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Technical Note

Application of CR-39 Microfilm for Rapid Discrimination Between Alpha-Particle Sources

Nidal Dwaikat * *and Anan M. Al-Karmi* *

Department of Physics, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

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ABSTRACT

This work presents a new technique for discriminating between alpha particles of different energy levels. In a first study, two groups of alpha particles emitted from radium-226 and americium-241 sources were successfully separated using a CR-39 microfilm of appropriate thickness. This thickness was adjusted by chemical etching before and after irradiation so that lower-energy particles were stopped within the detector, while higher-energy particles were revealed on the back side of the detector. The number of tracks on the front side of the microfilm represented all alpha particles incident on that side from the two sources. However, the number of tracks on the back side of the microfilm represented only the long-range alpha particles of higher energy that arrived at that side. Therefore, by subtracting the number of tracks on the back side from the number of tracks on the front side, one could easily determine the number of tracks for the short-range alpha particles of lower energy that remained embedded in the microfilm. Discrimination of the two energy levels is thus achieved in a simple, fast, and reliable process.

1. Introduction

Polymer-based solid-state nuclear track detectors are widely used for radiation detection in several important nuclear research applications, including cosmic ray measurements [1, 2], radon monitoring [3–5], particle identification, and neutron dosimetry [6–13]. At present, the most important type of detector is the poly allyl diglycol carbonate or CR-39 detector. Exposure of the CR-39 detector to heavy charged particles, such as alpha radiation, produces extensive ionization of the CR-39 material and dissociates the chemical bonds in the polymer, forming permanent tracks of the radiation path in the detector. The tracks vary in size, shape, and depth depending on radiation type, intensity, energy, and angle of incidence. For that reason, these tracks can be extensively investigated using different spectroscopic techniques such as ultraviolet–visible, Fourier transform infrared, and photoluminescence [14].

Spectroscopy using CR-39 to estimate the energy of incident alpha particles from the geometric measurements of the recorded tracks is an extremely challenging application. This is because alpha particles have a very short range in materials and can penetrate only a very thin layer of the CR-39 surface. For example, according to the Stopping and Range of Ions in

* *Corresponding authors.*
E-mail addresses: ndwaikat@kfupm.edu.sa, nidaldwaikat@yahoo.com (N. Dwaikat), alkarmi@kfupm.edu.sa (A.M. Al-Karmi).
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Matter (SRIM) program [15], the range of 5-MeV alpha particles in CR-39 is 28.9 μm. In general, the range is highly correlated with the energy of the incident alpha particles [16]. Consequently, this generates a problem in the case of different alpha particles having very close energy levels. In that case, the ranges will be very similar, and the ability to discriminate between alpha particles will seem difficult to achieve.

Previous works on alpha spectroscopy have developed a matrix of energy equations as a function of the track diameter [17–20]. However, these approaches have used complicated geometric analyses of the track parameters, as well as calibration curves of the track diameter versus alpha energy. Another work on alpha particles from radon gas and radon daughters used two detectors [21]. The first was a CR-39 track detector to determine the incident fluence; the second was an LiF thermoluminescent detector to deduce the average energy of the alpha particles. However, that study was time consuming and required calibration of the two detectors. Therefore, it is important to search for a faster and less complicated method of alpha spectroscopy.

In this work, we present a new method using a CR-39 microfilm for the discrimination of the energy of alpha particles emitted from two different sources. The method is based on the experimental observation that the greater the energy of an alpha particle, the longer its range in the material. Therefore, by adjusting the thickness of a CR-39 microfilm to match the range of higher-energy alpha particles, low-energy particles will stop within the microfilm, whereas high-energy particles will pass the microfilm and can be revealed on the back side by chemical etching. It can readily be understood that, under these conditions, discrimination of the two energy levels is achieved accordingly. This work is a continuation of our previous work on improving radiation measurements using the CR-39 detector [22].

2. Materials and methods

2.1. Alpha-particle sources

We used two different alpha-particle sources from the commercially available reference standards. One source was ^{226}Ra, which emits alpha particles with a kinetic energy of 4.78 MeV; the other was ^{241}Am, which emits alpha particles with a kinetic energy of 5.49 MeV. Using the Bateman equation, we calculated the present activity of the two sources at the time of this study and found that both had the same activity of 150 nCi (5.55 kBq). In order to calculate the range of alpha particles in CR-39, we employed SRIM simulation software [15], available on the Internet. We chose the Transport of Ions in Matter (TRIM) section of the software to generate a list of stopping power and range values. The calculations were completed for 99,999 helium ions per simulation, a default used by the software. Fig. 1 is a plot of ionization, that is, the energy loss of the incident alpha particles to the target electrons as a function of the penetration depth in the CR-39 target. The dotted curve represents the 4.78-MeV alpha particles emitted from ^{226}Ra, and the solid curve represents the 5.49-MeV alpha particles emitted from ^{241}Am. End points of the curves represent the maximum penetration depth of the alpha particles in CR-39. The figure clearly shows that the greater the energy of the alpha particles, the longer their range. These range values were 33.3 μm for the 5.49-MeV particles and 27.0 μm for the 4.78-MeV particles.

2.2. CR-39 microfilm preparation and chemical etching process

Thin sheets of CR-39 microfilm (Fukuvi Chemical Industry Company, Tokyo, Japan) with $C_{12}H_{18}O_7$ molecular composition, 100 μm uniform thickness, and 1.32 g/cm^3 density were cut by a laser into pieces with dimensions of 1 × 1 cm^2. To determine the rate of the chemical etching process, five pristine CR-39 microfilms were etched under standard etching conditions in a 6.25N aqueous solution of NaOH maintained at 70°C by a water bath for 6 hours [22]. During the etching process, a magnetic stirrer was used to achieve uniform etching and to prevent accumulation of the etchant material on the surfaces of the microfilms. After etching, the microfilms were thoroughly rinsed with distilled water and dried in open air. The thickness of each microfilm before and after etching was measured using a sensitive micrometer; the average value of the bulk etching rate was found to be 1.06 μm/h, according to the following equation:

$$\text{Bulk etch rate} = \frac{\Delta d}{2t} \quad (1)$$

where Δd is the thickness reduction and t is the etching time. Our results for the etch rate agree exactly with those reported by Yamauchi et al [23]. In their work, it took about 40 hours to reduce the thickness of an unirradiated microfilm from 100 μm to 15 μm.

Next, a fresh set of six 100-μm-thick CR-39 microfilms was etched for 30.6 hours using the abovementioned etching conditions until the thickness of the residual active layer of each microfilm was reduced to 35 μm. This particular thickness is sufficient to prevent possible backscattering of alpha particles from a thick substrate at the back side of the detector. Indeed, alpha particles can penetrate the detector to the substrate, bounce from the substrate surface, and then enter a second time into the detector, which may contribute to the tracks at the back side of the detector. To ensure that alpha particles stop before reaching the substrate, the detector was etched to a thickness slightly larger than 33.3 μm (i.e., thicker than the range of the highly energetic 5.49-MeV alpha particles from ^{241}Am in CR-39).

Afterward, one blank microfilm was randomly selected and used as a control. The front and back sides of the control microfilm were scanned by a manual optical scanner to determine the existence of possible background tracks. Surface defects or high-density pits were not found in the control microfilm, and the background tracks were easily distinguished. The mean value of background track density was measured and found to be 4 ± 3 tracks/cm^2. This low count value indicated that the microfilm in hand had not been irradiated previously. At this point, the control microfilm underwent no further processing and was stored for future reference. It is worth noting that all the microfilms used in this work were kept away from the external environment in a clean room under controlled laboratory conditions. This