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Determination of the characteristic limits and responses of nuclear track detectors in mixed radon and thoron atmospheres

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HIGHLIGHTS

- Analysis of exposure in reference atmospheres according ISO 11929.
- Calibration of nuclear track detectors for ^{222}Rn and ^{220}Rn.
- Calculation of cross-correlation by calibration in pure ^{222}Rn and ^{220}Rn atmospheres.
- Thoron activity concentration should not be omitted in radon exposure determinations.

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ABSTRACT

Closed nuclear track detectors are widely used for the determination of Rn-222 exposures. There are also partial open systems available, which are specially designed for the determination of the exposure to Rn-220, which is a relevant exposure in special workplaces or in specific regions of the world. This paper presents data and a detail analysis of how to determine the cross-correlation by calibration in pure Rn-222 and pure Rn-220 atm. By these means calibration coefficients for the analysis of real mixed atmospheres can be obtained. The respective decision threshold, detection limit and limits of the confidence interval were determined according to ISO 11929 (ISO 11929:2010, 2010).

The exposure of detectors was performed at the radon reference chamber and the thoron progeny chamber of the Physikalisch-Technische Bundesanstalt (PTB). The analysis of track response was done at Parc RGM, while the analytical routines were developed in the Leibniz University Hanover, Institute Radioökologie und Strahlenschutz IRS at the working Group AK SIGMA (Arbeitskreis Nachweisgrenzen).

1. Introduction

The measurement of the Rn-222 exposure will in most cases be influenced by the presence of Rn-220. This is not an uncertainty to be taken into account but an error to be corrected – but the correction has an associated uncertainty influencing the final result.

Implementation of the ISO 11929 standard (ISO, 11929) for mixed exposures to Rn-222/Rn-220 is relevant to the determination of the exposure to Rn-222 and Rn-220 with adapted passive detector systems, each with the appropriate background. This is an exceptional case that has not been dealt with to date. This paper describes exposures of two types of nuclear track detectors (radon and thoron type) that were carried out at PTB's radon reference chamber and thoron progeny chamber with different activity concentrations. The exposure was followed by the analysis of the track densities. An analytical system based on the ISO 11929 was implemented finally. This is, in principle, applicable to all kinds of passive radon measuring systems. Moreover it is capable to optimize exposure plans.

2. Reference exposure of radon and thoron nuclear track detectors

A reference exposure has to have a traceability chain to a primary standard, in this case a reference atmosphere. These reference atmospheres are used to calibrate active monitors (secondary standards) for the exposure control in the chambers.

In case of Rn-222, the creation of reference atmospheres based on a radon gas standard (Picolo, 1996; Dersch, 1998) became a standard procedure worldwide (Paul et al., 2000, 2002). This

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procedure is limited in its usage for the calibration of commercial devices to activity concentrations above 1000 Bq/m^3, because the measurement uncertainty of the commercial devices is too large due to the limited statistic of counts in their active volumes. To close this metrological gap, time constant reference atmospheres below 1000 Bq/m^3 have been generated to perform long-term calibrations ($t \geq 5$ days) of commercial devices. With the development of the low-level radon reference chamber (Linzmaier, 2012), constant activity concentrations from 1900 Bq/m^3 down to 150 Bq/m^3 are available. For this purpose, several emanation sources have been manufactured. These emanation sources generate a reference atmosphere of a constant activity concentration in the low-level radon reference chamber. The emanation coefficients of the sources are measured and analyzed according to the count rate approach of a gas-tight closed Ra-226 source and a Rn-222 emanating Ra-226 source. Thus, for the first time, the calibration of commercial radon devices was possible in constant reference atmospheres and therefore small uncertainties were reached. The relative uncertainty for the radon activity concentration C at approximately 360 Bq/m^3 is $u(C)=2\%$ for $k=2$.

In case of Rn-220, a reference atmosphere has been available since 2009: This primary standard is based on a certified activity standard of Th-228, a certified known volume and measurement of the Rn-220 emanation factor for the activity standard, which is determined on-line and continuously over the whole time of calibration (Röttger et al., 2010). The Rn-220 gas emanating from the Th-228 source is determined by an online measurement via γ-ray spectrometry by the disequilibrium of the Th-228 activity (measured via Ra-224) and the Pb-212 activity.

The procedures described above were used to calibrate secondary standards (e.g. commercial devices, here an AlphaGuard and a RTM1688). These secondary standards provide the exposure data for the calibration of the passive detector systems in the radon reference chamber and the thoron progeny chamber for this work. By these means relative expanded uncertainties ($k=2$) of 6% to 8% and 3% can be obtained for the exposure of detectors to thoron and radon, respectively.

In this work, two types of passive nuclear track detectors have been investigated. The first type of detector consists of a standard passive Rn-222 dosimeter as utilised by Parc RGM. The second type consists of a Rn-222 dosimeter modified to enable the monitoring of both Rn-220 and Rn-222 (Figs. 1 and 2). The modification was a first attempt towards the development of a monitor pair aimed at the effective measurement of thoron exposure by gaining information of its behaviour when subjected to a range of different activity concentrations of radon and thoron. The Rn-222 detector was moulded from a dispersion of conductive carbon black in a modified polypropylene polymer (sourced from Colloids, UK). It measured 42.8 mm in diameter and 12.7 mm in height and was fitted with a TASTRACK PADC plastic element (CR39, 31.5 mm × 11.5 mm × 1.0 mm (Fig. 3)), acquired from Track Analysis Systems Ltd in the UK). The Rn-220/222 detector had in its base six holes, 2 of diameter 5.5 mm and 4 of diameter 4.4 mm, the holes covered with Cu Ni electro-conductive foam (1 mm thickness, obtained from Uvox Ltd, UK) fixed to the inside; the monitor was also fitted with a CR39 plastic element.

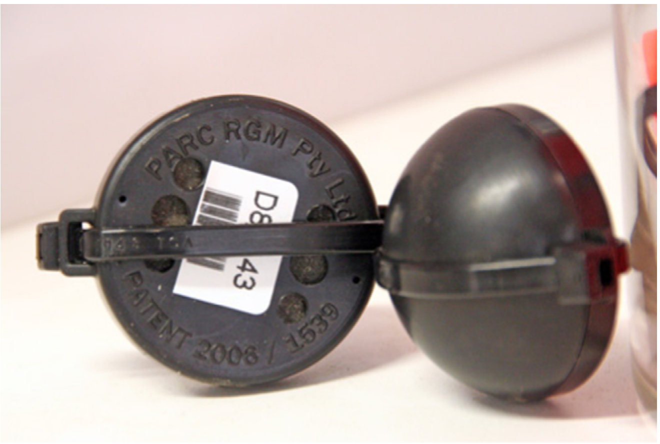

Fig. 1. A pair of radon and thoron detectors.

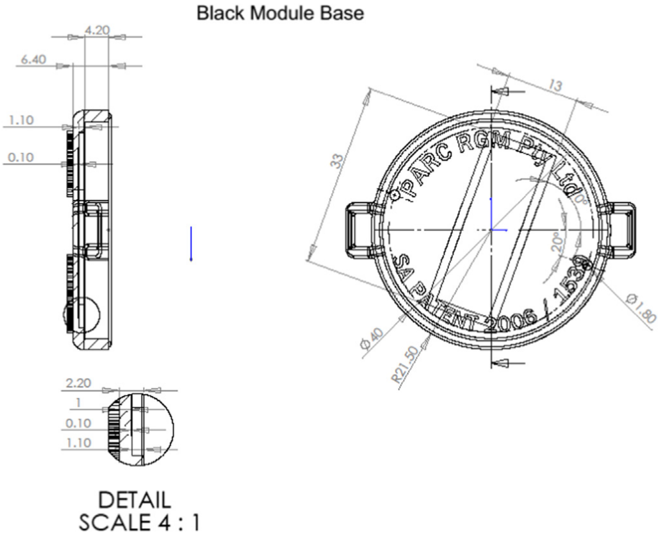

Fig. 2. Schematic drawing of the detector.

Fig. 3. Individual layout of CR-39 detector.

For exposure, the passive detectors were 120 non-indicating etch track detectors, 60 of the first type and 60 of the second type. Two detectors, one of each type, build a pair (Fig. 1) and were exposed always together to the same conditions. For exposure with Rn-220, 4 times 24 of the exposure objects were brought into the thoron progeny chamber of PTB, together with the active radon monitor RTM1688 S/N 066 which is calibrated as reference standard of PTB, and irradiated with Rn-220. For exposure with Rn-222, 1 time 16 passive detectors that were previously exposed to Rn-220, were brought into the radon reference chamber of PTB, together with the active radon monitor AlphaGuard 934, calibrated as reference standard of PTB, and irradiated with Rn-222. 24 of the 120 etch track detectors were not exposed and were available to determine the device-bound background effects. All exposures were performed at the standard (room) temperature of (21 ± 1) °C and a relative air humidity of 0.50 ± 0.05.

The resulting track density of the two types of passive detectors were obtained after etching of the plastic elements in 6.25 mol/L sodium hydroxide solution at 93.5 °C for 90 min by counting the resulting nuclear tracks with a TASL*IMAGE* radon laboratory dosimetry system (purchased from Track Analysis Systems Ltd).