PERSONAL & ENVIRONMENTAL DOSIMETRY WITH A DOSEMETER BASED ON CR-39 SSNTD IN QUASI-MONOENERGETIC NEUTRON FIELDS

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1) Calibration facilities used for neutron irradiation

PTB (Germany)

The irradiations were performed in air, i.e. without phantom at the following ISO reference mono-energetic neutron beams listed in table 1.

Reaction	$\langle E_n \rangle$ MeV	ΔE MeV	Target	dϕ/dt $cm^{-2} \cdot s^{-1}$	ϕ_{sc}/ϕ %	$dH^*(10)/dt$ $mSv \cdot h^{-1}$
$^7Li(p,n)^7Be$	0.565	0.015	LiOH	$1.2 \cdot 10^3$	1.8	1.5
$^2H(d,n)^3He$	8.0	0.2	D_2-gas	$1.9 \cdot 10^4$	<1.0	27.5
$^3H(d,n)^4He$	14.8	0.431	Ti(T)	$1.3 \cdot 10^4$	3	24.2
$^3H(d,n)^4He$	19.0	0.3	Ti(T)	$1.3 \cdot 10^4$	1.2	1.8

Table 1. Data on the monoenergetic neutron fields produced using solid-state targets and deuterium gas target.

Ithemba labs (South Africa)

The iThemba Laboratory (iTL) for Accelerator-Based Sciences can produce quasi-monoenergetic neutrons ranging from 25 MeV to 200 MeV through $^7Li(p,n)^7Be$ reaction on a thick Li target (6mm). The neutron beam is 10cm×10cm wide and the irradiations where done at 0° and 16° with respect to the direction of the beam. The neutron spectra used for the irradiations are shown in Figure 1 (b) and (c).

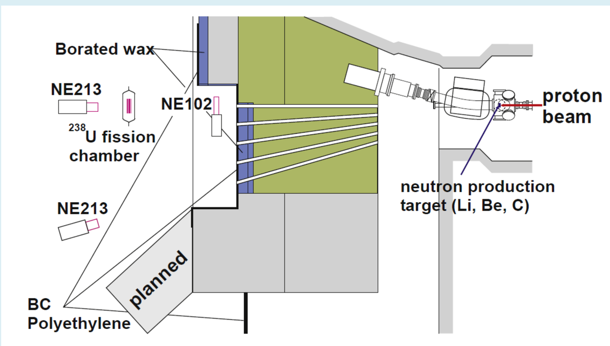

Fig 1(a). Top view of the iTL calibration facility showing a quasi-monoenergetic neutron source. The NE213 detector is drawn at 0° and 16° representing the positions of the PADC detectors.

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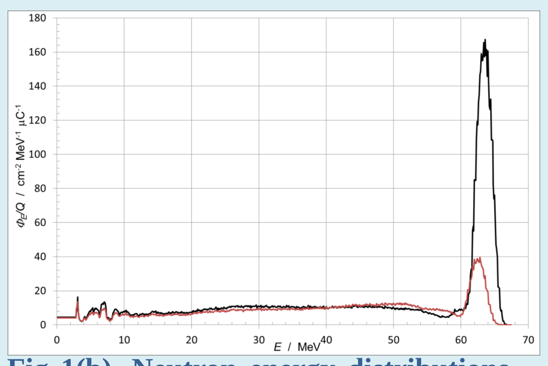


Fig 1(b). Neutron energy distributions of fluence for incident proton energy of 60 MeV at 0° (black) and 16° (Red)

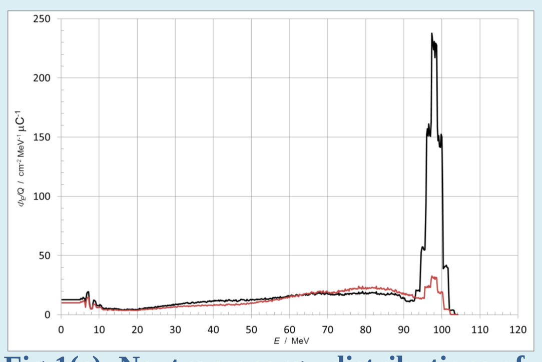


Fig 1(c). Neutron energy distributions of fluence for incident proton energy of 100 MeV at 0° (black) and 16° (Red)

2) Materials

The detection system consists of a CR-39 SSNTD (Solid State Nuclear Track Detector) covered with 1 cm of a PMMA radiator. Tracks in the PADC (Poly Allyl Diglycol Carbonate) detector are produced either by recoil protons and heavy particles produced by neutron interaction in the PMMA radiator and in the CR39 itself. This setup can be successfully used to measure high-*LET* particles.

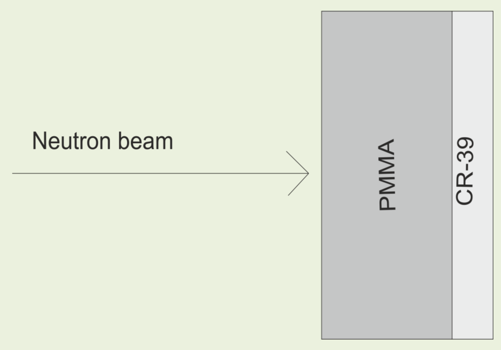


Fig 2. Layout of the passive detection system.

The etched plastics were then analysed using a commercial reader (Politrack) developed by the Polytechnic of Milan and Mi.am srl. The reader is an optical microscope having a 1024×768 pixel CCD camera with a spatial resolution of 0.37 µm. The system consists of a software which simultaneously drives the motorised plate that moves the detector under the microscope objective and performs the on line image analysis of the captured frames.

3) Track Analysis and LET determination

The track detectors were exposed to the neutron beams described in section 1. They were later etched for 90 minutes in a 6.25 mol aqueous NaOH solution at 98 °C in order to reveal the nuclear tracks. This etching time exhibits the best compromise in term of sensitivity and background reduction (more details in section 5).

As shown in Fig. 3, the ratio *V* between the track attack velocity and the bulk attack velocity, as well as the impinging angle θ are calculated from the track image parameters measured using the Politrack automatic detector reader, i.e. from the major (D) and minor (d) axes of the track opening measured for each track. D and d are measured by calculating the elliptical fit of the track opening (Figure 3c).

V=f(D,d)

The ratio *V* is a function of the mean *LET* of the particle: $V=Vt/Vb=f[LET_{mean}(E,x)]$

The *LET* can be measured by inverting the above equation. Figure 3d shows an example of mean *LET* distribution

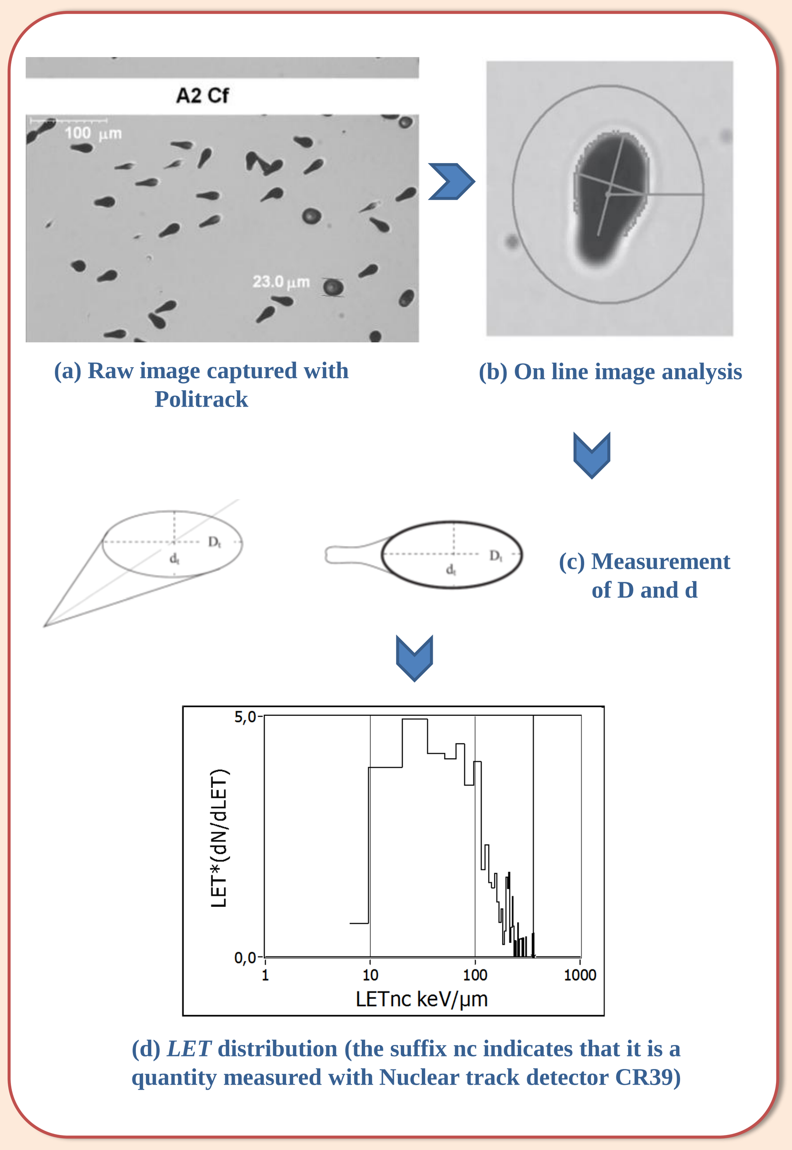
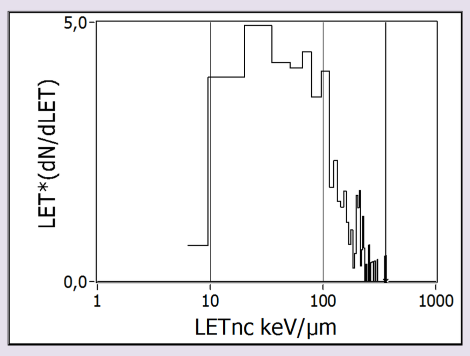
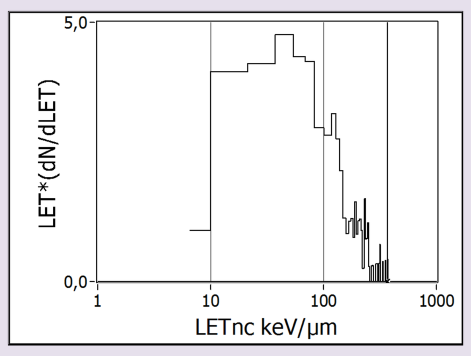


Fig 3. Example of *LET* determination from track image parameters

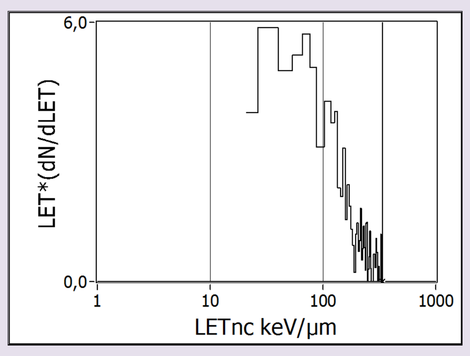
4) LET distributions



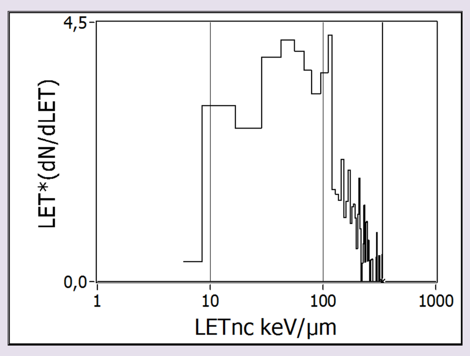
100 MeV 0° Dose in CR39=1,43 mSv
Dose<100KeV/µm = 0,68
Dose>100KeV/µm = 0,75
Ratio=1.1 (Dose>100keV/µm)/(dose<100keV/µm)



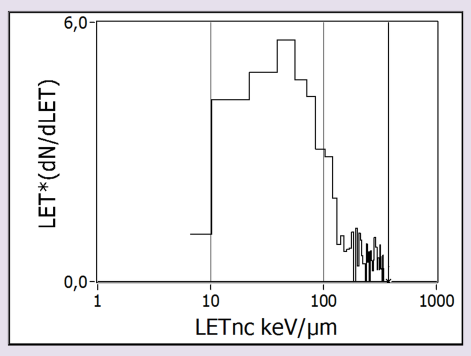
100 MeV 16° Dose in CR39=1,82 mSv
Dose<100KeV/µm = 0,8
Dose>100KeV/µm = 1.02
Ratio=1.2 (Dose>100keV/µm)/dose<100keV/µm)



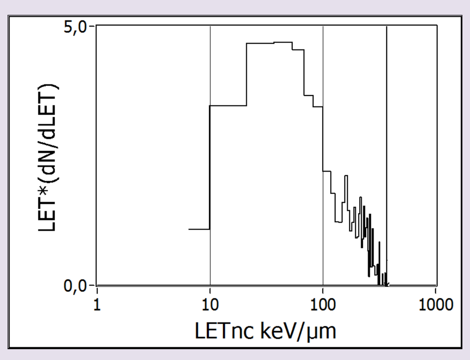
66 MeV 0° Dose in CR39=2.87 mSv
Dose<100KeV/µm = 1,25
Dose>100KeV/µm = 1.7
Ratio=1.36 (Dose>100keV/µm)/(dose<100keV/µm)



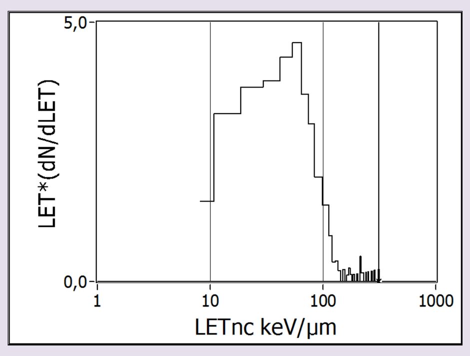
66 MeV 16° Dose in CR39=1,7 mSv
Dose<100KeV/µm = 0,76
Dose>100KeV/µm = 0,94
Ratio=1.24 (Dose>100keV/µm)/(dose<100keV/µm)



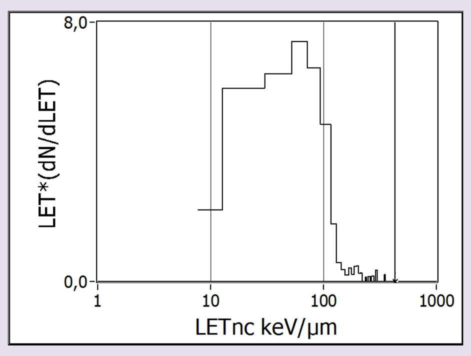
19 MeV Dose in CR39=2.03 mSv
Dose<100KeV/µm = 1,02
Dose>100KeV/µm = 1.01
Ratio=1.00 (Dose>100keV/µm)/(dose<100keV/µm)



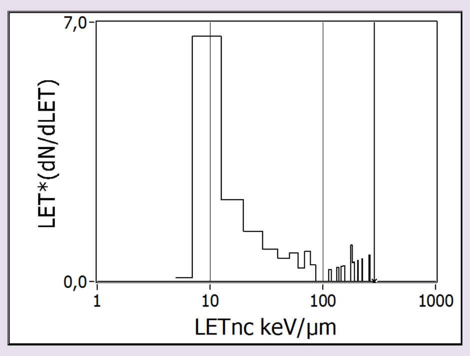
14.8 MeV Dose in CR39=2.2 mSv
Dose<100KeV/µm = 1,2
Dose>100KeV/µm = 1.0
Ratio=1.20 (Dose>100keV/µm)/(dose<100keV/µm)



8 MeV Dose in CR39=1.78 mSv
Dose<100KeV/µm = 1,58
Dose>100KeV/µm = 0.2
Ratio=0.12 (Dose>100keV/µm)/(dose<100keV/µm)



0.565 MeV Dose in CR39=1.95 mSv
Dose<100KeV/µm = 1,61
Dose>100KeV/µm = 0.34
Ratio=0.2 (Dose>100keV/µm)/(dose<100keV/µm)



Background dose in CR39=0.25 mSv
Dose<100KeV/µm = 0.07
Dose>100KeV/µm = 0.18
Ratio=0.9 (Dose>100keV/µm)/(dose<100keV/µm)

Comparison among the *LET* distributions at different neutron energies. For energies lower than 14 MeV, the high *LET* component (*LET*>100 keV/µm) is comparable with the background. The detectors meant for measuring the background show a subsequently high dose as the batch used was about 3 years old and had suffered from radiation produced by cosmic ray particles.

5) Detector sensitivity to fast neutrons

The response function of the detector is calculated with the following equation. It represents an approximation because the ICRP Q factors are not valid in the plastic detector.

$$H = \frac{1}{\rho} \times 1.602 \times 10^{-6} \cdot \sum_{i=1}^{n} \frac{\overline{LET}_i}{\cos\theta_i} Q(\overline{LET}_i)$$

$\overline{LET}_i$ is the average LET expressed in $keV.\mu m^{-1}$, ρ is the polymer density expressed in $g.cm^{-3}$, θ_i is the particle impinging angle with respect to the normal to the detector surface and $Q(\overline{LET}_i)$ is the ICRP quality factor. The numerical factor permits to obtain the dose equivalent H expressed in mSv.

The calculation of H with the above equation underestimates H*(10) as the track detector cannot detect particles with a low dip angle or protons with energy above about 10 MeV. Nevertheless the underestimation is about a factor 2 over a very wide neutron energy range (refer to table 2 and figure 4).

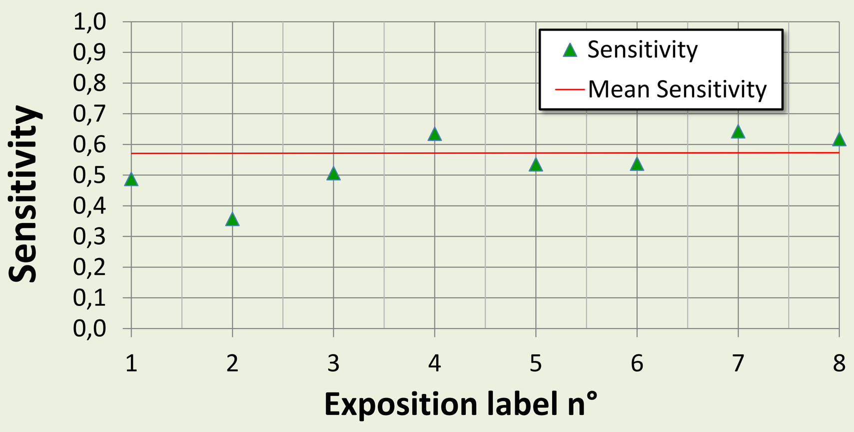


Fig 4. Detector sensitivity variation with neutron energy

Measured Dose (mSv)	Reference Dose(mSv)	Sensitivity	Beam	Exposition label n°
1.79	3.67	0.488	PTB 565 KeV	1
1.75	4.9	0.357	PTB 8 MeV	2
3.49	6.9	0.506	PTB 14 MeV	3
1.84	2.9	0.635	PTB 19 MeV	4
2.38	4.44	0.535	iTL 66 MeV 0°	5
1.72	3.2	0.537	iTL 66 MeV 16°	6
1.52	2.36	0.643	iTL 100 MeV 0°	7
1.75	2.83	0.618	iTL 100 MeV 16°	8

Table 2. Detector sensitivity at different energies

6) Repeatability of measurements

Detector	CHI²	Dose (*H*10*) in mSv		
1608	1.034	2.248	Mean Dose (mSv)	2.377
1614	1.066	2.290	St. Dev.	0.230
1640	1.114	2.537	St. Dev. %	9.7
1646	0.913	2.211	Ref. Dose (mSv)	4.440
1654	1.066	2.194	Sensitivity	0.535
1675	0.993	2.418	Beam	66 MeV 0°
1693	0.928	2.247		
1694	1.055	2.868		

Table 3. Dose measurement in different detectors exposed at 66 MeV

Table 3 reports the results for the measurement of 8 detectors simultaneously exposed at the iThemba beam 66 MeV 0°.

The CHI² is the statistical check to control that the tracks are Poisson distributed on the detector surface. The CHI² expectation value is 1.

The standard deviation of the measurement is around 10% and corresponds to the value found for the remaining irradiations.

7) Conclusion

- *The sensitivity is almost independent from the neutron energy and we can assume that the CR-39 detector has a rem-counter like behaviour.*
- *PADC detectors, when coupled with plastic converters, can be used to estimate the ambient dose equivalent component due to high-LET particles in mixed radiation fields. For many applications, this component is a good approximation of the ambient dose equivalent, and can be also used to estimate the personal dose equivalent.*

Perspectives:

- *Further investigation of the dose underestimation by means of Monte Carlo simulations.*
- *Investigation of the detector angular dependence*