SSNTD CALIBRATION AND EQUILIBRIUM FACTOR OF RADON PROGENY[*]

L.R.Gil, A.Marques and A. Rivera

CENTRO BRASILEIRO DE PESQUISAS FISICAS

Rua Dr. Xavier Sigaud 150, Urca 2290-180 Rio de Janeiro, RJ, Brasil

Abstract

The influences of the extended character of the distribution of alpha particle sources on the calibration of SSNTD and on handling track densities are discussed in connexion with measurements of equilibrium factor for radon daughters in air samples. Simple measures to avoid systematic errors are suggested.

Introduction

Activity data obtained when radiation emitters are uniformly distributed in space, as it happens in air samples or in underwater measurements, are usually treated as uniform in any space parameter, such as the area in a SSNTD. Uniformity means that: i) the number of trajectories of emitted particles going across surfaces of equal areas is the same, independently of their shapes; ii)the ratio of the number of trajectories across surfaces of same shape but different areas is the same as the areas ratio. Those conditions are satisfied, obviously, when the ranges of emitted particles are ideally infinite, that is, the test surfaces may be reached, no matter how far from them the particles are emitted. The finite ranges of alpha particles violate that condition and lead to the existence of finite `sampling volumes',that is, volumes around the test surface where physically acceptable trajectories are born (those whose length to the closest point belonging to detector window is not larger than the range of alpha particles in air). Sampling volumes show different geometric structures and values, for detector surfaces of different geometric shapes and sizes (Figs.1,2).

The non-uniform character of surface distributions can better be seen as follows: the distribution of number of tracks in an area S is given by:

$$n = cT \int_{v(S)} dv \int_{S} dS \cos\vartheta \ / (4\pi \ r^2) \tag{1}$$

where c is the activity concentration (supposed uniform), T the exposure time, $v(S)$ the sampling volume, r the length of trajectory from emission position down to detector's surface, and θ is the angle with the normal at the incidence point. To show that n will not, in general, be distributed uniformly over any plane surface, one recalls, first of all, that uniformity requires $dn/dS = n/S = $ const. As it will be shown later in this paper, the volume integration in (1) may be written as the product of two factors, one of which is $v(S)$; although the second one may contain S as a multiplicative factor, the combined dependance will deviate from $const.S$. It is worth mentioning, just to single out a concrete situation, that $v(S) = (2/3)\pi R_a^3 + \pi R_a^2 S^{1/2} + R_a S$, in the case of a square shape detector of area S (Fig.1).

That situation has consequences for the analysis of activity measurements in radon family, no matter the nature of the measuring device.

Alpha activities of radon and its progeny in air samples are estimated by means of the equilibrium factor (Jacobi (1972), Swjedemark(1983)):

$$F = \sum_1^4 f_i(c_i/c_o) \qquad (2)$$

where $f_1=0.105$, $f_2=0.516$, $f_3=0.380$, $f_4=5.27 \; 10^{-8}$; c_i $(1=1...4)$ are alpha activity concentrations for ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, and c_o that for ^{222}Rn .

Since precise identification of alpha emitters at low activity levels is often difficult to perform, one does not go through the measurements of the c_i in (2) to find F ; instead the detector is calibrated in such a way as to give the working level of the air sample as a function of the alpha particles counting. The value of the working level , normalized to that of the same activity concentration of ^{222}Rn as found in the sample, but in radioactive equilibrium with the progeny , fixes F. Table 3 of Khan et al (1990) shows results of calibration experiments for different track detectors.

The purpose of this note is to discuss a few questions involving the application of calibration results to new measurements where different geometric parameters may be involved.

Equilibrium Factor from Observed Track Counting

Let c_i be the activity concentration for the ith-nuclide in the progeny , supposed to be uniformly distributed in a volume of air. Suppose one registers alpha tracks from its disintegration in a foil of a track detector whose intrinsic efficiency is supposed to be 100% to all alpha particles of radon progeny[1] . Owing to their finite ranges, R^i_α , alpha particles emitted from positions outside a certain volume ("sampling volume") containing the detector will not be able to hit its surface ; let v_i be that volume. Let ε_i be the geometric efficiencies for each alpha particle group in the progeny, i.e., the fraction of trajectories emitted from

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[1] No critical incidence or energy threshold ; CR-39, for instance, is a good approximation. The conclusions of this note also hold in general but many points in discussion become simpler under the restrictive hypothesis above.

within v_i that succeed in hitting the detector; the number n_i of tracks registered during an exposure lasting a time T will be given by[2] :

$$n_i = c_i \, \varepsilon_i \, v_i \, T \qquad (3)$$

By replacing c_i from (3) in (2) one obtains

$$F = \sum_1^4 c_i^* f_i \qquad (4)$$

where:

$$c_1^* = \varepsilon_0 v_0 n_1 [\varepsilon_1 v_1 n_0]^{-1}; \; c_2^* = c_2 \, ; \, c_3^* = c_3;$$

$$c_4^* = \varepsilon_0 v_0 n_4 [\varepsilon_4 v_4 n_0]^{-1} \qquad (5)$$

n_0 stands for radon alpha particle track number and the exposure time, T, is supposed to be the same for the measurements of n_i and n_0. Now the parameters c_1^* and c_4^* are expressed in terms of the observed number of alpha tracks; c_2^* and c_3^* correspond to β-emitters that contribute to working level but not to the content in alpha tracks. Calibration tends to establish a one-to-one correspondence between alpha counting and working level but, for SSNTD and all devices insensitive to radiations from ^{214}Bi and ^{214}Pb , environment variables affecting the activity concentration of those isotopes should be controlled and explicitly given .

Calibration experiments correlate working levels to the density of alpha tracks in filtered and unfiltered samples, handled in such a way as to allow isolation of the daughter components , i=1...4, from the parent radon . If surfaces of different areas or different shapes are scanned for alpha tracks, in the filtered and unfiltered runs, owing to the nonuniform character of track distributions mentioned above,the ratios in c_1^* and c_4^* will be biased, embodying a dependance, not necessarily linear, with area values. Scanning surfaces of equal areas and same shape for alpha tracks, in filtered and unfiltered samples is therefore a necessary condition to assure one the results will be free from systematic deviations.

Geometric efficiencies are more easily calculated by Monte Carlo computation; emission positions are selected at random within the sampling volume and the ratio of successes, i.e., the number of trajectories that hit the detector to the total number of trials tend to the geometric efficiency as the number of trials becomes large enough.

The shapes and sizes of the sampling volumes, v_i, depend upon the geometry of the detector and the ranges of alpha particles in air. For a square shape detector with side length a, the sampling volume has the shape of Fig.1:cylindrical surfaces of height a, radius of basis R_a ,and spherical octants of radius R_a close the figure sideways; on top, the right projection of

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[2] (3) is obtained from (1) by taking ε_i as a value intermediate between the maximum and minimum of the surface integral within the sampling volume, according to the mean value theorem.

the detector and at bottom a square of side length $a + 2R_a$ complete the figure. For a disk shape detector of radius a the sampling volume is that of Fig. 2, obtained by turning a circle quadrant of radius R_a around a cilinder of radius a, having the cilinder axis as rotation axis. Values for the sampling volumes, in both cases, can be found by means of formulas of elementary geometry.

A final comment is to be done about the calculation of c_0 in a filtered sample. That parameter is necessary for finding a value for F as it is seen from (1). That value is to be obtained after an exposure to radon and its daughters in radioactive equilibrium, at the same activity concentration as in the unfiltered sample. Suppose one uses CR-39 that registers all alpha particles emitted by ^{222}Rn, ^{218}Po and ^{214}Pb. Let δ_i be the track density for each of those groups (i= 0,1,4); one has

$$\delta_i = (c_i T/S)\varepsilon_i v_i, i=0,1,4 \qquad (6)$$

where

$c_i = c_k$ (i,k = 0,1,4) (radioactive equilibrium). By taking $\delta = \delta_0 + \delta_1 + \delta_4$, one obtains from (5) and the condition for radioactive equilibrium:

$$\delta_0 = \delta \, \varepsilon_0 v_0 [\varepsilon_0 v_0 + \varepsilon_1 v_1 + \varepsilon_4 v_4]^{-1} \qquad (7)$$

Equ. (7) displays the correct way to convert the total track density into the density of alpha tracks corresponding to radon alone ; by taking $\varepsilon_i v_i \approx 1$ or by using as efficiencies the values obtained in experiments with collimated beams of particles, sizeable deviations are expected in the value of the equilibrium factor.

Electronic counting devices allways show the same active area to incident alpha particles and do not depend upon parameters as track densities; they dont show those problems except for eventual change of detectors for counting filtered and unfiltered samples. SSNTD could, however, show the same reproductibility if the practice for radon measurements is standardized so as to fix scanning areas and handling data from filtered samples according to (7).

References

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Captions for Figures

Fig.1 - Geometric structure of the sampling volume   for the case of a square shape SSNTD of side length a. R_a is the range of alpha particles in air.

Fig.2 - Geometric structure of the sampling volume for the case of a disk shape SSNTD of radius a. R_a is the range of alpha particles in air.
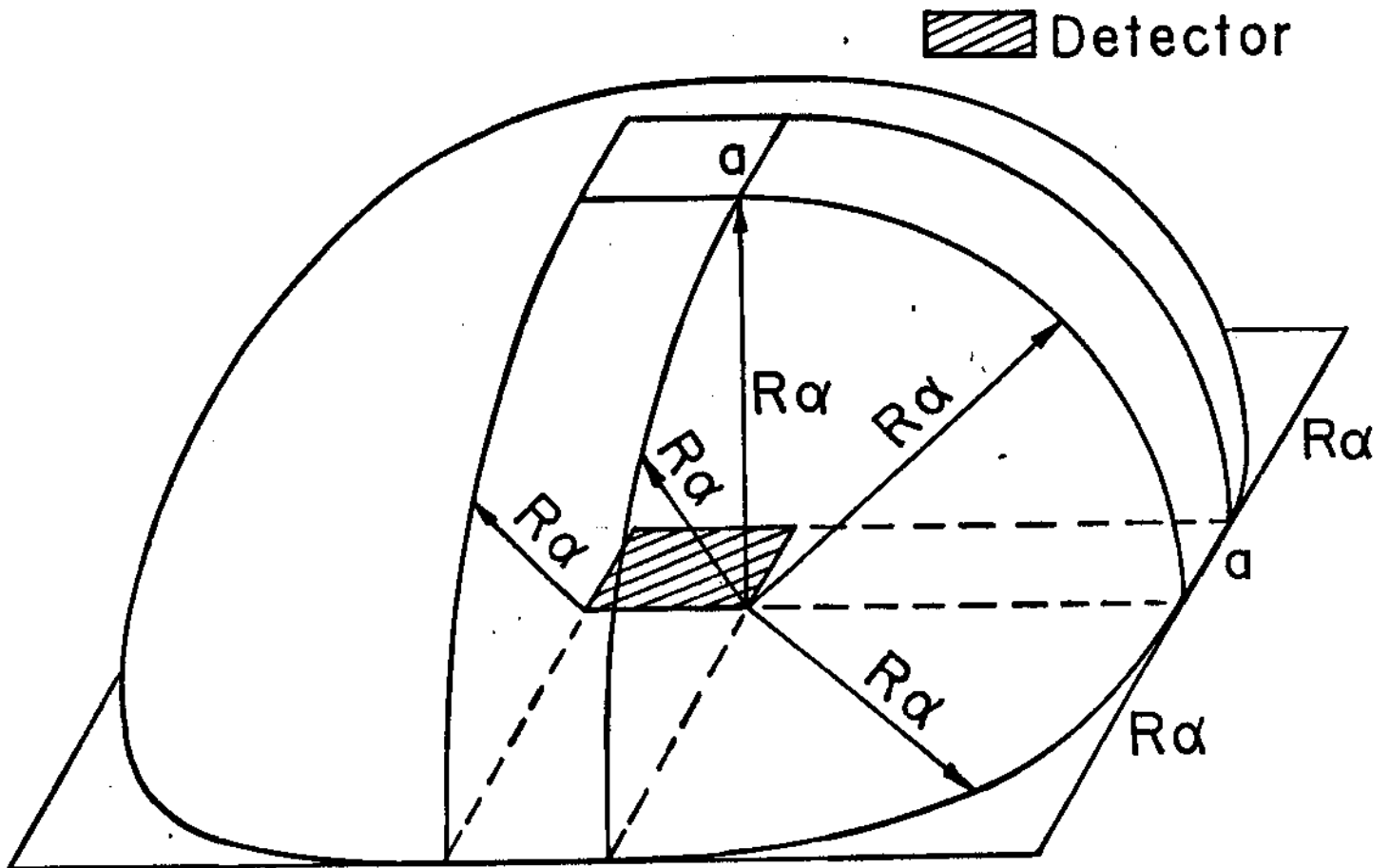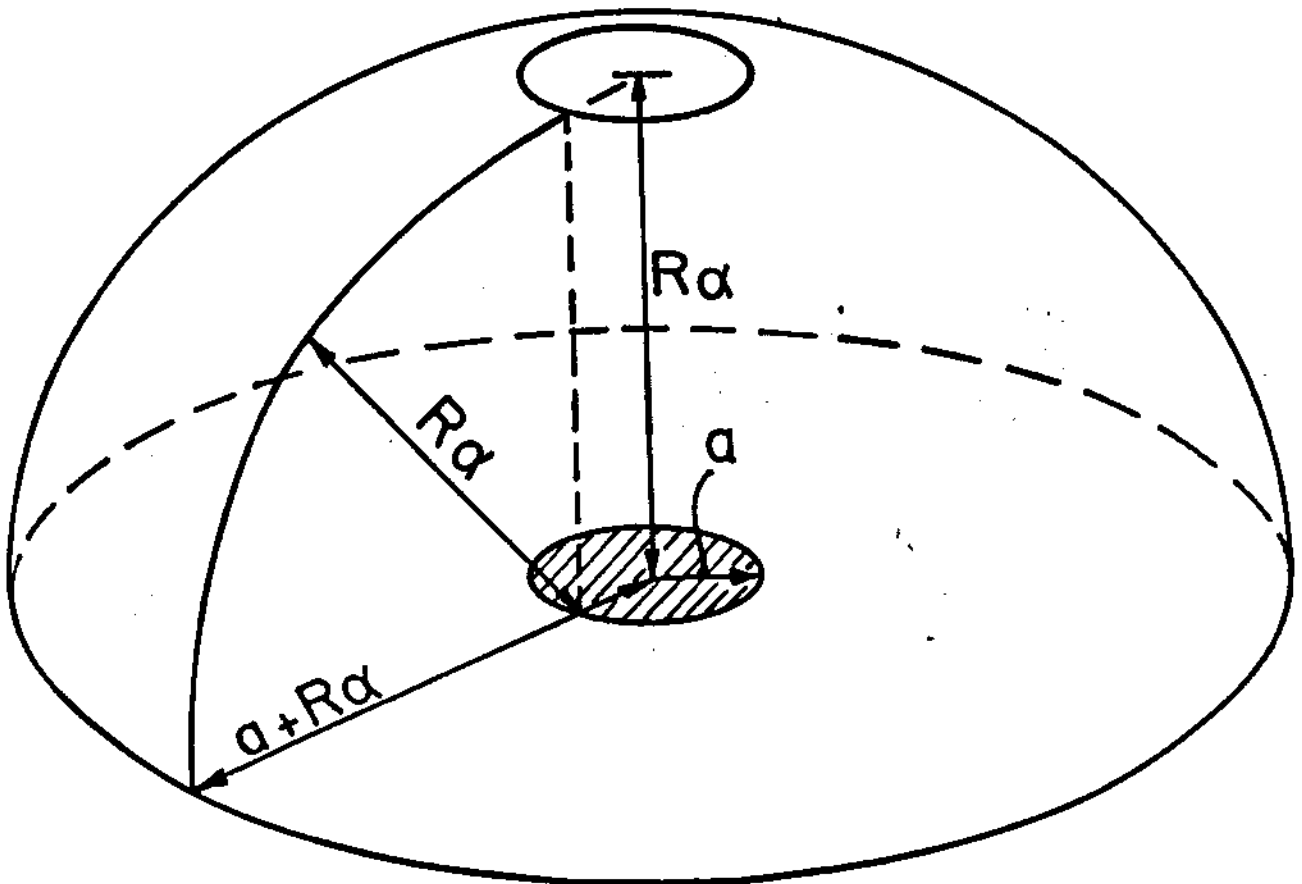
Fig. 1

Fig. 2