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Study of CR-39 and Makrofol efficiency for radon measurements

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ABSTRACT

This paper presents experimental and theoretical determination of CR-39 and Makrofol calibration coefficients in diffusion chambers for radon measurements. Experimental calibration was performed by irradiation of detectors in a calibration chamber; radon concentration in the chamber was continuosly measured by RAD7 device. Calculations were performed by the previously developed software for CR-39 detector. In addition the software was modified to enable calculation for Makrofol by implementing V function and other relevant data for this kind of detector.

A good agreement was found between experimental and theoretical approaches. The comparison enabled selecting V function for CR-39 that gave the best agreement with the experimental results.

Optimisation of chamber and detector dimensions was theoretically performed for different etching times. The dependence of calibration coefficient on ^{218}Po deposition fraction was also analysed.

1. Introduction

Solid state nuclear track detectors (SSNTD) are commonly used for radon measurements. Among them, the most often used are CR-39, LR115 and Makrofol. Detectors are used as a bare or in a cup closed with filter paper which is called “diffusion chamber”. Various designs and dimensions of diffusion chambers were described in literature and used in practice. Some new designs were described by Calamosca et al. (2003); Csige and Csegzi, 2001; Nikolaev and Ilic, 1999; Nikezic and Yu, 2004; Sciocchetti et al., 2003; Torabi Nabil et al., 2012 etc. The output result of detector application (bare as well as closed in a cup) was track density per unit irradiation time. A detector in a diffusion chamber is pure radon measuring device (if the filter is thick enough to stop thoron diffusion into the chamber), while bare detectors can register all alpha emitters present in air: radon, thoron and their progeny.

To obtain the absolute value of average radon concentration during the irradiation, it is necessary to convert track density per irradiation time to radon concentration, by using calibration coefficient, k. Determination of k can be performed experimentally (Antovic et al., 2007; Garawi, 1996; Ismail and Jaafar, 2011) by exposing of detector to the known concentration under controlled laboratory conditions. Another approach is to calculate k by analytical or Monte Carlo methods (Eappen et al., 2008; Palacios et al., 2008; Patiris et al., 2007; Sima, 2001).

In this work, both methods, experiment and calculation, were applied in order to determine k for CR-39 and Makrofol detectors placed in various diffusion chambers. Calibration coefficient for CR-39 was calculated by using different V functions found in literature and obtained results were compared with calibration experiment. Optimal chamber and detector dimensions were theoretically determined for different etching times. The dimensions that correspond to minimal dependence of calibration coefficient on ^{218}Po deposition fraction were also reported.

2. Materials and methods

2.1. Calibration experiment

The calibration experiment has been performed in Plexiglas chamber (of 30 L in volume) connected to RAD7 device (Durridge, Massachusetts, USA). A sample of uranium ore has been used as a source of radon in the chamber. Fig. 1 presents the build up of radon concentration measured with RAD7. Four Makrofol (Iupilon®, with the thickness of 300 μm) and four CR-39 (TASTRAK®, 1 mm thick) detectors were placed in different semi-conical plastic cups with dimensions given in Table 1. The open ends of the cups were covered with filter paper in order to prevent radon progeny and aerosols from entering the detection volume. The detectors were exposed for 9 days.

After the exposure, CR-39 detectors were chemically etched in 6.25 N NaOH solution at 70 °C for 5 h. Makrofol detectors were etched for 2 h using PEW solution (15 g KOH + 45 g H_2O + 40 g ethyl alcohol) at the same temperature. The etched detectors were rinsed with

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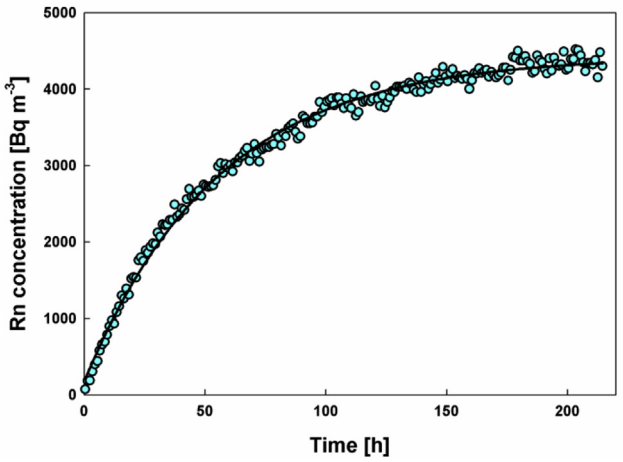

Fig. 1. The build up of radon concentration inside the chamber. Measured with RAD7 device.

Table 1
Dimensions of cups (R_1 – lower radius; R_2 – upper radius; H – height) and detectors (radius R_D) used in the experiment.

Cup dimensions				Detector radius R_D [cm]	
No	R_1 [cm]	R_2 [cm]	H [cm]	Makrofol	CR–39
1	2.6	3.3	10	2.5	1.13
2	2.4	3.5	8.2	1.13	1.13
3	2.1	3	9.4	1.13	1.13
4	2.7	3.2	4.7	2.5	1.13

distilled water in order to stop further etching. The tracks were counted manually using optical microscope with 1000 × magnification. Background track density was determined by observing unexposed detectors etched under the same conditions. Although some authors have reported the ability of polycarbonates to absorb certain amounts of radon in its volume (Möre and Hubbard, 1997; Pressyanov et al., 2000, 2003; 2004), a correction for radon absorption is not considered in this study. This effect is probably not too significant as the calibration factor due to radon absorption in Makrofol reported elsewhere (Pressyanov, 2009) is well lower than those for diffusion chambers, considered in the present study.

Calibration coefficient was obtained using the equation:

$$k = \frac{\rho}{\overline{C}\cdot\Delta t} \tag{1}$$

where ρ is the track density, Δt is the exposure time and $\overline{C}$ is the average radon concentration calculated from the equation (Stajic et al., 2015):

$$\overline{C} = \frac{\int_0^{\Delta t} C(t)dt}{\Delta t} = \alpha + \frac{\beta}{\gamma\cdot\Delta t}\cdot(1 - e^{-\gamma\cdot\Delta t}) \tag{2}$$

Parameters α, β and γ were obtained by fitting the experimental data presented in Fig. 1. Accordingly, the mean radon concentration in the chamber was estimated to be 3350 Bq m^{-3} (the uncertainty of the estimate was calculated to be less than 8%, considering standard error of the mean and RAD7 calibration uncertainty).

Calibration coefficient is given in units (track/m^2)/(Bq·s/m^3) = m. In literature it is also given in (track/cm^2)/(Bq·h/m^3) or in (track/cm^2)/(Bq·d/m^3).

Bulk etch rates corresponding to the current etching conditions were estimated by gravimetrical methods. Masses of Makrofol and CR-39 detectors were measured before and after the etching. An analytical balance with the precision of 0.1 mg was used for these measurements. The values of (15 ± 1) μm h^{-1} and (1.06 ± 0.11) μm h^{-1} were obtained for Makrofol and CR-39, respectively. These values have been used for theoretical calculations.

2.2. Determination of calibration coefficient by Monte Carlo calculation

Previously developed Fortran90 computer program named CR39_Sensitivity (Nikezic et al., 2014) was used for theoretical calculation of calibration coefficient for CR-39 detector in a conical or cylindrical chamber. The program calculates the partial calibration coefficients for alpha particles produced by the decays of ^{222}Rn, ^{218}Po and ^{214}Po (it can also be used for thoron and its progeny). Three geometrically different irradiation conditions were considered in this software; (i) alphas emitted in volume of the cup, (ii) alphas emitted by progeny deposited onto cup walls (including filter) and (iii) alphas emitted by progeny plated out on the detector itself. Partial calibration coefficients are different for all three exposure situations. Total calibration coefficient, k_{tot} is obtained as a sum of partial calibration coefficients according to the equation:

$$k_{tot} = k_0 + f_1 k_{1a} + f_4 k_{4a} + (1 - f_1)k_{1w} + (1 - f_4)k_{4w} + k_{1p} + k_{4p} \tag{3}$$

where f_1 and f_4 are fractions of ^{218}Po and ^{214}Po decayed in air of the cup, (volumetric fractions) respectively; k_0 is partial calibration coefficient for ^{222}Rn in the cup volume (assuming that there is no deposition of ^{222}Rn); k_{1a} and k_{4a} are calibration coefficients for ^{218}Po and ^{214}Po in the cup volume, respectively; k_{1w} and k_{4w} are calibration coefficients for ^{218}Po and ^{214}Po deposited on the cup wall; k_{1p} and k_{4p} are calibration coefficients for ^{218}Po and ^{214}Po deposited on the detector (plate out) (Nikezic et al., 2014).

Partial calibration coefficients are calculated separately, and total calibration coefficient is obtained by the formula given above. The following V functions for CR-39 detector were implemented in the software:

(A) $V = 1 + (11.45e^{-0.339R'} + 4e^{-0.044R'})(1 - e^{-0.58R'})$ (Durrani and Bull, 1987).
(B) $V = 1 + e^{-0.1R'+1} - e^{-R'+1.27} + e^{1.27} - e^{1}$ (Brun et al., 1999).
(C) $V = 1 + e^{-0.068R'+1.1784} - e^{-0.6513R'+1.1784}$ (Yu et al., 2005a).
(D) $V = 1 + e^{-0.06082R'+1.119} - e^{-0.8055R'+1.119}$ (Yu et al., 2005b).
(E) $V = 1 + \frac{390}{(R'+2)^{2.35}}\cdot\ln(R'+1)\cdot(1 - e^{-R'/5}) + \frac{R'}{80}$ (Hermsdorf, 2009).

where R′ represents residual range of alpha particles in CR-39. A detailed description of the software was given by Nikezic et al. (2014).

The same software has been modified in order to calculate the calibration coefficient for Makrofol. V function for Makrofol was found in literature (Benton and Nix, 1969; Somogyi et al., 1976; Vancraeynest et al., 1997):

$$V = 1 + \alpha\cdot REL^{\beta} \tag{4}$$

where REL represents restricted energy loss (in MeV cm^2 mg^{-1}) assuming the threshold energy for secondary electrons ω_0 = 1 keV. The values of parameters α = 0.096 and β = 2.82 have been applied in calculation (Somogyi et al., 1976). For the particle energies below 2 MeV (0.5 MeV/nucleon), total rate of energy loss, dE/dx (taken from SRIM-2013 computer code) (Ziegler et al., 1985) was used as REL. For the energies above 2 MeV, REL was obtained by substracting the energy lost through close collisions from the total rate of energy loss (Benton and Nix, 1969),

$$REL = \left(\frac{dE}{dx}\right) - \left(\frac{dE}{dx}\right)_{\omega > \omega_0} \tag{5}$$

The term $\left(\frac{dE}{dx}\right)_{\omega > \omega_0}$ was calculated according to formulae given by Somogyi et al. (1976).

V function for Makrofol determined in above described manner as a function of residual range (R′) is presented in Fig. 2.