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Calibration of commercial radon and thoron monitors at stable activtiy concentrations

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HIGHLIGHTS

- New calibration procedures for commercial radon and thoron monitors have been developed.
- Calibration in a constant level: emanation power of sources determined on-line.
- Activity concentrations of 200 Bq/m^3, with corresponding calibration factors.

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ABSTRACT

The upcoming revision of Council Directive 96/29/Euratom in the form of the proposed basic safety standards for protection against the dangers arising from exposure to ionizing radiation (BSS) evokes new challenges for the metrology institutes. In the case of the two radon isotopes, the corresponding public exposure will be part of legal metrology for the first time. Since the levels of activity concentration that are laid down in the draft of the BSS cover the range from 200 Bq/m^3 to 300 Bq/m^3 in general (with an exceptional top level of 1000 Bq/m^3), new calibration procedures for existing commercial monitors with their limited counting statistic have to be developed. This paper gives an overview how this metrological challenge can be overcome.

1. Introduction

The German radon measuring group at PTB maintains a research and calibration facility (Röttger et al., 2005 and Skliarov et al., 2009) for the development of new accurate techniques for measuring the activity concentration of radon, thoron and their respective short-lived progeny.

A rising level of requests for calibrations in the lower activity concentration range of Rn-222 has been initiated by the new recommended limit for radon activity concentration from the World Health Organization (WHO, 2009).

The PTB faces this situation with a shift in its calibration procedures from reference atmospheres created by a radon gas standard in a given volume towards an atmosphere created by an emanation source (including an online measurement of the emanation) in a given volume. Thus the limited statistics of commercial monitors are balanced by calibration measurements over a longer time period, which is possible only in stable activity concentrations. The metrological requirements for the creation of stable activity concentrations for radon and thoron are not identical, though. Nevertheless for both isotopes, stable atmospheres are now available at PTB.

Thus, for the first time, it is possible to compare the common aspects as well as the systematic differences in creating stable reference atmospheres as primary standards for both isotopes. The results are presented and discussed in respect of achievable uncertainties for the activity concentrations and the respective calibration factors of different monitors around 200 Bq/m^3.

Consequently, PTB started a project to develop a low level calibration facility in 2009, resulting in first calibrations of commercial devices in 2012. This development was flanked by systematic investigations of the calibration of thoron measuring devices at the thoron emanation measuring set-up (Röttger et al., 2010) in the same range of activity concentration. In the present state, at PTB the unit Bq/m^3 for both Rn-220 and Rn-222 can be realized in stable atmospheres in a range of 100 Bq/m^3 to 10 kBq/m^3 by emanation set-ups. The principal of these set-ups is expandable to higher activity concentrations as well. This offers the possibility of providing new reference atmospheres for radon calibrations without radon gas activity standards in the future.

2. Experimental set-up

The reference atmosphere is based on (1) a certified volume, (2) a certified activity standard of Ra-226 or Th-228, and (3) measurement of the Rn-222 or Rn-220 emanation factor for the activity standard, which is determined online and continuously over the whole calibration period. The emanation coefficient of the source is determined by an online measurement via γ-ray spectrometry of the disequilibrium of the activities of the respective

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isotopes in the source. The emanated gas can be transferred to the reference volume using a noble gas-tight flow cycle. Transfer can be very rapid (~0.3 s), if required. The reference volume is also equipped with a second flow cycle which can be used for the item to be calibrated. The homogeneity of the atmosphere inside the certified volume is assured by an activity distribution system.

A schematic drawing of the primary standard, the reference atmosphere for Rn-222- or Rn-220-calibration based on γ-spectrometry emanation measurements including the general connecting possibilities of systems under test, is given in Fig. 1.

In Table 1 the special requirements that have to be fulfilled for the realization of stable atmospheres either for Rn-222 or Rn-220 are summarized.

3. Realization of the reference atmospheres

The traceability of the activity concentration is given by the activity of radium A(Ra-226) or A(Th-228) in the emanation source, the emanation coefficient χ of the emanation source and the reference volume V. For practical reasons, in calibrations a factor $\varphi=1.0$ often is induced to assign an uncertainty to the homogeneity of the activity in the volume, see Figs. 2 and 3.

$$c=\frac{A\times\chi}{V} \quad \text{or} \quad c=\frac{A\times\chi}{V}\times\varphi. \tag{1}$$

The effective emanation coefficient χ of a source, the fraction of radon/thoron gas transferred to the reference volume, is given by

$$\chi_{\text{Rn}-222}=\frac{A(\text{Rn}-222)}{A(\text{Ra}-226)}=1-\frac{A(\text{Pb}-214)}{A(\text{Ra}-226)};$$
$$\chi_{\text{Rn}-220}=\frac{A(\text{Rn}-220)}{A(\text{Th}-228)}=1-\frac{R_2\times A(\text{Pb}-212)}{R_1\times A(\text{Ra}-224)} \tag{2}$$

where in the case of Rn-220, R_1 represents the recoil correction of Ra-224 activity. During the α-decay of Th-228, the produced Ra-224 nuclei can be recoiled from the open source and implanted in other surfaces nearby. The same is true in principle in the case of the α-decay of Po-216, resulting in the correction term R_2. This effect results in a small activity loss and also in an additional background, which in this publication will be called the

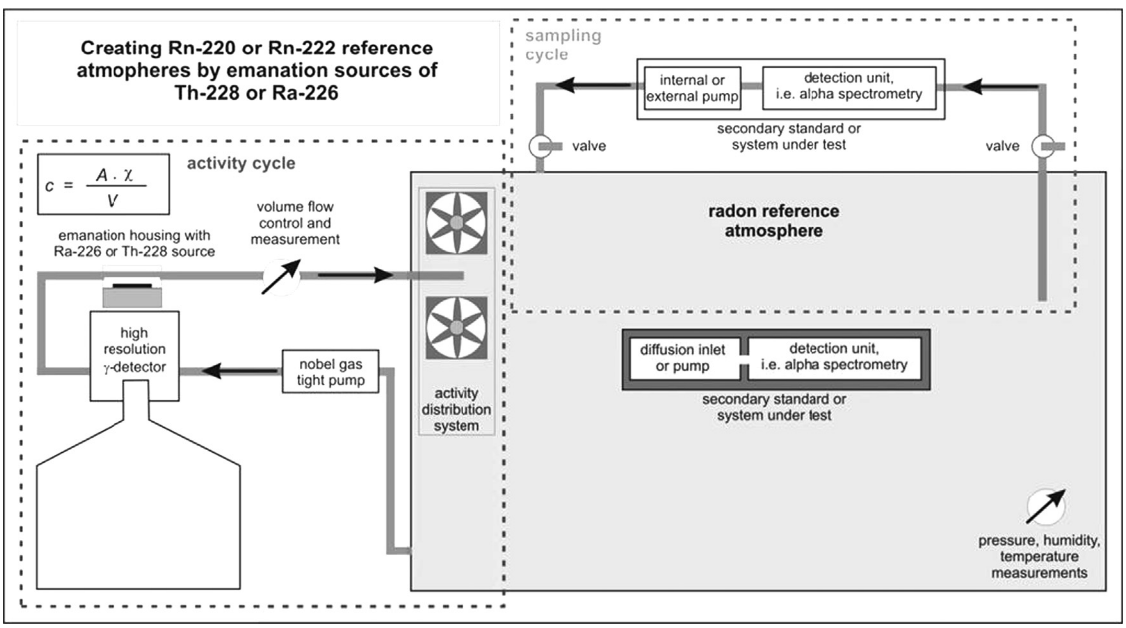

Fig. 1. Equipment to maintain stable reference atmospheres as a primary standard for the calibration of Rn-222 or Rn-220 monitors (i.e. system under test).

Table 1
Special requirements for the emanation set-up for the realization of Rn-222 and Rn-220 reference atmosphere. Dominating differences are underlined.

Reference atmosphere for the calibration of	
Rn-222 calibration items	Rn-220 calibration items
All parts of all cycles have to be noble gas-tight	All parts of the activity cycle have to be noble gas-tight
If the system under test (calibration item) is not assured to be noble gas-tight (tubes, fittings or pump), it has to be placed inside the reference volume	The system under test has to have a leakage- free in- and outlet. Noble gas-tightness is not required
A noble gas-tight system under test may be attached to the reference volume. In this case, it has to be equipped with a long-term stable pump	The system under test can only be attached to the reference volume. It has to be equipped with a long-term stable pump
Only a simple activity distribution system is needed	A highly sophisticated activity distribution system is needed
Activity transfer time in the range of seconds can be omitted	Activity transfer time has to be determined precisely. Keep it as small as possible: A high flow cycle is therefore necessary!
Ra-226 source emanating Rn-222: No electrolytic preparation possible	Th-228 source emanating Rn-220: Electrolytic preparation possible
Large varieties (10–80%) of emanation coefficients	Typical emanation coefficients ~40%
Activity of radon gas standard determined by solid angle counting (primary standard)	Activity determined by solid angle counting (primary standard)
Activity of Ra-226 certified by activity of the solution (secondary standard)	
Moderate good resolution for γ-spectrometry	High resolution for γ-spectrometry
Background analysis typical for γ-spectrometry	Plate out in the emanation housing yields an additional contribution to γ-ray spectra and has to be accounted for