

Photo-Spectro-Metric Study of CR-39 Detectors Irradiated with Heavy Ions

N. Ali¹, E. U. Khan², N. Ahmad³, S. M. Abbas³, M. A. Iqbal¹

1. Department of Physics, Faculty of Science, University Teknologi Malaysia, Skudai Johor, Malaysia.
2. CESET Islamabad, Pakistan.
3. National Centre for Physics Quaid Azam University Campus Islamabad, Pakistan.
Email; nisaraliswati@hotmail.com

Abstract

The fission fragments and heavy ions tracks in CR-39 detectors registered by Cf-252 radioactive source have been observed by using photo-spectrometric techniques. CR-39 detectors were exposed at 5 cm distance from radioactive source for registering nuclear tracks created by nuclear particles emitted from Cf-252 radioactive source. CR-39 detectors were etched in 6N NaOH solution at 70 °C for 400 minutes in the intervals between 20 to 25 minutes. The etching properties of CR-39, irradiated by ultra violet radiation has been examined. In un-etched condition, it is found that the transmittance is nearly 95% and in etched condition the transmittance decreases up to 72% due to the change in track densities inside CR-39 foils.

Key Words: Photo-spectrometric study, CR-39 detectors, Transmittance, Nuclear tracks, Cf-252 radioactive source, Etching.

1. Introduction

CR-39 is a solid state nuclear track detector (SSNTD) and has been widely used for the detection of charged and neutral particles. CR-39 is a passive detector (composition: C₁₂H₁₈O₇, density: 1.32 g/cm³) which can register the tracks of charged particles having energy above about 10 KeV/mm. These detectors are widely used for neutron dosimetric studies and are particularly useful for measurements in complex radiation environments around particle accelerators where discrimination of different radiation components is essential for estimating dose equivalent quantities appropriately. Another method to obtain the dose by measuring the neutron energy spectrum using CR-39 detectors but is found to be complicated and less accurate mainly because of the variation in track sizes even for mono-energetic neutrons [1]. The Coulomb scattering is an important process inside detector. It has negligible influence on the energy loss inside the detector material. As the nuclei of the detector material occupy only 10⁻¹⁵ of the volume of their atom, so the incident particles interact simultaneously with electrons only and thus lose its energy gradually and continuously as it travel [2-6]. Operation of solid-state nuclear track detectors is based on the fact that a charged particle will ionize the material when it

passes through it. Alpha particle with 6 MeV energy creates about 150000 of ion pairs in cellulose nitrate with the range of 40 μm. Alpha particle ionizes nearly all molecules close to its path inside the detector. This initial ionization process triggers a series of new chemical reactions that results in the creation of free chemical radicals and chemical species. Along the path of the alpha particles, a zone enriched with free chemical radicals and other chemical species are then created. This damaged zone is called latent track. If a piece of such damage materials is etched in some chemical solution, chemical reactions would be more rigorous along the latent tracks. In this way a track of the particles is formed, which may be seen under an ordinary optical microscope. The procedure is called track visualization and the effect is known as track effect. [7-9]

CR-39 detectors have the advantages over other polymers as it can be placed near the radioactive source without damaging. It is inexpensive and robust and can interact with both neutral and charged particles. It is insensitive to gamma rays, beta particles and also to electromagnetic radiations. The most important property of SSNTDs is that the signal in the material does not degrade with time. [10- 13]

When a light beam encounters CR-39 (transparent and uniform solid), the atoms of CR-39 scatter the iodine tungsten (I-W) light, and the scattered light interfere constructively in the forward direction and interfere destructively in all other directions. Thus most of the light energy will go into the forward direction rather than other direction. When the light beam falls on the interface of media, it will be refracted depending on the angle of incidence. For normal incidence (unexposed Detector) whole light is transmitted and no refraction occurs. [14] However for oblique incidence the light is refracted, depending on the angle of incidence. Due to etched tracks in CR-39 detectors, the light fell on wedge shape etched tracks, whose interface was oblique for normal incident light, thus refracted from its original path.

Heavy charged particles that impact the plastic material create a damaged zone along its path. The treatment with suitable etching solution enables the formation of tracks, easily observable with optical microscope. It is well established that the bulk etch rates for solid state nuclear track detectors are affected by the concentration and the temperature of the etchants.

Along with the above, SSNTDs have also some other useful uses in different area of science such as nuclear Physics, cosmology, material science, Geology, Geophysics, bio-medical Physics and environmental science.

SSNTDs can be considered to be a standard method for the dating known as "Fission Track Dating" of geological, archaeological, and cosmological samples and also in Ocean Bottom Spread and the Continental Drift.

This is indicated that latent tracks in CR-39 are produced through local irradiation induced oxidation process along the ion path. It is also observed that the reaction between the radiation induced radical and the dissolved oxygen play an important role in the formation of permanent track. This indicates that the damage in CR-39 was produced through the local irradiation-induced oxidation. It has been revealed that the UV-visible spectra of the irradiated CR-39 detectors were sensitively dependent on the absorbed dose and ion fluence, as well as ion type and energy.

The use of Californium (Cf-252) radioactive source for the registration of tracks inside foil was studied in the current study.

2. Experimental

The track densities registered from Cf-252 radioactive source was measured with U-4100 Spectrometer Serial number 1651-008 ROM Version 5300 05, at PRD PINSTECH Islamabad. For experimental study on plastic foils, ten samples of CR-39 plastic nuclear track foils of 0.1 cm thickness and 2×2 cm² size (supplied by Kurt J Lesker) were used. One of the foil was left un-irradiated and the remaining foils were irradiated with normal incidence ions from a Cf-252 source each for 30 minutes. Among those irradiated foils, one of the sample was left unetched and the rest of the samples were etched in 6N NaOH solutions at 70°C for a successive etching time up to 400 minutes in the interval of 15 to 25 minutes. [15]. Different graphs were plotted between etching time and transmission percentage. The graphs and their conditions are expressed as follow.

1. Unexposed and etched conditions 400 minutes etching.
2. Exposed to Cf-252 source for 30 minutes and unetched.
3. Exposed and etched conditions 400 minutes etching.
4. Exposed and etched conditions 200 minutes etching.

3. Results and Discussion

The percent transmittance was calculated through spectrometry techniques. The transmittance through these foils show a sporadic variation due to the presence of different dimension tracks in these foils. The difference may be due to the presence of fission fragment and alpha particles of different energy in the CR-39 foil.

Graph 1 is for unexposed and etched condition and graph 2 is for exposed and unetched condition, reveal 5% decay in transmittance due to discontinuity inside the foil and reflection at both interfaces, absorbance inside the foil along with interference in

the foil. When the exposed samples were etched, the transmittance start decreasing due to the appearance of the tracks. As the time of etchant increases, the transmittance starts appear to decay. This is shown in graph 3 as well as graph 4. In the beginning the transmittance percentage was calculated for few foils whose etching time was 200 minutes (Graph 3). No clear decay in graphs were noticed as all the tracks are not explored till yet. This is because this etching time was not sufficient to explore all the nuclear tracks registered by fission fragments and heavy ions. This indicate that some high energy tracks need more etching time to explore. For this purpose five more radiated CR-39 foils were etched for 400 minutes in order to explore all the nuclear tracks. It was found from the transmission percentage that all the tracks were explored when 300 minutes of etching was carried out (Graph 4). All of the samples show nearly 72% decay in transmittance and then the smoothness after ~72% is the indication of appearing of all the tracks created by fission fragments and alpha particles.

For comparison the data of all foils was plotted with the unexposed foil. Graph 5 illustrates the comparison of both etched and unetched foils.

The transmittance of light through foils depends on the discontinuities in the medium of the foils. For CR-39, which is uniform and transparent medium, the discontinuity is created by etched tracks. When the detectors were unetched and exposed from californium source, there is very little discontinuity in the medium and the transmittance remain nearly same. The transmittance is not 100% and varies from 85% to 95%. The reason for this is that each encounter of light with CR-39 can be viewed as a cooperative event arising when a stream of photons sails through, and interact with an array of atoms suspended in CR-39.

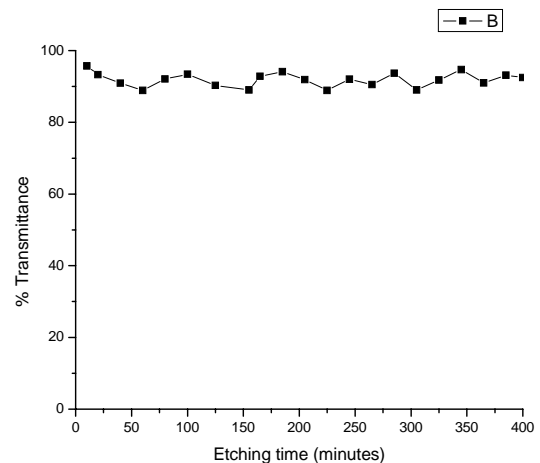
The transmittance for unexposed and etched foils is also unaffected due to no discontinuity in the medium. Only 5% to 7% decrease in transmittance is due to lateral scattering.

Finally the transmittance was also carried out for CR-39 foils exposed to Cf-252 heavy ion source. Due to tracks of nanosize in the material of CR-39,

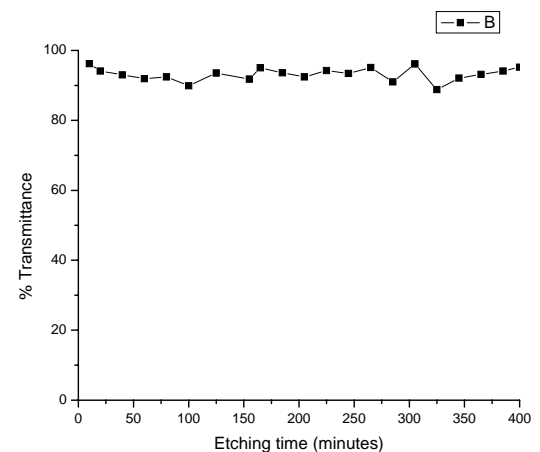
the transmittance of light is affected because of lateral scattering.

The foremost phenomena of decay of light is that when light falls on the interface of media, it will be refracted depending on the angle of incidence. For normal incidence (unexposed detector) whole light is transmitted and no refraction occurs. However for oblique incidence the light is refracted, depending on the angle of incidence.

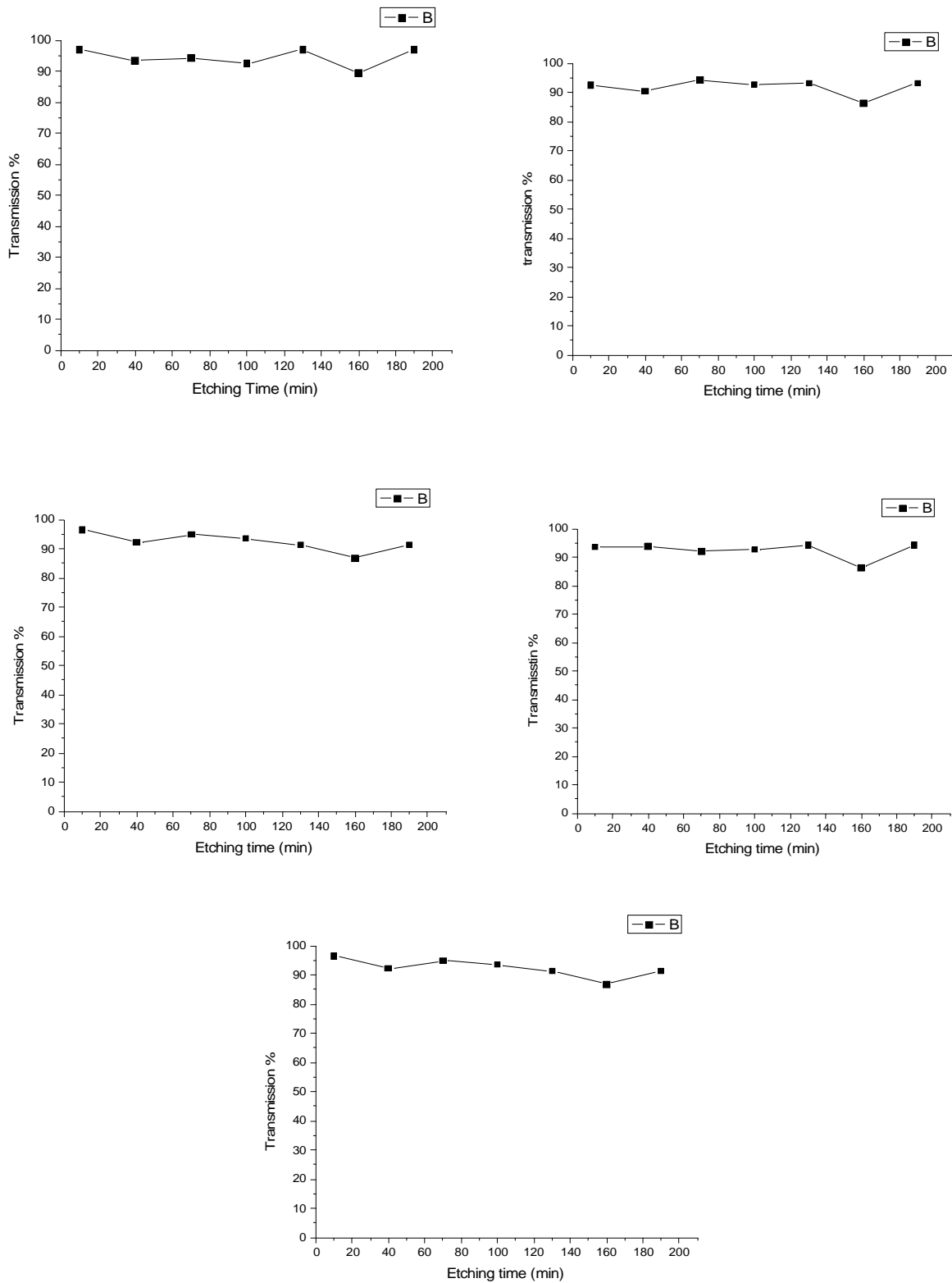
In case of unexposed and etched detectors, and exposed and unetched detectors no tracks were registered, therefore for normal incidence the light is transmitted without refraction and the transmittance is maximum.



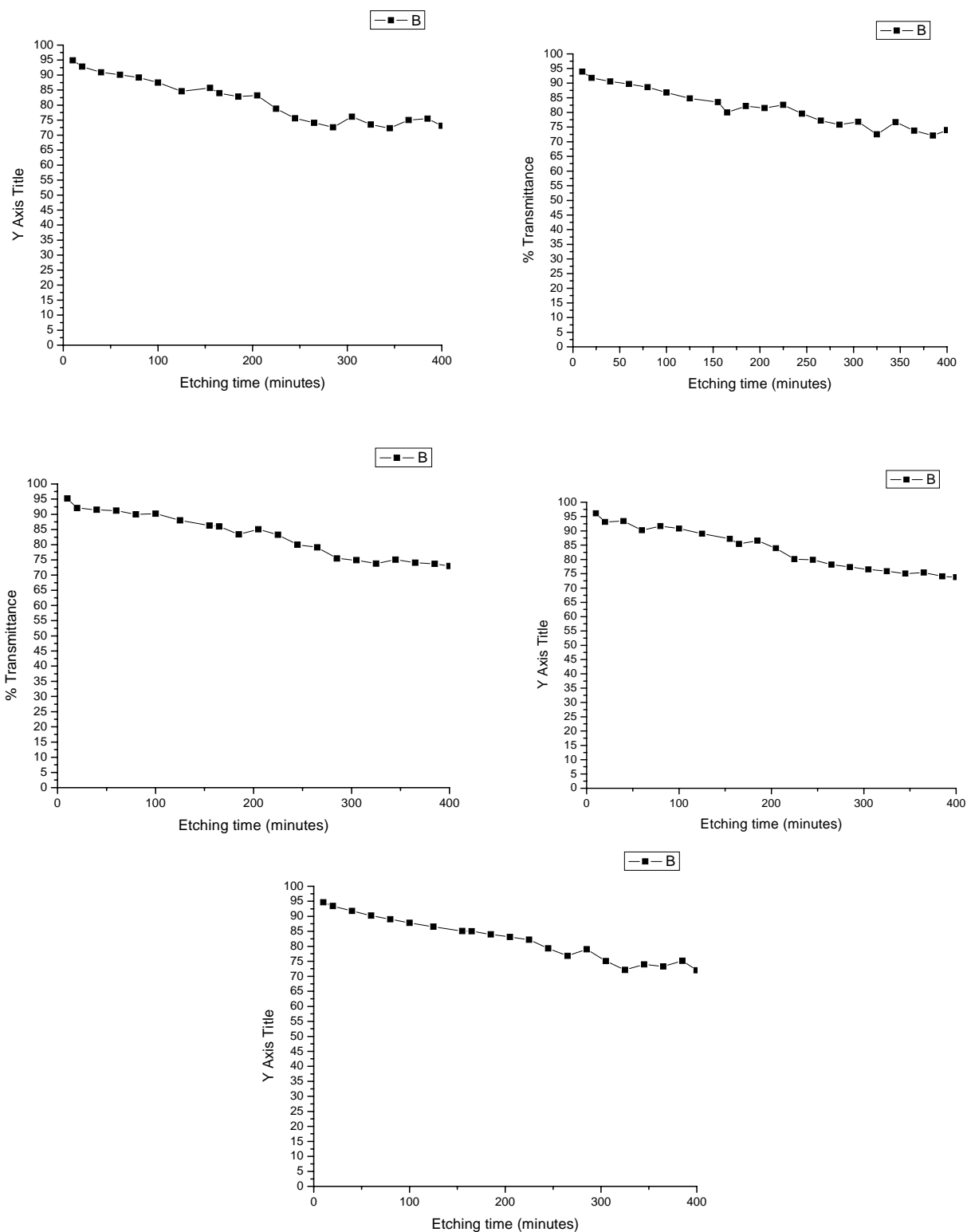
Graph 1 UV Transmission for unexposed and etched foils (400 minutes Etching)



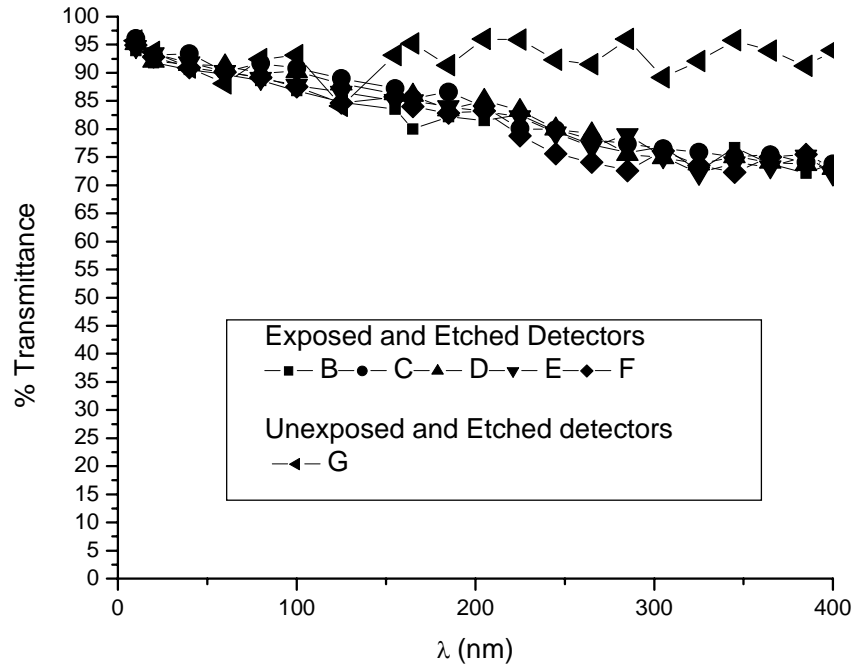
Graph 2 UV Transmission for exposed and unetched foils (400 minutes Etching)



Graph 3 Transmittance for exposed CR-39 foils. (200 minutes etching)



Graph 4 Five plots showing transmittance for CR-39 detectors exposed to Cf-252 radioactive source. (Etching time 400 minutes)



Graph 5. Comparison of exposed, etched and unexposed etched transmittance for CR-39 foils.

4. Theoretical Calculations

The amount of incident light transmitted through CR-39 detectors (unetched) was also determined from the amount of light reflected from the interface as well as the amount of light absorbed within the detector. Using the following theoretical calculation for CR-39 detector, absorption and reflection was calculated. [16]

For CR-39 detector, $\alpha = 0.0035/\text{cm}$ $t = 0.1 \text{ cm}$

$$\text{Reflectivity} = R = \left(\frac{n-1}{n+1} \right)^2$$

$$R = \left(\frac{1.501-1}{1.501+1} \right)^2 = 0.0401$$

$$\text{OR } R = 4.01 \%$$

$$\text{Absorbance } \frac{I}{I_0} = e^{-\alpha \cdot t} \quad \frac{I}{I_0} = e^{-\alpha \cdot t}$$

$$\text{where } I_0 = 1.00$$

$$I = I_0 e^{-\alpha t}, \quad I = 1.00 e^{-(0.003/\text{cm})(0.01)}$$

$$I = 0.9970$$

The fraction of light lost by absorption in CR-39 is

$$I = 1 - 0.9970 = 0.00299 = 0.29\%$$

The total decrease in the intensity of light is thus
 $4.01\% + 0.29\% = 4.30\%$

the remaining light is transmitted i.e.

$$100 - 4.30 = 95.70\%$$

Thus the decrease in transmittance (nearly 5%) is because of lateral destructive interference and the remaining decay in transmittance is provided by the etched tracks in CR-39 detectors.

5. Conclusions

The transmittance of UV light (800-400nm) through CR-39 detectors depends upon etched tracks

produced by any radioactive source (in our case fission fragments and α -particles from Cf-252 source). This dependence was measured for a set of foils by plotting transmittance percentage against etching time. From the transmission percentage of exposed, unetched CR-39 foils and unexposed, etched CR-39 foils, it is found that the transmittance is nearly 95%. Because 5% transmittance is due to reflection and absorption of UV-light from the CR-39 foils. Therefore the decay in transmittance for etched tracks started from 95%. In the detectors having etched tracks of fission fragments and alpha particles, exposed previously to Cf-252 radioactive source, the transmission shows a downy and slow decay up to 3 hour of etching, as only fission fragments appear during this period. After 3 hours of etching, rapid variation in transmittance occurs, as α -particles tracks start appearing in this period of etching along with the fission fragments. The range of α -particles in CR-39 varies according to their energies. Some of the α -particles penetrate more in CR-39 foils than the rest. With further etching more and more α -particles tracks appear along with the fading away of some low energy tracks. Also some of the low energy tracks diffuse during the process of etching. Due to these processes in CR-39 detectors, the discontinuities in the homogeneous media of the detectors are produced, which are responsible for the uneven behavior of the transmittance in CR-39 etched foils.

Mathematical Terms used:

α → Absorption coefficient.

t → thickness of the foil.

I_0 → Light initial intensity.

I → intensity of light after passing through the foil.

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