Track Analysis Systems Ltd, TASL*

TASL*Image*© training notes

*Track Analysis Systems Ltd, Napier House, Meadow Grove, Shirehampton, Bristol, BS11 9PJ, UK. Tel: +44 (0) 117 9381172; Email: info@tasl.co.uk
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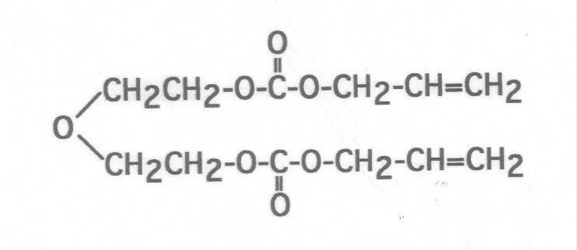
TASTRAK™ – TASL's own highly sensitive plastic track detector

The principal component of TASTRAK is the polymer derived from the polymerisation allyl diglycol carbonate, to produce poly allyl diglycol carbonate or PADC. The monomer has the structure:



TASTRAK has been progressively developed and refined by TASL for nuclear track detection in fields such as radon detection and dosimetry, neutron dosimetry, proton beam therapy and a wide range of research applications including laser plasma fusion diagnostic, space science experiments.

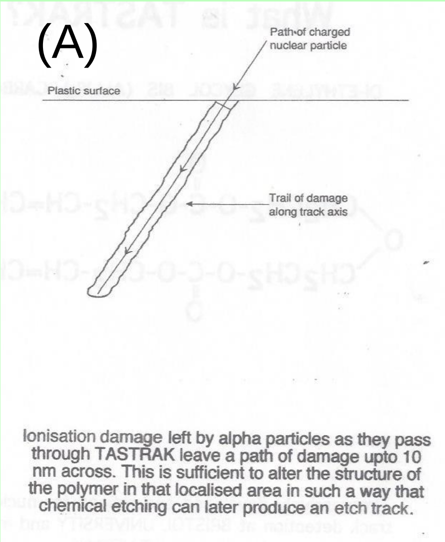
Part 1 – detection of alpha-particles – principal application: radon measurements

What is radioactivity?

- Radioactivity is the process by which the nuclei of some atoms emit radiation.
- The emission of alpha, beta and gamma radiation is well-known, but nuclear fission and the emission of neutrons also constitute forms of radioactivity.
- Alpha-radiation takes the form of alpha-particles which consist of two protons and two neutrons bound together as in a helium nucleus. In the periodic table of elements, alpha-radioactive elements are almost exclusively heavier than lead (atomic number 82).
- Radon detection is based on the recording of alpha-particles from the radioactive decay of ^{222}Rn (the principal isotope of radon) and its associated short-lived alpha-emitting decay products, ^{218}Po and ^{214}Po. (beta-emitting decay products are not recorded)
- Alpha-particles typically travel a few centimetres in air and a few tens of micrometres (μm) in TASTRAK. The distance they travel is known as their "range". Below is a table of ranges in air and TASTRAK.

Radionuclide	α-particle energy (MeV)	Range in air (cm)	Range in TASTRAK (μm)
^{222}Rn	5.5	4.0	33
^{218}Po	6.0	4.9	40
^{214}Po	7.7	7.0	58

How α-particle tracks are revealed in TASTRAK™ plastic



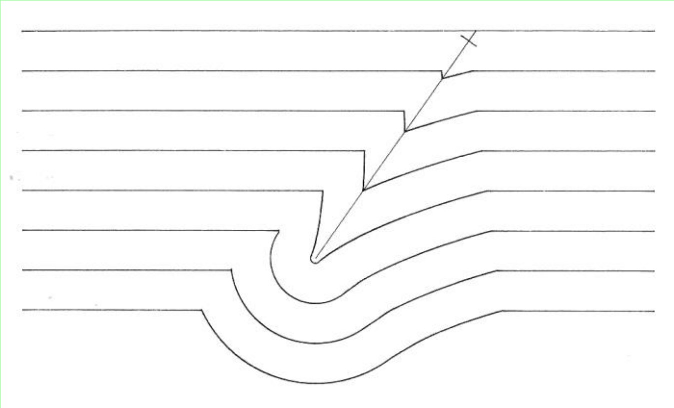
Note: there is a minimum level of ionization that will result in a joined-up trail of damage that will then result in preferential etching as described in (B) and (C). For this reason, TASTRAK is a selective detector that does not record tracks of beta-particles or gamma radiation. It will, however, record protons up to several MeV in energy, making it ideal for use in fast neuron dosimetry via recoil protons in the plastic.

(B)

(a)

(b)

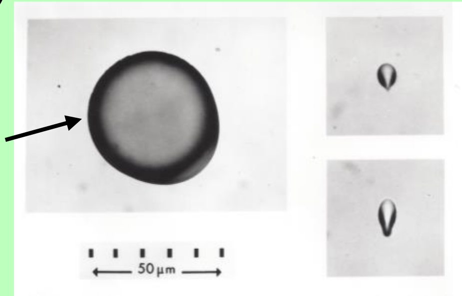
(c)



Simulated vertical section profile of the growth of etch pit along the trail of a ^{218}Po α-particle with range 40 μm and dip angle 55º in TASTRAK plastic. Etching is at 98ºC in 6.25 M NaOH.

(C)

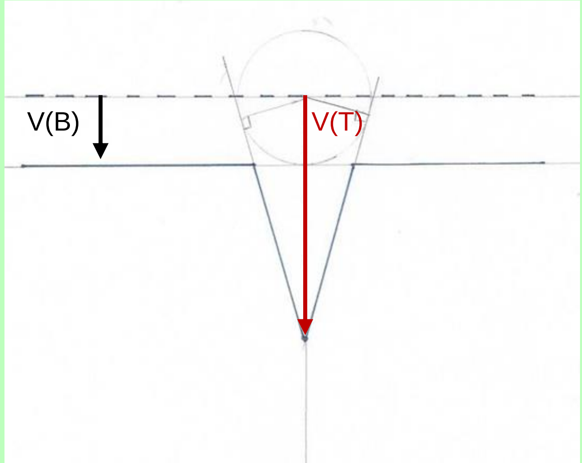
Etched for 5 h in 6.25 M NaOH at 98ºC



Shorter etch times

See notes below accompanying this slide

Bulk and track etch rates

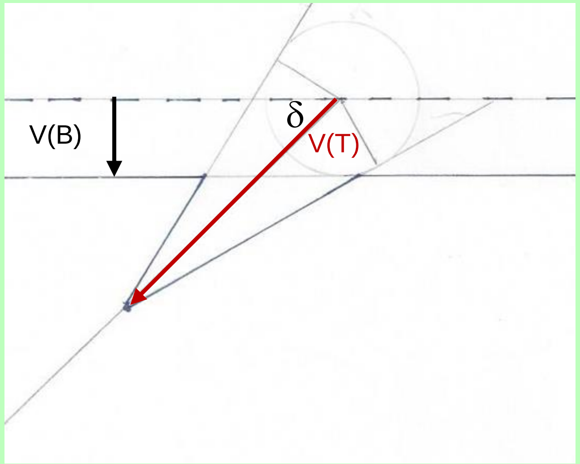


Normal incidence tracks

For a track to be formed, the etch rate along the track, V(T) must be greater than the rate of etching of the bulk plastic, known as the bulk etch rate V(B).

i.e. V(T) > V(B) is the condition for revealing a track.

This condition defines the ionisation threshold for revealing an etch track. Thus, electron tracks (beta-particles) are not revealed in TASTRAK because the density of the trail of damage along such tracks is insufficient for preferential etching.



Inclined incidence tracks

For a particle entering the plastic at a dip angle δ to the surface, the condition for revealing an etch track is:

$$V(t)\ \sin(\delta) > V(B)$$

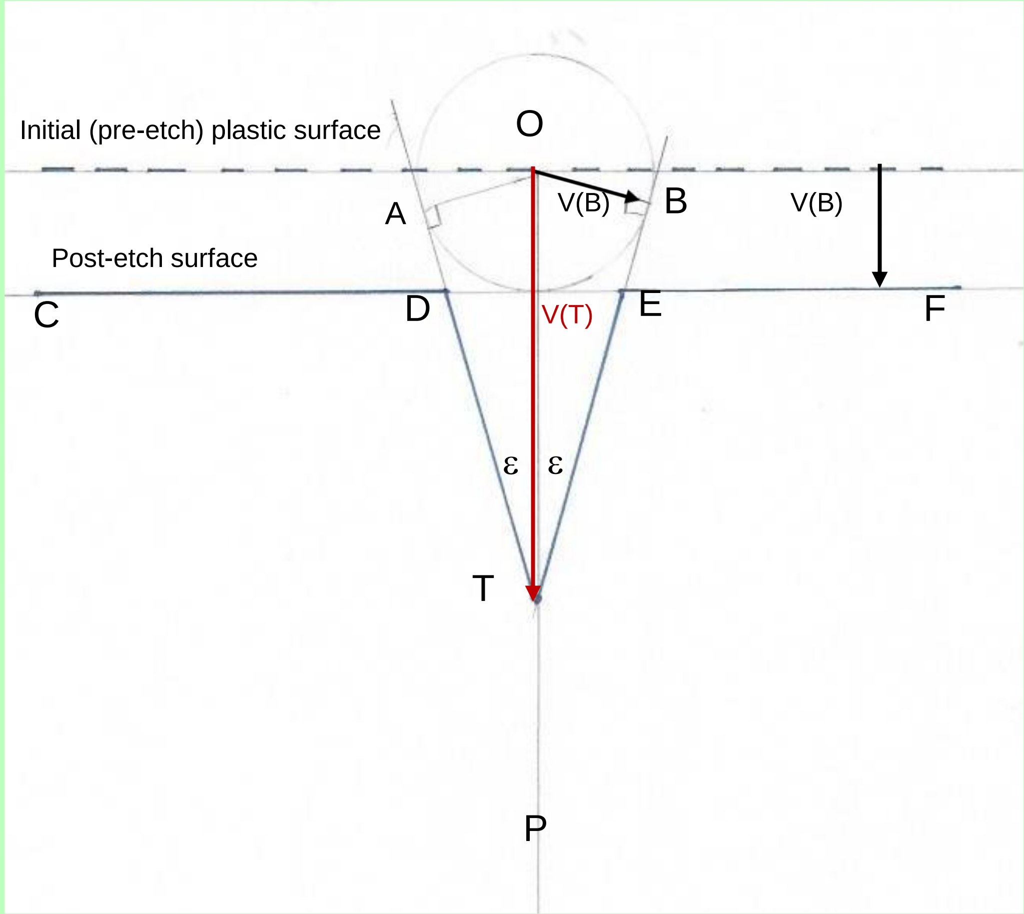
This means there is cut-off angle for revealing a track when:

$$V(t)\ \sin(\delta) \leq V(B)$$

However, track etch rates are not uniform along the trail of damage – see slide 8

How to draw an α-track etch cone

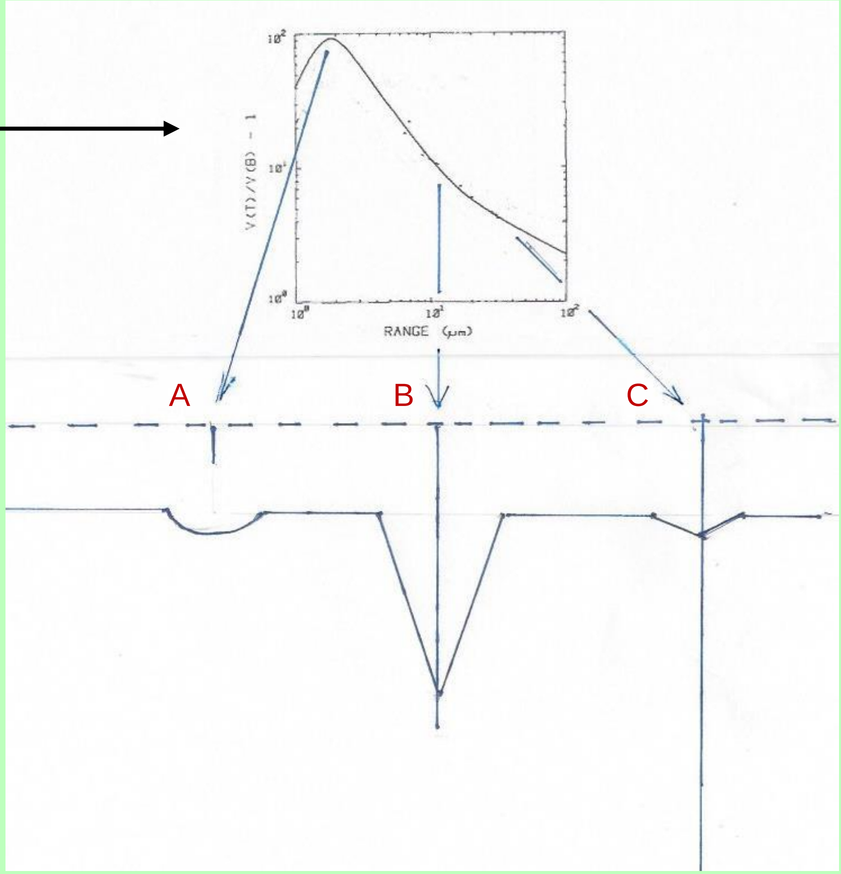
- Assume (i) that the plastic is etched for 1 hour; (ii) that the bulk etc rate is V(B) μm h^{-1} and that the track etch rate is V(T) μm h^{-1}
- Draw two parallel horizontal lines a distance V(B) apart representing the initial and post-etch plastic surface
- Draw a vertical line OP to represent the path of the α-particle at normal incidence in the plastic
- At point O describe a circle of radius V(B)
- Draw line OT to represent the track etch rate V(T)
- Sketch tangents to the circle TA and TB
- Firm in the line CDTEF. This represents the sectional view of the etch cone.
- Note that in this example, the cone half-angle is ε, where V(B)/V(T) = sin(ε)



High & low etch rate and short penetration α-particles

Etch rates along the track are not uniform

The graph shows the form of the track etch rate along α-particle tracks in TASTRAK. Its non-uniformity mimics the form of the energy loss rate (dE/dX) vs particle energy and residual range.



- Particle **A** has low energy and short penetration in the plastic. Under the etch conditions employed, only a spherical remnant of the etch track remains.
- Particle **B** has medium energy and penetration in the plastic. The track etch rate is relatively high along its path, resulting in a comparatively large etch cone.
- Particle **C** has high energy and penetration in the plastic. The track etch rate is relatively low along its path, resulting in a comparatively small etch cone.

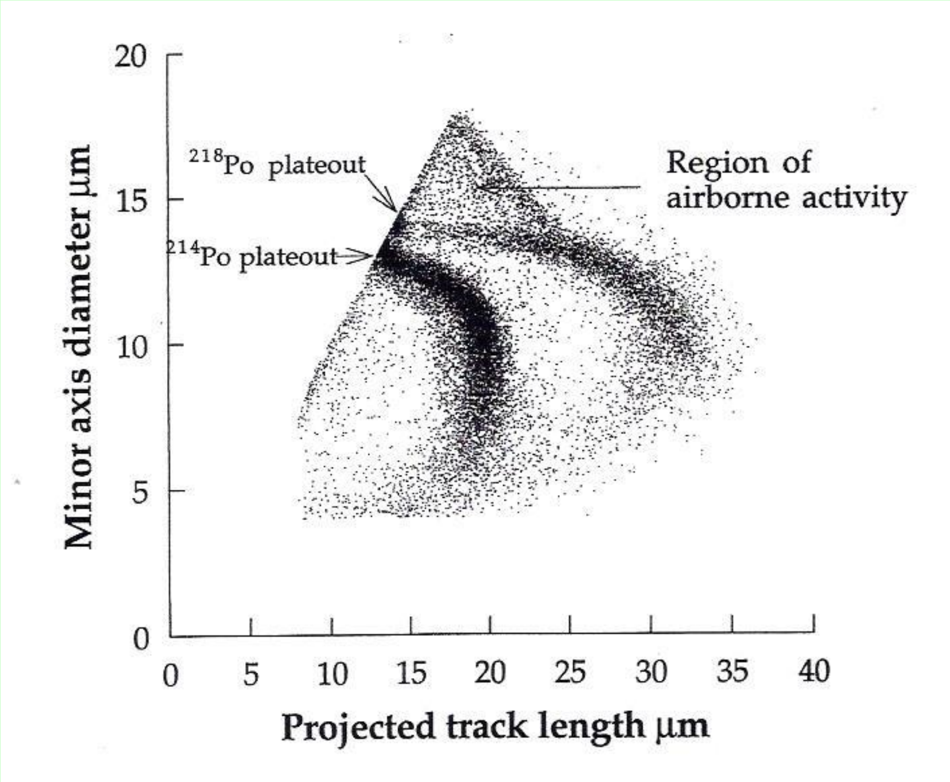
Photomicrograph of α-particle tracks in TASTRAK*

- In practice α-particles enter the plastic at a variety of dip angles and degree of penetration.
- In all cases the track structure can be simulated from the measured relationship between track etch rate and residual range/energy in the plastic shown in the previous slide.

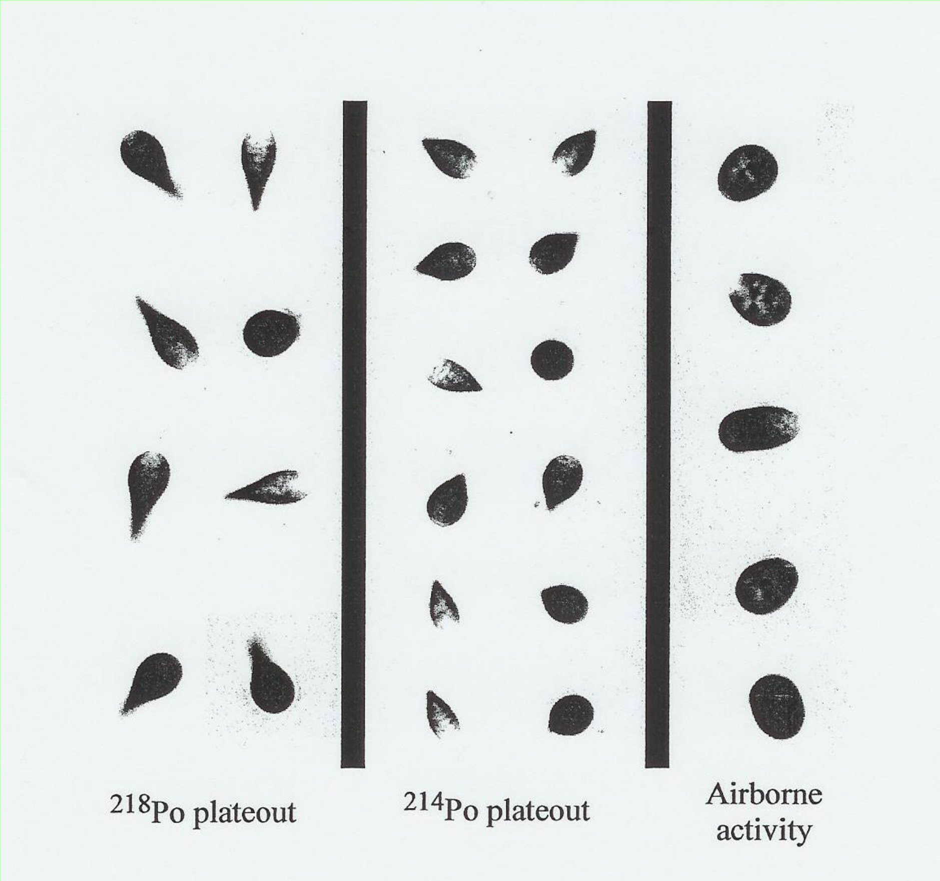
*Typical etch conditions:
1 h in 6.25 M NaOH at 98ºC
Solution s.g. 1.181

Track size acceptance envelope

- This is a plot of α-particle total projected track length as seen under the microscope vs the track minor axis diameter.
- All possible α-particle etch tracks fall into a well-defined envelope of sizes for the etch conditions employed.
- The "*Region of airborne activity*" represent α-particles emitted above and in the direction of the plastic surface but with sufficient residual range/energy in the plastic to result in an etch track.
- The bands *^{218}Po* and *^{214}Po* represent α-particle emissions at various dip angles from these radionuclides that have plated out on the plastic surface.

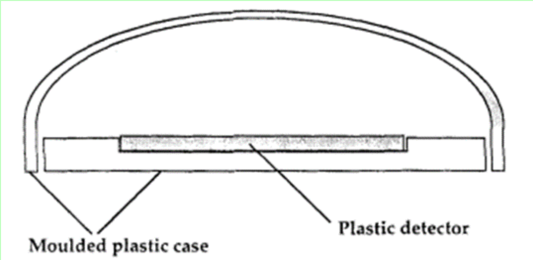


Examples of α-particle tracks from the size envelope in slide 10



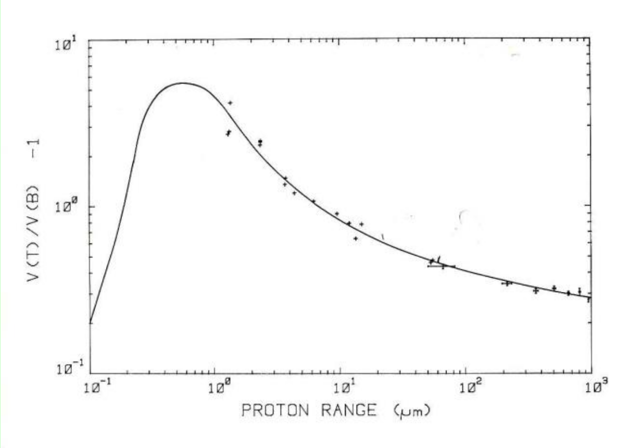
Description of the TASL "Radosure" radon detector

- The detector consists of a small plastic chamber housing a 2.5 x 2.5 cm TASTRAK plastic track detector.
- The chamber contains a small annular air gap, about 0.1 mm, through which radon (^{222}Rn), but not its short-lived decay products in the air, may pass.
- Radon inside the chamber may decay and a proportion of the emitted α-particles, including those from the subsequent short-lived decay products, ^{218}Po and ^{214}Po may be recorded in the plastic detector.

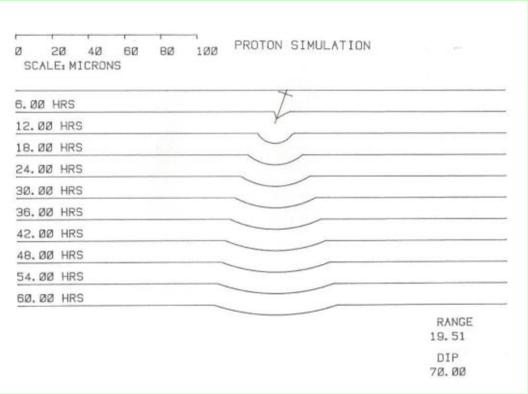


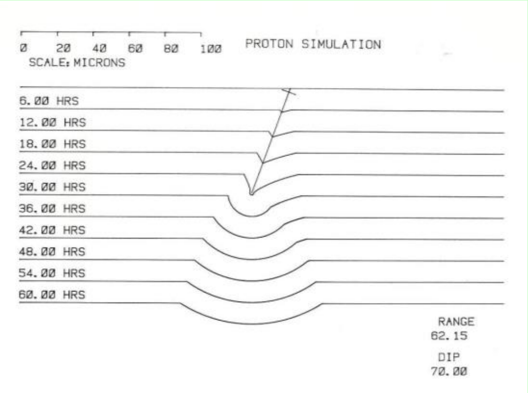
Part 2 – detection of protons – principal application: neutron dosimetry

Protons tracks in TASTRAK

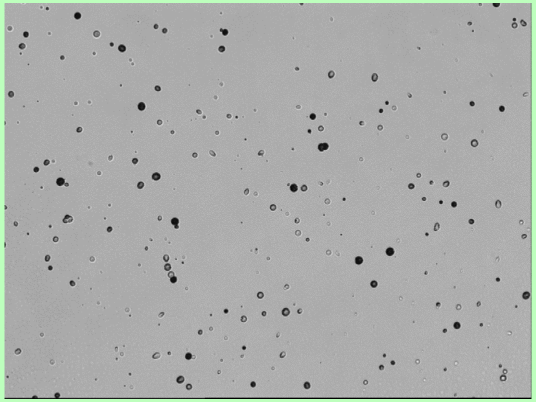


The etch rate ratio V(T)/V(B) is lower along proton compared with α-particle tracks



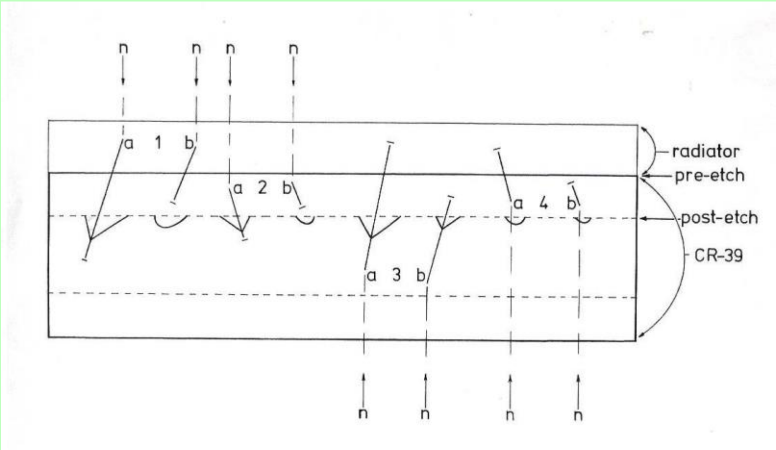


This is illustrated in these simulations of proton etch tracks: upper, 1 MeV; lower, 2 MeV

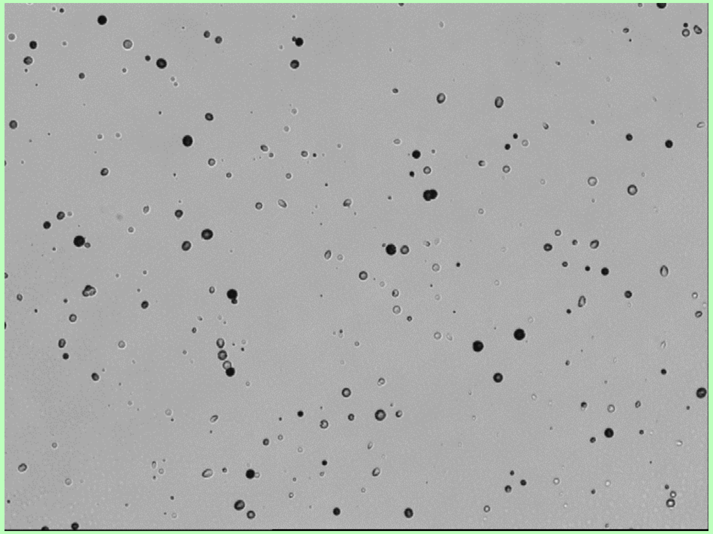


Etch tracks look very small under the microscope

Neutron dosimetry is based on detecting recoil proton tracks*



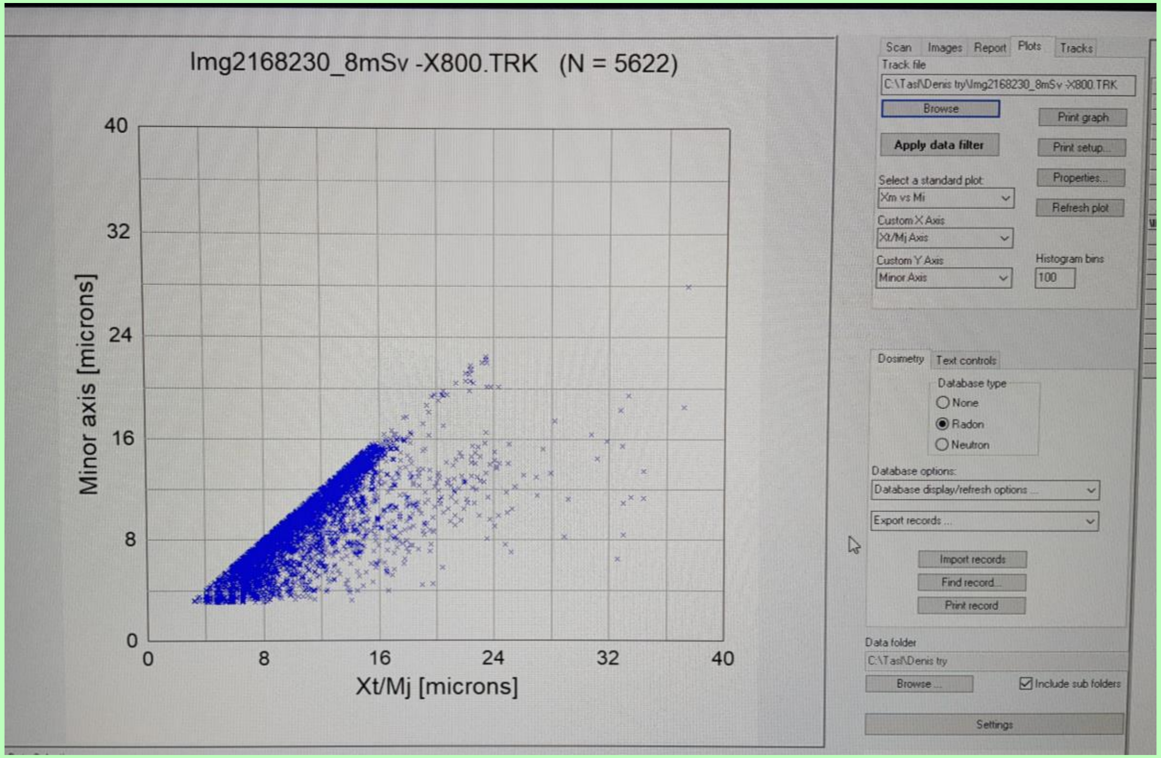
Such recoils can occur either in an overlying radiator or in the plastic itself, leading to a multitude of possible etch track shapes



As a result most etch tracks are small and appear circular under the microscope

*Recommended etch conditions: 2 h 50 mins in 6.25 M NaOH at 85ºC. Solution s.g. 1.184

Typical size envelope for tracks of recoil protons from fast neutron exposure



Note that the size envelope is
smaller than for α-particles

Part 3 – Use of the TASL*Image* analysis system

This will be explained by hands-on experience as part of the training session.

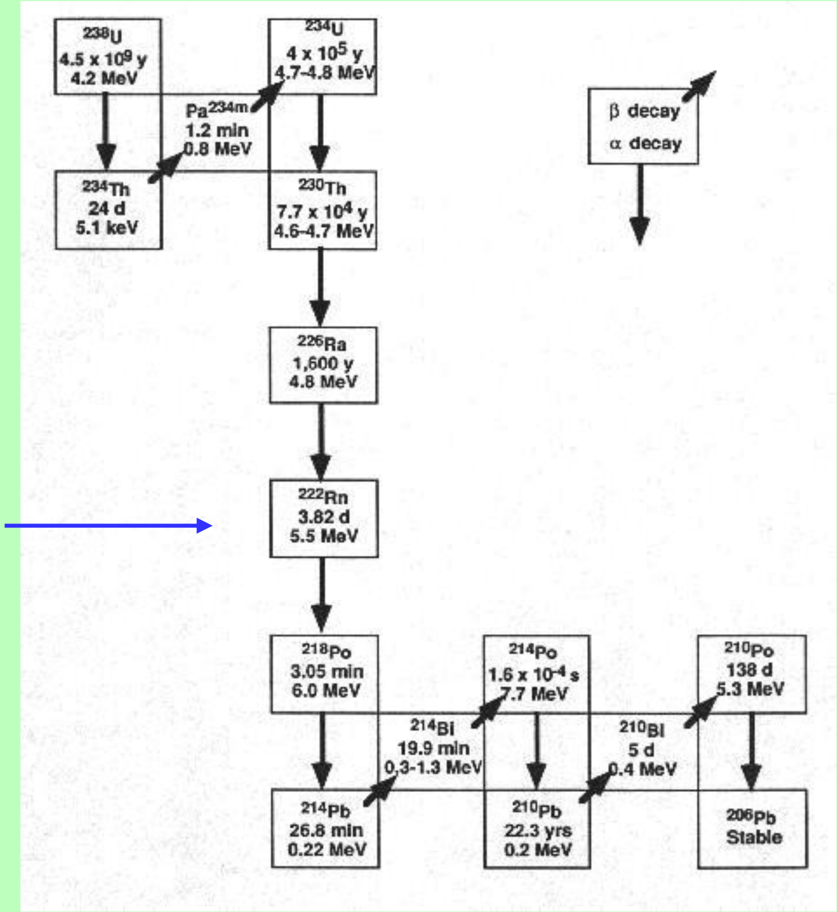
Readers should refer to the TASL*Image* manual on the system computer.

Appendix 1 – ^{238}U radioactive decay chain

^{222}Rn is the principal isotope of radon

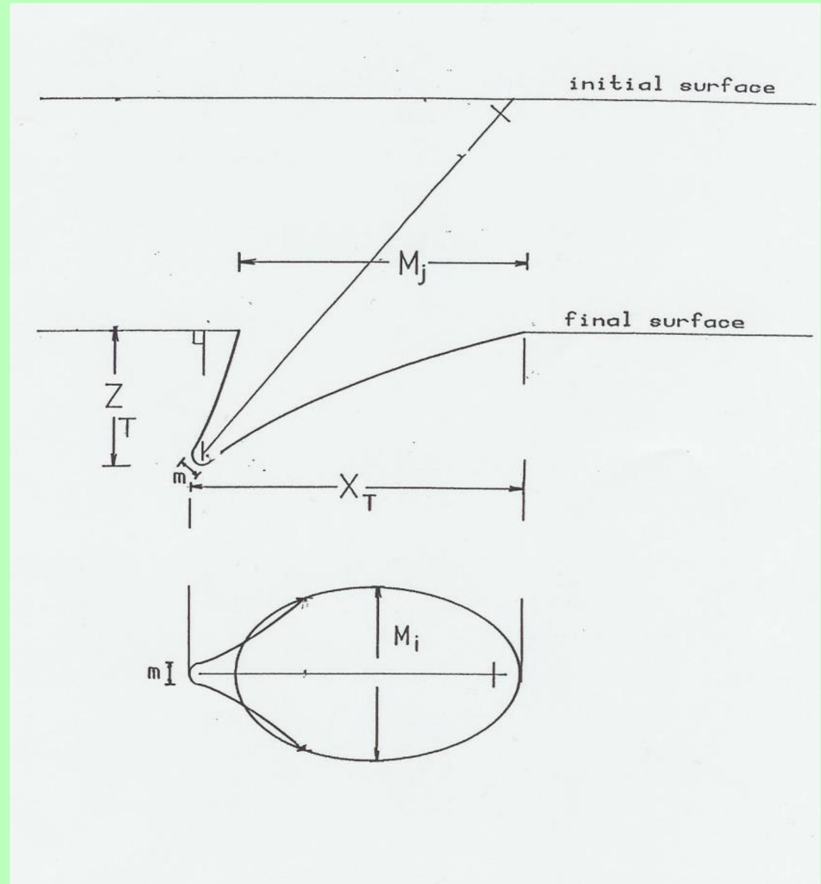
^{218}Po and ^{214}Po are the so-called α-emitting short-lived radon decay products.

^{210}Po is well decoupled from radon by the 22.3 year half life of ^{210}Pb



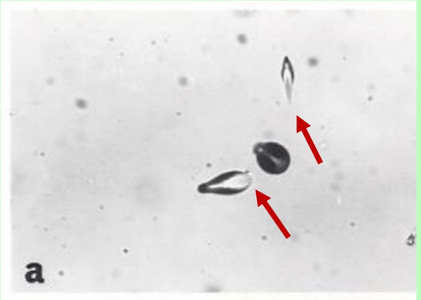
Appendix 2 - Measurable parameters on etch tracks (ideal geometry)

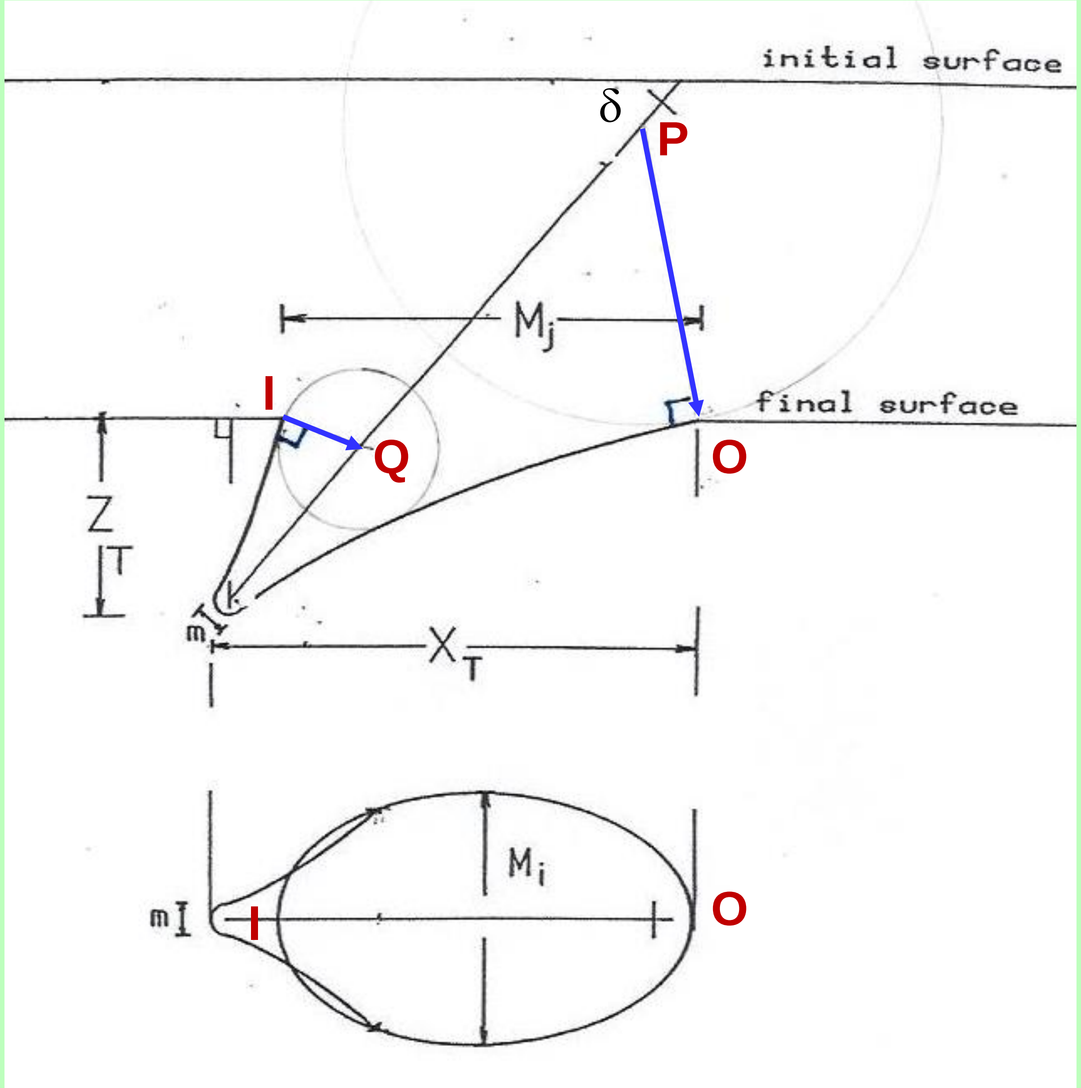
M_j = Major axis diameter
M_i = Minor axis diameter
X_T = total projected length
M = diameter of "etched-out" track end (where applicable)
Z_T = track depth (not measured by TASL*Image*)



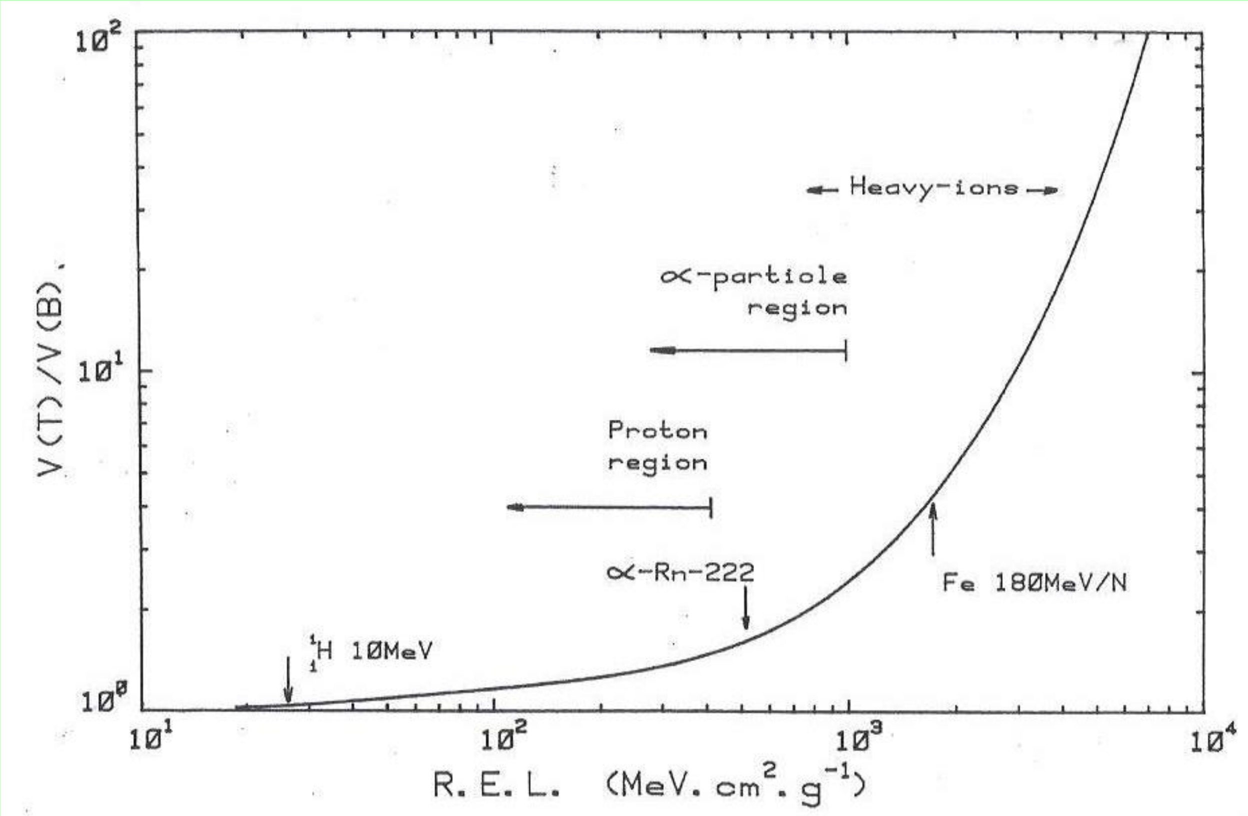
Appendix 3 - Etch tracks subtleties

- **Note:** On an inclined track with dip angle δ, the outer wall of the etch track at point O results from bulk etching from point P, but the inner wall at point I results from bulk etching from point Q, further towards the end of the α-particle range.
- From slide 8, the energy deposition rate (dE/dX) is higher at point Q than at point P.
- Depending on the dip angle, in contrast to point Q, point P may be below the threshold for track etching i.e. $V(T)\sin(\delta) \leq V(B)$
- This in turn explains the characteristic "pale ends" on the tracks arrowed below.





Appendix 4 - TASTRAK Response curve plotted as the ratio of track-to-bulk etch rate V(T)/V(B) vs restricted energy loss rate



Note that the α-particle response falls in the central portion of the response curve. In contrast, the proton response merges into the Ionisation threshold response. As a result, small changes in the threshold response can alter the response to the spectrum of recoil protons recorded in fast neutron dosimetry.

Appendix 5. NaOH Etch tank, acetic acid neutralisation tank and de-ionised/distilled water tank

WARNING !

Full protective clothing must be worn at all times, including eye protection and heavy gloves