Chapter 3: Track etching methodology, geometry and counting techniques
3.1. INTRODUCTION:

The first of all etching of particle tracks in the insulators was made by D.A. Young in 1958 at Harwell in England. Later, American scientists R.L. Fleischer, P.B. Price and R.M. Walker at G.E.C. Schnectady, New York, started a systematic study on the observation of charged particle tracks in the solids. They showed that the heavily ionizing charged particles produce radiation damage, which can be etched; not only in mica but in many other insulating solids such as inorganic minerals or crystals and glasses as well as organic polymers or plastics [1]. They found that this damaged region could be etched using etching solution of 2.5 N NaOH/KOH. The etching solution attaches the damaged region producing an enlarged track, which can be easily observed using an optical research microscope that appears similar to the tracks in nuclear emulsions. Subsequently, etched tracks have been observed in many crystals, glasses and wide variety of plastics [2]. In different materials by varying their sensitivities; the minerals and glasses are found to be least sensitive, but organic minerals are most sensitive. The organic materials, which have been used for the detection and measurements of radon and its progeny [3], are made of cellulose nitrate (LR-115 and CN-85), bis-phenol, A-Poly Carbonate (Lexan, Makrofol etc.) and poly Allyl-diglycol carbonate. Poly Allyl-diglycol carbonate is also known as CR-39 (Colombia Resin-1939), which is a most sensitive material and capable of recording the tracks of α-particles with a wide range of energy of about 1–60 MeV. CR-39 was discovered by Cartwright in 1978, it revolutionized the applications of plastic detectors in cosmic rays and radon dosimetry [4]. The tracks of fission fragments were observed in the inorganic minerals or crystals such as mica, quartz and glasses etc. from terrestrial and
extraterrestrial samples [1], and developed fission track dating method for age
determination [5]. Subsequently, the applications of charged particle tracks in the
nuclear physics, geophysics, space physics, heavy ion physics and many more
branches has been increased manifold [2, 6, 7]. Table 3.1 depicts the relative
sensitivities of some detectors.

### Table 3.1: Relative sensitivities of some detectors

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Detectors</th>
<th>Atomic formulae</th>
<th>Least observable ion track</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Allyl-diglycol Poly-carbonate</td>
<td>C_{12}H_{18}O_{7}</td>
<td>1.0 MeV, ^1H</td>
</tr>
<tr>
<td></td>
<td>(CR-39)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Amber</td>
<td>C_{2}H_{3}O_{2}</td>
<td>Full energy fission</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>fragments</td>
</tr>
<tr>
<td>3.</td>
<td>Bis-phenol, A-Poly Carbonate</td>
<td>C_{16}H_{14}O_{3}</td>
<td>0.3 MeV, ^4He</td>
</tr>
<tr>
<td></td>
<td>(Lexan, Makrofol etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Cellulose nitrate</td>
<td>C_{6}H_{8}O_{3}N_{2}</td>
<td>0.5 MeV, ^1H</td>
</tr>
<tr>
<td></td>
<td>(LR-115, Diacell, CA-80-15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Muscovite mica</td>
<td>KAl_{5}SiO_{10}(OH)_{2}</td>
<td>2 MeV, ^20Ne</td>
</tr>
<tr>
<td>6.</td>
<td>Polyethylene Terephthalate</td>
<td>C_{5}H_{4}O_{2}</td>
<td>36 MeV, ^16O</td>
</tr>
<tr>
<td></td>
<td>(Cronar, Melinex)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Poly methyl methacralate</td>
<td>C_{2}H_{8}O_{2}</td>
<td>3 MeV, ^4He</td>
</tr>
<tr>
<td></td>
<td>(Plexiglas, Lucite, Perspex)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Polyoxymethylene (Delrin)</td>
<td>CH_{2}O</td>
<td>28 MeV, ^11B</td>
</tr>
<tr>
<td>9.</td>
<td>Polypropylene</td>
<td>CH_{2}</td>
<td>1 MeV, ^4He</td>
</tr>
<tr>
<td>10.</td>
<td>Quartz</td>
<td>SiO_{2}</td>
<td>100 MeV, ^40Ar</td>
</tr>
<tr>
<td>11.</td>
<td>Silica glass</td>
<td>SiO_{2}</td>
<td>16 MeV, ^40Ar</td>
</tr>
<tr>
<td>12.</td>
<td>Flint glass</td>
<td>18 SiO_{2} : 4 PbO : 1.5 Na_{2}O : K_{2}O</td>
<td>2–4 MeV, ^20Ne</td>
</tr>
</tbody>
</table>
These data have been taken from various sources and observed the registration behavior of a material, which could be depend on the particular etching conditions [8, 9].

3.2. FORMATION OF PARTICLE TRACKS IN CRYSTALLINE AND POLYMERIC SOLIDS:

The heavily charged nuclear particle leads to intensive ionization, when it passes through insulating solids creates narrow paths of intense damage on the atomic level. Along the path of particle, a zone called ‘latent track’ is created, which is enriched with free chemical radicals and other chemical species. If a piece of material containing the latent track is etched in chemically aggressive solution such as NaOH or KOH, the chemical reaction would be more intensive in the latent track. After etching, the latent track becomes visible as a ‘particle track’, which may be seen using an optical research microscope. The effect itself has been known for long time, which is called the ‘track effect’ [6, 10, 11]. This simple technique of observing tracks is used in wide variety of technical fields such as geology, archaeology, sub-oceanic geophysics, lunar science, meteoritics and many more. Several books have already been published on this topic [2, 7, 12, 13]. Figure 3.1 shows the character of tracks in the crystalline and polymeric solids.
Figure 3.1: The character of tracks in the crystalline (a) and polymeric solids (b)

The study of tracks produced in thin films has been made by many researchers [14–19]. In these cases, the mechanisms of track formation are available that are peculiar to the proximity of a free surface [20–22]. The brief history of the development of particle tracks has been given by Silk and Barnes [11], and the discovery of track etching in mica by Price and Walker [23, 24]. The realization of the generality of track etching is reported elsewhere [5, 8, 25].

3.3. TRACK FORMATION MECHANISM:

It is important to mention that nowadays 150 dielectric solid materials are known, which can store etchable tracks of charged particles, Fleischer in 1981 found that barring some exceptions. The solids that register etchable tracks of charged particles, which have electrical resistivity \( \rho \) of about \( \geq 2000 \ \Omega \text{cm} \) and thermal
diffusivity of about $\leq 0.06 \text{ cm}^2\text{s}^{-1}$. Many relativistic models [2] of track formation in solids are as follows:

(i) Critical total rate of energy loss $(dE/dx)_{\text{crit}}$ model.
(ii) Critical primary ionization $(dJ/dx)_{\text{crit}}$ model.
(iii) Critical restricted energy loss $(\text{REL})_{\text{crit}}$ model.
(iv) Critical secondary electron energy loss model.
(v) Critical radius restricted energy loss $(\text{RREL})_{\text{crit}}$ model.
(vi) Critical lineal event density $(\text{LED})_{\text{crit}}$ model.

In all of these models, any model can not explain track formation completely. It is found that for inorganic solids the $(dJ/dx)_{\text{crit}}$ criterion of Fleischer fits the observed data [26], but for the polymers the $(\text{REL})_{\text{crit}}$ model of Benton turnout to be most useful for all practical purposes [27].

In dielectric solids, basically tracks are formed by positive ions at the energy for the dominant mode of energy loss of the particles [7]. The track formation completes in two steps.

(a) The creation of defects
(b) The relaxation of defects

3.3.1. ION EXPLOSION SPIKE MODEL:

The damage along tracks consists mainly of displaced atoms in the inorganic solids, but the damage results from interactions with electrons are not from direct scattering in the detectors. The name of this term was suggested by Fleischer [6]. The heavy ions passing through a solid lose their energy primarily by coulomb interaction with the orbital electrons of the atoms of the target material lying along their trajectory. The interaction time is of about $10^{-17}$ s shortly thereafter, the electronic collision starts and the colliding electrons move outward around the particle trajectory. Hence, produced chemically more reactive molecules outside the core zone, and leaving positive unstable ions along the trajectory. These unstable positive ions repel each other with Coulomb force and move into the interstitial spaces, which create...
vacancies into the lattice. This process is called ion explosion spike and lasts for about $10^{-12}$ s [6]. The atomic defects produced within the core zone were extended defects within a time of about $10^{-10}$ s. Finally, the relaxation of molecular defects takes place is due to secondary reactions of chemically activated species in the valance around the core zone known as ‘track halo’. This process takes place within a second.

The diameter of the track core zone produced by interstitial vacancies due to positive ions is of about 10 nm, but the track halo generated by electronic collisions lying between 100–1000 nm (figure 3.3). Figure 3.2 and 3.3 shows the formation of charged particle tracks in the inorganic solids and the track core zone, respectively.

![Figure 3.2: The ion explosion spike mechanism for track formation in the inorganic solids](image_url)
Figure 3.2 depicts that the original ionization left by the passage of a charged particle is unstable (at top). The ejected ions into the solid create interstitial vacancies (at middle). The stressed region relases elastically and strains the undamaged matrix, hence formed the latent tracks (at bottom) [2].

![Diagram of track core zone](image)

**Figure 3.3:** The track core zone

The annealing of tracks in the inorganic solids may erase the tracks due to filling up of the vacancies partially or completely [28]. Similarly, the plastic track detectors having ‘latent tracks’ by UV light or their exposure to O₂ etc. could be affected the track stability and detection sensitivity because of their interaction with molecular defects in the track halo [29, 30].

**3.3.2. UNREALISTIC MECHANISM:**

The direct atomic collision may produce interstitial vacant atomic sites either as a trail of nearby separate defects [31] or as final dense clump of damage (i.e., a displacement spike) at the end of trajectory, where the mean free path for collision is equal to the atomic spacing [32]. Since these direct collisions with atoms are not the
usual cause of tracks by charged particles. But it is expected that they occur equally in the conductors and insulators, and become more prevalent near the end point of a charged particle.

It seems that the atomic displacements are essential for very low energy heavy particles such as solar wind particles of mass of about 50 amu [33, 34] and heavy recoil fragments of mass of about 200 amu. These results were obtained from α-decay of heavy nuclides [35]. In these cases, the energy for each case is of about 1 keV/amu. Figure 3.4 shows the regimes of etchable damage by direct displacement of ionization.

![Figure 3.4: The regimes of etchable damage by direct displacement of ionization](image_url)
3.4. ETCHING PROCEDURE AND METHODOLOGY:

The detailed study of the etching procedure and its methodology are described in the following sections.

3.4.1. CHEMICAL ETCHING:

The chemical etching is the most basic and widely used method in SSNTDs. Generally, the chemical etching is carried out in the thermostatically controlled water bath (figure 3.5) at a temperature of about 40–90°C. The common etchant used is aqueous solution of NaOH/ KOH at a molarity of about 2–6 M means aqueous solution of 240 g NaOH in a liter of double distilled water. Typically, the etching time is of about 2–6 h as the molarity of etching reagent, etching time and etching temperature increases; consequently, the size of resulting etch pits increases. In many cases, a definite proportion of ethyl alcohol may be added in the solution. Therefore, the alcohol helps to increase the registration sensitivity of some plastics (i.e., Poly-carbonates). Table 3.2 depicts the general etching conditions of some commonly used SSNTDs with critical angle.
Figure 3.5: The etching apparatus
Table 3.2: The general etching conditions of the detectors and critical angle

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Detectors material</th>
<th>Atomic formulae</th>
<th>Etching conditions</th>
<th>Critical angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Allyl-diglycol Poly-carbonate (CR-39)</td>
<td>C_{12}H_{18}O_{7}</td>
<td>6 N NaOH, 70°C, 1–4 h</td>
<td>~ 10°</td>
</tr>
<tr>
<td>2.</td>
<td>Bis-phenol, A-Poly Carbonate (Lexan, Makrofol etc.)</td>
<td>C_{10}H_{14}O_{3}</td>
<td>6 N NaOH, 60°C, 60 min</td>
<td>~ 2–3°</td>
</tr>
<tr>
<td>3.</td>
<td>Cellulose nitrate (Diacell, LR-115, CA-80-15)</td>
<td>C_{6}H_{8}O_{9}N_{2}</td>
<td>3–6 N NaOH, 50°C, 40 min</td>
<td>~ 4–8°</td>
</tr>
<tr>
<td>4.</td>
<td>Muscovite mica</td>
<td>KAl_{5}SiO_{10}(OH) _2</td>
<td>48% HF, 23°C, 3 sec–40 min</td>
<td>~ 4°3’</td>
</tr>
<tr>
<td>5.</td>
<td>Sodalime glass</td>
<td>-</td>
<td>48% HF, 23°C, 3 sec</td>
<td>~ 50°</td>
</tr>
<tr>
<td>6.</td>
<td>Phosphate glass</td>
<td>-</td>
<td>48% HF, 23°C, 3 sec</td>
<td>~ 1–5°</td>
</tr>
<tr>
<td>7.</td>
<td>Olivine</td>
<td>-</td>
<td>KOH, 160°C, 6 min or 10% HF, 23°C, 3 sec</td>
<td>-</td>
</tr>
<tr>
<td>8.</td>
<td>Quartz</td>
<td>SiO_2</td>
<td>KOH, 210°C, 10 min</td>
<td>-</td>
</tr>
<tr>
<td>9.</td>
<td>Zircon</td>
<td>-</td>
<td>85% H_3PO_4, 500°C, 1 min</td>
<td>-</td>
</tr>
</tbody>
</table>
The plastic track detectors are generally suspended by attached wires. Alternatively, a suite of detectors may be suspended vertically in frames, which holds the individual foils at a fixed distance apart. The detectors were immersed in the etching solution inside beaker with their tops covered. The beaker was placed in a constant temperature water bath (figure 3.5). After etching, the detectors were removed and washed in fresh running water, consequently placed for ultrasonic bath for few minutes to remove the residue from the etch pits. After drying, the detectors are ready to be counted using an optical research microscope. The diameters of etched tracks are typically a few µm in size, but they grow up to 50 µm or more after prolonged etching.

Now, they can be viewed using an ordinary optical microscope. This is an only procedure that has succeeded for revealing tracks of extremely low energy of about 1 keV/amu nuclei in the solids such as solar wind ions [33], and the recoil nuclei that are produced as a result of α-decay of the heavy elements like uranium and thorium [35].

The etching of tracks in the nuclear track detectors (NTDs) has been a subject of theoretical investigations of many researchers [36–45]. The track formation is determined by two parameters, bulk etch rate of undamaged detector surface $V_B$ and track etch rate along particle track $V_T$, the problems become rather geometrical in nature [2]. In addition to the geometrical considerations, there are theories which describe the physical and chemical aspects of latent track formation. The track parameters, depth, major and minor axes, vertical profiles, and opening contour have been calculated and plotted for CR-39 detectors, which were irradiated with alpha particles [46]. Another frequently used NTD is LR-115 detector, based on cellulose nitrate. Descriptions of these two detectors and their application in radon measurements and other fields have been summarized [7, 12]. As it was mentioned above, the etched track of a charged particle in NTD is formed by simultaneous action of two etching rates $V_B$ and $V_T$ during the etching, the track wall moves parallel to itself [47].
Present method is applied for LR-115 detectors for both possible direction of etching (direct etching and reverse etching). Reverse etching may be important in neutron dosimetry, where protons and other secondary charged particles are created in different directions. It is highly possible that the recoil protons created in \((n,p)\) reaction moves in opposite direction to etching solution. To investigate the shape and parameters of such tracks, it is necessary to develop software, which simulates reverse etching. In addition, reverse etching was interesting in some kinds of radiobiological experiments with LR-115 and CR-39 detectors [48, 49].

The track development kinetics has been described by many researchers reported elsewhere [7, 38, 44, 50], who did emphasize the consequences of application of physically not always realistic assumptions. These concepts are supported by track etch models generally based on two distinct etching velocities \(V_T\) and \(V_B\) [2, 7, 36–38, 51, 52]. \(V_B\) stands for the bulk etch rate (isotropic) and the \(V_T\) symbolizes the specific track etch rate (anisotropic and longitudinal).

The problem of track development has attracted much attention for a long time [36–43, 53]. Recently, a method for calculating the track parameters based on analytical and three-dimensional consideration was reported elsewhere [50]. Consideration was restricted to tracks in the first phase of development, where etching does not reach to the end point of the particle range. Therefore, the track is conical in shape. Figure 3.6 shows the critical angle of etching.
3.4.2. ELECTROCHEMICAL ETCHING:

The main purpose of electrochemical etching is to further enlarge the etch pits of about $10^2 \, \mu m$. Thus, they can be counted using a low magnification device such as a microfiche reader, a slide projector or microscopes at a low magnification of 10X. The tracks after electrochemical etching are really easy visible to the naked eyes. It consists of two or three sequential steps mentioned below:

1. A period of chemical etching, in which a track develops into a needle like or conical shape.
2. Treeing takes place in proper electrochemical etching.
3. A post electrochemical etching step, in which enlargement of the etch pits.

Now, the size of electrochemically etched pits may be about 100–200 $\mu m$. Suppose, if the track density is too high, which is greater than $10^3 \, cm^{-2}$. The average size of etch pits become small due to the natural repulsion of electrical charges, but some tracks may totally or partially fail to spark on account of ‘shielded’ from the electric field.

\[ \theta_c = \sin^{-1}\left(\frac{V_B}{V_T}\right) \]

**Figure 3.6:** The critical angle of etching
3.5. TRACK GEOMETRY:

The shape and size of the etched track is determined by track etch rate, $V_T$, and bulk etch rate, $V_B$, namely. The track etching is dictated in a simplest way by simultaneous action of two etching processes, which are chemical dissolution along the particle track at a linear rate $V_T$ and general attack on the etched surface and on the interior surface of the etched track at a lesser rate $V_B$ [8, 25]. Generally, it is now experimentally clear that in most materials, whether plastic [54–59], glass [52, 60] or crystalline [1, 9] $V_T$ increases with ionization rate. Figure 3.7 shows the track geometry with constant $V_T$ and $V_B$.

![Figure 3.7: The track geometry with constant $V_T$ and $V_B$](image)

Figure 3.7 depicts the incident of a particle vertically (a) and at a dip angle $\phi$ (b) [61], respectively. Consider the simplest case of normal incidence, figure 3.7a shows the surface material removed at the time of developing the etched track. Since both
the diameter D and visible track length l is being less, smaller the excess of \( V_T \) over \( V_B \) [8].

Thus, 

\[
l = (V_T - V_B) t
\]

(1)

\[
D = 2 V_B t \sqrt{\frac{(V_T - V_B)}{(V_T + V_B)}}
\]

(2)

If, \( l = 0 \) and \( D = 0 \)

Since 

\[
V_T = V_B
\]

Equation 1 and 2 applies, when \( V_T t < R \) and for a longer time, respectively, which is given by

\[
t < \frac{R}{V_B} \left( 1 + \frac{(1 - \sin \theta)(\cos \theta / 2 + \sin \theta / 2)}{(\cos \theta / 2 - \sin \theta / 2) \cos \theta} \right)
\]

The etching parameters are also written in terms of measurable quantities.

\[
\frac{V_T}{V_B} = 2 \left( \sqrt{(D/2)^2 + l^2 / D} \right) = \text{Cosec} \theta
\]

\[
V_B t = \frac{D}{2} \left( \frac{D}{2l} + \sqrt{(D/2)^2 + l^2 / l} \right)
\]

\[
= \frac{D}{2} [\tan \theta + \text{Sec} \theta]
\]

\[
V_B t = \sqrt{(D/2)^2 + l^2} \left( \frac{D}{2l} + \sqrt{(D/2)^2 + l^2 / l} \right)
\]

\[
V_B t = D \text{Cosec} \theta \left( \frac{\tan \theta + \text{Sec} \theta}{2} \right)
\]
In figure 3.7b, the major axis of the ellipse approaches infinity as $\Phi$ approaches the cone angle $\theta$. The relations for the angles and track length in terms of measurable quantities $z$, $p$, $a$, and $V_B$ given as:

$$
\Phi = \frac{\arctan\left(\frac{z}{(a+p)}\right) + \arctan\left(\frac{z}{p}\right)}{2}
$$

$$
\Phi = \arcsin\left[\frac{\sqrt{z^2 + p^2} \sqrt{(a+p)^2 + z^2 - p^2 - ap + z^2}}{2 \sqrt{(a+p)^2 + z^2}}\right]^{1/2}
$$

$$
\theta = \frac{-\arctan\left(\frac{z}{a+p}\right) + \arctan\left(\frac{z}{p}\right)}{2}
$$

$$
\theta = \arcsin\left[\frac{\sqrt{z^2 + p^2} \sqrt{(a+p)^2 + z^2 - p^2 - ap - z^2}}{2 \sqrt{(a+p)^2 + z^2}}\right]^{1/2}
$$

$$
L = \left(\frac{z + V_B}{\sin\phi}\right)
$$

The dimensions of the elliptical interaction with etched surface are given by:

$$
b = \frac{1 - \left(\frac{\sin^2\theta}{\sin^2\phi}\right)}{(1 - \sin^2\theta)}
$$

$$
b = 2 V_B \frac{\{\sin\phi - \sin\theta\}}{\sqrt{\sin\phi + \sin\theta}}
$$
These geometrical relations were given by Price and Fleischer, and Henke and Benton [36, 61].

**3.6. ETCHING EFFICIENCY:**

The track, which inclined at an angle less than the cone angle $\theta$ to the surface are not etched [5, 8]. We consider etching efficiency $E_e$ for non zero $\theta$. Thus, the fraction of tracks intersecting on a given surface that are etched under specified etching conditions is known as etching efficiency. The etching efficiency has to do with purely geometrical requirements for revealing the tracks that are present, but registration efficiency is a different concept. The fraction of particles passing through a surface that produces radiation damage tracks as continuous damage with $V_r > V_b$. A qualitative picture of how tracks are revealed by etching is depicted in the following figure 3.8, which shows the track registration geometry.
Figure 3.8a depicts the track pit shape, which is determined by $V_T$ and $V_B$; when $V_B/V_T < 1$. It is clear from figure 3.8b that no track could be observed, if incidence angle $\phi$ is less than the critical angle. Figure 3.8c shows the critical angle $\theta_c (= \arcsin V_B/V_T)$ at which the particle enters. After etching, the tracks will be visible, if the particle enters at an angle greater than critical angle.

It is assumed that after etching, a track existing perpendicular to the surface of the detector. As a simplified model, it is assumed that the undamaged surface is eroded away at a velocity $V_B$ perpendicular to the surface of the detector. Moreover, it is assumed that the etching velocity $V_B$ along damaged track is less than $V_T$. It is adequate to explain many features of the observed track behavior. The tracks, which make an angle less than the critical angle on the surface of the detector, will not be detected because they will be erased during the process of chemical etching. Therefore, it is clear from the above model that the angle of incidence must be
greater than the critical angle to avoid its disappearance due to chemical etching from the surface of detector. The critical angle for track registration is of about 5–15$^0$ in polyester. Due to the variability of etching conditions and energy loss threshold, the etching behavior should be demonstrated in advance. A number of environmental factors have a significant effect on the behavior of etching. The formation of tracks can be enhanced through the electrochemical etching. A fraction of the solid angle, over which tracks are not formed, is given by:

$$\frac{1}{2\pi} \int_{0}^{\theta} 2\pi \cos \theta' \, d\theta' = \sin \theta$$

Since

$$E_c = 1 - \sin \theta$$

It is expected that the particle tracks originate throughout the detector may be revealed by etching, which originate at a depth of ranging from 0 to H. Here H is the maximum depth at which particle produce an etchable track. Figure 3.9 shows a fraction of the revealed track.

Figure 3.9: A fraction of the revealed track
3.7. TRACK REVELATION METHODS:

The principle of detection of SSNTDs is based upon the fact that a heavy charged particle passing through the dielectric materials produces damage along their trajectory. This damaged region has their physical and chemical properties. Thus, the damage trails produced by the incident ion is called as “latent track”. These tracks do not see naked eyes and optical research microscope because of their size of about 50 Å, typically. It can be seen using a Scanning Electron Microscope (SEM) [10, 62, 63]. The important application of the tracks in solids started only after the selective chemical etching process of track revelation in 1962. There are various methods of track revelation such as TEM, selective chemical etching [5, 8, 25], track decoration [64, 65], use of color centers [66], grafting and dying of tracks [67, 68], and electrochemical etching [69]. Subsequently, they can be viewed using an optical research microscope. In all of these, the selective chemical etching is a simplest and most widely used method.

3.8. TRACKS COUNTING TECHNIQUES:

The information stored in the SSNTDs may be extracted, easily. This is an extremely important factor in personnel dosimetry. Whereas in many research fields involving track detectors, the analysis of a large number of tracks under a high power microscope may be in a viable proposition, but in dosimetry a large number of detectors must be dealt with on a routine basis, generally. Therefore, the track detectors are to provide a realistic means of radiation monitoring, some methods of rapid evaluation of these detectors must be devised.

There are many techniques reported in the literature for tracks counting produced in the SSNTDs. I have used optical research microscope and spark counter for this purpose.
3.8.1. SPARK COUNTING TECHNIQUE:

The Spark counting technique was first of all devised by Cross and Tommasino [70], thereafter undergone several improvements [71–73]. This is a most widely used non-optical technique for α-particle tracks counting. A typical schematic diagram and the spark counter are shown in figure 3.10 and 3.11, respectively. The setup consists of a spark head, adjustable HV circuit, display for counts and pulse shaping circuits. As shown in figure 3.11, the spark head is in the form of a circular electrode of area 1 cm² and other electrode is in the form of a spring loaded contact.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{spark_counter_diagram}
\caption{A schematic diagram of the spark counter}
\end{figure}
**Figure 3.11:** The Spark Counter
A number of automatic techniques have also been developed for this purpose. Many of them are based on the optical methods, in which computer controlled microscope allows examination of each individual track using a photomultiplier tube. Automatic counting can be carried out through a spark counter [74] of chemically etched SSNTDs, which is a well documented technique [71]. The application of spark counting is also in the counting of tracks of more lightly ionizing particles. The success has been achieved in spark counting of thin foils of α-sensitive detectors [75]. The top thin red layer (i.e., sensitive surface of the detector) or detector foil of pelleculable (i.e., strippable) LR-115 detectors is used for α-particles track counting.

The detector foil is placed on the spark head (i.e., round electrode). Thereafter, the aluminized foil of size of about 3 × 3 cm is placed on it in such a way that its aluminized side faces the detector foil and covers the circular electrode and also touches other electrode. Then, a circular weight is placed on the electrode base so as to press the spring loaded contract. Subsequently, a high voltage of about 950 V is applied across the electrodes and the counting is started by pressing a start switch, provided on the front panel of the instrument. This process is called pre-sparking, which is necessary for clearing partially developed holes during the etching process. It is usual for the detector foil of about 10–20 µm thick. After pre-sparking, the aluminized foil is removed and a fresh one is placed on the detector foil without disturbing it. By sparking the detector foil at several voltages, it may be seen that a plot of track count against sparking voltage yields a plateau region. The central region of plateau indicates that the optimum counting voltage is of about 480 V [72]. Before the actual counting of the detector foil, its plateau characteristics were studied. Figure 3.12 depicts plateau of the spark counter.
Counts

Figure 3.12: Plateau of the spark counter

Now, the operating voltage (i.e., counting voltage) set across the electrodes and counting started, again. The obtained counts are noted down at the end of the counting, and same process repeated twice again with fresh aluminized foil at every time and finally averaged the three reading. This method is simple and relatively low time consuming. This technique has many applications besides dosimetry.

As usual every technique have some disadvantages, thus this technique is not an exception. The efficiency of this technique decreases as rapidly as the angle of incidence of the track with the detector surface decreases [76].
3.8.2. OPTICAL TECHNIQUE:

The optical transmission microscope is an easiest and most widely used track counting tool, which is made of transparent materials. The microscope, which has a magnification in the range of about 100–1000X can scan tracks of the detectors in the length of about 1–15 µm.

For radon monitoring, it is often required to count α-tracks. This method is known as manual counting technique of α-tracks, which is tedious and more time consuming. In less tedious manner, through the use of a projection microscope by which images of etched tracks are displayed on screen of the system. The track density is calculated by counting the tracks in graticules of 10 × 10 squares fitted in one of the eye-piece of an optical research microscope (figure 3.14). The dimensions of the graticule are calibrated using a standard scale.

The track density of about $10^4$ tracks.cm$^{-2}$ can be counted using this simple technique. The information other than track density such as track size or orientation can also be obtained using an optical microscope. Figure 3.13 shows the tracks of α-particles formed in LR-115 detectors, which were seen using an optical research microscope and figure 3.14 shows the optical research microscope used in the present study.
Figure 3.13: The tracks of alpha particles formed in LR-115 detector

Figure 3.14: The optical research microscope
References:


