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A fast method for the determination of the efficiency coefficient of bare CR-39 detector

Nidal Dwaikat [a,b,*], Mousa El-hasan [b], Masto Sueyasu [a], Wataru Kada [a], Fuminobu Sato [a], Yushi Kato [a], G. Saffarini [b], Toshiyuki Iida [a]

[a] Department of Electronics, Information Systems and Energy Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka, Japan
[b] Department of Physics, An-Najah National University, Nablus, Palestine

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ABSTRACT

A fast and simple method for the determination of the efficiency coefficient (η) of bare CR-39 detector is presented and discussed. The efficiency coefficient of bare CR-39 detector is then calculated by different ways and the obtained values are found to be comparable to each other. The average value of η of bare CR-39 is found to be 0.20 ± 0.01 tracks cm^{-2} day^{-1} per Bq m^{-3}.

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1. Introduction

Radon is a problem all over the world because it accounts to about 50% of natural radiation [1]. Radon measurement is routinely performed and many laboratories proposed different types of detector for its measurement. Measurement methods are divided into: (1) grab sampling which provides instantaneous measurements of radon or radon progeny in air; (2) continuous active sampling which involves multiple measurements at closely spaced time intervals over a long period; and (3) integrative sampling which collect data on radon levels over a fixed period of time. The suitable choice of detector depends on measurement method, purpose, sensitivity, cost, etc. In general radon detectors are divided into two types: (a) passive detectors, which do not need power in the sampling process, and the sampling method is done by the natural diffusion of the radon gas (b) active detectors, which need power supply in the sampling process. Among the passive detectors CR-39 (polyallyl diglycol carbonate, AADC; [$(C_{12}H_{18}O_7)_n$] is the simplest, cheapest, and most effective. CR-39 is a solid state nuclear track detector (SSNDs) and has been widely used in radon measurement. CR-39 detector is extensively used in various experiments in space sciences, nuclear science, fusion research, radiation detection, and identification of the nature of nuclear particles [2,3]. The technique of track etch is widely applied in Europe for measuring the total indoor radon level [4]. The sensitivity of CR-39 for radon radiation depends on: method used (bare or inside diffusion chamber), measurement period, etching process, filter type, calibration, etc. Though, CR-39 detector can respond to radon radiation for short-term measurement (e.g. one week), it is considered an integrated detector. In other words it gives more accurate results for long-term measurement.

Theoretical [5–7] and practical [8–16] methods for the determination of the efficiency coefficient of solid state nuclear track detectors (SSNTDs) have been introduced. Theoretical methods have a major drawback of fundamental importance: the equilibrium factor between radon and its daughter products is not exactly known. Also the plate out process of radon decay products on the detector surface has to be taken into account when calculating the theoretical efficiency coefficient.

This work presents a fast and simple method for determining the efficiency coefficient of bare CR-39 detector for alpha radiation measurement. By simple and fast we mean that the process can be done anywhere with simple tools and in less than 5 h. The exposure process was modeled by a geometrical model and associated with mathematical analysis. The counting of etch pits on CR-39 detector is an important process and different counting methods, manually and automated, were used. In the present work, a new automated counting system for counting etch pits on CR-39 detector is also described. The system is consisted from a film scanner for scanning the detector and software for analyzing and counting etch pits on track detectors. The system is simple, cheap, and reliable.

* Corresponding author at: Department of Electronics, Information Systems and Energy Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka, Japan. Tel.: +81 6 6850 4749; fax: +81 6 6879 7774.
E-mail address: nidaldwaiakt@yahoo.com (N. Dwaikat).

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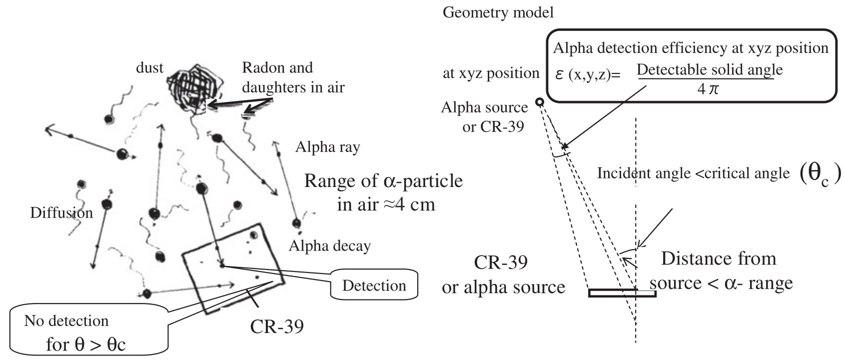

Fig. 1a. Geometry model for the determination of the efficiency coefficient of bare CR-39 detector used in radon measurement.

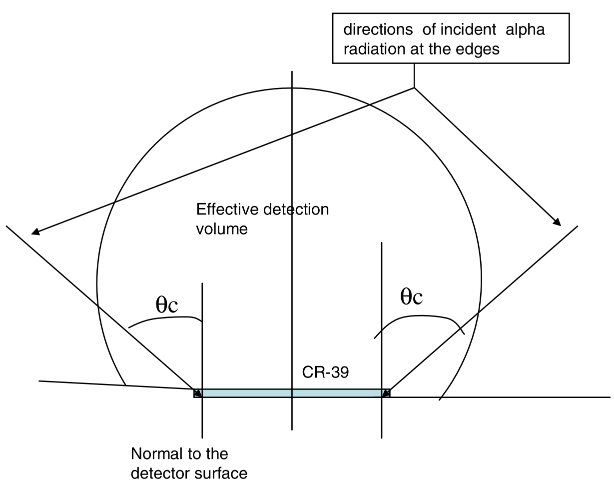

Fig. 1b. Effective detection volume of alpha particles around bare CR-39 detector.

2. Materials and methods

2.1. Geometrical model

As a gas, radon atoms are in random thermal motion and the emitted alpha particles from the decay of radon and their decay products hit the detector surface from different directions (see Figs. 1a and 1b). CR-39 detector has a critical angle of incidence for alpha particle detection. The alpha particles, to be registered by CR-39, must approach the detector from a distance less than the range of the alpha particle in air and with an angle less than the critical angle θc.

2.2. Irradiation of CR-39 with alpha particles

The experimental setup is shown in Fig. 2. CR-39 detector (10 × 10 cm) of thickness (1 mm) (Fukuvi Chemical Industry Co., Ltd., Japan) is used in this study. Six samples are irradiated with alpha particles from ^{241}Am of activity 150 nCi (Chiyoda Technol. Corporation, Japan). The energy of the emitted alpha particle from ^{241}Am is comparable to that emitted from radon. The distance between the sample and ^{241}Am alpha source is controlled by a vertical stage and varied from 0 to 5 cm, with equal increments of 1 cm. The exposure time is controlled by an automated shutter (see Fig. 2). In this experiment the model in Fig. 1b is inverted. The radiation source (^{241}Am) and the CR-39 detector are placed, respectively, at the pole and the center of the hemisphere (see Fig. 3).

2.3. Critical angle determination (θ_c)

The critical angle (θ_c) is defined as the angle above which no tracks can be registered. Samples of CR-39 detector were irradiated at different incidence angles, as Fig. 4 shows, for different distances. Polyethylene tube was used as a collimator. Part of the mouth of the tube was cut such that it can make an incline with angle θ (see Fig. 4). The angles ranged from 5° to 60°, with equal increments of 5°. However, no tracks were registered for angles larger than 55°. Thus, in this work, the value of θ_c is determined to be equal to 55° which is in agreement with the result reported in the literature [5].

2.4. Chemical etching

All the CR-39 samples are etched in 6.25 N NaOH at 70 °C for 3 h and subsequently washed with distilled water and dried in open air. During etching process a magnetic stirrer was used to achieve

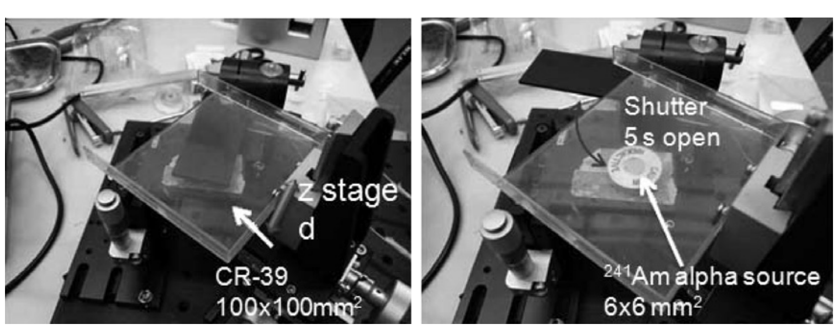

Fig. 2. Experimental setup for determination of efficiency coefficient of CR-39. An ^{241}Am source is used as an alpha source.

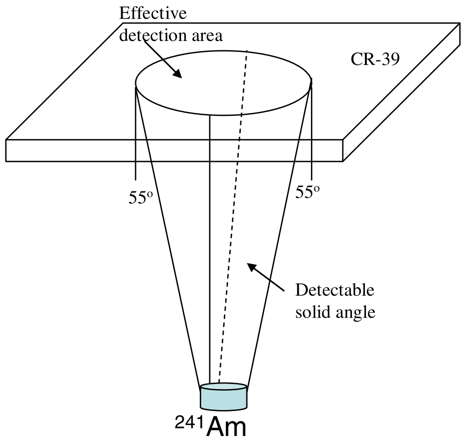

Fig. 3. Alpha radiation source (^{241}Am) is at the vertex of the cone and CR-39 is at the base of the same cone. No tracks were registered at distance ⩾5 cm.

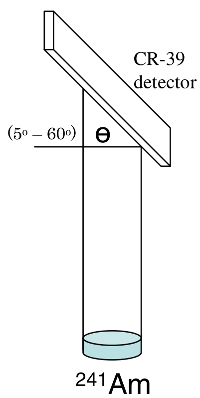

Fig. 4. Determination of the critical angle of CR-39 detector.

homogeneity and to prevent the accumulation of etchant material on the surface of detectors.

2.5. Counting system

An automated track counting system was developed and tested. The system consists of a film scanner and image-processing program. Fig. 5 shows a photographic picture of CR-39 samples set

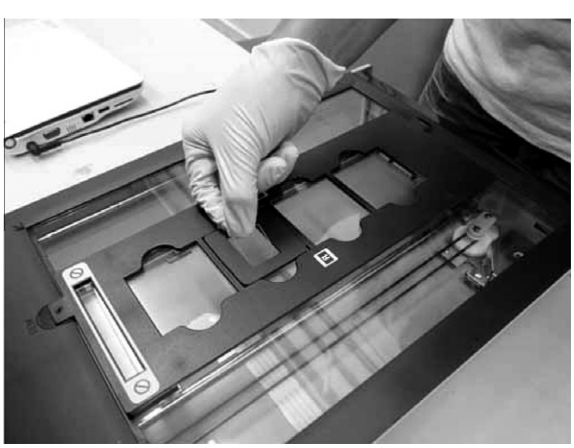

Fig. 5. CR-39 samples set on film scanner (CanoScan 8800F).

Table 1
Performance comparison between the present automated track counting system and the system reported by Yasuda et al.

Performance	The present system	System with CCD camera and microscope
Resolution	5 × 5 um^2/pixel	0.3 × 0.3 um^2/pixel
Scanning speed	1.2 s/cm^2	38 s/cm^2
Maximum of scanning area	56 × 220 mm^2	120 × 120 mm^2
Particle identification	No	Yes
Purpose	Radon monitoring, ion beam profile measurement	Cosmic ray detection, nuclear physics experiment
Space for use	On desk	In laboratory room
Cost	$200	Over $100,000

on the film scanner. Table 1 shows the characteristic comparison between the present system and that reported by [17]. The system reported by [17] uses a CCD camera and a microscope, while the present system uses only a film scanner, which renders it simple. As can be noted from Table 1, the present automated track counting system is simple, fast, cheap, reliable, and can be used in different fields. Moreover, the system can be used on desk. The resolution of the present system is lower than that reported by [17], but it is quite suitable for the purpose it is designed for (i.e. radon monitoring). The counting process can be accomplished by the following four steps:

(a) Setting of CR-39 sample on film scanner,
(b) Scanning process,
(c) Image processing with software,
(d) Particle analysis and etch pits counting.

To check the reliability of the system for radon monitoring, a 10 × 10 cm^2 CR-39 sample was irradiated with alpha particles from an ^{241}Am source and etched pits were counted with a film scanner. The counting time is about 10 min.

Table 2 compares the results of counting of etched pits measured with the film scanner and with a microscope and a result from calculation. The calculated value was determined from the activity of the used ^{241}Am alpha source, the irradiation time and the detector efficiency. It can be noted that measured and calculated results are in good agreement to within 2%.

Fig. 6 shows the relationship between the track density observed with the film scanner and the reference track density from calculation. It is clear from the figure that the film scanner system for CR-39 track detectors has good linearity in ~5 MeV alpha-particle measurements in the range of about 3000 tracks cm^{-2}.

2.6. Counting process

The tracks were counted manually and with an automated counting system. The automated counting system is calibrated before each counting session. The whole sample was scanned by the film scanner and the computer program analyzes the registered tracks and counts them. For manual counting, digital pictures were taken by a digital camera fitted with a microscope. Pictures

Table 2
Comparison of number of etched pits on CR-39 between measurement and calculation.

Method	Manual (with microscope)	Automatic (with film scanner)	Calculation
Number of etched pits (±16)	2436	2388	2.4 × 10^3

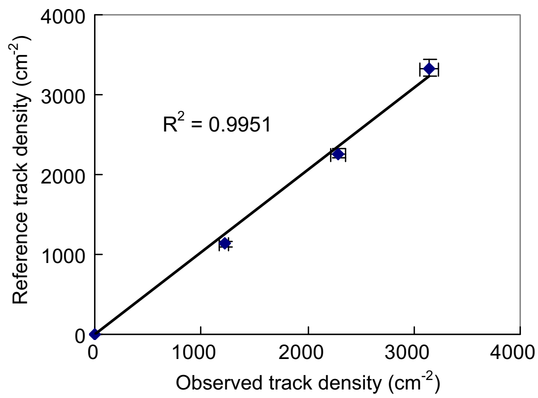

Fig. 6. Relation between reference tracks density and observed tracks density.

of fifteen fields of view, of known area, were taken and the average value of track densities (tracks/cm^2) was calculated for each detector. However, no tracks were counted at exposure distance of 5 cm. Background radiation was taken into account. Unexposed (fresh) sample was etched and the registered etch pits were counted. The average number of track density of fresh sample was subtracted from the average number of track densities of each exposed sample.

3. Results

3.1. Efficiency coefficient calculation by cumulative function

The efficiency coefficient (η) is expressed in cumulative form and was calculated, at each distance, by

$$\eta_i = \frac{\text{number of registered tracks}}{\text{number of emitted alpha particles}}, \tag{1}$$

$$\eta = \frac{1}{5}\sum_{i=0}^{4}\eta_i \tag{2}$$

and averaged over all distances. The efficiency coefficient was found to be equal to 0.20 ± 0.01 tracks cm^{-2} day^{-1}per Bq m^{-3}. The concentration of radon(C), tracks density, exposure time and the efficiency coefficient (η) are related via the following formula

$$\mathrm{C(Bq/m^3)} = \frac{\text{tracks density(tracks/cm}^3)}{\eta \times \text{exposure time(days)}} \tag{3}$$

3.2. Efficiency coefficient from critical angle

The efficiency coefficient (η) was calculated [2] by

$$\eta = 1 - \sin\theta_c \tag{4}$$

The efficiency coefficient (η) at θ_c = 55° was found to be 0.18 ± 0.01 tracks cm^{-2} day^{-1}per Bq m^{-3}.

3.3. Efficiency coefficient from integration over solid angle

The efficiency coefficient η is calculated by

$$\eta = \frac{1}{4\pi}\int\int d\Omega = \frac{1}{4\pi}\int_0^{55}\int_0^{2\pi}\sin\theta d\phi, \tag{5}$$

where Ω is the detectable solid angle.The calculated efficiency coefficient (η) using Eq. (5) was found to be equal to 0.21 ± 0.01 tracks cm^{-2} day^{-1}per Bq m^{-3}.

4. Conclusions

A simple and fast method for the determination of the efficiency of bare CR-39 using an ^{241}Am alpha source, as compared to the method that uses a standard source of radon gas, is presented. By simple and fast we mean that this method can be performed everywhere with simple tools and the process can be fully accomplished in less than 5 h. Once you determine the critical angle you can easily calculate the efficiency coefficient from Eq. (4) or Eq. (5). This is done by exposing the samples to alpha particles at different incidence angles from different distances. In this work, the critical angle, θ_c, is determined to be equal to 55°. Also, no tracks were observed at exposure distance $\geqslant$5 cm. Using the above findings, the detection region of alpha particles can be constructed and the effective exposure area on the detector can be determined. An example of the calculated alpha detection region above CR-39 detector is shown in Fig. 7a and b. The alpha detection region was constructed from data on alpha track images. A 5.5 MeV alpha particle from the farthest point loses energy of ~4.5 MeV in ~30 mm thick air layer and ~1 MeV in process of track formation in CR-39 detector. Circular and elliptical etch pits for angles of incidence equal to 0° (normal incidence) and θ_c are shown in Fig. 7b, on the left side and right side, respectively. The results of the efficiency coefficient of bare CR-39, obtained by different methods are summarized in Table 3. A simple and cheap automated counting system for etch pits on track detectors is also described. The film scanner scans the whole detector and special software, developed at Osaka University, analyses the registered tracks on CR-39 detectors. This system can also work with the software ImageJ

Table 3
Average values of the efficiency coefficient of bare CR-39 obtained by different methods.

	Cumulative function (tracks cm^{-2} day^{-1}per Bq m^{-3})	Critical angle (tracks cm^{-2} day^{-1}per Bq m^{-3})	Integration over solid angle(tracks cm^{-2} day^{-1}per Bq m^{-3})
η (±0.01)	0.20	0.18	0.21

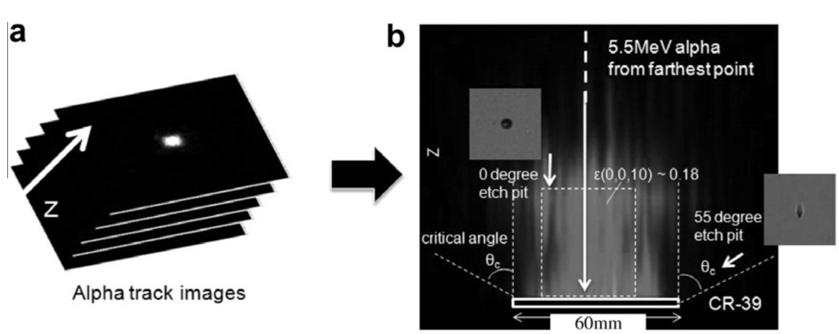

Fig. 7. Example of calculated alpha detection region above CR-39 detector. (a) Samples exposed at different distances, (b) detection region above CR-39 detector.

which is free to download from the web page of http://rsb-web.nih.gov/ij/download.html.

To this end, it is interesting to point out that the described method can be used to discriminate between the energies of the alpha-particles from different emitters. In normal incidence, for example, one varies the distance between the ^{241}Am source and the CR-39 and from data on etch pits, the CR-39 detector is thus calibrated for measuring different energies. This work is in progress and the details will be the subject of a forthcoming paper.

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