Radon Monitor Calibration using NIST Radon Emanation Standards: Steady Flow Method

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ABSTRACT

The National Institute of Standards and Technology (NIST) Polyethylene-Encapsulated $^{226}Ra/^{222}Rn$ Emanation (PERE) Standards (old SRM 4968 and new SRMs 4971, 4972, and 4973) provide precise radon emanation rate, certified to a high degree of accuracy (approximately to 2%). Two new SRM 4973 standards containing total of 1036 Bq (0.028 μCi) of ^{226}Ra, emanate 0.114 Bq (3.08 pCi) of ^{222}Rn per minute. Air passing over such sources at a flow rate of 1 L min^{-1} will have a radon concentration of 114 Bq m^{-3} (3.08 pCi L^{-1}). This paper describes a practical calibration system and the actual calibration verification data obtained at different flow rates, for E-PERM® passive radon monitors, Femto-Tech® and Alpha Guard® Continuous Radon Monitors. Use of such an affordable and easy to use system by the manufacturers and users of radon measurement devices will bring uniform standards with traceability to a NIST standard source and is considered an important step in standardizing radon measurement methods.

NOTE: This paper is in the process of publication in the Journal of Radiation Protection Dosimetry (2005)

INTRODUCTION

The new series of the National Institute of Standards and Technology (NIST) Polyethylene-Encapsulated $^{226}Ra/^{222}Rn$ Emanation (PERE) Standards (SRM 4971, 4972, and 4973) [(1)] provide precise radon emanation rate, certified to a high accuracy of about 2% (2 sigma uncertainty). Calibrating commercially available radon monitors, using such sources, is an important step in standardizing the calibration procedures for radon monitors. The low strength sources, SRM 4971 and 4972, with ^{226}Ra activity of 5 and 50 Bq are suitable for use in accumulation mode. Detailed procedures for using such sources are described in a related publication [(2)] .One of the problems encountered in using the sources in accumulation mode was enclosing the detectors in airtight enclosures and knowing the precise air volume of the enclosure. The stronger sources (SRM 4973) with ^{226}Ra activity about 500 Bq can be used in a continuous flow mode, overcoming the problems encountered in using the sources in accumulation mode. The present work describes the design and performance of a practical calibration system. As an illustration, the system is further used to verify the calibration of some popular radon monitoring systems.

MATERIALS AND METHODS

Calculation of expected radon concentration

Two factors that determine the emanation rate of a NIST standard are the ^{226}Ra activity and the emanation fraction. Both of these factors are certified with small uncertainties. Equation (1) gives the radon emanation rate:

$$R\,(^{222}\mathrm{Rn}) = f \cdot A\,(^{226}\mathrm{Ra}) \cdot \lambda \qquad (1)$$

Here $R\,(^{222}Rn)$ is the radon activity emanation rate by the standard in Bq s^{-1}

f is the emanation fraction,

$A\,(^{226}Ra)$ is the activity of ^{226}Ra in Bq,

λ is the decay constant of ^{222}Rn in s^{-1} ($2.09822 \cdot 10^{-6}$ s^{-1}), Radon concentration in air flowing over the source, C (^{222}Rn), is calculated using equation (2).

$$C(^{222}\mathrm{Rn}) = R(^{222}\mathrm{Rn}) / F \qquad (2)$$

Here C (^{222}Rn) is the concentration in Bq m^{-3},

R (^{222}Rn) is the radon emanation rate in Bq s^{-1},

F is the flow rate in m^3 s^{-1}.

For SRM 4973, the emanation rate R can be calculated with two sigma uncertainty of about 2%. In our tests air goes through a calibration chamber with a volume of 40 liters. This volume is large enough to hold most practical radon monitors. It can have penetrations for power chords. Reasonable sealing is required.

For a flow rate of 1 L min^{-1}

A (^{226}Ra) = (1036 ± 6) Bq;

f = 0.8736 ± 0.0063;

□ = (2.09822 ± 0.00016)·10$^{-□}$ s^{-1};

R (^{222}Rn) = (0.001899 ± 0.000017) Bq s^{-1};

F = 1 L min^{-1} = (1.667± 0.017)·10$^{-□}$ m^3 s^{-1}

Radon concentration in 40 L of the air at a flow rate of 1 L min^{-1}, C = (113.9 ± 1.6) Bq m^{-3}.

Experimental setup

Figure 1 shows the schematic of the experimental arrangement. Air is drawn from ambient environment with low radon concentration, through a filter and a flow meter with a regulator. The output of the pump is taken through a primary flow calibrator [(3)], the NIST source holder into the calibration chamber. Volume of cylindrical calibration chamber is about 40 liters. The lid of the calibration chamber can be opened and closed for introducing detectors. Reasonable leak tightness is required. Power cord penetrations are sealed using commercially available materials. The air from the calibration chamber is let out to the room exhaust or to outside the building. The radon-laden air is injected at the top and the let out from the tube that starts from near the bottom and out. This arrangement is intended to provide mixing of the radon-laden air inside the chamber.

Experimental Procedure

The detectors that need to be calibrated or whose calibrations need to be verified are installed inside the chamber and chamber is closed. Start the pump and adjust the desired flow rate using flow meter with control. It is not desirable to use the primary flow calibrator continuous mode over extended period. Because of this reason the exact flow rate was determined in the beginning and at the end of calibration procedure. With a good quality pump and a good quality flow controller used in the current work, once set, the flow rates did not change more than ± 2 % over 2 to 7 days. At the end of the calibration period, radon monitors are taken out and measured concentrations are recorded.

Experiments at different flow rates

The calibration verification was done on two types of continuous radon monitors and one type of passive integrating radon monitors. The Alpha Guard® [(4)] continuous radon monitor manufactured by Genitron instruments in Germany and the Femto-Tech® [(5)] continuous radon monitor manufactured by Femto-Tech Corporation in USA, are used in this study. Both these monitors operate on the principle of pulsed ionization chamber and use sophisticated data processing software to analyze the results. The E-PERM® [(6)] electret ion chambers are widely used passive integrating radon monitors manufactured by Rad Elec Inc. in USA. These are more fully described [(2)] in the associated publication that described the use of NIST source in accumulation mode.

At the beginning of the test, the desired flow rate is set. Air flows through the NIST source holder for at least two hours to establish the initial condition, before introducing the air stream into the test chamber. In one experiment, two continuous radon monitors, Alpha Guard® (AG) and Femto-Tech® (FT) are installed inside the calibration chamber. The chamber is closed. These log the data in their memory for nearly 24 hours. Results are read out at the end of the test period. Such a study is repeated for different flow rates starting from about 0.1 L min^{-1} to about 1 L min^{-1}. In another experiment, sets of E-PERM® (EP) radon monitors are installed inside the chamber for 2 to 3 days.

Precision of parameters

NIST certifies the radon emanation fraction with an uncertainty of ± 2 % at 2 sigma level. The primary flow calibrator [3] used in this work is NIST traceable and certified with an uncertainty of ±1 % at 1 sigma level.

RESULTS

Figure 2 shows the data from AG continuous radon monitor for different flow rates. Steady state concentration is the mean of radon concentrations in the plateau region. This is computed by the software. NIST radon concentration is calculated using equations (1) and (2) and parameters of the NIST capsules. In these experiments, the inlet air comes from the ambient air with a radon concentration of about 15 Bq m^{-3}. This background also contributed into the detector readings in addition to the NIST capsules contribution. This background was measured without the NIST capsules and subtracted from measurements with capsules.

Table 1 gives the summary of test results. The first column gives the flow rates. The second column gives calculated NIST predicted concentration. The third column gives decay corrected predicted concentration. Column 4 gives the mean steady state radon concentration as measured by AG unit after subtracting the background. Column 5 gives the ratio of measured to predicted concentration. Column 5 and 6 give data for FT unit. From Table 1, it follows that the continuous radon monitor results agree very well with the NIST predicted radon concentration.

Because of the large volume (40 liters) of the exposure chamber and relatively low flow rates (0.1 L min^{-1} to 1 L min^{-1}), finite time is required for the radon concentration to reach the steady sate. Using data charts of Fig 2, it is possible to estimate the time to reach the steady state (TTRSS) in 40-liter exposure chamber. Further as expected, the time to reach the steady state depends upon the flow rate. The lower the flow rate, the longer is the TTRSS.

The column 2 of Table.2 gives the estimated TTRSS in hours. It varies from about 2 hours to 12 hours. This is of significance while calibrating passive integrating radon monitors. This should be small compared to the total duration of measurements. For example, for a 48-hour calibration with the flow rate in the range of 0.4 L min^{-1} the TTRSS is about 5 hours and will not affect the calibration significantly. However, calibration over extended period is desirable. Anther parameter of interest is the mean residence time (MRT) for radon. This time is calculated by dividing the volume in liters by the flow rate in L min^{-1}. This time (in hours) is given in column 3. Column 4 gives the radon decay correction for the MRT. The NIST predicted radon concentration should be multiplied by this coefficient for calculating decay corrected radon concentration. For example, the calculated radon concentration given in column 2 (Table 1) is multiplied by the decay correction factor (column 4 of Table 2) and introduced in column 4 of Table 1. As can be seen this correction is negligible for flow rates of 0.4 L min^{-1} and higher. However, the corrections become significant at low flow rates. Tables 3 and 4 give the results for EP electret passive radon monitors at two different flow rates; 0.281 and 0.602 L min^{-1}, at two different duration of exposure. The detailed methods of analysis of these detectors are given in a related publication [(2)].
Results are excellent indicating that these monitors have been calibrated well.
The arrangement for the passage of radon-laden air through the chamber appears to provide sufficient mixing, as demonstrated by the results.
When air is taken from ambient environment, the background can be varying and may introduce some uncertainty. For the continuous radon monitors of pulsed ion type, nitrogen can be used as carrier gas to do away with this uncertainty. This can not be done for E-PERMs, because the calibration of E-PERMs can be different for different carrier gases.

CONCLUSIONS

The NIST sources provide an easy method of calibrating radon monitors. The steady flow method offers many advantages over the accumulation mode [(2)]. First, the requirements to the sealing of the exposure chamber with radon counters are not as high as in the case of accumulation method because of slight positive pressure inside the exposure chamber. Second, it is not necessary to know the exact air volume of the chamber. A 24-hour run is recommended for calibrating continuous monitors, so as to provide multiple data points to calculate the steady state radon concentration. Because of the relatively large exposure chamber (40 liters), the flow rates should be larger than 0.5 L min^{-1} to minimize the correction due to decay of radon. For calibration of integrating passive radon monitors, the recommended flow rate is above 0.5-L min^{-1} and the exposure duration of three days or above. Outside these limits, corrections are required.

A 40-liter exposure chamber is large enough for several instruments at a time. It is important to have a good pump with a flow controller as well as a primary flow calibrator with a precision of about 1 % to take full advantage of the high precision of the NIST certified radon emanation fraction of about 2%. Reasonably priced commercially available components meet these needs. The more active NIST capsules (with 5000 Bq activity of ^{226}Ra) would be more convenient for steady flow calibrations. If manufacturers and the primary users of radon detector use this method many ambiguities present in radon data will be resolved.

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3. Bios International Corporation, 10 Park Place, NJ 07405 USA
4. Genitron Instruments GmbH,D-60488,Heerstrausse 149, Frankfurt, Main/ Germany
5. Femto Tech Inc. 325, Industry Drive, Carlisle, OH 45005 USA
6. Rad Elec Inc. 5714-C, Industry lane, Frederick, MD 21704 USA

Table 1
Steady state radon concentration as recorded by Alpha Guard® and Femto-Tech® continuous radon monitors compared to calculated NIST reference radon concentration. NIST Standard: 1036 Bq of ^{226}Ra; Emanation coefficient: 0.8737

Flow rate varied from 0.1 $L\ min^{-1}$ to 1 $L\ min^{-1}$.

Flow Rate $L\ min^{-1}$	NIST $Bq\ m^{-3}$	NIST DC $Bq\ m^{-3}$	AG-BG $Bq\ m^{-3}$	(AG-BG)/ NIST DC	FT-BG $Bq\ m^{-3}$	(FT-BG)/ (NIST DC)
0.104	1097	1046	1013	0.969	985	0.942
0.203	562	549	576	1.050	606	1.104
0.392	291	287	280	0.977	289	1.007
0.607	188	186	190	1.023	191	1.027
0.796	143	142	144	1.009	141	0.993
0.961	119	119	118	0.993	126	1.059

Table 2
Time taken to reach steady state (TTRSS) at different flow rates in a 40-liter radon exposure chamber, Mean residence time (MRT) and mean radon decay correction (MDC)

Flow Rate $L\ min^{-1}$	TTRSS Hours	MRT Hours	MDC Coefficient
0.104	12	6.3	0.953
0.203	7	3.3	0.975
0.392	5	1.7	0.987
0.607	4	1.1	0.9924
0.796	3	0.8	0.995
0.961	2	0.7	1.000

Table 3

Calibration verification for E-PERM® Electret Ion Chambers. These are passive integrating radon monitors. Flow Rate: 0.602 L min^{-1}; NIST Standard: 1036 Bq of ^{226}Ra; Emanation coefficient: 0.8737

Electret #	Exposure period Days	Start Charge volts	End Charge Volts	EP-BG Radon Bq m^{-3}	NIST Radon Bq m^{-3}	(EP-BG)/ NIST Ratio
SBE230	2.8333	319	285	212	204	1.04
SBE756	-do-	353	320	202	-do-	0.99
SBD828	-do-	486	450	213	-do-	1.04
SBD757	-do-	393	358	213	-do-	1.04
SBE949	-do-	457	423	202	-do-	0.99
SBD469	-do-	405	372	199	-do-	0.98
SBD550	-do-	442	408	203	-do-	1.00
SBD460	-do-	405	372	199	-do-	0.98
SBD464	-do-	410	374	219	-do-	1.07
SBD447	-do-	410	376	205	-do-	1.01
			Average	**207**		**1.01**

Table 4

Calibration verification for E-PERM® Electret Ion Chambers. These are passive integrating radon monitors. Flow Rate: 0.281 L min^{-1}; NIST Standard: 1036 Bq of ^{226}Ra; Emanation coefficient: 0.8737

Electret #	Exposure period Days	Start charge volts	End Charge Volts	EP-BG Radon Bq m^{-3}	NIST Radon Bq m^{-3}	(EP-BG) /NIST Ratio
SBD828	1.8750	449	405	421	420	1.00
SBD688	-do-	373	329	431	-do-	1.03
SBD757	-do-	357	312	444	-do-	1.06
SBD757	-do-	285	242	433	-do-	1.03
SY2130	-do-	372	330	411	-do-	0.98
SBD986	-do-	422	379	414	-do-	0.99
SBE949	-do-	435	391	423	-do-	1.01
SBD201	-do-	417	371	446	-do-	1.06
SBD686	-do-	319	277	418	-do-	1.00
SBE756	-do-	550	505	418	-do-	1.00
			Average	**430**		**1.01**

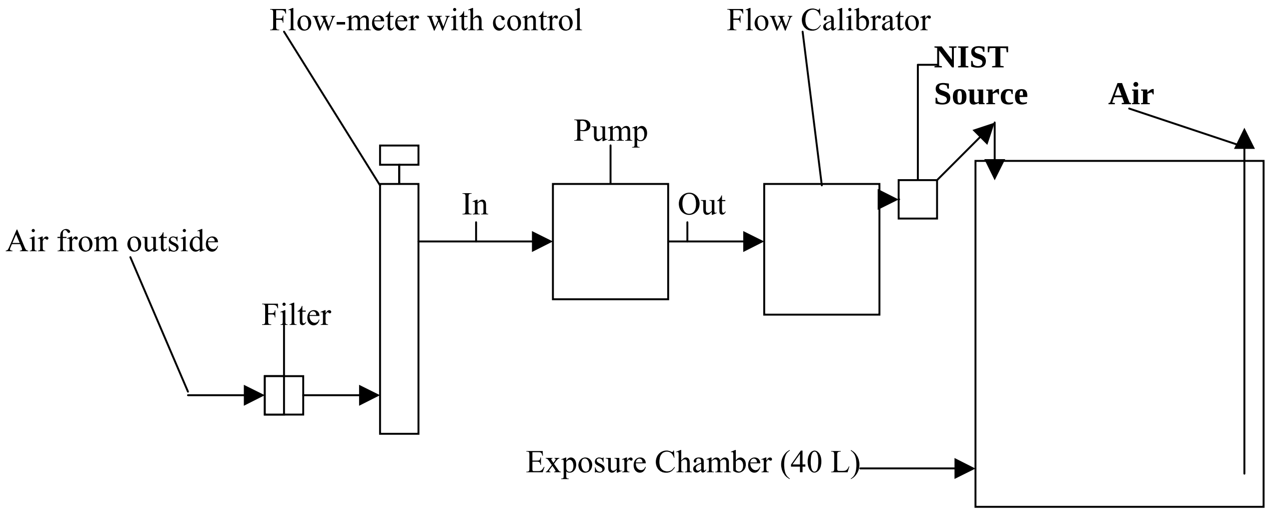
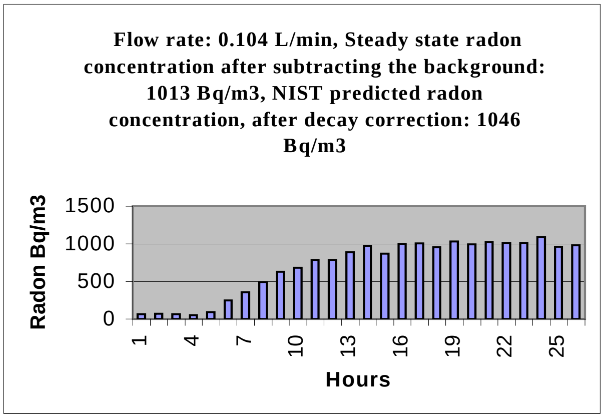
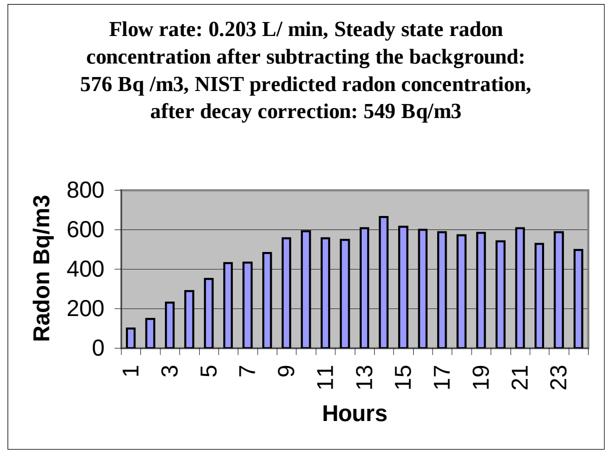
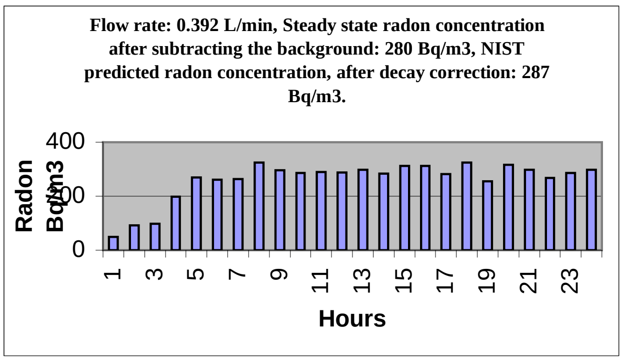
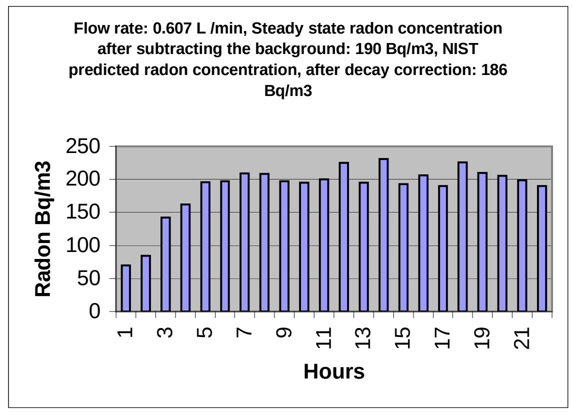


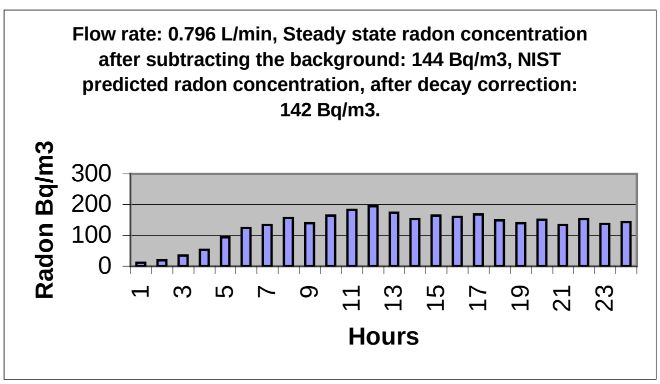
Figure 1. Schematic of the Experimental Arrangement

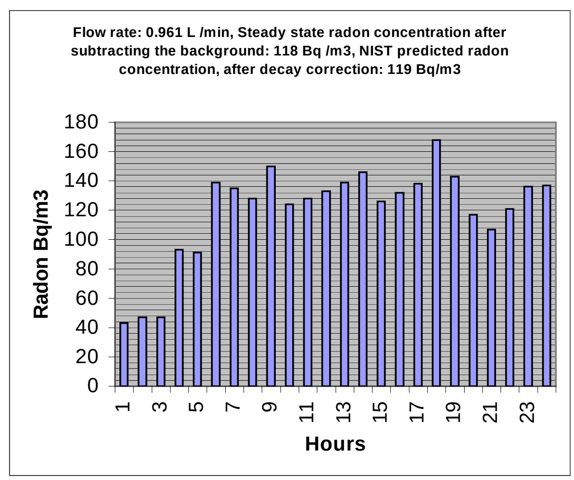

Flow rate: 0.104 L/min, Steady state radon concentration after subtracting the background: 1013 Bq/m3, NIST predicted radon concentration, after decay correction: 1046 Bq/m3
Radon Bq/m3
Hours


Flow rate: 0.203 L/ min, Steady state radon concentration after subtracting the background: 576 Bq /m3, NIST predicted radon concentration, after decay correction: 549 Bq/m3
Radon Bq/m3
Hours


Flow rate: 0.392 L/min, Steady state radon concentration after subtracting the background: 280 Bq/m3, NIST predicted radon concentration, after decay correction: 287 Bq/m3.
Radon Bq/m3
Hours


Flow rate: 0.607 L /min, Steady state radon concentration after subtracting the background: 190 Bq/m3, NIST predicted radon concentration, after decay correction: 186 Bq/m3
Radon Bq/m3
Hours


Flow rate: 0.796 L/min, Steady state radon concentration after subtracting the background: 144 Bq/m3, NIST predicted radon concentration, after decay correction: 142 Bq/m3.
Radon Bq/m3
Hours


Flow rate: 0.961 L /min, Steady state radon concentration after subtracting the background: 118 Bq /m3, NIST predicted radon concentration, after decay correction: 119 Bq/m3
Radon Bq/m3
Hours