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Performance evaluation of a new reading technique of LR115 cellulose nitrate track detectors

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ABSTRACT

LR115 cellulose nitrate SSNTD are routinely used for Radon detection. A reading technique with high resolution optical microscope coupled with a scanning system has been recently proposed.

In this technique, the efficiency correction that was formerly performed on the residual thickness of the detector is performed on the track area distribution. So all the information that is needed for the measurement is obtained directly during the scanning. This leads to a much simpler and faster reading procedure, when compared to the classical technique that required both spark counting and micrometer residual thickness measure.

A complete characterization and performance evaluation of the detector response is discussed, including a measuring range evaluation, a combined uncertainty theoretical calculation and a blind test validation at HPA.

1. Introduction

Since few years ago cellulose nitrate (known as LR115) track detectors (Azimi-Garakani et al., 1988; Torri, 1990, Bochicchio et al., 1992, Bochicchio et al., 1996, 2003, and Campi et al., 2004,) were widely used for radon detection in air, but in the last years many laboratories shifted towards PADC (commercially known as CR39) detectors. This migration was mainly due to two reasons: PADC detectors show a wider measuring range than LR115, and techniques based upon LR115 are much more time consuming. In fact the procedure described in the above cited papers uses Type II strippable LR115. After the etching bath the detectors must be manually stripped, the residual thickness must be manually measured and finally the track density is manually measured with the spark counter technique. Owing to the fact that the track density is a function of the residual thickness the measurement procedure provides a normalization of the track density to an arbitrary value of the residual thickness (usually 6.5 μm).

A novel technique has been proposed some years ago (Caresana et al., 2005). This technique does not need the measurement of the residual thickness but uses the average track radius, instead of the residual thickness, to normalize the track density for the effects due to the unevenness in the chemical etching. This approach reduces the operator time because there is no need to strip the track detector and the optical reading can be automatized. Moreover the technique has almost no saturation in usual measuring condition, thus achieving a much wider measuring range.

In this work a further improvement and a full characterization of this novel technique is described, that can support the laboratories in embedding it in their routine procedures.

2. Theory

In the classical theory of track detectors (Fleischer et al., 1974) the part of the material damaged by the alpha particles is removed by the etching bath with a velocity V_T, while the undamaged material is removed with a velocity V_B. Moreover it is well known that in thin track detector, such as LR115, the detectable tracks are passing holes.

The major (D) and minor (d) axis of a hole, depend on the inclination of the track, on the ratio V_B/V_T, on the etching time and conditions (temperature, etchant concentration and stirring) and on the etching delay time T_D.

In order to understand the meaning of T_D let us consider that the LR 115 detector has an upper energy limit between 4.1 and 4.6 MeV, (Nikezic and Yu, 2004) which is dependent on the etching conditions and readout criteria. This means that an alpha particle with an impinging energy higher than the upper limit, produces an etchable damage when its energy drops below the threshold. This happens at a certain depth x with respect to the detector surface (Fig. 1). In this case the delay time T_D can be defined according to Eq. (1)

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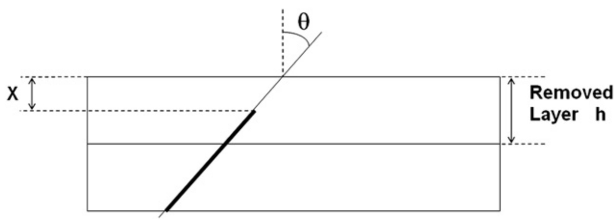

Fig. 1. Schematic of the delay time definition. The bold portion of the particle path represents the region where the particle produces an etchable damage.

$$T_D = \frac{x}{V_B} \tag{1}$$

It is easy to understand that a particle cannot be detected if $x > h$, where h is the removed layer, because the etchant does not reach the damaged region.

For a given energy and angle distribution of the particles impinging on the detector surface, tracks due to particles with higher impinging energy or lower impinging angle θ, that is with higher T_D, are etched if a thicker layer is removed.

This consideration explains why the track density is an increasing function of the removed layer. The relationship can be approximated by a linear function, and an etching correction factor is applied to each detector.

The track density is normalized to a residual thickness $S_n = 6.5$ μm after Eq. (2)

$$C(S_n) = \frac{C(S)}{1 - \beta\cdot(S - S_n)} \tag{2}$$

Where $C(S)$ is the track density measured on the detector with residual thickness S and $C(S_n)$ is the track density normalized to 6.5 μm of residual thickness. β is a parameter whose value is found by fitting experimental data. This technique is described in detail elsewhere (Bochicchio et al., 1996 and Bochicchio et al., 2003)

Caresana et al. (2005) demonstrated that it is possible to bypass the direct measurement of the residual film thickness by measuring the mean track radius, and formulate an equation similar to Eq. (2) where the correction is based on the mean track radius rather than on the residual film thickness.

The present study uses the same approach of the above cited paper, but uses as attack parameter (*AP* in the following) the 80th percentile of the distribution of the holes area square root instead of the mean radius. Fig. 2

3. Material and methods

In this work LR115 type 2 non strippable detectors (supplied by Dosirad, Lognes, France) nominally 12 μm thick, have been used. They have been exposed inside an ANPA holder (Torri, 1990; Campi et al., 2004). Each holder contains two LR115 films.

The radon exposures were made at the Politecnico di Milano in a radon chamber consisting in a glove box of about 0.8 m^3 of volume. Radon is released from a thin flat radium source encased in a plastic foil, whose emanation power can be considered equal to 1, and it is introduced in the radon chamber through a volumetric dosage system that permits to obtain different concentrations. Inside the radon chamber, an Alphaguard PQ2000 works as reference instrument and surveys environmental temperature, pressure and humidity. The devices are introduced through a double air lock door (SAS) once the appropriate exposure conditions in the chamber have been obtained.

The detectors have been analysed using the Politrack track detector reader, developed at the Politecnico di Milano and supplied by Mi.Am srl (Fabiano di Rivergaro, PC, Italy). The reader is

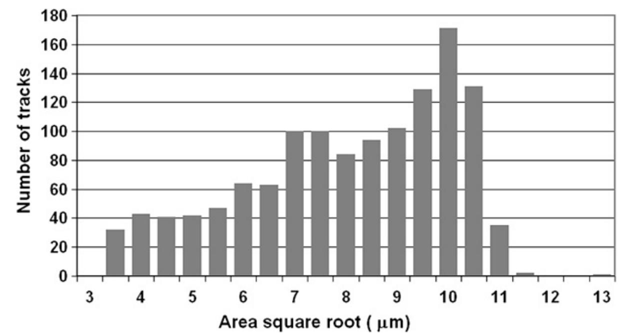

Fig. 2. Area square root frequency distribution.

based on an optical microscope with a magnification about 100×, coupled with a 1024 × 768 pixel CCD camera. The spatial resolution is 0.92 μm/pixel. The image is acquired via Firewire and analyzed by an image analysis software installed on a conventional PC. The same software drives a motorized Cartesian table that moves the detectors under the microscope objective. In this way a 1-cm^2 surface is completely scanned in about 1 min.

The characterization of the method has been carried out in three steps. At first the dependence of the track density from the attack parameter has been assessed, to calculate the β parameter of the etching correction factor.

Than a complete calibration has been carried out, and finally the method has been validated through a blind test at HPA.

As in the classical method, for each detector the track density is corrected for the etching conditions normalizing to a reference attack parameter with Eq. (3)

$$C\left(AP_{\mathrm{ref}}\right) = \frac{C(AP)}{1 - \beta\cdot\left(AP - AP_{\mathrm{ref}}\right)} \tag{3}$$

Several quantities related to the parameters of the track images have been taken into consideration as attack parameters. According to our experience, from a statistical and operational point of view the 80th percentile of the distribution of the square root of the track area is the best parameter, showing a better repeatability and reproducibility compared to the previously used average track radius.

The β parameter of the etching correction equation has been obtained using 24 radon measurement devices. The detectors have been exposed to a radon reference concentration atmosphere with a total exposure of 2050 ± 100 kBq h m^{-3}.

The detectors have been divided into three groups, that have been etched at the same time in the same solution (aqueous NaOH solution 10% in volume at 60 °C) but for different etching times, namely 85, 95 and 105 min.

Fig. 3 shows the dependency of the measured track density against the *AP*. The data are fitted to a linear regression ($y = mx + q$) with the weighted least square method (Allisy, 1976).

From the linear fit parameters m and q, the parameter β can be derived by Eq. (4).

$$\beta = \frac{m}{m\cdot AP_{\mathrm{ref}} + q} \tag{4}$$

The reference attack parameter has been chosen to be $AP_{\mathrm{ref}} = 10$ μm, giving a value of $\beta = 0.146 \pm 0.005$ μm^{-1}.

The calibration has been carried out exposing three groups of 8 radon measuring devices at three exposure values.

A further group of 8 unexposed devices was used to estimate the background.