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# On the consistency among different approaches for nuclear track scanning and data processing

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ABSTRACT

The article describes various approaches for space radiation track measurement using CR-39™ detector (Tastrak). The results of comparing different methods for track scanning and data processing are presented. Basic algorithms for determination of track parameters are described. Every approach involves individual set of measured track parameters. For two sets, track scanning is sufficient in the plane of detector surface (2-D measurement), third set requires scanning in the additional projection (3-D measurement). An experimental comparison of considered techniques was made with the use of accelerated heavy ions Ar, Fe and Kr.

## 1. Introduction

Solid state nuclear track detectors (SSNTD) have been used successfully for a long time in various experiments for space radiation investigation on board spacecrafts [1]. Such measurements usually involve a number of problems. On the one hand, they are due to the features of space radiation: its multicomponent composition and complex spectral and space distributions. On the other hand, SSNTD are limited in their detection capabilities mainly because of relatively high registration threshold. Strictly speaking, the measurements of LET value by SSNTD can be considered reliable only for long-range particles entering detector from pre-etched surface. Additionally to that LET value is presumed to be constant along the entire track length. Usually cosmic particles LET distributions are measured under these assumptions. Data presented in literature [2,3] give evidence that a noticeable fraction of tracks in detector do not always correspond to these requirements. In particular, these events are caused by short-range secondaries of different origin with LET values in the Bragg peak vicinity. The fraction of secondaries can be formed in nuclear interactions of high-energy primaries in the bulk of detector itself. Such events require extended approach for track scanning and data processing.

Our first attempts to find alternative ways for such track interpretation [4] showed a noticeable difference in the spectral distributions as compared to conventional measurement methods, especially in the region of $dE/dx > 100$ keV/μm ($H_2O$).

The main aim of this article is the investigation of different methods for particle track scanning, allowing to reduce the restrictions on events to be measured, and thus to expand the capabilities of SSNTD in space radiation experiments.

## 2. Theory

The key parameter of track detectors is sensitivity $V$ determined as the ratio of track etch rate $V_t$ to the etch rate of undamaged bulk material $V_B$: $V = V_t/V_B$. It is assumed that sensitivity depends on the value $dE/dx$ of the particle in detector. The relationship between the parameters is established by the calibration curve: $V = f\,(dE/dx)$.

The algorithm for $V$ calculation is determined by the kinetics of track formation during etching and described in early works [5,6]. Main geometric track parameters are connected with each other by equations (for simplicity, written in trigonometric form) (Fig. 1):

$$\frac{D}{2H} = \frac{\cos\delta}{\sin\delta + \sin\theta} \tag{1}$$

$$\frac{d}{2H} = \sqrt{\frac{\sin\theta - \sin\delta}{\sin\theta + \sin\delta}} \tag{2}$$

where: $D$ and $d$ are major and minor track opening diameters consequently, $H$ — etched off layer thickness, $\theta$ — particle incidence angle, $\delta$ — track cone angle. Sensitivity $V = \sin^{-1}\delta$. In Eqs. (1) and (2) — $D$, $d$

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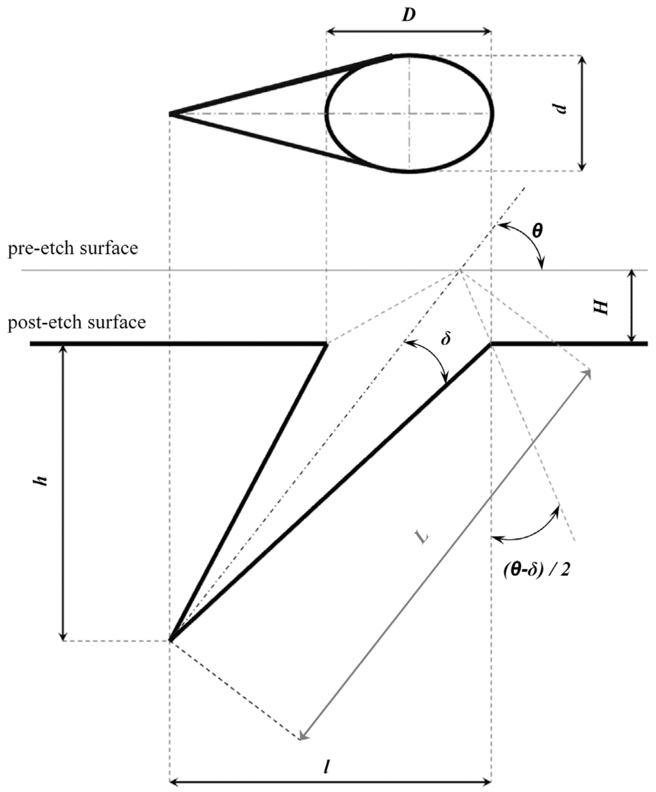

**Fig. 1.** Etched track geometry in conical shape. Measured parameters: $D$ and $d$ — major and minor track opening diameters; $l$ — track projected length; $h$ — track pit depth. Calculated parameters: $\theta$ — particle incidence angle; $\delta$ — track cone angle; $H$ — etched off layer thickness; $L$ — track etched length (this parameter is discussed earlier in [7]).

and $H$ are the measured parameters. Etched off thickness $H$ is usually obtained from independent measurement and noted by $H_0$. The solution of Eqs. (1) and (2) is:

$$V = \sqrt{1 + \frac{4 \cdot \left(\frac{D}{2H}\right)^2}{\left(1 - \left(\frac{d}{2H}\right)^2\right)^2}}. \tag{3}$$

Just this expression is commonly used as an algorithm for determining the desired $V$ value.

Strictly speaking, the relation (3) is valid under two necessary conditions:

- $V$ value remains constant along the entire length of etched track;
- Track formation starts from pre-etch detector surface;

The main advantage of algorithm (3) is simplicity in measuring of parameters $D$ and $d$ in the plane of detector surface (2-D measurement).

Solution (3) in the form of sensitivity $V$ versus dimensionless parameter $D/2H_0$ is shown in Fig. 2(a) by curves for different incident angles $\theta$. It can be seen in Fig. 2(a) that $V$ shows unlimited growth in the vicinity of $D/2H_0$ maximum values. From practical point of view, it limits the range of the measured sensitivity by values $V < 5$–6. At higher values, insignificant variations in the parameters $D$ and $H_0$ lead to large uncertainty in solution (3). Obviously the simplified $V(D, d, H_0)$ approach is unacceptable for secondary particle tracks formed in the bulk of detector because the parameter $H_0$ in this case is undefined.

To eliminate these limitations, several approaches can be used. The first of them is to measure the additional parameter $l$ — track length projection on detector surface (Fig. 1). Such measurements can be applied for oblique tracks only. Etched off layer thickness $H$ in this case is assumed to be unknown. It is important that all measurements are carried out in the plane of detector surface (2-D measurement). The idea of such an approach was proposed earlier in [5], but it was not used in space radiation measurements. Eqs. (1) and (2) in this method remain unchanged, additional equation for the projection $l$ is given by:

$$\frac{l}{H} = \frac{\cos\theta}{\sin\delta} + tg\frac{\theta - \delta}{2}. \tag{4}$$

The solutions $\delta$ and $H$ are given in detail in [7]. It is sufficient that in Eqs. (1), (2), (4) $H$ is a calculated parameter.

Solutions in most compact geometrical form can be expressed as follows:

$$tg\,(\delta) = \frac{d}{2} \cdot \frac{\sqrt{1 - \left(\frac{d}{D}\right)^2}}{\sqrt{\left(l - \frac{D}{2}\right)^2 - \left(\left(\frac{D}{2}\right)^2 - \left(\frac{d}{2}\right)^2\right)}} \tag{5}$$

$$H = \frac{d}{2} \cdot \sqrt{\frac{\left(l - \frac{D}{2}\right) + \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{d}{2}\right)^2}}{\left(l - \frac{D}{2}\right) - \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{d}{2}\right)^2}}}. \tag{6}$$

The expression for incident angle $\theta$ is not given since the finding of this parameter is not discussed here. Eventually: $V(D; d; l) = \sin^{-1}\delta$; $H = H(D; d; l)$.

Sensitivity $V$ derived from Eq. (5) versus dimensionless parameter $2l/D$ is shown in Fig. 2(b) for different incident angles $\theta$. In contrast to unlimited growth of solution (3) for a simplified $(D, d, H_0)$ approach (Fig. 2(a)), the $(D, d, l)$ method provides a smooth change of sensitivity over a wide range of values.

Another approach involves measurement of track pit depth $h$ instead of track length projection $l$ (Fig. 1). In this case, Eqs. (1) and (2) remain valid but Eq. (4) is replaced by:

$$\frac{h}{H} = \frac{\sin\theta}{\sin\delta} - 1. \tag{7}$$

It is important that scanning procedure in this approach is complicated because parameter $h$ is measured in the depth of the detector (3-D measurement). Additionally, the measurement accuracy of $h$ can be worse in comparison with $D$ and $d$ variables that are obtained in the plane of detector surface. The solution of Eqs. (1), (2), (7) is as follows:

$$V(D; d; h) = \sqrt{1 + \left(\frac{2 \cdot h \cdot D}{d^2}\right)^2} \tag{8}$$

$$\frac{H}{h} = \left(\sqrt{1 + \left(\frac{2 \cdot h}{d}\right)^2} - 1\right)^{-1}. \tag{9}$$

We note here that all relations (3), (5), (6), (8), (9) are derived from the same geometric model of track growth, based on invariable $V$ parameter. The only difference is in the set of measured values. This means the consistency of all the unknown variables, regardless of how they are obtained: $V(D, d, H_0) = V(D, d, l) = V(D, d, h)$ and $H(D, d, l) = H(D, d, h) = H_0$.

Eqs. (1), (2), (4) and (1), (2), (7) are sufficient to describe track geometry in conical phase of development.

In present work, experimental research for consistency of the results obtained by different approaches for track evaluation is carried out. All measurements were made with long-range particles to provide tracks in conical shape ($V$ = const) formed from pre-etched detector surface.

## 3. Experimental design

CR-39™ TASTRAK (Tasl Co. Ltd., Bristol, UK) detector plates of 1 mm thickness were irradiated with long-range heavy ions at HIMAC accelerator. All meaningful ion parameters are summarized in Table 1. After irradiation detectors were etched in 6N NaOH solution at 70 °C for 2 and 6 h. The bulk etch rate $V_B$ was determined from the growth