results

In Figure 2 are shown the pulse-height spectra in the region for the ⁴⁰K photopeak produced by standard 0, 3 and 5.

In figure 2 can be noticed that photopeak increases as the KCl mass raises being in agreement with equation (1).

The relationship between net count rate under the ⁴⁰K photopeak and the mass of K in each standard is shown in figure 3.

In figure 3 is also included the fitted function shown in equation (4), where N is the net count rate in counts/s and M_K is the mass of K in grams.

$$M_K(N) = - (10.79 \pm 1.70) + (5.21 \pm 0.69) N \tag{4}$$

The correlation coefficient is r² = 0.9495. The likelihood of a statistically significant difference between experimental values and those obtained with equation (4) is less than 0.0049.

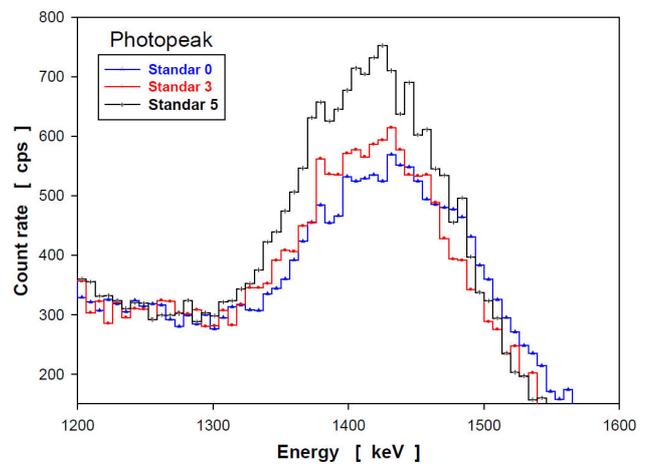


FIGURE 2. Pulse-height spectra.

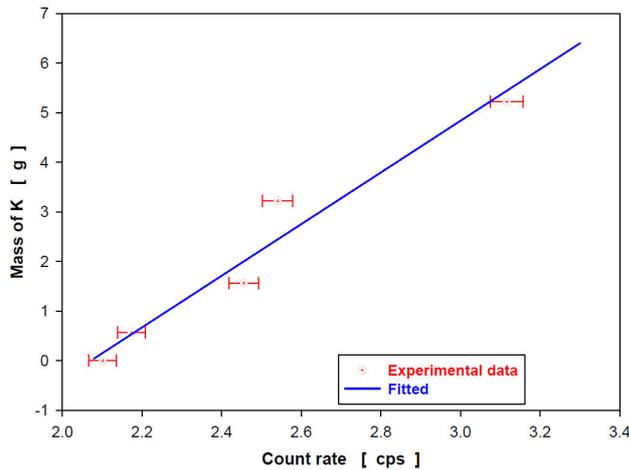


FIGURE 3. Calibration curve.

TABLE II. Unknown sources ⁴⁰K photopeak count rates

Unknown source	Net Counts under the photopeak of ⁴⁰ K [counts/1800 s]	Net Counts under the photopeak of ⁴⁰ K [cps]
T1	3883 ± 63	2.16 ± 0.04
T2	5570 ± 118	3.09 ± 0.07

In table II is shown the count rates of two sources used to test the procedure.

With data on table II the KCl, K, ⁴⁰K masses as well as the ⁴⁰K activity were determined, these results are in table III.

The actual KCl mass in the unknown sources are 1.03 ± 0.02 g and 10.48 ± 0.22 g for T1 and T2 respectively; in comparison with values in table III the relative difference is 4.6%.

Using the ⁴⁰K activity and the mass of K for T1 and T2 the specific activity was calculated resulting 30.58 ± 0.35 Bq/g for T1, and 30.91 ± 0.66 Bq/g for T2. These values are consistent to that reported in the literature being 30.18 ± 0.72 to 31.00 ± 0.33 Bq/g [10,15].

TABLE III. Results for the unknown sources

Unkown Source	Mass of KCl [g]	Mass of K [g]	Mass of ⁴⁰ K [g]	Activity [Bq]
T1	1.03 ± 0.02	0.45 ± 0.01	5.33 × 10 ⁻⁵ ± 8.55 × 10 ⁻⁷	13.76 ± 0.22
T2	10.48 ± 0.22	5.33 ± 0.11	5.38 × 10 ⁻⁴ ± 1.35 × 10 ⁻⁵	164.73 ± 3.49

To determine the amount of ⁴⁰K the ⁴⁰K-to-K ratio used was 0.0117% [2], however for soil this ratio varies from 0.0085% to 0.0167% [8]. The ⁴⁰K-to-K ratio here used gives out results that are consistent with values reported in literature. It is also important to note that this ratio is lesser than the ratio reported by Gilmore [16], and Gilmore and Hemingway [17] which reports a value of 0.117%.

Nevertheless in this work a scintillation detector was used, the ⁴⁰K specific activity here determined is consistent to values obtained with an HPGe detector [10, 15].

In order to use the procedure here shown standards and unknown samples must have the same shape and geometry to avoid solid angle corrections during measuring, the unknown sample density must be close to KCl density to avoid self-shielding corrections.

4. Conclusions

A procedure for determining the concentration of KCl, K, ⁴⁰K and ⁴⁰K activity has been developed using the net count rates under the ⁴⁰K photopeak, with a γ -ray spectrometer with detector scintillation NaI(Tl).

Six standards with KCl graduated with boric acid were prepared having the same dimensions to keep the measuring solid angle constant.

The rate of change between the mass of K and the net count rate in the 1.46 MeV photopeak, due to ⁴⁰K decay, is constant.

⁴⁰K specific activity is approximately 31 Bq/g.

This procedure is not destructive, and results are obtained fast and easily.

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