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RANGE OF ALPHA-PARTICLES IN SSNTD'S (CR-39)

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ABSTRACT

In the present work, a newly constructed irradiation system has been designed to get alpha particles with different energy values from ^{241}Am radioactive source. The range of these alpha particles in solid state nuclear track detectors SSNTD's (CR-39) have been determined using the over-etched track profile technique. The experimentally obtained range values were found to be in good agreement with the theoretical ones.

INTRODUCTION

In recent years SSNTD's achieve a great success in numerous fields due to their excellent properties in data analysis. These polymeric detectors, being highly sensitive **[El-Asser et al., (2000)]**, have been extensively used in long-term exposure experiments without any additional cost and relatively low background events **[Ibrahim et al., (2000)]**, such as radon-level determination **[Enge, (1980); Barillon and Chambaudet, (2000)]**, alpha-particle methodology **[Espinosa and Silva, (2001)]**, measuring of ionizing radiation **[Zhitariuk et al., (1996)]**, dosimetry application **[Waheed et al., (1990)]** and observation of high energy particles in cosmic rays.

The aim of the present study is to determine experimentally the range of alpha particles of different energies in CR-39 polymeric detectors. The bulk and track etching rates V_T, V_B and the response functions of these detectors V have been also determined. A comparison between the experimentally obtained values and the corresponding theoretically calculated ones **[Almâsi and Somogyi, (1981)]** are given. A

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new irradiation system has been designed to get α-particles with different energy values.

Irradiation Facility

Figure (1) represents the newly constructed irradiation system which has been designed to get α-particles with different energy values, it consists of the following three main parts:

(1) An alpha ^{241}Am point thin source from Spectrum Techniques, Inc., Oak ridge, USA. It is a thin layer of ^{241}Am electroplated on a stainless steel disk, its width a 4 mm diameter, and its activity was 0.98 ± 0.05 μCi.

A source of one μCi activity generally emits ~ $2x10^4$ particles per second.

(2) Distance collimator adapters with 0.5 mm hole diameter and with suitable different heights (35, 30, 25, 20, 15, 10, 5 mm) have been used, the air lengths inside the collimators at (NTP) reduce the energy of 5.486 MeV from ^{241}Am source (Abou El-Khier et al., 1987; Amrani and Belgaid, 2001).The collimators heights reduce the alpha energy to 1.60, 2.34, 2.97, 3.55, 4.08, 4.58, 5.05 MeV respectively.

(3) The commercially known Polyallyl diglycol carbonate (PADC) SSNTD's CR-39 obtained from American Technical plastic, Inc. CR-39 is made from the monomer allyl-diglycol carbonate (diethlene-glocal) by polymerization in the form of highly cross-linked homopolymers $C_{12}H_{18}O_7$. Its density is about 1.31 g/cm^3.

The monomer is polymerized using peroxide initiators as a catalytic agent at elevated temperature (ranging between 50-70°C). The resulting plastic is totally amorphous, optically transparent, extremely sensitive to bath light and heavy charged particles, and highly isotropic and homogenous.

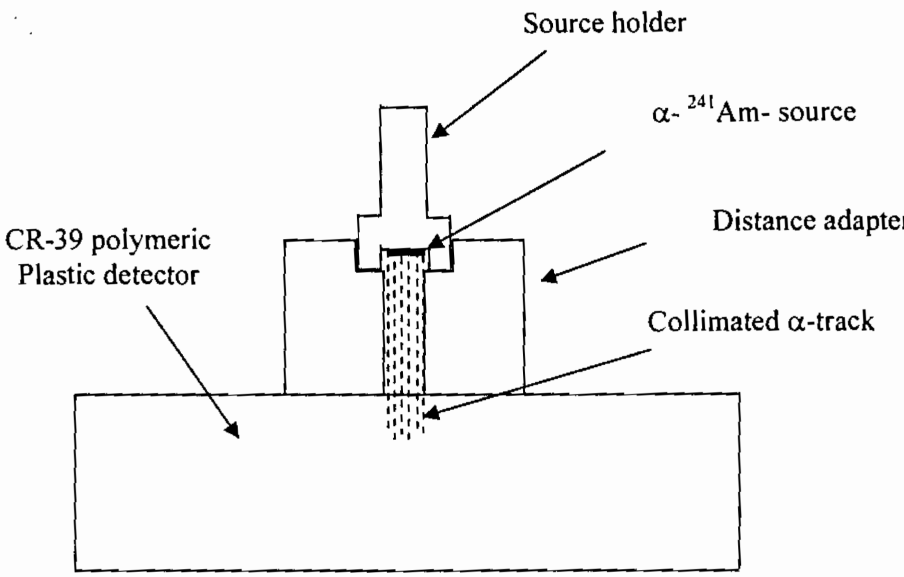

Fig.(1a): Irradiation system with normal incidence of α-particles.

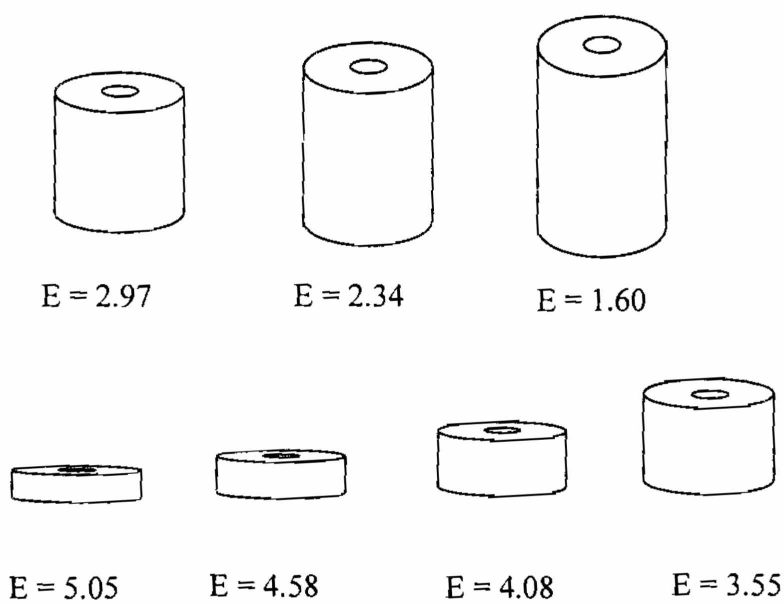

Fig.(1b): Distance adapters used for getting different α-energies (MeV).

EXPERIMENTAL PROCEDURE

The detector samples were cut into square pieces 1.5 x 1.5 cm^2 and then exposed to α-particles with energies: 5.05, 4.58, 4.08, 3.55, 2.97, 2.34 and 1.60 MeV. Suitable irradiation time was chosen to get a relative fixed number of tracks per cm^2 **[Hassib et al., (1995)]**. Densities of less than ~ 10^5 tracks per cm^2 are usually desirable.

The irradiated samples were then chemically etched under optimum conditions in 6.25 N NaOH solution at 70±1°C for large enough time to get tracks in spherical phase. The etched detector samples were then rinsed in flowing distilled cold water for some 10-20 min, the cold water quickly stops the etching of the left over NaOH on the tracks **[Enge, (1980)]** ; the samples were then dipped for few minutes in 3% acetic acid solution, and finally they were left to dry after washing with distilled water **[Hafez et al., (1991); Hafez and Hussein, (2001)]**.

The track diameters were measured with a calibrated 16X-eyepiece screw micrometer, each division corresponding to 0.16 μm. the eyepiece was attached to 640X transmission optical microscope.

Bulk Etching Rate (V_B)

The V_B is corresponding to the etching rate of the undamaged detector material. It depends, beside the detector composition, on the etching conditions i.e., temperature and concentration of the etching solution and etching time (t) **[Barillon et al., (1997)]**.

V_B can be determined by the mass difference method given by the following relation **[Waheed et al., (1990); Ibrahim et al., (2000)]**.

$$V_B = \frac{\Delta m}{2\rho A t} = \frac{h}{t} \qquad (1)$$

where (Δm) is the dissolved mass of the detector of surface area (**A**), density (ρ) in time (**t**). **h** is the thickness of the removed layer from CR-39.

Track Etching Rate (V_T)

The V_T corresponds to the specific etching rate of the damaged detector. It depends on another factors besides the above mentioned etching conditions, namely on the sensitivity of the detector material, irradiation conditions and post-irradiation conditions; and especially depends on the energy loss (REL) deposited along and around the trajectory of the ionizing particle.

In the framework of the δ-ray theory, the maximum radial dimension, r, of the damaged zone surrounding the ion's trajectory remains less than 10°A. In contrast, for energies between 0.1- 10 MeV, the total range R of alpha particles in the polymeric detectors material is typically from 1 to 100 micrometers [**Barillon et al., (1997)**].

In our work the track etch rate V_T was estimated by using the relation:

$$V_T = V_B \frac{h^2 + r^2}{h^2 - r^2} = V_B \frac{1 + (r/h)^2}{1 - (r/h)^2} = V_B \frac{1 + (D/2h)^2}{1 - (D/2h)^2} \tag{2}$$

Where D=2r is the surface diameter of an α-particle track, while h is the thickness of the removed layer from the detector surface.

Response (Sensitivity) Function (V)

Response function (V) of CR-39 detectors depends on the incident particle's mass, energy and is defined by the ratio between track & bulk etching rates [**Fleischer et al., (1975)**]:

$$V = \frac{V_T}{V_B} = \frac{1 + (D/2h)^2}{1 - (D/2h)^2} = \frac{1 + (D/2V_B t)^2}{1 - (D/2V_B t)^2} \tag{3}$$

Range Determination

Alpha Range (R) has been calculated at various energies using the over-etched track profile method [**Fromm et al., (1993)**] based on track-diameter kinetics [**Somogyi and Szalay, (1973)**], where a thickness or range (R) is assumed to etch out a layer from the detector surface during an etching time (t_R) forming α-tracks; the track diameter (D) can be measured using an optical microscope with a calibrated eyepiece. The diameter square of the track (D^2) is linearly related to the range (R) and the etching time (t) by the following relation

$$D^2 = 8\,(V_B R - t_R V_B^2)\, t + 4(V_B^2\, t_R^2 - R^2) \qquad (\text{where } t >> t_R) \tag{4}$$

From Eq. (4) the range (R) is given by:

$$R = \frac{S}{16V_B} - \frac{I}{S}V_B \qquad (5)$$

where S is the slope = $8(V_B R - t_R V_B^2)$ (6)

and I is the intercept with (y) axis and it equal to:

$$I = 4(V_B^2 t_R^2 - R^2) \qquad (7)$$

RESULTS AND DISCUSSION

The bulk etch rate (V_B) of the CR-39 detector was determined by using the mass difference method given by Eq. (1). By plotting the mass difference (Δm) in μgm via the etching time (t) we get a straight line as shown in Fig. (2). From the slope of this straight line, V_B was calculated and it was found to be equal 1.3 ± 0.1μm/h. This result agrees with other authors such as **[Somogyi et al., (1976); Somogyi, (1990); Barillon et al., (1997); Hafez et al., (1991); Ibrahim et al., (2000); Nikezić and Janiijev, (2002)]**.

In case of α-particle normally incident on the detector CR-39, the resulted track opening in plastic foils takes the shape of circles whose diameter is strongly dependent on the energy of the incident particles as long as the etching conditions are fixed. The measurements were taken, for each energy, at different etching conditions. The measurements of the track diameters (D) were taken at different etching times (t), which must be large enough in order to get tracks in spherical phase. A perfectly constant circular mouth of maximum area (20-30 tracks) has been used through all the measurements of the energy track diameter. Also the background tracks were easily distinguished and discarded.

Fig. (3) represents the ratio between D^2 and t for one of the selected α-particle energies namely 3.55 Mev. This figure consists actually of two parts, representing the relation before and after the end of the range in the detector. The upper part is a straight line with a slope $S \approx 8V_B R$ (Eq. 6) and its intercept with the y-axis $I \approx -4R^2$ (Eq. 7).

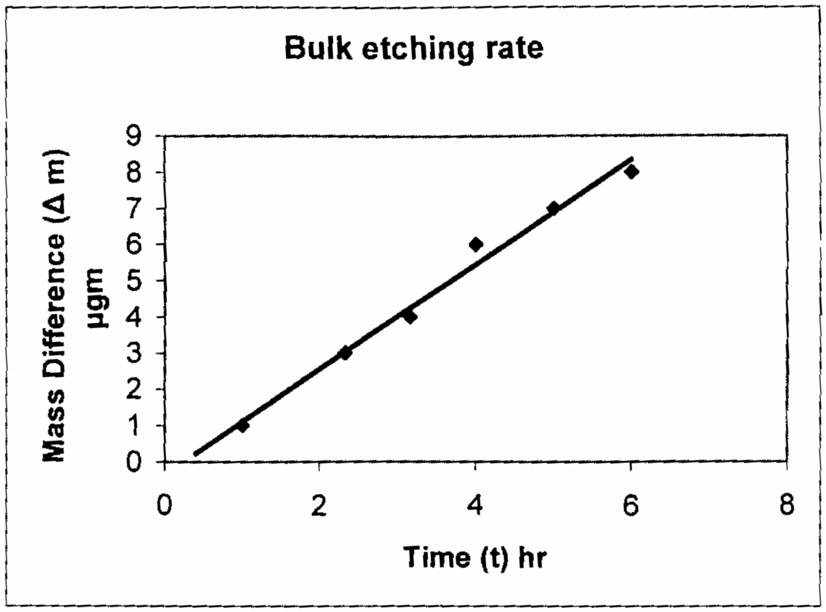

Fig. (2): Variation of mass difference as a function of etching time.

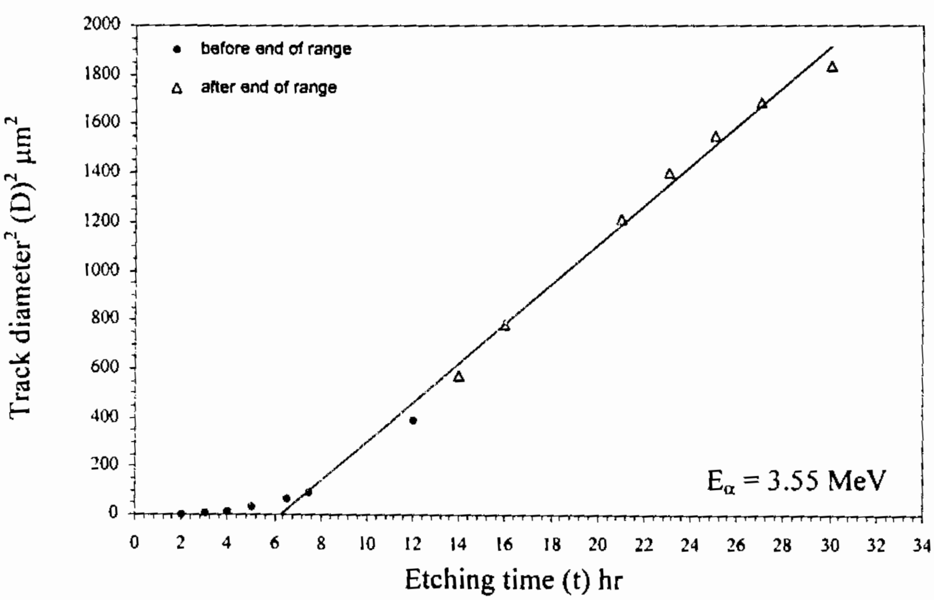

Fig. (3): The relation between diameter square with etching time for $E_\alpha = 3.55$ MeV.

The experimental values of R are easily determined from Eq. (5). They are represented in table (1) and Fig. (5) as well as the theoretical calculated values from **[Almàsi and Somogyi, (1981)]**.

Figs. (5 and 6) show the variation of track diameter (D) and the sensitivity function (V) with alpha particle energies (E_α) at different removal thickness layers (h) which is corresponding to different etching time.

From the two figures, it can be seen that each of D and V increases with the energy E_α until a value of ≈ 3 MeV then drops again.

Table (1): Comparison between theoretical and measured range for alpha particles energies in CR-39 detector.

Energy (MeV)	Theoretical range (μm)	Experimental range (μm)
5.05	28.45	19.62
4.58	24.67	21.42
4.08	20.92	16.66
3.55	17.22	14.62
2.97	13.53	13.51
2.34	9.93	8.64
1.60	6.24	4.62

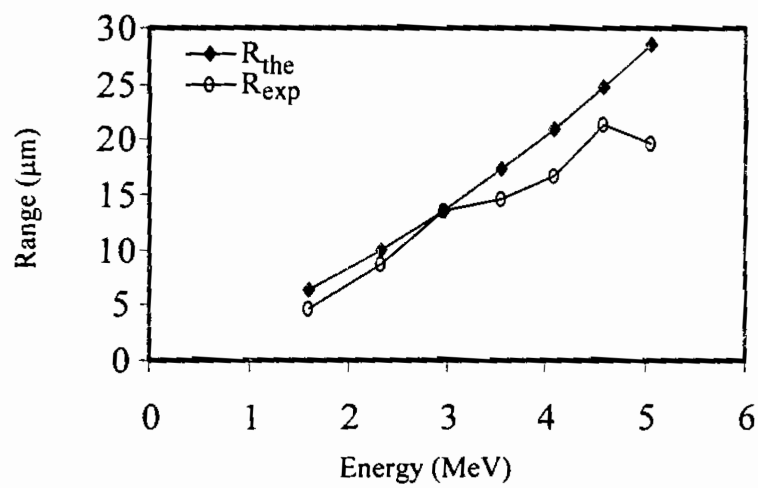

Fig. (4): Measured and calculated Alpha ranges as a function of alpha energies.

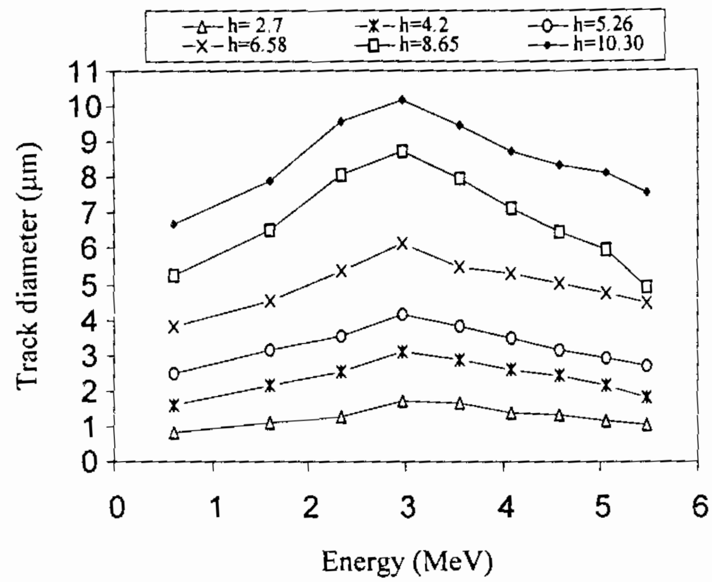

Fig. (5): Variation of track diameter as a function of incident alpha particle energies at different removal thickness layers.

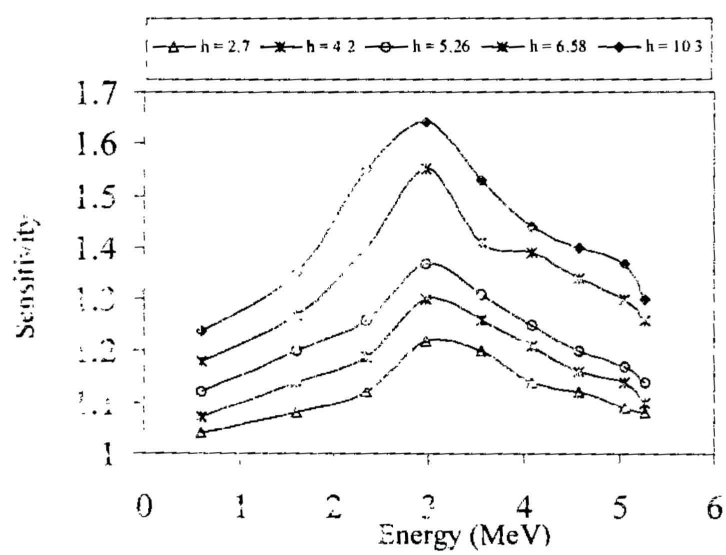

Fig. (6): Variation of sensitivity as a function of the incident alpha particle energy at different removal thickness layers.

CONCLUSION

From the obtained data on the bulk etching rate of the present detector (CR-39), it can be seen that there is a good ability of using this polymeric detector in radon dosimetry. From Table (1) and Fig. (3), we can conclude that there is a good agreement between the measured and calculated ranges at all the selected α-energies, except for 5.05 MeV. In general the measured values of alpha ranges are less than theoretical ones. This behavior may be explained on the basis that in the theoretical evaluation of (R), the contribution from δ rays is limited i.e. there is a reduction in the energy loss evaluation, which is deposited along the track trajectory in the plastic detectors. This is in agreement with previously published data.

The over-etched profile technique is proved to be successfully applicable in range determination. From figures (3 and 4), it can be seen that the track diameter (D) and consequently the sensitivity function (V) increases with the alpha particle energy (E) until a value of 3 MeV which can be considered as the best energy at which the sensitivity function is maximum.

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قياس مدى جسيمات ألفا في

كواشف الأثر النووى الصلب CR-39

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تم بناء نظام تشعيع حديث للحصول على جسيمات ألفا ذات طاقات مختلفة المنبعثة من المصدر العيارى ^{241}Am ثم قياس مدى جسيمات ألفا فى كواشف الثر النووى الصلب CR-39 عند كل هذه الطاقات وذلك بتتبع شكل ومسار الجسيمات باستخدام تقنية الحفر المتتابع بعد نهاية الأثر ومن النتائج يتضح أن قيم مدى جسيمات ألفا العملية تتوافق مع الحسابات النظرية وفقا لهذه التقنية بالنسبة للكاشف الصلب CR-39.