Range and maximum etchable track length for \(^{93}\text{Nb}\) ion in CR-39 detector

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Abstract

In recent years, solid state nuclear track detectors (SSNTD) have been used increasingly in a variety of field ranging from archeology and geophysics to fission physics and space research. In nuclear physics their advantages lie in their small and flexible geometry, in their ability to withstand high temperature and in their being able to discriminate against high background of less ionizing radiation. When ionizing radiation falls on a SSNTDs detector it produces minute trails of damage (perhaps 10-100 Å in diameter) in a material whether by the thermal spike effect of more by ion explosion effect. We in this work irradiate CR-39 SSNTD detector sample by ion beam of \(^{93}\text{Nb}\) with varied energy in the range 20 MeV to 1600 MeV. The damage trials produced were enlarged thousand times by subjecting the material to a suitable etching process (6N NaOH at 60°C Temperature). Then using continuous process of etching the maximum etchable track length was measured. Using well established SSNTD techniques the range and energy loss of the ion in polymer was calculated. The experimental result was then compared with theoretical data of SRIM and DEDXT programme. The theoretical data are in close agreement with our data.

Keywords: SSNTD, Etching, Range, Track length, CR-39, \(^{93}\text{Nb}\), SRIM, DEDXT

1. Introduction

A large number of detector systems have been developed over the time to study the interaction of charged particles with matter, Solid state nuclear track detectors (SSNTDs) have found increasing use in the study of heavy ion interaction with matter. The knowledge of energy loss and mean ranges for heavy ions in elemental and complex media are of great importance in many nuclear physics experiments because a number of such materials are utilized in form of targets, absorbers, filters, windows and backing.\[1,2\] SSNTDs are essentially dielectric materials which when subjected to energetic ionising particles, produce damage trails in bulk of the materials. The sizes of these latent tracks depend on the rate of ionisation produced in the dielectric materials as well as on the energy mass and charge of the ionising particles.\[1\] In this present work the mean ranges and true track length of 18.04 MeV/u \(^{93}\text{Nb}\) in CR-39 acting as both detector and target has been experimentally determined using SSNTD technique.\[3, 4\]. The experimental results are compared with the theoretical ranges obtained from SRIM\[5\] and DEDXT\[6\] in order to assess their validity.

2. Experimental Procedure

2.1 Detector used

CR-39: (Chemical name allyl-diglycol Carbonate \(\text{C}_{12}\text{H}_{18}\text{O}_{7}\), density 1.32 gm/cm\(^3\)) The abbreviation stands for Columbia Resin 39 because it was the 39th formula of a thermosetting plastic, first developed for the Columbia Resins project in 1940. CR-39 has been successfully used in nuclear and cosmic ray physics to detect the presence of ionising radiation. CR-39 is uniform, clear and background free and is one of the most sensitive detector known till date.

2.2 Irradiation
The detector was irradiated at XO channel of UNILAC, GSI Darmstadt, Germany with a well collimated beam of 18.04 MeV/u \(^{93}\text{Nb}\) ions at an incident angle of 45° w.r.t detector surface. An optimum flux of ~10^4 cm\(^{-2}\) was used for irradiation.

2.3 Chemical etching
After irradiation the CR-39 detectors were etched in 6N NaOH at 55°C for a period of 2 - 4 hour till rounded track tips were observed. After complete etching and thorough washing the detectors were dried in a vacuum desiccator.

2.4 Observation and Measurement of Tracks
Diameters (D) and projected track lengths (l) were measured at random all over the detector surface using an optical microscope at a magnification of 1560 X (for \(l \ll 90 \mu\text{m}\)), whereas longer tracks were measured at a magnification of 650 X. From these track parameters, the maximum etchable true track lengths (L) were obtained using the formula given by Dwivedi and Mukherji [7].

3. Technique used [4]
Figure 1 gives a schematic diagram showing the basic idea of the measurement of range of incident ion in complex media acting both as target and detector. With this technique, the range and stopping power can be obtained in a solid media that can form the ion tracks; here we use a well defined single nuclear track in a single detector instead of using 10 to 15 target detector assemblies. The detector (CR-39) itself is considered as both the target as well as the detector by considering a division into two segments. For different values of target thickness (\(X_i\)), the true track lengths (L) are obtained and the corresponding energy is then obtained from the calibration curve [8] (which is a variation of true track length with incident ion energy as plotted in figure 2). From these data, the energy loss curves are constructed by plotting ion energy as a function of target thickness.

The mean range can easily be obtained by extrapolating the energy loss curve to energy. Range at energy \(E\) may be obtained from the equation

\[
R(E) = R - X(E)
\]

where, \(R\) is the total range of the ion, \(X(E)\) is the target thickness which reduces the ion energy from \(E_i\) to \(E\).

![Figure 1: Schematic Diagram of the technique used.](image)

4. Results and discussions
Table 1 contains the values of target thickness, measured track length of \(^{93}\text{Nb}\) ion transmitted through CR-39 and corresponding ion energies from the calibration curve (figure 2). From these tabulated data, energy loss curves are generated and is shown in figure 3. From the energy loss curve we have found that mean ranges of 18.04 MeV/u \(^{93}\text{Nb}\) ions in CR-39 is equal to 269 ± 2 μm. The ranges of several lower energies are also determined and are listed in table below along with corresponding theoretical values from DEDXT [6] and SRIM [5] program and are shown in figure 4.

5. Conclusions:
Experimental range values for the passage of \(^{93}\text{Nb}\) in CR-39 are obtained for energies up to 18.04 MeV/u, which were not available in earlier literatures. The theoretical values of range for \(^{93}\text{Nb}\) ion in CR-39 obtained from SRIM program are in very good agreement with the experimental values. The values obtained from DEDXT program are higher by ~
10 - 40 μm in the energy range 3 - 18 MeV/u, while below 3 MeV/u they are in good agreement with our experimental data.

**Figure 2:** Calibration curve for $^{93}$Nb in CR-39

**Figure 3:** Energy loss curve for $^{93}$Nb in CR-39.

**Figure 4:** Measured range-energy data for $^{93}$Nb in CR-39 along with the theoretical values calculated from (b) SRIM and (c) DEDXT program.

**Table I:** Values of CR-39 target thickness, maximum etchable track length of $^{93}$Nb in CR-39 detector, energy of the transmitted ion, absorbed energy by the target and the ranges obtained in CR-39, along with the corresponding theoretical values.
| Effective Target Thickness (μm) | Track Length (μm) | Ion Energy (MeV/u) | \(^9\)Nb ranges in CR-39 (μm) |
|-------------------------------|------------------|-------------------|-------------------------------|
|                               |                  | Transmitted       | Absorbed                      | Experimental (Present work) | Theoretical |
|                               |                  |                   |                               | (Present work)              | (b)         | (c)         |
| No Target                     | 266±2            | 18.0±0.1          | 0.0                           | 269±2.0                     | 267.2       | 313.5       |
| 33                            | 233±2            | 16.2±0.1          | 1.8±0.1                       | 236±2.2                     | 232.2       | 269.5       |
| 70                            | 196±4            | 14.4±0.2          | 3.6±0.2                       | 199±2.1                     | 200.7       | 233.8       |
| 86                            | 180±4            | 13.3±0.2          | 4.7±0.2                       | 183±2.5                     | 181.4       | 212.1       |
| 106                           | 160±3            | 12.3±0.2          | 5.7±0.2                       | 163±2.7                     | 165.5       | 194.2       |
| 111                           | 155±3            | 11.3±0.2          | 6.7±0.2                       | 158±2.9                     | 150.2       | 177.0       |
| 130                           | 136±3            | 10.5±0.1          | 7.5±0.1                       | 139±2.9                     | 137.5       | 165.0       |
| 171                           | 95±4             | 7.7±0.3           | 10.3±0.3                      | 98±3.2                      | 98.3        | 118.4       |
| 212                           | 54±3             | 4.6±0.3           | 13.4±0.3                      | 57±3.5                      | 59.7        | 73.6        |
| 225                           | 41±3             | 3.1±0.3           | 14.9±0.3                      | 44±3.6                      | 42.6        | 53.1        |
| 233                           | 33±3             | 1.8±0.3           | 16.2±0.3                      | 36±3.6                      | 28.7        | 36.4        |
| 246                           | 20±3             | 1.0±0.2           | 17.1±0.2                      | 23±3.8                      | 19.0        | 26.0        |

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