TRAINING COURSE ON RADIATION DOSIMETRY:

Instrumentation 3

Passive detectors Part 1

Antonio PARRAVICINI, *MI.AM*

Thu. 22/11/2012, 14:00 – 15:00 pm

Passive detectors

- Electrets
- Track detectors (LR115 - CR-39)

    Radon dosimetry

    Neutron dosimetry

Electrets

An electret is a dielectric material (Teflon) that carries a quasi permanent electrical charge.

A disc of few cm diameter and few mm thickness is manufactured by heating the material in the presence of an electric field and than cooling to “freeze” electric dipoles in place.

With proper encapsulation, this stored charge may be stable over periods longer than an year, even in presence of humidity.

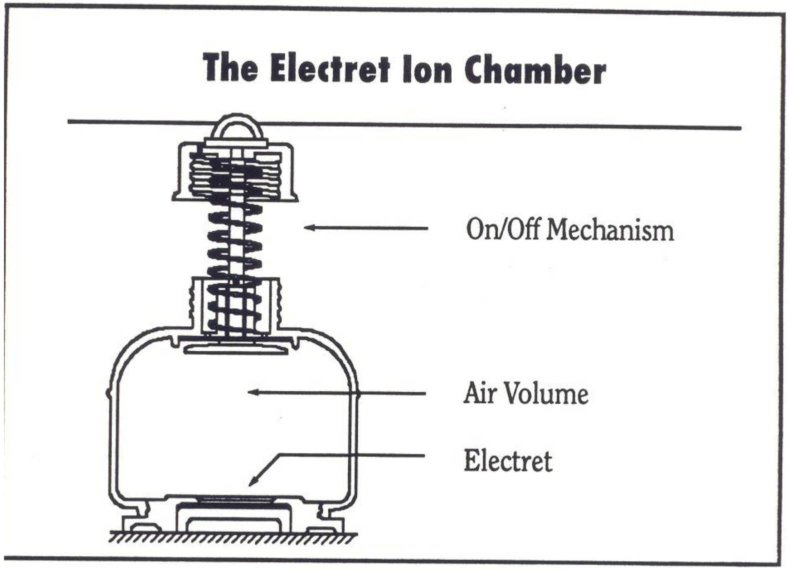
The charge is measured using a portable charge reader.
The electret serves both as a source of electric field and as a sensor.

Electrets

Electrets

RADON MEASUREMENT

Electret is placed in a conductive plastic ionization chamber that acts as a Faraday cage.
The positive charge of the Electret will create an electric field that attracts free ions to its surface.
Radiation entering the chamber causes ionization in the air volume, and the ions produced inside the air volume are collected by the electret.

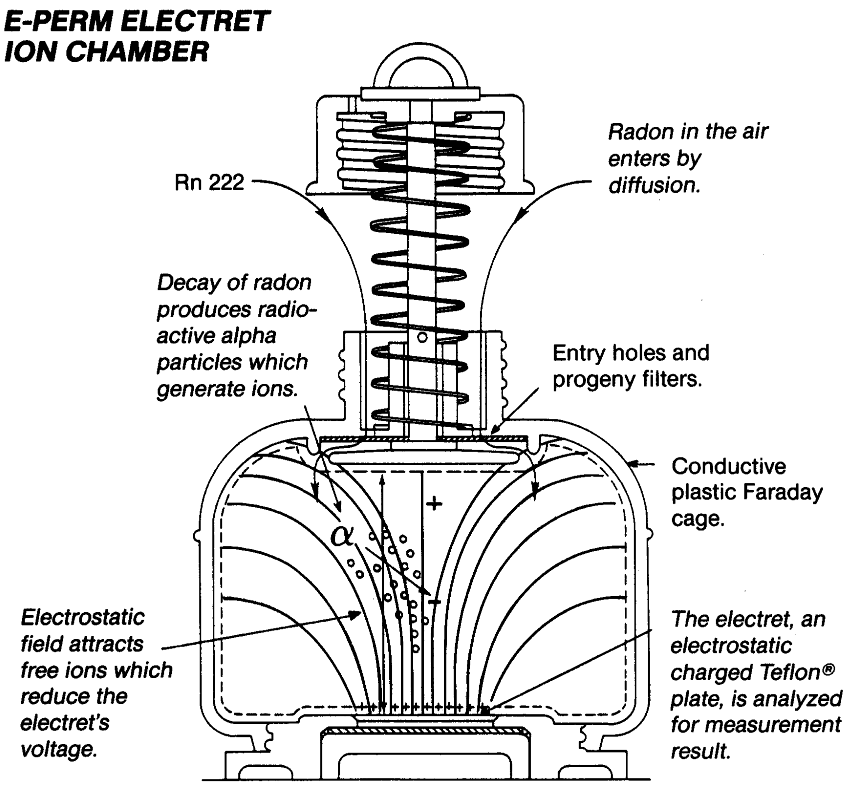


Electrets

The charge change (read as voltage discharge ΔV) is proportional to Rn concentration and background gamma field.
It is the measure of the integrated ionization over the sampling period.

$$E_{Rn} = \frac{\Delta V}{CF_{Rn}} - C \cdot D$$

$$CF = q + m \cdot \ln\left(\frac{V_i + V_f}{2}\right)$$



q and m depend on configuration (chamber, electret)
C is radon equivalent due to gamma, D is exposure lenght

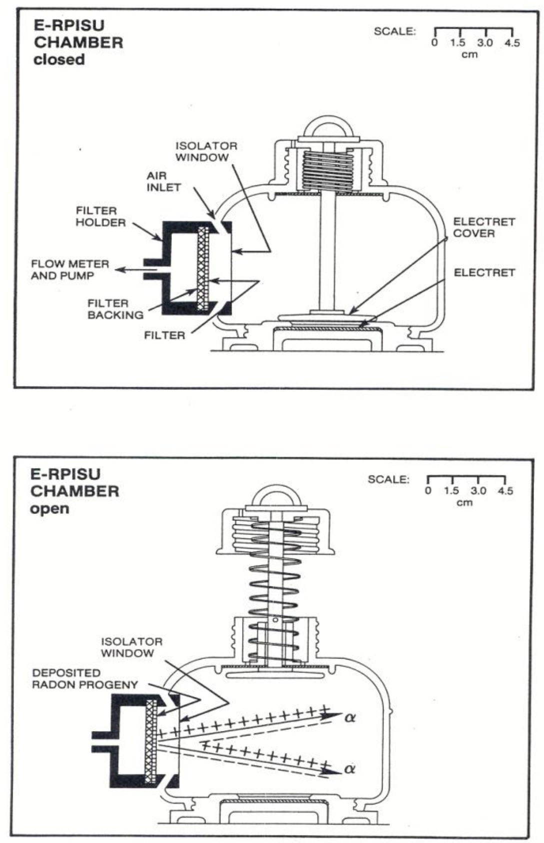
Electrets

RADON PROGENY MEASUREMENT

An air-sampling pump is used to collect the radon progeny for a known sampling time on filter sampler mounted on the side of an electret ion chamber.

The progeny collected emits radiation into the interior of the chamber. The alpha radiation emitted by the progeny collected on the filter ionizes air in the electret ion chamber.

E-RPISU™
(Electret-Radon Progeny Integrating Sampling Unit)
Schematic



Track Detectors

Widely used for several applications:

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

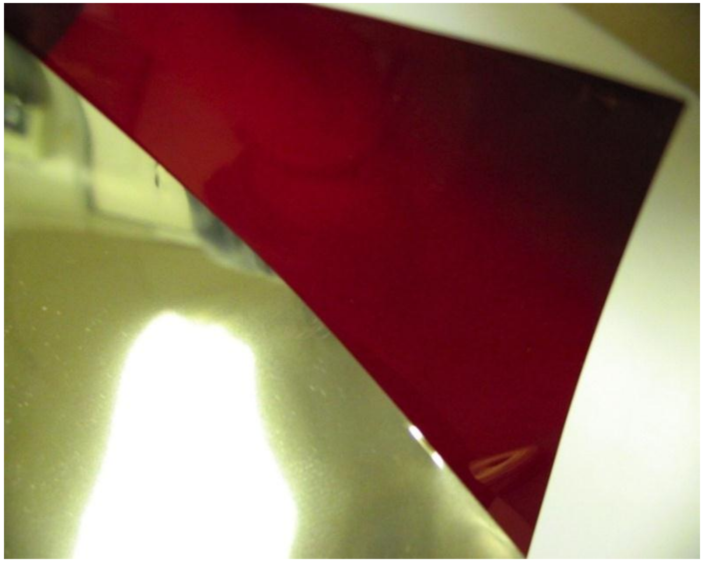
LR115

Cellulose nitrate layer on a clear polyester base

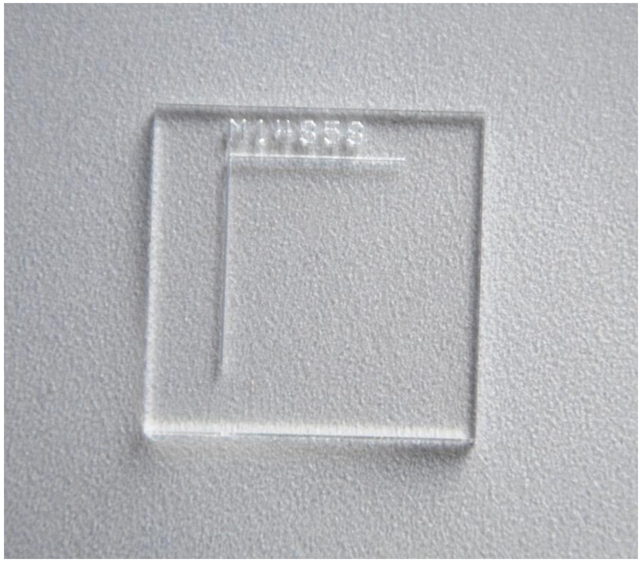
CR-39

PADC- Poly allyl diglycol carbonate

Track Detectors

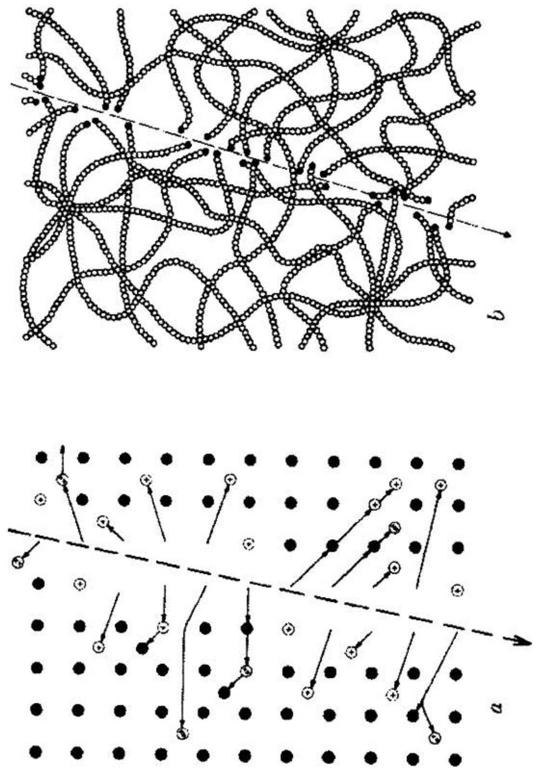


LR115



CR-39

Track Detectors



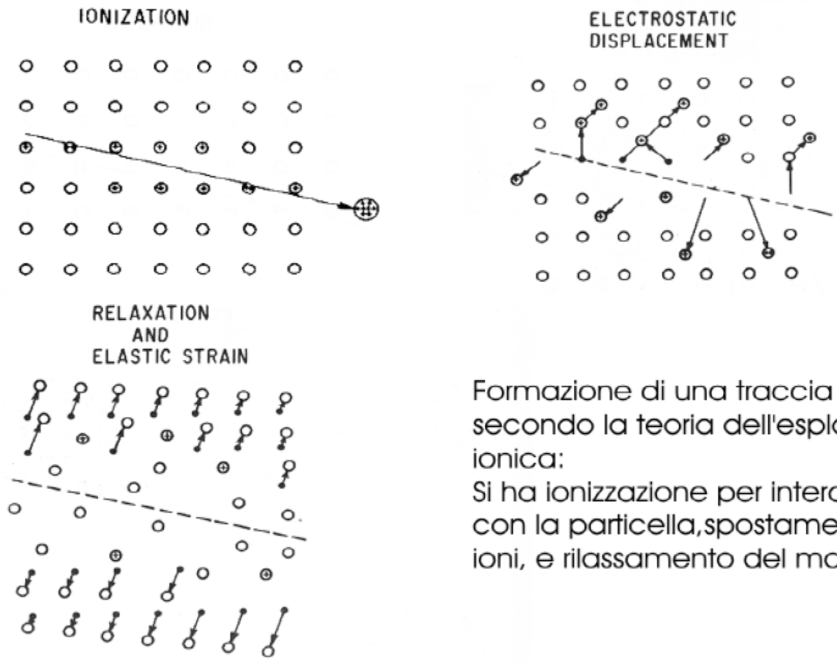
PRINCIPLE OF TRACK DETECTORS

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 particle
The track can be made visible by etching in an acid or basic solution

Track Detectors

Ion explosion theory

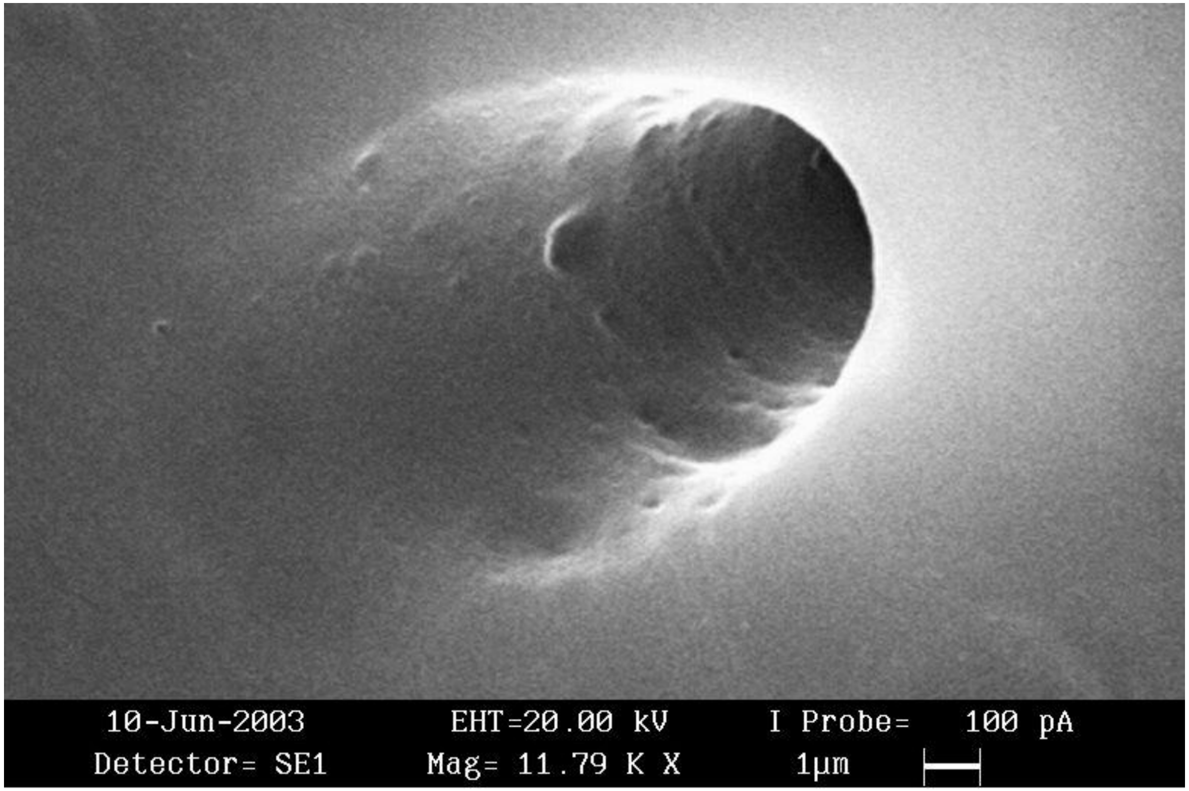
- Ionization
- Electrostatic displacement
- Relaxation and elastic strain



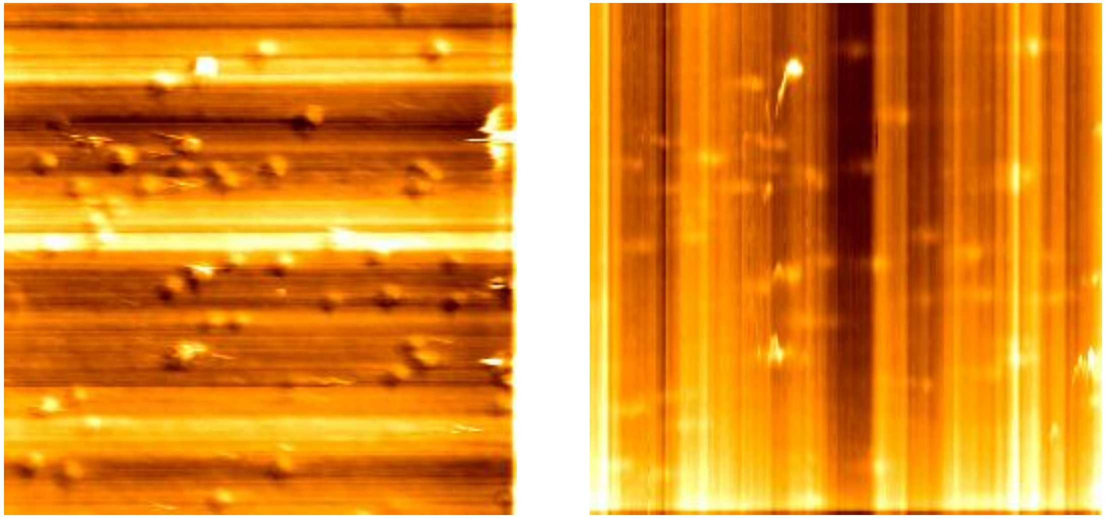
Formazione di una traccia secondo la teoria dell'esplosione ionica:
Si ha ionizzazione per interazione con la particella,spostamento degli ioni, e rilassamento del materiale

Track Detectors

Example of after etching track in a LR115 film



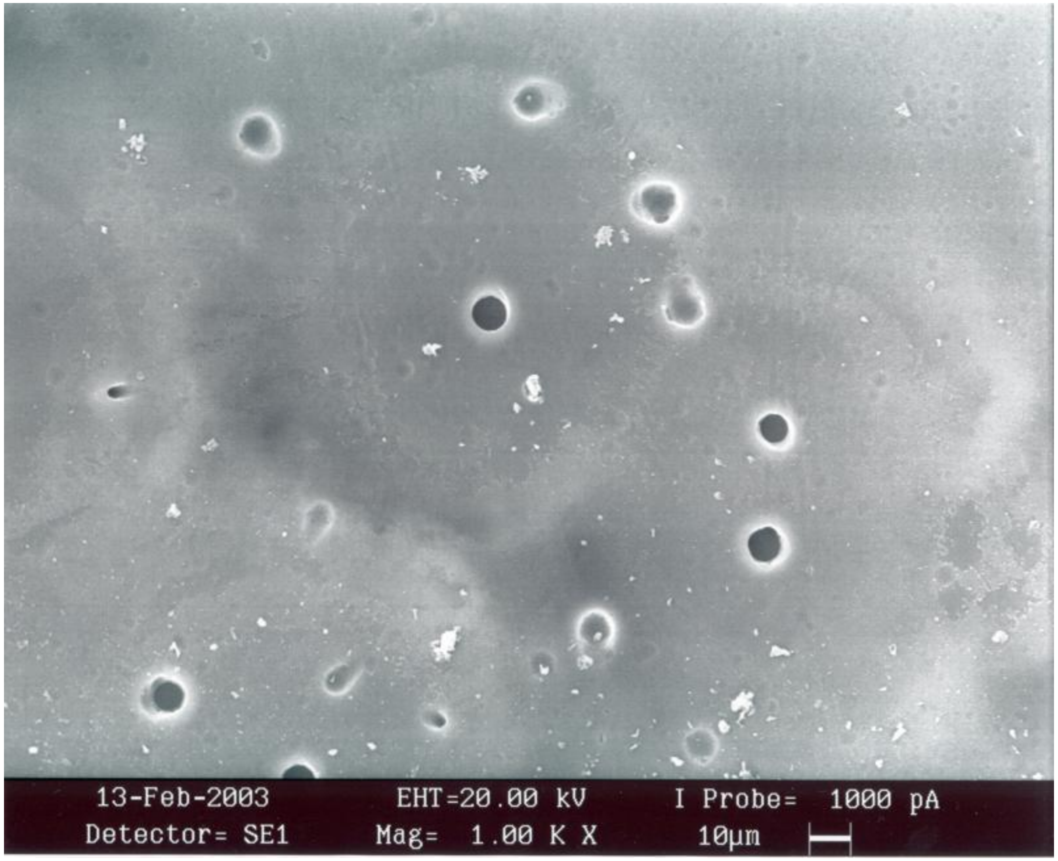
Track Detectors



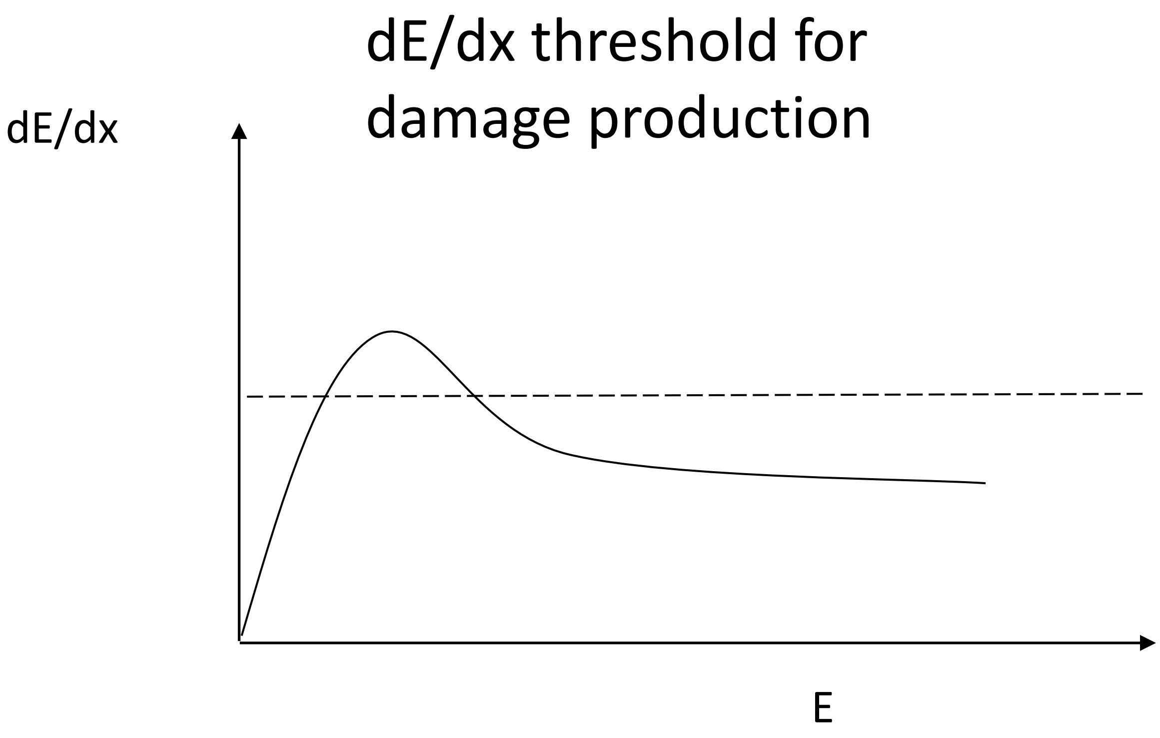
CR-39 detector irradiated by alfa particles (before etching)
Diameter of latent tracks is 70-100 nm. Frame is 5 micrometer (AFM).

Track Detectors

Example of after etching tracks in a CR-39 detector



Track Detectors



Track Detectors

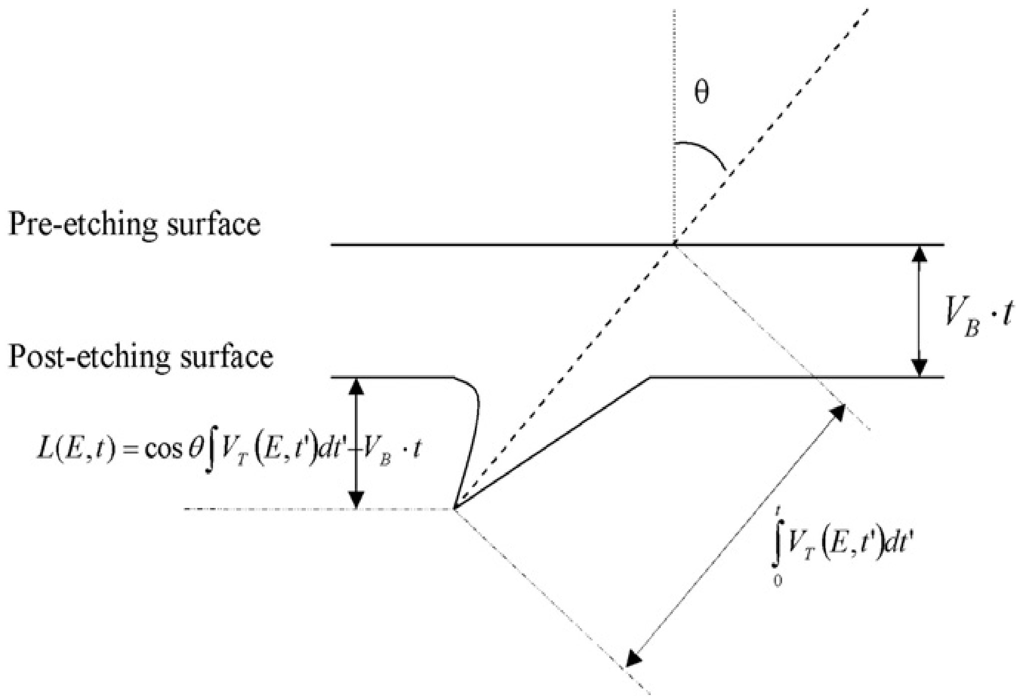
During the etching, material is removed at Vt velocity along the track and isotropically at Vb velocity from the bulk material.

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

The shape of the tracks depends on:

V = Vt (LET)/Vb
Incidence angle
LET = LET(y)
Etching procedure (etchant, temperature, duration)

Track Detectors



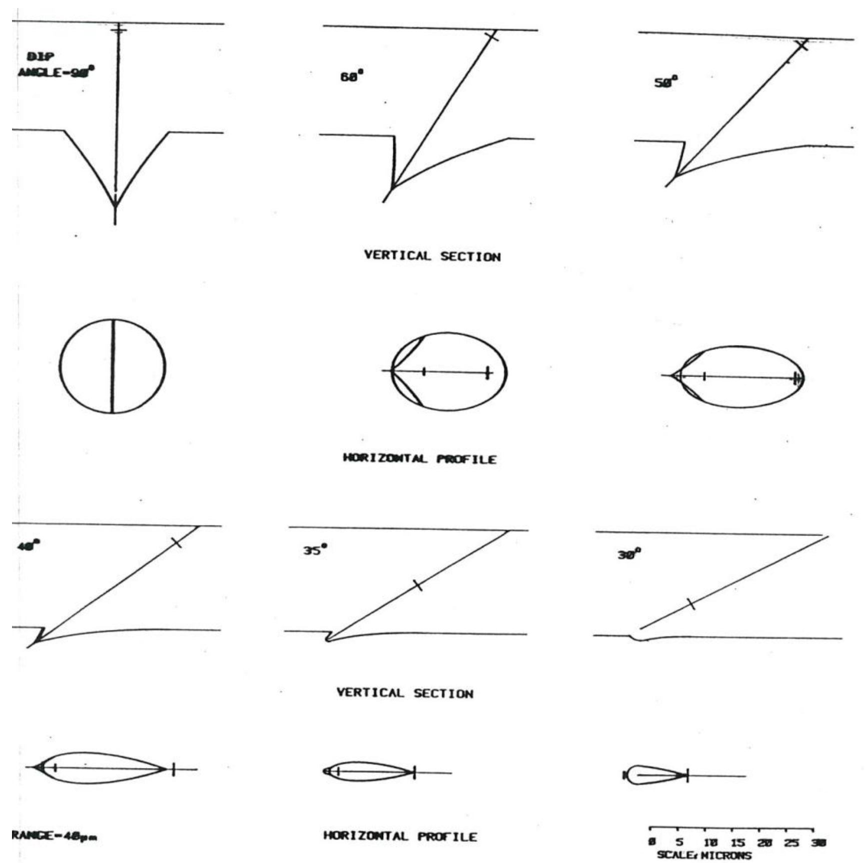
Track is visible if

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

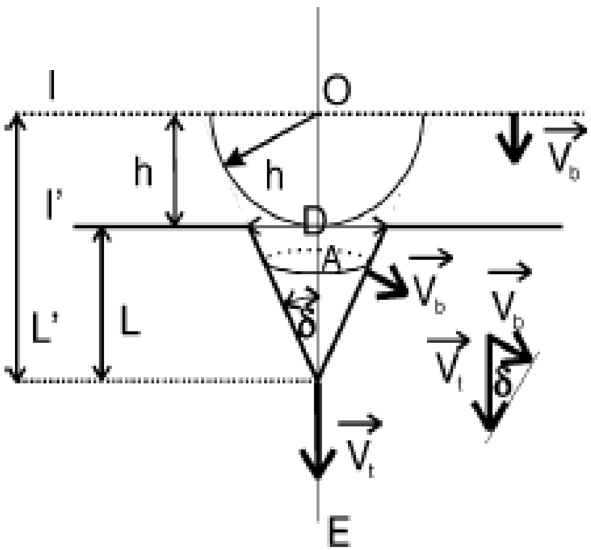
There is a limit angle: if θ> limit angle →no track

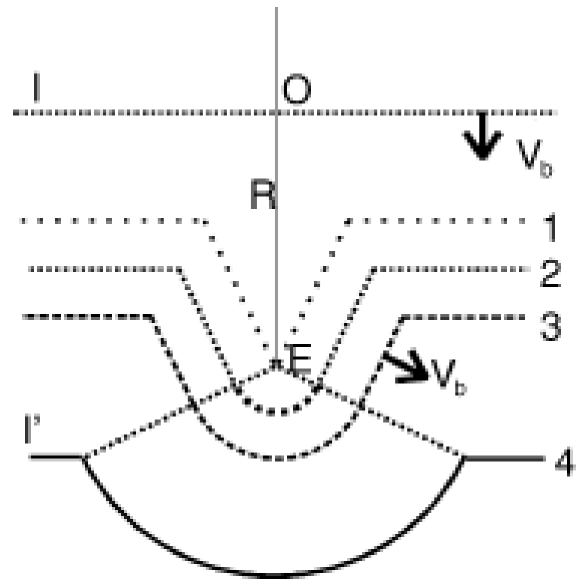
Track Detectors

Shape of the track as funtion of incidence angle



Track Detectors





overetching: round shape

Track Detectors

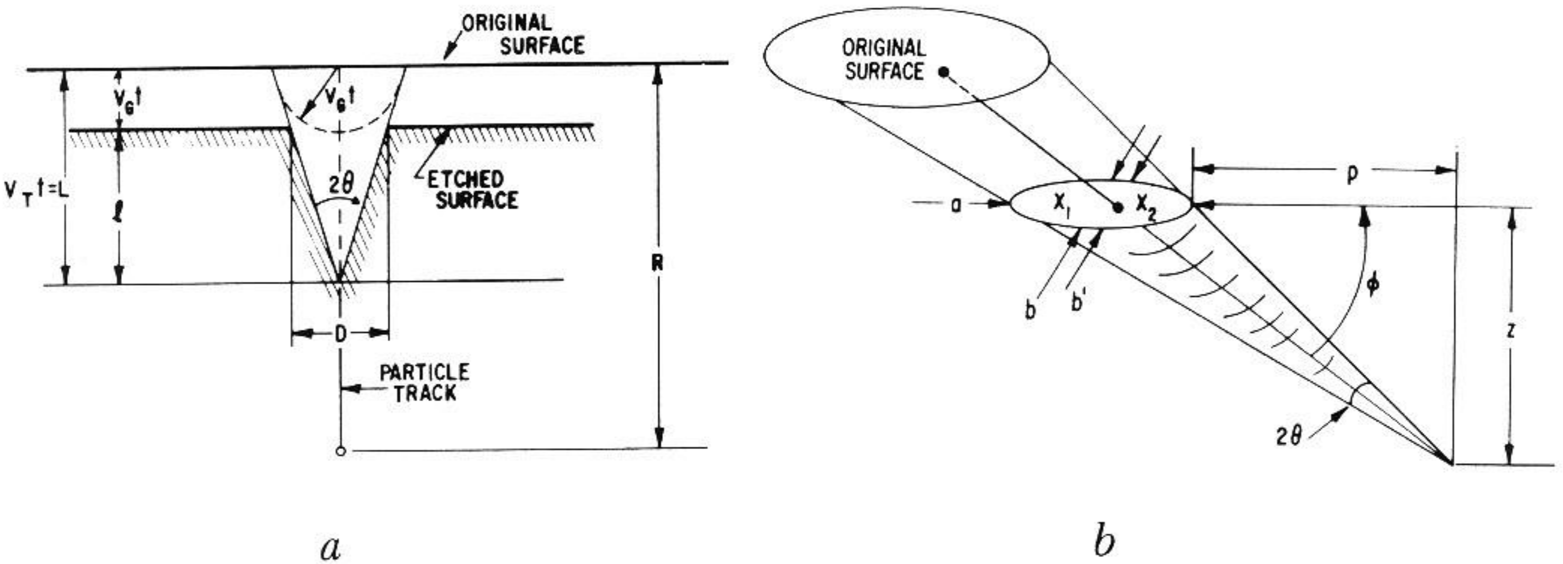
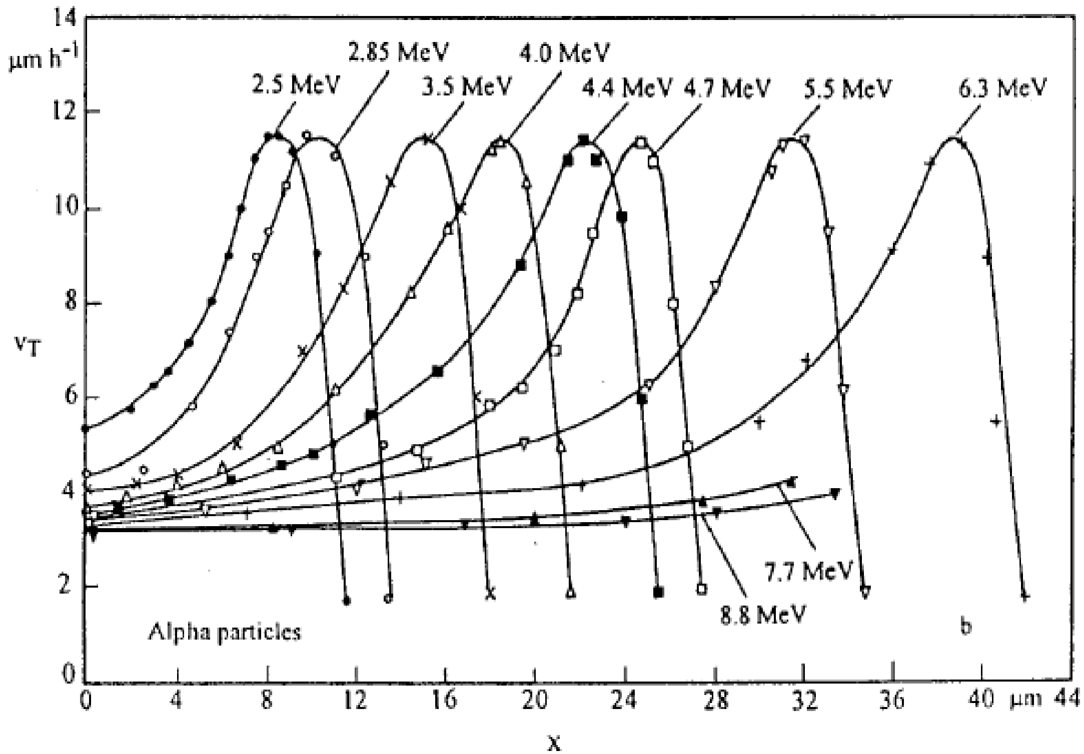


Fig. 2-1. *Track geometry with v_T and v_G constant and (a) a vertically incident particle or (b) a particle incident at dip angle ϕ. (After Price and Fleischer, 1971.)*

Track Detectors

Variation of Vt along track path

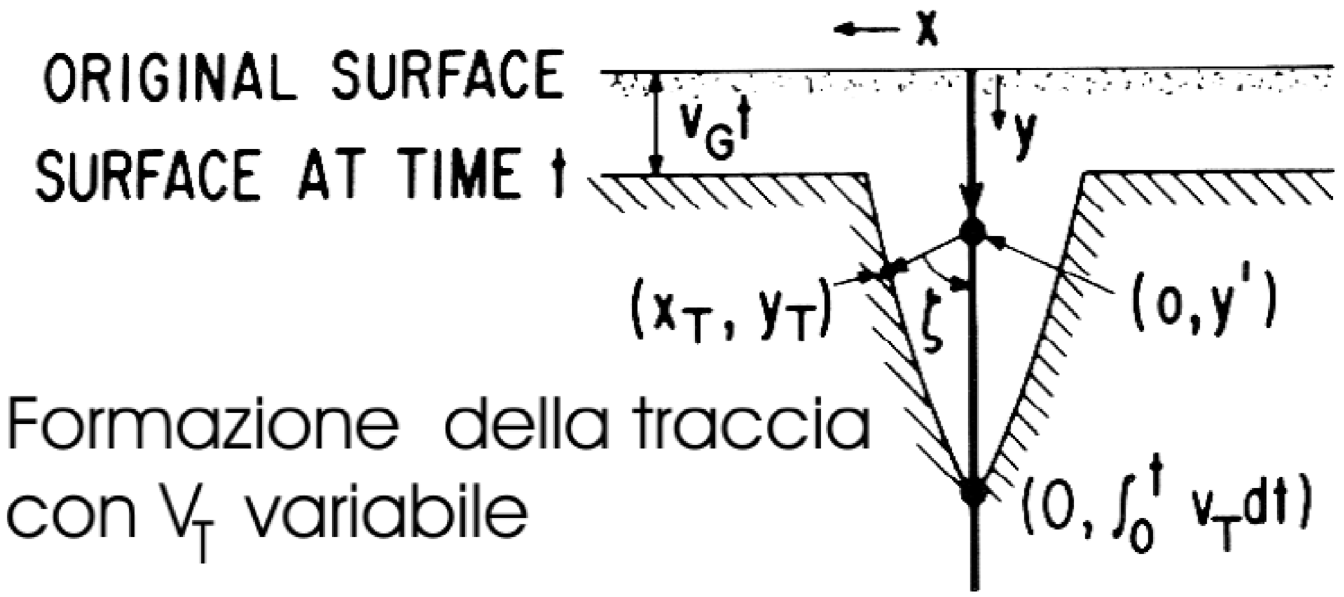


Vb=1.83 µm/h

Track Detectors

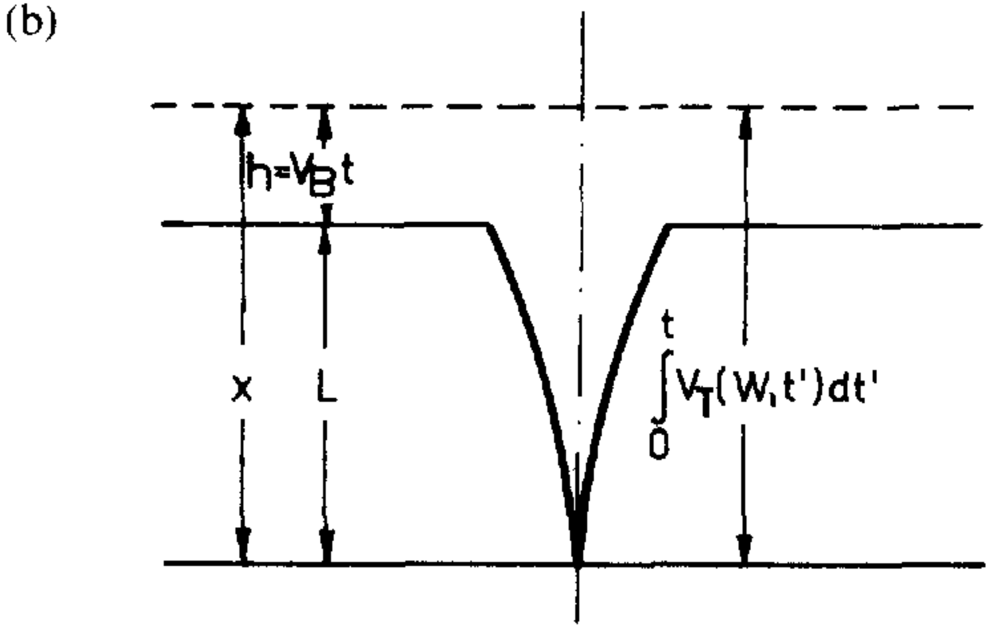
Variation of the track etch rate along the alpha particle trajectories:

Vt decreasing



Track Detectors

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



Track Detectors

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

Track Detectors

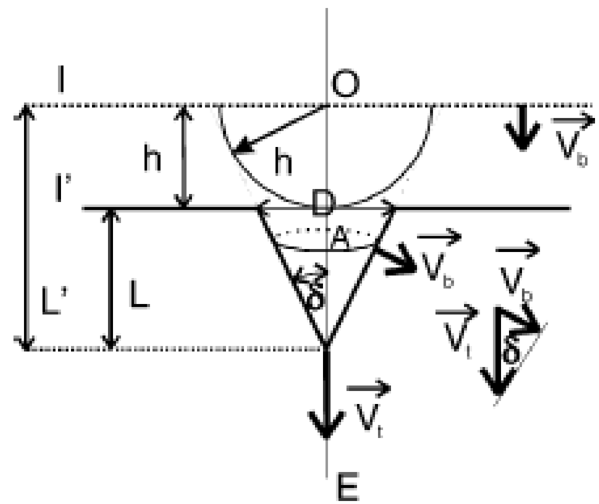
Measure of Vb - Bulk velocity

Fission fragments tracks Vt >> Vg

V = Vt/Vg

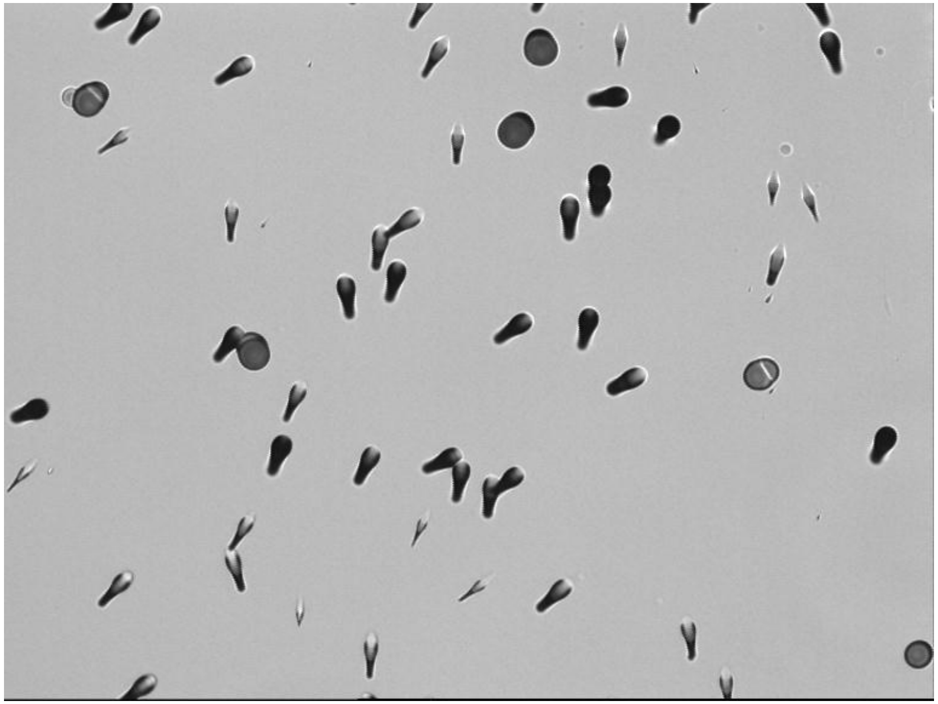
$$D = 2h\sqrt{\frac{V-1}{V+1}}$$

If $V \gg 1$ then $D \simeq 2h$



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

Track Detectors



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

Track Detectors

Track lenght as function of etching time

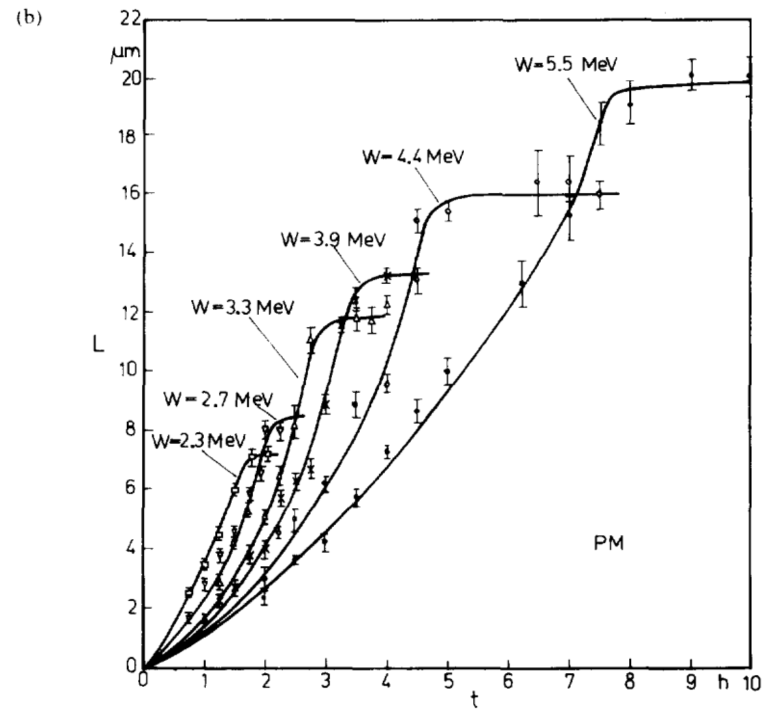


Fig. 4. Track length, *L*, as a function of etching time, *t*, for various initial alpha energies, *W*: (a) PATRAS; (b) PM.

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

Track Detectors

Track lenght as function of etching time

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

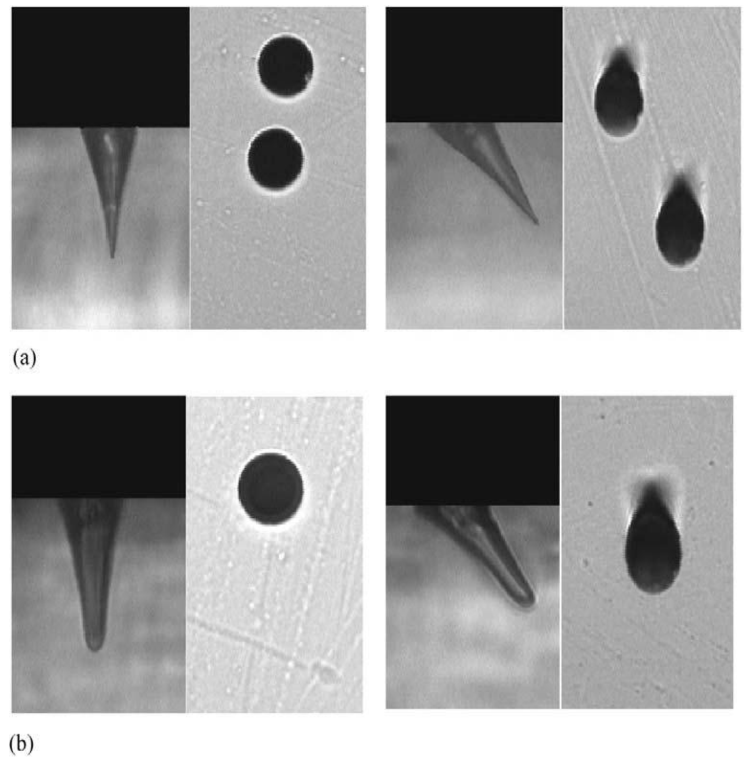
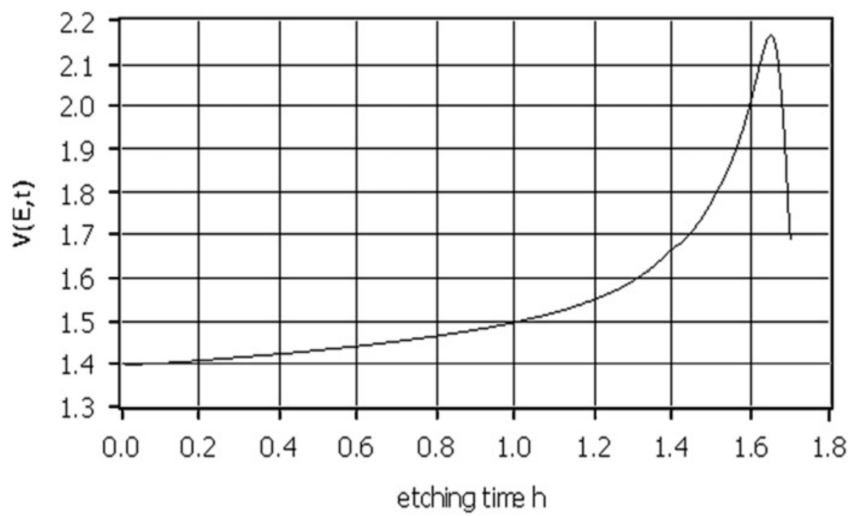
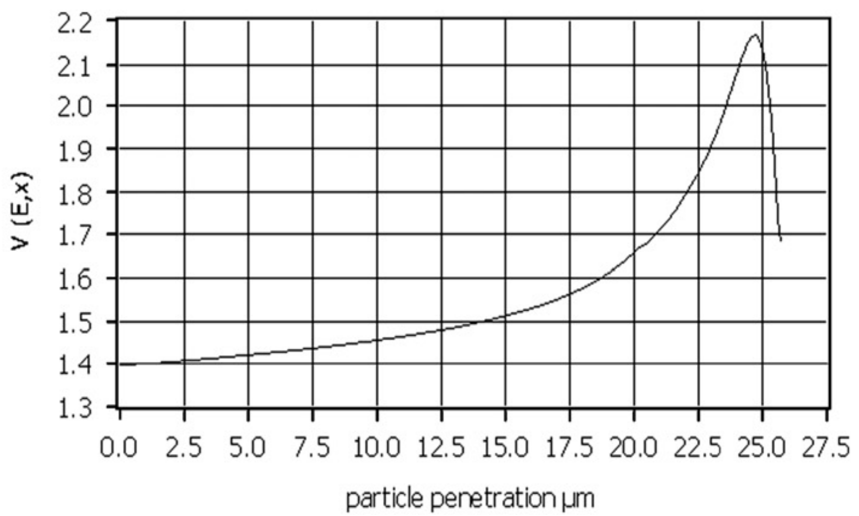


Fig. 4. Longitudinal section and top view of etched tracks of 90 MeV 7Li ions entering the detectors at = 0◦ (left side) and = 40◦ (right side) for diferent etching times, t (a) t = 3:5 h, (b) t = 4:33 h. Magnification: 950.

Track Detectors





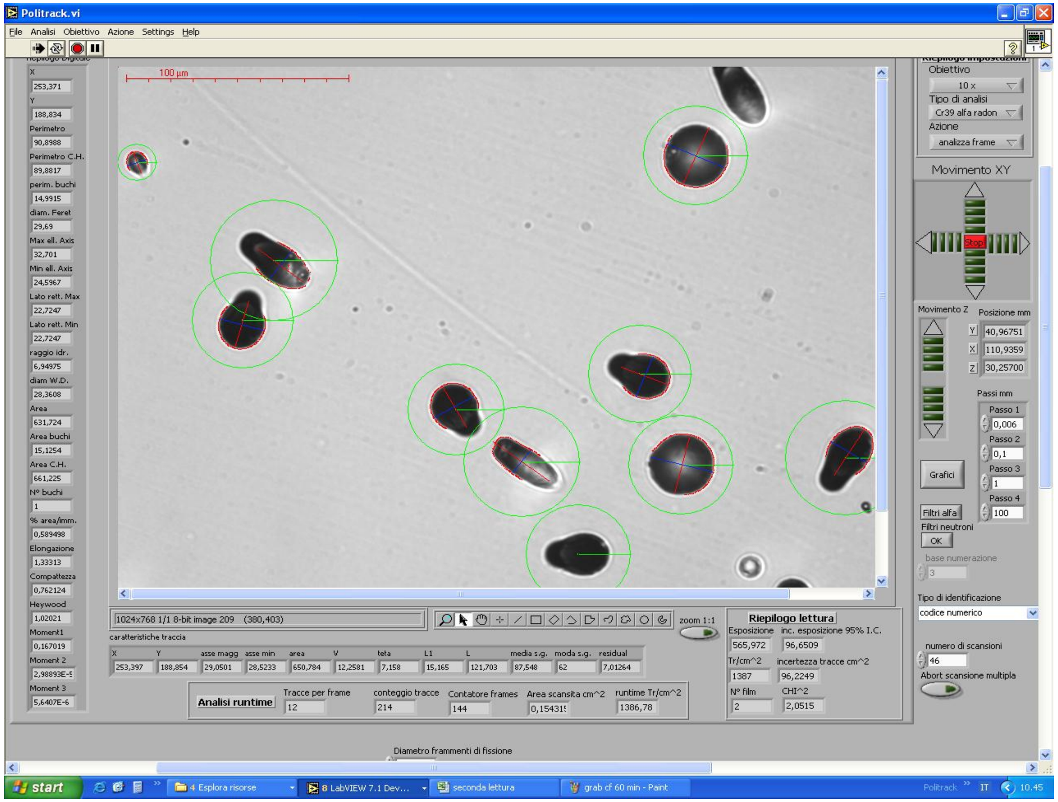
V=V(E,t) and *V=V(E,x)* functions calculated through the *V=V(REL(E,x))* function for 1.2 MeV protons impinging perpendicularly on the detector surface. The simulated etching conditions are Vb=9.8 µm h^{-1} and 1.5 h of etching time.

Track Detectors

CR39 detector analysis

Measure of track parameters using automatic systems

- Count the tracks
- Filter tracks (reduce background)
- Calculate LET (discriminate the particles) and impinging angle



Track Detectors

RADON DETECTION

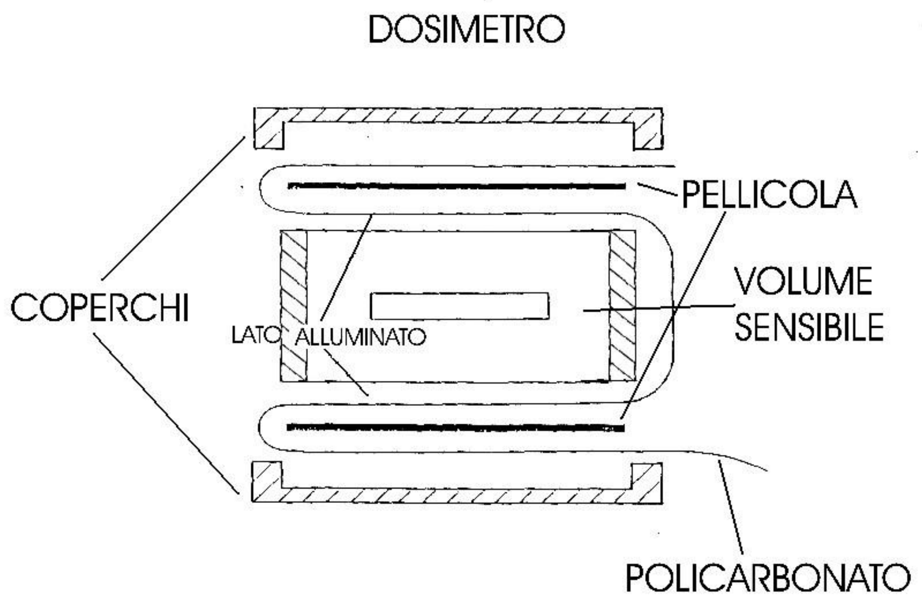
Radon concentration measurement must be carried out on a long integration time (several months) to smooth radon concentration variations. The physical quantity measured is exposure ($Bq*h/m^3$)

The most common radon track detectors are:

- LR115 track detectors
- CR-39 track detector

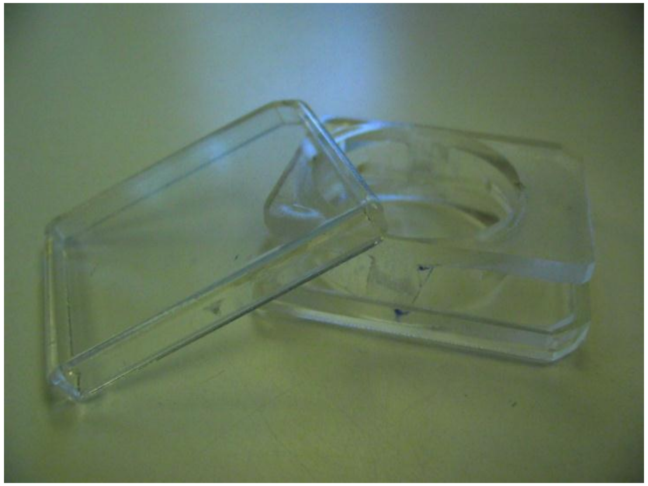
Track Detectors

LR115 radon detector (ANPA type)



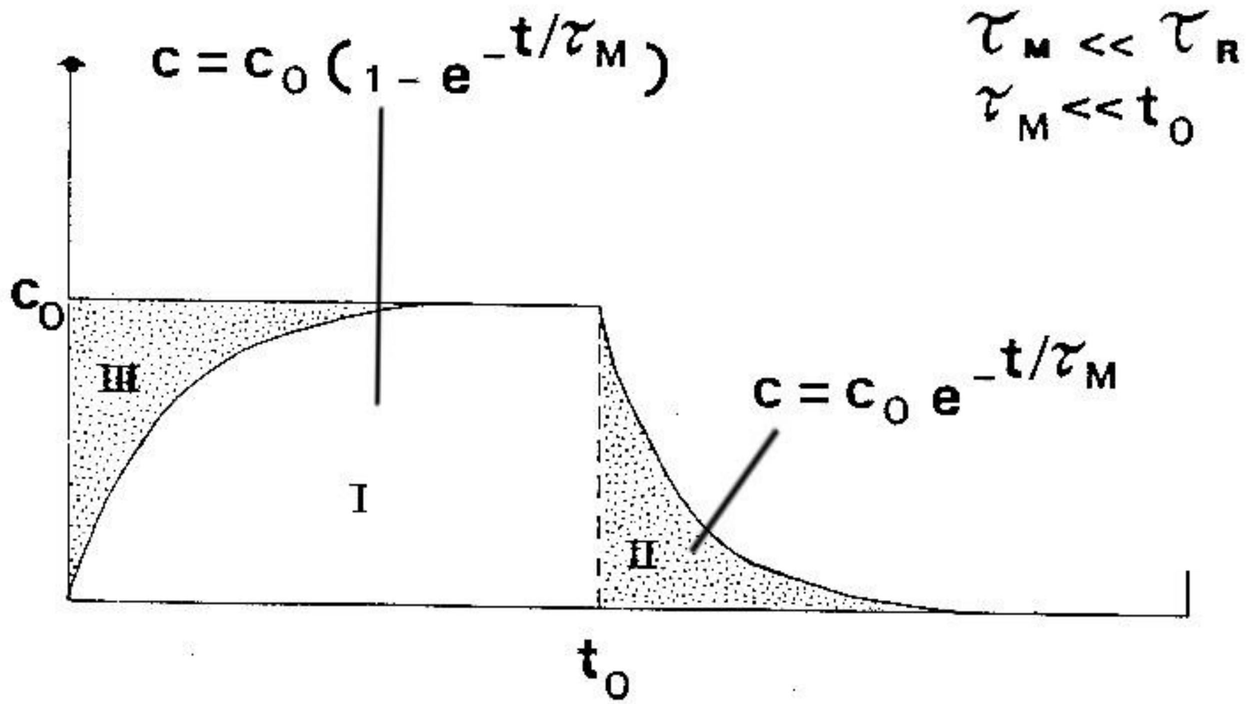
Track Detectors

LR115 radon detector



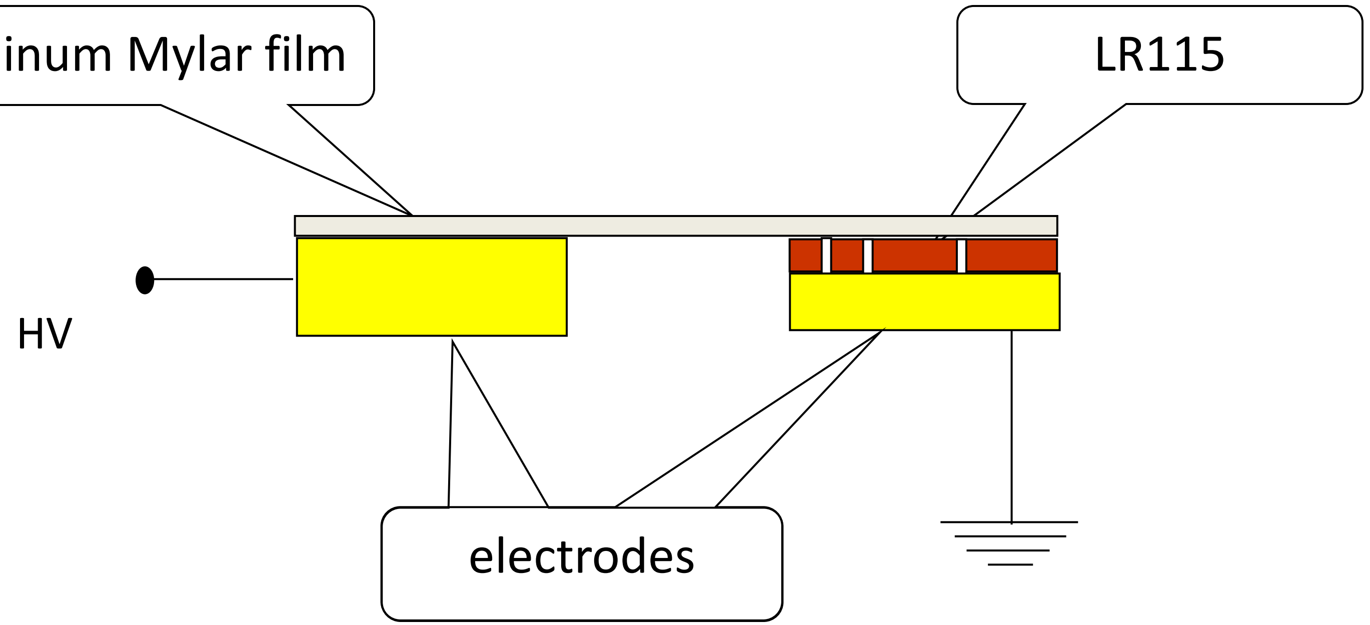
Track Detectors

LR115



Track Detectors

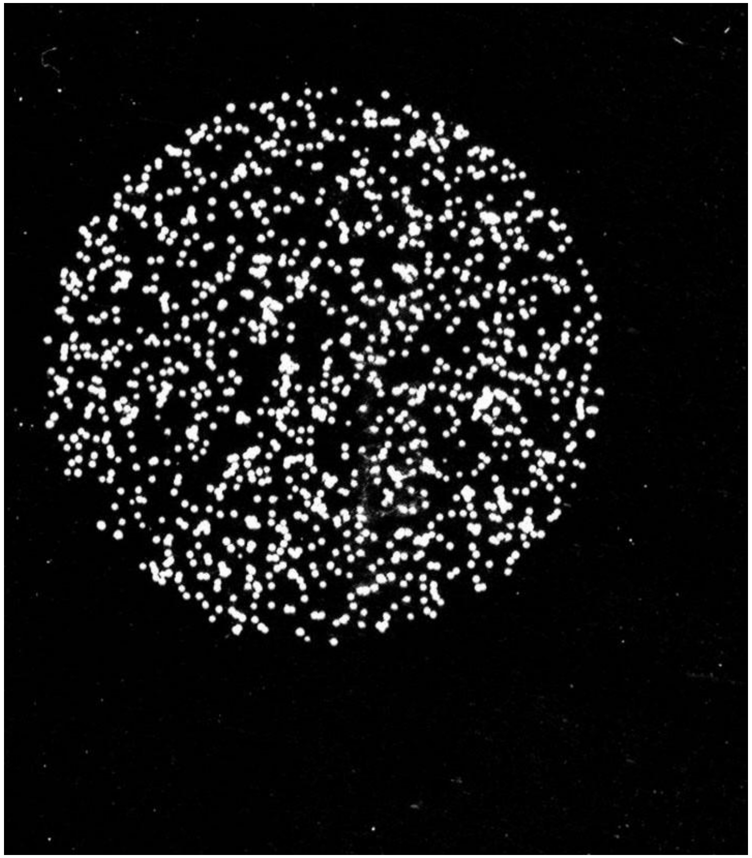
LR115 reading: Spark counter



Track Detectors

LR115 reading
Spark counter

Track Detectors



Spark counter

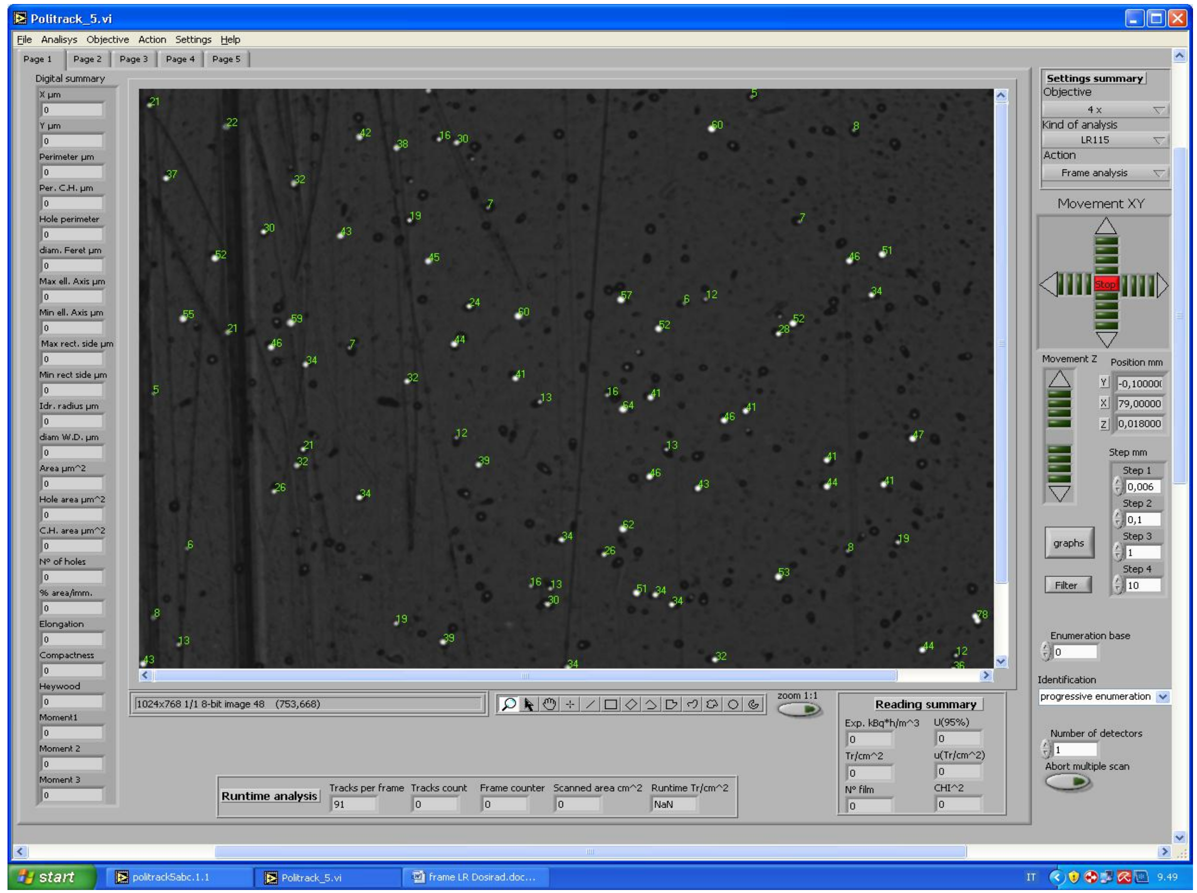
Aluminum Mylar film after spark counter reading

Track Detectors

LR115 reading: optical system

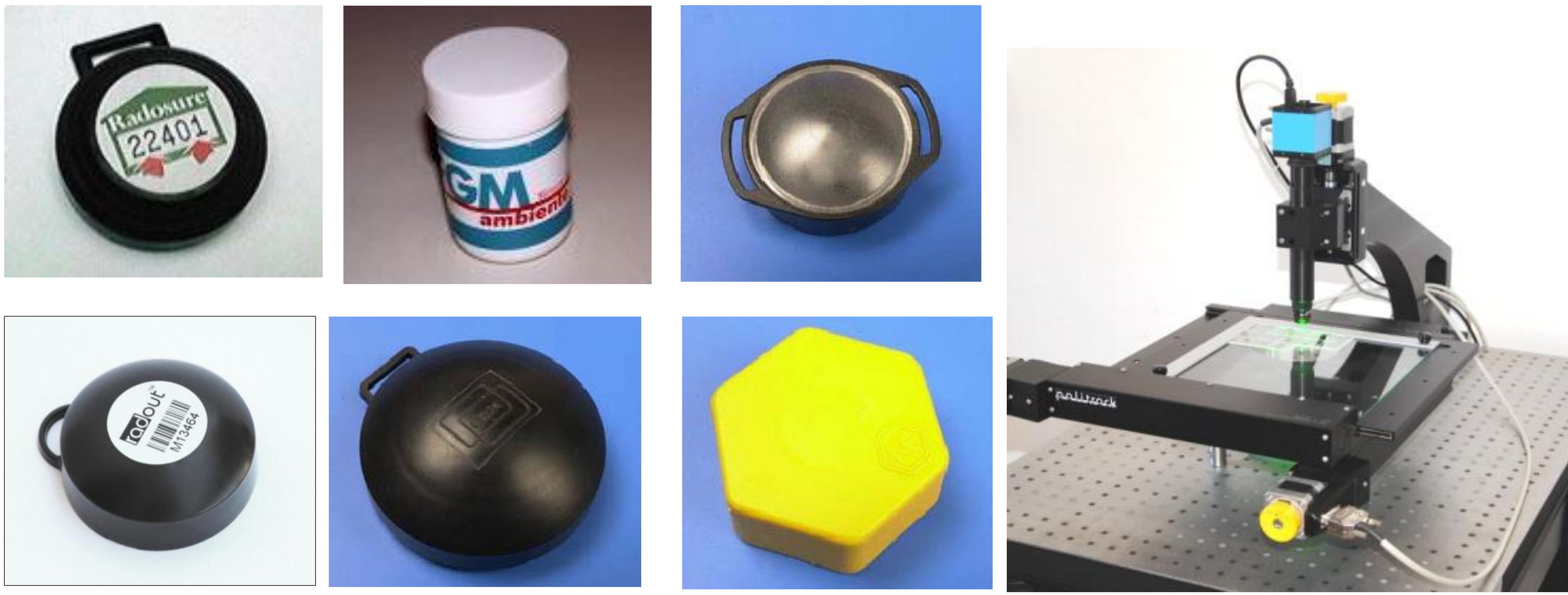
Tracks appear as white holes on dark background

Tracks are automatically counted and area is measured for etching correction



Track Detectors

CR-39 radon detectors and optical reading system

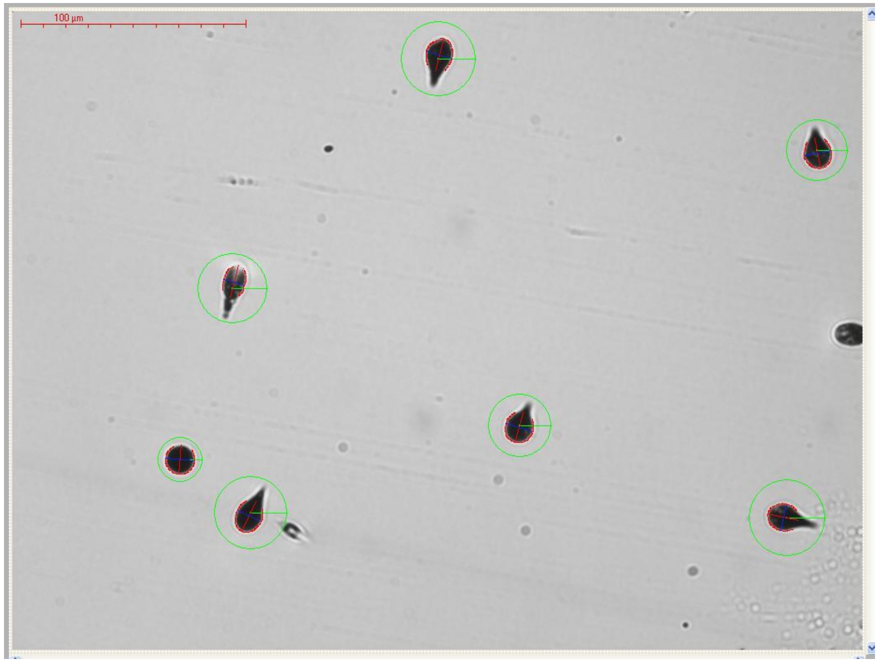


Track Detectors

CR-39 radon detectors

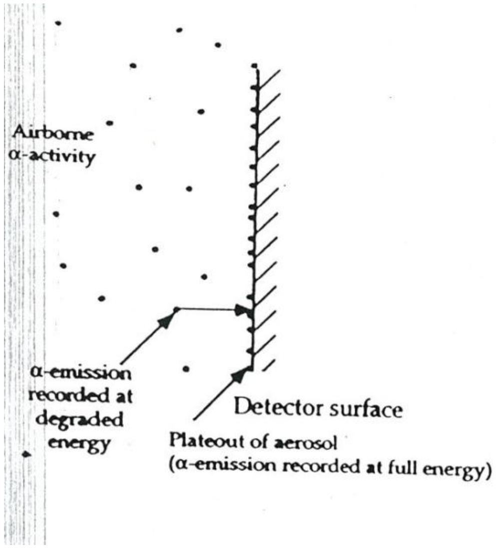
- Exposure in ambient
- After exposure, the detector is chemically etched.
- Detertors are scanned by optical system and morphological analysis of the track is performed
- The analysis allows to filter tracks (background reduction)
- The number of tracks from radon and daughters (Po-218 and Po-214) is proportional to radon concentration

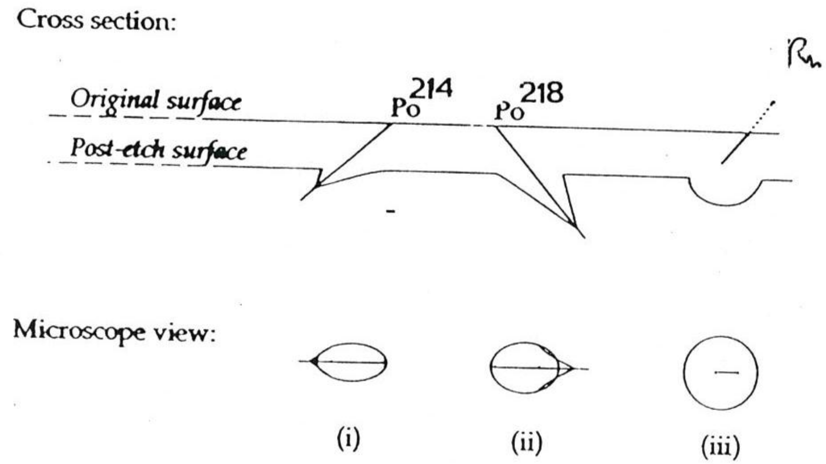
Track Detectors



Alpha tracks from radon and radon daughters in CR39 detector

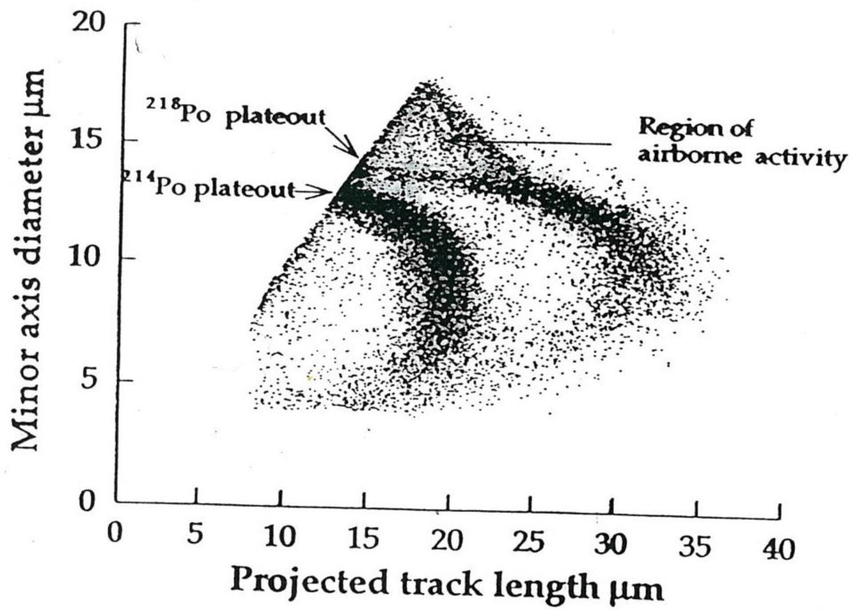
Track Detectors





Alfa tracks from radon and radon daughters in CR39 detector

Track Detectors



Tracks from plateout and airborne activity in bare exposed detector
Etching conditions: NaOH 25% w/v, 98°C, 60’

Track Detectors

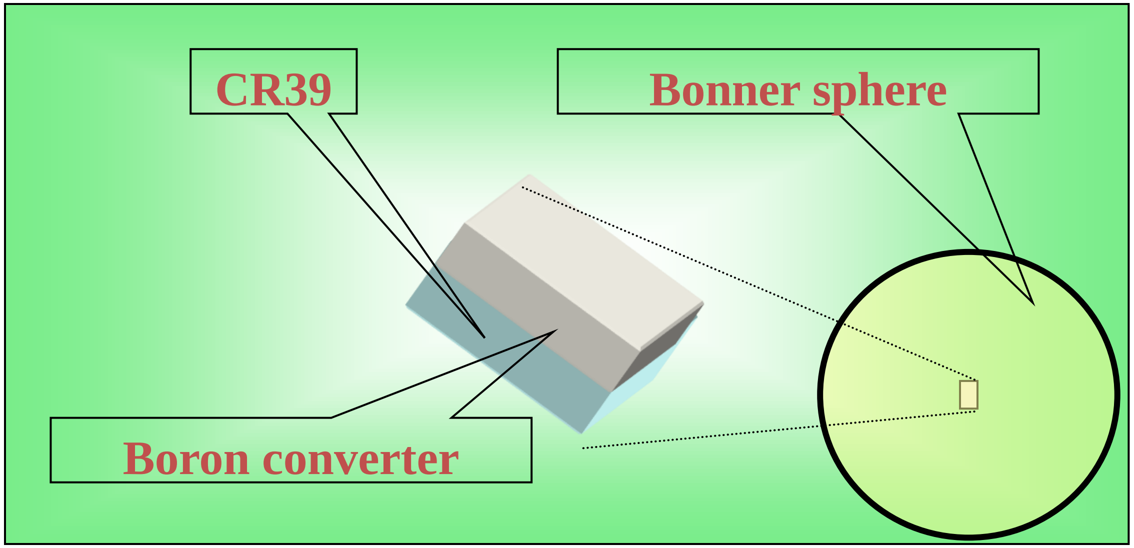
CR-39 NEUTRON DOSIMETRY AND SPECTROMETRY

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.

Track Detectors

CR39- neutron dosimetry – Bonner sphere (polyethylene neutron moderator)

The neutron is detected by the 1.47 MeV alfa particle
Number of tracks is proportional to thermal neutron fluence (inside Bonner sphere)

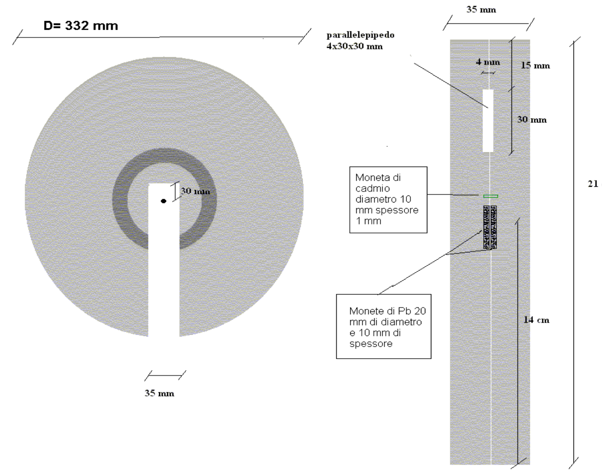


$^{10}B(n,alfa)^{7}Li$

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

Track Detectors

CR39- neutron dosimetry – Bonner sphere

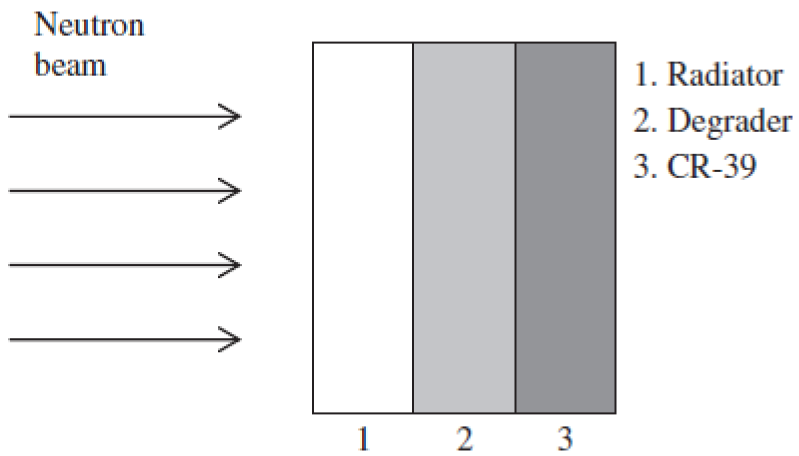


Versione un rivelatore sensibilità 10 tracce/cm^2 per µSv

Versione 2 rivelatori Sensibilità 6 tracce/cm^2 per µSv

Track Detectors

CR39- radiation degrader neutron spectrometer



Radiator: high density polyethylene
Degrader: aluminium (purity 99%)

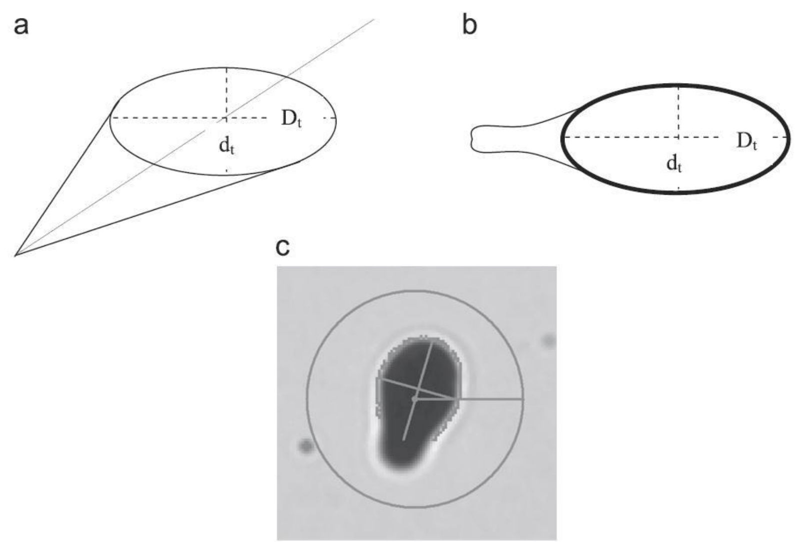
(1) Recoil protons generated inside the radiator(external radiation component).
(2) Recoil protons generated inside the detector(proton self radiator).
(3) Carbon and oxygen recoil nuclei generated inside the detector (ion self radiator).

Track Detectors

CR39- neutron dosimetry based on LET spectrometry

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

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



D, d and h are measured

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

Track Detectors

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

It 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, from LET and θ we can calculate dose

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

Track Detectors

Assuming n particles impinge on the unit area 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

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

D e H are expressed in mGy e mSv respectively
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

If a 1 cm PMMA radiator is used, H is a good approximation of H*(10)

Track Detectors

Relationship between V and REL - restricted energy loss (related to LET)

$V = V_t / V_b = 0.93 + 3.14\times10^{-3} REL - 7.80\times10^{-6} REL^2 + 1.11\times10^{-8} REL^3 - 5.27\times10^{-12} REL^4$

33 MeV/cm < *REL* < 560 MeV/cm

and

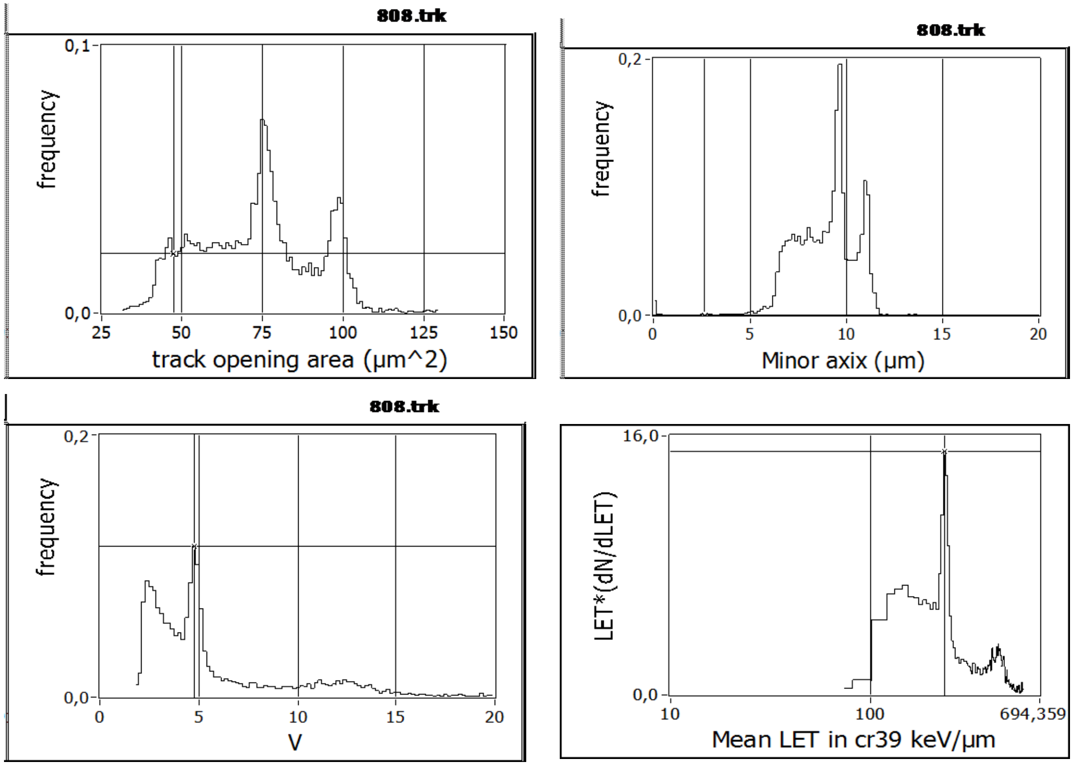
$V = V_t / V_b = 1.30 + 3.80\times10^{-4} REL + 4.9\times10^{-7} REL^2$

for *REL* > 560 MeV/cm.

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.

Track Detectors

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



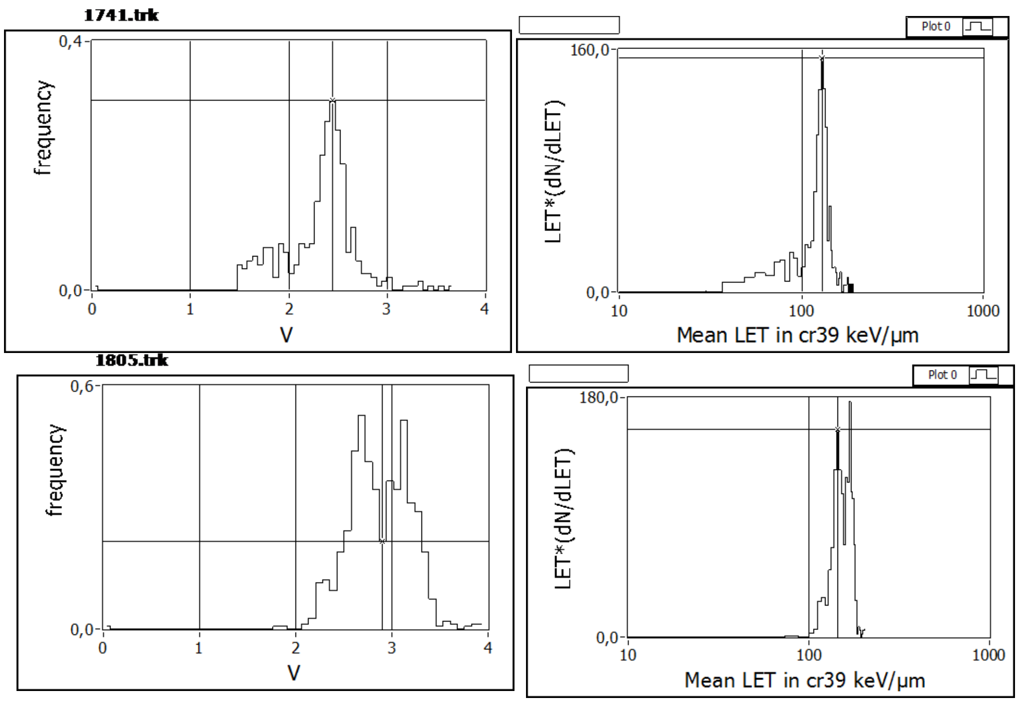
E_{alpha} =1.47 MeV
$E_{lithium}$ =0.84 MeV

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

Track Detectors

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

Passive detectors

THANK YOU FOR YOUR ATTENTION