ELEVATION CORRECTION FACTORS FOR E-PERM® RADON MONITORS*

P. Kotrappa and L. R. Stieff†

Abstract—**E-PERM® radon monitors are based on the principle of electret ion chambers and are usually calibrated in a standard radon chamber located at sea level. Corrections are needed if the monitors are used at elevations other than sea level. These were experimentally determined for three models of commercially available electret ion chambers (E-PERM®) as functions of elevation above sea level. These corrections are minor and should be applied for obtaining more accurate results.**
Health Phys. 62(1):82–86; 1992

Key words: ^{222}Rn; instrumentation; ionization chamber; monitors, radon

INTRODUCTION

^{222}Rn monitors based on electret ion chamber technology, known as Electret Passive Environmental Radon Monitors (E-PERM®s), are used widely for measuring ^{222}Rn in air. They have been described fully in earlier publications (Kotrappa et al. 1988, 1990). (In this note, Rn means ^{222}Rn unless otherwise stated.)

Electret ion chambers are ionization chambers that have a filtered opening and operate at ambient pressures. It is well known that ionization chambers used for making x- or gamma-radiation measurements need correction if used at atmospheric pressures different from the atmospheric pressure at which the units are calibrated. Such correction factors are in direct proportion to the pressure ratios (Lapp and Andrews 1964). Proportionate pressure corrections are not applicable to alpha radiation, due to the limited range of alpha particles. Measurement of Rn using E-PERM®s involves measurement of ionization caused by alpha radiation from Rn and progeny inside the chamber. The ionization due to beta and gamma radiation associated with Rn and Rn progeny is very small (less than 1%) compared to that of alpha radiation. The purpose of the present study was to make an experimental determination of the altitude correction factors for three commercially available models of E-PERM®s.

MATERIALS AND METHODS

E-PERM® radon monitors

E-PERM® chambers of three volumes and electrets of two sensitivities are commercially available. Chambers of different volumes have been designated "L" (50-mL volume), "S" (210-mL volume), and "H" (960-mL volume). These are schematically shown in Fig. 1. Electrets of two sensitivities, termed "short-term" (high-sensitivity) and "long-term" (low-sensitivity) electrets (Kotrappa et al. 1990), are also available. The atmospheric pressure effect currently under investigation depends on the shape and size of the chamber and not on the type of electret used. When used properly, E-PERM®s provide radon concentrations with an accuracy of 5% to 6% over the range of Rn concentrations of about 4000 Bq m^{-3} used in the current work (Kotrappa et al. 1990).

Leak-tight enclosures

The present investigation requires a leak-tight container to maintain the required pressure conditions for the entire period of measurement. Transparent, implosion-proof vacuum desiccators‡ certified to hold a vacuum of 3.3 kPa (25 mm Hg) for up to 24 h are commercially available.

This desiccator has a vacuum retention valve that can be connected to a source of vacuum and later isolated from the source. In addition, the valve has a fine control that permits a precise adjustment of the pressure inside the enclosure by bleeding before isolating. The desiccator has a volume (10 L) sufficient to hold five "L" or "S" chamber E-PERM®s in use at the same time. Such enclosures were used in the present work.

Pressure monitor

A commercially available altimeter§ with a resolution of approximately 60 m was found to be adequate

* E-PERM® is a registered trademark of the product patented and manufactured by Rad Elec Inc., Frederick, MD 21701.

† Rad Elec Inc., 5310 H Spectrum Drive, Frederick, MD 21701.

(*Manuscript received* 24 *December* 1990; *revised manuscript received* 6 *September* 1991, *accepted* 25 *September* 1991)
0017-9078/92/$3.00/0

‡ Bel Art 42027, Cat. No. 24988-277, VWR Scientific Apparatus Catalogue, 1989/1990, Bridgeport, NJ 08014.

§ Guide Tech Altimeter Model 2500 S, made in Japan for Cobbs Manufacturing Co., Des Moines, IA 50309.

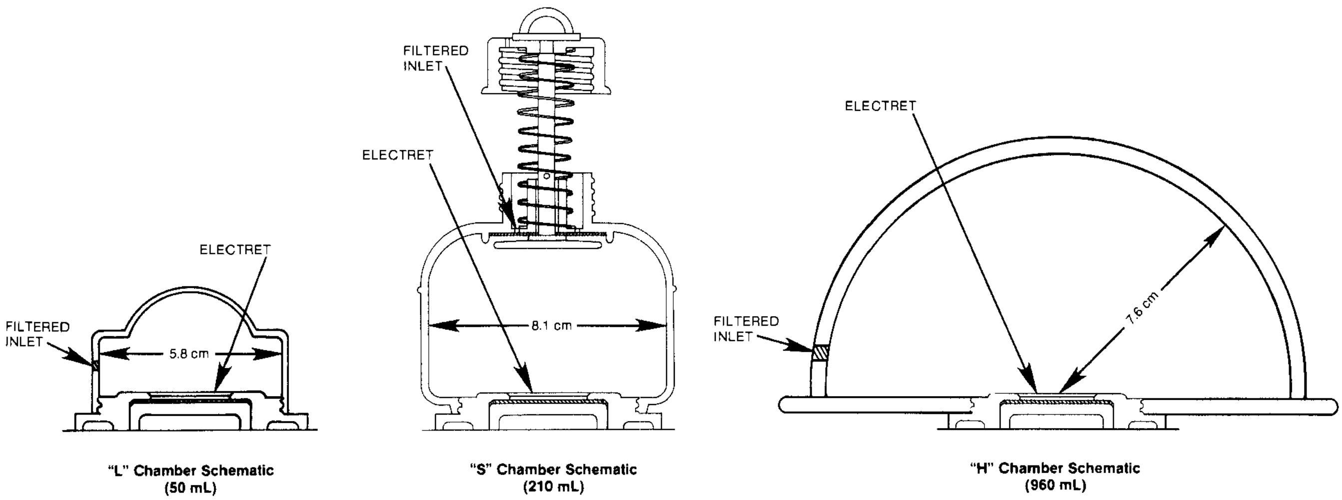

Fig. 1. Schematic of different E-PERM® chambers under investigation.

for the present work. This is small and does not require any connections. The unit was calibrated against a pressure gauge over a pressure range of 67 to 101 kPa (50 to 76 cm Hg). When left inside the transparent enclosure, the reading was visible during the entire period of experiment.

Radon sources

Experimental radon transfer standards, based on polyethylene-encapsulated radium solutions loaned by the National Institute of Standards and Technology,‖ were used as a source of radon. This standard is a small, sealed (2.5-cm long and 0.3-cm diameter) polyethylene vial containing 550 Bq of ^{226}Ra solution (Colle et al. 1990) that emits Rn at a predictable and reproducible emission rate. The source is attached by a thread to the middle of the enclosure. ^{222}Rn is released into the 10-L volume of the enclosure. This establishes an average Rn concentration of approximately 4000 Bq m^{-3} over 1 d.

Using two identical Rn sources in two identical enclosures, it is possible to establish the same Rn concentration over a particular time period. By maintaining identical pressures in these chambers, the radon concentrations were measured over a day and confirmed to be the same within experimental errors. If one of the enclosures is maintained at a pressure of 101.3 kPa (76 cm Hg), corresponding to zero elevation above sea level, and the other is maintained at 94.3 kPa (70.8 cm Hg), corresponding to 610 m above sea level, over the same period, the two chambers will show the same Rn concentration but at different pressures. If Rn detectors are enclosed in these chambers over the same period, the ratio of the response at 101.3 kPa (76 cm Hg) to the response at 94.3 kPa (70.8 cm Hg) would be the correction factor at an elevation of 610 m above sea level. The release rates of Rn from the sources do not depend on the pressures in the chamber over the pressure range 67 to 101.3 kPa (50 to 76 cm Hg) (see Discussion).

‖ Personal communication (1991), R. Colle, National Institute of Standards and Technology, Gaithersburg, MD 21309.

EXPERIMENTS

The experimental set-up included two high-vacuum desiccators, two Rn sources of nearly equal strength, 10 E-PERM® radon detectors, one altimeter, and a vacuum pump. Five detectors and a source were placed in each of the desiccators. The valve of enclosure no. 1 was connected to a vacuum pump and pumped down until the altimeter showed approximately 300 m more than the desired setting. The valve was then closed before disconnection from the pump. Before closing the valve, the fine control on the valve was used to bleed in some air from the outside until the altimeter showed the desired setting. The valve of desiccator no. 2 was also closed at this time. Both desiccators were left in that condition for one or more days, depending on the sensitivity of the units. At the end of the desired exposure period, the altimeter was checked to ensure that the reading had remained the same as it had been set. The valves were opened and the detectors taken out and analyzed for radon by standard procedure. The average of the five readings was taken. The ratio of the average result of enclosure no. 2 to that of enclosure no. 1 is the correction factor for that elevation.

Similar measurements were repeated for each of the chambers: "L," "S," and "H." For the "H" chamber, only one detector at a time could be accommodated in the enclosure for testing. Tests were repeated three times at each elevation setting to arrive at an average.

It should be noted that the sources were not of exactly identical strengths but were within 5% of each other. Results were normalized to the same source strength to correct for this difference.

The absolute strength and the absolute concentration of Rn in the chamber are not reported in this note since a detailed publication on this topic is expected to be published in the near future.‖ Absolute values are not important for this note, since we are looking for the ratios of two numbers.

RESULTS

Results of the experiments are shown in Table 1. Column 1 gives the altimeter reading. Columns 2 and 3 give the corresponding atmospheric pressures; columns 4, 5, and 6 give the correction factors for E-PERM® chambers "L," "S," and "H," respectively. Standard deviations of the correction factors were calculated based on the standard deviations of the radon concentrations obtained in five E-PERM® units used in each experiment. These ranged from 4% to 7%. Actual values are not reported in the tables.

Correction factors become significant for chamber "L" at an elevation of 300 m and above. Eqn (1) gives the linear regression equation fitting the data. This equation can be used for computing the correction factors for any elevation, over the ranges covered in this study.

$$C \text{ (for "L" chamber)} = 1.00 + 4.617 \times H/(30{,}480), \quad (1)$$

where C is the correction factor and H is the elevation in meters.

Correction factors become significant for chamber "S" only at elevations above 1200 m. Eqn (2) gives the linear regression equation fitting the data between 1200 m and 2500 m. This equation can be used for computing correction factors for elevations between 1200 and 2500 m.

$$C \text{ (for chamber "S")} = 0.77 + 6.30 \times H/(30{,}480), \quad (2)$$

where C is the correction factor and H is the elevation in meters. There are no correction factors applicable to chamber "H" up to an elevation of 2500 m.

DISCUSSION

At lower pressures (or at higher elevations), fewer air molecules are available for the radiation to produce ion pairs in a given path length compared to the ions produced at higher pressures (or at lower elevations). Therefore, the ionization chambers are expected to give a lower response at lower atmospheric pressures (or at higher elevations), i.e., the response depends on the air density. Air densities are almost proportional to atmospheric pressures over the pressure ranges of interest in the current study. Theoretically, the correction factors should be in proportion to the ratio of pressures. This is indeed so for the ionization chamber used for making x- or gamma-radiation measurements (Lapp and Andrews 1964).

The situation is slightly different when an ionization chamber is used for making a measurement of Rn where most of the ions are produced by alpha particles. In an E-PERM® chamber, Rn decays and emits alpha radiation anywhere in the chamber volume. The Rn progeny formed in the process go immediately to the wall of the chamber, where they undergo further delay causing alpha emission. This immediate plate-out of progeny to the wall occurs because the electret (being positively charged) repels the progeny (which are also positively charged immediately after their formation) to the wall. The small fraction (about 5%) of the progeny remaining neutral will also diffuse and eventually deposit on the wall. Therefore, most of the alpha emission takes place from or near the wall. The energy of these alpha radiations ranges from 5.5 MeV to 7.7 MeV, with corresponding ranges of approximately 4.0 cm to 6.6 cm in air. Three distinct situations can be envisaged:

1. If the dimensions of the ion chamber are smaller than the range of alpha radiation, only a portion of the energy is spent in the air volume, and all the alpha particles terminate at the inner surface of the chamber.

Table 1. Experimental correction factors for different E-PERM® chambers at stated elevations. Corresponding atmospheric pressures are also listed.

Elevation	Pressure		Correction factors (C) for different chambers		
(m)	(kPa)	(cm Hg)	"L"	"S"	"H"
000	101.3	76.0	1.00	1.04	1.03
305	97.7	73.3	1.04	1.02	1.04
610	94.4	70.8	1.10	0.97	1.00
915	91.0	68.3	1.14	1.01	0.98
1220	87.7	65.8	1.19	1.03	1.01
1525	84.4	63.3	1.23	1.07	1.05
1830	81.0	60.8	1.28	1.17	1.03
2134	77.7	58.3	1.32	1.22	1.05
2440	74.4	55.8	1.37	1.27	1.04

The correction factor (C) is the ratio of the response of E-PERM®s at 101.3 kPa (76.0 cm Hg) (0 elevation) to the response at the stated pressure (stated elevation). Chamber "L" has a volume of 50 mL, chamber "S" has a volume of 210 mL, and chamber "H" has a volume of 960 mL.

Table 2. Comparison of correction factors (C) and pressure ratios (P).

Elevation (m)	Pressure (kPa)	Pressure (cm Hg)	"L" (C)	"L" (P)	"S" (C)	"S" (P)
000	101.3	76.0	1.00	1.00	1.04	—
305	97.7	73.3	1.04	1.04	1.02	—
610	94.4	70.8	1.10	1.07	0.97	—
915	91.0	68.3	1.14	1.11	1.01	1.00
1220	87.7	65.8	1.19	1.16	1.03	1.04
1525	84.4	63.3	1.23	1.20	1.07	1.07
1830	81.0	60.8	1.28	1.25	1.17	1.12
2134	77.7	58.3	1.32	1.30	1.22	1.17
2440	74.4	55.8	1.37	1.36	1.27	1.22

Correction factors (C) and pressure ratios (P) for different chambers.

Chamber "L" has a volume of 50 mL, and chamber "S" has a volume of 210 mL. Correction factor (C) is the ratio of response of E-PERM®s at 101.3 kPa (76 cm Hg) to that at the stated pressure. Pressure ratio is the ratio of the pressure at which the correction factor is 1.00 to the stated pressure.

Under this condition the rule applicable to the gamma radiation should hold, i.e., total ions produced depend directly on the pressure or air density.

2. If the dimensions of the chamber are very much larger than the range of alpha radiation at sea level, then at lower pressures alpha particles will dissipate all their energy within the ion chamber. Under such situations there may not be any significant pressure effects at all, as has been observed for chamber "H."

3. There may be an intermediate situation in which the dimensions of the chamber are slightly larger than the range of the alpha radiation at sea level. In this situation, pressure effects may be manifested at somewhat lower pressure when the chamber dimensions become smaller than the increased range of the alpha radiation at that lower pressure.

The model discussed above can be used to provide a qualitative explanation for the experimental results obtained in this study.

The dimension of chamber "L" varies from a minimum of 2 cm to a maximum of 5.8 cm. In this chamber, the dimensions are smaller than the range of alpha radiation, and the pressure effect is expected at all elevations. Table 2 gives the correction factors and the pressure ratios for different elevations. It can be seen that the correction factors and the pressure ratios are similar, confirming the model proposed.

The dimensions of chamber "S" range from 5.5 cm to 8.1 cm. In this intermediate situation, the dimensions of the chamber are slightly larger than the range of alpha radiation. Table 2 gives the correction factors and the pressure ratios, beginning with the pressure at which there was no effect. Again the correction factors and pressure ratios are similar after the elevation of 1200 m, confirming the proposed model.

The dimensions of chamber "H" range from 7.6 cm to 15 cm. These dimensions are much larger than the range of alpha radiation. No significant pressure effects are expected down to a certain pressure. This prediction is confirmed by the experimental observation that there is no pressure effect up to 2500 m elevation.

The fact that chamber "H" did not show the elevation effect indicates that the Rn release rate is not affected in the pumped-down conditions or lower pressure conditions over the pressure ranges studied. Otherwise the response should have been higher at the lower elevation.

E-PERM® radon monitors also exhibit a minor response to environmental gamma radiation (Kotrappa 1988, 1990). The procedure for calculating radon concentration takes this into account. In the present experiments, the sources used did not pose any significant increase in gamma background over and above the natural levels.

CONCLUSIONS

A correction factor based on pressure ratios does not hold for Rn measurements using E-PERM®s. Because of the complex geometry, the correction factors must be determined experimentally. The experimental configuration described in this work is usable for determining correction factors for such other radon measuring units as alpha-track detectors or other instruments that use alpha detection as a mode of measuring radon concentration.

The correction factors become significant when the dimension of the chamber is smaller than the range of alpha radiation. A physical model described in this work appears to explain the results satisfactorily. In chamber "L" E-PERM®s, correction is approximately 4% to 5% for every 300 m. In chamber "S" E-PERM®s, there is no pressure correction up to 1200 m, and thereafter 4% to 5% for every 300 m. In chamber "H" E-PERM®s, there is no pressure correction up to an elevation of 2400 m. These corrections should be applied whenever E-PERM®s are used for making Rn measurement. Correction tables are provided by the manufacturer. Since corrections are minor and slowly varying, elevations in the area need not be known precisely.

Acknowledgement(s)—The authors are grateful to Dr. R. Colle of the National Institute of Standards and Technology for loan of the experimental Radon Reference Standards for this work. The authors are also grateful to out other colleagues, J. C. Dempsey and R. W. Ramsey, for useful discussions and to Lu Markland for editorial assistance.

REFERENCES

Colle, R.; Hutchinson, J. M. R.; Unterwerger, M. P. The NIST primary ^{222}Rn measurement system. J. Res. Natl. Inst. Standards Technol. 95:155–165; 1990.

Kotrappa, P.; Dempsey, J. C.; Hickey, J. R.; Stieff, L. R. An electret passive environmental ^{222}Rn monitor based on ionization measurement. Health Phys. 54:47–56; 1988.

Kotrappa, P.; Dempsey, J. C.; Ramsey, R. W.; Stieff, L. R. A practical E-PERM® (passive environmental radon monitor) system for indoor radon measurement. Health Phys. 58:461–467, 1990.

Lapp, R. E.; Andrews, H. L. Nuclear radiation physics. Third ed. Englewood Cliffs, NJ: Prentice Hall; 1964.

■ ■