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INFLUENCE OF EXPOSURE GEOMETRY ON THE RESPONSE OF CR39 SSNT RADON DETECTORS*

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Abstract. A number of about 130 solid state nuclear track detectors (SSNTD) of CR39 type were exposed in controlled conditions in a Radon Exposure Calibration chamber. The purpose of the work was to study the dependence of the response of the detector to the exposure conditions. Identically shaped CR39 detectors were placed in open cylindrical cups of various geometries (height and diameter). For each geometry the side surface of the detector cup was coated with three materials, paper, plastic and aluminum. The effect of the coating of the detector cup on the plate-out of the radon decay products, as well as on the detector response was investigated for each geometry of the detector cup. The dependence of the response on the geometry of the cup was also studied.

Key words: CR39, SSNTD, radon detector.

1. INTRODUCTION

Approximately half of the human exposure to natural radiation is due to the airborne short-lived progeny of the indoor radon gas (^{222}Rn) [1,2]. The radon gas is originated from the ground and other materials containing its predecessor, ^{226}Ra. In fact, there are different radioisotopes of radon. The most commonly discussed three radioisotopes are ^{222}Rn, ^{220}Rn (thoron) and ^{219}Rn, which are members of the natural radioactive decay series of ^{238}U, ^{232}Th and ^{235}U, respectively. Among these three radioisotopes, ^{222}Rn is the most important due to its longest half life of 3.825 d. Therefore, when radon is used without specification of a particular radioisotope, it is usually referring to ^{222}Rn. Being an inert noble gas, ^{222}Rn may diffuse from the place of formation and penetrates the boundary surface with the air. Accumulation

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of ^{222}Rn in a closed space, like the indoor environment of a dwelling, can pose a potential health hazard.

Many research papers and books have been devoted to the studies of ^{222}Rn and its short-lived progeny. Various problems related to radon have been investigated such as the measuring techniques, radon penetration properties into houses, dose determination, health risk estimation, etc. On the other hand, radon map on some terrains may help discover underground uranium/thorium ores. It can also serve as a pre-signal for earthquakes or volcano eruptions etc.

Many different methods have been developed for radon measurement. They can be classified according to the duration as grab sampling and long-term measurements. Grab sampling methods, among which the best known is the use of scintillation cells, give information on the ^{222}Rn concentration in a relatively short period of time. However, the airborne ^{222}Rn concentration is subjected to variations so the knowledge in a relatively short period of time might not be representative of the average concentration. In contrast to grab sampling, long-term measurements take much longer time and the average ^{222}Rn concentration during the exposure period can be acquired. The most often used long-term methods are based on Solid State Nuclear Track Detectors (SSNTDs) and activated charcoal canisters. These two methods do not require any power supply during the operation so that they belong to the group of passive methods.

To determine the radon concentration from SSNTD readings (which is the track density, or the number of tracks per unit area), one needs to know the detector sensitivity that relates the track density to the total exposure of the detector to radon and its progeny. Experimental determination of this sensitivity, *i.e.*, calibration of these detectors for radon and progeny measurements is carried out by exposing them to known concentrations of radon and/or its progeny in a radon exposure chamber.

Calibration should be carried out with the same procedures as those followed in the real life measurements (including procedures for detector processing and readout).

2. THE PRINCIPLE OF SSNTDs

Heavy charged particles, such as alpha particles, light and heavy ions or fission products, cause extensive ionization when they pass through a medium [3,4]. This primary ionization triggers a series of new chemical processes that result in the creation of free chemical radicals and other chemical species. Along the path of the alpha particle, a zone enriched with free chemical radicals and other chemical species is then created. This damaged zone is called a latent track and can remain stable for many years in some dielectric materials.

If a piece of material containing latent tracks is exposed to some chemically aggressive solution such as NaOH or KOH, chemical reactions would be more intensive along the latent tracks. The overall effect is that the chemical solution etches the surface of the detector material, but with a faster rate in the damaged region. In this way, a track (or sometimes called pit) of the particle is formed, which may be seen under an optical microscope.

One of the most commonly used SSNTDs is the CR-39 detector, which was based on polyallyldiglycol carbonate and was discovered by Cartwright *et al.* [5].

3. EXPERIMENTAL SETUP

In our work 136 SSNTD of CR39 type were exposed in the calibrated Radon Chamber of the Federal Office for Metrology and Surveying (BEV) [6]. Austrian Radon standard is a secondary standard, calibrated at PTB, Braunschweig (Germany). The calibrated Radon chamber is situated in a windowless, gastight cellar room. It is built of stainless steel panels to avoid electrostatic effects. The chamber is 11.4 m^2 and 27 m^3. The entire interior (tables, installations, air conditioning facilities) inside the chamber is made of stainless steel. The temperature inside the chamber was 21.71^{o}C and humidity 93.73%. ^{222}Rn source is provided by ARSENAL Research GmbH. The activity concentration of ^{222}Rn in chamber air was continuously surveyed by two AlphaGUARD PQ2000PRO devices, manufactured by Genitron Instruments GmbH (Germany). The average activity concentration in the chamber air was 2081 Bq/m^3.

In order to study the influence of exposure geometry on the response of CR39 detector open exposure chambers of cylinder type with different diameters (2, 3 and 4 cm) and heights (2, 3, 4 and 5 cm) were prepared. Three detectors were exposed in each geometry, for 91 hours and 45 minutes in the calibrated Radon Chamber.

After the exposure of CR39 SSNTD in the calibrated Radon Chamber, all detectors were etched in a specially designed bath with stable etching solution temperature and blender (Radosys GmbH, Hungary). Etching solution was prepared with 4 liter of water and 1 kg of NaOH. Etching was performed at 90^{o}C for 4 hours and 15 minutes. In these conditions, we obtained the bulk etching velocity of 3.89 µm/h.

CR39 response was read using RadoMeter 2000 system. This system consists of a microscope and a controller computer. The microscope unit has a B&W CCD camera with 100× optical magnification.

On each detector the microscope read one area about 47mm^2 divided in 12×12 fields. In Fig. 1 an image of one field obtained with this reading system is shown. Counted tracks are encircled in Fig. 1. Track shape is circular for normal incident particles, and has an elliptic shape for particles entering in the detector under an angle greater than the critical angle. From this image we can see that the reading system counts only tracks with the diameter in the range of 11 to 33µm; over-etched tracks are not counted.

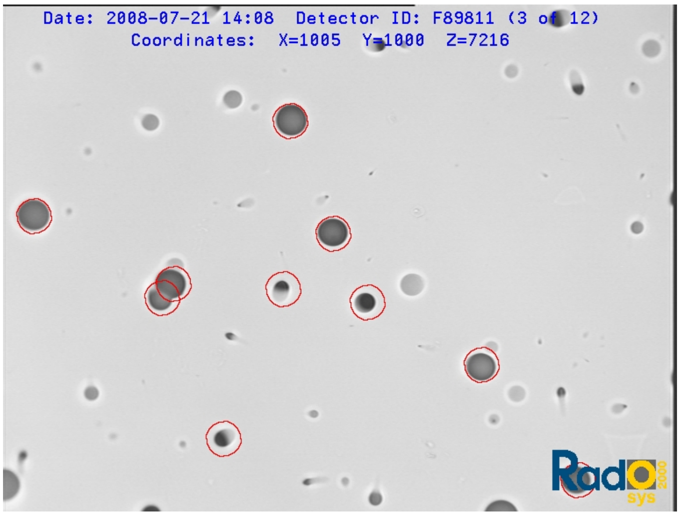

Fig 1 – Image of one reading field obtained with Radosys reading system.

4. RESULTS AND DISCUSSIONS

The track densities registered by the CR39 detectors exposed in the calibrated Radon Chamber were measured using the Radosys system. We observed that the track density depends on the geometry of the exposure chamber and on the material applied for coating the side walls of the chamber.

In Fig. 2 the dependence of the track density on the diameter of the chamber is represented for various heights (5 cm, Fig. 2a; 4 cm, Fig. 2b; 3 cm, Fig. 2c; and 2 cm, Fig. 2d) of the chamber. In Fig. 3 the dependence of the track density as a function of chamber heights for diameters of 4 (Fig. 3a), 3 (Fig. 3b) and 2 cm (Fig. 3c) respectively, is represented.

The non-linear dependences of track density on chamber geometry are explained by the opposite effect of track density variation due to the variation of the sensitive volume and to the variation of the contribution due to the plate-out effect. Both effects are sensitive to geometry modification. For example considering a chamber with constant diameter, the volume from where the alpha particles emitted by ^{222}Rn disintegration that can produce counted tracks decreases with increasing the height of the exposure chamber. On the other hand, the contribution of tracks resulting from disintegration of the ^{222}Rn daughter particles deposited on the wall of the exposure chamber increases with chamber height. The magnitude of each type of variation depends on the diameter of the exposure chamber. Calibration factors obtained in these conditions for different exposure chambers are in the range from 4.24 10^{+3} to 11.71 10^{+3} [Bq m^{-3} h / mean density track mm^{-2}].

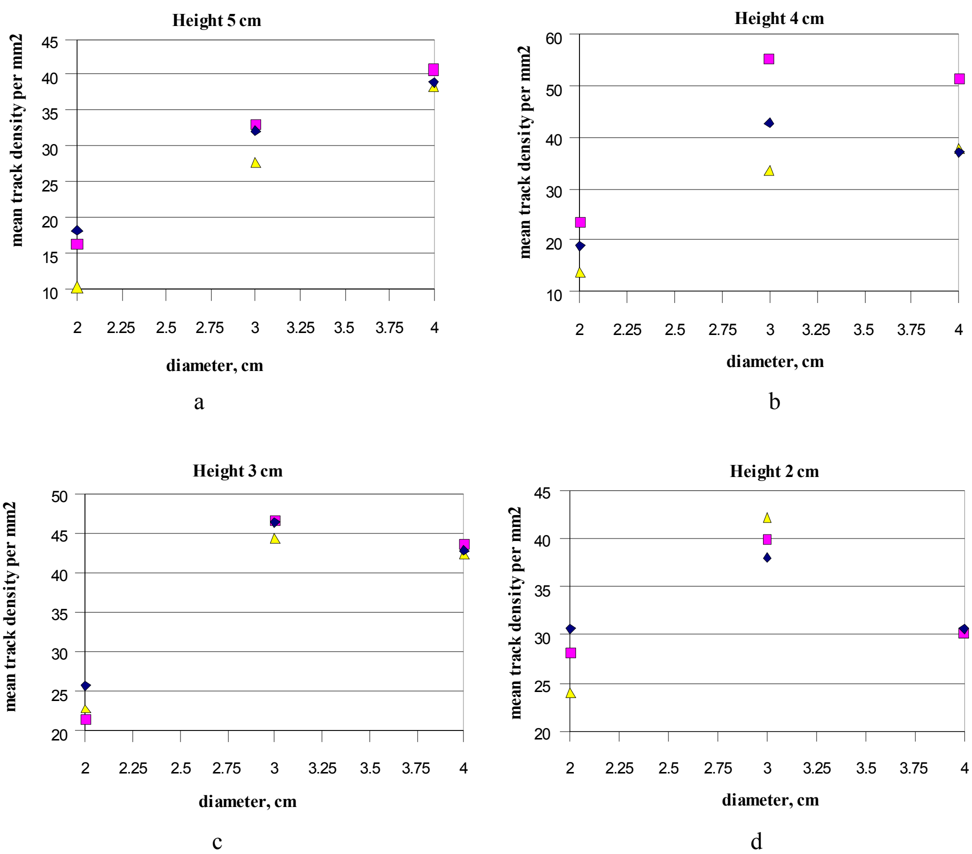

Fig. 2 – Track density for exposure chambers with heights of 5 (a), 4 (b), 3 (c) and 2 cm (d) as a function of chamber diameter for chamber wall coated with paper (rhombus), plastic (square) and aluminum (triangle).

For quantitative explanation of these effects it is necessary to know the characteristics of the alpha particles (incident energy, angle of incidence) that lead to counted tracks in the exact conditions of this experiment (exposure, etching, track counting using the Radosys instrument). These characteristics were established by simulation of track evolution during the development of the etching process using TRACK_TEST computer program developed by D. Nikezic and K.Yu [7, 4]. The program needs setup input data: alpha particle incident energy, angle of incidence, bulk etching velocity. The program permits visualization of the shape of the etched tracks and the assessment of the parameters (major and minor diameter, track length).

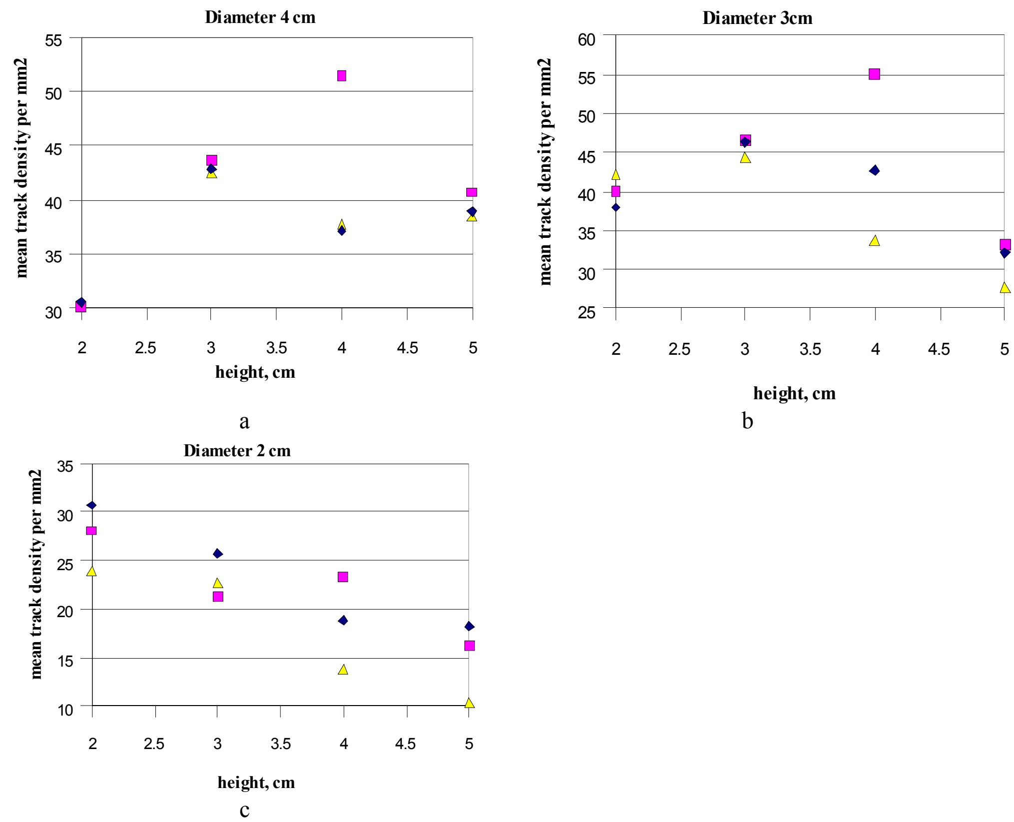

Fig. 3 – Track density for exposure chambers with diameters of 4 (a), 3 (b) and 2 cm (c) as function of chamber height for chamber wall coated with paper (rhombus), plastic (square) and aluminum (triangle).

In Fig. 4 the variation of the critical angle (in fact the cosine of the critical angle) as a function of alpha particle energy at the entrance of the exposed detector is represented. The critical angle represents the minimum incidence angle (with respect to the detector surface) that an alpha particle with given energy E should have when impinging on the detector in order to produce tracks that are counted.

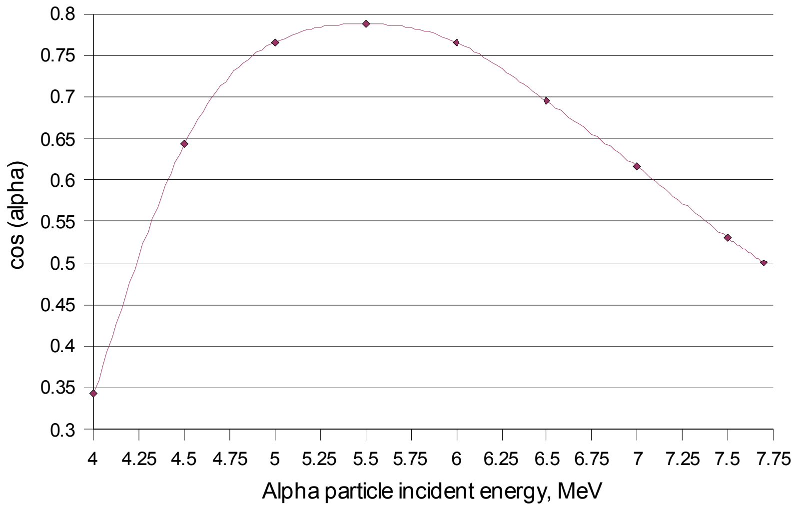

Fig. 4 – Critical angle variation as a function of incident alpha particle energy at the detector surface.

For the future work we intend to develop a Monte Carlo simulation code similar to that previously reported [8,9], to be applied for the computation of the calibration factor in the specific conditions of this experiment.

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