Studies on Trace Element Analysis of Uranium Using Solid State Nuclear Track Detection Technique

Dissertation Submitted in Partial Fulfilment of the Requirements for the Award of the Degree of Master of Philosophy in Physics

By

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(AMEER AZAM)
PREFACE

This dissertation is being submitted in partial fulfilment of the degree of Master of Philosophy (M.Phil) in Physics, which is an essential pre-Ph.D. requirement in the Aligarh Muslim University, Aligarh.

This dissertation has been divided into three chapters.

Chapter I contains brief description of the occurrence and uses of Uranium. This chapter also contains the mechanism of nuclear fission and the process of detection of fission fragments using plastic track detectors. Towards the end of the chapter a specific mention of the aims and results of present investigations has been made.

Chapter II contains brief description of historical development of the Solid State Nuclear Track Detection Technique. The track formation mechanism and track development process have also been explained in this chapter. Methods of track visualization and evaluation and threshold characteristics of the SSNTDs are also mentioned.

Chapter III is the original contribution of the author.

Chapter III describes the application of Melinex-O plastic track detector for the measurements of uranium content in soil and plant samples collected from various places of Uttar Pradesh. The chapter contains all experimental details.
result and discussion on the determination of Uranium content in various soil and plant samples. Finally the dissertation ends with a list of references of the work consulted by the author in the preparation of this dissertation.
# CONTENTS

## CHAPTER ONE

1.1 Introduction ................................................. 1
1.2 Nuclear Fission ............................................. 4
1.3 Mechanism of Nuclear Fission ............................. 7
1.4 Spontaneous Fission and Liquid Drop Model ............. 7
1.5 Deformation of the Liquid Drop ........................... 11
1.6 Detection of Fission Fragments Using Plastic Track Detectors ........... 18
1.7 The Present Investigations ................................. 21

## CHAPTER TWO

2.1 Introduction ................................................. 22
2.2 Principle of Detection ...................................... 23
2.3 Historical Background ..................................... 25
2.4 Track Formation Mechanism ............................... 27
2.5 Methods of Track Revelation and visualization ........... 30
2.6 Methods of Track Evaluation ............................... 39
2.7 Threshold Characteristics of SSNTDs and Place of Plastic Among These Detectors ............................... 40

## CHAPTER THREE

3.1 Introduction ................................................. 44
3.2 Experimental Details ...................................... 47
3.3 Results and Discussions ................................. 52

REFERENCES ...................................................... 56
CHAPTER - I

1.1 INTRODUCTION:

Uranium is a heaviest naturally occurring trace element. It has widespread occurrence and is found in minute quantities in all rocks, sand and soil. Although regarded as a rare element it has a considerable higher concentration in the earth's crust than other toxic elements such as Sn, Cd, Bi and Hg and the precious metals. It is not uniformly distributed and occurs mainly in a dispersed state. UNSCEAR reports 1966, 1972 indicate the typical content of uranium in the accessible lithosphere about 2.8 ppm but the content varies widely in different type of rocks. Some approximate abundances are shown in the following table.

<table>
<thead>
<tr>
<th>Type of Rock</th>
<th>ppm of U</th>
<th>$^{238}U/\text{kg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mafic igneous rocks</td>
<td>1</td>
<td>330</td>
</tr>
<tr>
<td>- basalts, gabbros</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate igneous</td>
<td>2</td>
<td>600</td>
</tr>
<tr>
<td>- rocks, diorites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acid igneous rocks</td>
<td>2.6</td>
<td>860</td>
</tr>
<tr>
<td>- granodiorites</td>
<td>4.7</td>
<td>1600</td>
</tr>
<tr>
<td>- granites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediments</td>
<td>4</td>
<td>1300</td>
</tr>
<tr>
<td>- normal shales</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- lime stones</td>
<td>2</td>
<td>660</td>
</tr>
<tr>
<td>- black shales</td>
<td>8</td>
<td>2600</td>
</tr>
</tbody>
</table>

There has been found a large variation (250-500) ppm in the concentration of uranium within each type of rocks.
In the economically viable uranium ores the concentration varies from 1000 to 3000 ppm while in few of the pitchblende samples 72% of U$_3$O$_8$ has been found in lenses or veins$^4$. The concentration in phosphate rocks can be as high as 0.12 mg/g$^5$. Sea water uranium concentration has been found to vary from 0.0003 to 0.003 mg/l$^6,7$. All of these sources come in contact with water and thus transfer certain concentration of uranium.

Uranium has also been found in phosphate deposits and can come from tailings and phosphate deposits as well as runoff from phosphate fertilizer$^8$. The average fertilizer uranium concentration is about 100 µg/g. Phosphate mineral from Florida indicate uranium concentrations 4.5-83.4 pCi/g$^5$. After processing uranium follows the phosphoric acid whereas radium found in phosphate deposit follows the by-product gypsum and is thus separated. In ammoniated phosphate and triple superphosphate the uranium contents have been estimated to be 25.3 and 26 pCi/g respectively. The use of phosphate fertilizer may lead to increase the uranium concentration in rivers and thereby in the soil in its neighbourhood and in the plants grown there. More than 99% of the uranium transported by runoff from land to fresh water systems remains with suspended particulates on the sediments. Only a small amount of uranium remains in true solution in fresh water$^8$. 
Uranium may be found in valence states +2, +3, +4, +5 or +6, the most common being the hexavalent and tetravalent states. As almost all the tetravalent compounds are practically insoluble, the hexavalent state is important one in water. Natural uranium has 99.27% $^{238}\text{U}$, 0.72% $^{235}\text{U}$ and 0.006% $^{234}\text{U}$ and 1 µg of uranium has an activity of 0.67 pCi. The uranium is found as uranyl ion ($\text{UO}_2^{2+}$) in nature and all the natural compounds of uranium contain oxygen.

The main use of uranium is in the form of fuel in nuclear power reactors and in nuclear weapons. It also finds uses in internal guidance devices, gyrocompasses, as a counterweight for missile re-entry vehicles and as x-ray targets. Uranium compounds are also used in photographic toners, coloured glasses, ceramic glasses, tiles and as catalyst.

Hydrolysis competes with organic and inorganic complexation and control the environmental behaviour of uranium. At pH6 and below uranium forms very stable complexes with oxygen rich organic compounds in the form of humic and fulvic acids in the natural environment. This interaction involves peats, coals, asphalts, as well as inorganic interactions with s'ales, phosphorites, and carbonates. When put into solution uranium forms the uranyl ion ($\text{UO}_2^{2+}$) and this ion forms soluble salts with
all common anions except phosphate\textsuperscript{10}. Uranium can also be introduced into the water supply by human activity in the mining and milling of uranium ore. The uranium concentrations of water may be inferred from nearby ground and surface soil.

1.2 NUCLEAR FISSION:

Nuclear fission\textsuperscript{11,12} was discovered in 1939 as a process in which a uranium nucleus after capture of neutrons splits up into two parts which are considerably different from the target nucleus. Although nuclear fission has been produced from the bombardment of heavy nuclides by neutrons, protons, deuterons, alpha particles and even electrons and gamma rays, nuclear fission of practical importance is the neutron induced fission of uranium and plutonium. A number of reviews of various aspects of fission have been published by many workers\textsuperscript{13-21}. The only naturally occurring nuclei that can be fissioned with thermal neutrons is $^{235}$U which constitutes 0.71% of naturally occurring uranium. When a nucleus of high atomic number undergoes fission, fission fragments having two almost equal parts are produced. The fission fragments contain too many neutrons for them to be stable. They can approach stability either by ejecting one or more neutrons or by the emission of beta-particles obtained from the conversion of neutron into proton.
Fission into more than two intermediate mass fragments is extremely rare. The fission fragments can be anyone of the nuclides in centre third of the Periodic Table. The fission yield curve for $^{235}\text{U}$ by thermal neutrons has been shown in Figure 1.1. From the fissioning of uranium altogether about 300 stable and radioactive nuclides have been found. About 180 different beta-emitters have been identified among the products resulting from uranium fissioning. As can be seen from the figure the maximum yield occurs for mass numbers near 95 and 140.

The energy released for fission of uranium has been estimated to be around 200 MeV. About 170 MeV of this energy is provided as the kinetic energy of the fission fragments. Except for a very small fraction all fission neutrons are emitted virtually instantaneously and are called prompt neutrons. According to the compound nucleus picture, these are the neutrons which are boiled off from the highly excited compound nucleus. In case of $^{235}\text{U}$ 0.64% delayed neutrons are emitted having a time lag of several seconds to more than a minute after the fission. They arise out of the radioactive decay of a fission fragment. The energy distribution consists of two distinct groups having mean energies about 70 and 100 MeV. Later studies based on the measurement of ionization velocities of the fission fragments indicate that
Figure 1.1
the K.E. of these fragments is 167 Mev for $^{235}$U fission produced by slow neutrons. The two groups of energies have maximum of about 68 and 99 Mev.

1.3 MECHANISM OF NUCLEAR FISSION:

The mechanism of nuclear fission has been explained by means of liquid drop model of the nucleus. It is capable of explaining some of its chief features and gives fair agreement with many experimental results.

According to this model the nucleus in equilibrium corresponding to its most stable configuration assumes a spherical shape. As long as the nucleus is not disturbed, it remains in this state and shape under the joint action of the

1) Cohesive short range nuclear forces acting throughout its volume and along its surface.

2) The Coulomb force of repulsion between the protons present in the nucleus. This force tries to disrupt the nucleus.

1.4 SPONTANEOUS FISSION AND LIQUID DROP MODEL:

Spontaneous fission can be predicted by empirical nuclear mass equation. Assuming the symmetric fission as a special case, the energy released, $E_f$, upon fissioning into two equal parts,
\[ E_f = \left[ \frac{A}{2} - 2 \left( \frac{A}{2} \right)^{1/3} \right] C^2 \]
\[ = 2 \left( B \cdot E \right) \frac{A}{2} - \left( B \cdot E \right) A \]

Considering Weizsaker's semi-emperical mass formula

\[ E_f = (-3.42 \frac{A^{2/3}}{Z^2} + 0.22 \frac{Z^2}{A^{1/3}}) \text{ MeV.} \]

From this equation it is clear that splitting of the nucleus affects coulomb energy and surface energy in such a way that the change in one tends to cancel the change in the other partially. This is expected as the separation between the proton groups increases by the division of the nucleus. Therefore reduces their coulomb potential energy. On the other hand the total nuclear surface is increased resulting in the increase of surface energy. Thus for spontaneous fission,

\[ E_f \gg 0 \]

or \[ (-3.42 \frac{A^{2/3}}{Z^2} + 0.22 \frac{Z^2}{A^{1/3}}) \gg 0 \]

or \[ \frac{Z^2}{A} \gg 15 \]

Therefore the nuclear fission should be energetically possible for nuclei with \[ A \gg 85 \]. However the slow neutron fission does not take place even in many of the heavy nuclei. This discrepancy was explained by Bohr and Wheeler.
considering the coulomb potential barrier of the two fragments at the instant of separation. The coulomb potential barrier prevents the immediate splitting of these two. The barrier height corresponding to the coulomb potential between the two symmetric fragments when they are just in contact with each other is given by

\[ E_b = \frac{1}{4 \pi \varepsilon_0} \frac{(z^2 e^2)}{2 R} = \frac{1}{4 \pi \varepsilon_0} \frac{Z^2 e^2}{8 R_0 \left( \frac{A}{2} \right)^{1/3}} = 0.15 \frac{Z^2}{A^{1/3}} \text{ MeV} \]

Thus the condition of stability becomes

\[ E_b - E_f \geq 0 \]

or \[ \frac{Z^2}{A} \leq 49 \]

It is concluded that nuclei for which the condition of stability is not fulfilled can not exist as the smallest disturbance would be sufficient to trigger the disruption of the nucleus.

Figure 1.2 shows the relationship between \( E_f \) and \( E_b \) and their general behaviour as a function of \( A \). The
Figure 1.2
graph shows that for \( A = 250 \) \( \epsilon_d \) becomes equal to \( \epsilon_f \), so that one does not expect nuclei with \( A > 250 \) to be found in nature.

1.5 DEFORMATION OF THE LIQUID DROP:

If the force is applied to the drop of the liquid, so that it is set into oscillations, the system passes through the series of stages some of which are shown in Figure 1.3.

The drop is elongated into an ellipsoid (B). If not enough energy is available to overcome the surface tension, the drop will return to its original shape, but if the deforming force is sufficiently large, the liquid acquire a shape similar to the dumb-bell (C). Once this stage is reached, it can not return to its spherical shape but will split into two droplets. These will be somewhat deformed (D) but finally will become spherical (E).

The situation in nuclear fission is believed to be analogous to the liquid drop. A compound nucleus is formed by the absorption of a neutron by the target nucleus. Its excitation energy is equal to the binding energy of the neutron and the kinetic energy, if any, the neutron may have had before capture. The introduction of excitation energy into nuclear system disrupts the equilibrium of the nucleus. Once the incoming neutrons sufficiently distort
Figure 1.3

Liquid-drop model of fission

Figure 1.4
the spherical shape of the nucleus, the equilibrium that existed in the undisturbed nucleus is irrevocably destroyed. If the energy is insufficient to cause deformation beyond (B) the int-ranuclear forces will compel the nucleus to its original spherical form and the excited compound nucleus will get rid of its excess energy by the expulsion of a particle. But once the critical point of distortion is reached, the total energy of the nucleus will continue to decrease with increasing deformation and will finally lead to an irreversible break up of the nuclear drop. The mutual potential energy of the two symmetrical fission fragments against the distance between them is shown in Figure 1.4. At E two fission fragments are far apart so that the potential energy is zero. As the fragments come close together, there is an increase in the potential energy due to coulomb force of repulsion between the fragments. When the fragments are roughly in contact, at the point C, the nuclear forces become dominant and the potential energy start decreasing.

The potential curve has a maximum value at C. The hump represents the barrier against spontaneous splitting. The potential energy barrier as seen from the inside of the nucleus is given by $E_b - E_f$ where $E_b$ denotes the height of coulomb barrier and $E_f$ is the deformation energy available for fission. The presence of this barrier explains why fission does not take place spontaneously in all cases.
where $E_f > 0$. An additional amount of energy $E_a = E_b - E_f$, the activation energy is required by the nuclear system to allow the fission to take place.

The first theoretical treatment of the fission process was given by Bohr and Wheeler in 1939 and they made detailed calculations about the behaviour of a nuclear drop under deformation. For small axially symmetric distortions the radius can be written as

$$R(\theta) = R_0 \left[ 1 + \chi_2 \cos \theta \right]$$

where $\theta$ is the angle of the radius vector, $\chi_2$ is a parameter describing quadrupole distortion and $R_0$ is the radius of the undistorted sphere. For spheroidal distortions additional terms starting with $\chi_4 P_4$ are required. However for small spheroidal distortions $\chi_4$ is considerably less than $\chi_2$. The surface and coulomb energies for small distortions are given by (Bohr & Wheeler 1939).

$$E_s = E_{s0} \left( 1 + \frac{2}{5} \chi_2^2 \right)$$

$$E_c = E_{c0} \left( 1 - \frac{1}{5} \chi_2^2 \right)$$

where $E_{s0}$ and $E_{c0}$ are the surface and coulomb energies of undistorted spheres. For the charged liquid drop to be stable against small distortions the decrease in coulomb energy $\Delta E_c = -\frac{1}{5} \chi_2^2 E_{c0}$ must be smaller than the
increase in surface energy $\Delta E_s = \frac{2}{5} \sqrt{2} E_s^0$. The drop becomes unstable when $|\Delta E_c| = E_s$ or when $E_c^0 / 2 E_s^0 = 1$. $E_c^0 / 2 E_s^0$ is known as the fissility parameter $x$.

For $x < 1$ the drop will be stable against small distortions. For $x > 1$ there will be no potential barrier to inhibit spontaneous division of the drop. For the idealized spherical nucleus we have

$$E_c^0 = \frac{3}{5} (2e)^2 / R_o$$

where $Z$ is the number of protons. The surface energy

$$E_s^0 = 4 \pi R_o^2 \sigma$$

where $\sigma$ is the surface tension. Green (1954) performed the analysis of these equations expressed in terms of mass number $A$ and nuclear charge $Z$ by fitting experimental masses with the semi-empirical masses and obtained

$$E_c^0 = 0.7103 Z^2 / A^{1/3}$$

and $$E_s^0 = 17.80 A^{2/3}$$

Substituting these values one gets $x = z^2 / 50.13 A$. Some typical values of $z^2 / A$ and $x$ are 35.56 and 0.71.
for $^{238}\text{U}$ and 38.11 and 0.76 for $^{252}\text{Cf}$ and are well below the limiting value of 45. This indicates that all naturally occurring nuclides are stable with respect to small deformation. For deformations that exceed the critical limit, the nucleus breaks apart. The critical energy required to cause such a break up (activation energy $E_a$) calculated on the basis of Bohr - Wheeler theory is given by the expression.

$$E_a = E_d - E_f$$

$$= A^{2/3} \times 0.89 (1-0.022 \frac{Z^2}{A})$$

If $E_a$ is less than the excitation energy $E_e$ provided by the absorption of a thermal neutron by a particular nucleus, the fission can be produced in this nucleus by thermal neutrons. The excitation energy, contributed to the resultant compound nucleus by the capture of a neutron is equal to the binding energy of the neutron in the compound nucleus.

$$E_e = B (A + 1, Z) - B (A, Z)$$

and can be calculated from the semi-emperical mass formula. The Table 1.1 shows the values of $E_e$ and $E_a$ for some nuclei.
<table>
<thead>
<tr>
<th>Compound</th>
<th>$E_e$ (MeV)</th>
<th>$E_a$ (MeV)</th>
<th>$E_e - E_a$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{234}U$</td>
<td>6.6</td>
<td>4.6</td>
<td>2.0</td>
</tr>
<tr>
<td>$^{236}U$</td>
<td>6.6</td>
<td>5.5</td>
<td>1.1</td>
</tr>
<tr>
<td>$^{239}U$</td>
<td>5.9</td>
<td>6.5</td>
<td>-0.6</td>
</tr>
<tr>
<td>$^{233}Th$</td>
<td>5.1</td>
<td>6.5</td>
<td>-1.4</td>
</tr>
<tr>
<td>$^{238}Np$</td>
<td>5.0</td>
<td>4.2</td>
<td>0.8</td>
</tr>
<tr>
<td>$^{240}Pu$</td>
<td>6.4</td>
<td>4.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>
It is clear that in the case of $^{238}\text{U}$ a critical deformation energy of 6.5 MeV is necessary for fission but it acquires only 5.9 MeV by absorbing a neutron of zero kinetic energy. Thus no fission is possible in $^{238}\text{U}$ with thermal neutrons, whereas the thermal neutrons can produce fission in $^{235}\text{U}$ as the excitation energy provided by the thermal neutrons is greater than the activation energy. However fast fission is possible with $^{238}\text{U}$. The experimental threshold energy for fast fission of $^{238}\text{U}$ is 1.1 MeV as compared to the predicted value of 0.6 MeV.

The liquid drop model has been applied successfully to explain some of the main features of nuclear fission. It fails to explain the observed non-symmetry of the masses of the fission fragments as symmetric fission should be most favoured division according to this theory.

1.6 DETECTION OF FISSION FRAGMENTS USING PLASTIC TRACK DETECTORS:

Nowadays a large number of plastic track detectors are available which can be used as a charged particle detector. The commonly used plastics are Cellulose Nitrate, Cellulose Acetate, Polycarbonates, Polyethylene terephthalates
etc. In the following table 1.2 are listed some well known plastic detectors used to record the tracks of charged particles. Column 2 gives their chemical composition. They have been listed in order of their increasing sensitivity. The last column indicates the smallest ionizing ion being detected by them.

It can be observed that Cellulose Nitrate and CR-39 plastics can even record the lowest ionizing ion (proton) whereas polycarbonates can not record proton. The polycarbonates such as Lexan, Makrofol etc, do not produce etchable tracks of protons but they are sensitive to low energy \( \alpha \)-particles and all other heavy ions. The polyethylene terephthalate plastic like Melinex, Cronar and Mylar etc, are not able to record the tracks of \( \alpha \)-particles and protons but they do record the tracks of heavier ions \( >^{\beta}{_{\Sigma}} \). Therefore the suitable plastic detectors can be used for the detection of fission fragments in the presence of light charged particles like \( \alpha \)-particles, protons etc, which they can not record. For the detection of fission fragments Lexan and Makrofol plastic detectors have been very extensively used. Melinex-O plastic has been rarely used as a fission product detector although it appears to be better than Lexan and Makrofol.
<table>
<thead>
<tr>
<th>Name of plastic detector</th>
<th>Chemical composition</th>
<th>Least ionizing ion detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene</td>
<td>CH&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Fission Fragments</td>
</tr>
<tr>
<td>Polyvinylchloride (PVC)</td>
<td>CH&lt;sub&gt;3&lt;/sub&gt;Cl + C&lt;sub&gt;2&lt;/sub&gt;H&lt;sub&gt;2&lt;/sub&gt;Cl</td>
<td>42 MeV &lt;sup&gt;32&lt;/sup&gt;S</td>
</tr>
<tr>
<td>Polyimide</td>
<td>C&lt;sub&gt;11&lt;/sub&gt;H&lt;sub&gt;4&lt;/sub&gt;O&lt;sub&gt;4&lt;/sub&gt;N&lt;sub&gt;2&lt;/sub&gt;</td>
<td>36 MeV &lt;sup&gt;16&lt;/sup&gt;O</td>
</tr>
<tr>
<td>Polyethylene terephthalate</td>
<td>C&lt;sub&gt;5&lt;/sub&gt;H&lt;sub&gt;4&lt;/sub&gt;O&lt;sub&gt;2&lt;/sub&gt;</td>
<td>28 MeV &lt;sup&gt;14&lt;/sup&gt;N</td>
</tr>
<tr>
<td>(Cronar, Melinex, Mylar)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyoxymethylene</td>
<td>CH&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>28 MeV &lt;sup&gt;11&lt;/sup&gt;B</td>
</tr>
<tr>
<td>(Delrin)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bisphenol A-polycarbonate</td>
<td>C&lt;sub&gt;16&lt;/sub&gt;H&lt;sub&gt;14&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>0.3 MeV &lt;sup&gt;4&lt;/sup&gt;He</td>
</tr>
<tr>
<td>(Lexan, Makrofol, Kimfol, Merlon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose triacetate</td>
<td>C&lt;sub&gt;3&lt;/sub&gt;H&lt;sub&gt;4&lt;/sub&gt;O&lt;sub&gt;2&lt;/sub&gt;</td>
<td>3 MeV &lt;sup&gt;4&lt;/sup&gt;He</td>
</tr>
<tr>
<td>(Cellit-T, Triatol-T, Koascel TA-401 unplasticized)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose acetate</td>
<td>C&lt;sub&gt;12&lt;/sub&gt;H&lt;sub&gt;18&lt;/sub&gt;O&lt;sub&gt;7&lt;/sub&gt;</td>
<td>3 MeV &lt;sup&gt;4&lt;/sup&gt;He</td>
</tr>
<tr>
<td>Butyrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose Nitrate</td>
<td>C&lt;sub&gt;6&lt;/sub&gt;H&lt;sub&gt;8&lt;/sub&gt;O&lt;sub&gt;9&lt;/sub&gt;N&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0.55 MeV &lt;sup&gt;1&lt;/sup&gt;H</td>
</tr>
<tr>
<td>(Daicell, Nixon-Baldwin)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polytech CR-39</td>
<td>C&lt;sub&gt;12&lt;/sub&gt;H&lt;sub&gt;18&lt;/sub&gt;O&lt;sub&gt;7&lt;/sub&gt;</td>
<td>1 MeV proton</td>
</tr>
</tbody>
</table>
plastic as it does not record the tracks of charged particles having low ionizing power. Also the background etch pits developed due to imperfections are much less and easily identifiable than those in the case of Lexan and Makrofol etc. Therefore, we have used Melinex-0 plastic detector to record the tracks of fission products produced by (n,f) reaction used for the determination of uranium content in soil and plant samples.

1.7 THE PRESENT INVESTIGATIONS:

The aim of the present investigations was to measure the uranium content of soil and plant samples collected from different places of Uttar Pradesh using SSNTD Technique. The appropriate etching condition for Melinex-0 was used as 6N, NaOH at 60°C for 90 minutes.

In our studies on uranium content measurement in soil and plant samples, we have found that the U-content varies very widely from place to place. The values of U-content varies from 0.023 ppm to 0.43 ppm in soil samples and from 0.026 ppm to 0.206 ppm in plant samples.
2.1 INTRODUCTION:

Unique information can be extracted from the permanent 'track' left in the structures of certain minerals and materials by the passage of high-energy, sub-atomic particles. Materials in which nuclear tracks have been observed are:

Glass Materials: Volcanic glass (obsidian), tektites, soda lime glass, phosphate glass, meteorites (glass and olivine) etc.

Minerals: Apatite, epidote, quartz, micas, sphene, zircon etc.

Organic Polymers: Cellulose nitrate (LR - 115, Daicel etc), cellulose acetate, polycarbonates (Lexan, Makrofol), polyethylene terephthalate (Cronar, Melinex), CR-39 etc.

These materials, when used to detect the charged particles, are known as Solid State Nuclear Track Detectors (SSNTDs) and the technique of detecting charged particles by these materials is known as Solid State Nuclear Track Detection (SSNTD) Technique. The so-called SSNTDs were first introduced as an important tool for applications in Nuclear
2.2 PRINCIPLE OF DETECTION:

All charged particles cause narrow trails of radiation damage in the materials when they pass through them. As a result of excitation and ionization material damage takes place along their trajectory. The damaged region of the solid has different chemical and physical properties than the bulk material and is called 'latent track' which is in the form of a cylinder of ~50-100 Å radius. This latent track is invisible under optical microscope. However, the latent track can be seen directly as diffraction contrast images using transmission electron microscopy (TEM). If, however, one places the organic plastic material in a chemical etching solution (e.g. 6N, NaOH) the volume around the latent track will be attacked preferentially. The trail of the nuclear particle becomes visible under an optical microscope as a cylindrical cone-shaped hole of ~1-30 μm length, if we consider α-particles or fission fragments.

Nowadays Solid State Nuclear Track Detectors (SSNTDs) are preferred over other prevalent nuclear detectors as they
have in themselves the properties of track recording detectors like the cloud chambers, nuclear emulsions etc., together with the compactness and single particle counting ability of semiconductor detectors without requiring any special dark room processing or costly electronic equipments. Due to their many useful features, these detectors have been used extensively for the last two decades in almost all branches of nuclear science and technology, radiation dosimetry, health physics and geo-sciences. SSNTDs have wide applications in the study of low cross-section nuclear reactions, nuclear fission reactions, identification of cosmic-ray particles of solar and galactic origin, neutron flux measurements, study of radiation history of meteorites and lunar samples, age determination of geological and archaeological samples, microdistribution studies and microanalysis of some elements like U, Th, Ru, Li, B, Be etc, neutron and charged particle radiography, radon and thoron dosimetry and their study for prediction of earth quakes, study of spreading of sea-beds, as micropore filters for filtration of cancer blood cells, virus and bacteria in beer industry, for measuring flight altitude of birds and for heavy ion lithography etc. In fact these detectors have been found to have potential applications in almost every branch of Science and Technology. In addition to the
book written by Fleischer et al.\textsuperscript{26} having excellent treatise on this subject and elaborate list of latest references covering all topics many review articles have appeared on special refinements of the SSNTD techniques and its applications\textsuperscript{25-37}.

2.3 HISTORICAL BACKGROUND :

The Nuclear Track Detection Technique (SSNTD) began in the late nineteen-fifties with two nearly simultaneous but apparently independent works by members of the same establishment, the Atomic Energy Establishment at Harwell, England. In the first of these Young\textsuperscript{38}, investigating the coloration induced in KCl by fission fragments showed that fission fragments in LiF left individual trails of damage which could be etched by a suitable reagent to reveal individual etch-pits. Each pit corresponds to the passage of a single fission fragment. E.C.H. Silk and R.S. Barnes\textsuperscript{39} directly observed a flake of mica bombarded with fission fragments by electron microscopy. The resulting (un-etched) tracks, annealed out and disappeared during prolonged observation under the electron beam.
In 1961, P.R. Price and R.M. Walker of the General Electric Company Research and Development Centre, at Schenectady (New York), apparently ignorant of the Young's observations, followed up the Silk-Barnes work by rediscovering the chemical etching of fission tracks and showed that the etched tracks in mica left permanent features which may be studied at leisure. In 1963, R.L. Fleischer joined the team of Price and Walker. Afterwards, for several years, almost all the work in this field was carried out by these investigators. During this time they not only developed and put the technique on firm footing but also applied it very successfully to Neutron dosimetry, Fission Studies, Biology, Cosmology, Geophysics, Archaeology etc. Finally they showed that fossil tracks could be induced in many materials other than mica. In fact they showed that almost any insulator could be used as a charged particle track detector. 

Today SSNTDs are being used in more than fifty laboratories of the world including Australia, Austria, Bangladesh, Brazil, China, Czechoslovakia, England, France, Hungary, India, Iraq, Iran, Italy, Japan, Mexico, Pakistan, Spain, Sweden, the U.S.A., the U.S.S.R., West Germany and Yugoslavia. C.W. Kraeser (USA), D. Lal (India), E.V. Benton
(USA), G.A. Wagner (W. Germany), G. Somogyi (Hungary), H.A. Khan (Pakistan), H.S. Virk (India), L. Tommasino (Italy), M. Monnin (France), R. Sphor (W. Germany), R.H. Iyer (India), V.P. Perelygain (USSR) and W. Enge (W. Germany) are some of the Scientists who have made some important contributions to this new field.

2.4 TRACK FORMATION MECHANISM:

Charged particle tracks in solids are narrow (< 50Å radius), stable, chemically reactive centres of strain that are composed mostly of displaced atomic rather than electronic defects. On the basis of experimental tests conducted (a) on the measurement of effects of electron irradiation on chemical dissolution rates of solids and (b) on the measurement of the radial distribution of etchable damage in solids, it has been concluded that two separate mechanisms of track formation exist. One for the inorganic solids and glass and the other for the organic solids or polymers (plastics).

(A) For Inorganic Solids: When a heavy charged particle passes through a solid it excites as well as ionizes the atoms of solid in its path. In the case of inorganic solids
the primary damage that results from the excitation and ionization caused by the incident heavy ion is believed to be mainly responsible for the development of an etchable track i.e. for the higher chemical etchability of the damaged trails. There are strong evidences that the secondary effects of delta rays are unimportant for the case of inorganic solids. In fact, in the inorganic solids the lasting thermally etchable damage consists of atomic disorder and vacancies.

Fig. 2.1 shows the formation of tracks in the inorganic solids according to the Ion-Explosion Spike model of Fleischer et al. The incoming heavy ion first knocks out electrons (black circles) from the atoms in its path (open circles) thus creating an unstable array of adjacent +ve ions. The charge centres or +ve ions, so produced, may produce secondary electrons or delta-rays from the atoms of the solid which may further produce excitation and ionization if they carry enough energy. The delta rays deposit energies around the trajectory of the incident particle. Then the +ve ions repel and force one another away from their normal sites into the interstitial positions in the crystal lattice, thus creating vacant
lattice sites due to their coulomb repulsive forces. Thereafter the elastic relaxation reduces the intense local stresses by spreading the strain more widely. The damage produced by atomic collisions consist of displaced atoms and resultant vacancies and can be etched preferentially with respect to the host.

(B) For Organic Polymers or Plastics: In the case of organic polymers or plastics the belief is that both the primary and secondary ionization and excitation play roles in the production of etchable tracks. In plastics, the long chain molecules that makeup the material are broken by the energetic charged particles. Free radicals and excited molecular states are produced which increase in the chemical reactivity at the broken ends, making the track areas more susceptible to etching (Fig 2.2). In the case of plastics the contribution of delta-rays in depositing the energy sideways of the trajectory of the incident ion is most important.^48,49^.

2.5 METHODS OF TRACK REVELATION AND VISUALIZATION:

Many methods have so far been used for the revelation and visualization of charged particle tracks in
Figure 2.2
dielectric solids. They are as follows:

(i) Direct observation of latent tracks in thin crystalline solids using Scanning Electron Microscope (SEM)\(^39, 50, 51\).

(ii) Selective chemical etching for all types of SSNTD viz plastics\(^41\), glasses\(^40\) and minerals\(^42\) and their subsequent observation using optical microscope.

(iii) Track decoration in minerals and their observations with optical microscope using violet or near ultraviolet light\(^52, 53\).

(iv) Track revelation in photochromic materials with the help of colour centres\(^54\).

(v) Detecting the presence of latent damage track in crystals using X-rays\(^55\).

(vi) Grafting and dyeing of tracks in some selected plastics and their observation using optical microscope\(^56-58\).

(vii) Electro Chemical Etching (ECE) technique\(^59-61\).

All the above mentioned methods except the selective chemical etching have some drawbacks and limitation associated with them. Although electrochemical etching (ECE) enlarges the tracks to very large sizes, its application is
limited to some plastics only and for specific type of tracks. It also requires high frequency and high voltage circuit elements. The selective chemical etching of tracks revelation and their visualization using optical microscope is the simplest and convenient technique. It has been most extensively used in the case of all types of SSNTDs (plastics, glasses and minerals) from the very inception of their discovery.

In the case of selective chemical etching the dielectric solid containing charged particle damage trails is immersed in suitable etching solution (See Table 2.1) maintained at a fixed temperature. Inside the solution, the bulk material of solid dissolves in general at a constant rate, \( V_G \) known as bulk or general etch rate while the material along damaged region dissolves at a much faster rate \( V_T \) called the track etch rate, here assumed to be constant at every point on the trajectory of the particle. Since \( V_T \) is greater than \( V_G \), after sometime the preferential chemical attack enlarges the damaged region in the form of a conical etch-pit. When the size of the etch-pit becomes comparable to the wavelength of visible light, it starts scattering the light and can be seen by optical microscope at magnifications of 100 x or more.
**TABLE 2.1**

Etching conditions for some Detectors

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of the Detector</th>
<th>Etching Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Soda Lime Glass</td>
<td>48% HF, 22°C</td>
</tr>
<tr>
<td>2.</td>
<td>Vitreous Quartz Glass</td>
<td>48% HF, 22°C</td>
</tr>
<tr>
<td>3.</td>
<td>Muscovite Mica</td>
<td>48% HF, 22°C</td>
</tr>
<tr>
<td>4.</td>
<td>Makrofol-E</td>
<td>6N, NaOH, 50±1°C</td>
</tr>
<tr>
<td>5.</td>
<td>Makrofol-N</td>
<td>6N, NaOH, 50±1°C</td>
</tr>
<tr>
<td>6.</td>
<td>Lexan</td>
<td>6N, NaOH, 50±1°C</td>
</tr>
<tr>
<td>7.</td>
<td>Melinex-0</td>
<td>6N, NaOH, 50±1°C</td>
</tr>
<tr>
<td>8.</td>
<td>CR - 39</td>
<td>6N, NaOH, 70±1°C</td>
</tr>
<tr>
<td>9.</td>
<td>Hostaphan</td>
<td>33% 6N, NaOH + 70% H₂O + 33% CH₃OH, 40±1°C.</td>
</tr>
</tbody>
</table>
Figure 2.3 shows the development of charged particle track by chemical etching process in an isotropic solid (like glass or plastic) assuming that the preferential track etching starts just from the surface of the detector itself. Since $V_T > V_G$, an etched pit is formed. The etched track remains conical till the time when the etchant reaches the end of the particle's trajectory (Fig. 2.3c). After that the preferential etching along the trajectory stops and the material etches out at the same general bulk rate $V_G$ all along the surface of the track hollow.\(^{62}\)

The wall of the track remains conical but the end of the track becomes spherical (Fig. 2.3d). This is called the transition phase.\(^{63}\)

Prolonged etching will lead to a position where the conical walls of the track-hollow will also vanish, and the entire etched hollow will become spherical (Fig 2.3e). This is known as 'spherical phase'.

The shape and size of the tracks depend upon the type of the particle as well as on the characteristics of the detector and etchants. These also vary with angle of entrance. The track section of normally entering particle is in general circular and that of obliquely entering particle is elliptical. Grazing tracks show conical
Figure 2.3
projections for short etching times (Fig 2.4).

The geometry of etched tracks for the isotropic as well as anisotropic solids have been studied in great details by Henke and Bentom\textsuperscript{64}, Somogyi and Szalay\textsuperscript{65}, Ali and Durrani\textsuperscript{63}, and Somogyi\textsuperscript{66}. The expressions for the diameter of the track $d$, critical angle $\delta_c$, and etching efficiency $\eta_{2\pi}$ in $2\pi$-geometry are:

\[ d = 2 V_G \cdot t \left( V_T - \frac{V_G}{V_T + V_G} \right) \]  \hspace{1cm} (i)

\[ \delta_c = \sin^{-1} \left( \frac{V_G}{V_T} \right) \]  \hspace{1cm} (ii)

and

\[ \eta_{2\pi} = 1 - \frac{V_G}{V_T} \]  \hspace{1cm} (iii)

Obviously, the greater the value of $\frac{V_T}{V_G}$, the smaller will be the critical angle $\delta_c$ and the greater will be the etching efficiency $\eta_{2\pi}$ for track etching in $2\pi$-geometry.
The projection of etched track on the detector surface.

Fig. 3.4, showing etched track development (a) for normal incidence (c) for oblique incidence (b) showing projecting track (b).

Projected etched track.

Original surface.

Etched surface.
2.6 METHODS OF TRACK EVALUATION:

Generally etched tracks are observed using an optical binocular research microscope at magnification of 100 x to 1500 x. In some cases total number of tracks and in some others track density $\int (\text{tracks/cm}^2)$ is required. For finding track density tracks are counted in about 50 to 100 fields and average is determined. A square graticule in the field of view is calibrated for its area by using a stage micrometer glass slide.

The track length and diameter of tracks contain information about the particle's charge $\text{Z}$, mass $M$ and energy $E$. The measurement of diameter and length is done by using a Filler type eye-piece micrometer. Entrance angle of the particle track can be measured by using $z$-axis motion screw of the microscope. The visual counting using optical microscope is very time-consuming and tiring, especially in the case of large number of tracks $> 10^4$. For avoiding such problems many more methods have been developed for track revelation but these have still not found great popularity among trackologists because of their inherent problems. Various methods of track evaluations are:
(i) Scanning Electron Microscope and Replicating Technique.

(ii) Track counting by Reflectance and Transmittance Measurements.

(iii) Counting with unaided Eye Using Projection Microscope or Slide Projector.

(iv) Automatic Scanning Using Electronic Circuit or Image Analysing Devices with Optical Microscopes.

(v) Automatic Scanning Using Jumping Spark Technique.

(vi) Locating charged particle tracks by Naked Eye.

(vii) Track counting by Conductivity Measurements through Etched Tracks.

2.7 THRESHOLD CHARACTERISTICS OF SSNTDS AND PLACE OF PLASTICS AMONG THESE DETECTORS:

Experimentally it has been found that the SSNTDs are threshold type of passive detectors. The relative sensitivity of the SSNTDs is understood in terms of critical value of primary ionization \((J)_{\text{crit}}\) or critical value of restricted energy loss rate \((\text{REL})_{\text{crit}}\) or \(\left(\frac{dE}{dx}\right)_{\text{crit}}\) or \(\left(\frac{dE}{dx}\right)_{\text{crit}}\) or \(\left(\frac{dE}{dx}\right)_{\text{crit}}\) or \(\left(\frac{dE}{dx}\right)_{\text{crit}}\) or \(\left(\frac{dE}{dx}\right)_{\text{crit}}\) or \(\left(\frac{dE}{dx}\right)_{\text{crit}}\). Practically for every SSNTD there exists a critical value of material damage only above which the tracks become
etchable. \((J)_{\text{crit}}\) or \((REL)_{\text{crit}}\) represents this critical damage. If a particle produces an excitation and ionization in a SSNTD to such an extent that resulting damage is above the \((J)_{\text{crit}}\) or \((REL)_{\text{crit}}\) for that material, its tracks can be preferentially etched and observed with the help of a microscope. If the damage produced by any particle is less than \((J)_{\text{crit}}\), that particular particle's track can not be etched in that SSNTD. These threshold or critical values are shown by horizontal lines in Fig. 2.5. Fleischer et al obtained these lines by experimentally detecting the registration and non-registration of tracks of accelerated heavy ions. The open circles represent non-registration, while the filled circles represent 100% registration.

It is evident from this figure that plastic track detectors are most sensitive as the threshold represented by critical value of primary ionization \((J)_{\text{crit}}\) is lower for plastics (Fig 2.5). Among the plastics themselves, the Daicell CN is more sensitive than Nixon-Baldwin. Melinex-O is the least sensitive plastic as it has the highest value of critical primary ionization \((J)_{\text{crit}}\). Melinex-O can not record the tracks of protons or \(\alpha\)-particle and is capable of recording the tracks of ions heavier than oxygen and fission fragments. The Lexan polycarbonate plastic records tracks
Figure 2.5
of fission fragments and low energy alpha particles (below \( \sim 0.5 \text{ MeV} \)) while it does not record the tracks of protons. Similarly the glasses are more sensitive than mica and meteoritic minerals. Muscovite mica and glass do not record the tracks of lighter charged particles viz alpha particles and protons whereas they record the tracks of fission fragments and other ions heavier than oxygen. Similarly the mica records the \(^{20}\text{Ne}\) ions of energy upto 2 MeV while the glass records \(^{20}\text{Ne}\) heavy ions of energy upto 20 MeV.

CR-39 plastic track detectors have been found to be the most sensitive track detector known so far. This plastic is made by the polymerization of a liquid monomer of allyl diglycol carbonate and is able to record even the tracks of 1 MeV protons.\(^{78}\)
3.1 INTRODUCTION:

Uranium is a normal constituent of organism and its concentration in organism varies between $10^{-4}\%$ and $10^{-9}\%$ by weight. It plays an important role in various cosmochronological, nucleo-synthesis events, toxicity and environmental pollution hazard. Its toxicity to plant is moderate but it can result in variation of colour in flowers, presence of abnormal fruits, increase in chromosomes of nucleus stimulation. Plant ash normally contains 0.2 to 1.0 ppm uranium. The uranium content of plants grown in ore however, may range from 1 to 100 ppm. Therefore, the high content of uranium in plant sample may be an indication of mineralized ground.

It has been established that some plant species absorb much more uranium than others. The underground root vegetables are high mineral absorber and can absorb the high degree of uranium from soil and when consumed by human beings can pose a health hazard. It has also been observed that plants that readily absorb large amount of sodium, sulphur, selenium and calcium but small amount of potassium will also absorb uranium readily. Due to this, conifers and desert shrubs of the rose family can be used
as indicator plants in sampling programs in uranium districts.

The radioactivity from $^{238}\text{U}$ series is transferred to plants and water from soil. When radio-isotopes are inside the body, they cause greater health hazard because the internal tissues are irradiated continuously till the isotope loses its radioactivity by natural decay or else eliminated in the faces and urine. The tetravalent form of natural uranium being unstable is oxidised to the more toxic hexavalent form. The hexavalent form then combines with active sites (phosphate group) on the surface of cells blocking normal metabolic processes for cell's survival.

Several methods such as Mass spectrometry, Activation analysis, X-ray fluorescence, Delayed neutron counting, Radiometric method, Alternating current polarography etc. are available for the determination of trace quantities of uranium. Solid State Nuclear Track detectors provide cheap, rapid and effective technique for trace element analysis. The technique having needed sensitivity and potential capability of micromapping even at sub ppb levels of fissionable impurities with $(n,f)$, $(n,\alpha)$ and $(p,\alpha)$ reactions etc. is the so-called Solid State Nuclear Track Detection (SSNTD) Technique. It has been widely used in diverse fields like anthropology, archaeology, biology, medical sciences and
technology. Many workers have utilised this technique for the determination of uranium in water, milk powders, semiconductors, cigarettes tobacco, human blood, plants, soils, portland cement, detergents and soaps, coal, flyash and steel etc. In the present case this technique has been exploited for the trace determination of soil and plant samples collected from various places of Uttar Pradesh. The external detector method was used in our case. This method consists of placing a sample whose uranium concentration is to be measured in intimate contact with a uranium poor track detector. A standard glass sample of known uranium concentration is also included and the entire assembly is irradiated with thermal neutrons in a reactor. The thermal neutrons cause fission in $^{235}$U and fission fragments produce latent damage in the plastic detectors which are in close contact with the samples. $^{232}$Th, if present in the sample contributes very little to the total damage from the (n,f) reaction due to its very low fission cross-section i.e. 40 micro barn as compared to 580 barn for $^{235}$U. Following irradiation, the detectors are etched in a proper etching solution and scanned under an optical microscope. The uranium concentration $C_\alpha$ of unknown samples can be calculated by comparing the measured track densities directly
with those of standard materials, simultaneously irradiated\(^8,16\), using the relation
\[
C_x = \frac{\int \rho_x}{\int \rho_s} C_s.
\]

where \(\rho\) refers to track densities and subscript \(s\) and \(x\) refer to the standard and the unknown, respectively.

3.2 EXPERIMENTAL DETAILS:

The soil and plant samples were collected from the places of Agra, Jawalapur (Haridwar), Nadrai (Etah), Rishikesh, Sahasradhara, Dehra Dun situated in the state of Uttar Pradesh. Washed polythene bags were used for collecting samples. In Agra soil samples were taken from the bank of the River Yamuna, Matola and Company Garden. Plant samples were also collected from the company Garden, Agra. Soil samples were taken from the bank of the Ganges canal and some distant places in Jawalapur (Haridwar). Samples were also collected from different depths at Jawalapur to study the variation of U-content with depth. In the same way samples were chosen from the bank of the River Kali and Tatarpur colony, some distance away from the bank. The soil samples were chosen from the bank and some distance places
to study the possible contribution of water in raising the U-content of the soil of the river bank as it might transport uranium from some distant source.

Soil samples were grinded properly and sieved through a 100 mesh sieve. Plant samples were first dried in an oven at $150^\circ C$ for 24 hours. These plant samples were fused in a contamination free silica crucible in a furnace at $700^\circ C$ for 2 hours. After grinding the plant ashes properly, these were sieved through 100 mesh sieve (1.5 x $10^{-2}$ cm aperture). A homogeneous mixture of accurately weighed sample powder and methyl cellulose in the ratio 1:2 by weight was pressed into a flat pellet of about 1.3 cm diameter by the hand-pressing pellet making machine, specially designed for this purpose. The pellet making machine is shown in Fig. 31 and consists of the following parts.

Part A - M.S. plate of size 1.25" x 5" x 10" having four holes, of size 3/8" for fitting the machine on table and having two side holes of the same size to support the pillars G & F.

Part B - M.S. Adjustable guide of size 1" x 4" x 10" to support the pillars having two side holes of size 3/8" to adjust the same upward & downward.
PELLET MAKING MACHINE

DRG. HALF FULL SIZE

S.J.
Part C - M.S. guide of size 1.25"x4"x10" fixed with pillars by M.S. nuts of heavy duty.

Part D - M.S. handle of size 0.75" ø x 16" to rotate the part H upward or downward.

Part E - C.I. bush to support part H.

Part F & G - M.S. pillars of size 1" ø x 15" having upper part 0.75" x 1.25" duly threaded to fix it with part C with nuts and lower part of size 0.75"x1.25" to fix them in the base.

Part H - High carbon steel screw of size 1" ø x 10.5" having upper part of 2" ø having hole of size 0.75" ø x 1.5" for handle.

Part J - M.S. disc of 1.5" ø x 0.75" as per drawing.

Part K - Special K steel punch having upper part of 0.5" ø x 1.5" and lower part of 13 mm ø x 3" duly hardened, tempered and grinded surface.

Part L - Special K steel die of 1.5" ø x 3.75" duly hardened, tempered and grinded surface.

Part M - Special K steel base of 2" ø x 0.75" lower part and 13 mm ø x 0.75" upper part duly hardened, tempered and grinded surface.
Each pellet was sandwiched between two already washed in double distilled water Melinex-O detector pieces of the same size. Several such sandwiched pellets along with a standard glass with known U-content were packed in an aluminium capsule and sealed tightly to make the intimate contact. This assembly was irradiated with thermal neutrons in the core of APSARA reactor for one hour at a place where the nominal neutron flux was $2 \times 10^{12}$ n/cm$^2$/Sec (10 to 15% fast neutrons).

After irradiation detector pieces were taken out and washed. These washed pieces were etched in 6N, NaOH at 60°C for 90 min as it is the optimum etching condition for Melinex-O plastic detectors. The etched detector pieces were air dried and scanned under binocular research microscope at a magnification of 430 X. The track densities were determined by counting the fission tracks in the entire area of the detector. Tracks were counted on both the pieces of the detector and mean was taken to determine the track density. The square marked on the graticule in the eye piece representing one field had a calibrated area of $1.69 \times 10^{-4}$ cm$^2$. The standard glass detector was etched in 48% HF at 23°C for 5 sec and track density was calculated.
3.3 RESULTS AND DISCUSSION:

Uranium content of unknown samples was determined using the relation (3.1). The U-content of soil samples and plant samples are summarised in Table 3.1 and Table 3.2 respectively.

It is observed from Table 3.1 that U-content of soil samples varies from 0.023 to 0.430 ppm. It is also evident that the U-content of the soil samples collected from the bank has higher value than that of the soil samples collected from some distant places. The higher value of uranium in the soil across the bank of the rivers may indicate the contribution of water in raising the uranium content through runoff phosphate fertilizers and some other sources. Among the river bank soil samples, the soil sample collected from the Yamuna river bank has the highest value of uranium content (0.430 ppm). This sample was taken from a place behind the Taj Mahal. Previously waste products were dumped in the river before this place, which might be the possible cause of this higher value. The uranium content of soil samples collected from the place 15 meter away from the canal bank and from different depths were found to decrease with increase in depth. Across the bank soil is deposited by water layer after layer. The
### TABLE 31

Uranium Content of Soil Samples

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Location</th>
<th>Total No. of tracks</th>
<th>U-content in ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Bank of Ganges Canal, Jawalapur (Haridwar)</td>
<td>1537</td>
<td>0.233±0.0054</td>
</tr>
<tr>
<td>2.</td>
<td>A place about 15 meter away from the Ganges canal bank and</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a) 6&quot; deep from the upper surface</td>
<td>1300</td>
<td>0.202±0.0050</td>
</tr>
<tr>
<td></td>
<td>(b) 12&quot; deep from the upper surface</td>
<td>850</td>
<td>0.132±0.004</td>
</tr>
<tr>
<td></td>
<td>(c) 18&quot; deep from the upper surface</td>
<td>611</td>
<td>0.093±0.0035</td>
</tr>
<tr>
<td>3.</td>
<td>A field about 4 Km away from the canal bank, Jawalapur.</td>
<td>937</td>
<td>0.143±0.0042</td>
</tr>
<tr>
<td>4.</td>
<td>Yamuna River Bank Agra</td>
<td>2786</td>
<td>0.430±0.0073</td>
</tr>
<tr>
<td>5.</td>
<td>Matola, Agra</td>
<td>151</td>
<td>0.023±0.0017</td>
</tr>
<tr>
<td>6.</td>
<td>Company Garden, Agra</td>
<td>1620</td>
<td>0.247±0.0056</td>
</tr>
<tr>
<td>7.</td>
<td>Kali River bank Nadrai (Etah)</td>
<td>1044</td>
<td>0.161±0.0045</td>
</tr>
<tr>
<td>8.</td>
<td>Tatarpur Colony about 300 meter away from the Kali River bank</td>
<td>508</td>
<td>0.077±0.0031</td>
</tr>
<tr>
<td>9.</td>
<td>Sahastradhara (Dehra Dun)</td>
<td>1489</td>
<td>0.232±0.0053</td>
</tr>
<tr>
<td>10.</td>
<td>Local Bus stand, Dehra Dun</td>
<td>1208</td>
<td>0.263±0.0048</td>
</tr>
<tr>
<td>11.</td>
<td>Bus Stand, Rishikesh</td>
<td>1500</td>
<td>0.230±0.0054</td>
</tr>
<tr>
<td>S.No.</td>
<td>Location</td>
<td>Common Name</td>
<td>Botanical Name</td>
</tr>
<tr>
<td>-------</td>
<td>----------------</td>
<td>-------------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>Jawalapur</td>
<td>Guava</td>
<td>Psidium guajava</td>
</tr>
<tr>
<td>2</td>
<td>Dehradun</td>
<td>Guava</td>
<td>Psidium guajava</td>
</tr>
<tr>
<td>3</td>
<td>Company Garden</td>
<td>Moor Paniha</td>
<td>Tamarindus indica</td>
</tr>
<tr>
<td>4</td>
<td>Company Garden</td>
<td>Mango</td>
<td>Mangifera indica</td>
</tr>
<tr>
<td>5</td>
<td>Agra</td>
<td>Neem</td>
<td>Azadirachta indica</td>
</tr>
<tr>
<td>6</td>
<td>Rishikesh</td>
<td>Ashok</td>
<td>Polyalthaca longifolia</td>
</tr>
<tr>
<td>7</td>
<td>Agra</td>
<td>Company Garden</td>
<td>Neem</td>
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**TABLE 3.2**

Uranium Content of Plant Leaves Samples
lower value of the uranium content indicates the higher age of the soil and the higher value indicates the lower age of the soil of that particular place.

It is clear from Table 3.2 that the uranium content of plant leaves samples varies from 0.026 to 0.206 ppm and that variation takes place from plant to plant and place to place. This is due to the fact that the uranium content might be different in soil and water where the plants were grown.

The uranium content of soil and plant samples reported by us are different from those reported by Goswani et al. and Virk et al. This disagreement is due to the fact that the plants samples chosen by Goswani et al. and Virk et al. were of different varieties from those investigated by us and the soil belongs to different regions of the country.
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