



International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS)

www.iasir.net

Calculation of the Probability for CR-39 Alpha Particles Detectors

Ali Farhan Nadir, Noori H.N. Al-Hashimi, Abdul Ridha.H.Subber

Department of Physics, College of Education for Pure Science,
University of Basra, Basra, IRAQ

Abstract: Numerical assessments of radon exhalation from soil and air samples together with the detection probability of alpha particles by the two most commonly detectors known as CR39 was the first objective of this work. The SRIM2013 technique has been applied to calculate the energy dependent of alpha particles registration probability. The detection probability for CR39 is different for each radioactive chain, exposition of each detector. It is found that the calculated values of alpha particle ranges and detection probabilities are not the same in two versions, SRIM1992 and SRIM2013, of software.

Keywords: energy, alpha range, detection probability, SRIM, CR39

I. Introduction

Detector sensitivity for radon measurements with CR-39 detector was given by many authors see for example [1-5]. Radon diffusion, transport through different media, and detected is a complex process and is effected by several factors. However, usually some of information which is used as input parameters in presented program was missing. For example, removed layer is very rarely given. Somewhere, etching conditions or chamber dimensions was not stated. For these reasons it was difficult to perform comparison with experimental results.. Radon concentration normally determined using diffusion chamber and techniques based on using CR-39 detector. This technique necessitates a calibration with standard sources of radon concentration. To evaluate the concentration in terms radon and thoron with their progenies present in air. The probability for alpha particles emitted by radon, thoron and their daughters and registered on the detector are calculated [6]. Detection efficiency is another important property of radiation detectors. As the general meaning implies, detection efficiency represents the probability of detection for a single radiation quantum. An accurate and precise calibration for detection efficiency is very important for quantitative measurement of an unknown radiation source [7]. The detection efficiency is obtained directly from the geometry factor, i.e. the ratio of the solid angle per 2π or 4π . The detection efficiency is depended on both radiation interaction with mater and size of a detector. Charged particles (electron, proton, alpha) interact more easily than neutral ones (X-ray, gamma-ray, neutron) and give high efficiencies. Theoretically, if we could create detectors with large enough volumes, we could always detect 100 % of the particles reach the detector surface. However, this is either impractical or even impossible, e.g. semiconductor crystals just cannot be grown large enough to be 100 % efficient for high energy photons. Neutrino detectors are already built in mineshafts. This is why the concept of detection efficiency was created. Not all particles can be detected, but if the proportion of detected particles is known, the number of particles can be calculated from the number detected ones [7]. The main objective of the present work is to apply the solid angle definition to the calculation of detection probability of CR39 detector.

II. Theory

The CR-39 plastic track detector is a C₁₂H₁₈O₇ polymer with density 1.3 g/cm³. This detector has characteristic response to every type of particles from any nuclear reactions. Charged particles are registered directly, and neutrons are detected through the secondary recoil particles or nuclear reactions. Particle tracks on the detector became visible after etching and are investigated using a microscope. α -events in CR-39 detector do not exceed one per few cm² and the investigation of yields for reaction from thick samples is difficult, because charged particles come to the detector with a large energy spread and their tracks have different diameters. This low background allows experiments to carry out using very long exposures. The main parameter of track detector is the ratio of etching rates at the start of the track and at the end of the track (V_T/V_B). This ratio is a function of energy loss (stopping power, dE/dx). Track diameter is related to this ratio by a parametric equation [8]. The dependence of track diameter on dE/dx makes possible identification of a particle. The critical angle of registration ($\theta_c = \arcsin(V_B/V_T)$) is also an important characteristic. θ_c is the minimum angle of particle incidence on the detector in which track formation is possible. It is easy to show that the detection efficiency for a given type of particles is determined by the relation [9]. The solid angle can be defined as [10]:

$$d\Omega = 2\pi \sin \theta \, d\theta \quad (1)$$

Then, the total solid angle is:

$$\Omega = 2\pi \int_0^{\theta_c} \sin \theta \, d\theta = 2\pi (1 - \cos \theta_c) \quad (2)$$

Where θ_c is the critical angle, which is defined as the angle between the vertical on the detector surface and the vector represent the range of the particle inside the detector [10].

The probability P of an alpha particle emitted from radioactive sources at the center of a sphere and hits the detector of area dA mounted on the surface of the sphere is defined as the ratio between solid angle to the total solid angle 2π and written as [11].

$$P = \frac{2\pi (1 - \cos \theta_c)}{2\pi} = 1 - \cos \theta_c \quad (3)$$

The probability depends only on the critical angle which is depends on the energy of alpha particle emitted from the source and traveling a distance (x) in the air to reach the detector. This means that the critical angle is a function of the distance x, in other word we can rewrite the probability as [12];

$$P = \frac{2\pi (1 - \cos \theta_c)}{2\pi} = 1 - \cos \theta_c (x) \quad (4)$$

The total distance between the detector and the source is $R_0 = x = n\Delta x$; divided by $\Delta x = 1 \mu\text{m}$ and then we can calculate the total probability by [13];

$$P_{\text{TOT}} = \sum_{x=0}^{x=\Delta x} [1 - \cos \theta_c(x)] + \sum_{x=\Delta x}^{x=2\Delta x} [1 - \cos \theta_c(x)] + \dots + \sum_{x=(n-1)\Delta x}^{x=n\Delta x=R_0} [1 - \cos \theta_c(x)] \quad (5)$$

Divide and multiply the RHS by Δx

$$P_{\text{TOT}} = \frac{1}{\Delta x} \int_0^{\Delta x} [1 - \cos \theta_c(x)] + \frac{1}{\Delta x} \int_{\Delta x}^{2\Delta x} [1 - \cos \theta_c(x)] + \dots + \frac{1}{\Delta x} \int_{(n-1)\Delta x}^{R_0} [1 - \cos \theta_c(x)] \quad (6)$$

$$P_{\text{TOT}} = \frac{1}{\Delta x} \int_0^{R_0} [1 - \cos \theta_c(x)] dx \quad (7)$$

$$P_{\text{TOT}} \Delta x = \int_0^{R_0} [1 - \cos \theta_c(x)] dx \quad (8)$$

The CR39 detector is sensitive to all energy range of alpha particles, [12].

$$P_i^{\text{CR}} = \frac{1}{\Delta x} \int_0^{R_0} [1 - \cos \theta_c(x)] dx \quad \text{for CR - 39} \quad (9)$$

The previous integral in equation (9) written in the form;

$$P_i^{\text{CR}} \Delta x = R_0 - \int_0^{R_0} \cos \theta_c(x) dx \quad (10)$$

To calculate the integral in equation (10); one needs to find an analytical expression for the relation of critical angle with rang in alpha particle in air [7]. This procedure similar to procedure in Ref.[10]. The value x taken to be vary from 0 to R_0 graduated by step of $\Delta x = 1\mu\text{m}$. Using curve fitting to the function by OriginPro8 software then, create the seven degree polynomial, which is shown in Figure (1) and written as;

$$\cos \theta_c(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6 \quad (11)$$

$$\int_0^{R_0} \cos \theta_c(x) dx = a_0R_0 + \frac{1}{2}a_1R_0^2 + \frac{1}{3}a_2R_0^3 + \frac{1}{4}a_3R_0^4 + \frac{1}{5}a_4R_0^5 + \frac{1}{6}a_5R_0^6 + \frac{1}{7}a_6R_0^7 \quad (12)$$

$$P_i^{\text{CR}} \Delta x = R_0 - (a_0R_0 + \frac{1}{2}a_1R_0^2 + \frac{1}{3}a_2R_0^3 + \frac{1}{4}a_3R_0^4 + \frac{1}{5}a_4R_0^5 + \frac{1}{6}a_5R_0^6 + \frac{1}{7}a_6R_0^7) \quad (13)$$

III. Result and Discussion

Table (1) shows the best fit parameter of a_n in equation (11). From the function in equation (13) one can calculate the detection probability for CR39 detector in the energy range 5.49 MeV to 8.78 MeV (radon and thoron alpha energies) as shown in table (2). Table (2) also shows at the side of the calculated detection probabilities, the range inside the CR39 detector. While Table (3) contains the same parameters used by reference [12] which is calculated using SRIM1992. There are differences between the two set probabilities, the probabilities using SRIM2013 are less than those of SRIM1992, and this due to adding CO_2 to the air composition. These probabilities are essential for the calculation of radon gas concentration. Also, there are differences in the ranges for the same alpha energy. This means that, one should use SRIM2013 to get precise results for radon and thoron concentrations. The relation between detection probability of CR39 detector and alpha particle energy is shown in Figure (2). After the calculation of detection probability using SRIM software, we applied these values in the fallowing equation:

$$\rho_c^{\text{CR}} = \sum_{i=1}^3 k_i P_i^{\text{CR}} R_i + \frac{A_c^{220}}{A_c^{222}} \sum_{i=1}^4 k_i P_i^{\text{CR}} R_i \quad (14)$$

The calculation steps for the constants in the above equation are presented in table (4). As a conclusion in this paper we reported a newly developed application of SRIM2013 in the calculation of alpha particle range in CR39 detector and the detection probabilities for different values of alpha energies. We found that, the range of alpha particles and detection probabilities calculations using SRIM2013 are inconsistence with those of

SRIM1992. These differences are due to the change in the air and detectors composition parameter in the program.

a_0	a_1	a_2	a_3	a_4	a_5	a_6
0.7866	-0.01984	4.38713×10^{-4}	-5.89552×10^{-6}	-1.94925×10^{-8}	1.26436×10^{-9}	-8.67955×10^{-12}

Table (1) a_n the best fit parameters

Nuclide	Energy (Mev)	Range (cm)	$P_i^{CR} * 10^{-3}$
Rn-222	5.49	3.05	1.2698
Po-218	6.00	3.50	1.5320
Po-214	7.68	5.15	2.6215
Rn-220	6.28	3.76	1.6891
Po-216	6.78	4.24	1.9937
Bi-212	6.08	3.57	1.5759
Po212	8.78	6.36	3.5328

Table 2 the detection probability for CR39 detector

Nuclide	Energy (Mev)	Range (cm)	$P_i^{CR} * 10^{-3}$
Rn-222	5.49	3.9	2.871
Po-218	6.00	4.65	3.383
Po-214	7.68	6.62	4.440
Rn-220	6.28	4.80	3.391
Po-216	6.78	4.75	3.433
Bi-212	6.08	5.45	3.527
Po212	8.78	8.36	5.711

Table (3) Detection probability for CR39 calculated by SRIM2013 detector used in reference [5]

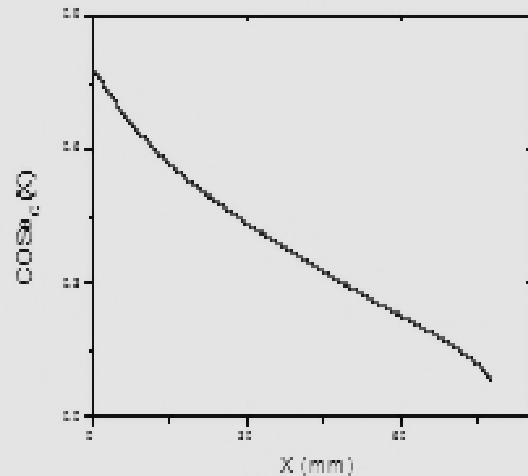


Figure (1) $\cos \theta_c(x)$ VS range of α -particles in air for CR-39 detector.

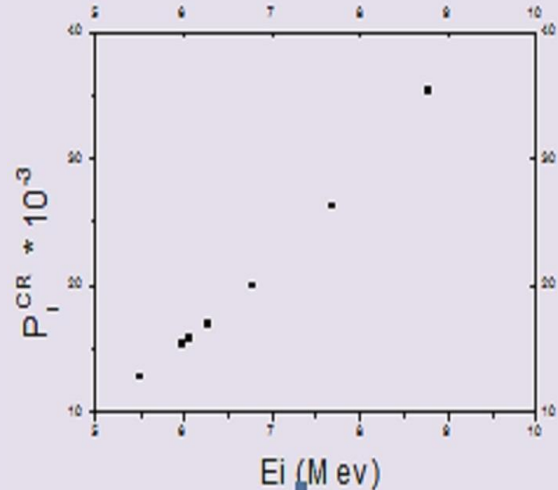


Figure (2) Detection probability VS alpha energy for CR39

Nuclide	E_i	R_i	K_i	P_i^{CR}	$K_i P_i^{CR} R_i$
Rn-222	5.49	3.05	1	$\frac{12.69}{8}$	38.73
Po-218	6	3.5	1	15.32	53.62
Po-214	7.68	5.15	1	$\frac{26.21}{5}$	135.01
				Σ	227.36

Table (4a) calculated parameters of equation 14

Nuclide	E_i	R_i	K_i	P_i^{CR}	$K_i P_i^{CR} R_i$
Rn-220	6.28	3.76	1	16.891	63.51
Po-216	6.78	4.24	1	19.937	84.53
Bi-212	6.08	3.57	0.36	15.759	20.25
Po-212	8.78	6.36	0.64	35.328	143.80
				Σ	312.10

Table (4b) calculated parameters of equation 14

REFERENCES

- [1] D. Nikezic, K. N. Yu,² and J. M. Stajic¹; " Computer program for the sensitivity calculation of a CR-39 detector in a diffusion chamber for radon measurements"; REVIEW OF SCIENTIFIC INSTRUMENTS 85, 022102 (2014)
- [2] D. Nikezic and K. N. Yu; "Computer program TRACK_TEST for calculating parameters and plotting profiles for etch pits in nuclear track materials"; Comput. Phys. Commun. 174, 160 (2006)
- [3] D. Nikezic and K. N. Yu; "Computer program TRACK_VISION for simulating optical appearance of etched tracks in CR-39 nuclear track detectors"; Comput. Phys. Commun. 178, 591 (2008)
- [4] A. H. Ismail and M. S. Jaafar; "Interaction of low-intensity nuclear radiation dose with the human blood: Using the new technique of CR39NTDs for an in vitro study"; Nucl. Instrum. Meth. Phys. Res. B69, 437 (2011).
- [5] D. S. Pressyanov; "Radon progeny distribution in cylindrical diffusion chambers"; Nucl. Instrum. Meth. A 596, 446–450 (2008).
- [6] M. A. Misdaq , F. Aitnough, H. Khajmi, H. Ezzahery, S. Berrazzouk,"A new method for *evaluating radon and thoron* α –activities per unit volume inside and outside various natural material samples by calculating SSNTD detection efficiencies for the emitted α –particles and measuring the resulting track densities", Applied Radiation and Isotopes 55(2001) 205-213.
- [7] Soo Hyu Byun, , Radioisotopes and radiation methodology, Med. Phys. 4R06/6R03, version 2014-15,ch. 3, Master university, Canada.
- [8] Samogyi G., Shalay S.A. Nucl. Instr. And Mem., 109, (1973), N 2, 211.
- [9] R. L. Fleisher, P. B. Price, R. W. Walker. Nuclear Tracks in Solids. Principles and Applications. University of California Press, 1975, v. 1.
- [10] M. A. Misdaq, A. Bakhchi, A. Ktata, A. Merzouki, N. Youbi,"Determination of uranium and thorium contents inside different materials using track detectors and mean critical angles", Applied Radiation and Isotopes 51(1999) 209-215.
- [11] S. A. Durrani, R. K. Bull, Solid state nuclear tracks, method and application, International series in natural philosophy.
- [12] M. A. Misdaq. C. Satif (1996) ,"A new metod for studying the influence of pollution and soil nature on the radon emanation from water samples", Jointly published by Elsevier Science S. A., Lausanne and Akademiai Kiado, Budapest Vol.207, No.1(1996)107-116.
- [13] M. A. Misdaq, S. Berrazzouk, A. Elharti, F. Ait Nouh, W.Bourzik (2000),"The hydraulic exchanges between the main water reservoirs of the Moroccan Middle Atlas region measured by solid state nuclear track detectors", Journal of Radioanalytical and Nuclear Chemistry, Vol. 246,No. 2 (2000)395-401.
- [14] Ali Farhan Nader; Abdul R.H. Subber; Noori.H.N. Al-Hashimi, An Analytical Approach is Developed to Estimate the Values of Range of Alpha Particles Emitted from Radon Gas, IOSR Journal of Engineering (IOSRJEN), ISSN (e): 2250-3021, ISSN (p): 2278-8719 Vol. 04, Issue 09 (September. 2014), ||V1|| PP 51-55.
- [15] Ali Farhan Nader, Abdul .R.H. Subber, Noori H.N. Al-Hashmi, Numerical and analytical calculations of efficiency and calibration factor for CR-39 detectors in the chamber diffusion by using Monte- Carlo method and the mean critical angle, Scholars Research Library,2014, 5(5):23-30.