Neutron Dosimetry and Spectrometry in Complex Radiation Fields using CR-39 Track Detectors

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1) Overview of the PhD project

CR-39 Plastic Nuclear Track Detectors (PNTDs) are widely used for neutron dosimetry in the nuclear industry, in space and around medical and research accelerators. However one important downside of this technique is the energy dependence of the response function. This is caused mainly by the analysis algorithm that correlates the track density produced by the secondary heavy charged particles to the neutron dose, both $H_p(10)$ and H*(10) (Trompier et al., 2013). A novel approach has been recently proposed (Caresana et al., 2013). In this case the detector response is calculated starting from a measurement of the average LET produced by secondary heavy charged particles. The average LET distribution is folded with the ICRP74 (ICRP, 1996) quality factor Q(LET) and the resulting H_{Cr} is the detector response expressed in mSv. H_{Cr} underestimates the actual reference dose by a factor about 2, mainly because of the limit angle that forbids the detection of particles impinging with a high dip angle (Caresana et al., 2010). This method has been tested with monoenergetic and quasi-monoenergetic neutron fields and it was demonstrated that the underestimation is fairly constant in the energy range 0.5 MeV to 100 MeV with a dimensionless calibration coefficient $C_c = 1.85 \pm 0.3$ (Caresana et al., 2013). The measurements performed in different facilities are now being compared with results from Monte Carlo codes for final validation.

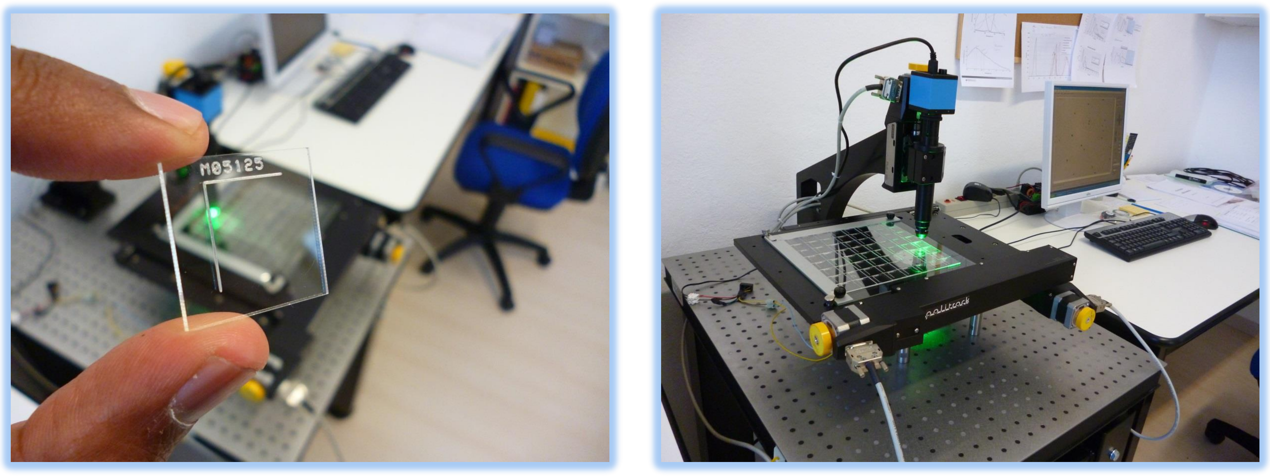
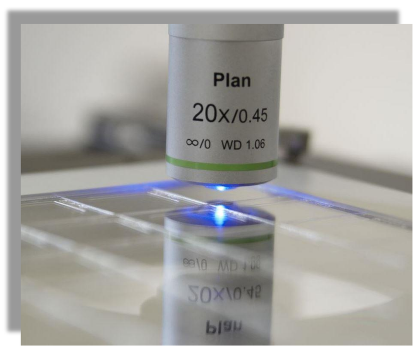
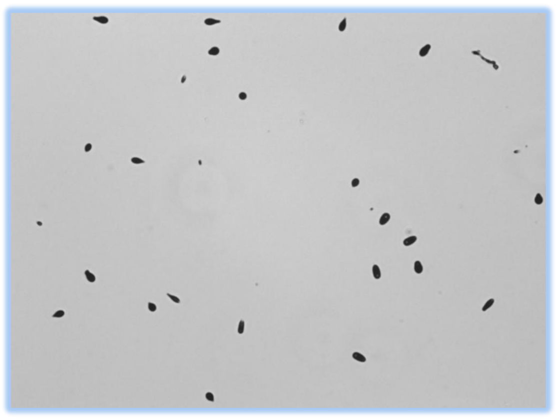


Fig 1. Intercast CR-39 Nuclear Track Detector (left) and the Politrack automatic PNTD reader (right) developed at the Politecnico di Milano and commercialised by Mi.am SRL

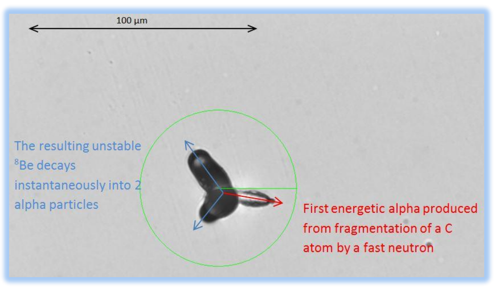
2) LET spectrometric method using CR-39 PNTDs



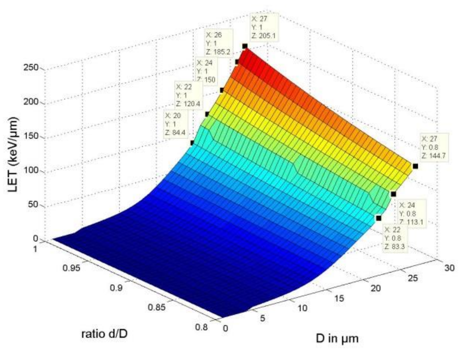
(a) Automatic reading using upgraded POLITRACK system



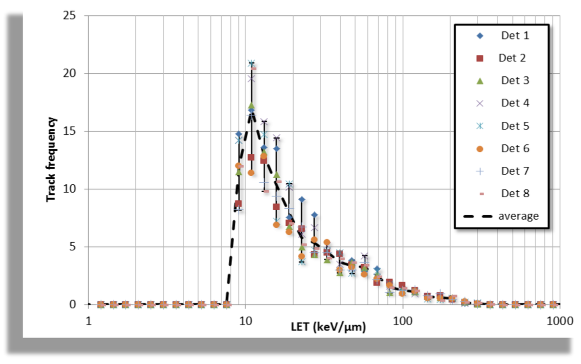
(b) Raw images captured



(c) On line image analysis



(d) Calculation of LET_{nc} w.r.t tracks' dimensions



(e) LET_{nc} distribution (the suffix nc indicates that it is a quantity measured with CR-39 PNTDs)

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

(f) H_{Cr} Dose Equivalent (mSv) computation for each dosimeter

3) Research Activities

a) Measurements performed

Measurements	Radiation Field type	Joint
CERN – Dose meas. w.r.t angular dependence	PuBe neutron source	Stuart
LANSCE – LET spectra + Dose meas.	Broad energy spectrum neutron beam	Benedikt
CERF – Dose meas. & LET spectra	High-altitude + space neutron field	Chris
CNAO – Dose meas.	Secondary neutron field around target	Chris
Trento (IRSN) – Dose meas.	Stray neutron field	Chris
CNAO – Dose calibration and LET calibration	Carbon and Proton beams	Andrej
IRSN Cadarache – Dose meas. + LET spectra	Monoenergetic neutron beams	-
Ithemba labs – Dose & LET spectra	Quasi-monoenergetic neutron beams	-
PTB – Dose & LET spectra	Monoenergetic neutron beams	-
Orsay Protontherapy Center (IRSN Paris) – Dose meas.	Stray neutron field around target	-

Table 1. List of measurements perfomed since the start of the project

b) Monte Carlo simulations (FLUKA and MCNPX)

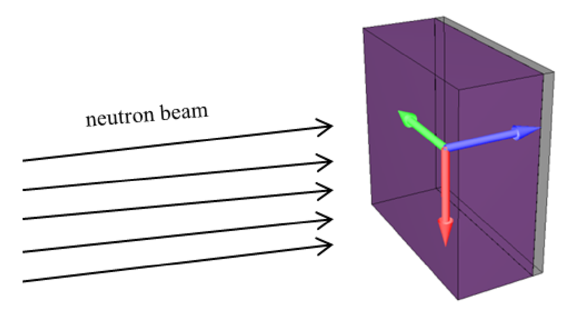


Fig 2. *Simulation of the CR-39 based neutron dosimeter irradiated in a quasi-monoenergetic 100 MeV neutron beam at Ithemba labs*

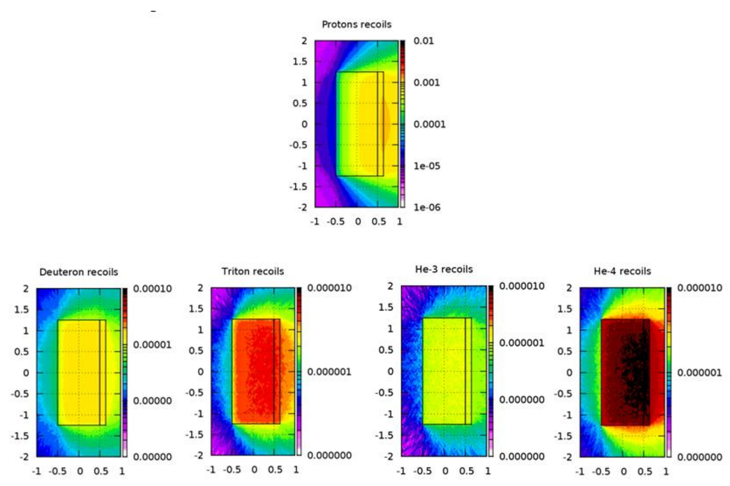


Fig 3. *Spatial distribution and fluence of secondary heavy charged particles producing tracks in the CR-39 detectors*

4) Results so far…

Neutron Dosimetry & Spectrometry

Fig 4. LET spectrum measured in 100 MeV Neutrons beam compared to FLUKA simulations. The simuations allowed to understand the different components to the dose.

Fig 5. Measured detector response, stable on a large neutron energy range, compared to FLUKA Monte Carlo simulations

In-beam LET Spectrometry and Dosimetry in Carbon ions' beams

Fig 6. LET measurements in a Carbon ion beam at CNAO compared to FLUKA

Fig 7. Measured fluence of C ions compared to FLUKA in 101 MeV/n Carbon ions' beam

Fig 8. In-depth dose deposition profile: measured and simulated with FLUKA

5) Advantages and drawbacks of CR-39 track detectors

- CR-39 acts as a low resolution spectrometer and a dosimeter at the same time
- It has a very low cost
- It can be used as a tissue equivalent personal and environmental dosimeter
- It is insensitive to stray radiation such as intense gamma ray pulses which are parasites to all active detection instruments
- The applications are very useful for high energy physics such as in particle accelerators or inertial fusion experiments

- However, the limits are its insensitivity to hadrons having a low-LET or high angle of incidence on the detector; thus reducing the response of the detector

6) List of Publications so far

- **M. Caresana, M. Ferrarini, A. Parravicini., A. Sashala Naik, "Evaluation of a Personal and Environmental Dosimeter based on CR-39 Track Detectors in Quasi-monoenergetic Neutron Fields.", Radiation Protection Dosimetry, DOI:10.1093/rpd/nct320, 14 November 2013**
- **F. Trompier et al., "Comparison of the Response of PADC Neutron Dosimeters in High Energy Neutron Fields", Radiation Protection Dosimetry, 1 December 2013.**
- **M. Caresana, M. Ferrarini, A. Parravicini., A. Sashala Naik, "Dose Measurements with CR-39 detectors at the CERF Reference Facility at CERN.", Radiation Measurements, April 2014.**
- **M. Caresana, M. Ferrarini, A. Parravicini, A. Sashala Naik, "Calibration of a passive rem counter with monoenergetic neutrons", Radiation Measurements(2014), doi: 10.1016/j.radmeas.2014.07.019.**