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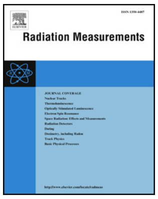

Passive radon monitors with part-time sensitivity to radon

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ABSTRACT

The recent European directive 59/2013 set reference levels for radon at working places. Since usually the personnel spend only part of the day (e. g. 8 h) at work, it is useful to have passive radon monitors that are sensitive only within a certain time window (e. g. the working hours). This work proposes a conceptual design of such a monitor and tests the feasibility of the approach. The design is based on a solid state nuclear track detector (SSNTD) that rotates over a radon absorber during the monitored period of the day. The SSNTD (Kodak Pathe LR-115 type II) has an energy window that makes it insensitive to ^{222}Rn and ^{220}Rn progeny plated-out on the surfaces. It only registers alpha particles of the absorbed ^{222}Rn and its short-lived progeny ^{218}Po, which is achieved by optimization of the absorber thickness. The absorber construction is further optimized to decrease the inertia of the signal. The modeling and the pilot experimental results show that with a composite absorber consisting of a stack of Makrofol N foils with thickness of less than 7 µm each, the inertia of the signal is less than 20 min. The estimated minimum detectable activity concentration (MDAC) for the proposed ^{222}Rn monitor is about 15 Bq m^{-3} for year-long working time exposure (2000 h/year) or 60 Bq m^{-3} for 3- month exposure period (500 h).

1. Introduction

The recent European directive (Council Directive, 2013) requests the European Union member states to set reference levels for the annual average ^{222}Rn concentration at working places that should not be higher than 300 Bq m^{-3}. While the occupational radon monitoring was considered as necessary part of the health physics service in the mining industry (uranium mining and milling, in particular) for many years, now radon surveys have to be planned in much larger number of working places. In underground mines 24 h shaft work is organized without large diurnal variations in the ventilation and radon levels, but the radon monitoring is challenged by the usually severe working environment (high humidity, dust, gases etc.). In contrast, most of the working places where occupational radon monitoring has to be initiated, like offices, commercial centers, schools etc., have "normal" indoor environment. The temperature and humidity there are close to these at normal room conditions, however, the personnel usually spends only part of the day (e. g. 8 h) at work. In such cases the "annual average" should refer to the occupancy time of the year. Up to now passive radon detectors provide signal that is integrated over the total duration of exposure (24 h per day). This can introduce bias in the workers' exposure estimates as the radon levels can vary significantly with time due to both the natural diurnal variations and the specific ventilation conditions (e.g. ventilation being switched on only during the working hours). To address this challenge, it would be useful to have passive radon monitors that are sensitive to ^{222}Rn only within a certain time window (e. g. the working hours). Ideally, such a monitor would only gather signal within the working time window and have zero sensitivity the rest of the time.

Recently, a novel design of passive ^{222}Rn monitors has been proposed (Tommasino et al., 2009) and studied theoretically (Pressyanov, 2011) and experimentally (Pressyanov et al., 2013; Tommasino et al., 2017). It employs foil of material that has high radon absorption ability (e.g. bisphenol-A based polycarbonate) coupled with a SSNTD. The SSNTD faces the foil that serves as ^{222}Rn radiator of α-particles. Based on this concept, herewith we propose a unique type of passive radon monitor that gathers signal only during a given time period each day. The monitor can be preconfigured (e.g. to be sensitive during the working hours of the monitored personnel). The approach utilizes a segment of absorber foil fixed on the metal holder and a piece of SSNTD that rotates uniformly with 1 rot/24 h, so that it faces the absorber/radiator only within the working time window. The results from experimental studies and theoretical modeling aiming to optimize this new radon monitor and test its feasibility are presented. At this pilot stage the monitor is designed to work mostly at close to the typical room environmental conditions, but the potential to expand its capacity

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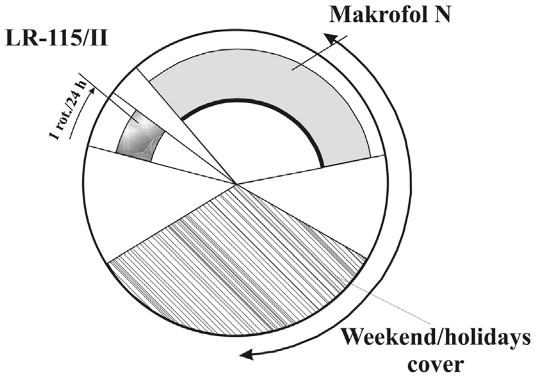

Fig. 1. Conceptual design of the proposed passive monitor with part-time sensitivity to radon consisting of a SSNTD detector (LR-115/II) rotating over radon absorber (Makrofol N). The cover serving to exclude longer time periods like holidays is optional.

for places with more severe environment is also discussed.

2. Concept

The basic concept is to arrange a SSNTD that faces the source - "radon absorber/radiator" only during specified time intervals (e.g. working hours). While various technical realizations of this concept are possible, in this paper the design shown in Fig. 1 is considered. A piece of Kodak Pathe LR-115/II detector rotates with a frequency of one rotation per 24 h. During that time the detector faces the radon-absorbing radiator only within the time window of interest (e.g. working hours). Outside this window the detector faces the metal holder surface. On that surface there are plated-out atoms of ^{222}Rn progeny and potentially ^{220}Rn progeny. However, the energy of their alpha particles is higher than the upper energy for track registration of this kind of detectors and they will not produce etched tracks. Additional cover can "close" the foil during holidays (Fig. 1). Therefore, the detector signal is produced only during the time it faces the Makrofol N absorber/radiator.

The material Makrofol N was chosen for its excellent radon-absorption characteristics. At room temperature this material has a partition coefficient (dimensionless measure for solubility) for radon of 112 ± 12 and diffusion length for ^{222}Rn of 39 ± 1 μm (Mitev et al., 2016). The chosen detectors were of Kodak Pathe LR-115 type II (energy window: $E_{min} = 1.5$ MeV; $E_{max} = 4.0$ MeV and critical angle to the normal of the detector surface 55°, similar values have been reported by other authors (Barillon et al., 1997)). The energy window of the detectors used is well below the energies of ^{222}Rn and ^{220}Rn progenies' alpha-particles (the energy of alpha particles of different isotopes are as follows: ^{222}Rn: 5.49 MeV, ^{218}Po: 6.0 MeV, ^{214}Po: 7.69 MeV; ^{220}Rn: 6.29 MeV, ^{216}Po: 6.78 MeV, ^{212}Bi: 6.05 and 6.09 MeV, ^{212}Po: 8.78 MeV). The selected distance between the absorber and the detector is small (1–2 mm), so that α-particles emitted by parts of the foil not immediately above the detector cannot reach the detector at an incident angle smaller than the critical and cannot be detected.

Theoretical modeling and experimental research was carried out to clarify the feasibility of this approach and to optimize it in terms of sensitivity and getting a response that follows closely (within minutes) the "ideal one". The results of the pilot modeling and experimental study are presented and discussed.

3. Modeling

Most of the passive detectors when placed suddenly from "low" to "high" radon levels (or vice versa) demonstrate some inertia in the detector response for the time needed for ^{222}Rn and its progeny to re-equilibrate in the detector/detector volume. If the α-particles of ^{214}Po (^{214}Bi + ^{214}Po) contribute to the signal this transitional time can be as long as 2–3 h and a bias can be incurred because of this. As the absorber foil serves as a "source" of α-particles that bombard the detector, we first modeled the time dependence of the absorbed ^{222}Rn and its progeny concentrations in the foil after the start, during and after the end of ^{222}Rn exposure. As shown elsewhere (Tommasino, 2010; Pressyanov 2011), instead of a single foil a "composite" absorber can be used, in which several thin foils are stuck together non-hermetically, so that radon can penetrate freely between them. In this way, the absorber volume and the absorbed activity are increased while the absorption/desorption kinetic is as fast as that of the thin foils that compose the absorber. When the foils are sufficiently thin with respect to the diffusion length of radon inside them, the absorbed activity distribution is practically uniform (Pressyanov, 2011).

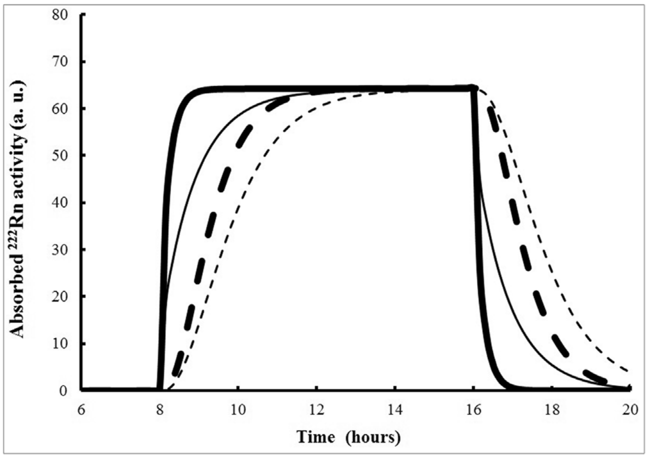

Fig. 2. The profile of ^{222}Rn (solid lines) and ^{214}Bi + ^{214}Po (dashed lines) activity in absorbers of 2 × 5 μm (thick lines) and 10 μm (thin lines). In this scale the profile of the ^{218}Po activity lies very close to that of ^{222}Rn activity.

We considered foils of Makrofol N. The radon sorption/desorption process was modeled using the analytical expressions given in (Pressyanov et al., 2009) and the corresponding change in ^{222}Rn decay products activity by combining these expressions with the radioactive decay chain equations (Pressyanov, 2002). Fig. 2 illustrates the time dependence of the radon activity in foils with thickness of 5 μm (stack of 2 foils of 5 μm each) and 10 μm exposed to radon. The ambient ^{222}Rn activity concentration was considered as constant (non-zero) within 8:00–16:00 time window and zero the rest of the day. As seen, the profile of the absorbed activity can get very close to that of the ambient ^{222}Rn concentration when the thickness of the single foil in a stack if foils is 5 μm (or less). The profile of ^{218}Po activity is very close to that of ^{222}Rn, but ^{214}Po (^{214}Bi + ^{214}Po) needs more time to reach equilibrium. If the signal due to ^{214}Po is not discriminated, there will always be inertia in the detector response of the order of minimum 2–3 h.

However, within the present approach the contribution of ^{214}Po alphas to the detector signal can be discriminated by using the energy window for registration and finding the proper thickness of the composite absorber. The absorber thickness influences the energies with which the alpha-particles produced by the absorbed radon and its progeny leave the absorber. Therefore, the absorber thickness influences the registration efficiency of the absorber-detector system for each of the alpha-emitting radionuclides. The registration efficiency was modeled for composite absorbers of different thickness assuming a uniform distribution of the activity inside. It was considered that the alpha-particles move in straight lines and they are detected if they leave the absorber with energy within the energy window of the SSNTD. The loss of energy in the small air gap between the absorber and the detector was neglected (less than 0.17 MeV for the less than 2 mm wide gap). To estimate the calibration factor (CF = net-track density/integrated radon concentration), the registration efficiency and the partition coefficient of radon in the absorber material, (which