Review of Electret ion chamber technology for measuring technologically enhanced natural radioactivity

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Abstract. Electret ion chamber (EIC) is a passive integrating ionization chamber used extensively for measuring technologically enhanced radioactivity. Commercially available electret ion chambers called [1]E-PERM® (Electret-Passive Environmental Radiation Monitors) electret ion chambers are relatively new and are in use only from the past 10 years. The EIC consists of a stable electret (electrically charged Teflon disc) mounted inside an electrically conducting chamber. The electret serves both as a source of the electric field and as a sensor. The ions produced inside the chamber are collected by the electret. The reduction in charge of the electret is related to total ionization during the period of exposure. This charge reduction is measured using a battery operated electret reader. Using appropriate calibration factors and the exposure time, the desired parameters such as radon concentration in air is calculated. These low cost monitors require neither power nor battery and several hundreds of these can be used simultaneously and serviced by one reader. These monitors do not provide on line readings, but provide an average value over a period of time. The EICs have been used for measuring: (a) indoor and outdoor radon, (b) thoron, (c) dissolved radon and radium in water, (d) environmental gamma, (e) radon emanating radon concentration in soil samples and in pipes, (f) radon flux from surfaces and building materials. The purpose of this paper is to describe these methods and give selected reference to the related publications for more detailed reading.

1. INTRODUCTION

Electret ion chambers (EIC), commercially available under trade name E-PERM ®, are extensively used for characterizing technologically enhanced radiation. Such applications include:

(a) Indoor and outdoor radon
(b) Thoron
(c) Dissolved radon and radium in water
(d) Environmental gamma
(e) Radon emanating radon concentration in soil samples and in pipes
(f) Radon flux from surfaces and building materials

These are extensively used because of several practical advantages. The purpose of this paper is to describe these methods and give selected references to the related publications for more detailed reading.

2. ELECTRET ION CHAMBERS-HOW DO THESE WORK?

Electret ion chambers (1) consists of a stable electret (electrically charged Teflon® disc) mounted inside an electrically conducting chamber. The electret serves both as a source of the electric field and as a sensor. The ions produced inside the chamber by radiation are collected by the electret. The reduction in charge of the electret is related to total ionization

[1] E-PERM® is a trade name for the Electret Ion Chambers manufactured by Rad Elec Inc., 5714-C Industry Lane, Frederick, MD 21704 USA

during the period of exposure. This charge reduction is measured using a battery operated electret reader. Using appropriate calibration factors and the exposure time, the desired parameters such as airborne radon concentration in air is calculated using hand held pocket computer with suitable software. **Figure 1** gives a photograph of electret, chambers and the electret reader. The scientific bases for the performance EIC are:

(1) The change in charge on the surface of the electret is caused only by the collection of ions and no other processes
(2) The change in charge on the surface of the electret after the collection of ions is permanent
(3) The charge on the surface of the electret is measured by a non-destructive method.

Figure 1. Components of electret ion chambers. Electret, chamber and reader.

These features make the EIC, a true integrating device. These low cost monitors require neither power nor battery and several hundreds of these can be used simultaneously and serviced by one reader. Normally encountered temperatures, humidities and mechanical shocks do not affect the performance of these monitors, making them robust for field use. Further, the method is purely a physical method and does not depend upon the chemical absorption of gases being measured or does it involve chemical processing.

Basic portable EIC System consists of:
(1) Several electrets
(2) Several chambers
(3) One electret voltage reader
(4) Data analysis tool

The electret is used and reused until the surface voltage falls too low (less than 200 volts) to collect the ions produced in the volume of the chamber. This feature provides multiple use of the same electret.

The data sets needed for analyzing the results are:

(1) The initial reading of the electret
(2) The final reading of the electret
(3) The exposure time

3. INDOOR AND OUTDOOR RADON IN AIR

Most popular application of EIC device is in measuring indoor and outdoor radon concentration (2,3).

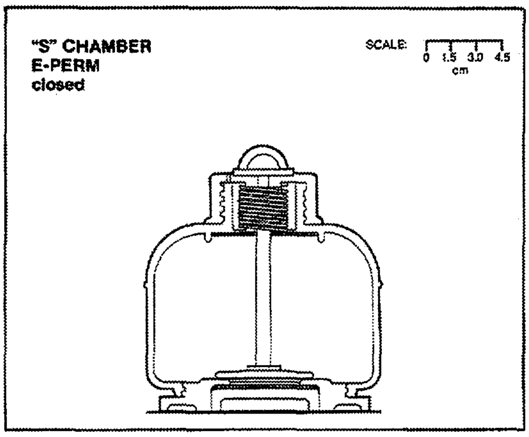
A typical radon monitor has a mechanical arrangement, shown in **Figure 2**, for opening and closing the electret from outside the monitor chamber. This feature allows flexibility of reading the electret in the laboratory. Following steps need to be done for making a measurements:

Take initial reading of the electret in the laboratory
Load the electret into the chamber
Turn the E-PERM to off position
Transport E-PERM to the place of measurement
Turn the E-PERM to on position
Continue exposure for desired length of time
Turn the E-PERM to off position
Transport to the laboratory
Unscrew the electret and take final reading of the electret
Electret can be left inside the chamber in off position or screwed back into the storage cap.
Use the data, initial reading, final reading, and exposure time for calculating radon concentration.

For certain chambers which do not have on-off mechanism, electret has to be loaded and unloaded at the place of exposure.

Corrections are applied for gamma background. If the gamma background is not known corrections are applied using 100 nGy/h as the background.

These have some similarity with alpha track (AT) detectors. In alpha track detectors, alpha particles from radon hit the special plastic and create a defect that will become visible when chemically processed. The number of tracks formed in the plastic over a time is related to integrated radon concentration over that period. In EIC, ions produced by alpha particles from radon are collected by electrets. The change in charge of the electret over a time is related to the integrated radon concentration over that time. Unlike alpha track detectors, no chemical processing is needed for EIC. Change in charge can be read rapidly, in seconds. Being a non-destructive mode of analysis, it is possible to take intermediate readings and continue the measurement. This is a distinct advantage over AT radon monitors.



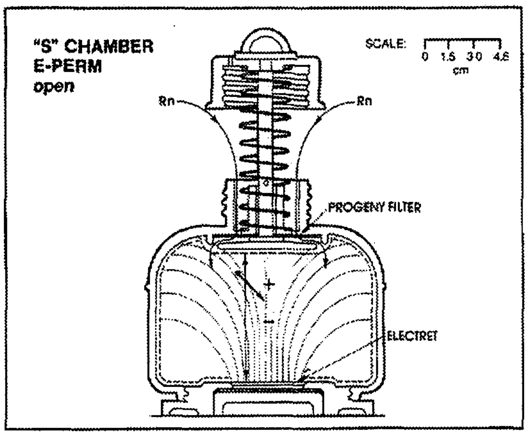


Figure 2. Radon Monitor with on/off mechanism. In closed position, ions do not reach electret. In open position ions discharge electrets.

The sensitivity is controlled by using electrets of different sensitivities and also by using chambers of different volume. Using different combination it is possible to measure radon concentrations ranging from 50 Bq m^{-3} to 3 million Bq m^{-3}.

These monitors are widely used and have performed well in the national and international inter-comparison exercise (4).

These have sufficient sensitivity to measure ambient radon concentration, provided the E-PERM is exposed for sufficient exposure period. United States Environmental Protection Agency used SST (S chamber with short-term electret) E-PERMs for their National Ambient Radon Project (5,6), and made 3-monthly average measurements.

4. THORON IN AIR

E-PERM® passive integrating electret ionization chamber for measuring radon in air has a restricted filtered passive access to radon (^{222}Rn). Area to volume ratio of access is designed to allow sufficient delay to decay ^{220}Rn effectively and respond only to radon (^{222}Rn) and not to thoron (^{220}Rn). A modified unit called thoron monitor, with unrestricted access to radon and thoron responds to both radon and thoron. Radon monitor and thoron monitor when used side by side allows measurement of both radon and thoron concentration in air. Such monitors were calibrated in a well-characterized thoron test chamber maintained by Canadian Mining Institute (CANMET). More details of this and the equations to be used for computing both radon and thoron concentrations are given by Kotrappa **(7). Figure 3** gives schematic of such chambers. These performed well in recent inter-comparison exercise at US Department of Energy thoron tests.

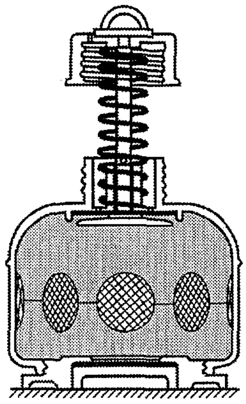


Figure 3. Thoron monitor.

5. DISSOLVED RADON IN WATER

This method belongs to the general class of "de-emanation method" of measuring dissolved radon in water. A small water sample is placed in the bottom of a glass jar. An E-PERM® is suspended in the air phase above the water. The lid of the flask is closed and sealed to make it radon-tight. Radon reaches equilibrium between the water and air phase. At the end of the desired exposure period, the flask is opened and the E-PERM® removed. The average radon concentration in the air phase is calculated using the standard E-PERM® procedure. A calculation using this air concentration in conjunction with the other parameters gives the radon concentration of the water. Kotrappa and Jester (8) give details on the theoretical basis for this method. Paper also evaluates the results of the measurements done with electret ion chambers and with liquid scintillation method on the same samples. **Figure 4** gives a schematic of the measurement arrangement.

For measuring very low levels of radon in water, slightly different method is used. The detector is immersed in the body of the water, after sealing it in a thin polyethethelene bag (9). Equilibrium gets established between radon in water and in air phase of the detector. Measuring radon concentration and using appropriate partition coefficients, it is possible to calculate the radon concentration in water.

6. DISSOLVED RADIUM (^{226}Ra) IN WATER

The arrangement used for measuring radon in water can also be used for a quantitative measurement of radium in water. Using equations that take into account build up and decay of radon emanated from radium in the sample, the integrated average radon concentration as measured by E-PERM radon monitor over a time is used to calculate the radium concentration in water. The immersion method increases the sensitivity by a factor of five from 5 pCi/L(0.18 Bq/L) to (0.036 Bq/L) (9).

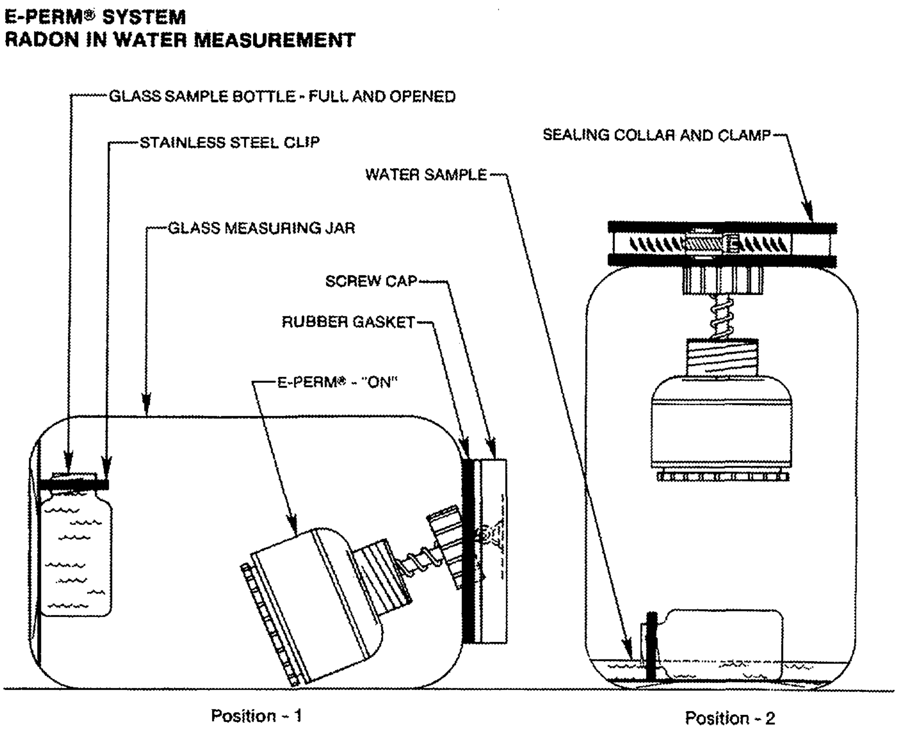


Figure 4. Schematic for measuring radon in water.

7. RADON EMANATING RADIUM CONCENTRATION IN SOIL AND RADIUM IN PIPES

By taking a sample of soil or other materials in the place of water in the arrangements used for measuring radon in water, it is possible to calculate radon-emanating radium in soil sample. Using equations that take into account build up and decay of radon emanated from radium in the sample, the integrated average radon concentration as measured by E-PERM radon monitor over a time is used to calculate the radon emanating radium concentration in the sample. Several investigators have successfully used this method (10, 11). Figure 5 gives schematic of the arrangement. Same principle can be used for measuring radium inside the pipes. Enclose an E-PERM inside the pipe, seal both ends of the pipe, and expose the detector for a known period. The data on the radon concentration, the exposure time and the volume of the pipe is used to calculate radon emanating radium concentration. If emanation coefficient is known, it is possible to calculate gross radium concentration.

8. E-PERM® RADON MONITORS FOR MEASURING UNDISTURBED RADON FLUX

The measurement of radon flux from the ground or other surfaces is useful for determining the (a) radon emanating potential of a building site, (b) to meet the regulatory requirements for uranium mill tailings or phosphate tailings or gypsum stacks, and to determine the radon flux from test materials such as bricks and other surfaces.

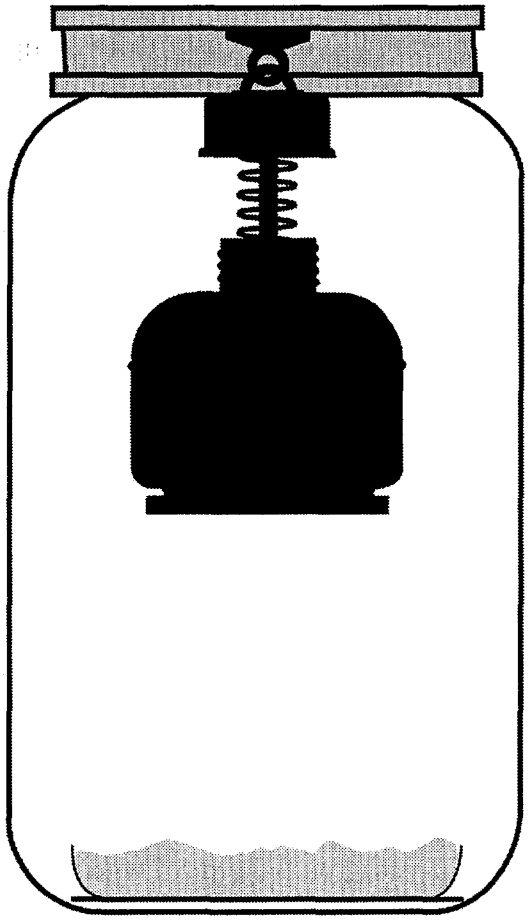


Figure 5. Schematic for measuring radium in soil sample.

8.1.Passive method

A large, one-liter hemisphere with a large, carbon coated Tyvek$^{(R)}$ diffusion window, allows radon to get into the chamber volume. Filtered outlets vent the chamber so that it will not accumulate radon (Figure 6). When the E-PERM® flux monitor is placed on radon emanating surface, the radon enters through the Tyvek® barrier and exits through the vents. The semi-equilibrium radon concentration established inside the chamber is representative of dynamic flux from the surface. Because of the equilibrium between the ground and outside environment through vents, the flux emanation from the ground is not disturbed. The electret discharge rate of the electret is a measure of the radon flux. E-PERM® flux monitors are calibrated on the well-characterized radon flux beds at CANMET (Canada). These flux beds consist of ^{226}Ra bearing material (well-characterized uranium tailings) 5.5 cm thick and 5 meter in diameter. The bed is precisely characterized by CANMET* to provide a radon flux of 7.7 pCi m^{-2} sec^{-1} (0.285 Bq m^{-2} sec^{-1}).

Details of the methods are described in a published papers (12,13) describe the comparative evaluation of the flux measured by electret ion chamber method and by other base line technologies that uses large area charcoal detector method on the same measurement area.

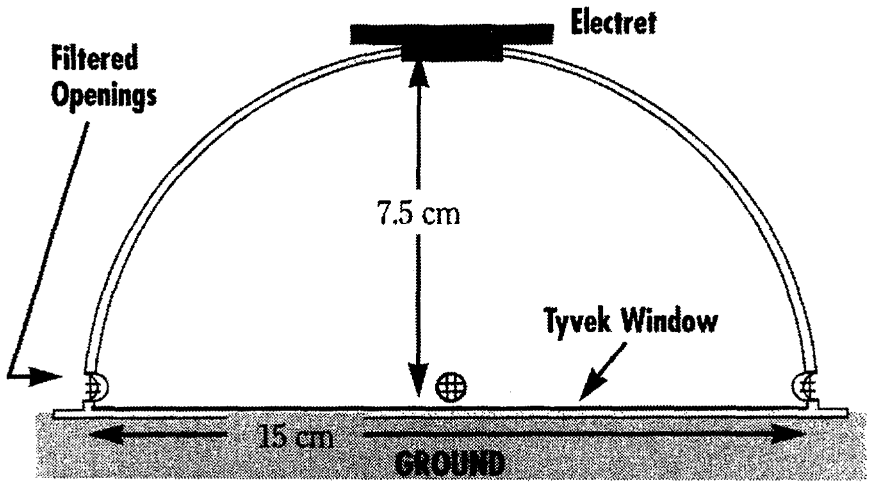


Figure 6. Schematic of passive radon flux monitor.

8.2. Dynamic method

A rectangular enclosure is placed on the ground where radon flux has to be measured. Establish a steady known air flow. Quickly, a steady radon concentration is reached inside the enclosure that depends upon the radon flux, flow rate and the area of ground in the enclosure. By measuring the radon concentration inside the enclosure using E-PERMs it is possible to calculate radon flux from first principles.

9. ENVIRONMENTAL GAMMA

The EICs are ionization chambers and respond to any ionizing radiation including gamma radiation. The radon monitors can be used as gamma monitors, if sealed inside a radon leak tight bags, such as Mylar bags, which prevent the entry of radon into the sensitive volume of the chamber. The E-PERM is made of materials that are near tissue equivalent and therefore do not have energy dependence. It makes correct gamma measurements irrespective of the energy of the gamma radiation. Once it is calibrated properly using a standard source of any particular energy such as Cs-137, it can be used for a true measurement of gamma radiation of any energy or a combination of different energies.

Even though the respective national authorities have published an average level of natural gamma radiation, there can be some isolated spots of higher dose rates, from the technologically enhanced sources such as those from granites and refractory materials used in the construction of buildings. Other sources could be the storage yards of pipes and other accessories used in mining/petroleum industry. Another source could be an operating Nuclear Power Plant or other nuclear facility.

These are usable wherever TLD (thermo-luminescent dosimeters), but provide a tissue equivalent and energy independent response. These are widely used for perimeter monitoring of nuclear facilities (14,15).

10. DISCUSSIONS AND CONCLUSIONS

The E-PERM® Electret ion chamber technology is an integrated method providing capability of measuring several diverse technologically enhanced sources of radiation. It is important to note that you use the same sensors and same reader, whether you are measuring radioactive gases or radiation. This unified approach saves money and training needed. It is not surprising that this is one of the most popular methods for indoors and workplace radon monitoring in USA and in several other countries in Europe. The E-PERM System manual (16) gives exhaustive description of all the applications in one place.

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