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Effect of the Time of Irradiation with Different Sources of Radiation on the SSNTDs (CR-39)

Mustafa Ali Abbas[1*] **Zahraa Sadiq Karim[2]**

[1] College of Education, University of Al-Qadisiyah, Mustufa.alobaidi@qu.edu.iq, Al-Qadisiyah, Iraq.
[2] College of Education, University of Al-Qadisiyah, phy.post19@qu.edu.iq, Al-Qadisiyah, Iraq.
***Corresponding author email:** Mustufa.alobaidi@qu.edu.iq

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Abstract

In this study, the CR-39 solid nuclear track detector was used in order to know the effect of the irradiation time of Am-241 and P0-210 sources of alpha particles on the parameters of the CR-39 detector, with different times (1, 2, 3, 4, 5) h. The track density of alpha particles, average diameter, bulk etching rate, track etching rate, detector sensitivity, and etching efficiency were calculated. The highest values were obtained at a time (5) h, so the value of the track density at radioactive source was polonium (739) track/mm², while it decreased at the radioactive source americium (451) track/mm², while the diameter average had the highest value at Am-241 is (2.544) µm, while its value decreased at Po-210 to reach (1.855) µm. The etching rate was (0.212) µm/h at Am-241 and (0.154) µm/h at Po-210, and the impact rate was (1.597) µm/h at Am-241 and (0.524) µm/h at Po-210. While the sensitivity of the commercial etching was at Am-241 (7.477) and at Po-210 (3.40), and finally the etching efficiency was (0.876) at Am-241 and (0.706) at Po-210.

Key words:

CR-39, Am-241, Po-210, Track etch rate, Bulk etch rate, Sensitivity, Etching efficiency.

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تأثير وقت التشعيع بمصادر مشعة مختلفة على كواشف الاثر النووي الصلبة (CR-39)

مصطفى علي عباس[1*] **زهراء صادق كريم[2]**

[1] كلية التربية، جامعة القادسية، Mustufa.alobaidi@qu.edu.iq، القادسية، العراق.

[2] كلية التربية، جامعة القادسية، phy.post19@qu.edu.iq، القادسية، العراق.

***Corresponding author email:** Mustufa.alobaidi@qu.edu.iq

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الخلاصة

في هذه الدراسة تم إستخدام كاشف الاثر النووي الصلب CR-39 من أجل معرفة تأثير زمن التشعيع للمصدرين (Am-241) و (P0-210) المشعين لجسيمات ألفا على معلمات الكاشف CR-39 بأوقات مختلفة هي (1، 2، 3، 4، 5) ساعات. تم حساب كثافة الاثار لجسيمات الفا، ومعدل القطر، ومعدل القشط العام، ومعدل قشط الأثر، وحساسية الكاشف، وكفاءة القشط. تم الحصول على اعلى القيم عند زمن (5 ساعات) فكانت قيمة كثافة الأثار عند المصدر المشع Po-210 (739) أثر/ملم^2 في حين قلت عند المصدر المشع Am-241 (451) أثر/ملم^2 بينما معدل القطر أعلى قيمة له عند Am-241 هي (2.544) مايكرومتر، بينما قلت قيمته عند Po-210 فبلغت (1.855) مايكرومتر. أما معدل القشط العام كانت قيمته (0.212) مايكرو/ساعة، عند Am-241 و (0.154) مايكرو/ ساعة عند Po-210 ومعدل قشط الأثر بلغت قيمته (1.597) مايكرو/ساعة، عند Am-241 و(0.524) مايكرو/ساعة عند Po-210. بينما كانت حساسية الكاشف التجاري عند Am-241(7.477) وعند Po-210 (3.40) وأخيرا كفاءة القشط بلغت قيمتها (0.876) عند Am-241 و(0.706) عند Po-210.

الكلمات الدالة

CR-39، Am-241، Po-210، معدل قشط الاثر، معدل القشط العام، الحساسية، كفاءة القشط.

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Introduction

The best types of devices currently used in the detection of ionizing radiation are solid polymeric detectors because they are simple, unaffected by environmental variables, transparent, and have a very high sensitivity to uncharged and charged particles (alpha and protons), [1 and 2]. Solid-state nuclear track detectors (SSNTDs) are electrically insulating plasticized materials that can measure the concentration and spatial distribution of radioactive isotopes. SSNTDs can store the effect of ionizing radiation in them for long periods and appear as tracks of dense fibrosis [3 and 4]. SSNTDs are widely used in plasticizers and are very popular in various fields such as cosmic rays, nuclear physics, nuclear reactors, geology, geophysics, neutron monitoring, space science [5-7], radon studies [8-10], and in the fields of medicine and charged particle detection because they are inexpensive, easy to use, available and durable and effective [6 and 7]. The plastic detector CR-39 is one of the most important organic detectors and it contains a substance containing a polymeric substance abbreviated CR derived from the two words (Columbia Resin) [11]. The detector was found in (1978) by Cartwright and Shirk and is known commercially as CR-39. This detector is prepared from the polyallyl diglycol carbonate, its partial formula ($C_{12}H_{18}O_7$), its density =1.32 g/cm³ [4 and 5].

It is possible to show the areas of damage (hidden tracks) formed in the plastic nuclear track detectors, and detect it by etching the damaged areas and showing them either by chemical etching or by electrochemical etching using an appropriate alkali chemical solution such as NaOH. There are many researches that have been carried out to understand the mechanisms of track growth and development in nuclear track detectors, all of these researches relied on two basic etching parameters. The bulk etching rate V_B of the plastic detector, the track etching rate V_T and, the effects resulting from the etching process can be photographed and direct measurement of the lengths, depth and thickness of the tracks removed from the surface of the detector, and follow the shape of the impact profiles and its development with the progress of the etching process, which was a difficult challenge in the applications of nuclear track detectors, specifically the shallow effects resulting from short etching ranges.

Using direct measurement of the length and measurement of the length of the main axis and the secondary axis of the impact aperture, provided a great opportunity in calculating many of the track parameters accurately [1-12 and 13]. Bulk etching rate V_B is defined as the rate of thickness that is removed from the surface of the detector per unit time by the action of the chemical solution. The track-etching rate is defined as the amount still from the surface of the detector material during the period towards the depth of the track along the track of the charged particle inside the detector material because of chemical etching [14]. V_T it is a scout parameter in addition to being an etching parameter, as found that the way it changes with the time of etching contributes significantly and importantly

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to the formation of the effect and the evolution of its form and shape. Hassan studied the track parameters of the alpha particles by irradiating models of the solid nuclear track detector CR-39, the alpha particles of (1-20) MeV, and the detector was etched with NaOH solution at a concentrated of (6.25) N and its temperature of (70) °C. Bulk etch V_B and Track etch V_T rates were calculated. The thickness of the removed layer is an important factor in all applications of solid-state nuclear detectors. It was found that the diameter of the track hole and the length of the nonlinear track depend on the etching time [15].
Khalil & Al-Jubbori studied the bulk etch rate V_B, track each rate V_T, and etch rate ratio at an energy of (2.4) MeV at different angles, the CR-39 solid nuclear track detector was used. The detector samples measuring (1×1) cm² were irradiated with a radioactive source Am-241, then samples were etched with a weight of (6.25) N at a temperature of (70) °C. The generated track length was measured as a function of etching time. The tracking rate and the etch rate were calculated [16]. On the other hand, Flaih studied the parameters that affect the rate of etching in bulk V_B of the solid nuclear track detector CR-39 with different temperatures, times, and concentration of NaOH. The nuclear track detector CR-39 was engraved with a chemical solution of NaOH, and the result was that the etching rate increased in a sentence with the increase like the solution and temperature, and the thickness of the polymer decreased with increasing temperature, etching time, and the concentration of NaOH solution. The optimum etching conditions where the concentration of NaOH (6.25) N solution at a temperature of (70) °C in time (3) h [17]. The goal of this research studies the effect of the preparation of the two-dimensional exporters on the characteristics of the Solid-nuclear-related nuclear detectors CR-39**.**

Materials and Exposure

Solid nuclear track detector CR-39 with (500) μm thickness (Tasl Company, UK) used in this study. Two groups of CR-39 detector were cut with an area of (1×1) cm and irradiated with two alpha particle radioactive sources, americium Am-241 with an energy of (5.5) MeV and a activity of (370) kBq, as shown figure (1A) and polonium Po-210 with an energy of (5.3) MeV and a activity of (0.01) μm, as shown figure (1B), at different times (1, 2, 3, 4, 5) h and the detectors were in direct contact with the radioactive sources.

Chemical Etching

CR-39 solid nuclear track detectors were etched. Using a water bath device, as shown in the figure (1C). In the presence of alkaline chemical etching solution NaOH of normal weight (6.25) N, the detectors were suspended vertically with a thin copper wire inside a glass beaker in the etching solution for (6) h, which are the ideal conditions for chemical etching of CR-39 track [18]. The detectors were then washed in distilled water and dried in air for several minutes. Optical microscopy at 10X a magnification was used to calculate the density of the tracks and the average diameter of the alpha particles, as shown in figure (1D).

Calculation

- **Diameter Average (D)**

To calculate the diameters of the alpha particles, a lens with a magnification of 10X and a 10-step scale was used.

- **Density of the Tracks (ρ)**

To calculate the density of the track for alpha particles in a solid nuclear track detector, a lens with a magnification of 10X and an area of (0.0676) mm^2 was used. Ten views were taken under the light microscope and the average was taken for the density of the tracks and by applying the equation (1) [18].

$$\rho = \frac{N}{A} \qquad (1)$$

Where
ρ: density of the tracks.
N: the average of the track.
A: the area of field view.

- **Bulk Etch Rate V_B**

The bulk etch rate is an important etching parameter, by measuring the value of this parameter, we can measure many physical changes of the tracks formed in the plastic detector. It was calculated by measuring the diameter of the nuclear tracks of the radioactive detector after etching twice, and calculating the rate of change in diameter after etching through the change of time, V_B was calculated using equation (2) [19].

$$V_B = \frac{D}{2t} \qquad (2)$$

Where, D is the average diameter of the tracks of alpha particles, and t is the etching time of the solid-state detector.

- **Track Etch Rate V_T**

The diameter ratio method was used to find its value, which can be calculated through the following equation (3.4) [19].

$$V_T = V_B \frac{1+(\frac{V_D}{V_B})^2}{1-(\frac{V_D}{V_B})^2} \qquad (3)$$

where V_D is the diameter rate of the track were computed from the slope of the relation (3.5) [19]

$$V_D = \frac{\Delta D}{\Delta t} \qquad (4)$$

- **Sensitivity of CR-39 Detector V**

Detection sensitivity can be calculated from the ratio of the bulk etch rate on the rate of track etch through the following equation [19].

$$V = \frac{V_T}{V_B} \qquad (5)$$

- **Etching Efficiency η**

The etching efficiency of CR-39 detector is defined as the rate between bulk etching rate V_B and track etch rate V_T [19].

$$\eta = 1 - \frac{V_B}{V_T} \qquad (6)$$

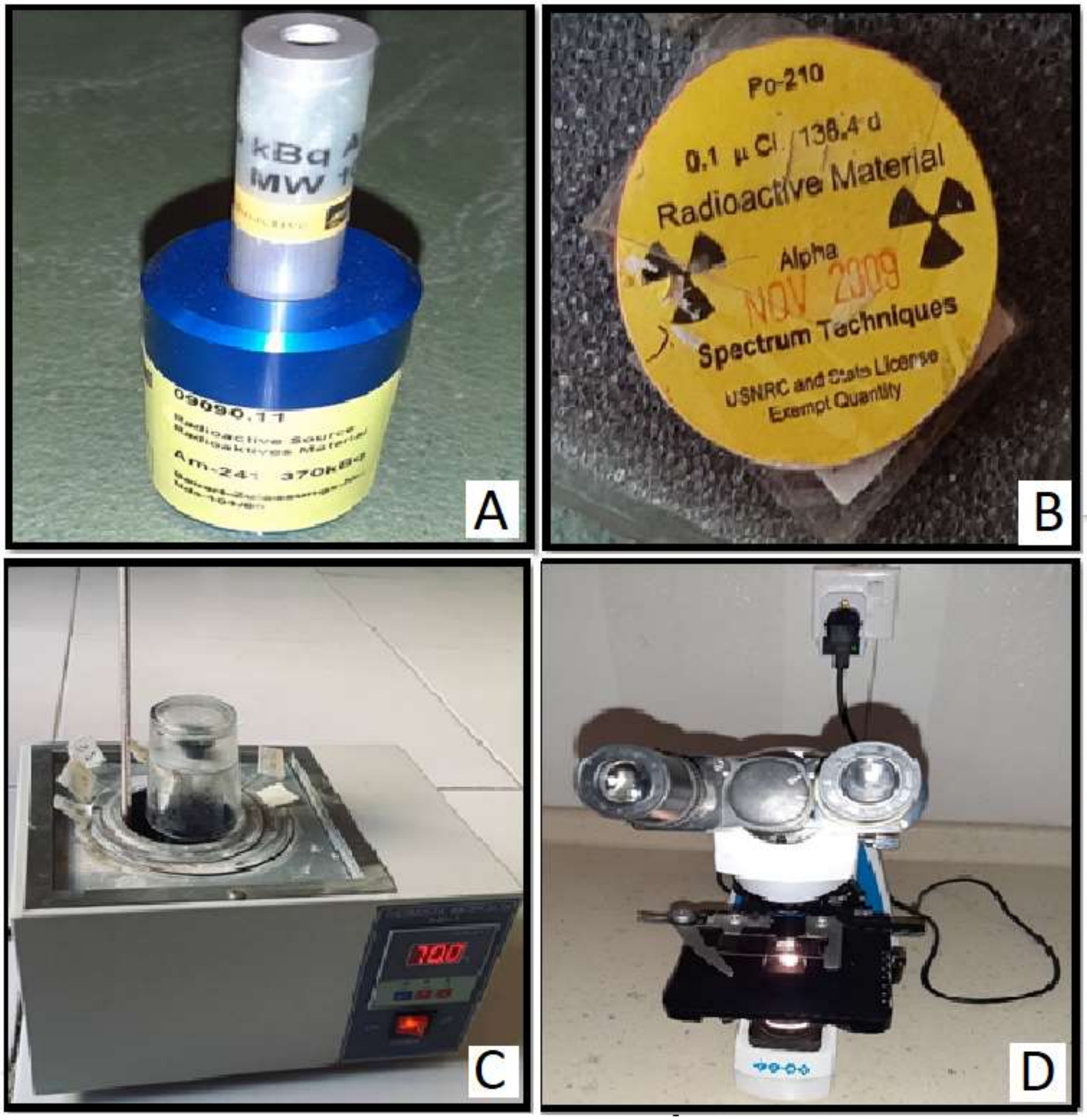

Figure 1: (A) Radioactivity Source Am-241,(B) Radioactivity Source Po-210, (C) Water Bath, (D) Optical Microscope.

Results and Discussion

In this study, two types of radioactive sources that emit alpha particles, americium Am-241 and polonium Po-210, were selected for irradiation with the solid nuclear track detector CR-39 for (1, 2, 3, 4, 5) h. The results were calculated as presented in table (1). The results showed that the increase in the irradiation time increases the density of the paths and the average diameter of the alpha particles. The value of tracks density at the radioactive source was polonium (739) track/mm², as shown in figure (2A), while it decreased at the radioactive source americium (451) track/mm², as shown in figure (2B), while the average diameter has the highest value at Am-241 which is (2.544) µm, as shown in figure (2C), while its value decreased at Po-210 and it reached (1.855) µm, as shown in figure (2D), where we notice that with the increase in the irradiation time, the value of the effective diameter increases and depends on the angle of incidence, as shown in figure (3B). As for the bulk etching rate, its value was (0.212) µm/h at Am-241, (0.154) µm/h at Po-210. We notice an increase with the irradiation time, as shown in figure (4A) and the track etching rate of (1.597) µm/h, at Am-241 and (0.524) µm/h at Po-210 as shown in figure (4B), while the sensitivity of the commercial detector was Am- 241 at (7.477) and Po-210 at (3.40). In addition, there is an increase in the sensitivity of the commercial detector CR-39 with the irradiation time, as shown in figure (5A). Finally, the etching efficiency reached (0.876) at Am-241 and (0.706) at Po-210 figure (5B) shows Increasing the etching efficiency of the CR-39 detector with the irradiation time of the radioactive source. The reason for the increase in the tracks density of alpha particles is due to the effectiveness of the radioactive source, as it reached (0.1) µci for the radioactive source Po-210, while it was less than that for the radioactive source Am-241 (270) kBq The increase in the impact diameter is due to this is due to the energy of alpha particles, which breaks the polymeric bonds of the CR-39 detector, where the energy of Am-241 is (5.5) MeV, while the energy of Po-210 is (5.3) MeV [13], [20].

Table 1: The characteristics of the solid state nuclear track detector CR-39 at depending on the irradiation time.

Radiation of Source	Group of CR-39	T (h)	ρ (track/mm²)	D (µm)	V_B (µm/h)	V_T (µm/h)	V	η
Am-241	A1	1	207	1.298	0.108	0.176	1.629	0.386
	A2	2	290	1.802	0.150	0.449	2.993	0.665
	A3	3	335	1.987	0.165	0.952	5.769	0.826
	A4	4	384	2.226	0.185	1.230	6.648	0.849
	A5	5	451	2.544	0.212	1.597	7.447	0.867
P0-210	B1	1	316	1.033	0.086	0.123	1.403	0.300
	B2	2	390	1.325	0.110	0.271	1.583	0.591
	B3	3	458	1.537	0.128	0.313	2.44	0.6
	B4	4	628	1.722	0.143	0.416	2.90	0.656
	B5	5	739	1.855	0.154	0.524	3.40	0.706

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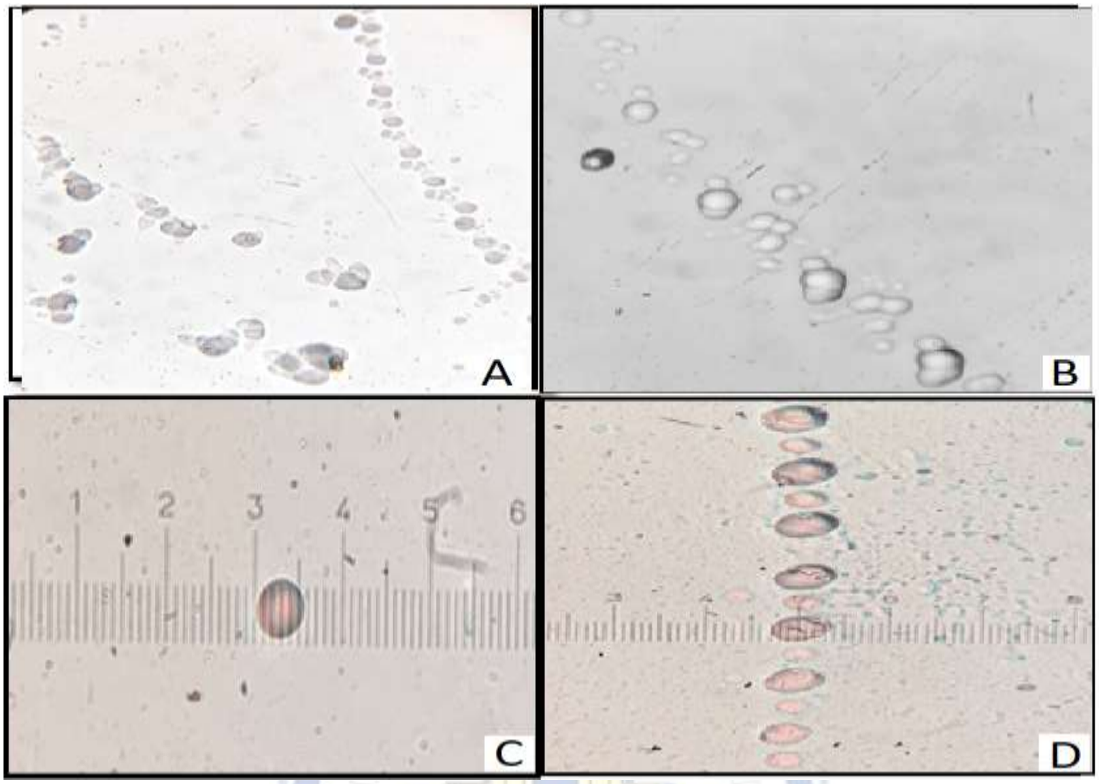

Figure 2: (A) The density of the tracks at Am-241, (B) The density of the tracks at Po-210, (C) The diameter of the alpha particle at Am-241, (D)) The diameter of the alpha particle at Po-210.

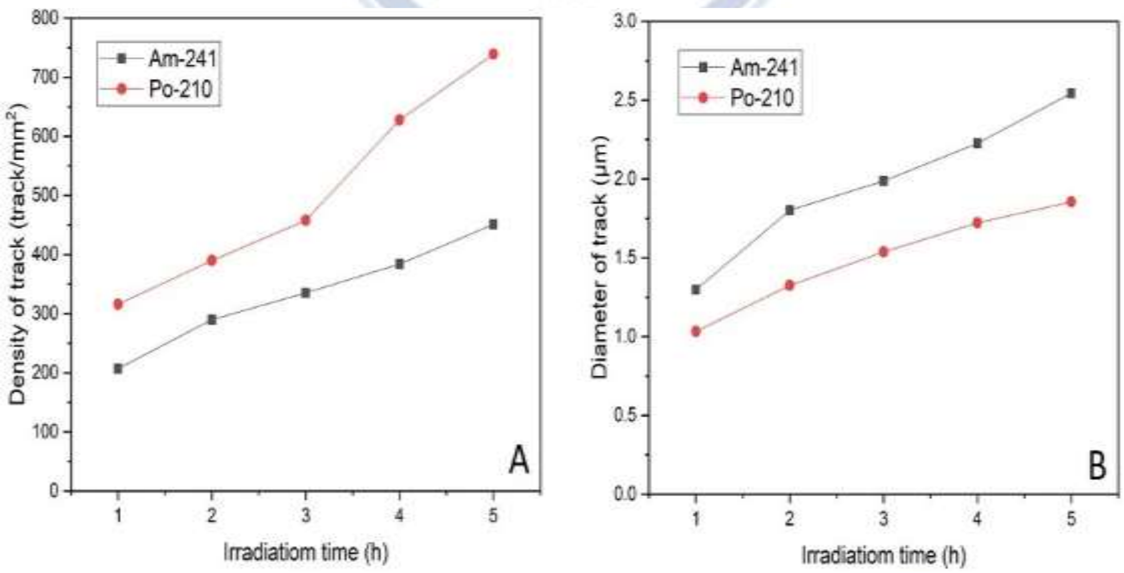

Figure 3: (A) The relationship between the density of the tracks of alpha particles and the irradiation time, (B) The relationship between the diameter of the alpha particles and the irradiation time.

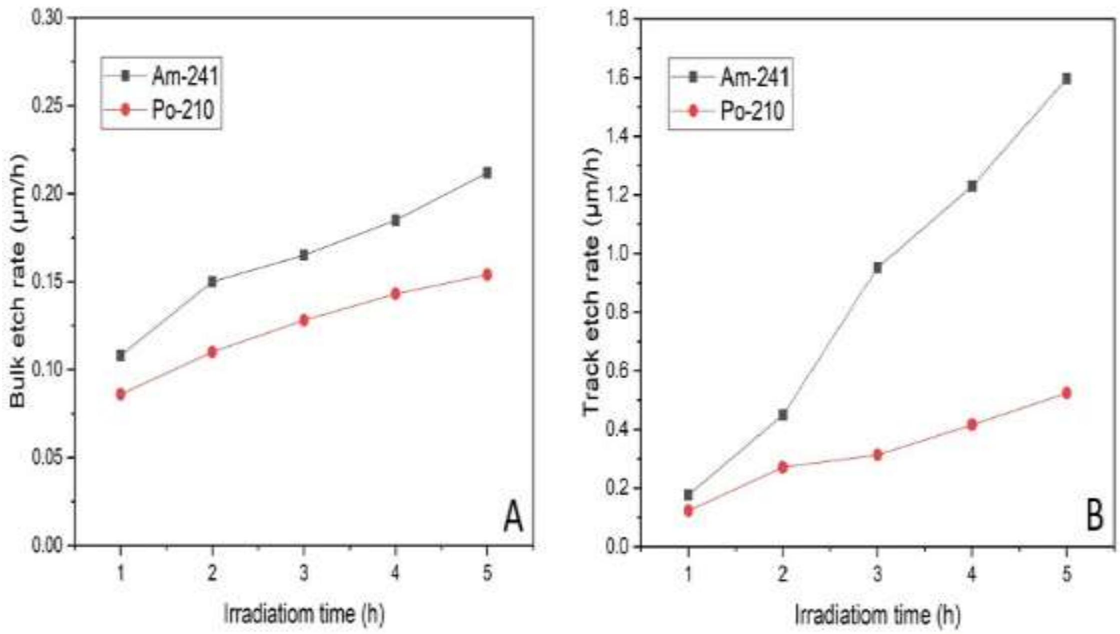

Figure 4: (A) The relationship between the bulk etching rate and the irradiation time, (B)Relationship between track etching rate and irradiation time.

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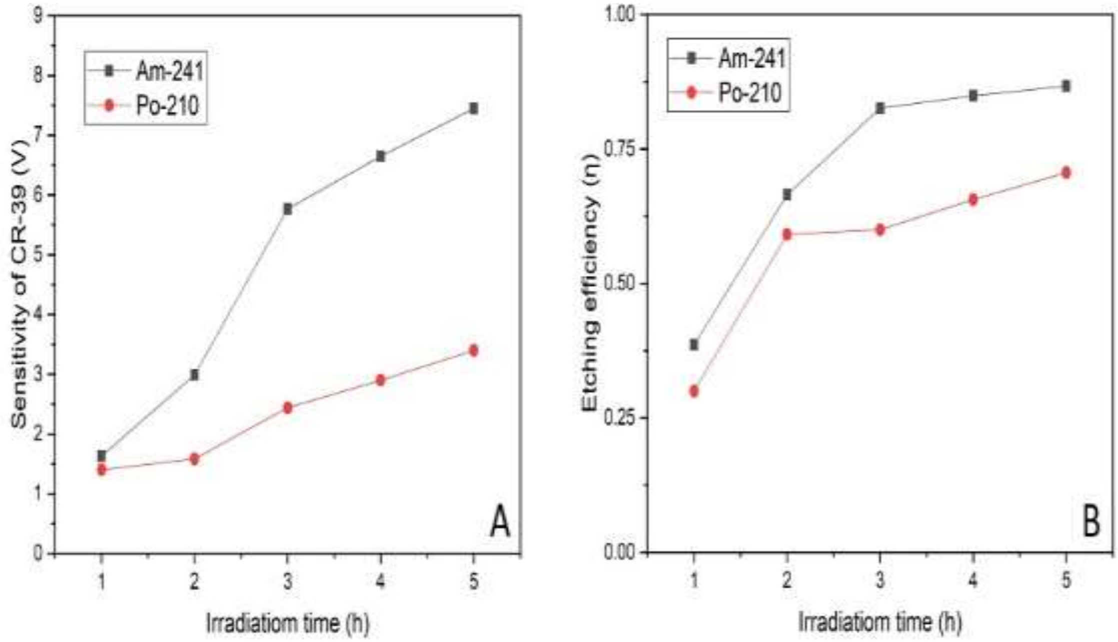

Figure 5: (A) The relationship between sensitivity of the CR-39 detector and irradiation time, (B) Relationship between etching efficiency of CR-39 and irradiation time.

Conclusions

The solid nuclear track detector CR-39 has been tested with two radioactive sources of alpha particles at different times, and through the results, we show that with the increase in the irradiation time, the density of tracks and diameters of charged alpha particles increases, and the density of tracks also increases with the increase in the effectiveness of the radioactive source, as in Po-210, and the diameter of the tracks increases with the increase in the energy of the source radioactive as in Am-241.

Conflict of interests.

There are non-conflicts of interest.

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