Simulation of Neutron Dosimetry with CR-39 Track Detectors and Comparison against Experimental Campaigns

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Workshop: NWK3/RD1 – Radiation Protection and Dosimetry

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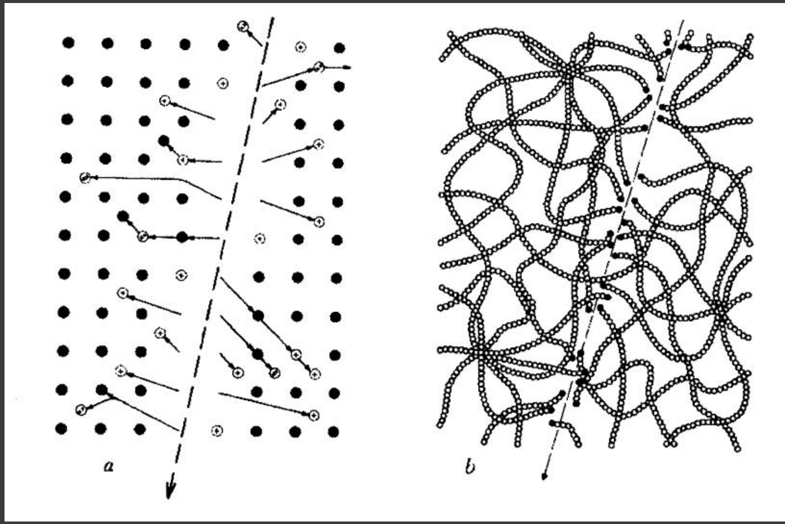
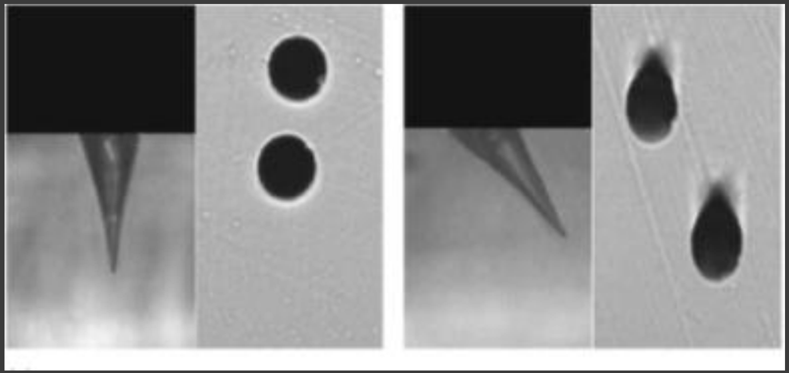
Outline

- Neutron dosimetry with CR-39 track detectors
- Irradiation in 0.5 to 100 MeV monoenergetic (PTB - Germany) and quasi-monoenergetic (Ithemba labs - South Africa) neutron beams
- Monte Carlo simulations and comparison with Experiments
- Conclusion & Perspectives

Neutron Dosimetry with CR-39 detectors





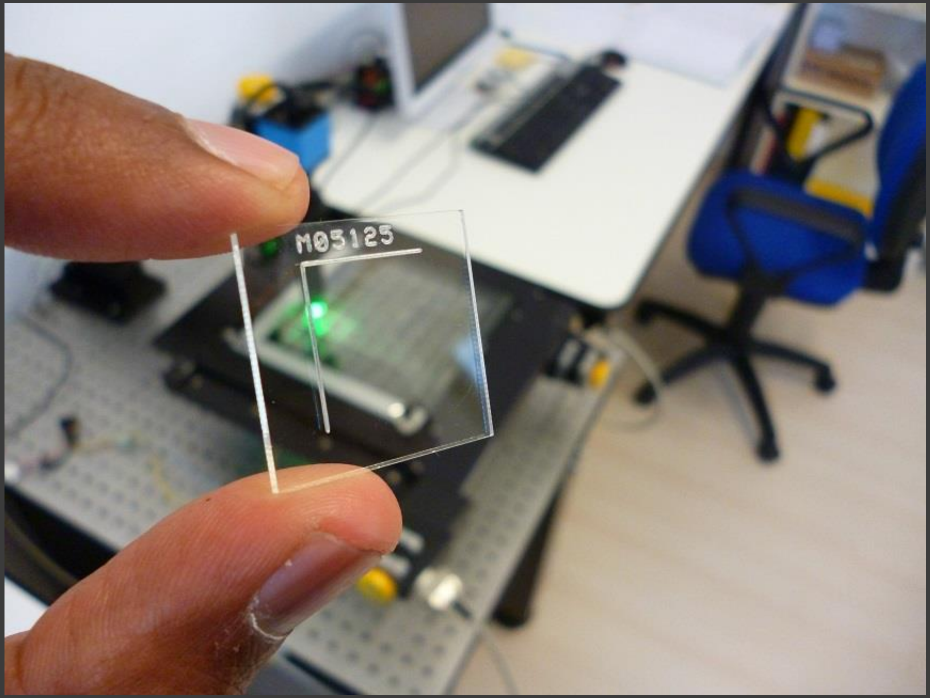
B. Dorschel et al. / Radiation Measurements 37 (2003) 563 – 571

Physics of track detectors

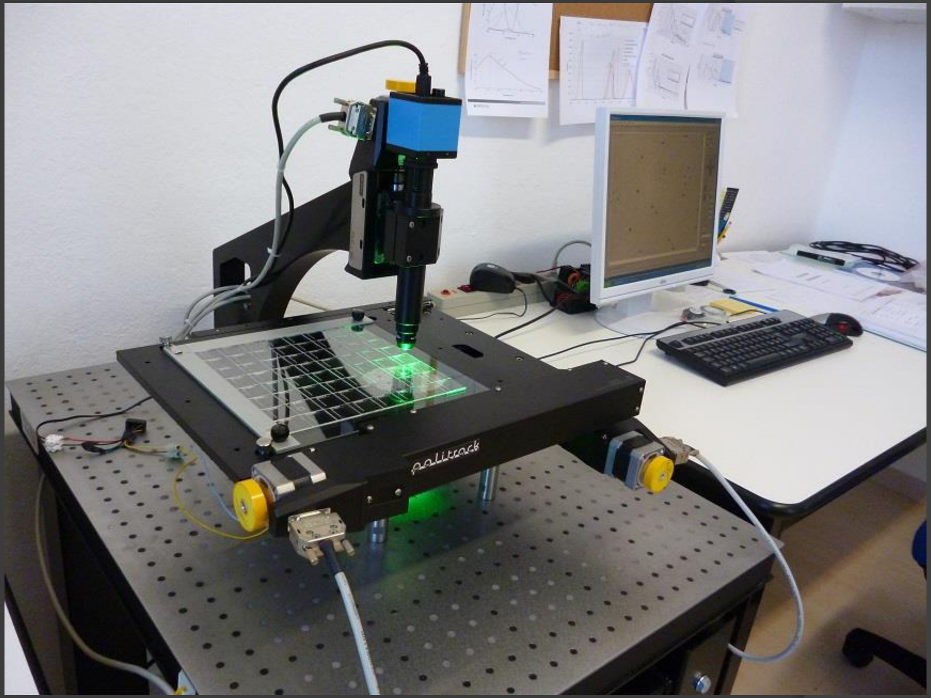
When an ionizing charged particle passes through a dielectric material the transfer of energy to electrons results in a trail of damaged molecules along the particle's track

The tracks can be made visible by etching in NaOH at 98°C for 90 minutes. The opening of the track is then of about 5-20 µm depending on the type and energy of the hadrons

Neutron Dosimetry with CR-39 detectors



Intercast® CR-39 track detector

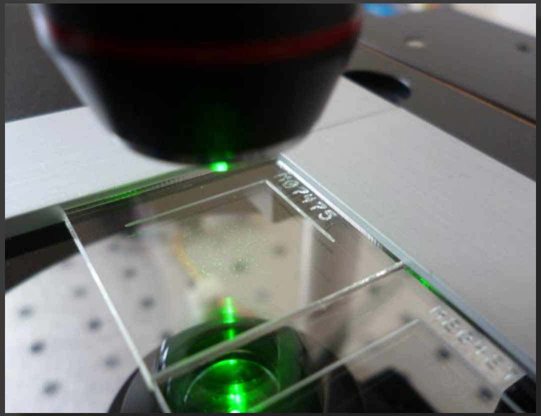


Politrack™ automatic CR-39 reader

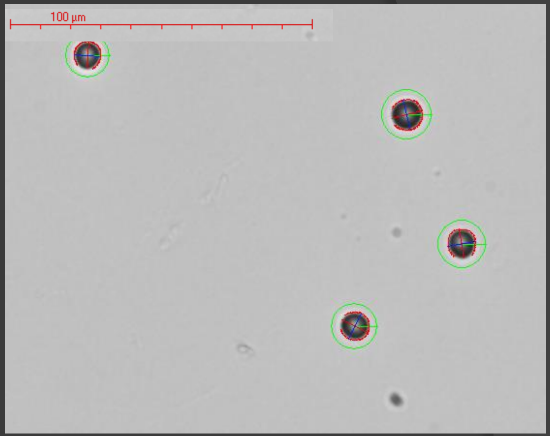
Neutron Dosimetry with CR-39 detectors

CR-39 detector analysis with POLITRACK™

- Automatic counting and geometrical analysis of the tracks (a)
- Track filtering (account for dust particles or surface defects) (b)
- V_t and LET_{nc} and impinging angle determination (c)
- LET_{nc} distribution (d)



(a)



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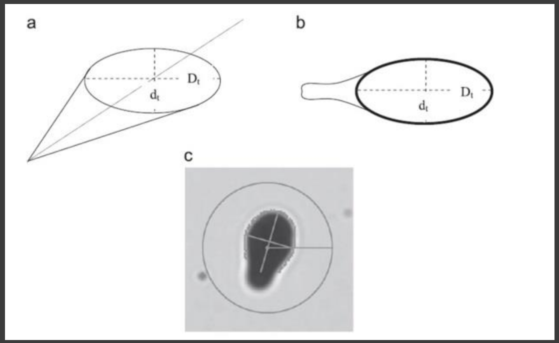
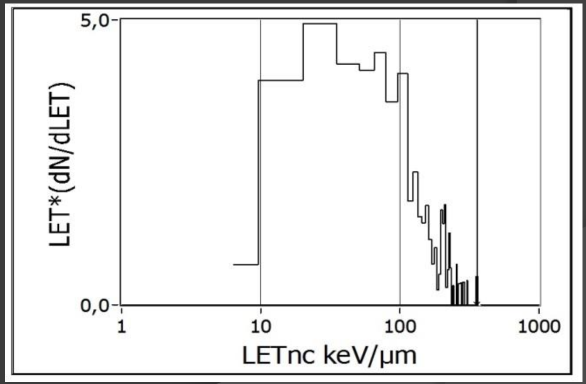


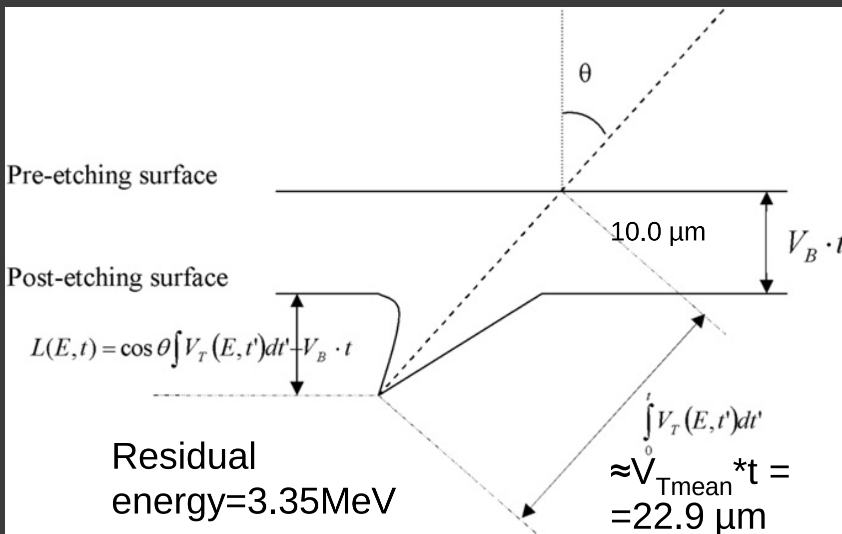
(c)



(d)

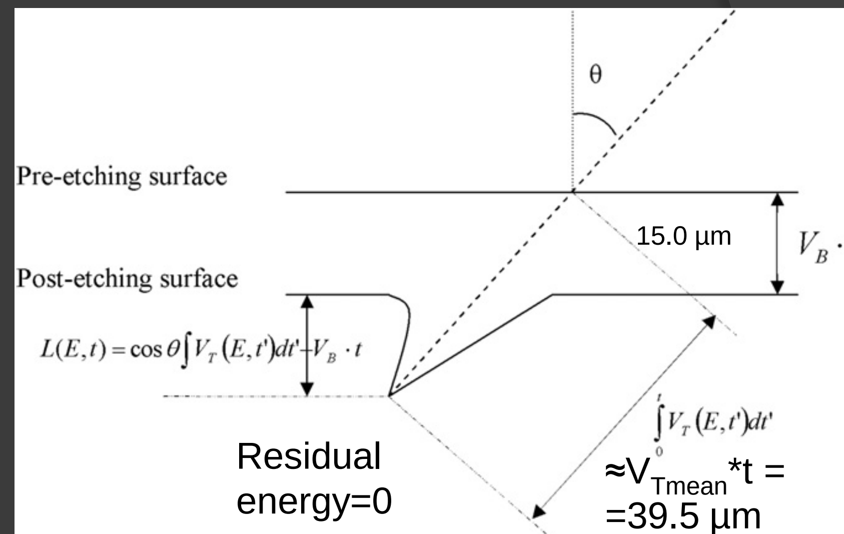
What is LET_{nc} measured in CR-39?

Etching time 60 min
Alpha energy 6.1 MeV (Cf-252)



$$LET_{nc} = \frac{E_i - E_r}{x} = \frac{6100 - 3350}{22.9} = 120\left[{keV}/{\mu m}\right]$$

Etching time 90 min
Alpha energy 6.1 MeV (Cf-252)



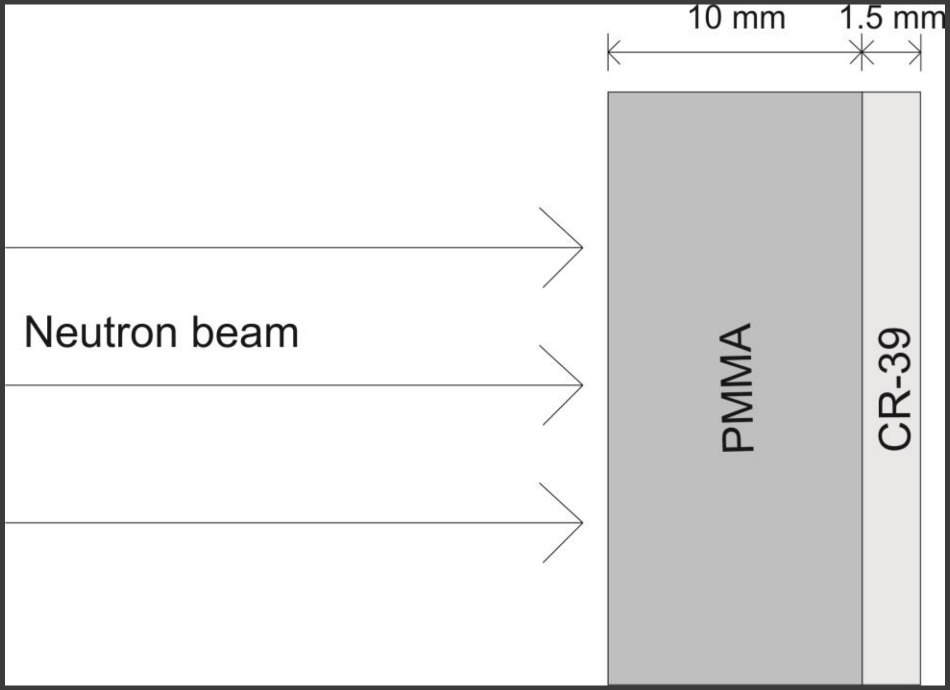
$$LET_{nc} = \frac{E_i - E_r}{x} = \frac{6100 - 0}{39.5} = 154\left[{keV}/{\mu m}\right]$$

LET_{nc} is also commonly referred to as the mean LET.

Uses of CR-39 track detector

- Personal dosimetry
  - Routine dosimetry in nuclear facilities
  - Hadrontherapy centers for oncology
- Ambient dosimetry
  - Stray radiation around particles accelerator
    - CERN, Paul Scherrer Institute (PSI), etc.
  - Complex radiation fields
    - In Space: International Space Spation (ISS)
    - Cosmic rays: aboard commercial aircrafts
- Advantages:
  - Cheap, easy to use, convenient size to mount as a dosimeter

Irradiation in 0.5 to 100 MeV neutrons



In the PMMA radiator, the type of secondary particles produced is strongly dependent on the neutron beam energy (E_n):

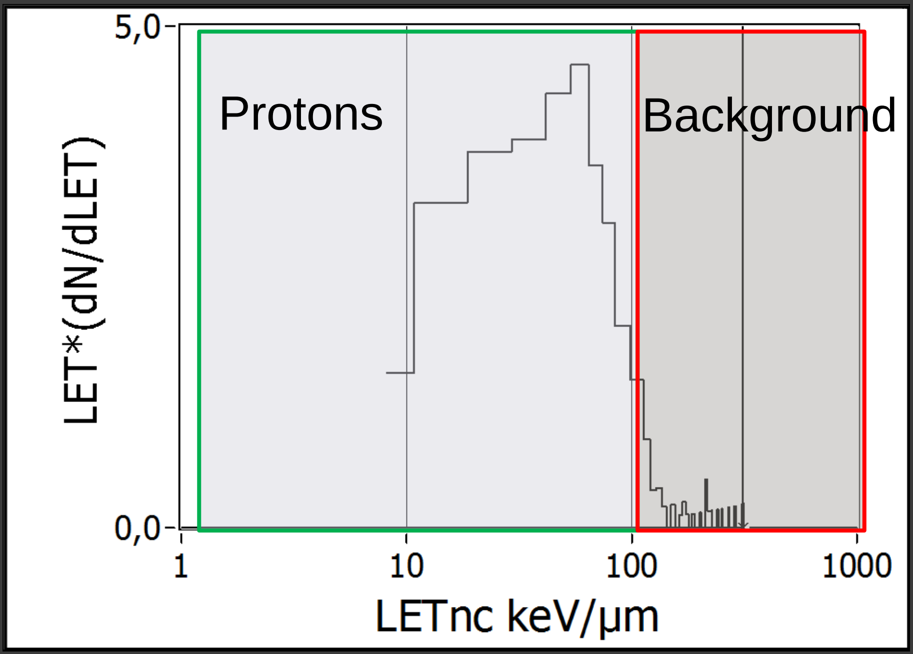
- E_n < 10 MeV : (n,p) reactions
- E_n > 10 MeV : (n,p) reactions
  + (n,α) reactions
  + (n,d) reactions
  + (n,t) reactions

http://www.oecd-nea.org/janis/

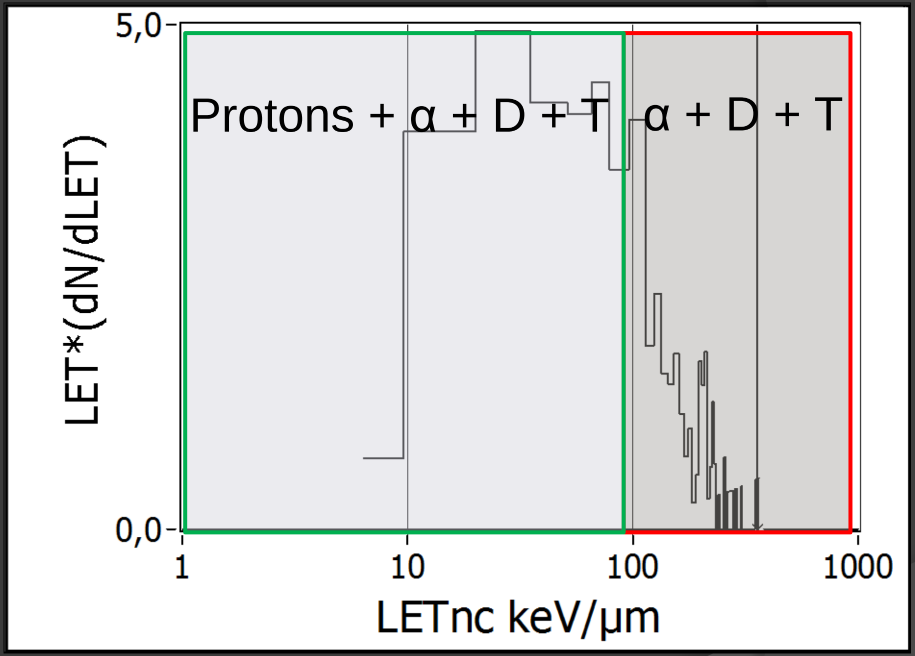
Fragmentation of O and C atoms due to inelastic scattering as the neutron cross section becomes non-negligeable for E_n > 10 MeV

LET$_{nc}$ measured in CR-39 detectors

8 MeV neutron beam



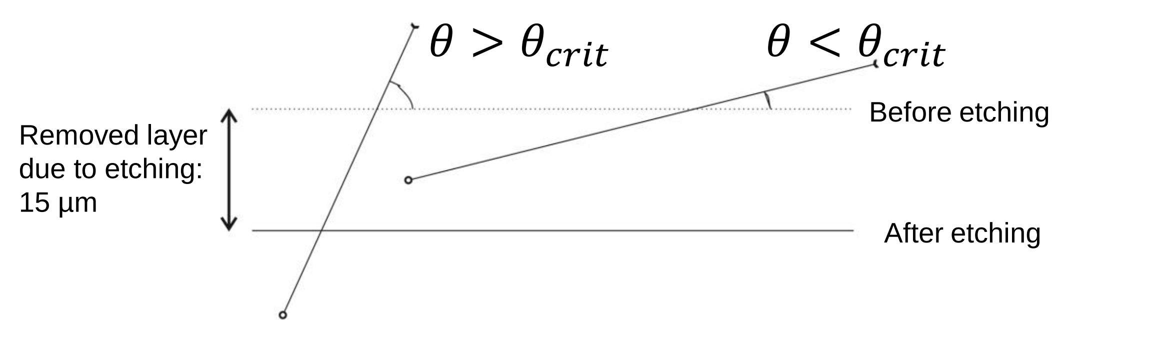
100 MeV neutron beam



Protons delivering the dose for LET < 100 keV/µm and heavier hadrons delivering the dose for LET > 100 keV/µm

Irradiation in 0.5 to 100 MeV neutrons

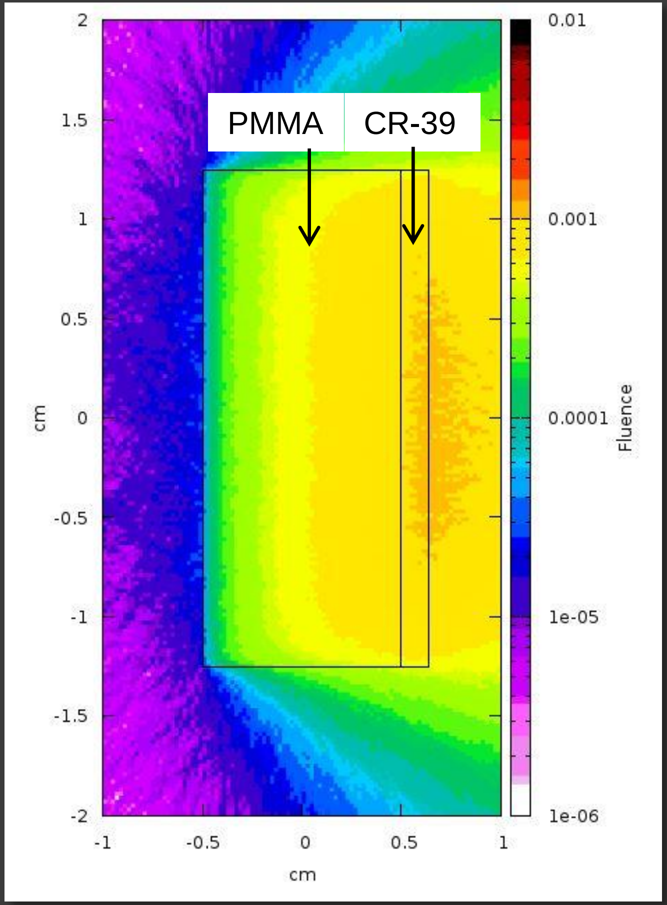
Beam	Measured Dose (mSv)	Reference Dose(mSv)	Detector Response
PTB 565 KeV	1.79	3.67	0.49
PTB 8 MeV	1.75	4.90	0.36
PTB 14 MeV	3.49	6.90	0.51
PTB 19 MeV	1.84	2.90	0.64
iThemba 66 MeV 0°	2.38	4.44	0.54
iThemba 66 MeV 16°	1.72	3.20	0.54
iThemba 100 MeV 0°	1.52	2.36	0.64
iThemba 100 MeV 16°	1.75	2.83	0.62
Average Sensitivity			0.54 ± 0.09

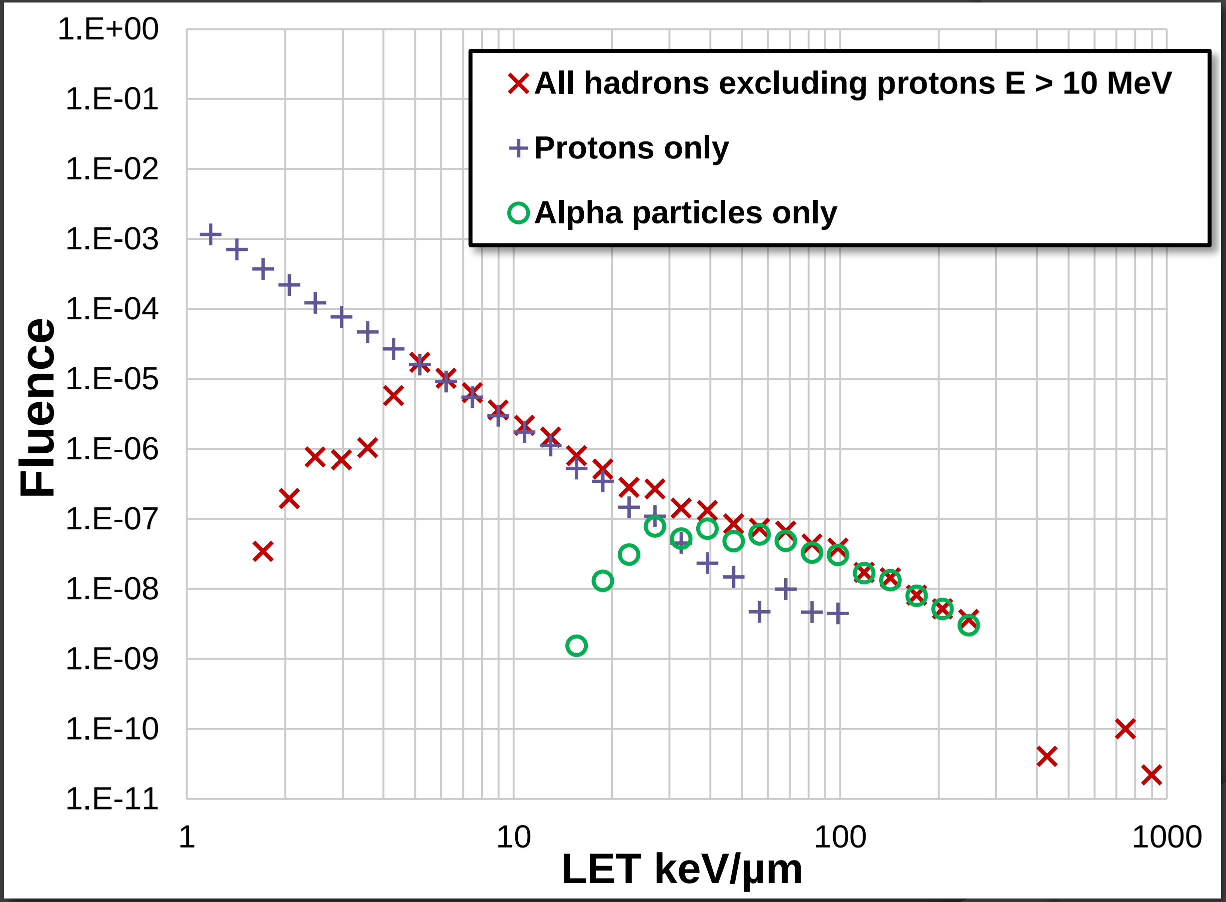


- Etching removes the first 15 µm of the surface of the detector.
- Around 50% of the dose is not measured because:
  - Hadrons impinging at a low angle with respect to the detector surface are not detected due to etching.
  - Hadrons having a low LET, e.g. protons with energy > 10 MeV are not detected due to etching
- Yet, a stable response of 0.54 ± 0.09 is measured for the whole range of neutron energies

Caresana, M., Ferrarini, M., Parravicini, A., Sashala Naik, A. *Evaluation of a Personal and Environmental Dosimeter based on CR-39 Track Detectors in Quasi-Monoenergetic Neutron Fields*. Radiat. Prot. Dosim., submitted in the proceeding of Neudos12 conference

Simulated LET distribution with FLUKA

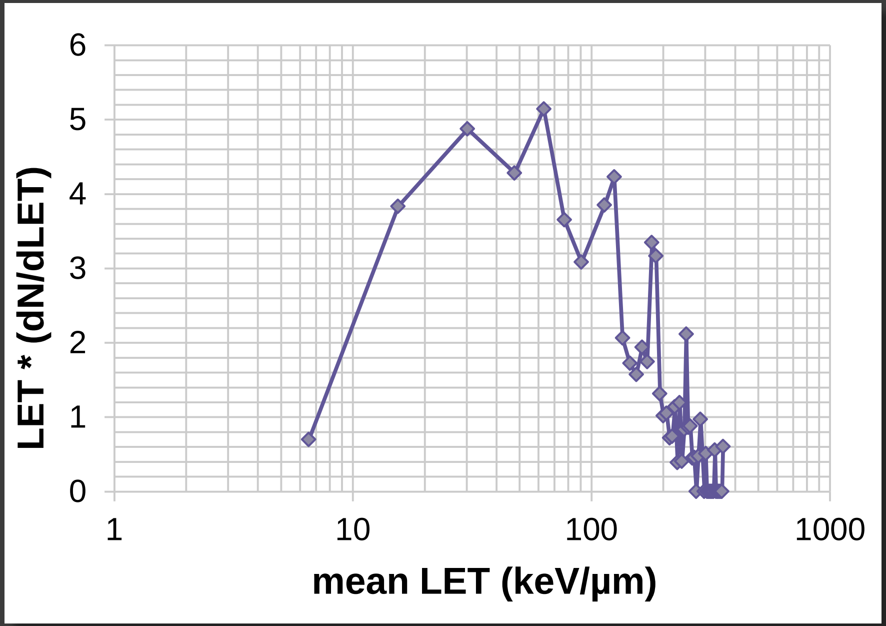




LET distribution obtained using FLUKA for <u>100 MeV neutrons</u>: the LET plot illustrates the dose contribution due to the different types of secondary particles produced in the PMMA

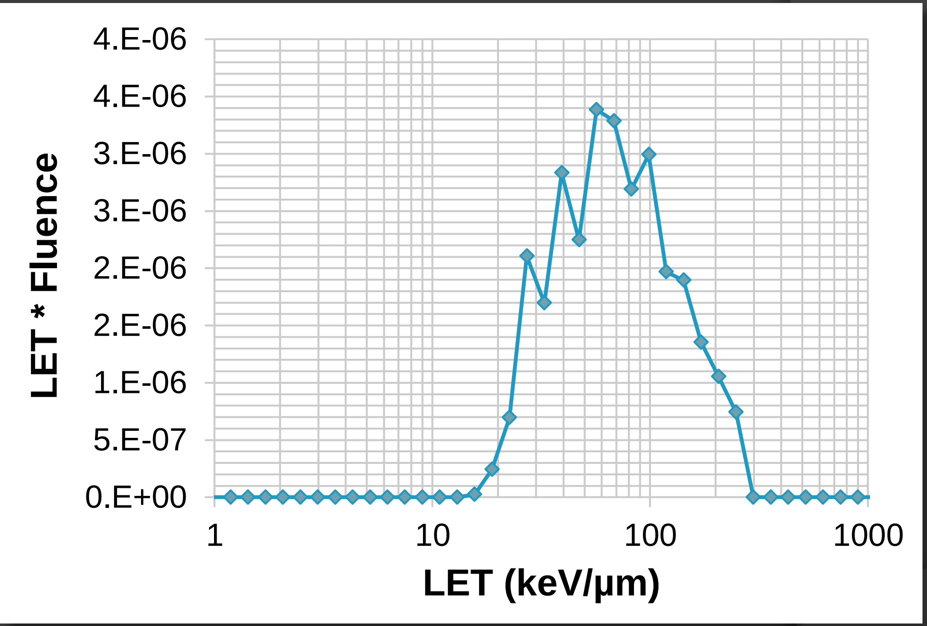
Comparison using irradiation in 100 MeV neutrons

Measured LET_{nc} in CR-39



Measured mean LET spectrum

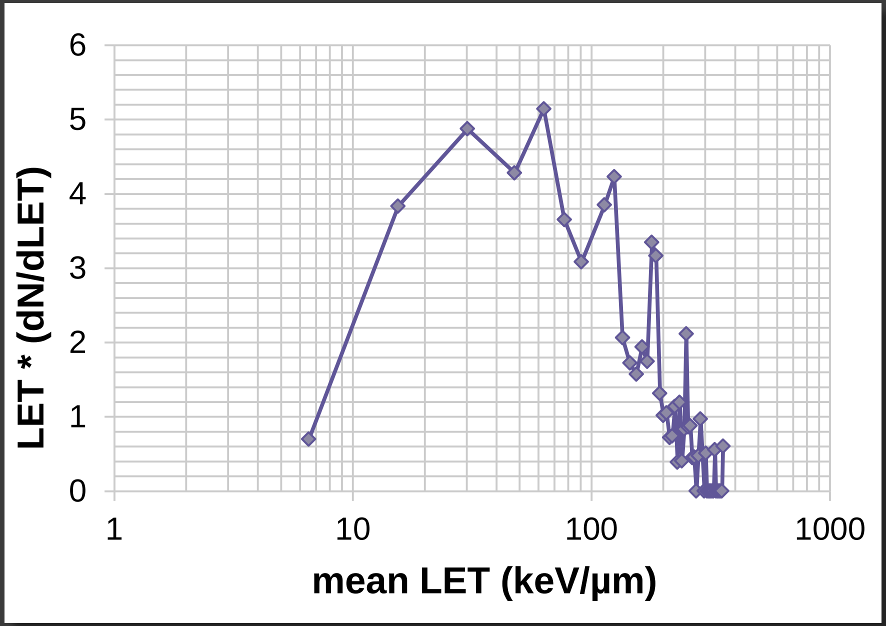
Simulated LET in CR-39 with FLUKA



Alpha particles LET spectrum from FLUKA

Comparison using irradiation in 100 MeV neutrons

Measured LET_{nc} in CR-39



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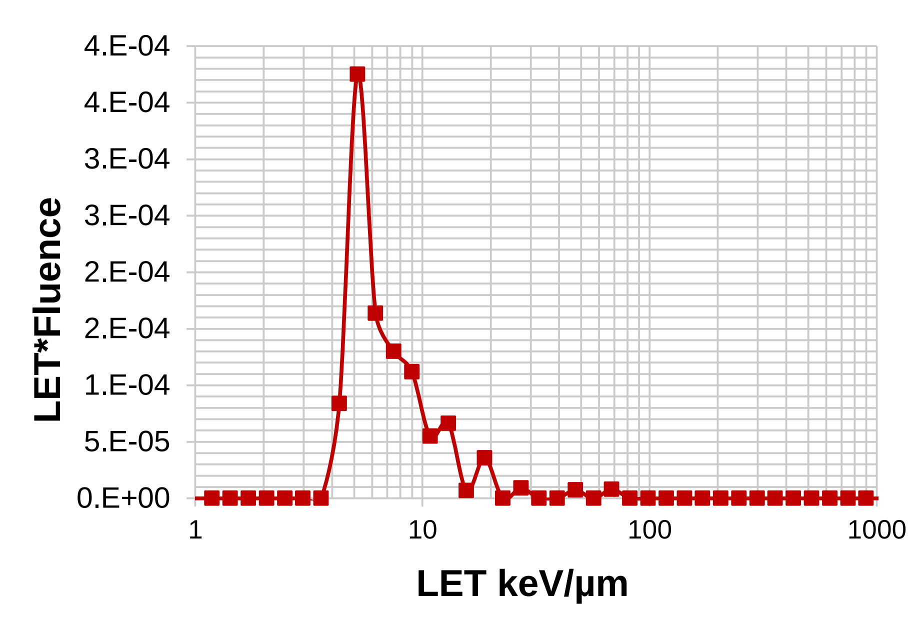

Protons LET spectrum with a cut to protons higher than 10 MeV in a 10° cone normal to the detector

Monte Carlo simulations for neutron dosimetry (FLUKA)

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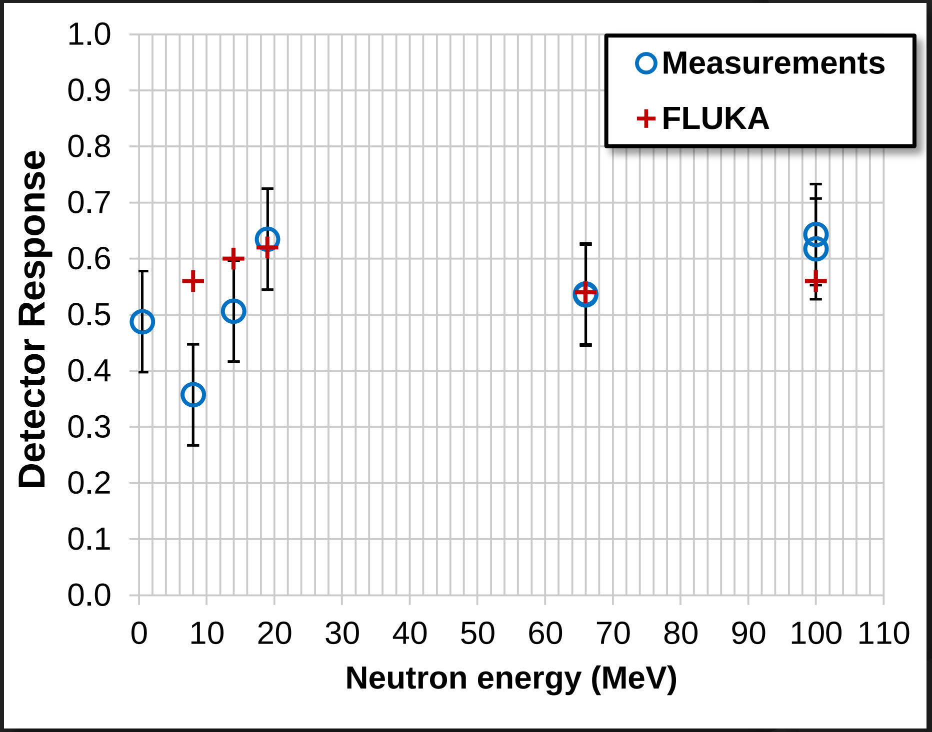

When looking at the energy deposited at the surface of the detector, where the tracks are produced, a simulated response close to the measured response can be found when removing the dose contribution from the particles that are not detected in CR-39.

Conclusion & Perspectives

- More calibration points at IRSN (lower + intermediate energies) and Los Alamos (higher energies) to have more experimental data
- More issues regarding the detection limit caused by etching have to be taken into account in the simulations in order to improve the LET comparison between experiments and simulations
- Evaluate the angular dependence of the detection system with a PuBe source at CERN and verify results against Monte Carlo simulations (MCNPX and FLUKA)

THANK YOU FOR YOUR ATTENTION!

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