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Traceability of CDs/DVDs used as retrospective ^{222}Rn detectors to reference STAR laboratory

D. Pressyanov [a,*], E. Foerster [b], S. Georgiev [a], I. Dimitrova [a], K. Mitev [a]

[a] Sofia University St. Kliment Ohridski, Faculty of Physics, 5 James Bourchier Blvd., Sofia, Bulgaria
[b] Radon Calibration Service Laboratory, Federal Office for Radiation Protection (BfS), Berlin, Germany

HIGHLIGHTS

- A procedure to ensure traceability of retrospective ^{222}Rn measurements by CDs/DVDs is proposed.
- A real traceability-chain to a primary ^{222}Rn standard through certified STAR laboratory is demonstrated.
- Seven sets of CDs/DVDs were exposed to four reference integrated ^{222}Rn concentrations.
- The relative bias in all 7 groups varied from 3.4% to 23.4%.

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ABSTRACT

The practical applications of the method for retrospective ^{222}Rn measurements by home stored CDs/DVDs need a proper metrological assurance. The specific feature of this method, as compared to other methods for retrospective ^{222}Rn measurements is the possibility for an individual a posteriori calibration of the used CD/DVD-detectors. This paper describes a procedure to ensure the traceability of this method to a reference STAR laboratory. A set of 7 groups of CDs/DVDs were exposed to 4 reference ^{222}Rn exposure levels. After that they were treated in the etching laboratory as "real" detectors and the ^{222}Rn concentrations were determined by applying an individual a posteriori calibration, correction for high track density and correction for depth at which the alpha tracks were etched. The results from all 7 groups of exposed detectors demonstrated relative variation from the reference values in the interval 3.4–23.4%. The results provide evidence that the routine measurements by the CD/DVD method warrant measurements with a relative uncertainty better than 25% and therefore this method is acceptable for large-scale applications.

1. Introduction

The method for retrospective measurements of ^{222}Rn based on CDs/DVDs was first proposed in 2001 (Pressyanov et al., 2001). The method is based on the high radon absorption ability (Möre and Hubbard, 1997) and the track-etch properties (Pressyanov et al., 1999) of the material from which commercial CDs/DVDs are made (bisphenol-A based polycarbonate, trade names Makrolon®, Makrofol® etc.). When a CD/DVD (made of bisphenol-A) is exposed to ^{222}Rn (e.g. in a dwelling), ^{222}Rn is absorbed and concentrated in the disk's material (Pressyanov et al., 2009). In the volume of the disk ^{222}Rn and its short-lived progeny ^{218}Po and ^{214}Po decay and emit alpha-particles, which form tracks in the material. The key concept is to remove after the exposure a surface layer thicker than the range of the most energetic alpha-particles of ^{222}Rn and ^{220}Rn decay products and to etch electrochemically the alpha tracks at that depth. This removal warrants that any contribution from ^{222}Rn and ^{220}Rn progenies deposited on the surface is effectively removed (Pressyanov et al., 2003, 2004) and the signal (net track density) is related only to the absorbed ^{222}Rn. The conducted laboratory experiments have demonstrated that the correlation between net track density and ^{222}Rn exposure (that is the time integrated ^{222}Rn activity concentration) is almost perfect and that CDs/DVDs could serve as precise radon monitors (Pressyanov et al., 2003, 2004).

In the last decade the performance of the method was comprehensively studied by laboratory experiments and measurements in real buildings (Dimitrova et al., 2011; Pressyanov et al., 2010). It was shown that the method allows fast, inexpensive measurements to be made remotely (i.e. without visiting the place) and thus is very suitable for large campaigns (Dimitrova

* Corresponding author. Tel.: +359 2 8687009.
E-mail address: pressyan@phys.uni-sofia.bg (D. Pressyanov).

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et al., 2011). In particular, one clear benefit of the method is the possibility to make accurate measurements by performing individual a posteriori calibration of the disks. This is an important step as it allows to overcome the individual variations between different brands of disks and to ensure precise measurements. The algorithm for practical application includes the following steps:

- Collecting disks for analysis;
- A posteriori calibration – each disk is cut into several pieces. One piece is additionally exposed to reference integrated ^{222}Rn concentration;
- Chemical pre-etching (CPE) and electrochemical etching (ECE) of the pieces (one additionally exposed and one not).
- Counting tracks and data processing.

The a posteriori calibration is unique and does not have equivalents in the other methods for integrated (incl. retrospective) measurements of ^{222}Rn. Therefore, with the ongoing efforts for practical implementation of this method, there is a clear need to develop metrological procedures for calibration and quality assurance, which account for the specifics of this method. These procedures are necessary for the establishment of traceability chain from the field retrospective ^{222}Rn measurements with CDs/DVDs to the corresponding radon primary standard.

As quoted in the recent IEC standard (IEC, 2009), "the need for a reference atmosphere arises from the necessity for a complete and standardized testing, under controlled conditions, of the measuring instruments concerned". It is assumed that laboratories which satisfy the conditions requested for a system for test atmospheres with radon (STAR) will ensure traceability of much larger number of units that provide radon measurements for the public, business and authorities. The procedures to ensure STAR traceability for widely used passive detectors (e.g. alpha-track detectors, electret chambers etc.) are well described in the literature (Butterweck et al., 2002; Picolo et al., 2000; Röttger et al., 2005). However, the CD/DVD method is specific among other passive methods with the possibility for a posteriori calibration and it requires specific procedures to be developed and tested. Collaborative research was organized to address this task and to develop specific calibration/check procedures for the CD/DVD method.

The primary goal of this paper is to present a real, working procedure for traceability assurance in the case of ^{222}Rn measurements with CDs/DVDs. The procedure is intended for laboratories which perform ^{222}Rn measurements by etching CDs/DVDs and aim to warrant traceability of measurement results to a STAR laboratory standard. The key concept of the proposed procedure is the exposure of CDs/DVDs at reference STAR conditions and their full processing (including a posteriori calibration) in the etching laboratory. In that laboratory the CDs/DVDs are processed in a standard way as disks exposed under real conditions. The obtained results are compared with STAR reference exposure and tested for consistency. In this report a practical realization of such procedure is described and the results are presented and discussed.

2. Materials and methods

The organization of the calibration/comparison that was carried-out included three basic steps:

- Exposure of new CDs/DVDs at STAR at the BfS Radon Calibration Service Laboratory, Germany to reference ^{222}Rn concentrations. Sending the disks for processing in the etching laboratory (along with unexposed disks for background control);
- Processing the disks in the etching laboratory at the Sofia University, Bulgaria. Cutting the disks. Performance of a posteriori exposure of a quarter of each disk to another reference ^{222}Rn concentration.
- Etching pieces (quarters of the whole disk) together with the a posteriori exposed pieces. The procedure included CPE to depth about 80 μm beneath the surface and after that ECE, track counting and data processing.

Further, the technical details of each step are described.

2.1. Exposure experiments in BfS

In total 50 disks (CDs and DVDs) were exposed to four ^{222}Rn reference atmospheres for a defined period of time. The exposures were carried out at the Radon Calibration Service Laboratory at the Federal Office for Radiation Protection Bundesamt für Strahlenschutz (BfS) in Berlin, Germany (Hamel and Schmidt, 2001). The exposure duration and the mean ^{222}Rn activity concentration were chosen to cover a wide interval of integrated activity concentrations (corresponding to ten-year exposure to activity concentrations of about 70–550 Bq/m^3). Before the beginning and after the end of exposure the devices (CDs and DVDs in their cases) were stored in an automatically ventilated room with low ^{222}Rn activity concentration. It was guaranteed that after the exposure the disks were kept for at least 10 days, so that ^{222}Rn absorbed in them outgassed before re-packaging.

2.1.1. Description of the experimental facility

The reference atmospheres for the calibration exposures were created in a stainless steel calibration container with a volume of about 0.4 m^3. The ^{222}Rn activity concentration C_A within the container was adjusted once to a predetermined value by a singular injection of ^{222}Rn gas via the following procedure:

1. A ^{222}Rn sample is drawn from a dry specific ^{226}Ra-source into an evacuated syringe.
2. The gamma activity of the whole content of the syringe is measured.
3. The volume of radon gas, which is needed to achieve the required value of C_A, is calculated and injected once into the calibration container.

To continually compensate the loss of ^{222}Rn due to the radioactive decay, a flow-through source containing ^{226}Ra is connected to the container. By means of pumps and ventilators the activity concentration of ^{222}Rn within the container can be kept sufficiently homogenous and temporally constant during the exposure time. The container is equipped with a flow-through scintillation cell for the measurement of ^{222}Rn activity concentration and with sensors to measure the temperature and humidity. All parameters are monitored and registered every 10 min using a control panel.

Additional measurements of the ^{222}Rn activity concentration are carried out by manual sampling from the reference atmosphere into evacuated scintillation cells every working day to check the monitored data and to secure redundancy. The flow-through scintillation cells and scintillation cells for manual sampling are used as working standards of the calibration laboratory. They are regularly recalibrated against the reference standard of the calibration laboratory, a commercially available radon measurement device of the type AlphaGUARD® (Genitron GmbH, Germany). The reference standard is directly traced back to the national standard at the German Metrology Institute *Physikalisch-Technische Bundesanstalt (PTB)*.

2.1.2. Exposure conditions

The 50 disks were divided into four exposure groups. Each exposure group was exposed to a reference ^{222}Rn atmosphere for a