Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 572 (2007) 922–925
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

A novel methodology for online measurement of thoron using Lucas scintillation cell

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Received 4 April 2006; received in revised form 24 October 2006; accepted 28 November 2006
Available online 19 December 2006

Abstract

The use of Lucas scintillation cell (LSC) technique for thoron estimation requires a modified methodology as opposed to radon estimation. While in the latter, the α counting is performed after a delay period varying between few hours to few days, in the case of thoron estimation the α counting has to be carried out immediately after sampling owing to the short half-life of thoron (55 s). This can be achieved best by having an on-line LSC sampling and counting system. However, half-life of the thoron decay product ^{212}Pb being 10.6 h, the background accumulates in LSC during online measurements and hence subsequent use of LSC is erroneous unless normal background level is achieved in the cell. This problem can be circumvented by correcting for the average background counts accumulated during the counting period which may be theoretically estimated. In this study, a methodology has been developed to estimate the true counts due to thoron. A linear regression between the counts obtained experimentally and the fractional decay in regular intervals of time is used to obtain the actual thoron concentration. The novelty of this approach is that the background of the cell is automatically estimated as the intercept of the regression graph. The results obtained by this technique compare well with the two filter method and the thoron concentration produced from a standard thoron source. However, the LSC as such cannot be used for environmental samples because the minimum detection level is comparable with that of thoron concentrations prevailing in normal atmosphere.

Keywords: Lucas cell; Thoron

1. Introduction

The Lucas scintillation cell (LSC) is commonly used all over the world for the estimation of radon. The cell was originally devised by Vandilla and Taysum [1]. The cell has been since modified by others [2–4]. The air sampled is admitted inside the cell through a filter and the concentration is evaluated from the measured integration rate and the calibration factor obtained from the theoretical build up of radon decay products due to a pure radon source. The principle of detection is counting of photons resulting from the interaction of α particles produced by radon and its progeny with the ZnS(Ag) phosphor. A photomultiplier (PM) tube assembly counts the photon events. In the case of radon estimation with the LSC, the cell is reusable after a few hours as the progeny concentrations decay completely within about 3 h. However, this is not so in the case of thoron, as its progeny ^{212}Pb has a half-life of 10.6 h and hence the cell would require about a few days to come to the background level of activity. Several techniques have been attempted to estimate thoron concentrations with the Lucas cell [5–7]. Hutter [7] used a 1 min counting immediately after sampling followed by a second counting after a delay of 5 min for a duration of 10 min. The counts in the first counting period due to radon and its progeny are calculated from the known radon concentration and then subtracted from the total counts obtained in the first counting period. The remaining counts are due to thoron and its progeny and are used to calculate the thoron concentration. The overall uncertainty of this method lies between 10 and 20 percent.

This paper discusses an on-line Lucas cell sampling and counting technique which estimates the thoron concentration, corrected for the contribution of ^{212}Pb, which leads to temporally increasing background counts in the cell.

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doi:10.1016/j.nima.2006.11.074

A simple mathematical formulation has been derived to arrive at the true counts due to thoron alone. Experiments have been performed to compare this on-line measurement technique with the standard two-filter counting technique. Validation of the methodology was also done using a standard thoron source with varying thoron concentrations passing through the LSC.

2. On-line thoron estimation technique

Fig. 1 shows the experimental set up for sampling of thoron using the on-line LSC technique. Thoron from the Pylon model TN—1025 source was sampled into the LSC at a flow rate of about 3–10 lpm. The LSC was coupled to a PM tube based counting unit. The thoron gas was allowed to flow through the cell for a minimum of five air changes to attain a steady concentration of thoron inside the cell. This was ascertained by recording the counts obtained online. Flow of thoron gas was then stopped and the counting started instantaneously with the counts being recorded every minute. Repeated measurements were carried out with the cell at varying flow rates and the counts obtained for each minute were recorded. The true thoron concentration in the cell was estimated using the mathematical formulation discussed in the following section.

After the Lucas cell measurements for a given flow rate were completed the thoron gas flow was then diverted to the double filter set up and sampling was continued for ten minutes. Post-sampling, and after a delay of 1 min (time taken for removing the filter for counting), the second filter was kept for counting for sufficiently long interval. The counts at every 10 min were recorded. Thoron concentration is calculated for the two filter method using the method given by Kotrappa et al. [8].

3. Mathematical formulation for online measurement

Let C_0 be the initial concentration ($\mathrm{Bq\,m^{-3}}$) in the cell at time $t=0$ and $C(t_n)$ be the average thoron concentration

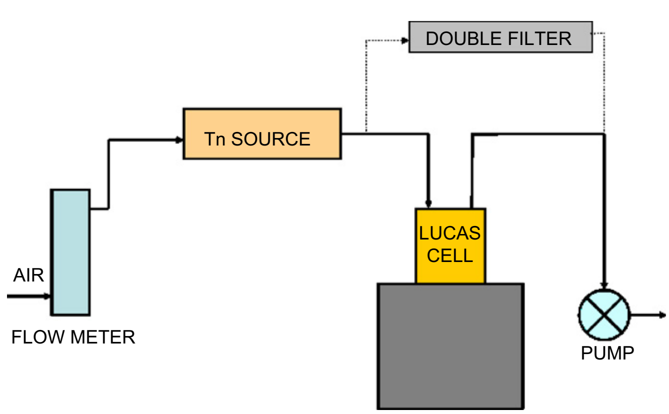

Fig. 1. Experimental set up for thoron measurements using Lucas cell.

($\mathrm{Bq\,m^{-3}}$) at time t_n after sampling in the cell. Then,

$$C(t_n) = C_0 \mathrm{e}^{-\lambda t_n} \tag{1}$$

where λ is the decay constant of ^{220}Rn ($\mathrm{min^{-1}}$).

The counts recorded in the cell during an experiment are those due to thoron and the background built-up during the successive sampling. Let $D_{(n,n+1)}$ be the counts recorded between any two successive intervals T_n and T_{n+1} and let the corresponding average thoron concentration in that time interval be denoted by $C_{(n,n+1)}$. Then,

$$D_{(n,n+1)} = 2V\eta \int_{T_n}^{T_{n+1}} C_{(n,n+1)}\,\mathrm{d}t + \int_{T_n}^{T_{n+1}} B_{(n,n+1)}\,\mathrm{d}t \tag{2}$$

where V is the volume of the cell (L); η is the efficiency of the counter (fraction); 2 signifies 2 α's (^{220}Rn and ^{216}Po); B is the background counts for the counting interval.

Using Eq. (1) in Eq. (2) and integrating for the time intervals T_{n+1} and T_n, we get

$$D_{(n,n+1)} = 2V\eta C_0 \frac{(\mathrm{e}^{-\lambda T_n} - \mathrm{e}^{-\lambda T_{n+1}})}{\lambda} + B(T_{(n+1)} - T_n) \tag{3}$$

Since the counts are taken for every minute: $T_{n+1} = T_n + \Delta T$; $\Delta T = 1\,\mathrm{min}$.

Eq. (3) can be written as

$$D_{(n,n+1)} = \frac{2V\eta C_0}{\lambda} \mathrm{e}^{-\lambda T_n}\left[1 - \mathrm{e}^{-\lambda \Delta T}\right] + B \tag{4}$$

where B will the average background during the counting interval.

Define

$$m = \frac{2V\eta}{\lambda}\left[1 - \mathrm{e}^{-\lambda\Delta T}\right];\quad X_n = \mathrm{e}^{-\lambda T_n},\ \text{here } [\Delta T = 1\ \mathrm{min}].$$

Then Eq. (4) can be written as

$$D_{(n,n+1)} = mC_0 X_n + B \tag{5}$$

A linear regression plot of the counts $D_{(n,n+1)}$ versus X_n will give the slope as mC_0 from which C_0 can be calculated for the known experimental parameters occurring in the constant m. B is then the background build-up due to ^{212}Pb.

The results of a typical experiment using the on-line Lucas cell technique are shown in Table 1. The linear plot of the counts $D_{(n,n+1)}$ obtained versus X_n is shown in Fig. 2.

For the cell used, $V = 0.132\,\mathrm{L}$, counting efficiency $\eta = 0.69$, hence $m = 1278$ (L/min.), the slope of $D_{(n.n+1)}$ versus X_n obtained from Fig. 2 is 0.1278 C_0 ($=772$). The concentration C_0 (Bq/L) can be calculated for the slope of the graph $D_{(n.n+1)}$ vs. X_n (Fig. 2) as follows:

$$C_0\left(\frac{\mathrm{Bq}}{\mathrm{L}}\right) = \frac{\text{Slope}}{0.1278 \times 60}. \tag{6}$$

For the typical results obtained (Table 1), the graph gives a slope of 772 (Fig. 2). The ^{220}Rn calculated using Eq. (6) for the slope is $100.7\,\mathrm{Bq\,L^{-1}}$ and the average background for the counting period is 17.1 cpm from fitting the data (Fig. 2).