# A COMPARISON OF 'RADON' MEASUREMENT DEVICES

## R. Rolle

*Goettingen, Germany        rrolle@gwdg.de     www.alpha-spectrometry.de*

## 1. Introduction

Radon gas and decay product concentrations in air range from a few Bq/m$^3$ outdoors with wind, to occasionally several kBq/m$^3$ or more indoors, the high decay product concentrations presenting a health concern (risk situation) on extended exposure. During any one day particularly the elevated concentrations would vary greatly. Inclusive cost minimization is sought in screening measurement and in (potential) remediation, which includes measurement of daily varying concentrations for decisions on remediation.

The measuring systems for Rn decay product, (potential alpha energy) PAE-concentrations used 50 years ago have given way largely to Rn gas screening systems that use low-cost integral measurement devices of low sensitivity, and to more sensitive Rn-gas and Rn-decay product spectrometers additionally used for remediation decisions (and device calibration). From the measured Rn gas concentration usually the risk relevant Rn decay product potential alpha energy 'PAE' concentration is tacitly inferred (at <2.5 times underestimation ranging to overestimation, when assuming a 'prescribed' Rn equilibrium factor F = 0.4). From spectrometric Rn decay product measurements the PAE concentration is available directly. Furthermore, from the measured $^{218}$Po concentration, the $^{222}$Rn concentration is, in the majority of situations, determined more accurately (at usually negligible delay). A more important advantage of spectrometric Rn decay product measurement, however, is that from measured activity ratios the air exchange rate and, in turn, the Rn source strength into a room can be evaluated to elucidate the dynamic (Rn and) decay product flow characteristics for remediation decisions.

The comparison below covers some basic aspects of measurement for present day needs, with emphasis on (potential) remediation decisions, where clarification of the dynamics of sources and sinks is sought rather than mere concentration levels.

## 2. 'Radon' measurement devices and methods

A wide range of 'Rn' measurement devices and different methods are used:

a) Devices for Rn gas measurement include a barrier for Rn decay products (filter or diffusion) and detection by track etch, electret, thermoluminescence, charcoal γ, liquid scintillation or tld, ZnS flask, ionization chamber, electrostatic concentrator onto Si or ZnS (, tld). Usually α-decays are measured, in some instruments spectrometrically and in some also β-decays.

b) Devices that concentrate Rn decay products on a filter or screen, or by impaction on foils, use α(β)-detection by Si, ZnS, track-etch or thin thermoluminescent detectors. Main hardware difference to a) is a pump.

c) In the earliest methods grab sampling of small air volumes and subsequent gross α measurement was used. Nowadays most long term screening measurements provide an integral value after the end of a device exposure period. Measurements for assessing hourly or shorter changes in concentrations require fairly sensitive instruments – here Rn gas instruments with a much larger detection volume (behind the entrance barrier) are used, and Rn-decay product instruments in this category are operated in continuous or quasi-continuous concentrating mode, while continuously detecting α-signals spectrometrically (+ β-signals in some instruments) at enhanced efficiency and optimized differentiation.

In customary Rn **gas** measurement (only the) Rn gas enters the device measurement chamber by diffusion or pumping – the external Rn decay product concentrations do not reach the measurement chamber. In many device types both external $^{222}$Rn and $^{220}$Rn reach the chamber, however, in a few device types, by design, the $^{220}$Rn ($t_{1/2}$ = 56s) essentially decays during entry. Inside the chamber the Rn-decay products are also formed and they too contribute $\alpha$- (and $\beta$-) signals. All the detected signals ought to be recorded in spectrometric and successive time intervals and evaluated if an accurate time progression of the external $^{222}$Rn- (and $^{220}$Rn-) gas concentrations is sought. This is, however, seldom provided and accordingly only approximate, steady state evaluation, or a single integral evaluation is available for most Rn gas measurements, and $^{220}$Rn in most cases is ignored.

The range of alpha particles is limited to a few mg/cm$^2$ which is a few cm in air. As a result, for open air gas concentration detection, a 1 cm$^2$ outer detector surface (Si, ZnS or tack etch) open to a >8cm air layer receives an $\alpha$-flux equivalent to all the $^{222}$Rn decays in 1.01cm$^3$ of air and for $^{218}$Po, $^{214}$Po and $^{212}$Bi/Po decays in respectively 1.16cm$^3$, 1.71cm$^3$ and 1.73cm$^3$ of air. For a restricted height above the detector surface the air $\alpha$-flux is still less, and any absorbing detector window further reduces the equivalent air volume per active detector surface. When using mere detector surface for detection of concentrations in air, the available detection surface thus limits the effective gas volume measured, i.e. the sensitivity – accuracy per time. Inside Rn gas measurement devices there are no aerosols so that the Rn decay products rapidly attach to internal surfaces of the device, and in the case of electrostatic collection can be concentrated onto a detector surface for high resolution $\alpha$-spectrometry.

In Rn-decay product measurement the various decay products of $^{222}$Rn as well as of $^{220}$Rn are concentrated at a flow rate f and collection efficiency $_c\varepsilon$ onto a collector (filter, screen). The collector can preferably be measured in contiguous time intervals at optimised detection efficiency (up to ~30%), in spectral regions of interest ($_{ROI}\varepsilon$), while collecting (filtering) and during possible collecting breaks. Here enhanced sensitivity from concentrating, and usefulness of activity ratio information warrants more accurate, dynamic state evaluation.

## 3. Sensitivity comparison – steady state

Radon gas and Rn decay product measuring devices are used here towards the same purpose, instrumentation essentially differs only by the additional regulated concentrating pump, and their results can, to a certain degree, be mutually converted. It is useful to compare the measurement sensitivity of both instrument categories when operated <u>steady state</u> (concentrations constant for >> longest decay product halflife). An easy sensitivity comparison is the <u>volume of air</u> $V_e$ effectively presented to the detector:

a) In a gas monitor $V_e$ is the internal measurement chamber volume $V_i$ in which equal decay chain activities from Rn to Bi are variously distributed and are counted at efficiencies corresponding to their individual distributions in $V_i$

b) A monitor concentrating Rn decay products from air, at a collection efficiency $_c\varepsilon$ ($\cong$ 1) and flow rate f $\ell$/min, effectively presents effective air volumes -

$$V_e = {_c\varepsilon} \cdot f \cdot \lambda^{-1}$$

for each of 5 short lived decay chains, on a collector (filter or screen) usually very close to the detector for high detection efficiency.

Example: A monitor concentrating decay products at a flow rate of 2 $\ell$/min, $_c\varepsilon$ = 1, detects:

$$(f \cdot \lambda^{-1})$$

from an air volume of  8.8 $\ell$ the activity of $^{218}$Po + equal activities of $^{214}$Pb and $^{214}$Bi

from an air volume of  77 $\ell$ the activity of $^{214}$Pb + an equal activity of $^{214}$Bi

from an air volume of  57 $\ell$ the activity of $^{214}$Bi

from an air volume of 1840 $\ell$ the activity of $^{212}$Pb + an equal activity $^{212}$Bi

from an air volume of  175 $\ell$ the activity of $^{212}$Bi

(whereas the $V_e$ 7 m$\ell$ of the $^{216}$Po + $^{212}$Pb + $^{212}$Bi decay chain is negligible).

When comparing instruments for Rn gas measurement the Rn-decay product concentrating instruments readily yield the $^{218}$Po concentration, which, due to the short $^{218}$Po halflife (3.05 min), has a value close to the $^{222}$Rn concentration even in most non-steady state situations. Table 1 shows that with evaluation of $^{222}$Rn and $^{218}$Po signals, properly compensated for other signals, the sensitivity of the 2$\ell$/min on filter concentrating instrument shows roughly 4 times higher sensitivity than a typical ½$\ell$ Rn ionisation chamber or 9× higher sensitivity than a ½ $\ell$ electrostatic Rn monitor (which offers the simplest spectrum unfolding).

Table 1. Steady state α-sensitivity of various types of α-'spectrometric' measuring systems for **Rn gas** - approximated as detected nuclide α-counts/hour at a Rn concentration of 100 Bq/m$^3$ (360 Rn atom decays/hour.liter); the Bi/Po α-signals require incorporation in Rn evaluation.

| Instrument / α-counts.h$^{-1}$ | $^{222}$Rn | $^{218}$Po | $^{214}$Bi/Po* | $^{220}$Rn | $^{216}$Po | $^{212}$Bi/Po* |
|---|---|---|---|---|---|---|
| Rn track-etch dosimeter | ~0.2 | ~0.2 | ~0.2 | ~0.2 | ~0.2 | ~0.2 |
| track-etch environmental monitor† | 0 | 0.2 | < 3‡ | 0 | 0 | <45‡ |
| ½ liter Rn ionisation chamber | 120 | 90 | 90 | 120 | 90 | 90 |
| ½ liter electrostatic Rn monitor | 0 | 90 | 90 | 0 | 90 | 90 |
| 2 $\ell$/min concentrating on filter | 0 | **800** | <13000‡ | 0 | 0 | <180-000‡ |

* delay from $t_{½}$ of $^{214}$Pb and $^{214}$Bi, and particularly of $^{212}$Pb and $^{212}$Bi, need to be taken care of non-steady-state

† 2 $\ell$/min concentration on filter with collimated detection

‡ equilibrium dependable rates from respective decay product concentrations should normally be compensated for.

## 4. Evaluation of dynamically changing concentration from measurement records –

High accuracy is hardly needed in long-term screening measurement as, at a low percentage of potential remediation situations, considerable underestimation can be accommodated. Thus steady state evaluation suffices for screening measurements that are usually made over several days or months. For decisions on (potentially) costly remediation, however, far more accurate evaluation of dynamically changing concentrations can be most valuable to quantify sources and sinks besides mere concentrations of the Rn decay chains. Dynamic evaluation is needed because concentration changes by a factor 4 per hour are not unusual and Radon and decay product measuring instruments respond with various delays to changes in air activity concentrations.

Most instruments, including sensitive ones, are calibrated for, and their signal evaluation was designed for steady state conditions. Due to substantial response delays, of signals from decay chain members in the instrument relative to concentration changes in air of the parent nuclides of the various decay chains, such instruments are not generally suited for accurate measurement of dynamic changes in concentration. True changes in concentration are reflected in most conventional signal evaluations in altered magnitude due to decay progression of the instrument 'sample'; some instruments record 'data quality questionable!' warnings that are of little help.

From an accurate spectrometric calibration table for all the decay chain members vs. α-spectrometrically differentiated channels (ROIs – regions of interest – judiciously chosen), the measurement time response factors for each ROI to unit air concentration sampling time steps can be calculated for any sampling time step. If an adequate time-sequential (interval) record of signals in each ROI is accessible, this record can be unfolded to the individual concentrations in air during the past sampling intervals, i.e. without decay delay error. Evaluated data accuracy can be improved by including β-signals, and for decay product determination by using quasi-continuous sampling to enhance nuclide differentiation; where a significant portion of $^{212}$Pb and $^{212}$Bi are present quasi-continuous sampling is definitely needed.

Software for very accurate fundamental parameter, α-spectrometric calibration has been developed for fairly complex sample/detector α-absorption geometries, including measurement-

specific exponential depth distribution of activity in filters. If warranted, this calibration software can be extended to wire screen collectors and modified also for $\beta$-detection. Further software has been developed to unfold time-sequential, spectral ROI data that is obtained from an efficient trial monitor for unattached and attached Rn decay product concentrations. The feasibility of making accurate dynamic measurements of Rn decay product concentrations has thus been demonstrated.

Steady state measurement data evaluation strictly applies only to continuous measurement of constant concentrations, or at least measurement over a period of many multiples of the longest halflife involved. An integral mean concentration value over a long period ($>> t_{1/2}$ of $^{214}$Pb and $^{212}$Pb) can also be considered the steady state mean value of concentrations that exhibit strong oscillations. From commercial instruments the raw measurement data, calibration table and evaluation procedure is generally not obtainable – only practically steady state evaluated results are provided.

## 5. Benefits of accurate Rn decay product measurement

The concentrations of Rn and decay products in a room depend on the sources and sinks to the room volume. At steady state the activity ratios are a function of only the air exchange (and mixing), while the concentrations are functions of the sources and air exchange. At dynamic changes the activity ratios also are functions of both source(s) and air exchange. When trying to calculate sources and air exchange from measured decay chain activity concentrations and ratios it readily becomes apparent that the quality of the answers is strongly dependent on the accuracy of the measurements.

In a (potential) remediation situation, instead of being faced with mere concentrations, a clear assessment of sources and sinks is key information on which to base remediation decisions. Sometimes costly tracer gas measurements are performed to determine air exchange, whereas accurate decay product measurement can provide this information directly. Suitable software ought to be developed with flexible input options to evaluate Rn decay product measurement series for common room models with sources of Rn and (passive) air exchange. The automatic evaluation of $^{212}$Pb and $^{212}$Bi concentrations (which would go unnoticed in Rn gas measurement) offers additional information for dynamic changes in sources and sinks if a (fixed) relationship between $^{222}$Rn and $^{220}$Rn source strengths can be ascertained.

A secondary benefit for exposure evaluation is that efficient Rn decay product measurement offers the direct assessment of all PAE concentrations, including $^{212}$Pb, $^{212}$Bi and of unattached Rn decay products, not afflicted by a very imprecise prescribed $F_{PAE}$ conversion.

## 6. Conclusions

When screening for potentially high Rn concentrations there is little point in choosing one type of Rn-gas measuring device over another for reasons of accuracy, and practically any registered service at lowest cost may be sought. When, however, subsequent significant remediation decisions need to be made, sensitive measurement of Rn decay product concentrations would be the best choice for evaluating key source and sink dynamic features. Measurements with optimized test instruments have demonstrated the feasibility of evaluating dynamic situations, and appropriate instruments should be made available, together with modelling software and/or a centralized service for online modelling of the data to evaluate the source, sink and concentration dynamics for optimal remediation decisions.