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ELEVATION CORRECTION FACTORS FOR E-PERM(R)[1] RADON MONITORS[2]

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ABSTRACT

E-PERM(R) radon monitors are based on the principle of electret ion chambers and these are usually calibrated in a standard radon chamber located at sea level. Corrections are needed if these are used in elevations other than sea level. These were experimentally determined for three models of commercially available electret ion chambers (E-PERMS(R)) as functions of elevation above sea level. These constitute a slowly varying minor corrections.

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1 E-PERM(R) is a registered trademark of the product patented and manufactured by Rad Elec Inc., Frederick, MD 21701 USA

2 Modified version of this paper is in the process of publication in Health Physics Journal (1992).

INTRODUCTION

Radon-222 monitors based on electret ion chamber technology known as Electret Passive Environmental Radon Monitors (E-PERMS) are used widely for making radon-222 measurements in air. These are described fully in earlier publications (Kotrappa et al. 1988, 1990). For further discussions in this paper, Rn means radon-222 unless otherwise stated.

Electret ion chambers are ionization chambers that have a filtered opening and operated 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 with the pressure ratios (Lapp and Andrews 1964). Proportionate pressure corrections are not applicable to alpha radiation due to the limited and finite range of alpha particle. Measurement of Rn using E-PERMS 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 by alpha radiation. The purpose of the present work was to make an experimental determination of the correction factors for three different commercially available models of E-PERMS.

MATERIALS AND METHODS

E-PERM RN MONITORS

Depending upon the sensitivity and range requirements needed for a particular Rn measurement, E-PERM chambers of three different volumes and electrets of two different sensitivities are commercially available. Chambers of different volumes have been designated as "L" (50 mL volume), "S" (210 mL volume), and "H" chambers (960 mL volume). These are schematically shown in Fig.1. Electrets of two different sensitivities termed as "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-PERMs provide radon concentrations with an accuracy of 5 to 6 % over the range of Rn concentrations of about 4000 Bq m used in the current work (Kotrappa et al. 1990).

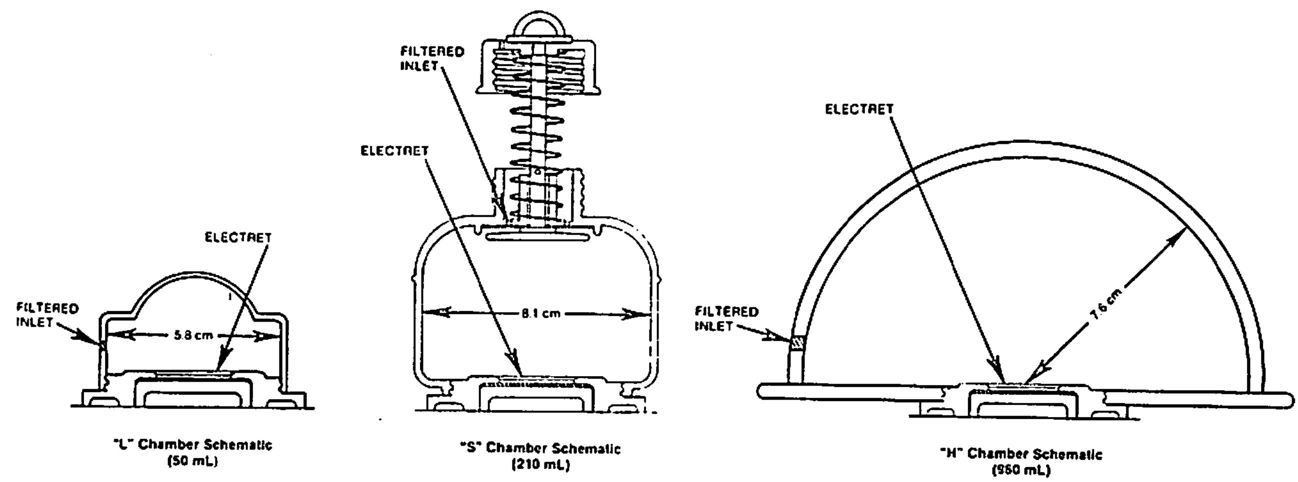

FIGURE - 1

Schematic of different E-PERM chambers under investigation.

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 which permits a precise adjustment of the pressure inside the enclosure by bleeding before isolating. The desiccator has a sufficient volume (10 L) to hold five "L" or "S" chamber E-PERMS under investigation 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 (about 200 feet) was found to be adequate for the present work. This is small in size and does not require any connections. The unit was checked for calibration against a pressure gauze over the pressure ranges from 67 to 101 KPa (50 to 76 cm Hg) and was found to be satisfactory. When left inside the transparent enclosure, the reading was visible during the entire period of experiments.

RADON SOURCES

The NIST experimental (National Institute of Standards and Technology, Gaithersburg,MD,20899,USA) radon transfer standards based on polyethylene encapsulated radium solutions were used as a source of radon. This standard is a small sealed (2.5 cm long and 0.3 cm in diameter) polyethylene vial containing 550 Bq of radium-226 solution (Colle et al. 1990) and emits radon at predictable and reproducible emission rate. The source is attached by a thread to position at the middle of the enclosure. Rn is released into the 10 L volume of the enclosure. This establishes an average Rn concentration of approximately 4000 Bq m over one day.

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1 Guide Tech Altimeter Model 2500 S, made in Japan for Cobbs Manufacturing Co., Des Moines, Iowa 50309, USA
the same period, then the ratio of the response at 101.3 KPa (76
2 Bel Art 42027 Cat. No. 24988-277, VWR Scientific Apparatus Catalogue, 1989/1990, Bridgeport, NJ, 08014 USA

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 the same pressure in these chambers, the radon concentrations were measured over a day and confirmed to be the same within experimental errors. If one of the enclosure is maintained at a pressure of 101.3 KPa (76 cm Hg) corresponding to zero elevation above sea level and the other maintained at 94.3 KPa (70.8 cm Hg) corresponding to elevation of 610 m above sea level, over the same period, then we will have two chambers at the same Rn concentration, but at different pressures. If Rn detectors are enclosed in these chambers over 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 rate of Rn from the sources do not depend upon the pressures in the chamber over the pressure ranges of 67 KPa to 101.3 KPa (50 to 76 cm Hg). Please see the discussion section.

EXPERIMENTS

The experimental set up included two high vacuum desiccators, two Rn sources and ten 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 the enclosure number one was connected to a vacuum pump and pumped down until the altimeter showed approximately 300 m more than the desired setting. Then the valve was closed before disconnecting from the pump. The fine control on the valve was used to bleed in some air from outside until the altimeter showed the desired setting before closing the valve. The valve of the desiccator number two was also closed at this time. These were left in that condition for one or more days depending upon 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 that at which it was 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 number two to that of enclosure number one is the correction factor for that elevation.
Similar measurements were repeated for each of the different types of chambers: "L", "S" and "H". In the case of "H" chamber, only one detector could be accommodated in the enclosure for testing at a time. Tests were repeated three times at each elevation setting to arrive at an average.

It should be noted that the two sources were not of exactly identical strengths. An appropriate normalization procedure was followed.

RESULTS

Results of the experiments are shown in Table 1. Column 1 gives the altimeter reading. Column 2 and 3 give the corresponding atmospheric pressures. Column 4, 5 and 6 give the correction factors for "L", "S", and "H" E-PERM chambers, respectively.

Correction factors become significant for "L" chamber at an elevation of 300 m and above. Equation 1 gives the linear regression equation fitting the data with a correlation coefficient of 0.9995. This equation can be used for computing the correction factors for any elevation, over the ranges covered in this study.

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

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

Correction factors become significant for the "S" chamber only at elevations above 1200 m. Equation 2 gives the linear regression equation fitting the data between 1200 m and 2500 m with a correlation coefficient of 0.9902. This equation can be used for computing correction factors for elevations between 1200 and 2500 m.

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

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

There are no correction factors applicable to "H" chamber up to 2500 m elevation, since the values for C are not signifiantly different from 1.0 .

DISCUSSIONS

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 lower response at lower atmospheric pressures (or at higher elevations) i.e., the response depends upon the air density. Air densities are almost proportional to the 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).

TABLE-1

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

Correction factor(C) is the ratio of the response of E-PERMS at 101.3 KPa (76.0 cm Hg) (0 elevation) to the response at the stated pressure (stated elevation). "L" chamber has a volume of 50 mL, "S" chamber has a volume of 210 mL, and "H" chamber has a volume of 960 mL.

Elevation (m)	Pressure (KPa)	(cm Hg)	Correction factors (C) for different chambers		
			"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 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 is decaying and emitting 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 decay causing alpha emission. This immediate plate out of progeny to the wall occurs because the electret (being positively charged) repels the progeny which is also positively charged immediately after their formation) to the wall. Small fraction (about 5 %) of the progeny remaining neutral will also diffuse and deposit on the wall eventually. Therefore, majority of the alpha emission takes place from or near the wall. The energy of these alpha radiations range from 5.5 MeV to 7.7 MeV with corresponding ranges of approximately 4.0 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 air volume and all the alpha particles terminate at the inner surface of the chamber. Under this condition the rule applicable to the gamma radiation should hold i.e., total ions produced depend directly upon 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 "H" chamber.

(3) There can be an intermediate situation in which the dimensions of the chamber is slightly larger than the range of the alpha radiation at sea level. In this situation pressure effects may be manifested at some 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 "L" chamber varies from a minimum of 2 cm to a maximum the largest of 5.8 cm. This comes generally under the category of the chamber with the dimensions 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.

TABLE-2

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

"L" chamber has a volume of 50 mL, and "S" chamber has a volume of 210 mL. Correction factor (C) is the ratio of response of E-PERMS 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.

Elevation (m)	Pressure (KPa)	Pressure (cm Hg)	Correction factors (C) and pressure ratios (P) for different chambers			
			"L"		"S"	
			(C)	(P)	(C)	(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

The dimensions of "S" chamber varies from a minimum of 5.5 cm to a maximum of 8.1 cm. This comes generally under the category of intermediate situation where the dimensions of the chamber are slightly larger than the range of alpha radiation. Table 2 gives the correction factors and the pressure ratios starting from 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 dimension of "H" chamber varies from a minimum of 7.6 cm to a maximum of 15 cm. This comes under the category of the dimensions being much larger than the range of alpha radiation. No significant pressure effects are expected down to certain pressure. This prediction is confirmed by the experimental observations that there is no pressure effects up to 2500 m elevation.

The fact that "H" chamber did not show the elevation effect indicate 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 lower elevation.

CONCLUSIONS

A correction factor based on pressure ratios does not hold for Rn measurements using E-PERMS. When faced with electret ion chambers with complex geometrical configuration, the correction factors must be determined experimentally. The experimental configuration described in this work is usable for determining such correction factors for other radon measuring units such as alpha track detectors or other instruments which 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 appear to explain the results satisfactorily. In "L" chamber E-PERM correction is approximately 4 to 5 % for every 300 m. In "S" chamber E-PERMS, there is no pressure correction up to 1200 m and thereafter 4 to 5 % for every 300 m. In "H" chamber E-PERMS there is no pressure correction up to an elevation of 2400 m. These corrections should be applied whenever E-PERMS are used for making Rn measurement. Correction tables are provided by the manufacturer to the users of these devices. Since the correction is small and slowly varying, elevations in the area need not be known precisely.

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