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A PERSONAL RADON DOSEMETER

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Radioprotection
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Abstract

In the last decade the radon issue has become one of the major problems of radiation protection. Animal studies as well as epidemological studies showed an increased lung cancer risk. A new personal radon-dosemeter on the basis of a CR-39 (polyallyl diglycol carbonate) track-etch detector has been developed. The read-out of the detectors is based on the image-processing technique. The actual efficiency of the new dosemeter, obtained with a semi-automatic personal-computer based image-analysis system, is 1.43 ± 0.15 tracks/cm^2/(kBq/m^3 h), which is about three times that of the widely used Karlsruhe-type detector based on polycarbonate detectors.

1 Introduction

The radon problem was first recognized among mine-workers in 1924. The number of lung-cancers, first diagnosed as the 'Schneeberger Bergkrankheit [1]', was attributed to the high radon exposures due to radon concentrations of about 10^5 Bq/m^3 [2]. About 30 years later [3,4,5] it was recognized that the high lung dose is not due to radon but to the inhalation of the short-lived radon-daughters ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po. These radioactive particles, formed by the decay of ^{222}Rn in the air, deposit in the lung. As shown in different surveys, e.g refs. [6,7,8,9], the occurence of high radon concentrations is not limited to mines and industrial facilities, but can also be met in normal households due to radon exhalation from radium contaminated grounds. There is an indication that the exposure to radon is related to an increased lung-cancer risk.

The purpose of the present project was therefore, to develop a dosemeter, which is capable to monitor the individual exposure down to average radon concentrations typical for Belgian dwellings. The general aim was to systematically investigate possible detector materials as well as their handling before and after radon exposure and to establish a high quality read-out procedure based on image analysis technique. A further recommendation was aligned on the limited number of possible objects in Belgium. Therefore, design and handling of the dosemeter should be as highly as possible cost effective.

In the following the design of the dosemeter as well as the experimental setup used for the calibration is described. In Chap. 4 the read-out procedure based on image processing is discussed. In the last chapter the results are summarized, and an outline for further investigations is given.

2 Design of the dosemeter

For a radon dosemeter, which can be used to monitor the radon exposure of individual persons, e. g. mine workers, the exposure interval has to be reasonably short. For an average radon concentration of 50 Bq/m^3 an integration period of 1 working month (= 170 h) has been suggested. This requires a high efficiency of the dosemeter. Additionally, the systematic uncertainty coming from the read-out procedure of the dosemeter has to be as low as possible. For personal monitoring generally, passive radon detectors are used consisting of a plastic material sensitive to nuclear particles. The method is based on the counting of etched tracks produced by $\alpha-$ particles stopped in the detector material, called track-etch detectors. The analysis of the detectors has to be kept as simple as possible at a high level of reproducibility. The general problems related to the quality assurance for so-called passive radon concentration monitors has been discussed by Miles [10] in great detail. The development of our personal radon dosemeter is performed under the outline of his recommendations.

In general passive radon dosemeters may be divided into two different types, open and closed. Open-type dosemeters are more sensitive than closed-type, but their response depends on the airborne decay product contribution and on different external conditions, e. g. humidity, dust and accidential surface damage. Therefore, at our institute a dosemeter of the closed type has been considered. The design of our personal dosemeter is shown in Fig. 1. The dosemeter is based on a small box made of plastic, which is commercial available. The length, width and height inside are 60 mm, 25 mm and 9 mm, respectively, which is sufficiently small in order to avoid any influence on the person's activity. The detector is placed at the back side of the box. The detector area is 5.3 cm^2. In use, the cover is closed and the radon can enter through the slit between the box and its cover. In order to prevent radon daughters from entering the dosemeter a fiberglass filter is placed inside the cover.

For the detector material CR-39 (polyallyl diglycol carbonate) has been selected. It was purchased in sheets with a thickness of 1 mm. CR-39 is known to be sensitive for $\alpha-$ particles over a broad energy range, superior to that of LR-115 (cellulose nitrate), and is widely used in different fields of nuclear physics where charged particles have to be measured [11,12]. However, due to manufactural reasons the background track density on the sheets may fluctuate and has therefore to be carefully monitored. In order to prevent an additional background contribution after purchase the sheets were immediately covered with an adhesive plastic foil on both sides until exposure starts. The detectors are cut from the sheets with a circle machine saw. This procedure is much cheaper than using laser-technique, but leads to surface damage diminishing the useful detector area by up to 20 %. However, it will be shown in the following, this is not a severe drawback for the present outline of this project. If a large number of detectors has to be produced indeed, the laser-technique might become cost effective.

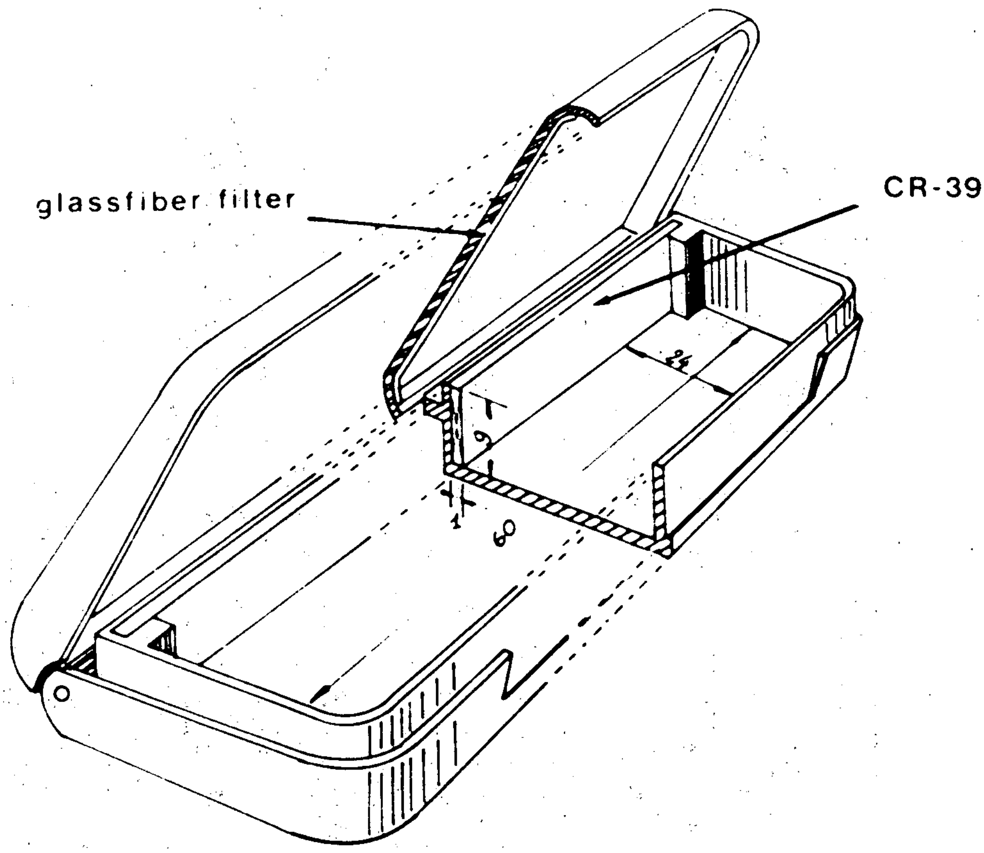

Fig. 1: Schematic representation of the personal radon dosemeter (all measures are in mm). The CR-39 detector is placed on the backside of the dosemeter.

3 Experimental setup

For the efficiency calibration the personal radon dosemeters were exposed to radon in a chamber with a volume $V_0 = 95.2$ l. The air inside is circulated at a flow-rate of 0.5 l/min through a vessel containing the radon source. The radon concentration is continuously monitored by a lucas-cell [13]. The experimental setup is shown in Fig. 2. Before the exposure starts the protection foil on the front side of the detector is removed. After exposure the dosemeter is kept closed for about one hour in order to correct for the non-equilibrium activity in the beginning. The plastic foil on the backside of the detectors may stay during exposure in order to individually determine the background track density of each detector. This method for the background determination is recommended by the authors, but not followed during this basic investigations.

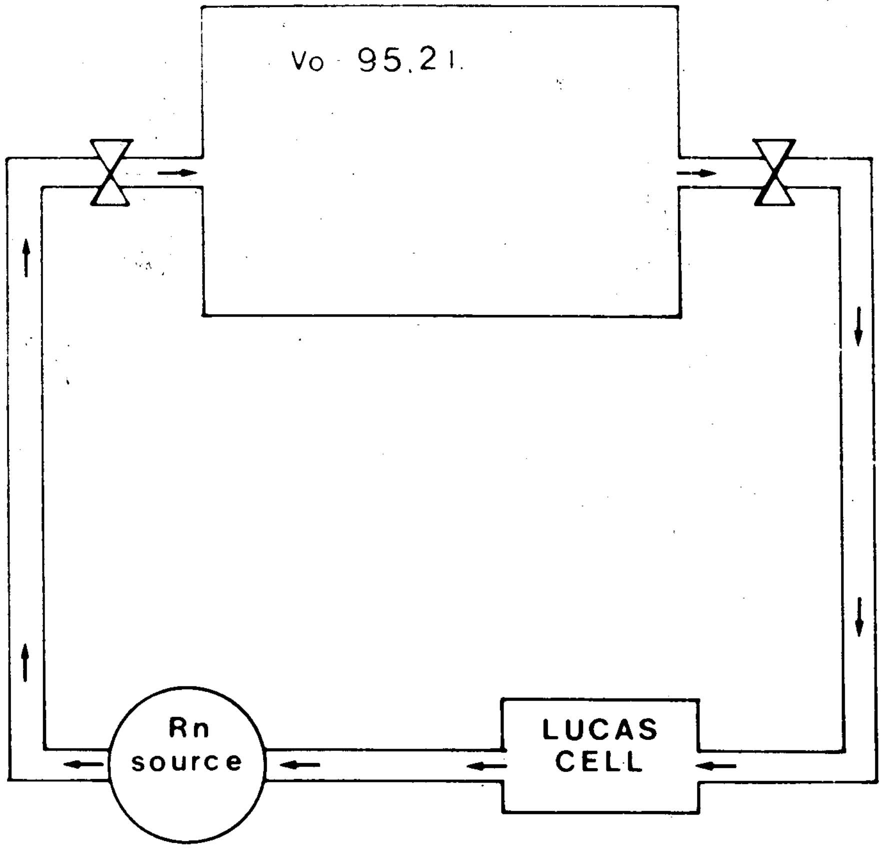

Fig. 2: Experimental setup used in the calibration phase of the personal radon dosemeter.

In total 25 detectors have been exposed to 4 different exposures. Additionally, 9 detectors were used for the determination of the background track density. Details to the calibration runs are listed in Tab. 1.

The etching procedure

In order to fix the $\alpha-$ particle tracks, with a diameter of typically a few nm, and to make them visible under a microscope, the detectors have to be brought into an etching bath enlarging the tracks to diameters of several μm . Pairs of detectors are put back-to back into a small cylindrical vessel containing 35 ml of the etching fluid, which is a mixture of $1:3.698$ of NaOH and H_2O. This vessel is then put into a heating bath. After optimization the etching period was chosen to be 16 hours at a temperature of 70 ± 1 ^oC. Thermal equilibrium between the etching fluid and the heating bath is reached after about 5 min. Up to 50 detectors may be treated simultaneously. An example of etched $\alpha-$ particle tracks is shown in Fig. 3.

Table 1: List of all calibration runs and their respective radon exposure. The number of detectors is splitted into exposed detectors plus background detectors.

number of run	number of detectors	exposure (kBq/m^3 h)
1	4+0	6653.7
2	7+3	130.7
3	7+3	365.7
4	7+3	404.1

First results

In a first phase the detectors were analysed by manual counting. The counting was performed using a ZEISS 'Photomicroscope II' at a magnification of 200. On each detector a total area of 0.1152 cm^2 was analysed. A rough estimate of the detectors efficiency ϵ_{man} leads to an average value of about 2.0 indicating a possibly four times higher efficiency than that of the widely used Karlsruhe-detector [14].

For high exposures the track density on the detectors reaches saturation and a manual counting turned out to be not appropriate.

4 Read-out optimization

In general the method of manual track-counting is very time consuming (at least 1 h for a single detector at medium track density) and rather tiresome. The efficiency does strongly fluctuate amongst the detectors of one run due to the varying selection criteria, i. e. the varying efficiency, of the counting person. Therefore, a necessary improvement was to perform the track-counting by using a computer-based image analysis technique in order to reach a unique and reproducible read-out procedure.

The image analysis system

Basically, an image analysis system consists of an acquisition system, a detector holder connected to a variable x-y stage and the image-analysis software. The aquisition is usually performed with a CCD-camera mounted on a microscope. For $\alpha-$ particle track-counting the detector is illuminated by transmission light.

First it has to be pointed out, that computer-based image processing may be done either full- or semi-automatically, i. e. with a motor driven or a manually adjustable x-y stage,

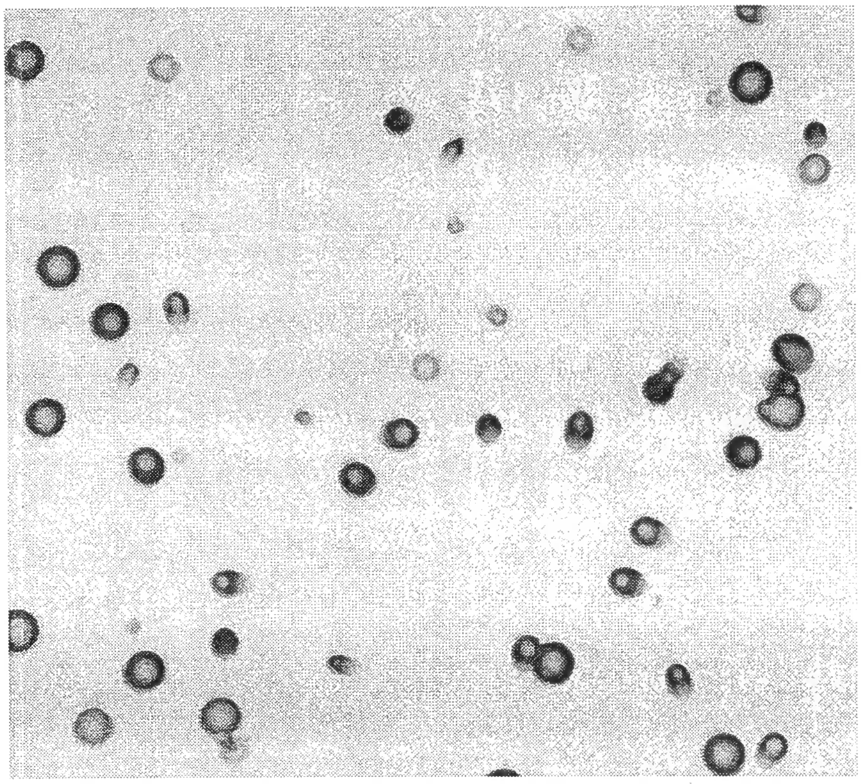

Fig. 3: Example for etched $\alpha-$ particle tracks in CR-39 material. The size of the tracks depends on the $\alpha-$ particle energy. The shape of a track becomes more excentric with an incident angle deviating from being perpendicular to the surface (the height and width of the image is 0.562 mm and 0.612 mm, respectively).

respectively. The choice is mainly influenced by the budgetary limitations and the expected manyfold of applications.
The fully automatized image analysis is about 10 times faster than the semi-automatic and allows a larger area to be read out leading to a better statistics. However, this technique requires a highly sophisticated handling of the detector material from purchase until reading-out in order to avoid any surface damage as well as deposition of dust and grease and therefore, is much more expensive (about 10 times). The semi-automatic image analysis allows at least for an automatized image processing sequence for each part of the detector surface, but requires a manual positioning of each section. In turn, the user himself may decide to discard possibly damaged surface areas online during repositioning the detector. For a reasonably small number of detectors this technique is sufficiently

productive.

For the present project the semi-automatic personal-computer based image-analysis system Quantimet 500 [15] has been purchased at SCK-CEN. It consists of a microscope 'LEITZ Labolux S', a CCD-camera 'SANYO model VC2512 (b/w)' and the image analysis software [16] running on an AT-compatible personal computer. The detector surface may be scanned by driving the x-y stage manually in x-and/or y-direction under the microscope (actually done in steps of 1.00 ± 0.05 mm).

The image-processing and read-out routine

The basic magnification of the microscope was set to 10x corresponding to an effective magnification on screen of 285. On that magnification real $\alpha-$ particle tracks are easily distinguished from dust, scratches and other surface damages. The respective area of one image is about 0.326 mm^2.

The image processing sequence applied to each segment of the detector surface consists of different steps.

- The *image setup* defines gain and offset of the CCD-camera.
- The *image detect* identifies all pixel which are darker than a given threshold and transfers them into a binary image.
- *Binary identify* detects all features with a hole, which is typical for an $\alpha-$ particle track as shown in Fig. 3, and fill it to a closed feature.
- With a *binary amend* an eroding function is applied to the features in order to erase small and thin background structures from the image. A successive dilation approximately restores the original size of the remaining features.
- Finally, features are measured and filtered by conditions defined by the *feature accept* option. According to the typicle size and shape of an etched track the selected conditions are the feature area, the aspect ratio and the roundness, which is proportional to the ratio of the squared length of the feature's boundary devided by the feature area, in the respective order of priority.

As the result the number of accepted features, i. e. $\alpha-$ particle tracks, and the corresponding distributions of the area, aspect ratio and the roundness, respectively, are stored on disk. The sequence used in the present analysis is given in the Appendix.

Efficiency determination of the personal radon dosemeter

From each exposed detector 30 images with a total area of 9.778 mm^2 were processed. From background detectors twice this area has been read out. The segments lay on a grid of 2 mm × 15 mm and 3 mm × 20 mm, respectively, in the central region of the detector surface. The reading-out of each detector (background detector) took about 15 min (30 min). In Figure 4, a-d, the track density of each detector is shown for the respective exposure, seperately.

As it might be seen from Tab. 2 the background track density n_{bg} is consistent in run (2), (3) and (4). Therefore, it is valid to assume an average value n_{bg} for the background correction of run (1). The average value $n_{bg} = 12 \pm 5$ is consistent with that from ref. [18] for non pre-etched CR-39 material and shows, that a plastic foil is a reasonable protection.

Table 2: $\alpha-$ particle track densities for different radon exposures. The background track density from run (1) is the average value obtaind from run (2), (3) and (4).

number of run	exposure (kBq/m^3 h)	n (tracks/cm^2)	n_{bg} (tracks/cm^2)	$\Delta n/n$ (%)
1	6653.7	$(10.5 \pm 2.5) \times 10^3$	12 ± 5 *	22
2	130.7	198	7 ± 7	23
3	365.7	506	17 ± 6	21
4	404.1	506	11 ± 12	22

In order to determine the average track density for each exposure some care has to be taken on the data. In Figure 4 (a) and 4 (c), i. e. run (1) and (3), respectively, one data point does obviously deviate to higher track densities in a non statistical way. A possible explanation is, that the fibreglass filter was not properly placed inside the cover during exposure. This leads to a higher contribution of extern produced radon daughters inside the dosemeter, especially of ^{214}Po, which, due to the higher $\alpha-$ particle energy, results in a stronger component of small tracks as it might be seen in Fig. 5 (b). Compared to part (a) there is indeed a higher yield of small tracks. Therefore, the fourth detector of run (1) and at least the seventh detector of run (3) have to be discarded.

The respective efficiency ϵ as a function of radon exposure is shown in Fig. 6. The data implies an almost constant efficiency at this level of accuracy. Thus, a simple averaging is appropriate leading to

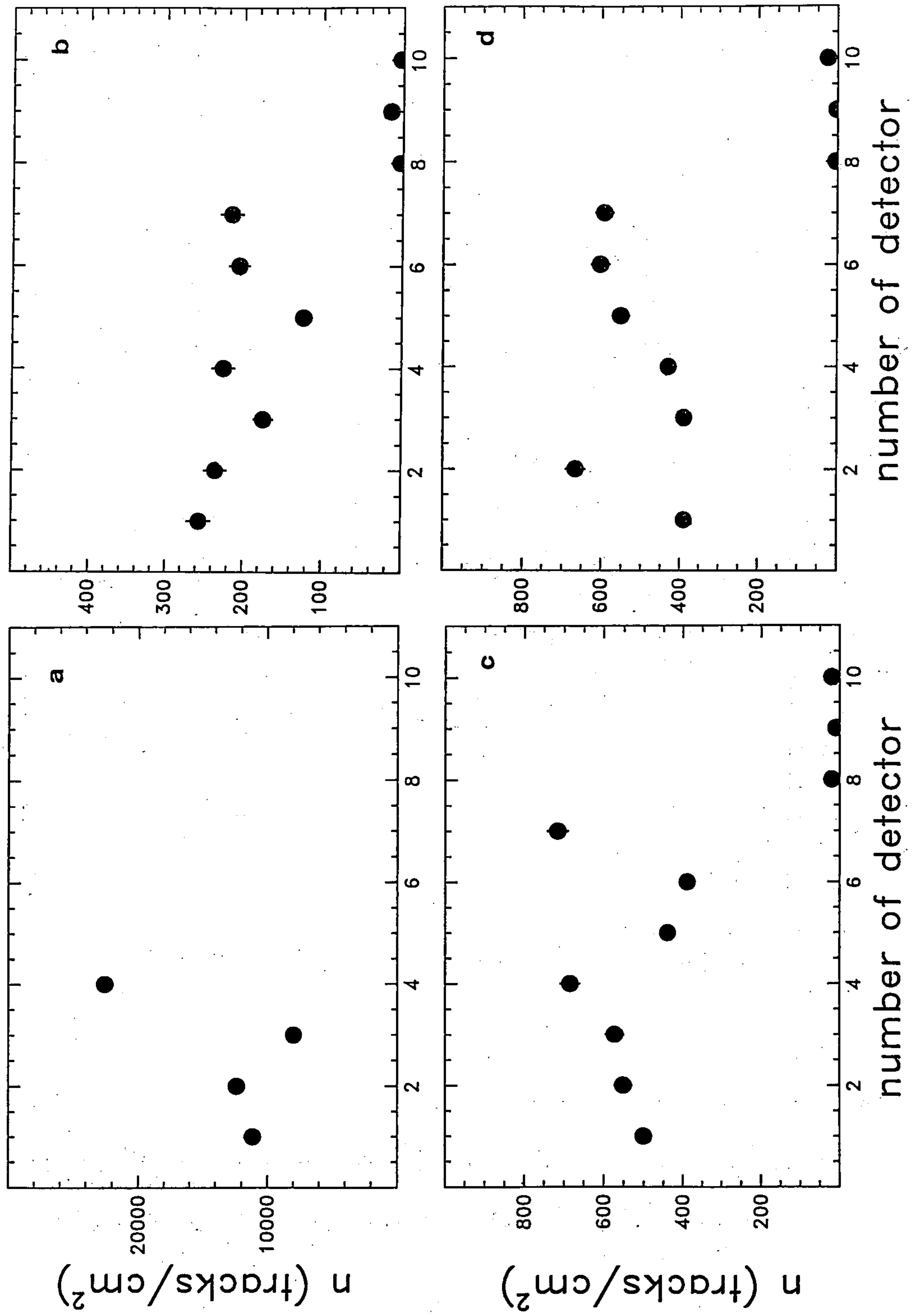

Fig. 4: $\alpha-$ particle track density as a function of the detector number obtained by image processing. The labels (a)-(d) correspond to numbers (1)-(4) in Tab. 1.

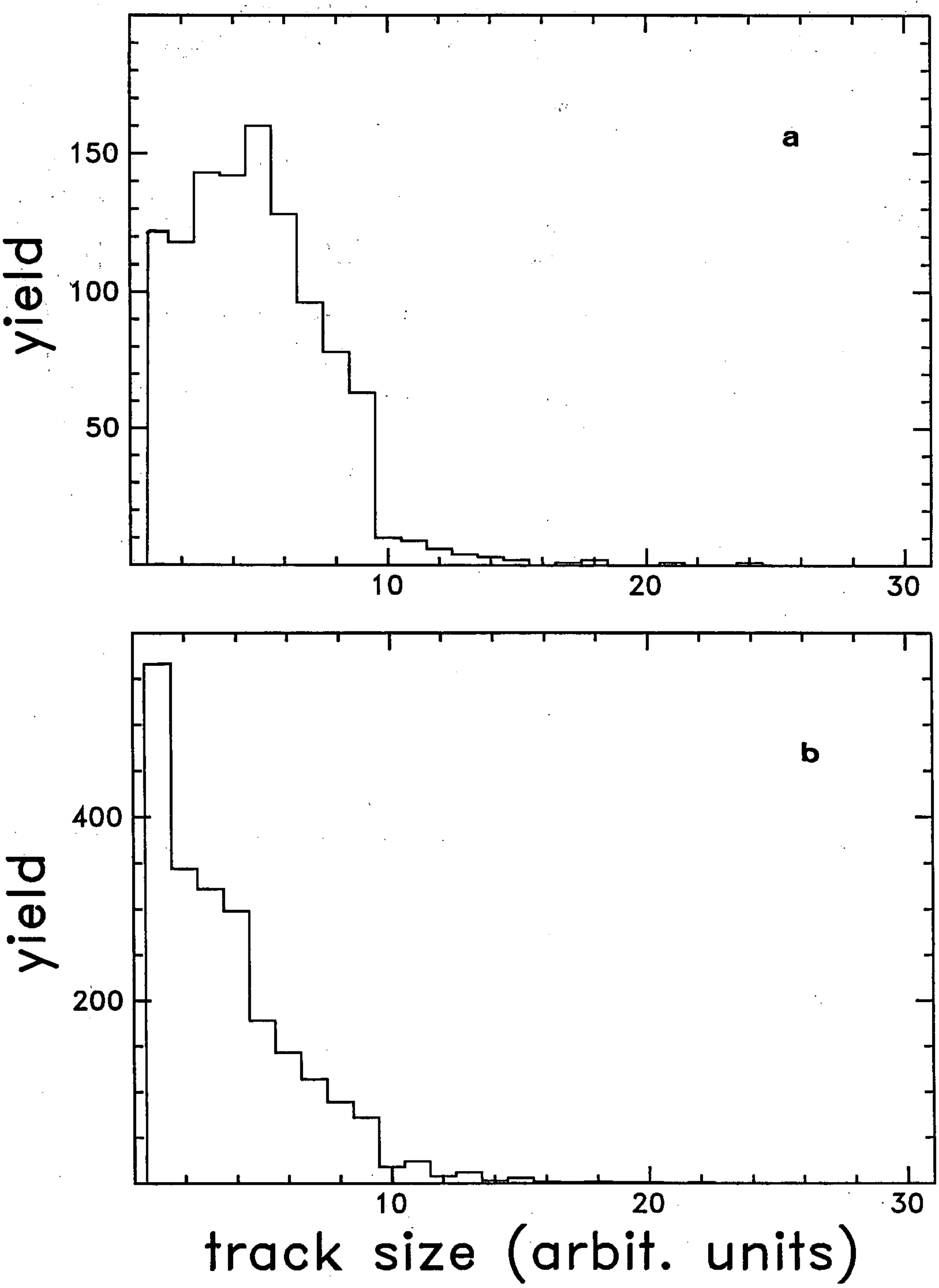

Fig. 5: In part (a) a characteristic track area-distribution is shown consisting of two components. In part (b) the respective distribution for detector (4) from run (1) is displayed showing a strong enhanced component of small areas due to a higher contribution of high energy $\alpha-$ particles from ^{214}Po (see text).

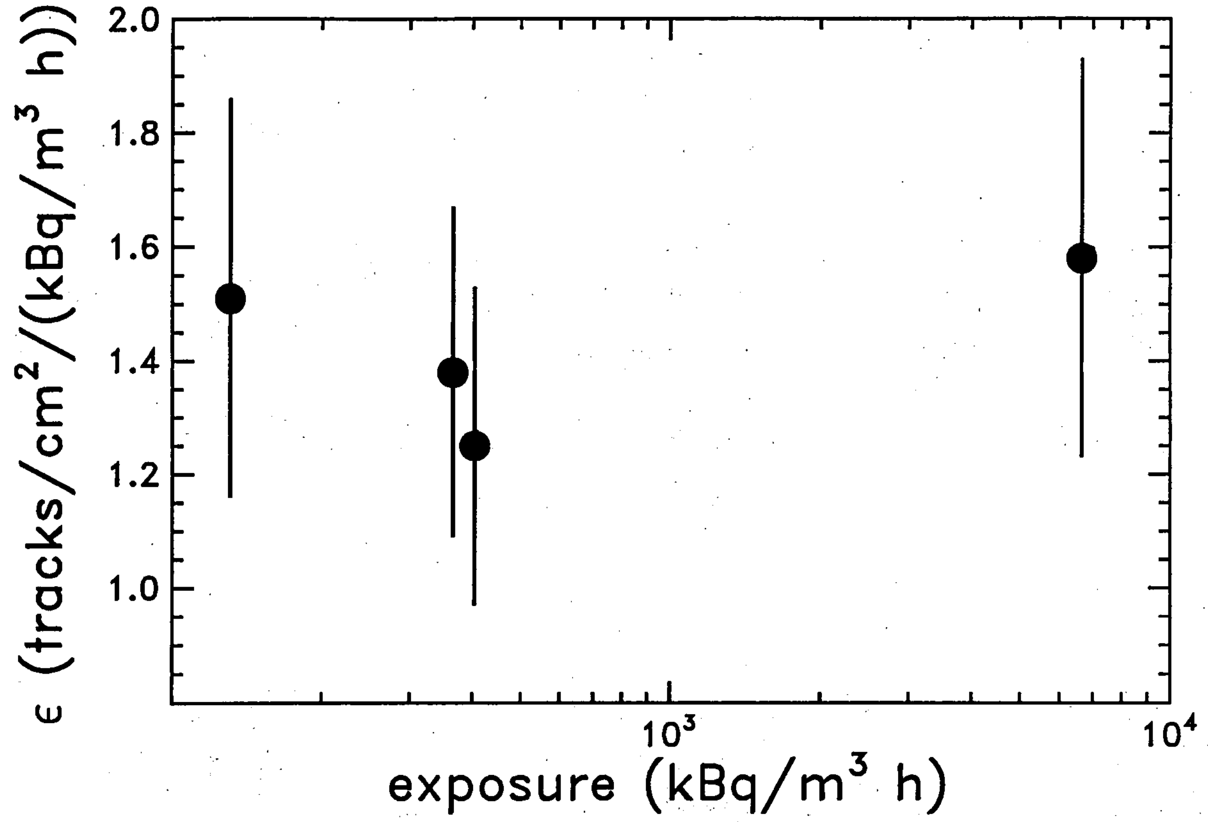

Fig. 6: Efficiency of the personal radon dosemeter as a function of the radon exposure for image processing based track-counting.

$$\epsilon = 1.43 \pm 0.15\,\mathrm{tracks/cm^2/(kBq/m^3h)} \quad , \tag{1}$$

within a reasonable accuracy of about 11 %.

5 Summary

At SCK-CEN the design and test of a personal radon dosemeter has been completed. The new radon dosemeter is based on $\alpha-$ particle track counting in CR-39 material and endures a rather simple handling procedure as well as a cheap storage condition. The reading-out of the detectors is performed semi-automatically with a commercially available image processing system at a reasonable speed of about 15 min per detector. The gained efficiency $\epsilon = 1.43 \pm 0.15$ tracks/cm^2/(kBq/m^3 h) is about 3 times higher than that of the widely used Karlsruhe-type dosemeter based on polycarbonate track-etch detectors. Therefore, average radon exposures down to 200 Bq/m^3 could be monitored within the required period of 170 h at an accuracy of better than 20 %. With additional investigations concerning e. g. an extra cleaning applied to the detector material before exposure and the cutting technique it might be expected to increase the dosemeter's efficiency by at least 50 %.

Finally, it has to be noted, that with the acquired knowledge and experience in detector handling as well as analysis technique during this project, the SCK-CEN would be able to set up a measurement service at general disposal.

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Appendix

(A) List of the image processing sequence , which is repeatedly called for each detector segment until the condition (field = number of fields) is fullfilled.

Routine Header :

Number of fields: 30

Standard frames

Results header:

Date and time, Measured units

User name: "...

Specimen ID : ...

Frames :

Image frame (x0, y0, width 512, height 470)

Measure frame (x8, y8, width 498, height 458)

Calibrate (1.195402 microns per pixel)
Image setup (Camera 1, gain 40, offset 66, Volts 50)
Pause (Buttons, 'select next area')
Acquire (into Image1)
Grey util (copy Image1 to Image2)
Detect (blacker than 182, from Image2 to binary Detected)
Binary identify (Fill holes from Detected to Detected)
Binary amend (Open from Detected to Amended, cycle 1)
Feature accept :

Area from 30. to 3000.

Aspect ratio 1. to 2.

Roundness 1. to 3.

Measure feature (plane Amended, 8 ferets, minimum area: 4)

Selected parameters : Area, Aspect ratio, Roundness

Label feature (area)
Feature Histogram # 1 (y param Number, x param Area, from 0. to 3000., linear, 30 bins)
Feature Histogram # 2 (y param Number, x param Aspect ratio, from 1. to 2., linear, 10 bins)
Feature Histogram # 3 (y param Number, x param Roundness, from 1. to 3., linear, 20 bins)
File Feature Results
File Histogram Results (# 1, statistics, bin details)
File Histogram Results (# 2, statistics, bin details)
File Histogram Results (# 3, statistics, bin details)
If (field = 30)

    Pause (Buttons, 'delete histograms')

    PauseText ('don't forget to delete all histograms !')

Endif
End