4th ANNUAL ARDENT WORKSHOP
TRAINING COURSE

Passive detectors Part 2
(Nuclear Track Detectors)

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Thu. 25/06/2015, 09:00

Track Detectors

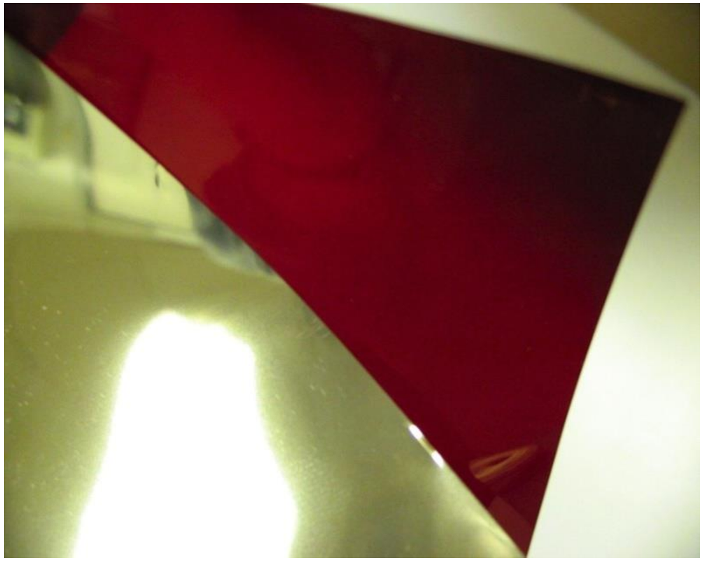
SSNTD are solid dielectric materials (photographic emulsion, crystal, glass or plastic). Widely used for several applications:

- Radon measurement
- Fast neutron dosimetry
- Thermal neutron dosimetry
- Cosmic rays detection

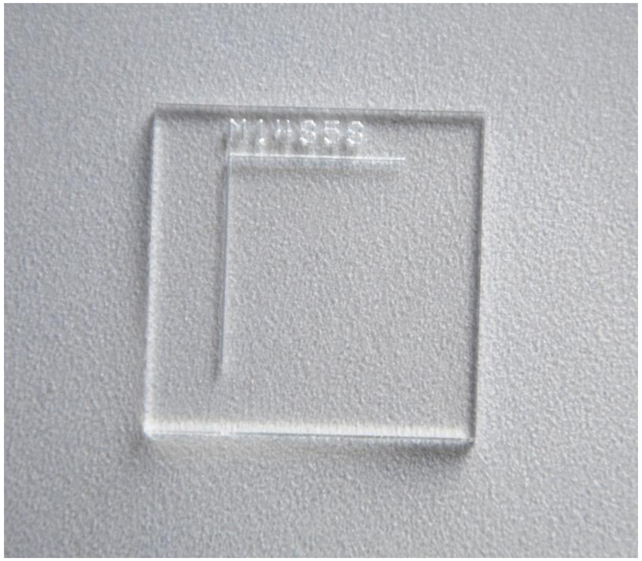
LR115 Cellulose nitrate layer on a clear polyester base

CR-39 PADC- Poly allyl diglycol carbonate

Track Detectors

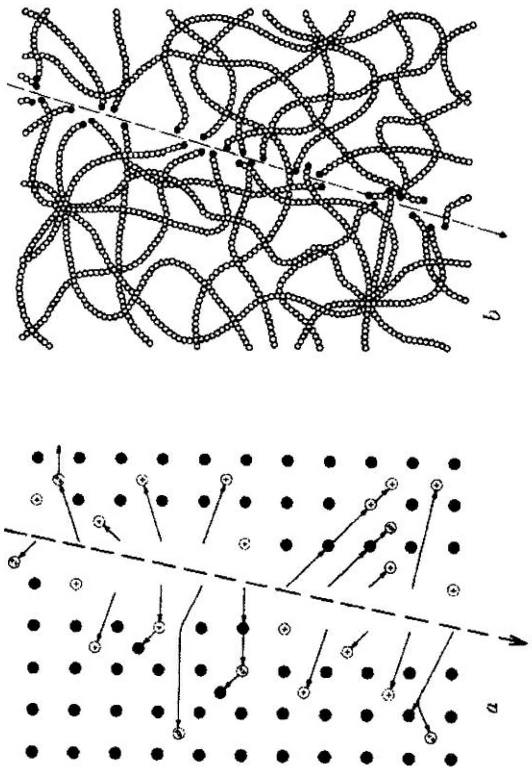


LR115



CR-39

Track Detectors



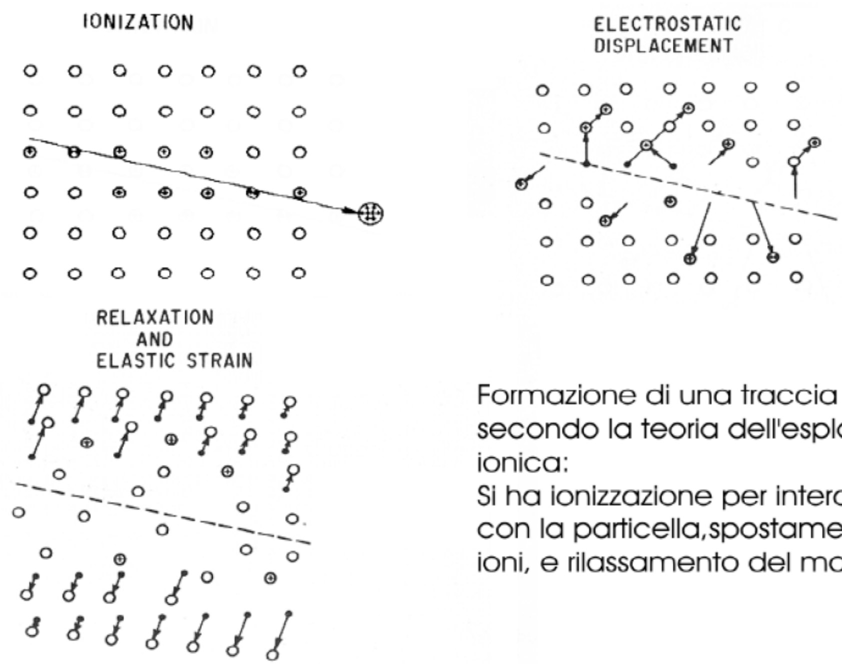
PRINCIPLE OF TRACK DETECTORS

When a ionizing charged particle pass through a dielectric material the transfer of energy to electrons results in a trail of damaged molecules along the track path

Track Detectors

Ion explosion theory

- Ionization
- Electrostatic displacement
- Relaxation and elastic strain



Formazione di una traccia secondo la teoria dell'esplosione ionica:
Si ha ionizzazione per interazione con la particella,spostamento degli ioni, e rilassamento del materiale

Track Detectors

The tracks bacame visible by a chemical etching (acid or basic solution): during the etching, material is removed at Vt velocity along the track and isotropically at Vb velocity from the bulk material.

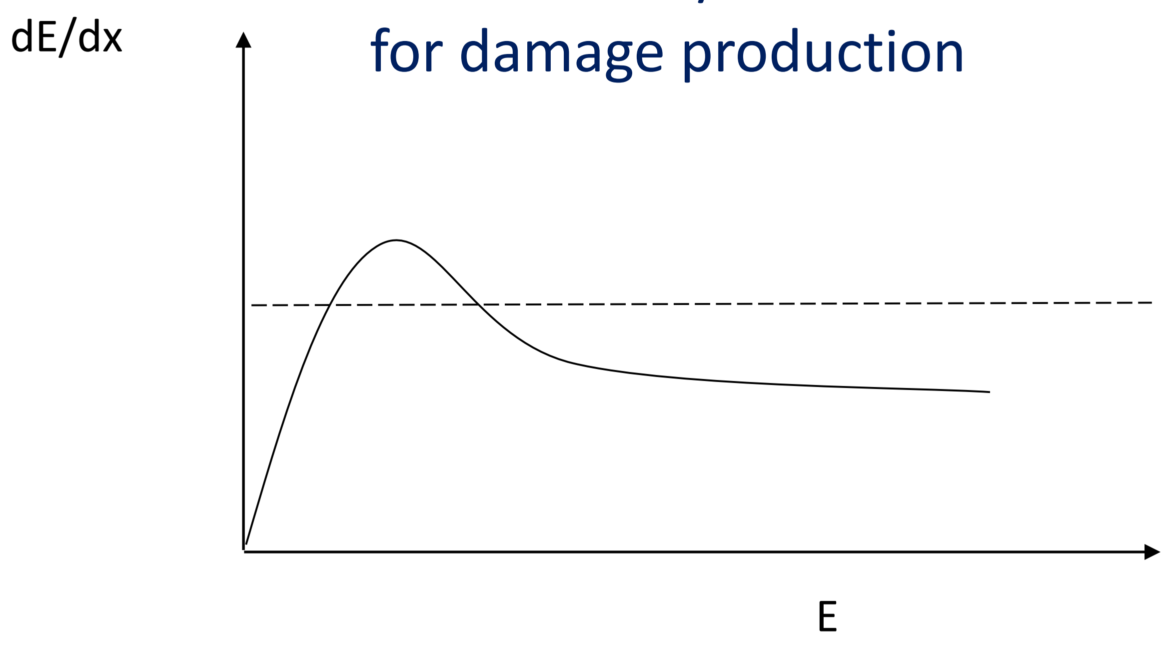
Principle of the track detector: Vt (track etch rate) >Vb (bulk etch rate)

The dimension and shape of the track depend on:

- Energy of the impinging particle
- Incidence angle
- Etching procedure (etchant, temperature, duration)

Track Detectors

There is a dE/dx threshold for damage production



CR-39 Track Detectors

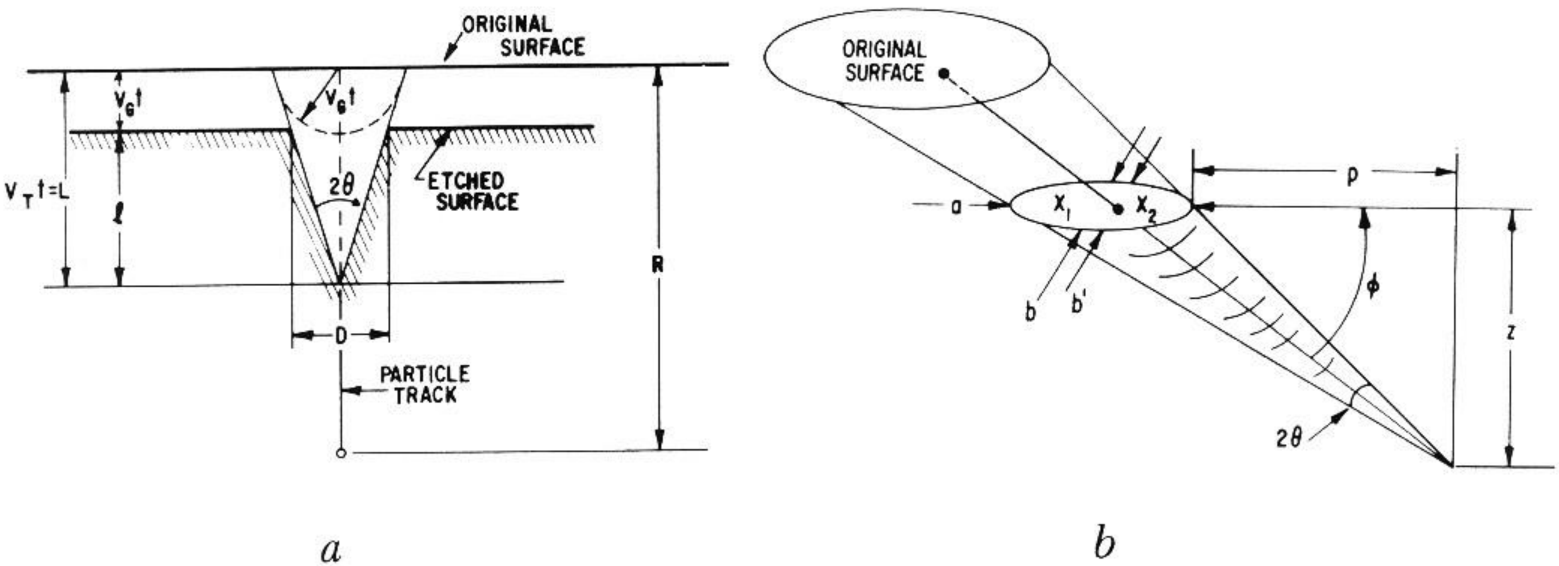
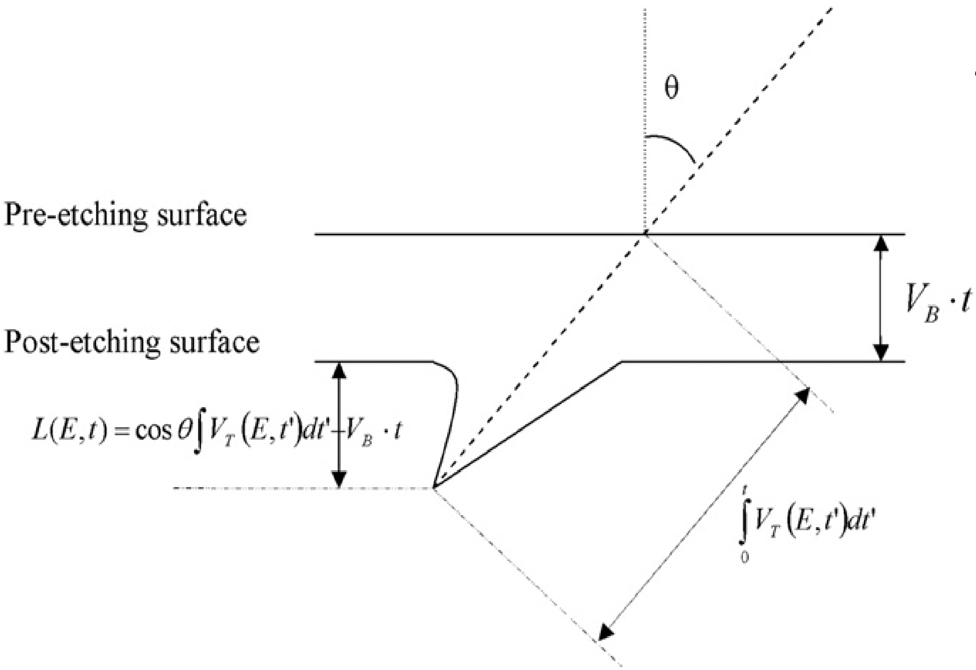


Fig. 2-1. *Track geometry with v_T and v_G constant and (a) a vertically incident particle or (b) a particle incident at dip angle ϕ. (After Price and Fleischer, 1971.)*

Track Detectors



There is a limit angle: if θ> limit angle →no track

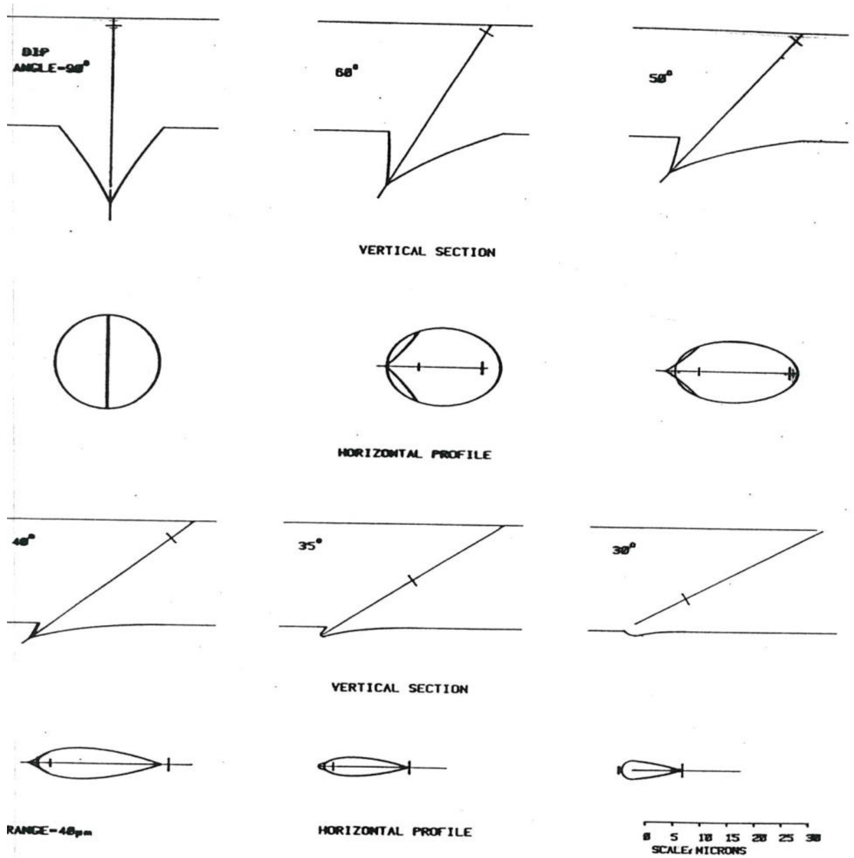
Track is visible if

$$\cos\theta \int V_T(E,t')dt' - V_B \cdot t > 0$$

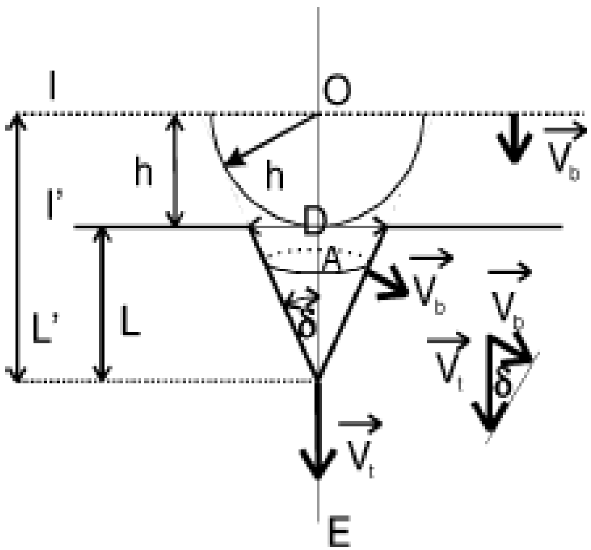
the lenght of the removed material along the track path, multiplied by cosθ, must be bigger than the thickness of the surface layer removed during etching

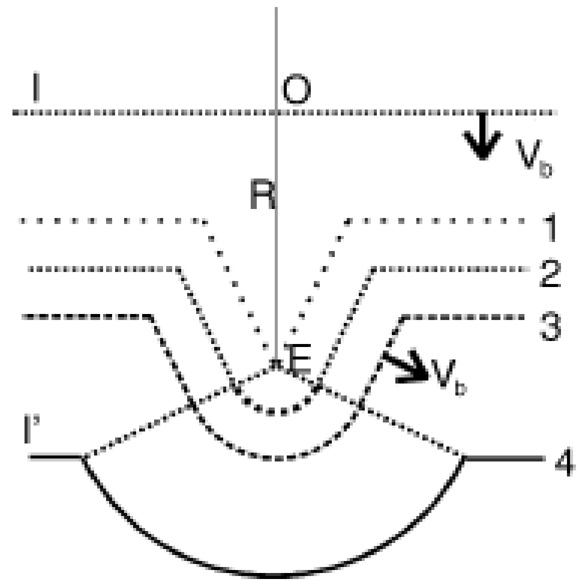
CR-39 Track Detectors

CR-39
Shape of the track as funtion of incidence angle



CR-39 Track Detectors

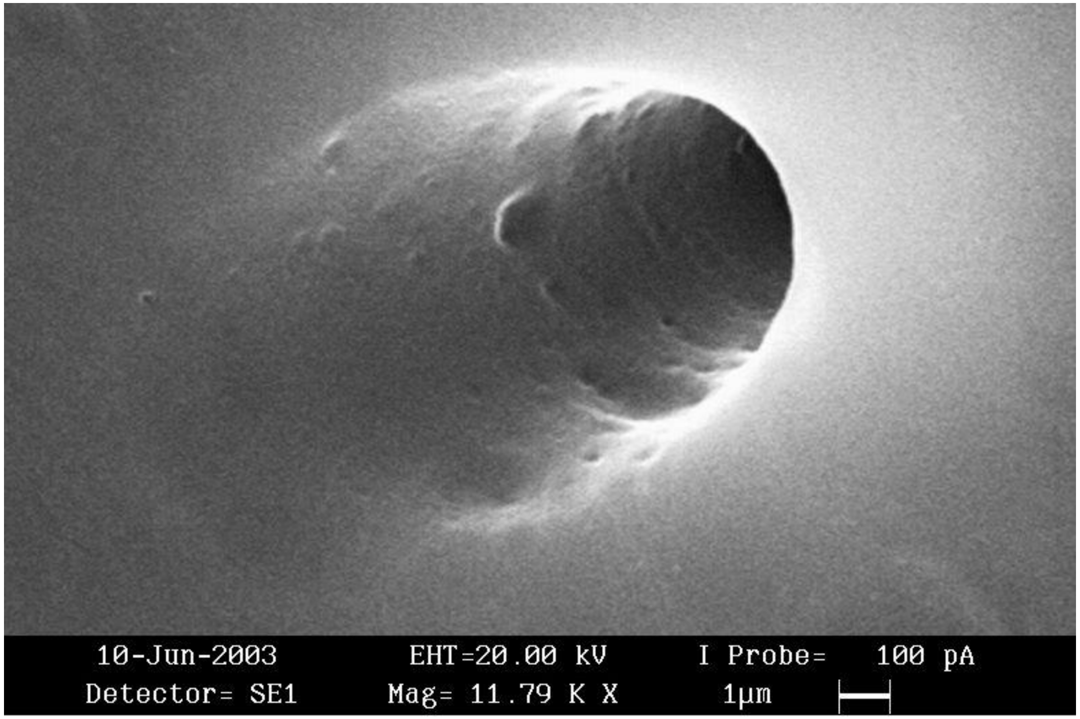




overetching: round shape

LR115 Track Detectors

Example of after etching track in a LR115 film

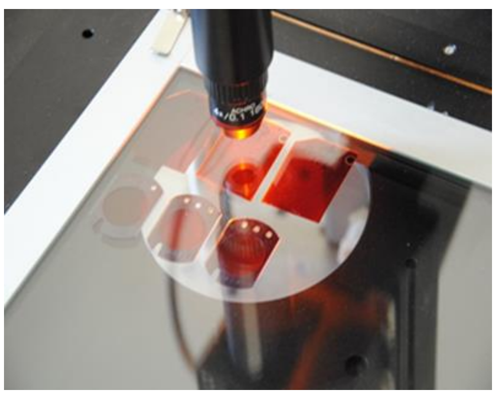


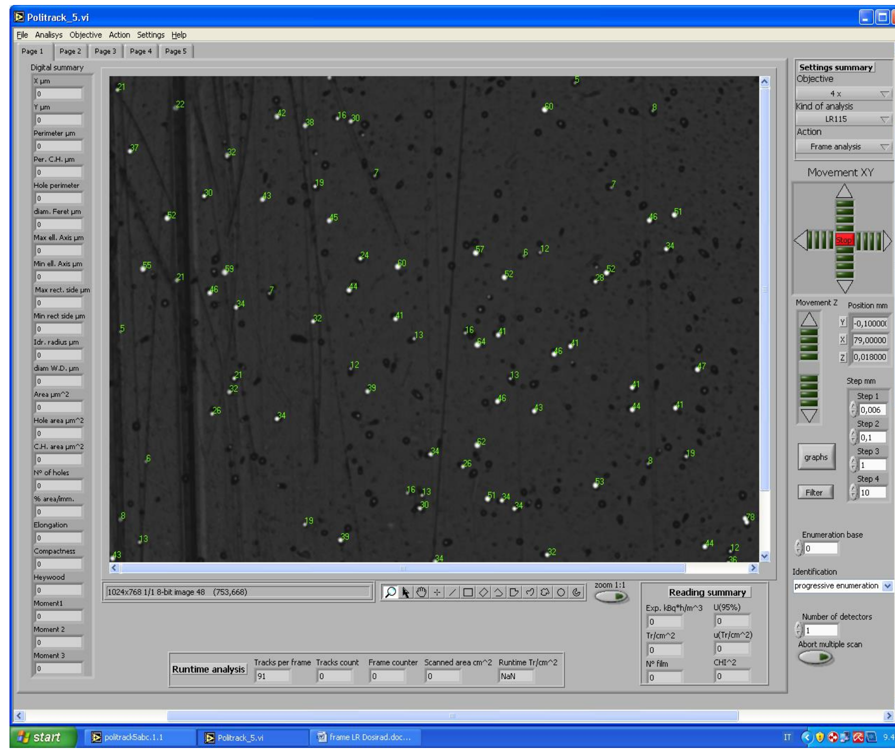
Reading LR115 Detectors

LR115 OPTICAL READING

Tracks appear as white holes on a dark background.

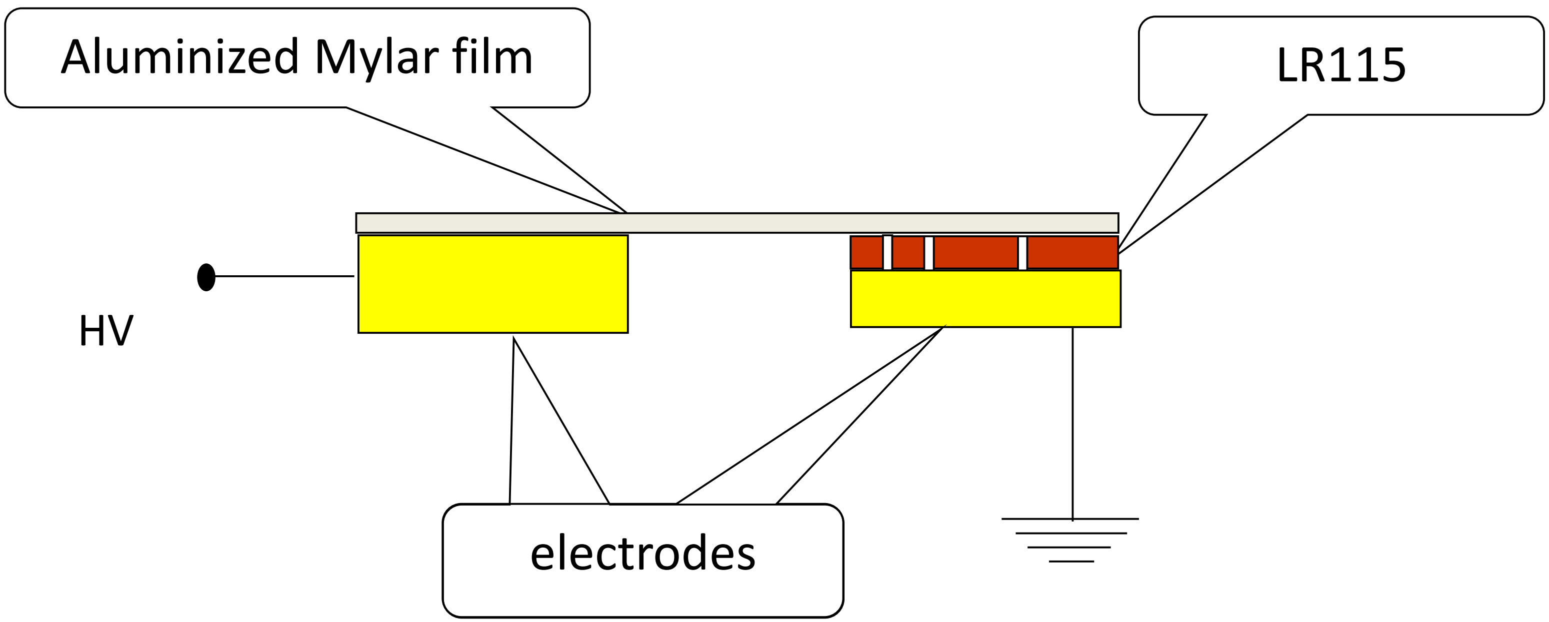
- Count the tracks
- Measure the track area (correction for etching)



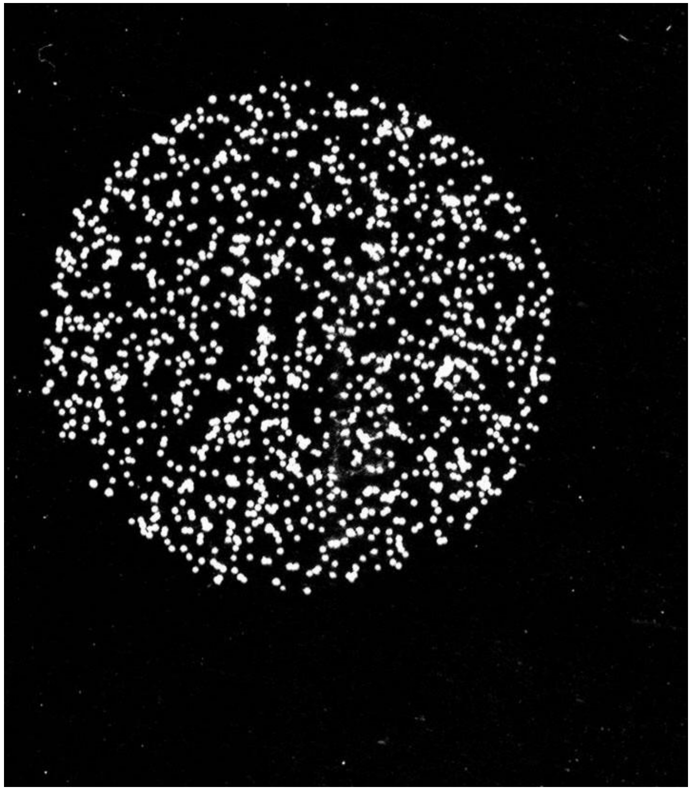


Reading LR115 Detectors

Spark counter



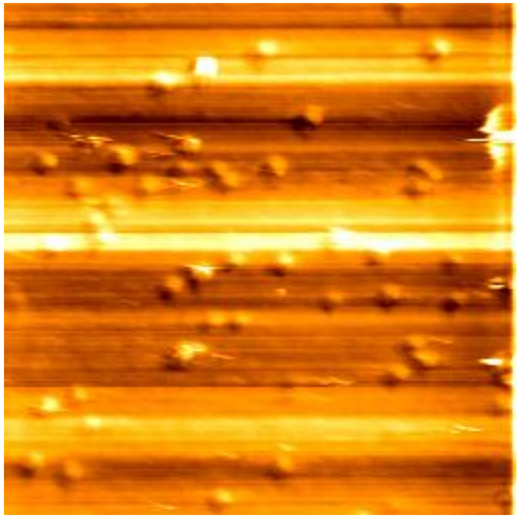
Reading LR115 Detectors

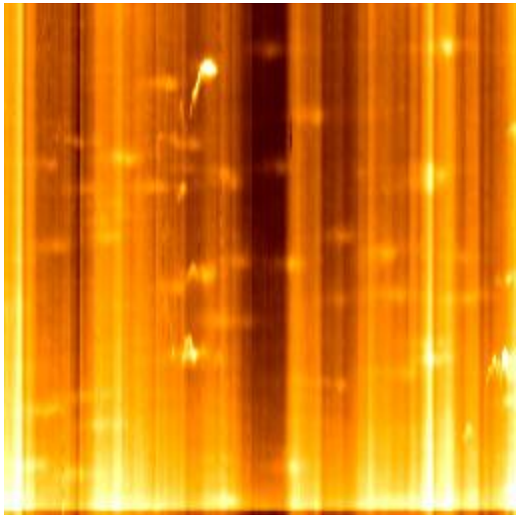


Spark counter

Aluminum Mylar film after spark counter reading

CR-39 Track Detectors

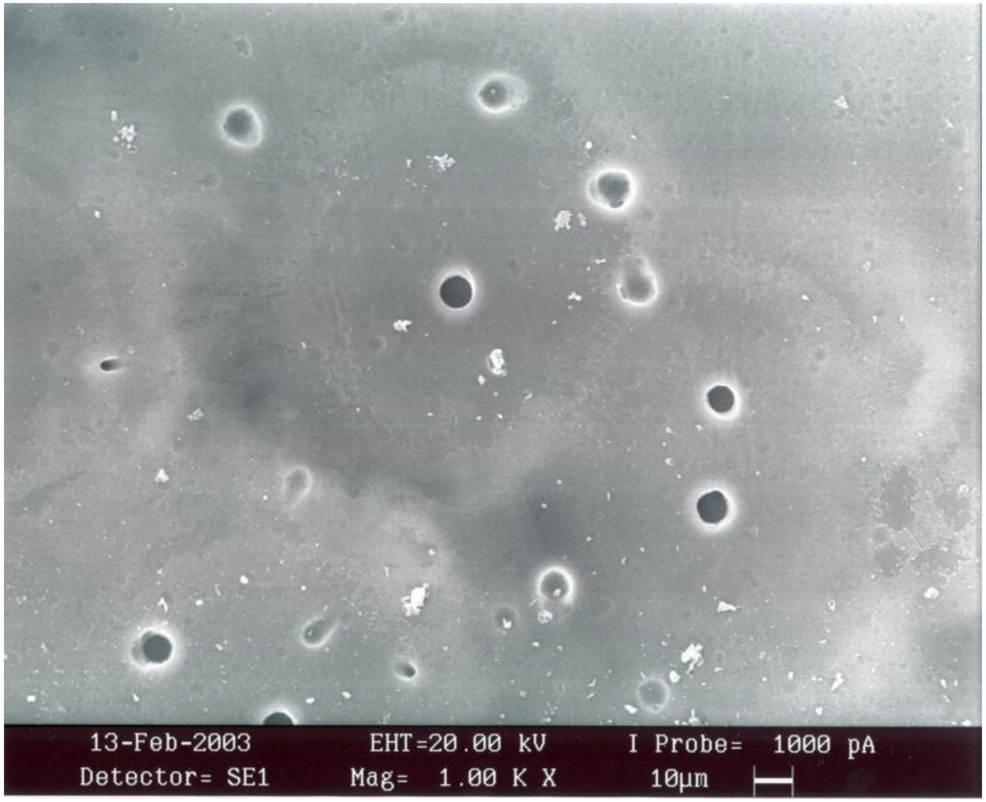




CR-39 detector irradiated by alfa particles (before etching)
Diameter of latent tracks is 70-100 nm. Frame is 5 micrometer (AFM).

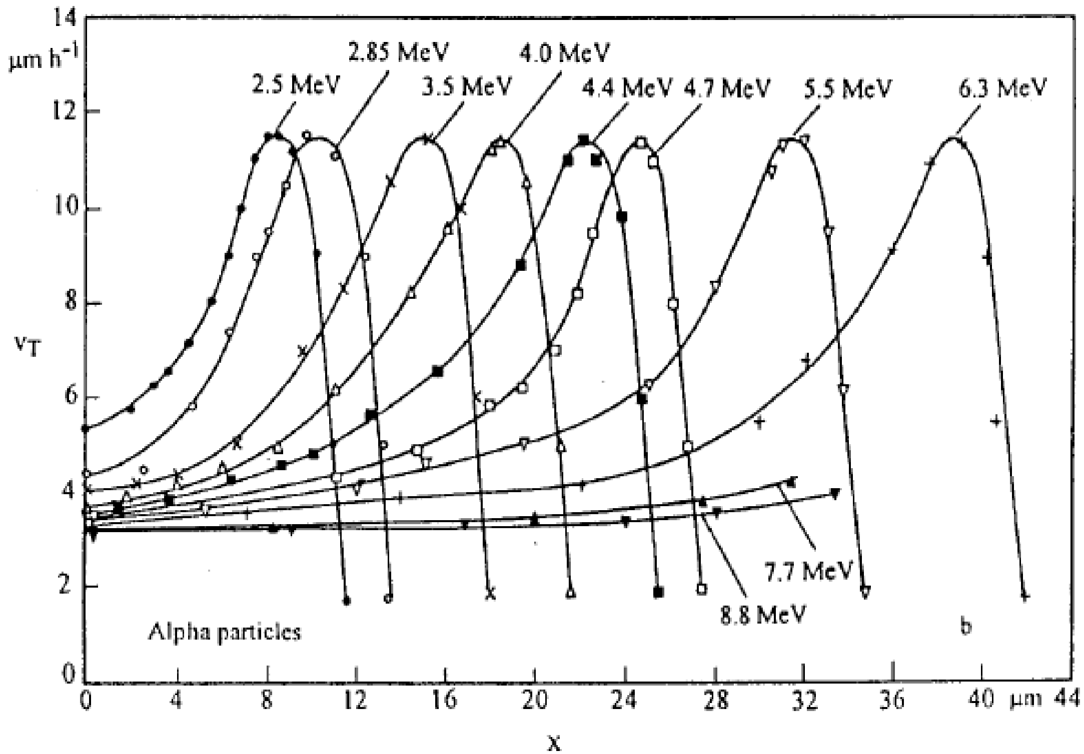
CR-39 Track Detectors

Example of after etching tracks in a CR-39 detector



CR-39 Track Detectors

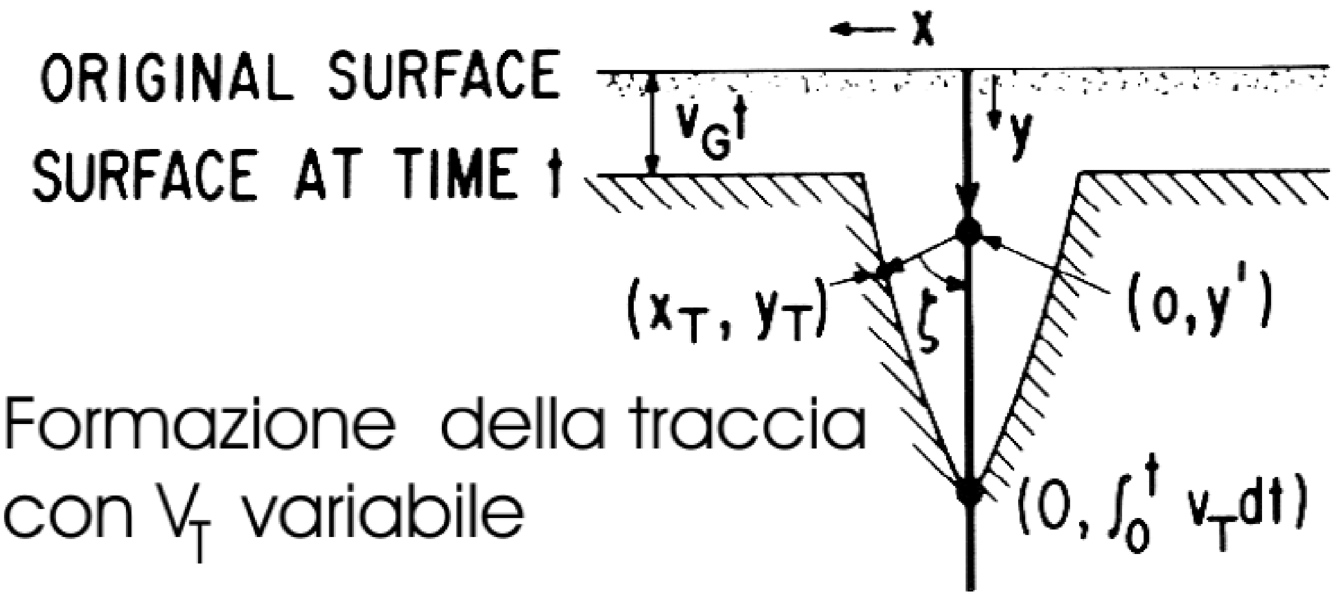
Variation of Vt along track path



Vb=1.83 μm/h

CR-39 Track Detectors

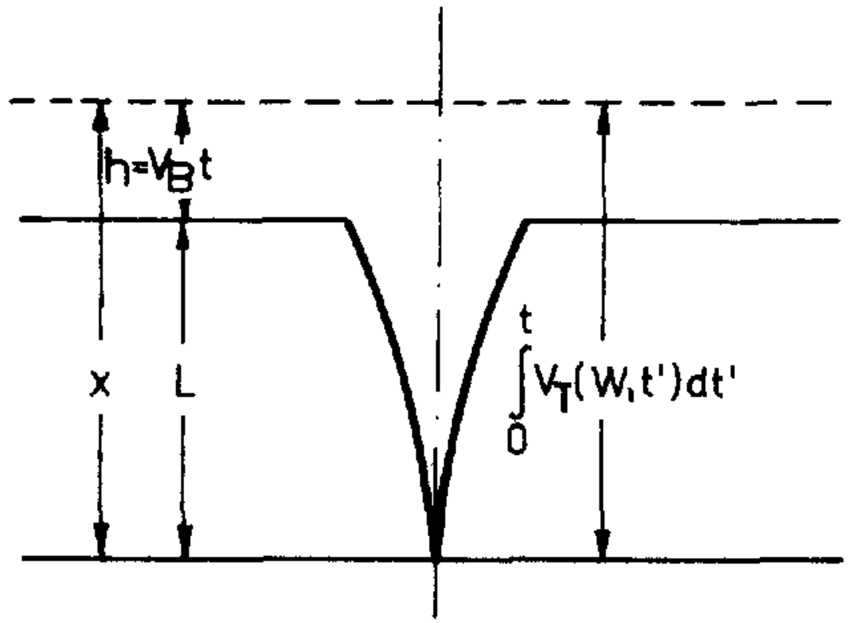
Variation of the track etch rate along the alpha particle trajectories: Vt decreasing



CR-39 Track Detectors

Variation of the track etch rate along the alpha particle trajectories: Vt increasing

(b)



CR-39 Track Detectors

To understand chemical etching geometry think as Vt is the velocity of the ship and Vb is the wave motion velocity in water

CR-39 Track Detectors

Track lenght as function of etching time

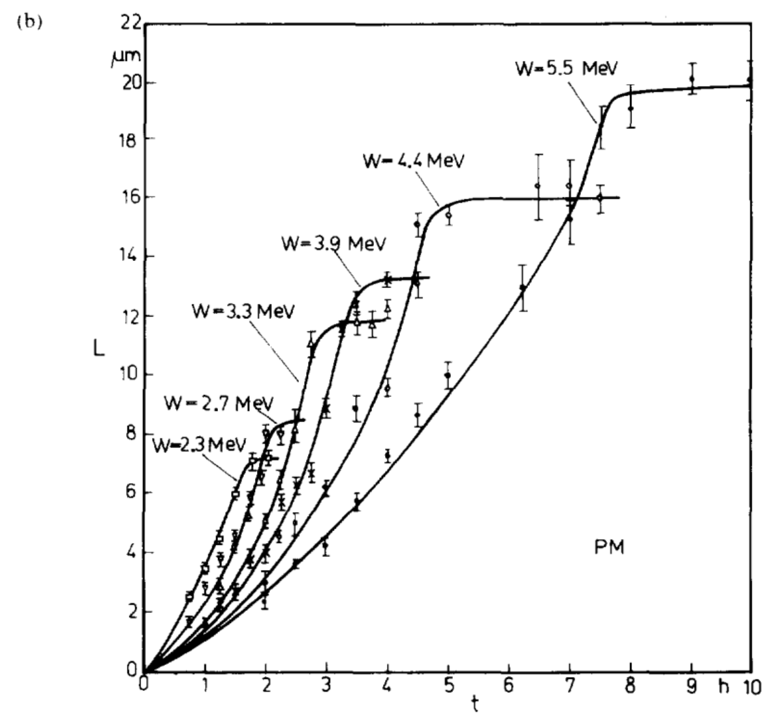


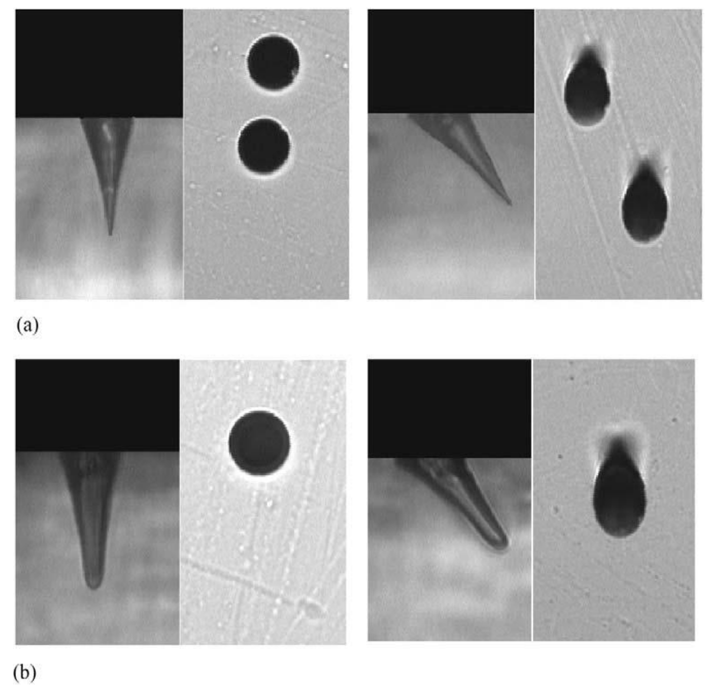
Fig. 4. Track length, L, as a function of etching time, t, for various initial alpha energies, W: (a) PATRAS; (b) PM.

Radiation Measurements, Vol. 26, No. 1, pp. 51–57, 1996

CR-39 Track Detectors

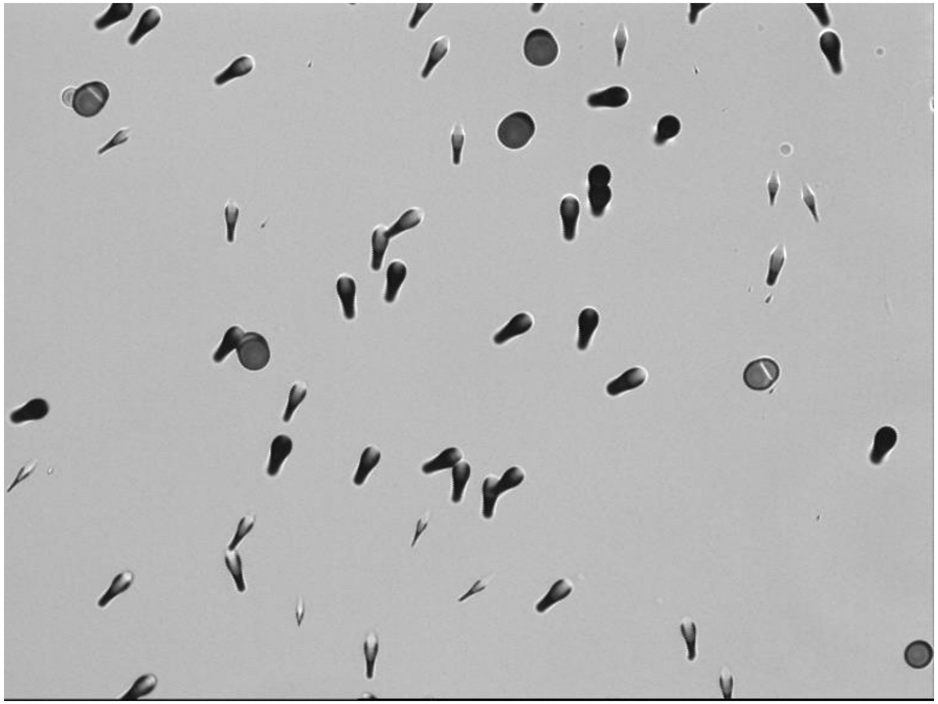
Track lenght as function of etching time

Longitudinal section and top view of etched tracks of 90 MeV 7Li ions entering the detectors at = 0◦ (left side) and = 40◦ (right side) for different etching times, t (a) t = 3:5 h, (b) t = 4:33 h. Magnification: 950.



B. Dorschel et al. / Radiation Measurements 37 (2003) 563 – 571

CR-39 Track Detectors



Alpha and fission fragment tracks in CR-39 exposed to Cf-252 source.

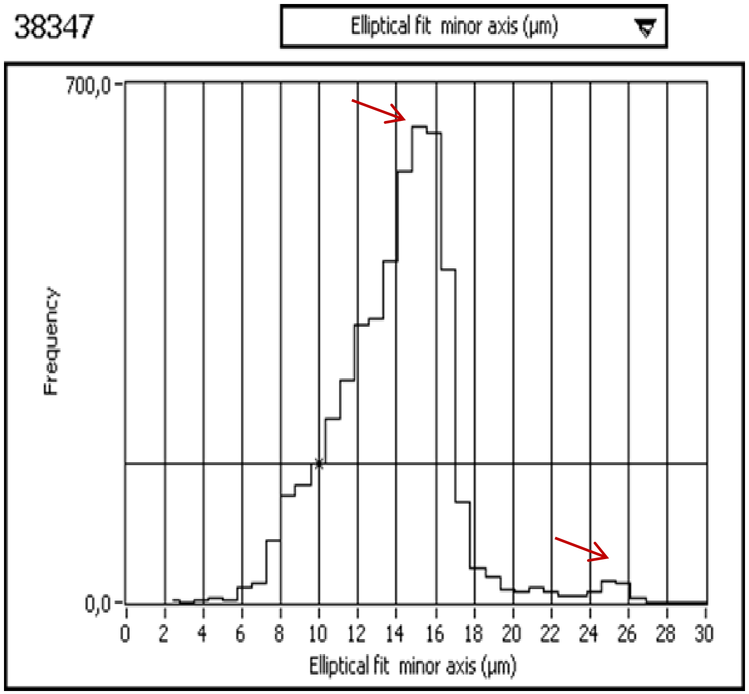
CR-39 Track Detectors

CR-39- Etching NaOH, 98°C, 1 hour

CR-39 exposed to Cf-252
Minor axis histogram
Two peaks:

- alpha particles
- fission fragments

The second peak allows to evaluate Bulk velocity (Vb) during etching, in this case about 12 microns/hour.

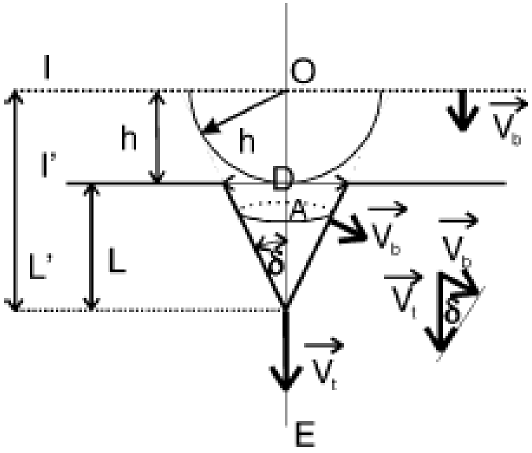


CR-39 Track Detectors

Measure of Vb - Bulk velocity

Fission fragments tracks Vt >> Vb

$$D = 2h\sqrt{\frac{V-1}{V+1}}$$



V=Vt/Vb, If *V*>>1 then

$$D \cong 2h$$

h removed bulk material thickness, D track diameter (dip angle 90°)

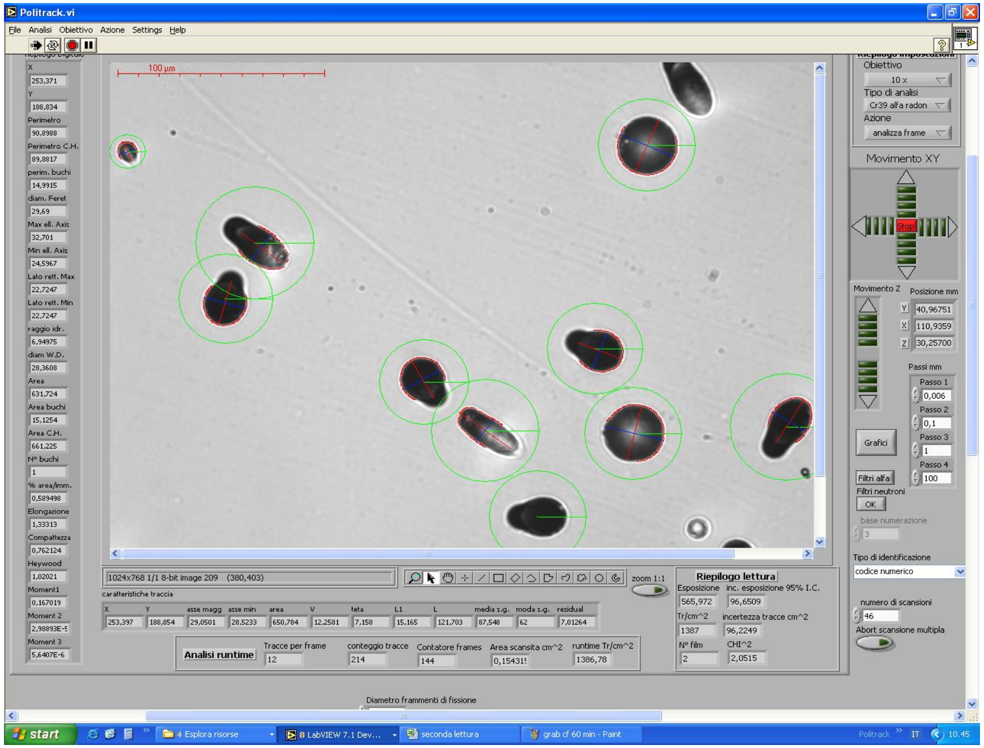
We can measure D and since h=D/2

=> Vb is equal to D/2 (removed thickness) / time of etching

CR-39 Track Detectors

Measure of track parameters using automatic systems

- Count the tracks
- Filter tracks
(reduce background)
- Morphological analysis
(discriminate the particles and impinging angles)



NTD Application

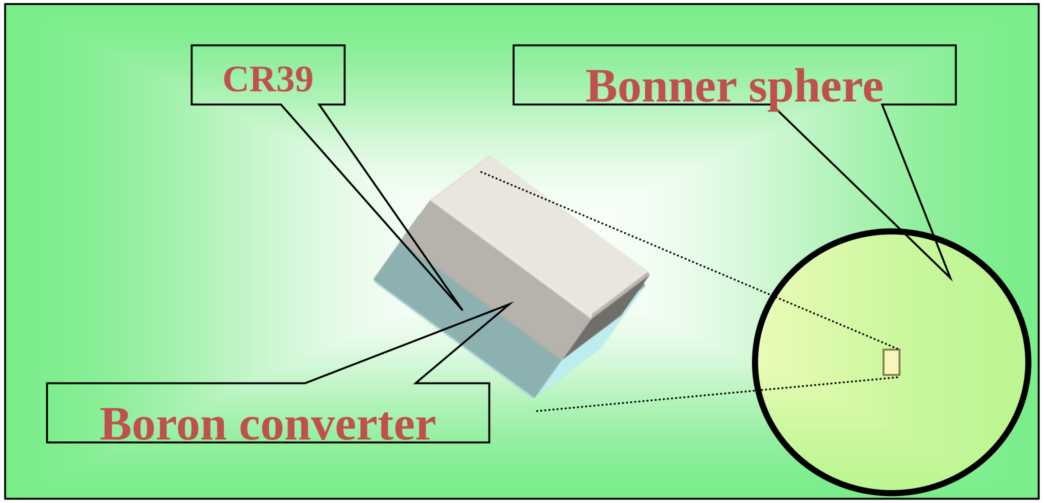
CR-39 NEUTRON DOSIMETRY AND SPECTROMETRY

1. CR39 coupled to a Boron converter as thermal neutron detector inside Bonner sphere
2. Use of recoil protons (radiator-degrader tecnique)
3. Calculation of particle LET and impinging angle with direct estimation of equivalent dose

CR-39 neutron dosimetry

1. Bonner sphere (polyethylene neutron moderator)

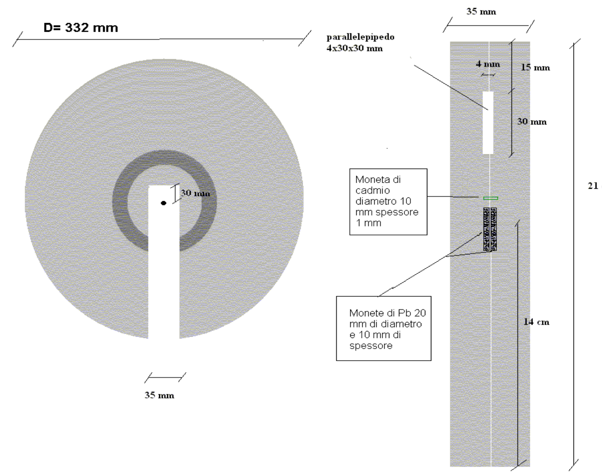
CR-39 coupled to a Boron converter. The reaction is $^{10}B(n,alfa)^{7}Li$
The neutron is detected by the 1.47 MeV alfa particle
Number of tracks is proportional to thermal neutron fluence (inside Bonner sphere)



M. CARESANA ET AL. *Radiat Prot Dosimetry (2007) 126(1-4)*

CR-39 neutron dosimetry

Bonner sphere

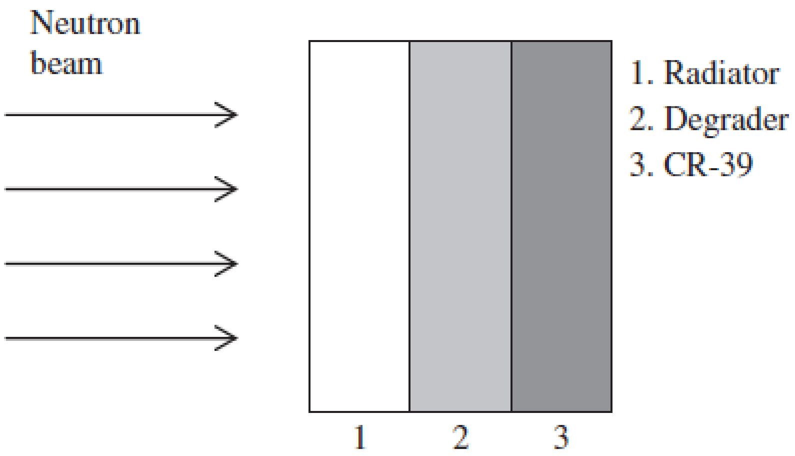


Single detector version: sensitivity 10 tracks/cm^2 per µSv

Double detector: sensitivity: 6 tracks/cm^2 per µSv

CR-39 neutron dosimetry

2. CR39- radiation degrader neutron spectrometer



1. Radiator: high density polyethylene
2.Degrader: aluminium (purity 99%)
3. Detector CR-39

a) Recoil protons are generated inside the radiator (external radiation component)
b) Recoil protons generated inside the detector (proton self radiator)
c) Carbon and oxygen recoil nuclei generated inside the detector (ion self radiator)

CR-39 neutron dosimetry

3. LET spectrometry

The adsorbed dose delivered by a charged particle impinging at an angle θ on the surface of a material of ϱ density is

$$D = \frac{\varepsilon}{m} = \frac{\left(dE/dx\right) \cdot x}{\rho \cdot A \cdot l} = \frac{\left(dE/dx\right) \cdot \left(l/\cos\vartheta\right)}{\rho \cdot A \cdot l} = \frac{\overline{LET}}{\rho \cdot A \cdot \cos\vartheta}$$

ϵ is the energy imparted to the mass m, A is the area, x the lenght of the track,
l the thickness of the material affected by the energy deposition
(dE/dx) is the stopping power averaged over the lenght x
avg LET is the mean LET averaged over x

Note: the particle energy loss (stopping power) is considered equal to the energy transferred to the target (mean LET) as the energy loss by secondary electrons bremsstrahlung is considered negligible)

CR-39 neutron dosimetry

Assuming n particles impinge on the unit area (A=1 n= tracks/cm^2) the dose (**mGy**) can be calculate using

$$D = \frac{1}{\rho} \times 1.602 \times 10^{-6} \sum_{i=1}^{n} \frac{\overline{LET}_i}{\cos \vartheta_i}$$

And the dose equivalent (**mSv**) can be calculated by

$$H = \frac{1}{\rho} \cdot 1.602 \cdot 10^{-6} \cdot \sum_{i=1}^{n} \frac{LET_i}{\cos \vartheta_i} \cdot Q(LET_i)$$

Avg. LET is expressed in keV μm^{-1}

Q(LET) is the ICRP quality factor

ρ is the density of the material ($\rho = 1.31\ g \cdot cm^{-3}$ for CR-39)

CR-39 neutron dosimetry

A) Vt=Vt(E,x) is related to restricted energy loss REL(E,x) and we can use this relation [1]

$$V = V_t / V_b = 0.93 + 3.14\times10^{-3} REL - 7.80\times10^{-6} REL^2 + 1.11\times10^{-8} REL^3 - 5.27\times10^{-12} REL^4$$ for 33 MeV/cm < *REL* < 560 MeV/cm

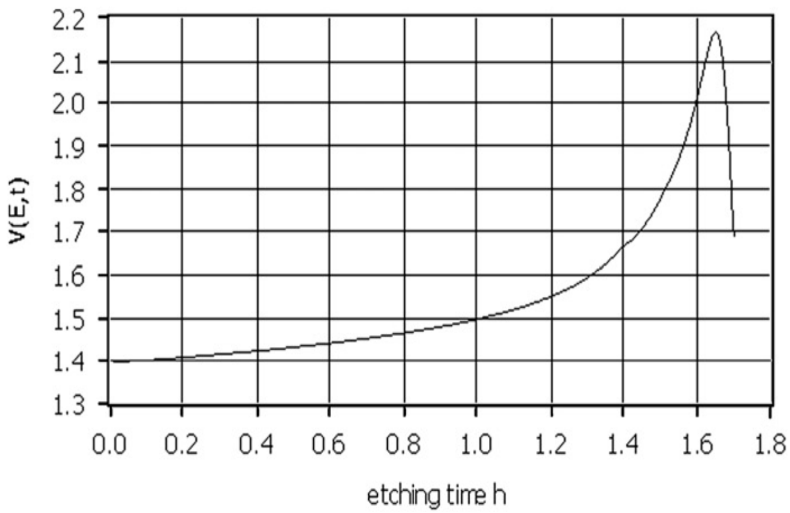
$$V = V_t / V_b = 1.30 + 3.80\times10^{-4} REL + 4.9\times10^{-7} REL^2$$ for *REL* > 560 MeV/cm

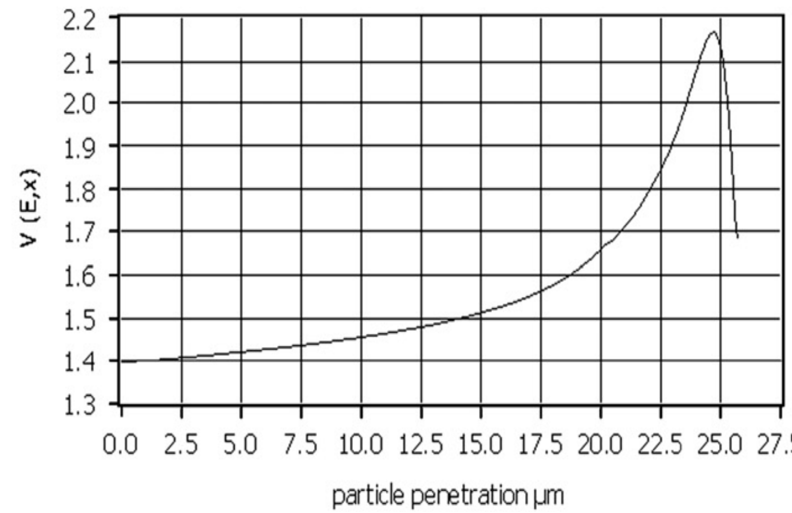
B) Assuming that delta electrons with E>350eV do not contribute to track formation, we can use a polynomial fit we to relate LET and REL.

→we can relate V to LET

(1) B. Dorschel , et al. 2002 Dependence of the etch rate ratio on the energy loss of light ions in CR-39 Radiat. Meas. 35, 287-292.

CR-39 Track Detectors



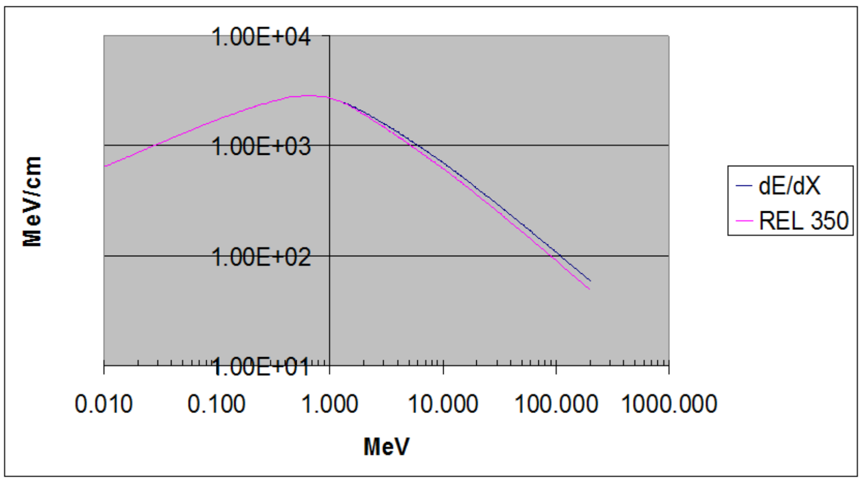


V=V(E,t) and *V=V(E,x)* functions calculated through the *V=V(REL(E,x))* function for 1.2 MeV protons impinging perpendicularly on the detector surface. The simulated etching conditions are Vb=9.8 µm h^{-1} and 1.5 h of etching time.

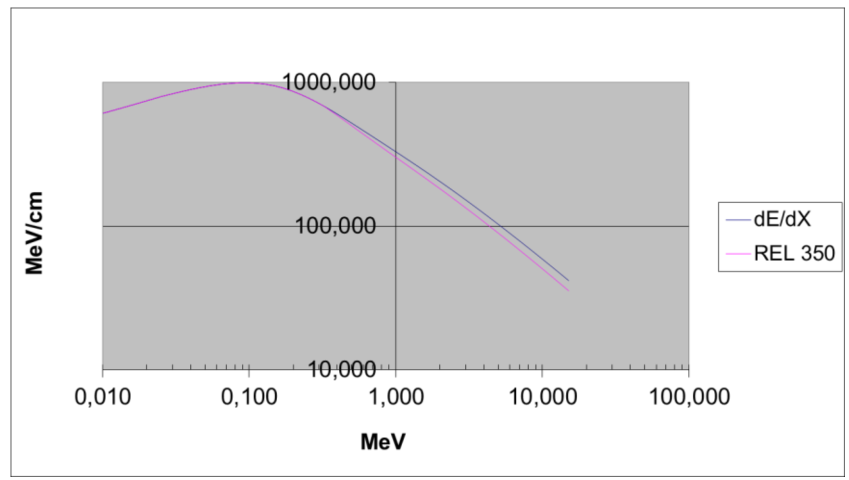
CR-39 neutron dosimetry

LET and REL in PADC for alpha particles and protons

Alpha particles



Protons



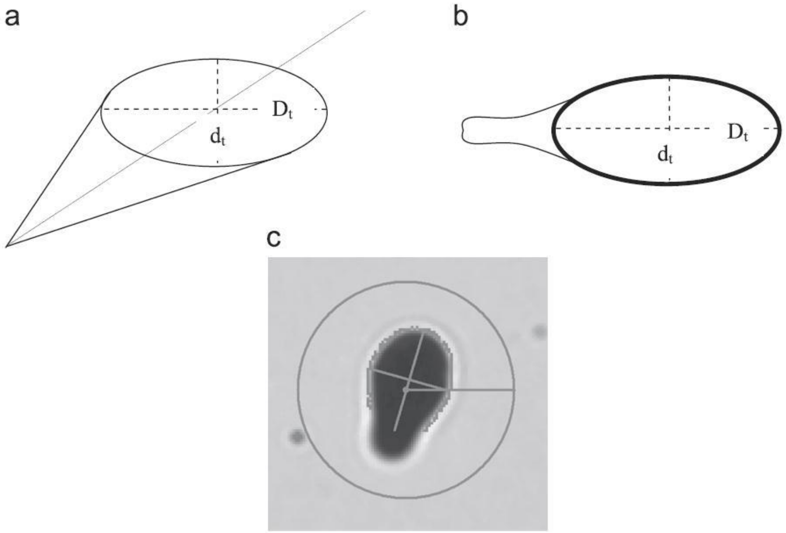
CR-39 neutron dosimetry

LET spectrometry – experimental procedure

d= track opening minor axis
D= track opening major axis
h= removed thickness

$$d = 2 \cdot h \sqrt{\frac{V \sin\theta - 1}{V \sin\theta + 1}}$$

$$D = 2 \cdot h \frac{\sqrt{V^2 - 1}}{V \cdot \sin\theta + 1}$$



D, d and h are measured

CR-39 neutron dosimetry

By defining
$$R = \frac{D}{2 \cdot h} \qquad r = \frac{d}{2 \cdot h} \qquad K = \frac{1 + r^2}{1 - r^2}$$

It is possible to calculate V and θ from the track parameters

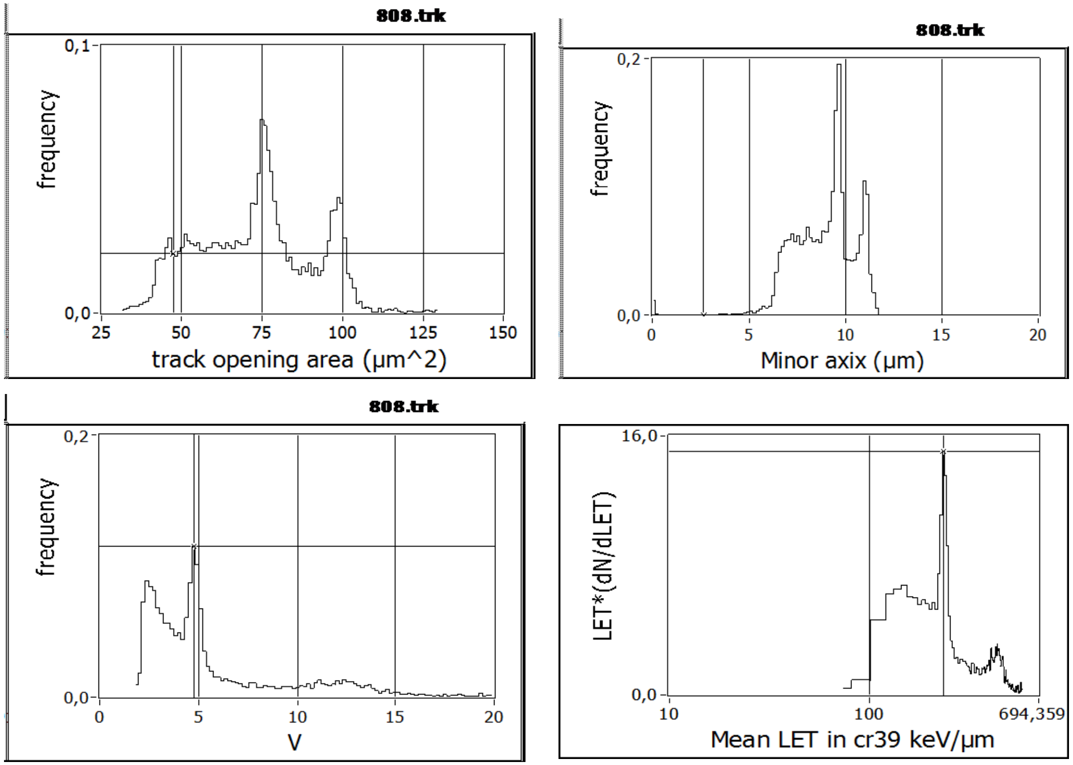
$$V = \sqrt{1 + R^2 (K+1)^2} \qquad \theta = \arcsin \frac{K}{V}$$

Since relationship between V and LET is known, we can calculate dose

$$D = \frac{1}{\rho} \times 1.602 \times 10^{-6} \sum_{i=1}^{n} \frac{\overline{LET}_i}{\cos \vartheta_i}$$

CR-39 neutron dosimetry

$^{10}B(n,alfa)^{7}Li$



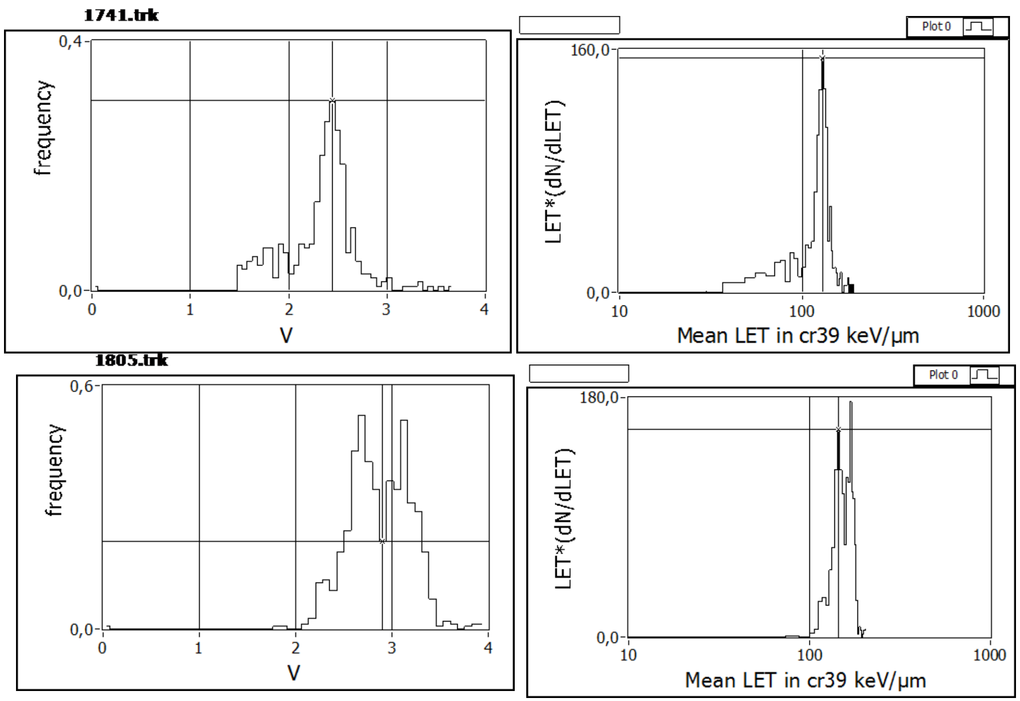
E_{alpha} =1.47 MeV
$E_{lithium}$ =0.84 MeV

Ion	Mean LET meas	Mean LET calculated
Alfa	220 keV/µm	250 keV/µm
Li	400 keV/µm	280 keV/µm

M. Caresana et al. Study of a radiator degrader CR39 based neutron spectrometer NIMA 620 (2010), p.368–374

CR-39 neutron dosimetry

LET measurement Am-241 and Uranium



Am-241 E=5.5MeV
Etching 60’
Removed thickness 10 µm
Avg LET measured 130 keV/µm
Avg LET calculated 140 keV/µm

Unat E_1=4.2MeV E_2=4.77MeV
Etching 40’
Spessore rimosso 6.7 µm

Source	Mean LET meas	Mean LET calculated
U-234	145 keV/µm	148 keV/µm
U-338	170 keV/µm	187 keV/µm

THANK YOU !