VENTILATION RATE IN EQUILIBRIUM FACTOR MEASUREMENTS WITH SSNTD*

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Abstract

Ventilation rate values are calculated from track density measurements in solid state nuclear track detectors(SSNTD), both when ventilation is the main cause of radioactive disequilibrium in radon progeny and when it shares importance with other agents. The method consists in exposing a SSNTD of high intrinsic efficiency (CR-39) in filtered and unfiltered conditions and, in addition, covered with a thin Aluminum foil, to stop alpha particles from ^{218}Po and ^{222}Rn. No calibrations are required but, when necessary, independent measurements of the loss rates of radioactivity to aerosol and to the walls have to be performed. Ventilation rates depend upon geometric detection efficiencies for alpha particles, here obtained by Monte Carlo simulation, taking into account the space distribution of emission positions. This may lead to sizeable corrections in ventilation and equilibrium factor values. Since geometric detection efficiencies depend upon alpha-particle ranges in air, the influences of barometric variables are also discussed.

Introduction

Ventilation rate is one of the parameters used to describe the perturbations caused in radioactive equilibrium of radon and its descendants in air. Other parameters are the attaching of daughter nuclei to aerosol particles and their deposition on the walls of the confination volume Jacobi (1972); Swedjemark (1983). Radon itself may diffuse into or out the confination volume freely in most situations.

When a steady state is reached,radon daughter activities may be described by a set of equations such as:

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$$dN_i/dt = \lambda_{i-1}N_{i-1} - \Lambda_i N_i, \quad (i=1...4); \qquad (1)$$

the first term on the right is the rate of formation of the i^{th}-member of the progeny by radioactive decay of the $(i-1)^{th}$-member, with constant λ_{i-1}; the second term describes the radioactivity leakage rates, owing to ventilation V, to aerosol grains A_i and deposition on the walls W_i to which it is added the rate of radioactive decay of the i^{th}-member of the progeny,
λ_i[1] :

$$\Lambda_i = V + A_i + W_i + \lambda_i \qquad (2)$$

The index i, running from 1 to 4, lables the relevant daughter in the family: ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po. ^{222}Rn itself will be labled with i=0; its concentration may be affected, in general, only by ventilation. Ventilation rate affects equally all members of the family.In terms of activity concentrations, c_i, (1) and (2) lead to:

$$c_i = \frac{\lambda_i}{\lambda_i + \Lambda_i} c_{i-1} \qquad (3)$$

Equation (3) represents the changes induced by the environmental factors,changing the correlation between successive activity concentrations characteristic of radioactive equilibrium, $c_i=c_{i-1}$; all information about disequilibrium is contained in that correlation.

In many situations ventilation is either the only factor of disequilibrium or the dominant one; these cases were treated by Planinic and Faj (1990). In general, however, one finds competition among different environmental factors; both cases will be treated here . The treatment here differs from the one in Planinic and Faj (1990) mainly because no restrictions are imposed to geometric detection efficiency of alpha particles.

Geometric corrections depend, among other parameters, on the fact that not every emission angle and position within the volume of the experiment can be connected to detector's surface by a physically acceptable alpha particle trajectory; alpha particles emitted from outside a certain volume - the "sampling volume" - will be forbidden to reach the detector. The shape and size of the sampling volume depend on detector's shape and dimensions, as well as on alpha particle ranges.

Theory

. When ventilation is the only environmental parameter affecting disequilibrium or when it is the dominant one, ventilation rates and equilibrium factor are obtained by means of two exposures one to an unfiltered, the other to a filtered sample of air (depleted of daughter activities), during controled time intervals, followed by track density measurements. The problem of obtaining ventilation rates and equilibrium factor values,in that case, was analyzed theoretically by Planinic and Faj (1990), under the assumptions that geometric efficiencies for alpha particle detection are 100% and the sampling volumes are equal for different alpha groups. That problem can be solved under less restrictive conditions by means of the following procedure:1) the number of tracks registered by

[1] That term is negligible except for ^{214}Po

scanning a given surface, after an exposure lasting a time interval T, n_i, will now be given by:

$$n_i = c_i T \varepsilon_i v_i, \quad i = 0,1...4 \qquad (4)$$

where c_i are activity concentrations, ε_i and v_i, respectivelly, geometric efficiencies ($\leq$100%) and sampling volumes, for the i^{th}-member of the family, (including ^{222}Rn). The `intrinsic' efficiency is here assumed to be 100% for all groups of alpha particles involved, (approximately true for CR-39; in general a multiplying factor should be inserted in (4) to take into account the actual value of that parameter; energy or dE/dx thresholds can also be handled easily); 2) by means of (4) one obtains the ratio of track densities in the unfiltered exposure to the filtered one as

$$n_t/n_o - 1 = \sum_{i=1}^{4} \frac{c_i \varepsilon_i v_i}{c_o \varepsilon_o v_o} \qquad (5)$$

3) By using (3) the ratios c_i/c_o can all be expressed in terms of the disintegration constants and Λ_i=V; under the hypothesis that V $<<\Lambda_4$=4.234 10^3 s^{-1}, one obtains the following equation :

$$v^3 + \left[\sum_1^3 \lambda_i \frac{\varepsilon_1 v_1}{\varepsilon_o v_o} \lambda_1 \rho\right] v^2 + \left[\sum_1^3 \lambda_i \lambda_j - \frac{\varepsilon_1 v_1}{\varepsilon_o v_o} - \lambda_1(\lambda_2 + \lambda_3)\rho\right] v$$

$$+ \lambda_1 \lambda_2 \lambda_3 \left[1 - \frac{\varepsilon_1 v_1 + \varepsilon_4 v_4}{\varepsilon_o v_o}\right] \rho = 0 \qquad (6)$$

where

$$\rho = (n_t/n_o - 1)^{-1}$$

Equation (6) is the generalization of equ.(12) of Planinic and Faj(1990) for the case where geometric efficiencies are not 100% and the sampling volumes corresponding to different progeny members have different values. Ventilation values are the solutions of (6), obtainable by means of standard algebraic procedures.

Values for the equilibrium factor, F, follow from the solution of (6) combined with (3) and with

$$F = \sum_1^4 \frac{f_i c_i}{c_o} \qquad (7)$$

where $f_i = E_i/(k_e\lambda_i)$, E_i are potential alpha energies and k_e =34.565 MeV Planinic and Faj (1990).

When ventilation is not the only relevant factor of disequilibrium, ventilation rates can yet be obtained but the procedure now involves either an independent knowledge about A_i and W_i or calibration of the SSNTD. The analysis here will be restricted to the first case.

Even in the case where A_i and W_i are known from other data, the leakage rate Λ_i affecting all radon progeny cannot be computed if one does not know the ventilation rate, according to (2); therefore activity concentrations and equilibrium factor cannot be found as well, as they depend on Λ_i. An estimate of the ventilation rate can be obtained, in that case, by means of an additional exposure to the unfiltered sample now with a detector covered with a foil thick enough to stop all alpha particles but those from ^{214}Po; an Aluminum foil 28 m thick is good enough for that purpose. The number of registered alpha particle tracks,n' , will now be $n' = c_4 T\varepsilon_4 v_4$ (apostrophes indicate parameters related to the detector covered with the Aluminum foil); one obtains, from (4):

$$n_4 = n'_4 \frac{\varepsilon_4 v_4}{\varepsilon'_4 v'_4}$$

From the expression above and the track numbers resulting from the bare and filtered exposures,n_t and n_o, the number of tracks corresponding to alphas from ^{218}Po, n_1, is determined:

$$n_1 = n_t - (n_o + n_4)$$

By using the result above in (3) one obtains:

$$\Lambda_1 = \frac{n_o \varepsilon_1 v_1}{n_1 \varepsilon_o v_o} \qquad (8)$$

and from (8), (2) and the values of A_1 and W_1 one obtains the ventilation rate:

$$V = \Lambda_1 - (A_1 + B_1) \qquad (9)$$

where $B_1 = W_1 + \lambda_1$. That value has to be added to all other A_j, W_j in order to find L_j for $j \neq 1$ and then the activity concentrations and equilibrium factor.

Geometric efficiencies for alpha particle detection, when their sources are uniformly distributed over a confination volume are more easily obtained by Monte Carlo simulation. Alpha particle emission sites are sampled randomly within the sampling volume;10^5 positions were chosen in each run. Exact shape and dimensions of sampling volumes are irrelevant for the calculation of geometric efficiencies as long as all points within them are physically acceptable (length to detector's surface ≤ range of alpha particles in air;when detector's surface is covered with a thin Al foil,the condition that the length of the trajectory is physically acceptable is slightly changed, to include the part of the range developed within the cover foil).The exact shape of sampling volumes is somewhat complex but simplified models may be used satisfactorily in most computations (Gil et al (1993)).The shape of the sampling volume may also be obtained by Monte Carlo calculations.

Ranges of alpha particles in air were estimated by integration of stopping power values obtained by completing first principle calculations for H_2,O_2 and N_2 of Bichsel and Porter (1982) with empirical results for those gases given by Ziegler and Chu (1974). The combined data was then reduced by least squares to give stopping power curves good enough for range calculations in air, under variable conditions of temperature, humidity and barometric pressure .

Results and Discussion

As a result of this study, deviations from standard operational conditions (sea level, moderate altitudes and humidity values) of meteorological variables, as met usually, bear little or no influences on the results. Temperature is somewhat more critical; with detector dimensions unrestricted, air temperature contributes a non-negligible amount to final values of geometric detection efficiencies and sampling volumes. When ventilation is the main agent of radioactive disequilibrium, equ. (6) yields values for the specific rate of ventilation,Λ; solutions are obtained in closed form by standard algebraic procedures (Abramowitz and Stegun (1972)). The coefficients of the cubic equation involve the ratios $\varepsilon_1 v_1/\varepsilon_0 v_0$ and $(\varepsilon_1 v_1 + \varepsilon_4 v_4)/\varepsilon_0 v_0$ and since temperature and sampling volumes affect both members of each of those ratios much in the same way, solutions of (6) are rather insensitive to variations in temperature and changes in detector's dimensions. Figs.1 and 2 show typical results; values of the ventilation rate are there plotted as functions of the *excess track number* (or density), n_t/n_0 -1, for different temperatures and a given detector dimension (fig. 1) and at a given temperature for different detector dimensions (fig.2). It is worth noting that fig.2 shows that the effect on ventilation is slightly greater for the case where detector has the shortest size (1 cm x 1 cm), which is also expected since in that case range variations are relatively more significant.

Fig.3 shows a comparison between the equilibrium factor found here and that found in Planinic and Faj (1990); it is seen that, by taking geometric effects into account, sizeable deviations are obtained.

Cancelation of influences induced by temperature and detector's dimensions is also obtained when one uses equ. (8) to find the specific leakage rate in the presence of other important agents of radioactive disequilibrium.Here ventilation values depend also on the ratio $\varepsilon_1 v_1/\varepsilon_0 v_0$ which, as before, stay fairly constant with temperature and detector size, within the limits here investigated.

The characteristics of insensitivity to meteorological conditions and geometric dimensions, besides the absolute character of the results, requiring no calibrations or comparisons involving detectors of different intrinsic performance, make this method specially atractive for ventilation rate and, when possible, equilibrium factor measurements.

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