

A comparison of a track shape analysis-based automated slide scanner system with traditional methods

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Received: 16 December 2014
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Abstract During recent years, CR-39 detector measurements have gained attention due to improvements in image processing methods. An assessment method based on the application of a high-resolution slide scanner and its quality checks is introduced, using commercially available software and hardware. Using the conventional (visual) comparing analysis for 563 detectors, the method was found suitable for high-precision and reliable track analysis. The accuracy of the measurements were not disturbed by any other pseudo-tracks (scratches or contamination) due to the signal shape of the analysis.

Keywords CR-39 · Track detector · Slide scanner · Image processing · Track counting

Introduction

Etched track detector measurements have one of the longest histories in nuclear measurement techniques. The first tracks in a LiF crystal were detected by Young in 1958 [1]. A year later, similar findings in damaged regions of mica were documented by Silk and Barnes [2]. Initially, a transmission electron microscope was used for track detection; eventually, the counting of tracks was established by using an optical microscope [3]. The manual counting method using an optical microscope has remained one of

the most widely used methods, primarily due to its low costs; however, why this method is unsuitable for the assessment of a large number of samples is evident [4]. Consequently, automation of this rather time-consuming method was attempted [5]. In 1984, a summarizing paper was published on the first automated track counting systems [6]. During the past three decades, several semi-automated or fully-automated systems have been elaborated on [7–10]. However, most of these systems were designed and built for a specific application and not all the details of their hardware and software are available. According to the most recent overview by Hulber [11], only four devices are available; these are the Autoscan 60 (Thermo Electron Corporation, Santa Fe, MN, USA), the Radometer 2000 Series (Radosys Ltd., Budapest, Hungary), the Taslimage System (Track Analysis Systems Ltd., Bristol, U.K.) and the HSP-1000 (Seiko Precision, Chiba, Japan). These commercially available systems are usually too expensive and therefore not affordable to all laboratories. As a result, track detector assessment improvements have been researched in several ways; one of these was the elaboration of commercial apparatuses to provide large amounts of data quickly for ambient or epidemiological surveys of different large volumes. Another was the three-dimensional display of tracks and a high-precision analysis of each track [12, 13]. Thirdly, the elaboration of cheap measurement processes was investigated; these were primarily based on scanner-based imaging, as the conventional optical microscopic or CCD camera processes are generally capable of only imaging one detector at a time and as a result involve demanding expensive mechanics during automation. Therefore, the scanner was soon selected during the cost optimization of the research. This method, which has been the basis for processes elaborated on ever since, was established by Steele [14]. Since then, several processes

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based on slide scanners and their publications have been published [15–17]. Examples of the routine application of the slide scanner and its quality control are available, as track detector analyses are performed by the Health Protection Agency (HPA); more than 116,000 detector assessments have been completed since 2003 [15]. Assessment of the track detectors and their quality control was intended to be performed in a similar way to those described in this study using open-source software available on the market. During the application of the optical microscope or the slide scanner, the issue of image processing arose after imaging had been completed. One of the initial methods used for track identification was the edge recognition algorithm [18]. In most of the current systems, track recognition and any filtering out of false tracks work according to this principle [19]. There are several ways to filter out false tracks; centroidity and the shape of tracks should be identified and analysed, as this assists in identifying several parameters of the impacting particles. Several models have been established to describe track formation and the geometry of the track surface. The most well-known of these are the Somogyi–Szalay model [20], the Fewes and Henshaw model [21], the Fromm model [22] and the Nikezic–Yu model [23]. All of these models are identical in that the surface shape of the alpha-particle's cross-section arriving at a right angle is circular, while that of an angular particle is elliptical at first, and in the case of over-etching, its cross-section becomes circular. These methods do not play any role in identifying radon and thoron quantities, as the knowledge and precise measurements of several parameters are needed. It is evident in this case that to over-etch the tracks, the tracks of the particles impacting at a right angle or diagonally have to become circular; therefore, only tracks showing centroidity should be counted. However, it is evident that in cases with a large number of tracks, twin tracks form, or multi-impacts may cause considerable inaccuracy; despite this, it remains the most widely used method for identification. Software based on the recognition of track shapes and certain types of tracks appeared relatively early on. An automatic system based on one of the shape-recognizing methods was published in 1996 Pálfalvi et al. [24]. Where reflection imaging occurred during the processing of the image obtained, the contamination of the applied background had to be addressed; this contamination is avoidable in transmission image processing; however, the issues of the autofocus setting [11], together with that of establishing on which side of the detector the track is located remain. Intelligent image processing software will be able to avoid this by measuring the intensity of the tracks. As was previously stated, due to rising demand, the scanner-based track assessment system needed to be elaborated, validated and quality controlled. This had to be done in such a way that

the number of tracks and the statistical analysis of their size could be identified according to shape, even from a scanner or any image not specified for this system.

Experimental

The utilized track detector

In this study, $10 \times 10 \times 0.5$ mm CR-39 (allyl diglycol carbonate) type polymer track detectors were used. The material of the track detector was disturbed by the alpha radiation, but these disturbances were not detected by microscopes or other optical devices. However, the tracks can be made visible using the appropriate etching process. During etching, the damaged parts dissolved faster than undamaged parts, causing the appearance of tracks (based on the incoming angle they could either be circular or elliptical) that could be detected. The CR-39 detectors were etched in a 6 M NaOH solution at 90 °C for 3 h prior to examination.

Evaluation methods

The microscope method

Due to a growing number of detectors, automated and cheap track detector evaluation systems were required. The method currently used consists of a CCD camera mounted on a microscope, a monitor for viewing images and a controlling unit with electro-motors responsible for the precise movements of the slide. The primary data processing unit is a monitor that shows images from the camera in real-time, while on the computer, the Virginia 99 software [24] is run, which is capable of signal recognition and morphology analysis. During evaluation, after cleaning with alcohol the detectors are placed under the microscope; the camera positioned, the focus set and the tracks on the detector at 14 positions counted. In this case the scanned area was 1.025 mm^2 . The process works well, but is elaborate, slow and therefore not acceptable for evaluating a high number of samples.

Scanning step

A semi-automatic CR-39 detector evaluating system was developed by our research group. The system is made up of a high resolution photo scanner (Canon Canoscan 9000F) and a computer workstation (Fujitsu Celsius W520; 16 GB RAM). The system's operation consists of two steps: the scanning and evaluation phases. The flatbed scanners currently on the market are capable of working in two operation modes (reflective and transmissive). In reflexive

mode, the detectors are illuminated by the light source and the image is created from scanning the reflected light. In transmissive mode, the image is rendered by the simultaneous movement of the light source and scanning head. The settings are the same in both methods and are as follows; resolution: 4800 dpi, colour: eight bit grey, filtering: none. The images created in reflective and transmissive modes are shown in Fig. 1.

The first part created in reflective mode, in this case, many of the images contained blurred, unfocused areas due to the reflected light. The second part created in transmission mode, where the contour lines are sharper. For reflective mode, a black background over the detectors in the scanning phase was used. At first, a nano-grain black painted glass plane was used, but too many false objects emanated from the grains passing the border criteria. To mitigate the problem, black welding glass was used instead. Subsequently, the false tracks could be eliminated. The background images gained from using nano-grain painted glass and welding glass are shown in Fig. 2.

In Fig. 2, the first part created with nano-grain painted glass and the second part created with welding glass. To sum, due to the reflection of light, not all of the tracks could be identified in reflective mode. The latter pictures were made in transmission mode to sharpen the contour lines and eliminate disturbances caused by the background. The high resolution pictures in the two modes (reflective and transmissive) were processed first by using open-source software (ImageJ) then self-developed Image Analyser (IA) software.

The operation of the open-source software (ImageJ) In the early stages, ImageJ software was used to determine the number of tracks in the picture. The software works in three steps, as shown in Fig. 3:

- converting the scanned picture to a monochrome image
- selecting the examined area
- counting the tracks in the area

The method was tested in reflective and transmissive modes but did not produce satisfactory results, because the

Fig. 1 Pictures made in reflective and transmissive modes

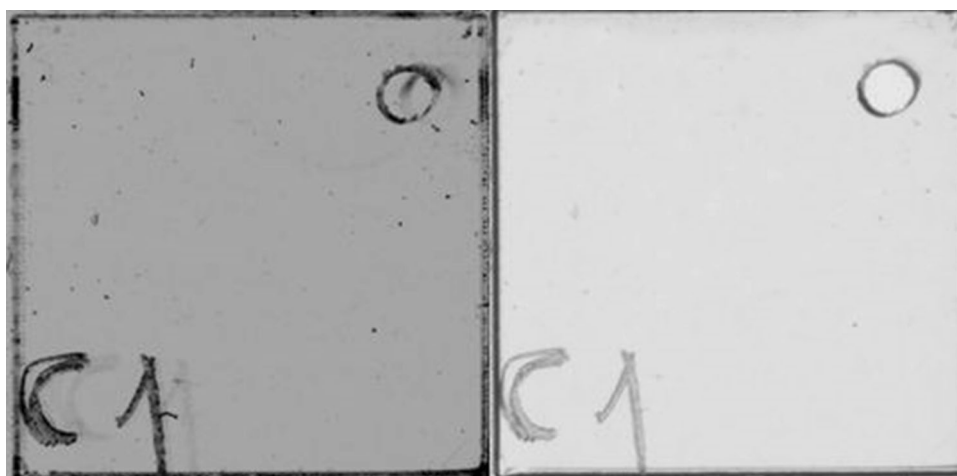


Fig. 2 Pictures with different backgrounds in reflective mode

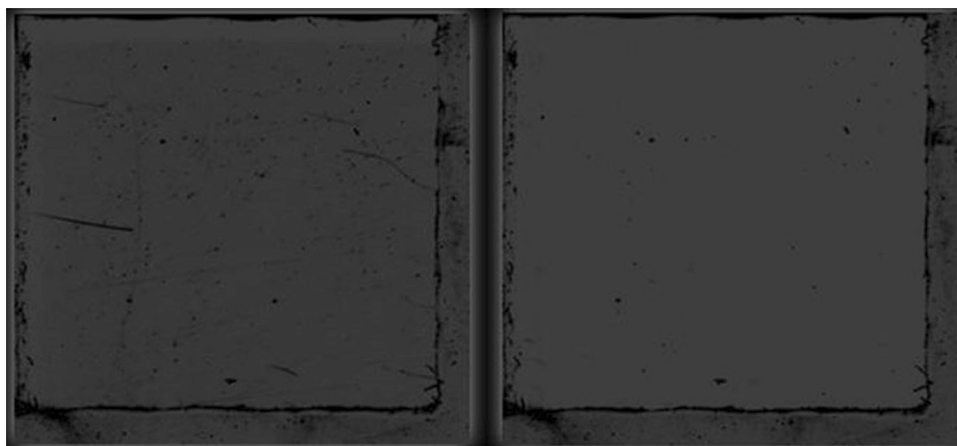


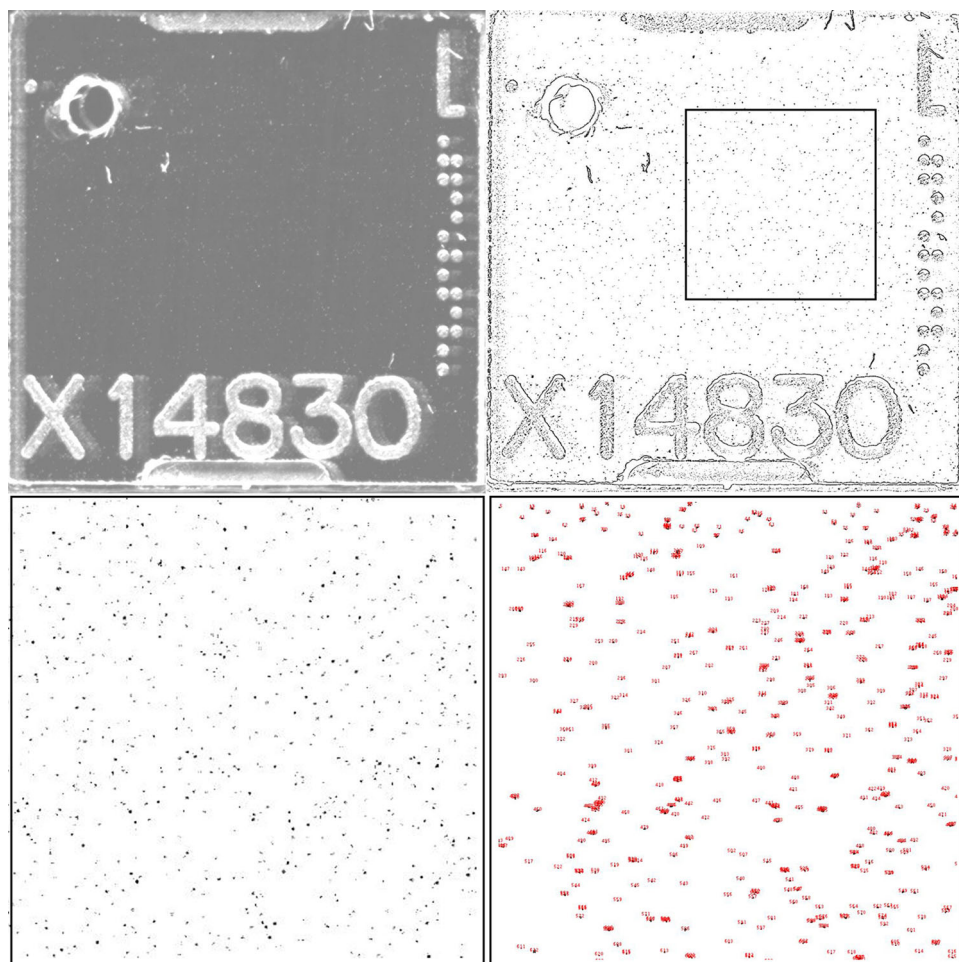
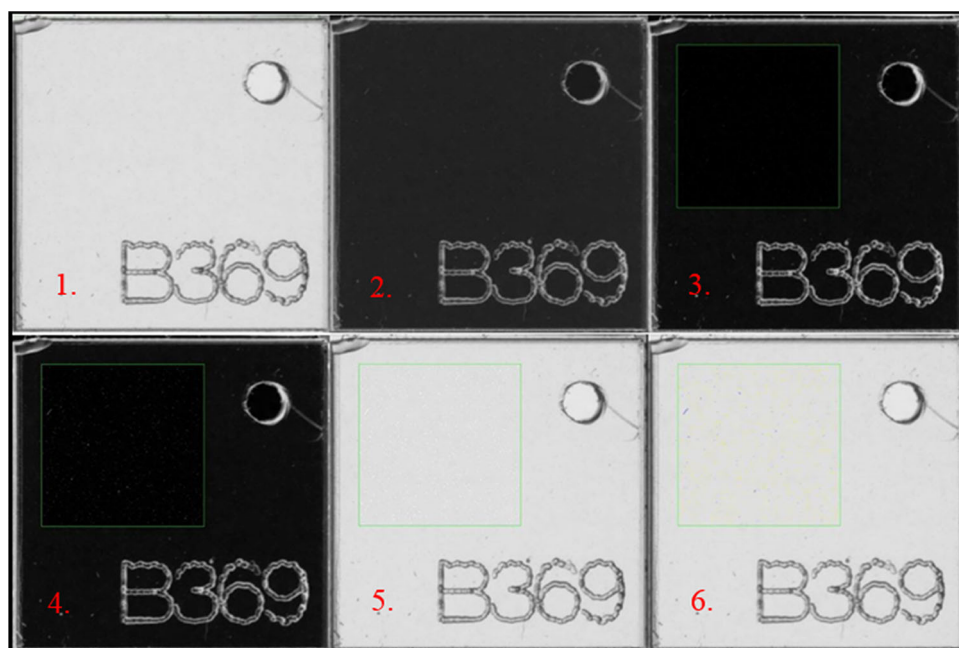
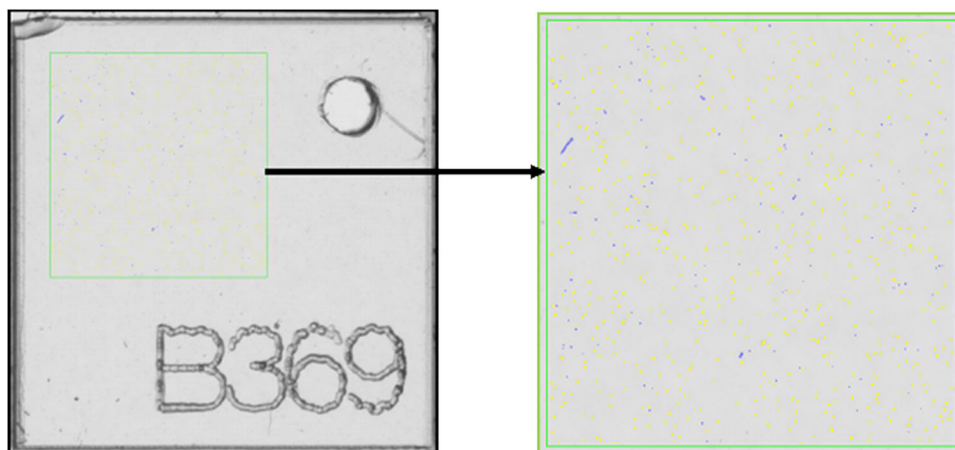
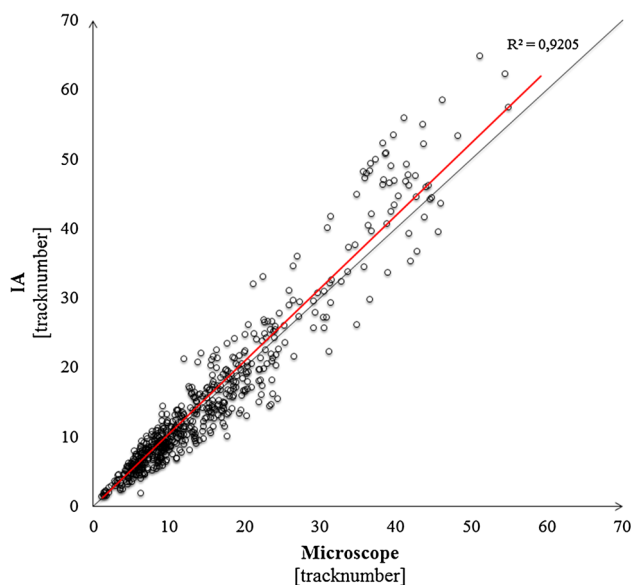
Fig. 3 ImageJ evaluation steps**Fig. 4** Image Analyser evaluation steps

Fig. 5 Classification of tracks based on pre-defined parameters**Table 1** Measured and calculated parameters

Parameter	Determined values [number of tracks]
Reference value (20 pieces)	17.87
Gross bias of reference value	1.03
Average value (20 pieces)	17.59
Gross bias of the average value	1.08
Limit of detection	1

**Fig. 6** Comparison of track counts

ImageJ software is incapable of classifying the tracks according to shape.

The operation of the Image Analyser (IA) software Pictures from both reflective and transmissive scans using the IA software were evaluated. The evaluation was divided

into two steps. Firstly, the raw picture was cut and secondly, the picture correction and comparison of the objects with a value based on pre-defined criteria was completed by the IA software. The pre-defined values are programmed into the program in a similar fashion to with the software of the optical microscope method. The mapped objects are compared to the pre-defined criteria based on five parameters:

- area
- area/perimeter²
- the greater axle of the ellipsoid
- the inclination of the ellipsoid
- shape parameter

Owing to these parameters the real objects can be distinguishable from tracks, which are not caused by radiation. The tracks are drawn into polygon shapes and distinguished accordingly by the object classifying process. The sections of the image are evaluated using the following steps (see Fig. 4):

1. load image
2. inverting the picture
3. enhancement of contrast
4. selecting the examined area
5. filtering
6. the classification of tracks

The classification of tracks can be seen in Fig. 5.

In this picture can be seen two different colour. The scratches, dust specks and other contamination indicated by blue colour. The yellow colour indicate the etched tracks.

Results and discussion

Parameter optimization and evaluation

Our newly-developed process was compared to the well-known and accepted microscope evaluation method used previously. 20 CR-39 track detectors were placed into a known radon concentration and following chemical etching, every detector was evaluated by five people using the old method and the average was accepted as the result. Consequently, the results were compared using the measured values of our newly-developed method. The calculated parameters are shown in Table 1.

Repeatability and reproducibility tests were also conducted. During testing, the results from subsequent measurements without moving the detectors showed a 0 % deviation. When the detectors were removed and cleaned, the deviation was 2 %. When placement of the detectors changed between measurements the deviation was 3 %. According to the analyses of scanning and track evaluation,

the edges of the detector, cracks, scratches, dust specks and other particles were found not to have caused significant changes during picture processing or in track counts on the CR-39 detectors. Problems were only detected if there was visible contamination of the detector (greater than 10 % of the examined area) between the scanner glass and the detectors, because larger object covered several smaller tracks. This problem can be prevented by properly cleaning the detectors and scanner. It is important to note that with an increase of radon concentration, the track density and thus the chance of overlaying tracks increases too to over 80 %. Tracks up to an 80 % overlay can be distinguished by the software; above this, they are counted as one track.

Results

563 detectors that had previously been analysed by optical microscope with our newly developed method were evaluated. The comparison between the results using an optical microscope and the IA results from the transmission image can be seen in Fig. 6.

Comparing the two methods, it was found that using the Pearson Chi square test yielded the following results: $\chi^2_{220} = 231$, $p = 0.292$. Thus, the results yielded by the optical microscope method and gained from the IA analysis of transmission images were of normal distribution. This is illustrated in Fig. 7 where the number of detectors is shown by the frequency.

Comparison of two evaluation systems

The detectors were placed on the glass of the scanner in a 5×19 grid to render a high resolution image using 95 detectors simultaneously. The number of detectors that could be processed at the same time was significantly more compared to with the microscope method and as such, the time needed for analysis decreased. The scanning and evaluation time for a chemically etched detector was 18 s. The examined area was 25.7 mm^2 . The parameters are shown in Table 2.

Conclusions

Based on the measurements conducted, it can be ascertained that our newly developed SSNTD evaluation

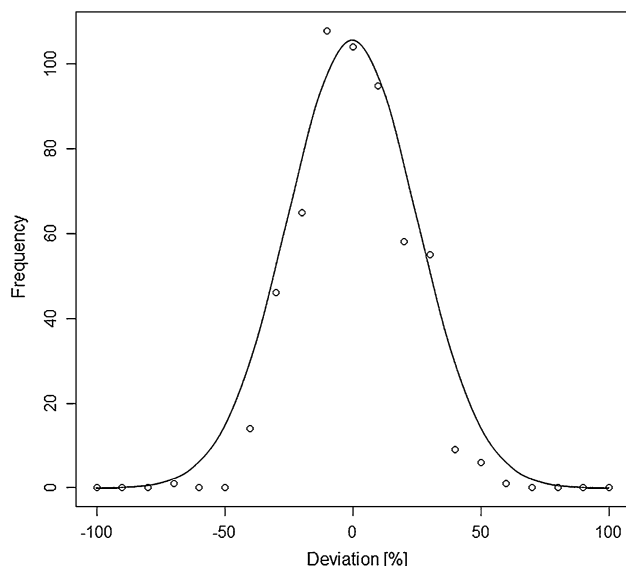


Fig. 7 Distribution of track counts

Table 2 Comparison of two evaluation systems

Parameter	Optical microscope	Slide-scanner
Number of detectors/one evaluation period (piece)	1	95
Evaluation time for one detector (s)	576	18
Examined area (mm^2)	1.025	25.7

method is fast, cost-effective, precise and reproducible. The utilized scanner was cheap and easily accessible. The use of our programs was easy and with their assistance, the evaluation could be conducted easily, thereby greatly reducing the required time when compared to the microscope method. As has been shown, the results are reproducible within good uncertainty limits and the human error factor of previous methods can be eliminated. Greater areas were examined, thus the effect of track inhomogeneity on the detectors was reduced. The correctly calibrated track counting program counts only the tracks and unlike previous programs, can not only distinguish single circular tracks, but also recognizes double tracks if the overlap makes this possible.

Acknowledgments This work was supported by the Hungarian Research Grant OTKA No. K 81975 and Hungarian State and the European Union projects Grant No. TÁMOP-4.2.2.A-11/1/KONV-2012-0071.

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