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Mathematical Calculation toFindtheBest Chamber andDetector Radii Used for Measurements theRange of □-Particle

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ABSTRACT

In this paper we design a new diffusion chamber which can used to record the number of alpha particle emitted by radon gas. A mathematical calculation is carried out to find the efficiency and sensitivityfor CR39 detector.. The software employed is the latest version of Monte Carlo code and SRIM2013. The result shows the influence of the initial energy on the detector parameter. Our calculations also show that, the best radius of detector is 1.5 cm and the best radius of the chamber is 3.5 cm for any experimental work i.e. the chamber radius should be as twice in size as the detector radius.

KEYWORDS:*detection probability, detection efficiency, CR39, LR115, Monte Carlo, SRIM2013*

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I. INTRODUCTION

Several techniques have been used to measure radon and its daughters. One of these techniques is the solid state nuclear track detector SSNTDs'. Such a technique has been increasingly used in passive time-integrated modes to measure the radon and throne in the environmental medium [1]. Nuclear Track Detectors is a plastic detector uses to register alpha particles in the form of tracks. That will become visible under the optical microscope upon suitable chemical etching of the SSNTDs', the most commonly used CR-39 [2]. SSNTDs are extensively used in environmental science and technology. Polyallyl diglycol carbonate, $C_{12}H_{18}O_7$, (CR-39) and made with cellulose nitrate materials (LR-115 II) track detectors are the most sensitive and popular detector for recording charge particles and neutrons [3-6]. Therefore, several studies have been carried out to determine the main factors which affect the sensitivity, etching conditions and the properties of the CR-39 and LR-115 polymer as a track detector[7-15]. CR-39 is widely used detector due to its high response with low uncertainty and suitable depth of chemical etching [16]. Any device used for relative measurement should be calibrated to convert the device reading to the value of measurements. The response of any radon dosimeter is the calibration factor in track density per unit integrated concentration The calibration factor can be used to determine the radon concentration, the mass and a real exhalation rate, the effective radium content, the radon diffusion coefficient and its diffusion length. The calibration factor or the response of SSNTDs' has a wide range depends not only on the geometry of the used configuration (filter and bare) but also on many parameters such as type of detector, detector efficiency and the dimension of dosimeter[17].The calibration factor may be determined experimentally or theoretically[18,19]. Several authors have presented various calculation methods for calibration factor determination such as analytical method, efficiency method, and the Mont Carlo method [18]. In this paperwe describe two methods to estimate the CR-39 detector efficiency and calibration factor based on, firstly, the mean critical angles calculation, and secondly, the Mont Carlo simulation by using the latest version of SRIM (SRIM2013) programs. A comparison between two methods is carrying on providinghigh accuracy relations. All results were compared with some experimental data.

II. THEORY

The efficiency in general can be define as the comparison of what is actually produced or performed with what can be achieved with the same consumption of resources. It is an important factor in determination of productivity. But in specific definition of the efficiency such as in our case, one can say is the probability of detection of charge particle by the detector or it is the ratio between the particles in solid angle φ to the total solid angle 4π.Let us assumed that a detector with area dA fixed on the surface of sphere and there is a radioactive source fixed on the center of the sphere, then by using spherical coordinate[20,21];

$$dP = \frac{dA}{4\pi r^2} = \frac{r^2 \sin\theta d\theta d\varphi}{4\pi r^2} = \frac{\sin\theta d\theta d\varphi}{4\pi} \quad (1)$$

$$\therefore P = \frac{1}{2}\int_{\theta_1}^{\theta_2} \sin\theta \, d\theta \; \theta_1 \le \theta \le \theta_2 \;, \quad 0 \le \varphi \le 2\pi \quad (2)$$

According to the definition of the critical angle; $0 \leq \theta \leq \theta_c$, we have

$$P = \frac{1}{2}\int_0^{\theta_c} \sin\theta \, d\theta = \frac{1}{2}(1 - \cos\theta_c) \qquad (3)$$

or in other word $\varepsilon = \frac{1}{2}(1 - \cos\theta_c)$ (4)

where θ_c is the critical angle. However some researcher used other relation for efficiency [17, 22].

$$\varepsilon = \frac{1}{2}(1 - \sin\theta_c^*) \qquad (5)$$

The detector efficiency (ε) depend on the critical angle (θc) for track registration[18],where $\theta_c^* = \frac{\pi}{2} - \theta c$

The response function $V(R_D)$ (tracks etched ratio) for a certain value of R_D written as.

$$V_{CR} = 11.6 \, R_D^{-0.464} \quad \text{for CR39} \quad (6)$$

The relation between the response function and the critical angle can be written as [23].

$$\cos\theta_c(x) = \frac{1}{V_{CR}} \Rightarrow \theta_c = \cos^{-1}\left(\frac{1}{V(R_D)}\right) \quad (7)$$

The mean value of the critical angle written as [23]

$$< \theta_c > = \frac{1}{E_i}\int_0^{E_i} \theta_c(E_{Res}) \, dE_{Res} \, forCR \qquad (8)$$

Where E_i the initial energy of alpha particle

III. RESULT AND DISCUSSION

To calculate the mean critical angle one need to find analytical expression for critical angle with alpha particle energy or any charged particle. This energy can express in term of the range of the particle in the detector (CR39 in present case). This is possible by making use of SRIM2013 and OriginPro8 to introduce the linear polynomial of the range versus energy.

$$R_D(E) = b_o + b_1 E_{Res} + b_2 E_{Res}^2 + b_3 E_{Res}^3 + b_4 E_{Res}^4 + b_5 E_{Res}^5 \quad \text{for CR} - 39 \qquad (9)$$

Where R(mm) the range of alpha particle , E_{Res}(MeV) is alpha particle residual energy in the (0.1 to 10 MeV), b_i (i=0...5) are fitting parameters and their values are in table (1). From equations (5-7) one can study the relation between θc andE_{RES}.as seen in figure (1). From this figure we can estimate an analytical relation between these parameters, which can be written as:

$$\theta_c(E_{Res}) = a_0 + a_1 E_{Res} + a_2 E_{Res}^2 + a_3 E_{Res}^3 + a_4 E_{Res}^4 + a_5 E_{Res}^5 + a_6 E_{Res}^6 + a_7 E_{Res}^7 + a_8 E_{Res}^8 + a_9 E_{Res}^9 \quad \text{for CR}$$

Where a_n parameters are listed in table (2). Equation (8)that describes the mean energy canbe describe by a polynomial form and can be written as;

$$< \theta_c > = a_o + \frac{1}{2}a_1 E_i + \frac{1}{3}a_2 E_i^2 + \frac{1}{4}a_3 E_i^3 + \frac{1}{5}a_4 E_i^4 + \frac{1}{6}a_5 E_i^5 + \frac{1}{7}a_6 E_i^6 + \frac{1}{8}a_7 i + \frac{1}{9}a_8 E_i^8 \frac{1}{10}a_9 E_i^9 forCR$$

Table (3) contains radon gas parameters; radon group energies and thorn group energies and the main values of θ_c together with the calculated values of efficiency. From figure (2) , we can see that the efficiency of the detector decreases as the energy of the charge particle increases. The critical angle is varying from $\theta_{c(\min)} = 65^o(\theta_c^* \approx 25^o)$ to $\theta_{c(\max)} \approx 72^o(\theta_c^* = 18^o)$ for CR-39 and the averge critical angle $\theta_c = 68.5^o$ or $\theta_c^* = 21.5^o$.Tables (4-8) show the detector efficiency for radon and throne with their progenies calculated by Monte-Carlo method. We are calculate the efficiency together with the energy of α-particle by two difference methods that are Monte-Carlo simulation method and Mean Critical Angle method, one can conclude that the behavior of the efficiency is the same for both methods of calculations as seen in figure (3). The calculation carried out in this work shows that the efficiency increases linearly with the detector diameter. Figure (4) shows that the efficiencies are almost equal if we used detector of radius 3cm, and the calculations by the two methods are combine togetherwhich is exactly equal to the range of alpha particle from radon in air. As a conclusion one can draw some points that are: the efficiency depend on the critical angle only, the critical angle depend on the detector type and the energy of α-particle,

b_o	$9.51342*10^{-4}$
b_1	0.00396
b_2	$2.69929*10^{-4}$
b_3	$1.37928*10^{-4}$
b_4	$-1.42234*10^{5}$
b_5	$5.04952*10^{-7}$

Table(1)

a_0	85.09436
a_1	-8.17899
a_2	3.77285
a_3	-2.0352
a_4	0.69029
a_5	-0.15045
a_6	0.02089
a_7	-0.00178
a_8	$8.46819*10^{-5}$
a_9	$-1.72089*10^{-6}$

Table(2)

Nuclide	$E_\alpha(Mev)$	$< \theta_c^* >$	ε_i
Radon group			
Rn^{222}	5.49	71.97	34.52
Po^{218}	6.00	70.97	33.63
Po^{214}	7.68	67.33	30.73
Thoron group			
Rn^{222}	6.28	70.30	33.14
Po^{216}	6.78	69.24	32.28
Bi^{212}	6.08	70.72	33.49
Po^{212}	8.78	64.98	28.85

Table(3)

Table(1-3) The best fit parameters

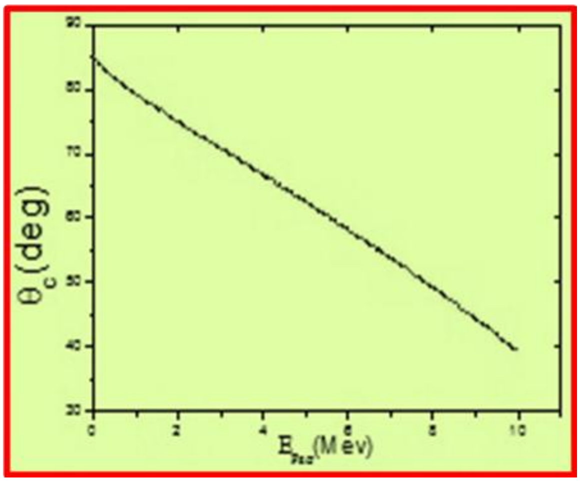

Figure (1) CR-39 Critical angle Vs α-particle energy

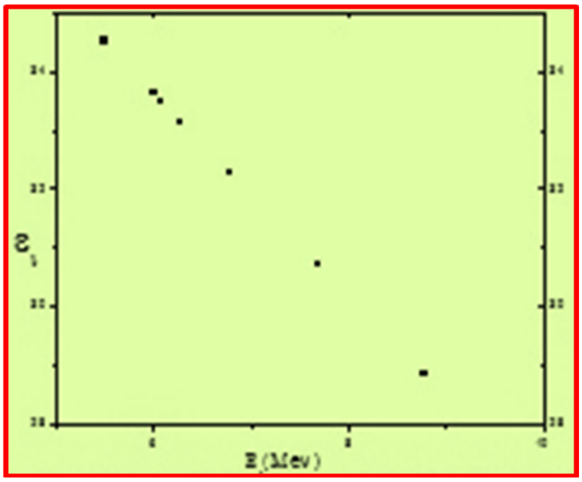
Figure (2) CR-39 Critical angle Vs α-particle energy

$D = 1.5\ cm\ \ h = 0\ \mu m$		
Nuclide	$E_{\alpha_i}(Mev)$	ε_i
Radon group		
Rn^{222}	5.49	15.88
Po^{218}	6.00	14.09
Po^{214}	7.68	9.82
Thoron group		
Rn^{222}	6.28	13.21
Po^{216}	6.78	11.82
Bi^{212}	6.08	13.83
Po^{212}	8.78	7.98

Table(4)

$D = 1.7\ cmh = 0\ \mu m$		
Nuclide	$E_{\alpha_i}(Mev$	ε_i
Radon group		
Rn^{222}	5.49	26.64
Po^{218}	6.00	24.42
Po^{214}	7.68	18.03
Thoron group		
Rn^{222}	6.28	23.22
Po^{216}	6.78	21.18
Bi^{212}	6.08	24.07
Po^{212}	8.78	14.95

Table(5)

$D = 3\ cm\ \ h = 0\ \mu m$		
Nuclide	$E_{\alpha_i}(Mev)$	ε_i
Radon group		
Rn^{222}	5.49	26.64
Po^{218}	6.00	24.42
Po^{214}	7.68	18.03
Thoron group		
Rn^{222}	6.28	23.22
Po^{216}	6.78	21.18
Bi^{212}	6.08	24.07
Po^{212}	8.78	14.95

Table(6)

Table(4-6) The best fit parameters

$D = 6\ cm\ \ h = 0\ \mu m$		
Nuclide	$E_{\alpha_i}(Mev)$	ε_i
Radon group		
Rn^{222}	5.49	35.15
Po^{218}	6.00	33.59
Po^{214}	7.68	28.21
Thoron group		
Rn^{222}	6.28	32.73
Po^{216}	6.78	31.28
Bi^{212}	6.08	33.35
Po^{212}	8.78	24.75

Table(7)

Nuclide	K_{θ_c}	K_{Monte} $D = 6cm$	K_{Monte} $D = 3cm$	K_{Monte} $D = 1.7cm$	K_{Monte} $D = 1.5cm$
Radon group	0.33	0.32	0.22	0.14	0.13
Thoron group	0.49	0.46	0.31	0.19	0.17

Table(8)

Table(7-8) The best fit parameters

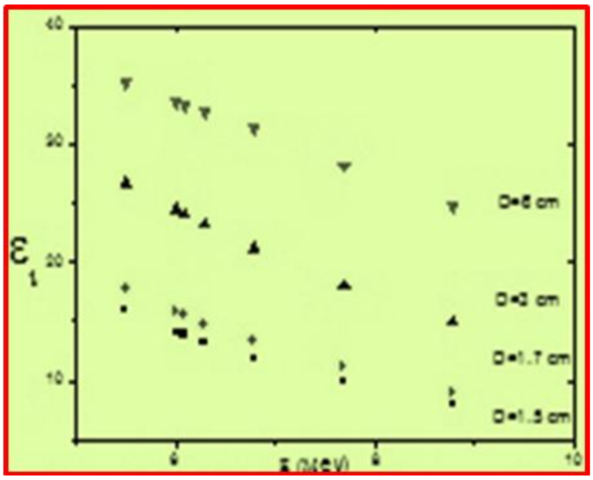

Figure (3) CR-39 efficiency Vs α-particle initial energy By using Mount-Carlo method only

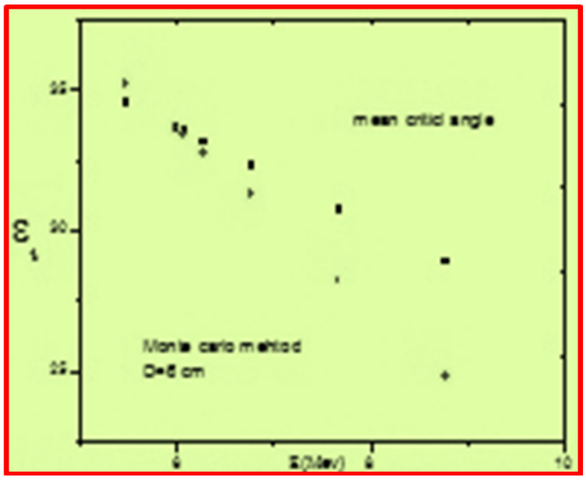

Figure (4) efficiency Vs α-particle initial energy By using Mount-Carlo and Mean Critical angle method

4. Conclusion

The radon atoms inside the chamber can decay and create new progeny, which mayfurther decay whilst in the air volume of the chamber or after their deposition on the chamberwall. There are three types of alpha-particle emitters in air (Rn, non-deposited fraction ofPo and Po), and those on the chamber wall (deposited fractionPo and Po) and emitters deposited on the detector itself(plate outPo and Po). Based on the above one can conclude that the calculations by two method are almost the same when the detector radius equal 3 cm. We find that the best radius of detector is 1.5 cm and the best radius of the chamber is 3.5 cm for any experimental work i.e. the chamber radius should be twice in size as the detector radius.

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