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# Effect of environmental conditions on radon concentration–track density calibration factor of solid-state nuclear track detectors

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**Abstract.** In this work, the effect of environmental conditions viz., temperature ($T$) and relative humidity (RH) on the track density–radon concentrations calibration factor ($K$) has been studied for CR-39 and LR-115 track detectors. The factor $K$ was determined using a reference radon chamber in the National Institute for Standards (NIS) in Egypt. Track detectors were etched at the recommended optimum etching conditions.

It is found that, the calibration factor $K$ varies with both $T$ and RH, so they should be considered for the sake of uncertainty reduction. Good agreement is found between the calculated and measured values of $K$ and the compatibility between them is in the range of experimental uncertainty.

**Keywords.** Radon; calibration factor; environmental conditions; solid-state nuclear track detectors.

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## 1. Introduction

It is well-known that the inhalation of short-lived $^{222}$Rn daughters contribute about 40% of the total exposure of population [1–7]. Time integrating long-term passive measurements of radon activity in air is necessary for an estimation of health hazard of the population in dwellings. The solid-state nuclear track detectors (SSNTDs) were proved to be a very convenient tool for this purpose.

The calibration factor $K$ of the SSNTDs can either be determined using standard Rn-chamber or calculated and then be used in Rn measurements. This factor $K$ is given by

$$\rho_0 = KC_0, \tag{1}$$

where $\rho_0$ is the track density and $C_0$ is the radon concentration.

Assuming radon as a thick source, $K$ is given by [8]

**Table 1.** Values of $(K)$ for different positions.

| Location of daughter | Nuclei | $K$ | Condition |
|---|---|---|---|
| On the detector surface | Rn-222 | $0.25 R\cos^2\theta_c$ | $R < a$ |
| | Po-218 or 214 | $0.25\ (V/A)(1-\sin\theta_c)$ | |
| On the wall | Po-214 | $0.25\ (V/A)(\cos\theta_c - a/R)$ | $0 < a < R$ |

$$K = \frac{1}{4} R\cos^2\theta_c, \tag{2}$$

where $R$ is the range of alpha particles emitted from Rn in air and $\theta_c$ is the critical angle of etching. Equation (2) is valid if and only if Rn isotope is only considered. Assuming the contribution from the $^{218}$Po and $^{214}$Po isotopes (on the can wall and plated out on the detector surface) and the detector is filtered in a diffusion chamber with radius $a$, the factor $K$ is given by

$$K = K_1 + K_2 + K_4, \tag{3}$$

where factors $K_1, K_2$ and $K_4$ are related to $^{222}$Rn, $^{218}$Po and $^{214}$Po, respectively. The values of $K_1, K_2$ and $K_4$ are given in table 1 [8,9]. In table 1, $V, A$, respectively are the volume and the total side area of the diffusion chamber and $\theta_c$ is the critical angle of etching which given by [8].

$$\theta_c = \sin^{-1}(V_B/V_T), \tag{4}$$

where $V_B$ and $V_T$ are the bulk and track etch rates, respectively. For CR-39 and for a direct exposure, the total track density due to Rn and its daughters are given by [8]

$$\rho_1 = \sum_i K_i C_i, \tag{5}$$

where $i$ (1, 2 and 4) relates to the isotopes $^{222}$Rn, $^{218}$Po and $^{214}$Po, respectively as thick sources and $K$ is defined in eq. (2). Due to the high deposition probability of $^{214}$Po, the factor $K_4 = 1 - \sin\theta_c$ as a thin source and its concentration unit in this case is Bq/cm$^2$ to keep the dimension of the equations.

The range $(R)$ of the alpha particles is calculated from the relation

$$R = \int_0^E \left[-\frac{dE}{dX}\right]^{-1} dE. \tag{6}$$

The rate of energy loss $(dE/dX)$ can be calculated from Beth-Bloch function [10] as follows:

$$\frac{dE}{dX} = \frac{Z_1^2 e^4}{4\pi\varepsilon_0^2 m_e v^2} N Z_2 \ln\frac{2m_e v^2}{I}, \tag{7}$$

where $Z_1 e$ is the total charge of the incident particle with velocity $v$ slowing down in a medium of atomic number $Z_2$, $N$, atoms per unit volume, $m_e$ is the mass of the electron and $I$ is the mean ionization potential of the media.

The radon dose equivalent $D$ can be obtained from the relation [7]

$$D = 7.85 \times 10^{-6} T F C_0, \tag{8}$$

where $T$ is the exposure time and $F$ is the equilibrium factor that is given by (for CR-39 only) [11,15]

$$F = 0.04 \left[\frac{\rho}{\rho_0}\right]^{2.3}, \tag{9}$$

where $\rho$ and $\rho_0$ are the bare and filtered track densities registered by CR-39 track detector.

The combined standard uncertainty in the factor $K(U_K), C_0$ $(U_{C_0})$ and $D$ $(U_D)$ are given by [16]

$$U_K^2 = \sum_{i=1}^{i=4} \left(\frac{\partial K_i}{\partial R_i}\right)^2 (U_R)^2 + \left(\frac{\partial K_i}{\partial \theta c_i}\right)^2 (U_{\theta c})^2, \tag{10}$$

where $i$ relates to the isotopes $^{222}$Rn, $^{218}$Po and $^{214}$Po, respectively.

$$U_{C_0}^2 = \left(\frac{\partial C_0}{\partial K}\right)^2 (U_K)^2 + \left(\frac{\partial C_0}{\partial \rho_0}\right)^2 (U_{\rho 0})^2, \tag{11}$$

$$U_D^2 = \left(\frac{\partial D_i}{\partial F}\right) (U_F)^2 + \left(\frac{\partial D}{\partial C}\right)^2 (U_{C_0})^2. \tag{12}$$

The main purpose of this paper is to calculate the factor $K$ by means of $R$ and $\theta$ at different environmental conditions due to their diurnal variations as also to check the agreement between the experimental and the theoretical values of $K$ and to calculate the combined uncertainty for the parameters $K, C_0$ and $D$.

## 2. Experimental

Sheets of CR-39 and LR-115 track detectors were exposed to Rn gas in reference Rn chamber of the National Institute of Standards (NIS) in Egypt for different Rn concentrations. The track detectors are etched at the optimum etching conditions as: CR-39 is etched in 6.25 N NaOH at 70°C for 6 h while LR-115 is etched in 2.5 N NaOH at 60°C for 1.5 h [11–13]. Track density was counted using an image analyzer system in NIS.

## 3. Results and discussions

### 3.1 *Alpha particle range in air*

Range of alpha particles emitted from Rn and its short-lived daughters were calculated from eqs (6), (7) using a computer program (STOPOW) [17]. Air density

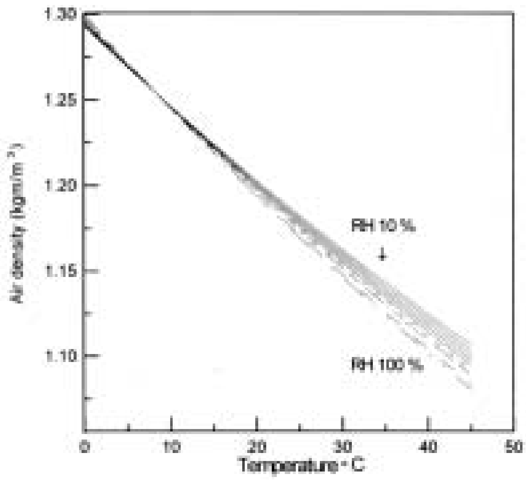


**Figure 1.** Air density as a function at $T$ and RH.

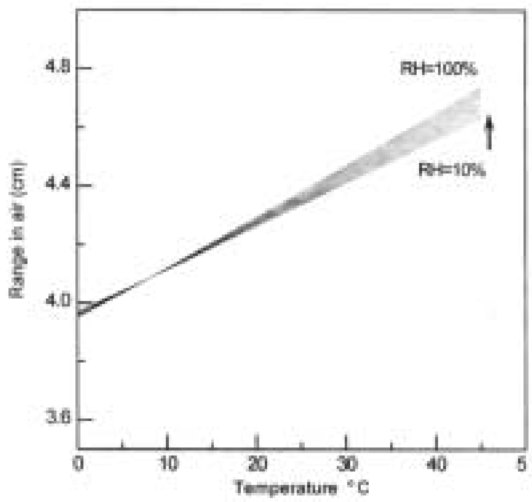


**Figure 2.** Range of alpha particles as a function of $T$ and RH.

affects the range of alphas becase the density depends upon the temperature ($T$), pressure ($P$) and relative humidity (RH) as shown by the formula

$$\rho_{\mathrm{a}} = \frac{0.348444P - \mathrm{RH}(0.00252T - 0.020582)}{273.15 + T}. \tag{13}$$

The dependence of air density ($\rho_{\mathrm{a}}$) on both $T$ (in the range of 0 to 45°C) and RH (from 10 to 100%) is represented in figure 1. It is obvious from this figure that, the density of air decreases as the air temperature or humidity increases. The range of alpha particles with energy 5.48 MeV emitted from Rn increases with increase in both $T$ and RH (see figure 2). Such increase in $R$ is obviously due to the reduction of air density.

### 3.2 *Determination of the calibration factor (K)*

The calibration factor $K$ of track detectors for Rn measurements can be obtained either by a calibration in a reference Rn chamber or calculated using eq. (3) by the mean of $R$ and $\theta_c$. Figure 3 shows the calculated values of $K$ as a function of air temperature (°C) and humidity for CR-39 track detectors. From the inspection of this figure, it is easy to notice that, the calibration factor of CR-39 is $T$ and RH-dependent and it increases if either $T$ or RH increases.

Figure 4 represents the variation between the measured [15] (dots) and calculated (line) track density of filtered CR-39 with different values of Rn concentrations under an environmental condition of $T = 25$°C and RH $= 50$%. It is obvious from this figure that a good agreement exists between the calculated and the measured values of the calibration factor of CR-39. Same treatment was performed using LR-115 track detectors. Figure 5 shows the comparison between the calculated and the measured track density and a good agreement is found between them.

### 3.3 *Uncertainty of $K, C_0$ and $D$*

Uncertainty in the measured calibration factor was deduced within the range of 5% due to the experimental uncertainty in the $\rho_0$. In the theoretical calculations, it is calculated from eqs (10)–(12). The uncertainty in $\theta_c$ is about 2° [12] and by assuming that the uncertainty in $R$ is about 1%, the combined uncertainty of $K$ was found to be about 4% of its value. To check the effect of the environmental conditions ($T$ and RH) on the uncertainty of $K, C_0$ and $D$, assuming that $T$ is

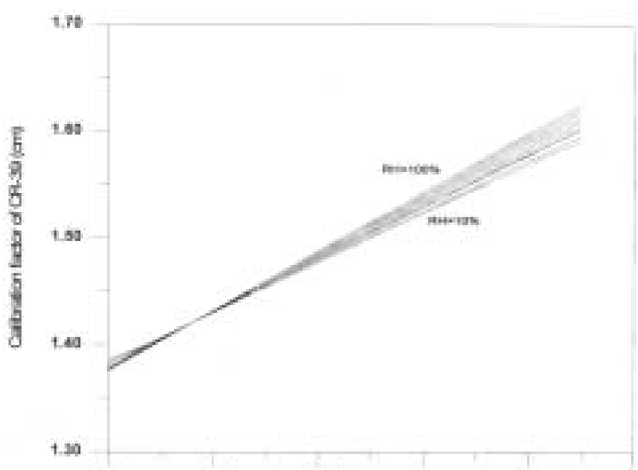


**Figure 3.** Dependence of CR-39 efficiency on $T$ and RH.

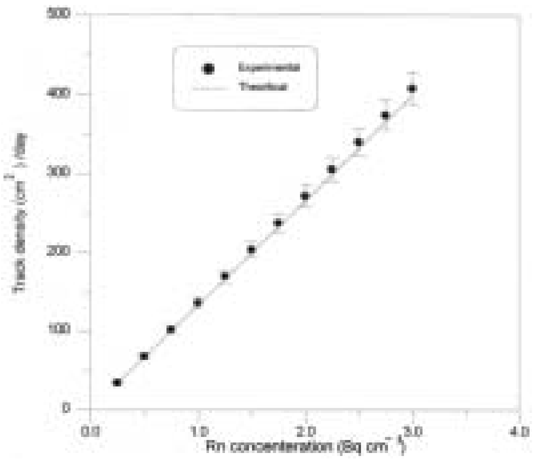


**Figure 4.** Comparison between measured and calculated CR-39 efficiency.

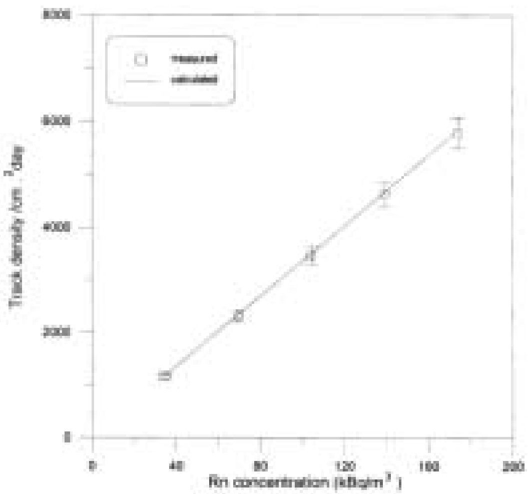


**Figure 5.** Comparison between measured and calculated LR-115 efficiency.

constant at 25°C and RH varies from 10 to 90% as a first step and RH constant as a second step at 50% and $T$ changes from 20 to 35°C the values of the uncertainties can be arranged as in table 2.

**Table 2.** Values of uncertainty at different conditions.

| Condition | $U_K$ (%) | $U_{C_0}$(%) | $U_D$ (%) |
|---|---|---|---|
| $T = 25°$C and $10 < \text{RH} < 90\%$ | 4 | 1.3 | 13 |
| RH = 50% and $20 < T < 35°$C | 10.96 | 3.4 | 17 |

## 4. Conclusion

Effect of environmental conditions on the air density and so on the range of alpha particles in air was determined and shown to be $T$- and RH-dependent. The Rn concentration–track density factor was estimated theoretically and experimentally and proved to be in excellent agreement with each other for the same environmental conditions. The experimental uncertainity is about 5% while in the theoretical calulations, its value is $T$- and RH-dependent and is given in table 2. The dependence of the uncertainity on $T$ is more obvious than its dependence on RH. From this work, it is suggested that the temperature is the important parameter that should be carefully adjusted in the radon chamber, which is used in the radon measurements.

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