E-PERM® System

User's Manual

Version 4.0.1
11 March 2024

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Introduction to the E-PERM® System

E-PERM® is an acronym for Electret Passive Environmental Radon Monitor. Rad Elec's E-PERM® System has revolutionized the radon industry with its patented electret ion chamber technology. Recipient of the American Nuclear Society's prestigious International Radiation Science and Technology Award, the accurate and low-cost E-PERMs® have gained acceptance with countless radon professionals in North America, and are used in over 30 countries worldwide.

An E-PERM® (also known generally as an Electret Ion Chamber) is a passive, integrating ionization monitor consisting of a very stable electret loaded onto a small chamber made of electrically conducting plastic. The electret, a charged Teflon® disk, serves as both the source for ion collection and as the integrating ion sensor. Radon gas passively diffuses into the chamber through filtered inlets, and the alpha particles emitted by the decay process ionize air molecules. Negative ions produced inside the chamber are collected on the positively charged electret, causing a reduction of its surface charge (or voltage). This reduction in surface charge (or voltage) is a function of the radon concentration, the duration of the testing period, and the chamber volume. This change in voltage is measured with Rad Elec's SPER-1E Electret Voltage Reader. The results can be calculated with software, spreadsheets, online tools, or even with pencil and paper. Client reports can be generated using the Radon Report Manager (RRM) software.

The basic components of the E-PERM® System comprise electrets, a SPER-1E voltage reader, ionization chambers, and calculation/analysis tools. There are chambers of different volumes and electrets of different sensitivities to meet a wide range of environmental and measurement situations. Typically, more sensitive electrets (known as ST) are used for short-term measurements, whereas LT Electrets are less sensitive and are used for measurements of a longer duration.

Visit our website at www.radelec.com to view tutorials, manuals, and a vast collection of published articles. If you are curious, we encourage you to locate these resource materials in the Documentation section of our website. These manuals and articles explain the theory behind electret ion chambers and provide a number of intercomparisons of our electret technology with other methods of measuring radon gas.

Starter Kit Components

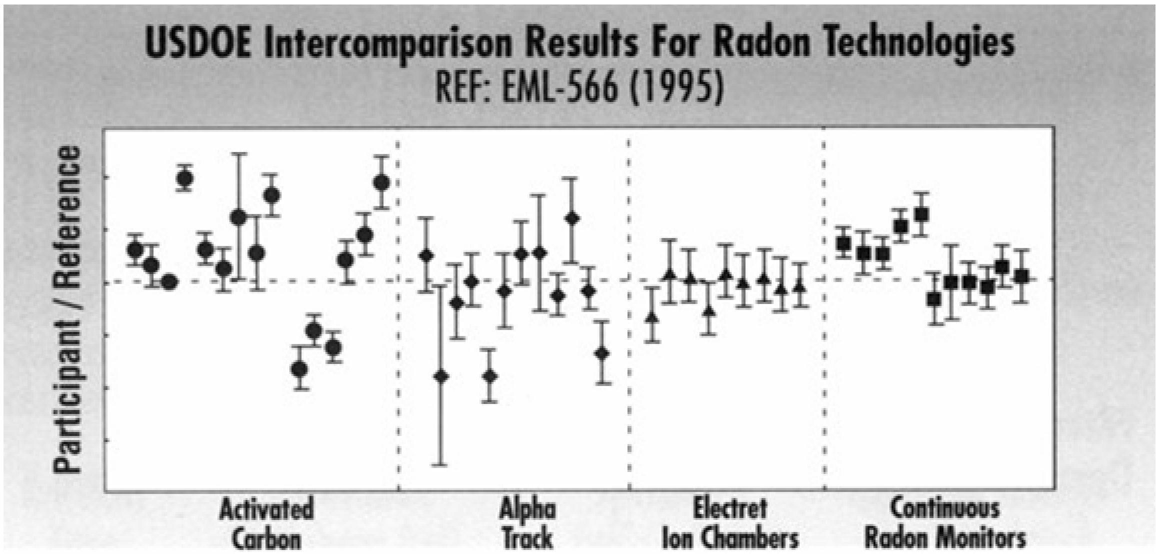
Each E-PERM® Starter Kit includes the following:

- **1 SPER-1E Reader** (with case and desiccant)
- **1 Zeroing Electret**
- **2 Reference Electrets** (comprising a single set)
- **6 Short-Term (ST) Electrets**
- **6 S Chambers**
- **3 Deployment Sleeves / Twin Boxes**
- **Radon Report Manager Software**
- **E-PERM® User's Proficiency Course**
- **E-PERM® System User's Manual**
- **Quality Assurance Plan**
- **Package of 100 4" Lock Ties**
- **Package of 25 14" Lock Ties**
- **10 Sheets of Tamper-Indicating Tape**
- **5 copies of Marketing Brochures**
- **10 "Radon Test in Progress" Door Hangers**

The purpose of this manual is to convey the basic theory and practice behind conducting electret ion chamber measurements, from start to finish.

Performance of E-PERMs®

E-PERMs® have demonstrated superior accuracy in independent studies. The U.S. Department of Energy's 1995 Intercomparison demonstrated that E-PERMs® performed as well as the more expensive continuous radon monitors and outperformed all other passive devices.



One of the best documented blind intercomparison tests was administered by the USEPA under the Radon Proficiency Program (RPP). Their report (EPA 402-F-93-003-1) lists the cumulative results for the period from January 1991 to April 1997. E-PERMs® had the highest pass rate of all participating detectors.

Relative Performance of Different Detectors

Detector Type	Activated Carbon	Alpha Track	E-PERM® Short-Term	E-PERM® Long-Term	Continuous Radon Monitor	Liquid Scintillation
# of Detectors Tested	1164	113	2206	1083	670	216
Device Pass Rate (%)	81.1	64.2	92.3	89.0	85.9	80.0

E-PERMs® constituted greater than 50% of the detectors that were tested in the Radon Proficiency Program in the 1990s, and they achieved a very high pass rate. There have been several intercomparison tests published in various journals that corroborate these results.

Quality Audit Report by USEPA

On 9 December 1997 the USEPA, represented by Shawn Price (SC&A RPP Quality Assurance Coordinator), Melinda Ronca-Battista (SC&A Senior QA Specialist), and Samuel Poppell (RPP Program Manager) conducted an on-site visit at Rad Elec. Below are relevant extracts from their five page report issued on 20 May 1998:

> Rad Elec has spent years identifying, maintaining, and verifying that the calibration factors employed are correct. Essentially the calibration of E-PERMs® has not changed in several years. This leaves only the SPER-1 and reference electrets in the hands of the users to calibrate annually (which means that the E-PERM® detectors do not require calibration in the hands of the users).
>
> The E-PERM® system is so adequately documented and reliable that a user would have to exhibit systematic carelessness to produce consistently invalid results. The friendliness, accessibility, and handwork by the Rad Elec staff are the main reasons that their product is so popular in today's market. If there is any indication of poor quality, the user can find the problem by investigating their procedures and comparing them to the manufacturer's recommendations. Radon testers intent on quality would be well advised to look into the E-PERM® system to see how it fits their needs.

True in 1998, and still true today!

Basic Components of the E-PERM® System

The E-PERM® system consists of five components:

- An **electret**, which is an electrostatically-charged Teflon® disk for ion collection.
- An **ion chamber** constructed of conductive plastic, onto which an electret can be loaded.
- A **voltage reader** to measure the surface potential (voltage) of the electret.
- **Reference electrets**, which ensure that your voltage reader is working properly.
- Software (and/or spreadsheets) to calculate radon concentrations and generate reports.

E-PERM® System Components

Chamber

Electret

+

Voltage Reader

+

Radon Analysis Software

These components are needed to make both short-term and long-term radon measurements, and can be used either indoors or outdoors. When an electret is loaded onto an ion chamber it is called an E-PERM®, which is also referred to as an electret ion chamber (EIC).

An E-PERM® is an electret (of any sensitivity) loaded into an ion chamber (of any volume).

The technical basis for the measurement of indoor radon using the E-PERM® system has been fully described in two papers in the Health Physics Journal. These papers, listed below, can be viewed online and/or downloaded from Rad Elec's website:

Health Physics Vol. 54, No. 1 (January), pp. 47–56, 1988
Printed in the U.S.A.

0017-9078/88 $3.00 + .00

● *Paper*

AN ELECTRET PASSIVE ENVIRONMENTAL ^{222}Rn MONITOR BASED ON IONIZATION MEASUREMENT

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(*Received* 5 *December* 1986; *accepted* 2 *August* 1987)

Abstract—The electret passive environmental ^{222}Rn monitor (E-PERM) is an extension of electret dosimeters used for measurement of x and γ radiation. An E-PERM consists of a small cup or canister, having an electret at the bottom, and a filtered inlet at the top. The ^{222}Rn gas entering through the filter and the decay products formed inside the cup generate ions which are collected by the electret. The reduction of charge (or surface potential) on the electret is a measure of time integrated ^{222}Rn exposure. An E-PERM of 220-mL volume with an electret of 0.23 cm thickness gave a surface potential drop of 2.5 V for 37 Bq m^{-3} d (1 pCi L^{-1} d). The electret voltage was measured with a specially built surface potential voltmeter. This sensitivity was found adequate for a 1-wk measurement of ^{222}Rn in homes. For longer term measurements, an E-PERM of 40-mL volume and an electret of 51-μm thickness was developed which gave a surface potential drop of 2.6 V for 37 Bq m^{-3} y (1 pCi L^{-1} y). Other combinations of chamber volume and electret thicknesses gave responses between these two values. The surface potential of electrets made from Teflon® FEP† were shown to stay stable even under extreme conditions of relative humidity. The ion collection process in E-PERMs was also shown to be independent of humidity down to an electret surface potential of 100 V.**

1. INTRODUCTION

AN ELECTRET (Se80) is a piece of dielectric material exhibiting a quasi-permanent electrical charge. The charge of the electret produces a strong electrostatic field capable of collecting ions of opposite sign. Until recently, electrets have been regarded as curious analogues of magnets, worthy only of academic interest. However, with the development of high dielectric fluorocarbon polymers such as Teflon, electrets have become reliable electronic components capable of maintaining constant electrostatic fields even under high temperature and humidity conditions (Tu75).

Marvin (Ma55) was the first to suggest that the reduction of charge on the electret was due to the collection of ions of opposite sign from the surrounding gas, and he proposed the use of an electret in a closed chamber as a γ dosimeter. His idea was not practical at that time because, as Wolfson (Wo61) soon showed, the charge was not stable in carnauba wax which was the best electret material available at the time. Recently, however, Bauser and Range (Ba78) used a pair of thin Teflon electrets of opposite charges to collect and measure the ions produced inside an ionization chamber. They showed that the radiation dose calculated from this measurement, agreed well with the actual dose received by the chamber. They also demonstrated that the performance was insensitive to variations in humidities and temperatures in the range normally encountered in the environment. The dose information on their electrets was retained without loss over a period of more than 1 y. This study laid a sound scientific basis for the further development of electret dosimeters.

The next innovation in electret ion chamber development was a single electret dosimeter, reported by Kotrappa et al. (Ko82b). These workers showed that the drop in surface potential of their single electret dosimeter also behaved according to established ion chamber theory, and they went on to demonstrate its use as a personal dosimeter (Gu85). Similar work was carried out later by Pretzsch (Pr83a). The theoretical aspects of electrostatic fields in such ionization chambers were worked out by Fallone (Fa83).

Kotrappa (Ko84) also used this technique to measure the potential α energy concentration of ^{222}Rn decay products. Pretzsch (Pr86) recently adapted the method for measurement of ^{3}H concentration in a flow through chamber. Kotrappa et al. (Ko81) found a rough correlation between the reduction of the surface voltage on a polycarbonate covered electret and the cumulative ^{222}Rn exposure in a passive chamber arrangement. They also observed that this charge reduction did not appear to be sensitive to humidity change.

* Currently with Rad-Elec, Inc., P.O. Box 310, Germantown, MD, 20874.
** Patent pending.
† Teflon® FEP fluorocarbon, manufactured by E. I. du Pont De Nemours and Co. (Inc.), Wilmington, DE 19898.

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Kotrappa, P., et al. "An Electret Passive Environmental ^{222}Rn Monitor Based on Ionization Measurement." *Health Physics*, Volume 54, No. 1, January 1988, pp. 47-56.

Kotrappa, P., et al. "A Practical E-PERM® (Electret Passive Environmental Radon Monitor) System for Indoor ^{222}Rn Measurement." *Health Physics*, Volume 58, No. 4, April 1990, pp. 461-467.

Health Physics Vol. 58, No. 4 (April), pp. 461–467, 1990
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Pergamon Press plc

● *Paper*

A PRACTICAL E-PERM™ (ELECTRET PASSIVE ENVIRONMENTAL RADON MONITOR) SYSTEM FOR INDOOR ^{222}Rn MEASUREMENT*

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(*Received* 21 *March* 1989; *accepted* 15 *November* 1989)

Abstract—The technical and scientific basis for the measurement of indoor ^{222}Rn concentration using an E-PERM™ (Electret passive environmental radon monitor) has been described in our earlier work. The purpose of this paper is to describe further development of a practical and convenient system that can be used routinely for indoor ^{222}Rn measurement. The ion chamber is now made of electrically conducting plastic to minimize the response from natural γ radiation. A spring-loaded shutter method is used to cover and uncover the electret from outside the chamber. The electret voltage reader has been modified to improve the accuracy and the ease in operation. The calibration, performance, error analysis, and lower limits of detection for these standardized versions of E-PERMs are also described.

INTRODUCTION

THE SCIENTIFIC and technical basis for the measurement of ^{222}Rn using an E-PERM™ has already been described in an earlier publication (Kotrappa et al. 1988).

Presently, we would like to describe two standardized versions of E-PERMs which are commercially available to perform short-term and long-term measurements of indoor ^{222}Rn. (For further discussion in the paper, Rn means ^{222}Rn unless otherwise mentioned.) Both versions have passed a series of tests conducted by the U.S. Environmental Protection Agency. These units differ substantially from the units described in our earlier work.

An electret is a charged Teflon† disk carrying a quasi-permanent electric charge. The charge of the electret produces a strong electrostatic field capable of collecting ions of opposite sign. The amount of charge that an electret carries is characterized by its surface potential, diameter, and thickness.

An E-PERM™ consists of a small chamber having an electret at the bottom and a filtered inlet at the top. Radiation from Rn gas entering the chamber and the decay products formed inside the chamber generate ions that are collected by the electret. An E-PERM™ functions as an integrating ionization chamber, wherein the electret serves not only as a source of an electrostatic field but also as a quantitative sensor. The drop in surface voltage of the electret over a known time period is a measure of time-integrated ionization during that time interval. These data can be converted readily into Rn concentration. The desired sensitivity, dynamic range, and statistical accuracies can be programmed into the design parameters of an electret ion chamber to get an optimum performance for a specific Rn measurement situation.

DESIGN FEATURES OF E-PERM™ CHAMBER

Our earlier study indicated that it is desirable to use a low-Z (atomic number) material for the ion chamber to minimize the response to the natural environmental γ radiation. Accordingly, the present E-PERM™ chambers and the electret holders are made of electrically conducting plastic. It was also indicated in our study that a mechanism must be provided to keep the electret covered in order to eliminate undesired background during storage or transport. The cup-in-cup arrangement described in that work proved to be somewhat complicated for homeowner use. To overcome this deficiency, a novel spring-loaded piston mechanism was adopted to turn the instrument on and off; Fig. 1 shows this feature. When the E-PERM is not in use or when it is in transit, the electret cover is kept down very close to the electret. This effectively cuts off the electret field to the interior of the chamber and shuts off the E-PERM™. The electret cover is attached to a screwcap on top of the E-PERM™ that is tightened to lock the electret cover. When the E-PERM™ is used, the screwcap is unscrewed and a spring lifts the electret cover up and away from the electret and holds it there to turn the E-PERM™ to the "on" position.

The filtered inlet is necessary to allow Rn into the chamber while excluding Rn progeny or environmental

* E-PERM™ is a trademark of the product manufactured by Rad Elec Inc., Frederick, MD 21701.
† Teflon™ is a trademark of the product manufactured by E. I. Du Pont de Nemours and Co., Wilmington, DE 19898.

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There are dozens upon dozens of published research articles on Rad Elec's website. You're encouraged to check them out!

Electrets

The electret used in the E-PERM® System is a disk of Teflon® which has been electrically charged and subsequently processed by special procedures in order to stabilize the charge across a wide range of humidities and temperatures. This dielectric Teflon® disk is secured in a holder, which can be loaded onto an ion chamber; this resulting combination is known as an electret ion chamber (marketed as an E-PERM®). The electret produces an electrostatic field within the ion chamber, capable of attracting negatively-charged ions generated by the decay of radon and its progeny (or daughter products) within the chamber. The electret's charge is gradually neutralized by the collection of ions, and the surface voltage of the electret decreases in proportion to the radon concentration, ion chamber volume, and exposure time.

Short-Term (ST)

Mid-Term (MT)

Long-Term (LT)

Rad Elec manufactures three types of electrets with different characteristics, identified by their distinct labels. Short-term (ST) electrets have high sensitivity and are used primarily for short-term measurements (typically from two to seven days). These ST electrets are identified by their **blue** labels. Next, mid-term (MT) electrets exhibit a sensitivity between their ST and LT counterparts; they have been optimized for 91-day measurements, and are identified by their **burgundy** labels. Lastly, long-term (LT) electrets are much less sensitive than their MT and ST counterparts, and are used principally for long-term measurements lasting from three months to one year. These LT electrets are identified by their **red** labels.

ST Electret serial designations begin with S, MT Electret serials begin with M, and LT Electret serials begin with L.

New electrets are produced with 700+ volts and can typically be deployed until their voltages drop to 100, resulting in a usable voltage range of 600+

volts. Electrets with fewer than 100 volts exhibit a weaker electrostatic field which is not as consistent in collecting ions efficiently. However, these lower voltage electrets can function as excellent field blanks (recommended for good QA/QC practices) and when fully discharged can be returned to Rad Elec for credit.

The electret surface should never be touched. Allowing anything to touch the electret surface will cause voltage loss and possibly lead to instability issues. Every electret is shipped with its own "keeper cap" that can be screwed onto the electret and prevent accidental voltage discharge. Keeper caps are perfect for storing electrets for long periods of time.

The electret surface should never be touched. This will lead to voltage loss and instability issues.

It is very important to keep the surface of the electret clean. Rad Elec recommends using industrial-grade nitrogen or an oil-free air compressor to routinely "blow off" the electret surface in addition to cleaning the ion chambers and keeper caps. When cleaning the electret in this manner, please do not touch the electret surface with the nozzle or blow gun. Rad Elec recommends cleaning the electret after its final voltage reading (and/or prior to its initial voltage reading). When used at an appropriate pressure of approximately 50 PSI (~350 kPa), both nitrogen and oil-free air compressors have proven to be a safe and reliable method of cleaning electret ion chambers.

Never use a can of compressed air to clean an electret. They contain propellants and refrigerants that will discharge the electret.

In lieu of a nitrogen cylinder, you may also use an oil-free air compressor in order to clean your electret ion chambers. It is very important that the compressor is oil-free.

Keep the electret clean, do not touch the electret surface, and read the initial and final voltages at similar temperatures.

Electrets should ideally be read in a controlled environment such as an office or laboratory. The initial and final voltage readings should be read at approximately the same temperature (within ±10°F or ±5°C). If the electrets are cold or warm when retrieved, it is important to allow them time (an hour or two is sufficient) to return to room temperature before conducting the voltage reading.

Ion Chambers

L Chamber

Ion chambers are constructed of conductive plastic and come in a variety of well-defined volumes. When an electret is fitted onto an ion chamber, it is called an E-PERM® (commonly referred to as an **electret ion chamber**). When assembled into this configuration, the electret serves as a sensor due to its electrostatic field; this field attracts ions produced by the decay of radon. As ions are collected, the surface voltage of the electret decreases in proportion to the radon concentration and the exposure time. The decrease in voltage is measured using an electret voltage reader, known as a SPER-1E reader.

S Chamber

Radon is an inert radioactive gas. As it diffuses into the ion chamber through filtered openings, the alpha particles emitted by the decay of radon causes ionization, which creates positive and negative ions in the air. When this decay occurs within the fixed volume of an electrically conductive chamber, the negative ions are drawn towards the surface of the positively charged electret. The electret carries a positive charge, and therefore attracts negatively charged ions in the surrounding air while repelling the positively charged ions to the interior walls of the electrically conductive chamber (which allows them to be neutralized).

H Chamber

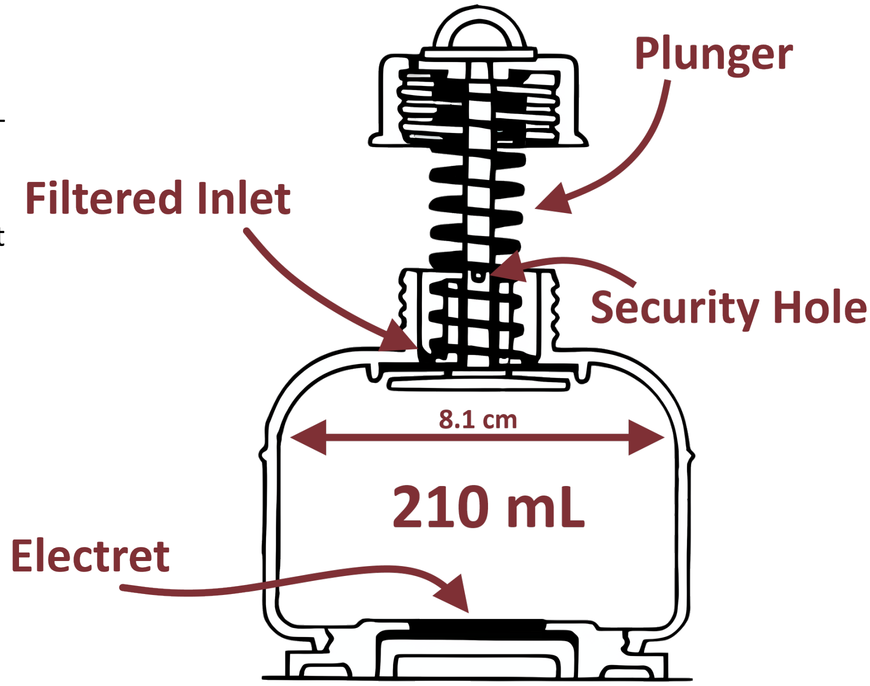
Most ion chambers require an elevation correction above a certain threshold, due to a decrease in atmospheric pressure as one's altitude increases. The decreased atmospheric pressure increases the distance between atoms and molecules in the air. This decreases the number of ions generated in a given volume, so a mathematical correction must be applied. This threshold is 4000+ feet / 1219+ meters above sea level for S Chambers, and 200+ feet / 61+ meters above sea level for L and L-OO Chambers. H Chambers do not require any elevation correction. Elevation correction factors are discussed later in this manual.

Rad Elec manufactures ion chambers in several different volumes, which allow for a wide range of exposure times and sensitivities. Larger chamber volumes allow for an increase in the number of ions actually generated from the decay of radon. When used in conjunction with one of the three types of electrets, the radon tester can assemble a tailored E-PERM® configuration that can accurately measure radon for their specific protocol (ranging from a few hours to over a year).

L-OO Chamber

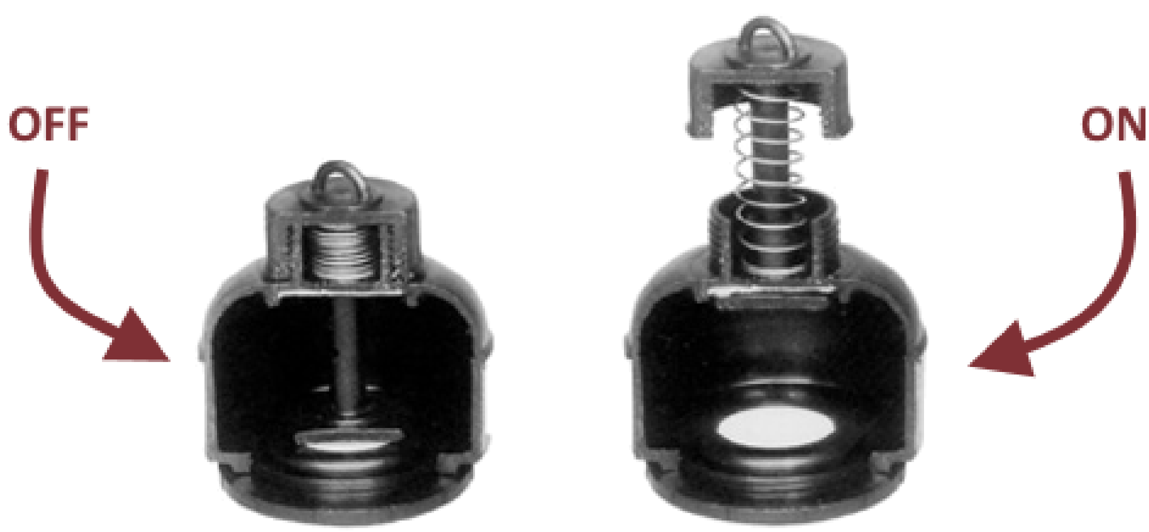
S Chamber

The S Chamber has a volume of 210 mL with an on/off mechanism in the form of a spring-loaded screw cap. When this spring-loaded cap is screwed all the way down, the electret will not measure radon (and will not lose any voltage from ionization). This is due to a plunger mechanism that covers the electret surface, thereby reducing the chamber volume to nearly zero (and preventing any ionization from being measured).



S Chamber Diagram

The interior of the chamber should be inspected before every use in order to ensure that the filter is not loose, and that the chamber itself is free from dust, fibers, and any environmental dirt or debris. When inspecting the chamber, gently tap it on a table to dislodge any dirt or debris; this is also useful to determine if the filter is loose. The chamber should also be cleaned with nitrogen or an oil-free air compressor in order to remove any dirt or dust particles. When the S Chamber is not in use, store it in a Tyvek® or ZipLoc® bag (such as the one that it was shipped in when purchased).



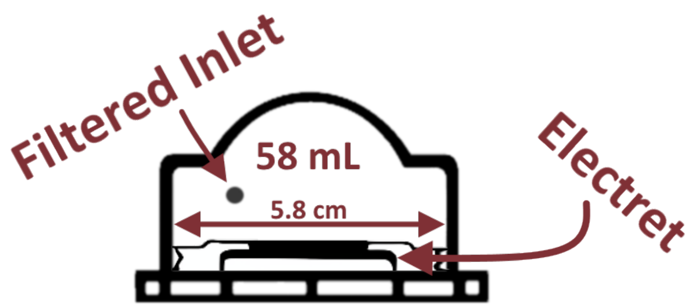
Why is it called an S Chamber?
"S" is short for "standard".

L Chamber

L Chamber

The L Chamber is a low-volume (58 mL) ionization chamber. It does not have an on/off mechanism, meaning that electrets will need to be loaded onto the chamber at the test site, or subsequently deployed shortly after loading the electret onto the chamber. Because of the absence of an on/off mechanism, electret ion chambers that utilize the L Chamber must be deployed as soon as possible after reading and loading the electret. The final voltage reading should also be measured as soon as possible after the exposure period, unless the electret is removed from the L Chamber and stored in its keeper cap.

The total non-exposure delay time (i.e. the sum of the delay period both before and after the intended exposure period) should be less than 5% of the total exposure period. This will help to ensure that the background ionizing radiation measured during the delay periods (e.g. during transit if shipped) is minimized when compared to the much longer exposure period.



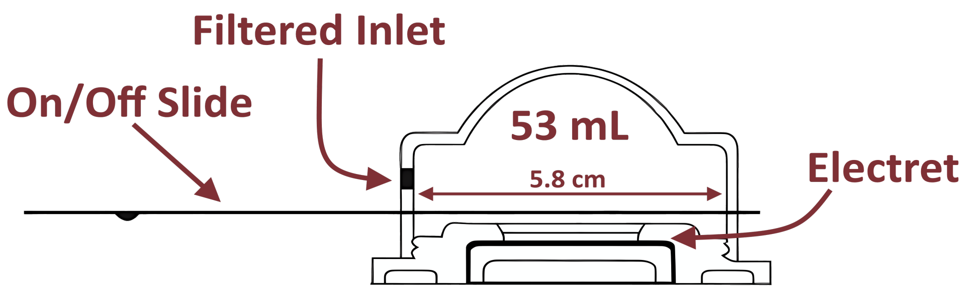
L Chamber Diagram

The interior of the L Chamber should be inspected before every use. If dust and/or dirt are found inside the chamber, it can be cleaned with industrial-grade nitrogen or an oil-free air compressor. To keep the L Chamber clean before deployment, Rad Elec recommends storing and transporting it inside a Ziploc® or Tyvek® bag (or alternatively loading a depleted electret onto it). Due to its lower relative volume, the L Chamber tends to be used for longer measurements, typically with ranges spanning from 91 to 365 days.

Why is it called an L Chamber?
"L" is short for "low-volume".

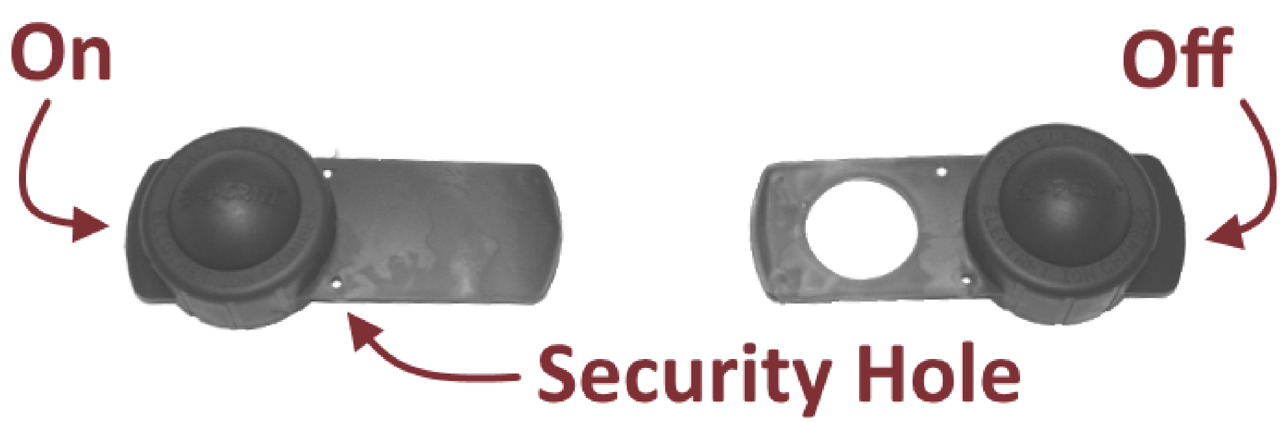
L-OO Chamber

The L-OO Chamber is a low-volume (53 mL) chamber with an integrated on/off slide mechanism, which allows electret ion chambers using L-OO chambers to be exposed (turned on) or covered (turned off) by using a slide. This mechanism allows for much finer control over the start and stop dates/times by removing the need to load electrets while out in the field. Similarly to the L Chamber, the smaller volume (relative to the S and H Chambers) reduces the total amount of ionization inside the chamber. This results in the L-OO Chamber usually being deployed for longer durations, typically between 30 and 365 days (depending on the electret type).



L-OO Chamber Diagram

To use the on/off slide mechanism, load the electret onto the bottom of the L-OO Chamber. Pull the slide to the OFF position (as shown below), with the hole visible on the slide. Place a locking mechanism (such as a paper clip, cotter pin, or lock-tie) in one of the security holes to ensure that the slide doesn't accidentally open until the exposure is ready to begin. To start the test, pull the slide to the ON position (as shown below). The hole in the slide will not be visible when the L-OO Chamber is in the ON position. Use a locking mechanism to secure the slide in the ON position. In order to stop the test, first cut or remove the locking mechanism, and then pull the slide back to the OFF position. Secure the L-OO Chamber in the OFF position with a locking mechanism of your choice.



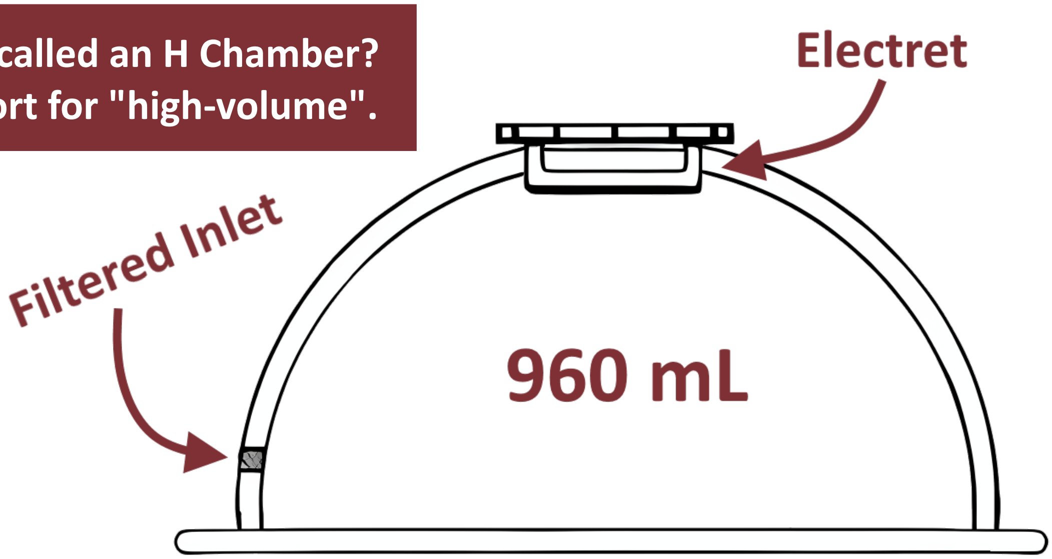
H Chamber

The H Chamber is a high-volume 960 mL ion chamber. As the largest ion chamber currently manufactured by Rad Elec, the H Chamber is ideally suited for making quick measurements. When combined with a short-term (ST) electret, this configuration can measure extremely low radon concentrations with a high degree of accuracy; such a configuration would be a good choice for testing ambient radon, or for measurements of a very short duration.

There is no on/off mechanism on the H Chamber, which means that the electret should be loaded onto the chamber immediately before beginning the measurement. Similarly, at the end of the exposure, the electret should be removed immediately and stored in its keeper cap.

As with all of the other chambers, the H Chamber should be inspected before every use. It should be free from dust or fibers before being loaded with an electret. If dust is found inside an H Chamber, it can be blown out using nitrogen (or an oil-free air compressor). When not in use, the H Chamber should be stored in a Ziploc® bag.

Why is it called an H Chamber? "H" is short for "high-volume".



H Chamber Diagram

Voltage Reader

The SPER-1E voltage reader is used to measure the voltage (surface potential) of an electret. The SPER-1E reader is a high-precision, non-contact voltmeter. It should be handled with care. When not in use, the reader should be stored in its storage case.

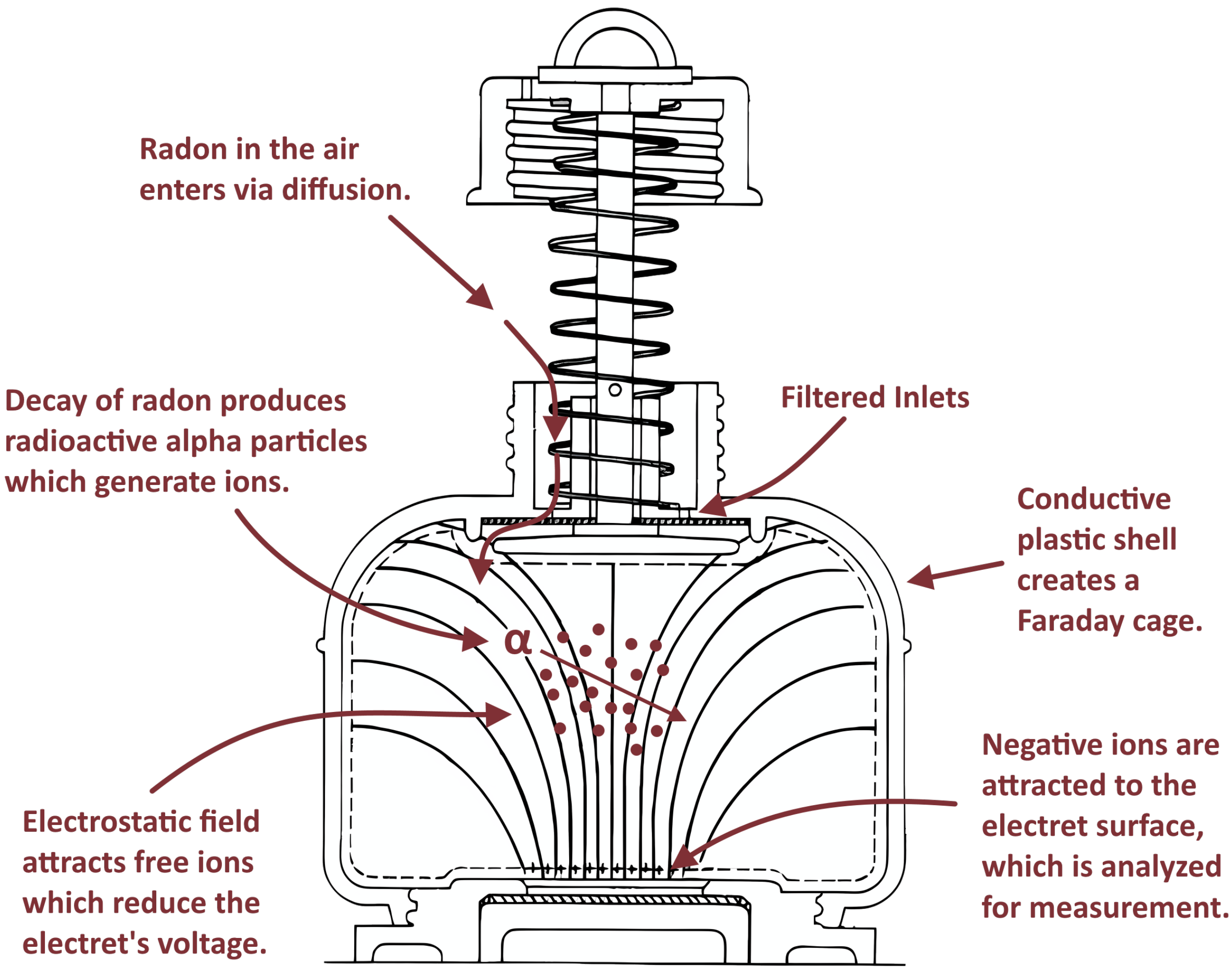
SPER stands for Surface Potential Electret Reader.

The carrying case contains a desiccant to keep the reader free from moisture. As the desiccant absorbs moisture from the environment, its crystals will slowly change color. Rad Elec recommends checking the desiccant regularly in order to evaluate the color of the crystals. When necessary, the desiccant can be renewed by placing it in an oven set to a specific temperature (typically at around 225° Fahrenheit / 110° Celsius) for a few hours. More detailed instructions will be written on the desiccant canister.

The voltage reader should be calibrated annually. During this process, Rad Elec will perform routine maintenance on the reader, change the batteries, and calibrate the readings across several known and traceable voltage ranges. At the end of this process, Rad Elec will certify the voltages of the reference electrets associated with the reader and issue a calibration certificate. Calibration forms can be found on Rad Elec's website. Please note that there is a charge for this calibration service.

Although the specific practice of reading an electret will be discussed later in this manual, the principle is easy to understand. Using the SPER-1E voltage reader, the surface voltage of an electret is measured before and after a radon test. As the electret ion chamber is exposed to radon, the surface voltage is reduced. This reduction in surface voltage is a measure of the time-integrated concentration of radon within the environment.

Principle Operation of the Electret Ion Chamber



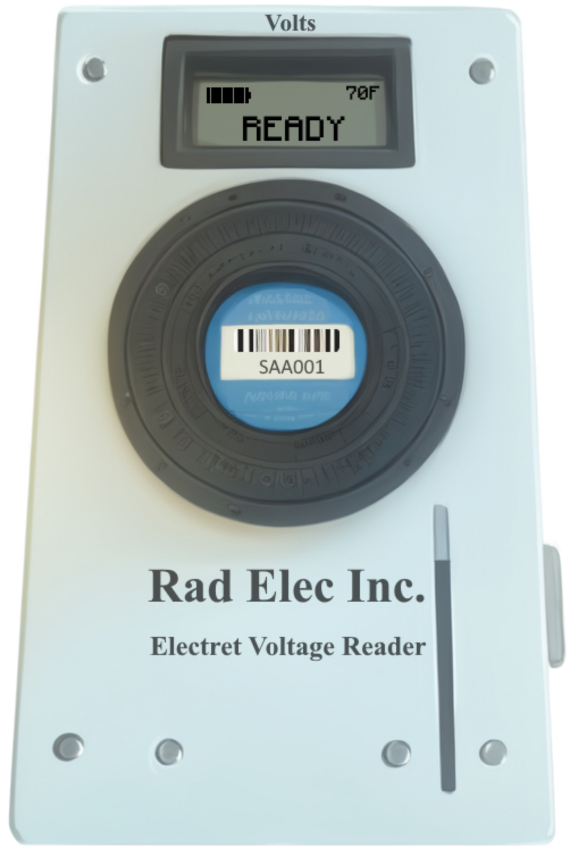
Radon gas (and **not** the progeny present in the air) diffuses through the filtered inlets into an electret ion chamber. This diffusion continues until the radon concentration inside the chamber is equal to the radon concentration outside (typically a room). Radiation emitted by the decay of radon and its progeny formed inside the chamber ionizes the air, which produces both positive and negative ions.

The positively charged electret surface attracts the negative ions (anions) generated during ionization. As the anions reach the electret surface, the surface charge of the electret is reduced. The positive ions (cations) are pushed to the interior walls of the ion chamber, where they dissipate.

The reduction in electret surface voltage allows the calculation of the radon concentration.

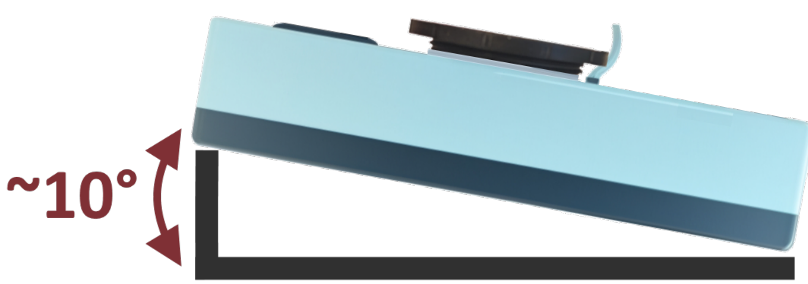
How to Measure Electret Surface Voltage

Understanding and employing the proper technique to measure an electret's surface voltage is arguably the most important part of conducting a successful electret ion chamber measurement. Overall, there are a few key points to keep in mind: measure the electret voltage several times in order to ensure an accurate reading, and employ an appropriate (and consistent) technique.



1. Remove the electret from its keeper cap or ion chamber, and place it face down onto the circular receptacle located on the SPER-1E reader. Pull the slide on the reader in order to turn it on, and let it warm up for a few seconds. When booting up, the SPER-1E will display some diagnostic information (such as the battery condition and the room temperature in Fahrenheit). After this diagnostic information is shown, the screen will display "READY".

2. Rotate the electret so that the serial number is parallel (and aligned) with the "Electret Voltage Reader" label etched onto the SPER-1E. For consistency, Rad Elec recommends keeping the reader in its case. Prop it up against the foam inside the case so that it sits at about a 10° angle. This ensures that gravity will pull the electret ever-so-slightly towards you, to remain consistent.



3 Place a keeper cap over the electret, which will cover the serial number. Gently place an index finger on top center of the keeper cap, and pull the slide with your other hand. When pulling the slide, your movement should be relatively consistent. Gently release the slide once a number appears on the screen.

4 The number that appears in the center of the SPER-1E screen is the current voltage of the electret. The battery condition is shown in the upper left of the screen, and a tiny three digit number in the upper right corner represents the time (in milliseconds) that it took to fully pull the slide.

5 After waiting a few seconds, repeat the measurement by pulling the slide again. When learning to read electrets, Rad Elec recommends repeating this process four or five times.

Typically it should take between 300 and 500 milliseconds to fully pull the reader slide.

6 Remove the electret from the SPER-1E reader, and protect it by replacing its keeper cap or returning it to an appropriate chamber that has an on/off mechanism. If additional electrets need to be read, repeat steps #1 through #5 in order to obtain the desired number of readings.

7 Congratulations! You've read an electret's voltage. The SPER-1E reader will automatically turn off after a few minutes of inactivity.

Reference Electrets

Reference electrets are an important part of ensuring that your SPER-1E voltage reader is accurately measuring the surface voltage of your electrets. Two reference electrets (comprising a pair) in addition to a specialized "zeroing" electret are assigned to every voltage reader, and are recertified every time the voltage reader is calibrated. The reference electrets are specialized low voltage electrets that are extremely stable, and whose voltages are traceable to the SPER-1E reader's calibration certificate. The purpose of these reference electrets is to confirm that the SPER-1E voltage reader is functioning within its calibrated parameters.

Reference electrets are never to be used for radon testing.

The reference electrets are **not to be used for radon testing**; their sole purpose is to ensure that your voltage reader is measuring voltages properly. The reference electrets should measure within ±3 volts of their certified voltages. The zeroing electret should measure within ±3 volts of zero.

To ensure your voltage reader is measuring accurately, the reference and zeroing electrets should remain within ±3V of their certified voltages.

A weekly record of the reference and zeroing electrets should be maintained and used as a part of your QA/QC (Quality Assurance and Quality Control) Plan. Record the voltage readings of the reference and zeroing electrets as you would a regular electret. Always keep the reference and zeroing electrets in their protective keeper caps when not being read. If the weekly readings remain within the aforementioned acceptable limits (±3 volts) you can be confident that your SPER-1E voltage reader is functioning correctly.

When reading the reference electrets, if one – but not both – of the electrets deviates significantly (greater than 3 volts) from its certified voltage, then it can be inferred that the SPER-1E reader is still functioning properly. It is likely that one of the reference electrets discharged due to either an accidental touch or from environmental particulates (such as dust or fiber). If this occurs, clean the electret with nitrogen (or an oil-free air compressor) and monitor it over the next several days until it becomes stable. If a reference electret drops below 100 volts, it should be exchanged for a new reference electret.

Routine readings of the reference and zeroing electrets allow you to be confident in your radon tests!

However, when reading the reference electrets, if both electrets deviate significantly from their certified voltages (greater than 3 volts), the SPER-1E voltage reader may need to be calibrated or repaired. Please contact Rad Elec, and we will be happy to assist with resolving this matter.

The reference and zeroing electrets should not be relied upon as a replacement for actual calibration. These electrets provide only one point of reference for the SPER-1E reader, and should not be construed as a method of calibration in and of themselves. During the official calibration process, the SPER-1E voltage reader is calibrated over a much wider voltage range.

Nevertheless, the reference and zeroing electrets do not serve as replacement for calibration.

E-PERM® Configurations

E-PERMs® comprise two independent and interchangeable components: an **electret** and an **ion chamber**. When combined into a specific configuration, the resulting E-PERM® (electret ion chamber) exhibits a sensitivity that makes it ideal for certain radon tests. Each of these configurations has a naming pattern that typically adds the electret type after the chamber type. For example, an S Chamber fitted with an ST electret is called an SST, and an H Chamber fitted with an LT electret is called an HLT.

The tiny wrinkle to this naming pattern involves the L-OO Chambers (with the on/off mechanism), to which the -OO suffix is attached to the end of the E-PERM® configuration. For example, an L-OO Chamber fitted with an ST electret is called an LST-OO. The various names of the E-PERM® configurations can be challenging even to those who have used electret ion chambers for years, so don't worry if it seems confusing at first.

The resulting sensitivity of an E-PERM® configuration is a function of both its electret type and the ion chamber volume. Larger ion chamber volumes allow for a greater amount of simultaneous ionization to occur, resulting in a more sensitive measurement. Similarly, the three electret types are divided into their respective sensitivities (which in turn is a function of the Teflon® thickness). The ST electret is the most sensitive electret type because it has the thickest Teflon® disk, while the LT electret is the least sensitive electret because it is constructed with a very thin Teflon® layer.

E-PERM® configurations with a larger total sensitivity will be

more greatly affected by the decay of radon. This means that very sensitive configurations, such as the HST (H Chamber + ST electret), are intended to measure a standard environment for a short time period (such as 8 to 24 hours). Alternatively, the HST configuration can be used to measure a low concentration environment over a few days.

On the other hand, E-PERM® configurations with a low total sensitivity are less affected by the decay of radon at any given moment. The least sensitive configuration is the LLT-OO (L-OO Chamber + LT electret). The LLT-OO configuration is typically deployed for around a year, although it can be deployed for a shorter time period when high radon concentrations are expected.

For the majority of radon tests conducted in the United States, the SST (S Chamber + ST electret) is the most prevalent configuration. This is because the overwhelming majority of radon tests in the United States are exposed for two to four days. In Canada (and many other countries around the world), a greater emphasis is placed on characterizing radon over several months; such long-term tests would typically utilize an LST-OO, SLT, or LMT-OO configuration. If a radon test were to be extended for 6 to 12+ months, then an LLT-OO configuration would be the most appropriate configuration to use.

The nine E-PERM® configurations are listed below. Although there is significant overlap between the typical exposure periods, this table exemplifies the remarkable versatility of electret ion chambers.

E-PERM® Configuration	Chamber Type	Electret Type	Typical Exposure	NRSB Device Code	NRPP Device Code	C-NRPP Listed
SST	S	ST	2 to 7 days	51203	ES-8212	Yes
SLT	S	LT	30 to 120 days	51202	ES-8211	Yes
LST	L	ST	30 to 91 days	--	EL-8230	No
LLT	L	LT	180 to 365 days	51201	EL-8210	Yes
LST-OO	L-OO	ST	30 to 91 days	--	--	No
LMT-OO	L-OO	MT	91 to 180 days	--	ES-8236	Yes
LLT-OO	L-OO	LT	180 to 365 days	51201	EL-8210	Yes
HST	H	ST	6 to 24 hours	--	--	No
HLT	H	LT	7 to 14 days	--	--	No

Conducting a Radon Test with Electret Ion Chambers

After learning about the various components that comprise the E-PERM® System, it's time to learn how to use them in order to conduct a radon test. This section will provide step-by-step instructions from start to finish, although it will require you to be familiar with the various system components and their operation (which have been described earlier in this manual).

This section describes how to conduct a duplicate measurement, but the instructions can be applied to any number of detectors.

Rad Elec recommends practicing a few tests at home to help boost your confidence.

1. In your office or laboratory, take a voltage reading for two electrets. This value is called the **initial voltage**. The specific technique for reading electrets is discussed in a previous chapter, How to Measure Electret Surface Voltage.

2. After reading the electrets, carefully load them onto their ion chambers if they have an on/off mechanism. If the ion chambers are not able to be turned off, instead screw on the keeper caps for each electret.

Do not touch the surface of the electret at any time.

3. Place the E-PERMs® (electret ion chambers) in a tamper-resistant twin box, deployment sleeve, or Tyvek® bag. Pack a few lock-ties into this container; they can be used to secure the detectors in a spot of your choosing in order to prevent tampering.

4. Upon arriving at the test site, ensure that closed building conditions are met if conducting a short-term radon test. If the desired exposure period is fewer than four days, then closed building conditions must have been maintained at least 12 hours prior to beginning the radon test. Inform the occupants of the radon test and of the required test conditions.

Short-term radon tests (which range from 2 to 90 days) require closed-building conditions to be maintained throughout the duration of the test.

5. Take the E-PERMs® to the lowest livable level of the test site, and choose an appropriate deployment location for the detectors. If using ion chambers with an on/off mechanism, open the ion chambers. If using chambers without an on/off mechanism, load the electrets onto their respective chambers. Record the **start date/time** in addition to the **location**.

If a short-term test is at least 96 hours in length, closed-building conditions *prior* to the test are not required.

6. Close the twin tamper box, deployment sleeve, or Tyvek® bag. If using a twin tamper box, ensure that the electret ion chambers are pushed all the way to the bottom of the box (to ensure that the plunger isn't accidentally depressed when the box lid is closed). If there are occupants at the test site, it is recommended to secure the detectors with lock-ties to prevent tampering.

7. Expose the detectors for the desired time period (usually 48+ hours). If the site is occupied, discuss the requirements for a short-term radon test with any occupants. Consider leaving a non-interference (compliance) agreement that can be reviewed and signed by the occupants.

8. Upon returning to the test site at the conclusion of the test, conduct a quick surveillance of the site to ensure that closed-building conditions are met (and that any tamper indicators are intact). Locate and close the electret ion chambers. If not using ion chambers with an on/off mechanism, carefully remove the electrets from the ion chambers and store them in their keeper caps.

9. Write the **end date/time** immediately after the chambers are closed (or the electrets are stored in their keeper caps).

10. Read the **final voltages** after returning to the office or laboratory.

11. Ensuring that the electret surfaces and chambers are clean, return them to storage either by loading them onto closed ion chambers or by placing them in their keeper caps.

If necessary, clean the electrets *after* reading final voltages, but *before* storing them.

12. To analyze the radon test, calculate the results by entering in the pertinent information into the Radon Report Manager software, an official Rad Elec spreadsheet, or online tools such as the Online Report Creator or the Quick Calculator.

Analysis Tools

Rad Elec offers several tools to analyze electret ion chambers, each of which will be described in this section. An important advantage of E-PERMs® is the freedom to choose your own approach. Because all of our algorithms are published, it's possible to create your own spreadsheets or applications that are more finely customized to your specific needs.

The utmost diligence must be exercised when creating your own spreadsheets or applications, as even a single misplaced parenthesis can cause errors when calculating the radon concentration. If you would like to have your spreadsheet or application reviewed, please reach out to Rad Elec and we'll do our best to look over your work.

With this in mind, Rad Elec recommends using our official analytical methods, as described below.

Radon Report Manager

The Radon Report Manager (RRM) is Rad Elec's primary analytical software for electret ion chambers, although it can also generate radon test reports using a wide variety of testing methodologies (including activated charcoal, liquid scintillation, alpha track detectors, and continuous radon monitors). In addition to generating radon test reports, the RRM also tracks your QA/QC obligations and state reporting requirements.

The RRM is Rad Elec's most comprehensive analysis tool, and is updated regularly. There are no subscription fees, and the application can function without any internet connection. Although the Radon Report Manager runs natively on Microsoft Windows® operating systems, the technical support staff at Rad Elec is happy to assist if you would like to install it on macOS or Linux.

It goes beyond the scope of this document to discuss all of the features and operations of the Radon Report Manager. Suffice it to say that the RRM software can generate dozens of reports, and can be tailored to your individual company's needs. There is a sample of a standard radon test report generated from the RRM at the end of this manual. If you wish to learn more, the software manual can be found in the Manuals section of Rad Elec's website.

Spreadsheets

Spreadsheets offer a quick and reliable method to analyze your results, whether it be a single E-PERM® or a few thousand. Spreadsheets are ideal when radon professionals do not need to generate radon test reports, and do not need reminders or guidance in QA/QC obligations. Spreadsheets can be downloaded from Rad Elec's website, and are released in both Microsoft XLSX and Open/LibreOffice ODS formats.

Rad Elec also creates spreadsheets for more specialized functions, such as:

- **Radon Flux**, to measure radon's exhalation rate from the ground or another surface.
- **Radon-in-water**, to measure radon's concentration in water samples.
- **Background Gamma**, to measure environmental background gamma radiation.
- **Thoron**, to measure radon's isotope from the thorium decay chain.
- And more...

Quick Calculator

The venerable Quick Calculator has been a mainstay on Rad Elec's website for many years. As long as the internet is available, this online tool can be used to calculate your E-PERM® test results. However, it will not generate a radon test report, and results will not be saved after navigating away from the page. Nevertheless, the Quick Calculator serves as a convenient way to analyze your results quickly when you're on-the-go.

Online Report Creator

Rad Elec's Online Report Creator (ORC) is a cloud-based platform for calculating your radon test results. Like the Quick Calculator, it requires a browser that is connected to the internet. The ORC allows you to generate tailored radon test reports, email them to yourself (or to your clients), and save these results remotely in a database so that you can access them later. Although it's more complex than the Quick Calculator, it is also significantly more customizable and powerful.

Environmental Effects on Electret Ion Chambers

Although electret surfaces are vulnerable to discharge due to accidental touches or dirt, a properly assembled electret ion chamber is quite durable and resistant to a wide range of environmental effects. In order to use electret ion chambers successfully, it's important to understand the effects of different environmental conditions on the E-PERM® System. This section will describe the following conditions in greater detail:

- **Temperature**
- **Elevation & Pressure**
- **Humidity**
- **Presence of Ions**
- **X-Rays**
- **Gamma Radiation**
- **Beta Radiation**
- **Electromagnetic Fields**
- **Air Drafts**
- **Airborne Particulates**
- **Thoron**
- **Dirt & Dust**

Temperature

Electrets can measure radon in a wide range of temperatures, in both indoor and outdoor environments.

E-PERM® measurements are not affected by usual temperature variations found in homes or outdoor environments. They have been used successfully by the USEPA to make ambient outdoor radon measurements through all seasons of the year in all fifty States. These and other controlled tests have proven that the effect of temperature on the accuracy of electret ion chambers is negligible.

However, you should be aware of temperature variations that can occur when reading an electret's voltage. Due to the different expansion coefficients of Teflon® and the conductive holder, the electret surface tends to concave or convex slightly when the temperature changes substantially. This causes the electret surface to move slightly closer to – or away from – the sensor in the SPER-1E voltage reader, which can result in a small change in voltage readings (typically a few volts).

Electrets should be read in controlled environments for both their initial and final voltage readings.

If electrets have been left out overnight in the winter (or left in a vehicle during the summer), simply take them inside and wait an hour or two before reading them.

The voltage variance can be as high as 1-2 volts for every 10° F (4° C) difference between two readings. This voltage change due to temperature is not permanent, and will return to normal when the electret is allowed to equilibrate in a controlled environment (usually in about an hour). In other words, if an electret is abnormally warm or cold, simply wait an hour for it to return to room temperature before reading the voltage.

Relative Humidity

Even the highest relative humidity levels found in homes or in environments do not affect electret ion chambers. In fact, E-PERMs® are routinely used for making radon-in-water measurements in environments with 100% relative humidity. If electrets are exposed in environments where condensation is allowed to form on their charged surfaces, it is important to exercise extreme caution when retrieving these detectors. They should be transported in keeper caps, and then opened in a controlled environment (preferably with a known low radon concentration) and be allowed to dry for an hour.

For all intents and purposes, electret ion chambers are immune to high humidity levels. The same cannot be said for the SPER-1E voltage reader – don't drop the reader in water!

Despite the de facto immunity to relative humidity with electret ion chambers, the same cannot be said of the SPER-1E voltage reader. The SPER-1E is a sensitive electronic instrument, and must be kept dry in order to measure the electret surface voltage properly.

Elevation and Pressure

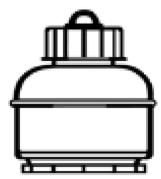
Electret ion chambers are affected by significant changes in elevation. The mechanism for this change is due to changes in barometric pressure (which decreases as elevation increases). As barometric pressure decreases, molecules in the air become more spread out, and this dispersion slightly reduces the chances for ionization.

H Chambers may require elevation correction factors on Mt. Everest. Or in outer space. We're not entirely sure, because we haven't done the research... yet!

This change is most easily observed in the lower volume ion chambers such as the L and L-OO Chambers; as such, these chambers require elevation corrections above 200 feet (61 meters). S Chambers, with a volume of 210 mL, do not require any elevation correction at elevations below 4000 feet (1219 meters). H Chambers, with a volume of 960 mL, do not require any elevation correction factors at habitable elevations.

Electret ion chambers are not affected significantly by barometric pressure changes brought about by most storms. However, hurricanes can cause huge changes in barometric pressure (which will also affect the rate of radon flux from the ground), so it's probably best to wait until after a hurricane has passed before conducting a radon test.

S Chambers



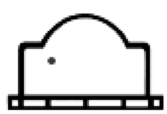
For Elevations <= 4000 feet

$$\text{ElevCF} = 1$$

For Elevations > 4000 feet

$$\text{ElevCF} = 0.79 + \left(\frac{6 \times \text{Elevation(ft)}}{100000} \right)$$

L / L-OO Chambers



For Elevations <= 200 feet

$$\text{ElevCF} = 1$$

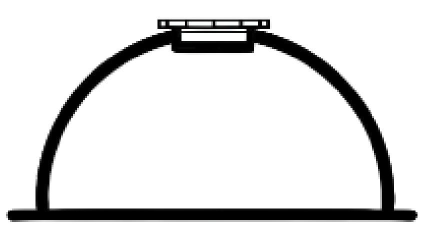
For Elevations > 200 feet

$$\text{ElevCF} = 1.005 + \left(\frac{4.5526 \times \text{Elevation(ft.)}}{100000} \right)$$

H Chambers

For All Elevations

$$\text{ElevCF} = 1$$



No Elevation Correction!

Presence of Ions

Stray ions will always be present in every room or location to be tested. Sometimes, large concentrations of ions can be found due to the presence of artificial ion generators or open flames.

Ambient ions, including those created by artificial sources, are blocked by the ion chamber's filters.

Ambient ions – in addition to those created by artificial ion generators or gas flames – are stopped completely by the filtered inlets located inside the electret ion chambers. In addition to preventing stray ions from entering the E-PERMs®, these filtered inlets also prevent radon progeny from contributing to electret voltage loss.

X-Rays

Electret ion chambers are sensitive to ions produced by penetrating, ionizing radiation such as by x-rays. Specifically, cabinet x-ray systems (which are often employed by airport security and used to check luggage) can cause substantial discharge of electret surface voltage (sometimes a few dozen volts will be lost). If you are transporting electret ion chambers as checked luggage when traveling, please be sure to read your electrets after arriving at your destination. This will help to ensure accuracy in your measurements.

Beta Radiation

Research has shown that electret ion chambers can be affected by nearby beta radiation emitters. Beta particles travel approximately a meter in air, although this distance can be affected by the particle energy and the air density. In most cases, a beta emitter will not be able to affect an electret ion chamber if it is greater than a few feet away, because it will not have enough energy to penetrate the ion chamber's exterior shell. Although extremely dusty environments with elevated radon progeny concentrations will produce beta radiation, these rare scenarios are unlikely to produce a significant bias.

Gamma Radiation

E-PERMs® are sensitive to gamma radiation, which is another form of ionizing radiation. In contrast to x-rays, the only source of gamma radiation at most measurement sites is natural background radiation. This will have a minor, albeit measurable, effect on electret ion chambers. Rad Elec's analytical tools will automatically correct for gamma based on state-wide averages; if calculating results manually, then the gamma table at the end of this manual will provide a compilation of the average background gamma levels by state or province.

If some other gamma source – apart from the normal background levels – is suspected at the site, it can be easily measured and subsequently corrected. A discrete gamma measurement can be conducted by sealing an E-PERM® inside an aluminized Mylar® (or other radon-proof) bag, and deploying it alongside electret ion chambers deployed in a standard manner. Radon will not be able to pass through the aluminized Mylar® barrier; however, gamma will not be attenuated.

Electric and Magnetic Fields

The overwhelming majority of external electric and magnetic fields have absolutely no effect on electret ion chambers. E-PERMs® are constructed of electrically conductive plastic, which creates a Faraday cage that shields the electret from external environmental electromagnetic fields (EMFs).

Electromagnetic fields occur both naturally (our planet generates an electromagnetic field that helps protect us from cosmic radiation) and artificially (from WiFi signals to radio waves). These lower frequency EMFs – such as those produced by cell phones, power lines, radio waves, network routers, etc. – will have no effect on electret ion chambers. In the entire electromagnetic spectrum, only the highest frequencies (which include gamma and x-rays) fall into the category of ionizing radiation. In addition to being a health risk, this radiation will discharge electrets.

High frequency EMFs include gamma and x-rays. These are ionizing radiation, and are considered health risks. Exposure to high frequency EMFs will also discharge electrets.

Research has shown that extremely strong magnetic fields (10,000+ Gauss) appear to have an effect on beta radiation. Depending on the magnetic field orientation, this effect can increase or decrease beta signals. This is largely academic, as these conditions (strong magnetic fields with a beta radiation emitter) do not typically exist naturally.

Air Drafts

Air drafts have no effect on the ability of E-PERMs® to detect the average radon concentration of an environment, even in a stream of flowing air. This has been confirmed by careful measurements inside and outside of a tunnel in which the airflow was significantly elevated.

Thoron

Thoron (^{220}Rn) is an isotope of radon; and just like radon, it is a radioactive gas that is part of a long decay chain. However, in contrast to radon's half-life of 3.8 days, thoron's half-life is only 55.6 seconds. In most environments, this shorter half-life limits the distance that thoron can travel, which means that it is usually present only in very small concentrations inside a home.

Thoron is an ionizing radioactive gas (just like radon). However, its short half-life usually means that it doesn't reach high concentrations inside homes.

Although the response to thoron varies slightly among the different ion chambers, E-PERMs® typically only detect 3% - 5% of the thoron in a given environment. For all intents and purposes, this means that a standard E-PERM® will not be able to measure a statistically significant concentration of thoron. If you wish to measure the thoron concentration of a specific environment, Rad Elec manufactures specialized Radon-Thoron (RT) chambers that allow for a much quicker response time; when deployed alongside standard chambers, this approach allows the characterization of thoron concentrations.

Dirt, Dust, and Airborne Particulates

Environmental dirt, dust, and other airborne particulates do not affect a properly deployed electret ion chamber. This is due to the filtered inlets, which prevent the particulates (in addition to radon progeny) from entering the ion chamber. In short, this means that an electret ion chamber is unaffected by airborne particulates, dirt, and dust in the testing environment. However, if you plan to conduct tests in extremely dirty conditions or outdoors, Rad Elec recommends using Tyvek® bags to help

Under no circumstances should cans of compressed air be used to clean electret surfaces.

protect your E-PERMs® in these environments.

When reading electrets, it is important to be mindful of dirt and dust in the air. The positively charged electret surface will attract dust in the immediate vicinity, meaning that it is vulnerable to becoming dirty when exposed to the open environment (i.e. when not loaded onto an ion chamber). If this dirt is allowed to accumulate on the electret surface or inside the ion chamber, it could discharge the electret during exposure or shipment; this would lead to a false positive bias in the radon calculation.

Equipment Maintenance

Just like with any other equipment, routine maintenance and proper care will ensure that your E-PERM® System will measure radon accurately for many, many years. Ideally, preventative maintenance should be conducted on a regular basis; these intervals will vary depending on the specific component. Nevertheless, it's important to note that Rad Elec's equipment is designed to be serviceable; this means that we should be able to handle any repairs if your instruments or gear are damaged due to an accident or malfunction.

Rad Elec still calibrates SPER-1 voltage readers that were manufactured in 1990. As long as your equipment receives proper care and maintenance, it will last for decades. We take pride in manufacturing equipment that stands the test of time.

Ion Chamber & Electret Maintenance

When reading this manual, it should be understood that an oil-free air compressor can serve as a suitable replacement for a nitrogen cylinder.

It is important to inspect both the electrets and the ion chambers between deployments, to ensure that the electret surface is clean and that the ion chamber is free from debris. It is also worthwhile to inspect the filtered inlets, in order to make sure that the filter is intact. For S Chambers, the spring should be checked by opening the plunger and ensuring that it pops up.

The cleaning inspection is best conducted after the final voltage readings have been made. To clean the electrets, Rad Elec recommends using nitrogen (which is an inert, noble gas) expelled through a blow gun. Alternatively, an oil-free air compressor can be employed; it is critical that the air compressor be oil-free. If any oil is sprayed onto an electret's surface, the electret will destabilize and be ruined. Under no circumstances should cans of compressed air be used, because the compressed refrigerants and propellants can freeze water vapor onto the electret surface.

Voltage Reader Maintenance

For the most part, the SPER-1E voltage reader preventative maintenance comprises the following practices:

- Keep the reader in its storage case when not in use, preferably in a controlled environment with low humidity.
- Check the desiccant every few months. If necessary, bake the desiccant in the oven (typically at 225° Fahrenheit / 110° Celsius for a few hours, although specific instructions will be written on the desiccant canister). Baking the desiccant will refresh its lifespan.
- If a "LOW BATTERY" message appears, carefully remove the battery cover on the bottom of the SPER-1E reader in order to replace the batteries.
- Once every few months, gently clean the circular metal receptacle with a cotton cloth.
- Read the reference and zeroing electrets at least once per week (or whenever using the reader), to ensure that the electrets are within ±3 volts of their certified voltages.

It is important to send the voltage reader to Rad Elec for annual calibration service. During this service, Rad Elec will update the reader firmware (if necessary), change batteries, replace the desiccant, conduct a courtesy cleaning of the reader case, and calibrate the instrument to a NIST-traceable voltage source. Afterwards, the reference electrets will have their voltages certified.

Updating Software & Spreadsheets

It's a good idea to periodically check in with Rad Elec in order to ensure that your software and spreadsheets are up-to-date. A good time to check for updates is whenever you conduct your annual reader calibration, or at any other interval throughout the year that is convenient. Updating your software is most easily accomplished by contacting Rad Elec at info@radelec.com, or by calling our office. We'll be happy to send you the latest versions of the software and spreadsheets!

Dynamic Range

In the context of electret ion chambers, the dynamic range is the total amount of ionizing radiation over time (i.e. the maximum total radon concentration) that a specific E-PERM® configuration is capable of measuring. The basis for this calculation and estimation of these parameters is discussed in "A Practical E-PERM System for Indoor ^{222}Rn Measurement", which was originally published in *Health Physics*.

In short, the dynamic range is the effective measurable lifespan of an electret loaded into an ion chamber.

To calculate the dynamic range, we must first understand the entire usable voltage range of an electret, which spans from approximately 100 volts to 750 volts. This can also be called the electret lifespan. The lower limit of this range (approximately 100 volts) is reached because ion collection becomes less efficient as the electret loses voltage. Conversely, at extremely high voltage ranges (approximately 780+), ion multiplication can occur inside the ion chamber. Both of these extremes can create biases in radon measurements, and therefore define the electret's usable voltage range, or lifespan.

When measuring radon, please refrain from deploying electrets with initial voltages *below* 100 volts. This is because the calibration curves begin to lose accuracy below this threshold.

This establishes the dynamic range of the integrated radon concentration (typically expressed in pCi/L-Days) which each E-PERM® configuration can measure over the lifespan of an electret. **An individual electret's dynamic range will decrease along with its voltage**, similar to a battery losing its stored energy. An electret that has lost much of its dynamic range is still perfectly capable of accurately measuring radon, provided that its midpoint voltage throughout an exposure remains above the lower limit of its dynamic range.

An example of an applied dynamic range is as follows. For an SST configuration (S Chamber + ST Electret), the dynamic range is approximately 340 pCi/L-Days. This means that an SST with a brand new electret at 750 volts would drop to 100 volts when exposed to 340 pCi/L for 24 hours (i.e. one day), and would expend the entirety of its dynamic range. Alternatively, this same electret would also drop from

750 to 100 volts if it were exposed to 34 pCi/L for 10 days, or to 3.4 pCi/L for 100 days (all of which reach the same dynamic range of 340 pCi/L-Days).

Although these dynamic ranges have been derived using decades of data, they are nevertheless representative of ideal "textbook" values. They will be very accurate estimates for the vast majority of short-term radon screenings, but both background gamma radiation and an individual electret's inherent voltage discharge will reduce these dynamic range values over time. In short, the dynamic ranges presented in the table below represent ideal models – your "real world" dynamic ranges will be a bit less.

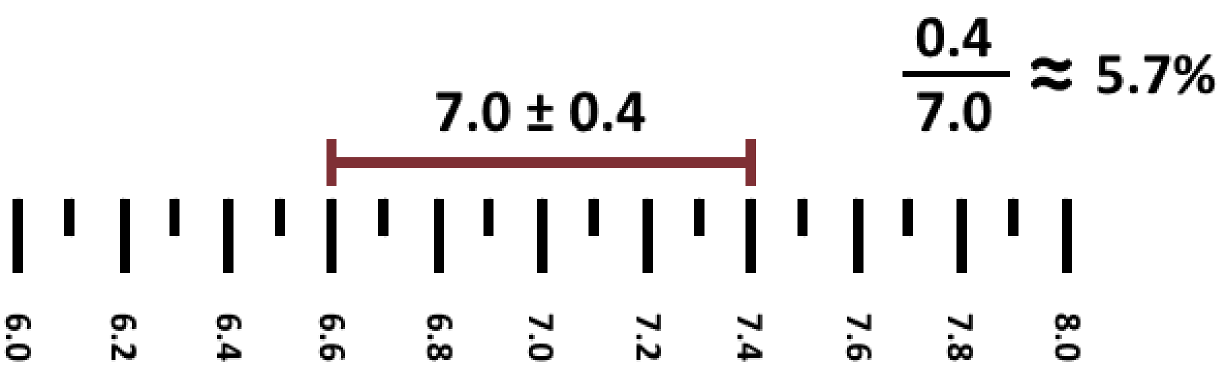
E-PERM® Configuration	Chamber Volume (mL)	Dynamic Range (pCi/L-Days)	Dynamic Range (Bq/m^3-Days)
SST	210	342	12650
SLT	210	3,970	146900
LST	58	1,753	64860
LLT	58	21,240	785880
LST-OO	53	2,151	79590
LMT-OO	53	7,289	269690
LLT-OO	53	26,475	979575
HST	960	58	2150
HLT	960	706	26120

Uncertainty Analysis

For better or for worse, uncertainty is a central component of our universe. It is an estimation of the error of any given measurement; in other words, how far away is this specific measurement from the truth? We can never be 100% certain that our radon measurements – or any measurements ever made throughout the entirety of human history, for that matter – are an accurate representation of the *thing being measured*. By calculating the uncertainty of a specific radon measurement, we can understand how close we are to the truth (i.e. the *thing being measured*, or the radon concentration).

> **Uncertainty is an estimation of the range of possible values wherein the true value can be found.**

Uncertainty is expressed in one of two ways: either as a percentage or as an absolute value. Both of these expressions of uncertainty represent a range around the measured value. For example, let's assume a radon concentration of 7.0 pCi/L with a resulting uncertainty of 0.4 pCi/L. This would typically be expressed as an absolute value, so the results would be reported as 7.0 ± 0.4 pCi/L. This means that the actual radon concentration could be as low as 6.6 pCi/L, as high as 7.4 pCi/L, or any value in between. With this in mind, calculating uncertainty actually generates more confidence in the measured results (because the range of possible values is now known).



After calculating uncertainty in this specific example, we can be confident that our measured radon concentration is within approximately 6% of the *actual* radon concentration. This percentile value can be calculated after dividing the absolute uncertainty by the measured radon concentration. Uncertainty is calculated automatically when using any of Rad Elec's analytical tools, but this section dives into the math behind this process.

There are three sources of uncertainty, or error, in electret ion chamber measurements:

1 The uncertainty associated with system component imperfections. This includes slight manufacturing uncertainty in chamber volumes, electret thickness, and other component parameters. This has been experimentally measured to be about 5%, and is therefore considered to be a constant.

$$\text{System Uncertainty (E1)} = \pm 5\%$$

2 The uncertainty in the electret voltage reading. There can be an uncertainty of as much as one volt in both the initial and final voltage readings. The error in the difference of the two readings is the square root of two (the raw sum of the total voltage uncertainty), which is divided into the absolute value of the difference between the initial and final voltages (ΔV).

$$\text{Voltage Reading Uncertainty (E2)} = \pm\left(\frac{\sqrt{1+1}}{\left(\text{Initial Voltage} - \text{Final Voltage}\right)} \times 100\right)\%$$

3 The uncertainty associated with the background gamma value. The maximum error introduced by the EPA-listed background gamma averages for each state can introduce an error of approximately 0.1 pCi/L (or ~3.7 Bq/m³), and is calculated as a fraction of the measured radon concentration. Like the previous two error components, the Background Gamma Uncertainty (E3) is calculated as a percentage.

US Units

$$\text{Background Gamma Uncertainty (E3)} = \pm\left(\frac{0.1}{\text{Radon (pCi/L)}} \times 100\right)\%$$

SI Units

$$\text{Background Gamma Uncertainty (E3)} = \pm\left(\frac{3.7}{\text{Radon (Bq/m}^3)} \times 100\right)\%$$

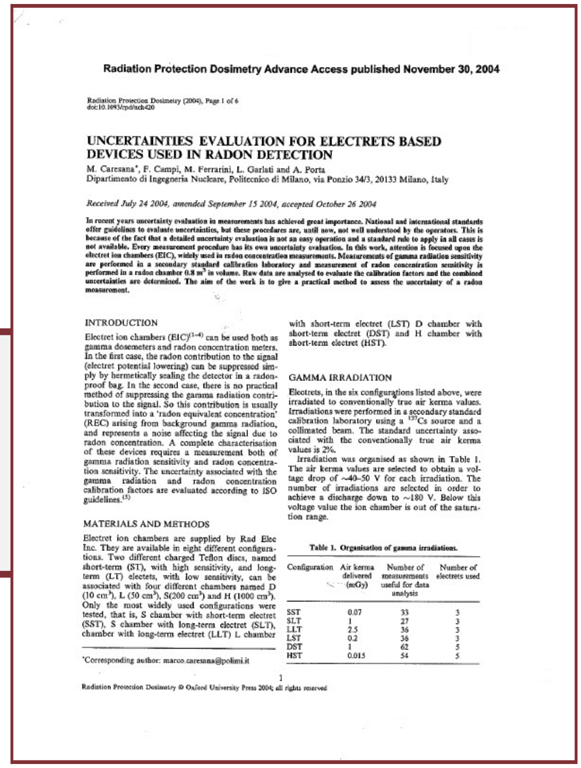
These three uncertainty components can be combined in order to create the **total uncertainty**, or total error, of a specific E-PERM® radon measurement. It can be determined by calculating the square root of the sum of the squares of the three individual error components. This is shown by the following equation.

$$\text{Total Uncertainty} = \pm\sqrt{(\text{System Uncertainty})^2 + (\text{Voltage Reading Uncertainty})^2 + (\text{Background Gamma Uncertainty})^2}\ \%$$

As shown above, the total uncertainty is calculated as a percentage; if you desire an absolute value, this percentage can be multiplied by the measured radon concentration.

When calculated as a percentage, total uncertainty will naturally increase as the measured radon concentration approaches zero.

Caresana, M., et al. "Uncertainties Evaluation for Electrets Based Devices Used in Radon Detection." *Radiation Protection Dosimetry*, Volume 113, No. 1, 18 April 2005, pp. 64-69.



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UNCERTAINTIES EVALUATION FOR ELECTRETS BASED DEVICES USED IN RADON DETECTION

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In recent years uncertainty evaluation in measurements has achieved great importance. National and international standards offer guidelines to evaluate uncertainties, but these procedures are, until now, not well understood by the operators. This is because of the fact that a detailed uncertainty evaluation is not an easy operation and a standard rule to apply in all cases is not available. Every measurement procedure has its own uncertainty evaluation. In this work, attention is focused upon the electret ion chambers (EIC), widely used in radon concentration measurements. Measurements of gamma radiation sensitivity are performed in a secondary standard calibration laboratory and measurement of radon concentration sensitivity is performed in a radon chamber 0.8 m^3 in volume. Raw data are analysed to evaluate the calibration factors and the combined uncertainties are determined. The aim of the work is to give a practical method to assess the uncertainty of a radon measurement.

INTRODUCTION

Electret ion chambers (EIC)(1–4) can be used both as gamma dosemeters and radon concentration meters. In the first case, the radon contribution to the signal (electret potential lowering) can be suppressed simply by hermetically sealing the detector in a radon-proof bag. In the second case, there is no practical method of suppressing the gamma radiation contribution to the signal. So this contribution is usually transformed into a 'radon equivalent concentration' (REC) arising from background gamma radiation, and represents a noise affecting the signal due to radon concentration. A complete characterisation of these devices requires a measurement both of gamma radiation sensitivity and radon concentration sensitivity. The uncertainty associated with the gamma radiation and radon concentration calibration factors are evaluated according to ISO guidelines.(5)

MATERIALS AND METHODS

Electret ion chambers are supplied by Rad Elec Inc. They are available in eight different configurations. Two different charged Teflon discs, named short-term (ST), with high sensitivity, and long-term (LT) electets, with low sensitivity, can be associated with four different chambers named D (10 cm^3), L (50 cm^3), S(200 cm^3) and H (1000 cm^3). Only the most widely used configurations were tested, that is, S chamber with short-term electret (SST), S chamber with long-term electret (SLT), chamber with long-term electret (LLT) L chamber with short-term electret (LST) D chamber with short-term electret (DST) and H chamber with short-term electret (HST).

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GAMMA IRRADIATION

Electrets, in the six configurations listed above, were irradiated to conventionally true air kerma values. Irradiations were performed in a secondary standard calibration laboratory using a ^{137}Cs source and a collimated beam. The standard uncertainty associated with the conventionally true air kerma values is 2%.

Irradiation was organised as shown in Table 1. The air kerma values are selected to obtain a voltage drop of ~40–50 V for each irradiation. The number of irradiations are selected in order to achieve a discharge down to ~180 V. Below this voltage value the ion chamber is out of the saturation range.

Table 1. Organisation of gamma irradiations.

Configuration	Air kerma delivered (mGy)	Number of measurements useful for data analysis	Number of electrets used
SST	0.07	33	3
SLT	1	27	3
LLT	2.5	36	3
LST	0.2	36	3
DST	1	62	5
HST	0.015	54	5

1

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Inherent Voltage Discharge

Electrets are subjected to multiple immunization and normalization stages throughout the manufacturing process in order to stabilize their surface charge. Nevertheless, there is a slight voltage decay over time. In many ways, this property is similar to a battery's inherent voltage loss when stored for a long period; this **Inherent Voltage Discharge** (IVD) is largely uniform for each electret type, and is included in the algorithms for calculating radon.

Because it is such a small value, the inherent voltage discharge can be mostly ignored for short-term exposures; however, it becomes increasingly important for long-term measurements, where the failure to account for IVD over many months would impact accuracy.

0.066667
Volts per Day

ST

To summarize, the IVD is factored into the E-PERM® algorithms. As long as you are using Rad Elec's software or spreadsheets to calculate your results, you will not need to worry about its effect on your radon concentrations.

0.066667
Volts per Day

MT

The inherent voltage discharge is comparable to a battery slowly losing voltage when stored for a long time.

0.022223
Volts per Day

LT

IVD is factored into our algorithm, so you don't need to worry about it!

Calibration Factors and Constants

Each E-PERM® configuration has its own set of calibration constants, which are derived from the electret sensitivity and the ion chamber volume. When used in conjunction with a specific electret's **midpoint voltage** (MPV) throughout a measurement, the specific **calibration factor** (CF) can be calculated. This section will explain the role of these calibration constants, which are divided into three constants: **A**, **B**, and **G**.

Unless you plan on creating your own calculation spreadsheet or application – or you're just really curious (and like math) – this section isn't necessary to understand. Rad Elec's software and spreadsheets will handle all of the calibration factors for you!

E-PERM® Configuration	Constant A	Constant B	Constant G
SST	0.314473	0.260619	0.087
SLT	0.031243	0.021880	0.087
LST	0.124228	0.040676	0.12
LLT	0.010189	0.003372	0.12
LST-OO	0.074671	0.037557	0.12
LMT-OO	0.013497	0.012499	0.12
LLT-OO	0.011965	0.002079	0.12
HST	7.2954	0.004293	0.07
HLT	0.60795	0.000358	0.07

Please note that the HST and HLT configurations still utilize the older linear calibration factors (without using the natural logarithm).

$$\text{EIC CF} = A + \left(B \times \ln\left(\frac{IV + FV}{2}\right)\right)$$

$$\text{EIC CF} = A + \left(B \times \left(\frac{IV + FV}{2}\right)\right)$$

Where...

- A = Constant A
- B = Constant B
- $\ln$ = Natural Logarithm ($\log_e$)
- IV = Initial Voltage
- FV = Final Voltage

L Chamber

S Chamber

L-OO Chamber

H Chamber

Constants A and B

Constants A and B are utilized alongside the midpoint voltage (MPV) in order to calculate the calibration factor (CF). The midpoint voltage is the average of the initial and final voltages of a given electret throughout an exposure period; it can be calculated by adding together the initial and final voltages, and then dividing the sum by two. This means that the MPV will need to be recalculated for each electret for every radon test.

$$\text{Midpoint Voltage (MPV)} = \frac{(\text{Initial Voltage} + \text{Final Voltage})}{2}$$

In contrast to the MPV – which is independent of the E-PERM® configuration and must be calculated anew for each radon test – the Constants A and B will stay the same as long as the configuration itself (i.e. SST, LMT-OO, LST, etc.) does not change. After the MPV is calculated, Constants A and B can be placed into the following equation in order to generate the specific calibration factor (CF).

$$\text{Calibration Factor (CF)} = A + \left(B \times \ln\left(\text{MPV}\right)\right)$$

Please remember to work from the innermost parentheses to the outside! Calculate the MPV before acquiring its natural logarithm, and then multiply this value by the Constant B. After all of this is done, add Constant A in order to arrive at the final CF.

Please note that $\ln$ is the natural logarithm, which must be applied to the midpoint voltage. Applying the natural logarithm to the MPV allows us to more accurately trace the curve of an interesting electret property wherein it is slightly easier to pull a volt from a highly-charged electret (700+ volts) and slightly more difficult to pull a volt from a low-voltage electret (~100 volts). In short, the greater an electret's voltage, the easier it is to discharge it.

Using the table at the end of this section to find Constants A and B, calculate the calibration factor for your specific configuration by following the proper order of operations. Congratulations! You've calculated the calibration factor, but what does this value actually signify? The calibration factor (CF) is a value that represents the amount of voltage lost per 24 hours per picocurie per liter, and it is a fundamental value when using electret ion chambers to measure radon concentration.

Constant G

The sole purpose of Constant G is to correct the background gamma (γ) contribution to the radon measurement. Low-volume ion chambers (such as the L-OO Chamber) will be slightly more influenced by background gamma than the larger chambers (such as the H Chamber). To calculate the total gamma correction required, simply multiply the appropriate Constant G by the estimated average background gamma in microroentgens per hour (µR/hr).

The resulting product is the gamma contribution to the radon measurement in picocuries per liter (pCi/L), which should be subtracted from the measurement result. Please note that this approach assumes US units, although it's quite possible to calculate the gamma contribution when using SI units. In order to do this, you must be sure to follow the conversion tips below.

The exact steps to integrate Constant G into the final measurement results are illustrated in the **Understanding the E-PERM® Algorithms** section later in the manual.

Background Gamma Contribution

$$\text{US Units (pCi/L)} = \mu\text{R/hr} \times G$$

$$\text{SI Units (Bq/m}^3\text{)} = \frac{\text{nGy/hr} \times G}{8.696}$$

Lower Limit of Detection

In the context of electret ion chambers, the **Lower Limit of Detection** (LLD) is defined as the radon concentration that can be measured with a total uncertainty (or error) of 50%. The LLD is also known as the Minimum Measurable Concentration (MMC) at 50% uncertainty. When the total uncertainty exceeds 50%, the ability to distinguish whether electret voltage loss is due to radon or another phenomenon is lost. This limit is reached when the measured radon concentration becomes smaller than the total uncertainties involved in the measurement; thankfully, this value is quite low.

The LLD is a function of the E-PERM® configuration and the length of the exposure. Generally speaking, the lower limit of detection decreases as the exposure period increases; this means that smaller targets can be measured accurately by increasing the exposure time.

		Radon Concentrations at Various Uncertainties						Specific Uncertainties	
Configuration	Days	50%		25%		10%		@ 4.0 pCi/L	@ 2.7 pCi/L
		pCi/L	Bq/m^3	pCi/L	Bq/m^3	pCi/L	Bq/m^3	(148 Bq/m^3)	(100 Bq/m^3)
SST	2	0.26	9.6	0.82	30.4	3.57	132.2	9.34%	11.93%
	7	0.20	7.6	0.43	16.0	0.20	7.6	5.99%	6.87%
SLT	30	0.23	8.4	0.59	21.9	0.23	8.4	7.96%	9.85%
	120	0.20	7.5	0.42	15.4	0.20	7.5	5.77%	6.51%
LST	30	0.20	7.5	0.43	15.8	1.36	50.3	6.06%	6.94%
	120	0.20	7.4	0.41	15.1	1.17	43.1	5.62%	6.27%
LLT	365	0.20	7.5	0.42	15.5	1.29	47.8	5.97%	6.78%
LST-OO	30	0.20	7.6	0.43	16.0	1.46	54.2	6.27%	7.25%
	91	0.20	7.5	0.41	15.2	1.19	43.9	5.67%	6.34%
LMT-OO	91	0.20	7.5	0.43	15.8	1.43	52.8	6.29%	7.23%
LLT-OO	365	0.20	7.5	0.42	15.6	1.35	50.0	6.14%	7.01%
HST	1	0.21	7.9	0.48	17.7	1.69	62.6	6.46%	7.65%
	2	0.20	7.5	0.42	15.7	1.29	47.6	5.82%	6.61%
HLT	7	0.24	8.8	0.64	23.8	2.62	96.9	7.84%	9.80%
	14	0.21	7.7	0.46	16.9	1.54	57.0	6.23%	7.28%
All values assume a midpoint voltage (MPV) of 450, a background gamma level of 10 µR/hr (87 nGy/hr), and no elevation correction.									

Understanding the E-PERM® Algorithms

Although the various analysis tools (such as the software, online platforms, and spreadsheets) are provided in order to make it easy to calculate radon concentrations, this section is intended for those who wish to understand exactly how to derive the radon concentration from an exposure involving E-PERMs®. Rad Elec recommends exercising caution when incorporating these algorithms into your own software platforms, as even a single misplaced parenthesis can yield incorrect results. Nevertheless, these algorithms are presented for those with the desire and curiosity to take the calculation process into their own hands.

These algorithms can be incorporated into your own software platforms or spreadsheets.

1 Look up the Calibration Constants (A, B, and G) for the desired E-PERM® configuration. The table below consists of Calibration Constants (A and B) in addition to the Gamma Conversion Constant (G). The Calibration Constants (A and B) are derived from a particular E-PERM® configuration during its characterization process, while the Gamma Conversion Constant (G) is based entirely on the ion chamber.

E-PERM® Configuration	Constant A	Constant B	Constant G
SST	0.314473	0.260619	0.087
SLT	0.031243	0.021880	0.087
LST	0.124228	0.040676	0.12
LLT	0.010189	0.003372	0.12
LST-OO	0.074671	0.037557	0.12
LMT-OO	0.013497	0.012499	0.12
LLT-OO	0.011965	0.002079	0.12
HST	7.2954	0.004293	0.07
HLT	0.60795	0.000358	0.07

2 Look up the estimated Background Gamma (BG) where the test was conducted. The Background Gamma table can be found at the end of this manual.

- The BG value is the environmental background gamma radiation that must ultimately be converted to imperial units of microroentgens per hour (µR/hr). The environmental gamma radiation can be measured or estimated. Due to gamma radiation's overall minor impact on the E-PERM® results, estimating the background gamma is perfectly acceptable. If it is suspected that the local test environment exhibits elevated gamma levels, E-PERMs® can be used to measure background gamma.

If you are using an SI value (nGy/hr) for your background gamma, divide it by 8.696 in order to convert it to µR/hr.

3 Calculate the number of days in the exposure period to three decimal places. For example, if the exposure period is 2 days and 3.5 hours, then:

$$D = 2 + \frac{3.5}{24} = 2.146$$

4 Calculate the Calibration Factor (EIC CF). The EIC CF is defined as the decrease in electret voltage when a specific electret and specific chamber are exposed for one day at a concentration of 1.0 pCi/L (37 Bq/m³) of radon. The EIC CF for E-PERMs® is logarithmically related to the electret voltage over a range of approximately 100 to 750 volts, and a self-correcting formula is used to develop the actual calibration factor appropriate to the average (or midpoint) voltage throughout the exposure period. Please note that the H Chamber configurations still use an older linear calibration factor, as listed below.

$$\text{EIC CF} = A + \left(B \times \ln\left(\frac{IV + FV}{2}\right)\right)$$

$$\text{EIC CF} = A + \left(B \times \left(\frac{IV + FV}{2}\right)\right)$$


L Chamber


S Chamber


L-OO Chamber

Where...

A = Constant A
B = Constant B
ln = Natural Logarithm ($\log_e$)
IV = Initial Voltage
FV = Final Voltage

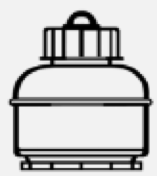

H Chamber

5

Look up the elevation at the test site, which must ultimately be converted to feet. This can be found online quite easily. Now calculate the Elevation Correction Factor (ElevCF). The ElevCF is only applied in certain circumstances. When deploying L or L-OO Chambers, a correction factor is only applied at elevations of 200+ feet (61+ meters). When deploying S Chambers, a correction factor is only applied at elevations equal to or greater than 4000 feet (1219 meters). H Chambers are not affected by habitable elevations, so no correction factor is required.

If you are using meters for your elevation, multiply this value by 3.281 in order to convert it to feet.

S Chambers



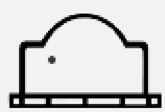
For Elevations <= 4000 feet

ElevCF = 1

For Elevations > 4000 feet

$$ElevCF = 0.79 + \left(\frac{6 \times Elevation(ft)}{100000} \right)$$

L / L-OO Chambers



For Elevations <= 200 feet

ElevCF = 1

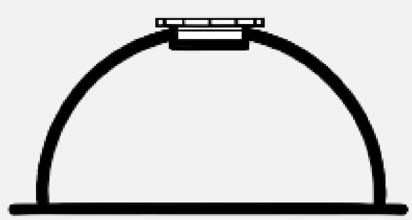
For Elevations > 200 feet

$$ElevCF = 1.005 + \left(\frac{4.5526 \times Elevation(ft.)}{100000} \right)$$

H Chambers

For All Elevations

ElevCF = 1



No Elevation Correction!

6 Calculate the radon concentration (RnC). Using the variables and constants calculated in Steps #1 through #5, you are now ready to calculate the radon concentration using the formula below. If the concentration is to be reported in SI units (Bq/m^3), then the equation must be multiplied by 37.

Radon Concentration (pCi/L) =

$$\left(\left(\frac{(IV - FV) - (IVD \times Days)}{EIC\ CF \times Days} \right) - (\overset{\mu R/hr}{\gamma} \times G) \right) \times (Elev\ CF)$$

Radon Concentration (Bq/m^3) =

$$\left(\left(\frac{(IV - FV) - (IVD \times Days)}{EIC\ CF \times Days} \right) - \frac{(\overset{nGy/hr}{\gamma} \times G)}{8.696} \right) \times (Elev\ CF) \times 37$$

Where...

IV = Initial Voltage
FV = Final Voltage
IVD = Inherent Voltage Discharge — 0.066667 for short-term electrets; 0.066667 for mid-term electrets; 0.022223 for long-term electrets
Days = Exposure Duration
EIC CF = EIC Calibration Factor
γ = Estimated or Measured Gamma
G = Constant G
Elev CF = Elevation Correction Factor

When using equations that you have formulated on your own, always confirm your results against an official spreadsheet or application that is known to be correct.

Remember to work from the inside to the outside, solving the sections inside the innermost parentheses first.

Frequently Asked Questions

How should I store the SPER-1E reader and E-PERMs®?

A protective case is provided with each SPER-1E reader. Alongside the reader, this case has enough space to hold a desiccant, two reference electrets, and zeroing electret. This protective case is the perfect place to store, ship, and travel with your SPER-1E voltage reader. Rad Elec recommends storing the reader in its protective case when it is not being used, in order to keep it dry and clean. This practice is especially important when the environment has elevated humidity.

When not being used, electrets should be stored in their keeper caps. If keeper caps are not practical, it's perfectly fine to store electrets loaded into ion chambers as long as the chamber is in the "off" position. Ideally, electrets should be stored in a controlled environment such as a home or office. If this isn't possible, it is important to bring the electrets inside and let them equilibrate to a controlled environment for an hour or two before reading them.

Consistent and stable electret readings are very important! If you encounter challenges, we are happy to help.

What should I do if my electret voltage readings keep jumping?

Although there can be a few reasons for electrets that seem to "jump" from one voltage to another, the first step is to ensure proper reading technique. This is described in the **How to Measure Surface Voltage** section earlier in the manual.

If the electret is still jumping, the next step is to clean! Use a nozzle with nitrogen to dislodge any dirt that has accumulated on the electret, taking care not to touch its surface. Also, clean the SPER-1E reader with a cotton cloth dabbed with isopropyl alcohol; afterwards, use nitrogen to remove any fibers or dirt that were left behind. During this process, please keep the slide closed and do not touch the sensitive detector board.

If you have eliminated all other culprits, sometimes the voltage reading will appear to "jump" during periods of very high humidity if the reader is not stored in a dry environment. If you suspect high humidity to be the cause, please store the reader in its case alongside a functioning desiccant for an hour or two; alternatively, you can move the SPER-1E voltage reader to a less humid environment.

If you still encounter challenges with stable readings, please call us (+1.800.526.5482) or send an email. We'll be happy to help!

How can I be sure that my voltage reader is functioning properly?

To confirm that your reader is functioning properly, read its reference and zeroing electrets. If the reference electrets are within ±3 volts of their certified voltages, and the zeroing electret is within ±3 volts of zero, then you have just proved that your voltage reader is functioning properly.

If only one reference electrets deviates from its certified voltage, then the voltage reader is still functioning properly; the anomalous reference electret is either dirty or was inadvertently discharged via touch.

However, if both reference electrets deviate by ±3 volts from their certified voltages, your voltage reader may need to be calibrated or repaired. Please contact Rad Elec, and we'll be happy to help out.

Please note that these reference and zeroing electret readings provide only one point of reference, and should not be construed as a method of calibration, which characterizes your reader over a wide voltage range.

How often should I replace the batteries in the voltage reader?

Not very often. If the battery is low, you will notice the battery icon on the display gradually being reduced.

When the battery voltage gets low enough, a "LOW BAT" warning will appear when you turn on voltage reader. This means that you should replace the two AA alkaline batteries at your earliest convenience. This can be accomplished easily by turning the reader over, and gently releasing the battery panel with a flat head screwdriver. Also, Rad Elec will replace your batteries as part of the annual calibration service.

How often should my voltage reader be calibrated?

Your reader should be calibrated annually, along with your reference and zeroing electrets. There is a calibration sticker on the back of your reader, which will let you know when its next calibration is due.

The calibration form can be found on our website in the Customer Forms section.

Since electrets basically look the same when covered, how do I identify the short-term (ST), mid-term (MT), and long-term (LT) from one another?

There is a colored label on the bottom of each electret. **Blue** is for short-term (ST), **burgundy** is for mid-term (MT), and **red** is for long-term (LT).

ST **MT** **LT**

Also, the electret's unique serial identifier will begin with a letter indicating its type.

Would I receive an electric shock if I touched the electret surface?

No, you will not feel any shock from touching an electret surface. Even though the surface of a new electret is 700+ volts, it can never give a shock because of the extremely high resistance of the electret surface, which is made of polytetrafluoroethylene (Teflon).

However, touching an electret will cause it to be discharged, potentially losing hundreds of volts. Set a touched electret aside for 15 minutes and then read its voltage again.

How durable is the electret? What happens if it is dropped or thrown?

Electrets are quite durable as long as they are stored in their keeper caps, and are able to withstand moderate mechanical shock (i.e. dropping it from a table onto a carpeted floor). Violent mechanical shock, such as throwing it against pavement or a wall, should be avoided.

If an electret experiences a violent mechanical shock or jolt, Rad Elec recommends measuring its voltage again before deploying it.

What do I do with electrets that have fewer than 100 volts?

Electrets with fewer than 100 volts should not be deployed for additional measurements because the weaker electrostatic field is not as consistent in collecting ions efficiently. However, these electrets make excellent field blanks. Alternatively, these depleted electrets can be returned to Rad Elec in exchange for store credit.

Please do not use any third-party companies that offer to recharge electrets, because these recharged electrets do not undergo the rigorous (and months long!) QA/QC processes. These "recharged" third-party electrets are no longer approved for use with E-PERMs®.

How do I know my electrets are stable and of good quality?

Rad Elec has a very thorough QA/QC process through which every electret must pass. Each electret undergoes a multifaceted stabilization procedure. Furthermore, to ensure correct calibration, a statistically significant number of electrets are checked in our NRSB-accredited radon chamber. An Electret Quality Certificate is provided to the purchaser with Rad Elec's QA information for each electret.

In addition to Rad Elec's QA/QC process, you are encouraged to conduct additional "drift tests" as specified by your own QA plan. ST and MT electrets should not discharge more than 6 volts per month, and LT electrets should not discharge more than 4 volts per month when measured over a three month period.

A drift test is a perfect way to ensure your electrets are stable. It's basically an extended field blank test that should be conducted in your home, office, or laboratory.

What should I do if I accidentally drop an open electret during a reading?

It's possible that the electret may have come into contact with dirt or other debris from the fall, which will be deposited onto the charged electret surface. If so, there could be a substantial voltage drop in the electret voltage.

Clean any dirt on the electret by using nitrogen, being careful not to touch the electret surface with the gas nozzle. To be safe, Rad Elec recommends conducting a "drift test" on this electret to ensure that it remains stable.

Can I store electrets in their ion chambers?

Yes! You can store an electret in an S or L-OO Chamber because these ion chambers have an on/off mechanism. Please make sure that the ion chamber is in the "off" position when storing electrets.

You cannot store an electret in H or L Chambers because they do not have on/off mechanisms.

I know that I should not use electrets below 100 volts, but what should I do if my final voltage reading is below this threshold?

As long as your final voltage reading is above zero, you have absolutely nothing to worry about. With our current logarithmic calibration factors, the midpoint voltage (which is the average of the initial and final voltages) can be as low as 50 volts.

If your final reading is zero volts, report the final radon concentration as equal to or above its value. For example, if the result was 3.4 pCi/L, then report the results as ≥3.4 pCi/L.

Does the label wrapped around the S Chamber serve a particular purpose? Can it be removed or replaced?

Yes, this wrapped label serves a purpose; it holds the top and bottom portions of the S Chamber together. Please do not remove this label, although you are welcome to add an additional layer on top of it (for example, if you would like to customize the E-PERM® with your company name). Although it should not be removed, the label can be replaced if it becomes torn or otherwise damaged. Please contact Rad Elec, and we'll help out.

What should I do if my final voltage reading is below zero volts?

Radon (and any other ionizing radiation) cannot reduce the electret below zero volts. However, touching the charged electret surface can drop the surface voltage into the negatives. Unfortunately, a negative voltage reading means your results are invalid.

How long is an electret's shelf life?

Provided that it is stored properly, the electret's shelf life is many, many years (if not decades).

How can I prevent someone from tampering with the E-PERMs®?

There are several anti-tampering practices that can be used. Rad Elec recommends deploying your E-PERMs® in tamper boxes, deployment sleeves, or Tyvek® bags which can be secured with lock-ties.

There are also tiny holes in both the S and L-OO Chambers that can be secured with lock-ties, ensuring that the chambers cannot be closed without cutting the lock-tie.

Can S Chambers be repaired if they develop problems over time?

The majority of the components in the S Chamber can be repaired very affordably, and all of our ion chambers have exceedingly long lifespans. For example, the progeny filter and the wrapped label can be replaced for a minimal charge.

After many years of usage, the threads on the ion chamber may begin to wear out. At this point, the chamber may need to be replaced. Nevertheless, when used responsibly, the ion chambers will last for a decade or longer.

Is there an exposure time limit for E-PERMs®?

Not in the traditional sense, although the ultimate exposure time for any specific test is when the electret is fully discharged. In other words, if your electret goes down to zero volts, you can only be confident that the radon exposure is *at least* the calculated value, and most likely greater.

In the United States, short-term radon measurements require a minimum exposure period of 48 hours.

What is the sensitivity of E-PERMs®?

There is no simple answer for this question. Since E-PERMs® are true integrating detectors, they can be used for any length of time to achieve the sensitivity needed.

In general, increasing the sensitivity can be achieved by increasing the duration of the exposure and/or the volume of the ion chamber. If there is a need to measure extremely low radon concentrations with high sensitivity, a sensitive E-PERM® configuration (such as an SST or HST) should be deployed, and/or the exposure period should be extended.

For more information, please refer to the **Dynamic Range** and **Uncertainty Analysis** sections of the manual.

What is the Lowest Level of Detection (LLD) of E-PERMs®?

The LLD varies according to the E-PERM® configuration and the exposure period, but it's usually between 0.2 and 0.3 pCi/L (roughly 7 to 10 Bq/m^3).

For a more detailed answer, refer to the **Lower Limit of Detection** section of the manual.

Can the SLT configuration be used for short-term radon measurements?

Yes, but only in environments with suspected or known elevated radon concentrations. If you are uncertain of the radon levels, it is preferable to use an SST configuration for a standard short-term radon test.

For example, when radon concentrations are above 50 pCi/L (1850 Bq/m^3) an SLT can be used to characterize this environment accurately in as little as two days. However, in environments with low radon concentrations, the SLT is just not sensitive enough to accurately measure radon after only two days. This is because the electret would only lose a few volts, and the resulting measurement uncertainty would be high.

This is the reason why we should not typically deploy low-sensitivity E-PERM® configurations (such as an LLT-OO or SLT) for a two day test. If these electrets only lose one or two volts, we cannot be certain whether the voltage loss is due to radon or to another factor such as the reading technique, a dirty electret, or another unknown contributing factor.

Can the SST configuration be used for long-term radon measurements?

Yes, but only in environments with a low radon concentration. If you are uncertain or expect elevated concentrations, it is not recommended to use an SST configuration for long-term radon tests.

For example, an SST would lose approximately 600 volts when exposed for 90 days in an environment with 2.5 pCi/L (nearly 100 Bq/m^3). In contrast, an SLT would only lose approximately 50 volts in the same environment, making it much more suited for long-term measurements.

Incidentally, the ambient radon level of 0.4 pCi/L, listed in *A Citizen's Guide to Radon* and published by the EPA, was determined by using SST E-PERMs®. Electret ion chambers are one of the few devices that can measure radon at low concentrations in outdoor environments across a wide range of temperatures and humidities.

Can I measure radon in an unoccupied home that has no heating or cooling?

Yes, an E-PERM® can be deployed in uncontrolled environments (and even outdoors in extreme conditions). However, it is important to remember that many states and testing protocols require that the thermostat be set at certain ranges. Lastly, please remember that the initial and final voltage readings should be taken at similar temperatures.

Can I deploy an E-PERM® next to a television, computer, or phone?

Yes, yes, and yes. Radiation emitted by these devices tends to be regulated by federal governments, and they are not permitted to emit measurable levels of ionizing radiation (which would be a health hazard). An E-PERM® is also a Faraday cage. As such, there is no measurable effect when placed adjacent to electronic devices.

Can I conduct an E-PERM® radon measurement in a highly dusty area, such as in a furniture factory or paper processing plant?

Yes, although Rad Elec recommends deploying the E-PERMs® in Tyvek® bags, which will create an additional protective barrier against dirt, dust, and other environmental particulates.

Can I deploy E-PERMs® in an area where an ion generator is being used?

Yes. The ion chambers have filtered inlets which prevent external ions from entering the chambers and discharging the electret.

Can I deploy E-PERMs® on top of a granite countertop or pool table?

No, it's not a good idea because granite and slate may be radioactive (primarily as gamma emitters). This would create a localized positive bias in your results. It's better to play it safe, and deploy the E-PERMs® elsewhere.

I understand that E-PERMs® respond to gamma and x-rays. Can I take them through airport security or transport them as checked baggage?

E-PERMs® are shipped all around the world, and in the majority of instances are not affected by security checks. When transporting or shipping electret ion chambers, please make sure that they are in keeper caps or closed ion chambers.

In recent years, there have been credible reports that transporting E-PERMs® in checked baggage through airports may expose them to cabinet x-ray systems and/or additional scrutiny which have caused significant electret voltage loss.

Interestingly, this phenomenon has not been observed when transporting the electrets as carry-on baggage. Until additional data is acquired, Rad Elec recommends transporting E-PERMs® in your carry-on baggage when possible, and **to confirm voltages after you arrive** at your destination.

Can I use E-PERMs® where there is high background gamma due to the presence of external radiation sources?

If you suspect elevated background gamma levels, then you should conduct a gamma background measurement. This can be done relatively easily by sealing an E-PERM® inside an aluminized Mylar® bag, which will block radon while still allowing gamma entry.

What is a false positive radon measurement?

A false positive reading means that your measured value is *higher* than the true value.

What is a false negative radon measurement?

A false negative reading means that your measured value is *lower* than the true value. False negatives can be dangerous because occupants will be receiving a higher dose of radiation than the measured value indicates.

If errors are introduced, do E-PERMs® tend to bias their results positively or negatively?

When mistakes happen with E-PERMs®, they almost invariably introduce false positive values. This is because it is very difficult to introduce voltage to the electret, whereas it is much easier to accidentally discharge the surface voltage. If the electret is touched or dropped, or if its surface is dirty, there is a high chance that additional voltage loss will cause a false positive bias.

Although rare, false negative readings with E-PERMs® are possible by accidentally leaving the ion chamber in a closed position, by partially closing the chamber (most commonly by accidentally "crunching" it with a tamper box lid), or through data entry errors.

What distinguishes true integrating radon detectors from other devices?

True integrating radon detectors respond to all changes in radon concentration during the measurement period, and are not biased to the beginning, middle, or end of an exposure period. True integrating radon detectors can be exposed for longer periods if radon concentrations are low, and for a shorter period if radon concentrations are elevated. Examples of true integrating radon detectors include electret ion chambers, alpha track devices, and continuous radon monitors.

Examples of radon detectors that are not true integrating devices include activated charcoal and liquid scintillation vials. Although these radon detectors can be very accurate, they adsorb (and desorb) radon throughout their detection periods; this means that they tend to bias their measurements toward the latter part of the exposure period.

If you have any other questions that you would like answered (and/or added to this FAQ section), please send us an email at info@radelec.com, or call our office at +1.800.526.5482.

Troubleshooting the SPER-1E Voltage Reader

"LOW BAT" appears on the screen.

This means that it's time to replace the batteries. Gently turn the SPER-1E over, and locate the battery panel. You will likely need to release the panel with a flat screwdriver. Remove the old batteries, and replace them with two new AA alkaline batteries.

Nothing appears on the display.

Pulling the slide/handle should turn on the reader. If it doesn't turn on, the batteries may either be dead or missing. If replacing the batteries does not fix the issue, please contact Rad Elec. Your reader will need to be repaired.

The voltage reader does not turn off after two minutes.

This symptom indicates a defect in the switch that is responsible for automatically turning off the reader. Although the reader can still be used, the batteries will not last long. It should be sent to Rad Elec for repairs.

My readings are not reproducible and/or they fluctuate. What can I do to make stable readings?

If you are sure that you are using a proper reading technique (as explained earlier in the **How to Measure Electret Surface Voltage** section), then the next step is to ensure that the electret receptacle is clean. The electret receptacle is the circular metal housing on the SPER-1E voltage reader where the electret sits. It may become dirty and prevent solid contact with the electret, so you should clean it with a cotton swab that has been dabbed with rubbing alcohol.

Use the cotton swab to wipe around the electret receptacle on the SPER-1E, cleaning any debris off the surface. Afterwards, blow off the receptacle with nitrogen and make sure that no lint or fibers are left behind. **Do not open the shutter and expose the interior of the reader while cleaning the electret receptacle.**

Following the tips above should allow you to make reproducible readings. If your readings are still fluctuating, make sure that the reader hasn't been sitting outdoors in the heat or cold, and bring it into a climate-controlled area where the humidity is less than 75%. Please try to keep the reader inside its protective case, and gently bake the desiccant every few months to ensure that it is minimizing the humidity inside the protective case.

"ER SLIDE" appears on the display.

This usually means that the slide handle was pulled too quickly, or held open for too long. Wait a few seconds, and try to gently pull the slide again. The motion to pull open the slide should be relaxed and steady; this maneuver should take approximately half of a second from start to finish. After the slide handle reaches the bottom of its track, and the voltage appears on the display, you can gently release the slide so that it returns to its resting position.

When reading a reference electret, its voltage differs by greater than ±3 volts from its certified voltage.

If only one reference electret deviates from its certified voltage, then the reader is perfectly fine. If both electrets deviate from their certified voltages, then the reader may have been dropped (or experienced significant mechanical trauma). In this scenario, you may try replacing the batteries in order to see if it makes a difference, but the SPER-1E will likely need to be sent to Rad Elec for repairs. Please contact Rad Elec.

The SPER-1E voltage reader is making a high-pitched whistling sound.

This sound indicates that the slide has not returned back to its resting position. This can sometimes happen because the metal-to-metal slide rail is binding the slide movement. Try gently moving the slide handle back and forth, which will usually unbind it and allow the slide to return to its home position.

It is important to gently wiggle the slide back to its resting / home position, or else the reader will remain powered on and drain the batteries.

The desiccant in my protective case has changed color.

This means that the desiccant has absorbed a large amount of humidity, and needs to be revived. This can be done by placing it in an oven at a low temperature (usually around 225 °F / 110 °C) for several hours. The specific instructions are written on the the metal desiccant canister.

Do I need to "zero" my SPER-1E voltage reader every time I turn it on?

No. Nevertheless, frequent reference and zeroing electret readings help to ensure that your equipment is functioning properly.

Additional Applications for Electret Ion Chambers

Electret ion chambers are very versatile, and can be employed to measure other types of ionizing radiation. The following list illustrates some of these applications apart from measuring radon in air:

Please reach out to us if you have any questions about these additional applications.

- Instant radon measurement
- Measurement of radon-in-water
- Electret radon sniffer for mitigation diagnostics
- Environmental gamma radiation measurements
- ^{226}Radium concentration from soil
- Personnel dosimeter radon monitor
- Measurement of undisturbed radon flux from the ground and other surfaces
- Modified E-PERM® for passive measurement of thoron
- Modified E-PERM® for passive measurement of airborne tritium
- Tritium concentration in water and contamination on surfaces
- Modified E-PERM® for measurement of alpha radiation from a contaminated surface
- A calibration system for integrating E-PERMs® using the NIST Radon Emanation Standard
- Modified E-PERM® for passive measurement of uranium and plutonium contamination in soils
- Measurement of radon emanation from granite countertops and building materials
- Measurement of radon progeny concentration in air
- Electrets for measuring ion concentration in air
- Glove box radon test chamber traceable to NIST radon emanation standard
- Measurement of radon in natural gas (in pipelines), butane, ethane, and propane

E-PERM® and SPER-1E Technical Specifications

This section contains the technical specifications for each E-PERM® configuration, in addition to the SPER-1E voltage reader. Its purpose is to provide a succinct yet detailed summary on the voltmeter and the various electrets and ion chambers.

Electrets

- The electret is a Teflon® disk that is electrically charged and stabilized by Rad Elec's proprietary manufacturing processes. It is mounted in an electrically conducting plastic holder and covered by a keeper cap.
- Initial surface charge (potential) of 700+ volts.
- An electret should not be deployed with an initial voltage below 100 volts, although its final voltage can be below this threshold. The logarithmic calibration factors hold true down to a midpoint voltage (MPV) of 50.
- ST and MT electret inherent voltage discharge should not exceed 6 volts per month (1.5 volts per week) when measured after 28 days. LT electret inherent voltage discharge should not exceed 4 volts per month when measured over a three month period.
- Usable in all E-PERM® applications.

Reference Electrets

- Highly stable electrets that have been certified to a known voltage by Rad Elec.
- Used to verify that the SPER-1E voltage reader is functioning properly.

Performance

- When used in accordance with all recommended procedures (deployment, retrieval, analysis, maintenance and calibration), E-PERMs® are expected to provide excellent accuracy (total uncertainty less than 10%).

Ion Chambers

- Constructed of electrically conducting plastic and can be re-used indefinitely.
- Electrets can be screwed into the threads of each chamber.
- L-OO Chamber has a volume of 53 mL with an on/off mechanism.
- L Chamber has a volume of 58 mL.
- S Chamber has a volume of 210 mL with an on/off mechanism.
- H Chamber has a volume of 960 mL.

SPER-1E Voltage Reader

- This voltmeter is an ultra-high impedance, non-contact electric field sensor that works on the principle of an electrometer with an on/off shutter.
- Range: 0 to ±2000 volts
- Resolution: ±1 volt
- Adjustments: Zeroing and Calibration
- Requires annual calibration
- Designed and manufactured in the United States
- Highly modular and repairable

Please check out our other manuals for technical information on measuring radon in water, soil, and natural gas.

S Chamber

SST

Short-Term Electret in S Chamber

Short-Term

Technical Specifications

Methodology & Purpose
True integrating electret ion chamber (210 ml) optimized for short-term radon measurements spanning 2-7 days.

Maximum Range
Approximately 340 pCi/L-Days (12,580 Bq/m³-Days) with new electret

Minimum Measurable Concentration
0.26 pCi/L (9.61 Bq/m^3) @ 2 days
0.20 pCi/L (7.58 Bq/m^3) @ 7 days

Total Expected Error @ 4.0 pCi/L (148 Bq/m^3)
9.34% @ 2 days
5.99% @ 7 days

Expected Error
Less than 25% error for concentrations greater than 0.82 pCi/L (30.42 Bq/m^3) @ 2 days
Less than 10% error for concentrations greater than 3.57 pCi/L (132.24 Bq/m^3) @ 2 days
Less than 25% error for concentrations greater than 0.43 pCi/L (15.95 Bq/m^3) @ 7 days
Less than 10% error for concentrations greater than 1.37 pCi/L (50.52 Bq/m^3) @ 7 days

Response to Thoron
Less than 3%

Response to Gamma Radiation
0.44 pCi/L @ 5 µR/hr (accounted for via corrections in calculations)

Not Affected By (under normal conditions typically found in homes)
Temperature
Air Flow
Sunlight
Environmental Ions
Environmental Dust
Non-condensing Humidity (less than 100% relative humidity)
Magnetic fields (up to 10,000 Gauss)
Electric voltages (up to 5,000 volts)
Normal shocks while handling and shipping

S Chamber

SLT

Long-Term Electret in S Chamber

Long-Term

Technical Specifications

Methodology & Purpose

True integrating electret ion chamber (210 ml) optimized for radon measurements spanning 30-120 days.

Maximum Range

Approximately 3,970 pCi/L-Days (146,900 Bq/m^3-Days) with new electret.

Minimum Measurable Concentration

0.23 pCi/L (8.39 Bq/m^3) @ 30 days
0.20 pCi/L (7.49 Bq/m^3) @ 120 days

Total Expected Error @ 4.0 pCi/L (148 Bq/m^3)

7.96% @ 30 days
5.77% @ 120 days

Expected Error

Less than 25% error for concentrations greater than 0.59 pCi/L (21.89 Bq/m^3) @ 30 days
Less than 10% error for concentrations greater than 2.63 pCi/L (97.44 Bq/m^3) @ 30 days
Less than 25% error for concentrations greater than 0.42 pCi/L (15.43 Bq/m^3) @ 120 days
Less than 10% error for concentrations greater than 1.24 pCi/L (45.84 Bq/m^3) @ 120 days

Response to Thoron

Less than 3%

Response to Gamma Radiation

0.44 pCi/L @ 5 µR/hr (accounted for via corrections in calculations)

Not Affected By (under normal conditions typically found in homes)

Temperature
Air Flow
Sunlight
Environmental Ions
Environmental Dust
Non-condensing Humidity (less than 100% relative humidity)
Magnetic fields (up to 10,000 Gauss)
Electric voltages (up to 5,000 volts)
Normal shocks while handling and shipping

L Chamber

LST

Short-Term Electret in L Chamber

Short-Term

Technical Specifications

Methodology & Purpose

True integrating electret ion chamber (58 ml) for radon measurements spanning 30-120 days.

Maximum Range

Approximately 1,753 pCi/L-Days (64,861 Bq/m^3-Days) with new electret.

Minimum Measurable Concentration

0.20 pCi/L (7.53 Bq/m^3) @ 30 days
0.20 pCi/L (7.44 Bq/m^3) @ 120 days

Total Expected Error @ 4.0 pCi/L (148 Bq/m^3)

6.06% @ 30 days
5.62% @ 120 days

Expected Error

Less than 25% error for concentrations greater than 0.43 pCi/L (15.75 Bq/m^3) @ 30 days
Less than 10% error for concentrations greater than 1.36 pCi/L (50.30 Bq/m^3) @ 30 days
Less than 25% error for concentrations greater than 0.41 pCi/L (15.14 Bq/m^3) @ 120 days
Less than 10% error for concentrations greater than 1.17 pCi/L (43.14 Bq/m^3) @ 120 days

Response to Thoron

Less than 3%

Response to Gamma Radiation

0.60 pCi/L @ 5 µR/hr (accounted for via corrections in calculations)

Not Affected By (under normal conditions typically found in homes)

Temperature
Air Flow
Sunlight
Environmental Ions
Environmental Dust
Non-condensing Humidity (less than 100% relative humidity)
Magnetic fields (up to 10,000 Gauss)
Electric voltages (up to 5,000 volts)
Normal shocks while handling and shipping

L Chamber

LLT

Long-Term Electret in L Chamber

Long-Term

Technical Specifications

Methodology & Purpose

True integrating electret ion chamber (58 ml) for long-term radon measurements spanning 91-365 days.

Maximum Range

Approximately 21,240 pCi/L-Days (785,880 Bq/m^3-Days) with new electret.

Minimum Measurable Concentration

0.23 pCi/L (8.41 Bq/m^3) @ 91 days
0.20 pCi/L (7.49 Bq/m^3) @ 365 days

Total Expected Error @ 4.0 pCi/L (148 Bq/m^3)

10.12% @ 91 days
5.97% @ 365 days

Expected Error

Less than 25% error for concentrations greater than 0.66 pCi/L (24.58 Bq/m^3) @ 91 days
Less than 10% error for concentrations greater than 4.09 pCi/L (151.28 Bq/m^3) @ 91 days
Less than 25% error for concentrations greater than 0.42 pCi/L (15.48 Bq/m^3) @ 365 days
Less than 10% error for concentrations greater than 1.29 pCi/L (47.75 Bq/m^3) @ 365 days

Response to Thoron

Less than 3%

Response to Gamma Radiation

0.60 pCi/L @ 5 µR/hr (accounted for via corrections in calculations)

Not Affected By (under normal conditions typically found in homes)

Temperature
Air Flow
Sunlight
Environmental Ions
Environmental Dust
Non-condensing Humidity (less than 100% relative humidity)
Magnetic fields (up to 10,000 Gauss)
Electric voltages (up to 5,000 volts)
Normal shocks while handling and shipping

L-OO Chamber

LST-OO

Short-Term Electret in L-OO Chamber

Short-Term

Technical Specifications

Methodology & Purpose

True integrating electret ion chamber (53 ml) with on/off slide optimized for radon measurements spanning 30-91 days.

Maximum Range

Approximately 2,151 pCi/L-Days (79,587 Bq/m^3-Days) with new electret.

Minimum Measurable Concentration

0.20 pCi/L (7.57 Bq/m^3) @ 30 days
0.20 pCi/L (7.45 Bq/m^3) @ 91 days

Total Expected Error @ 4.0 pCi/L (148 Bq/m^3)

6.27% @ 30 days
5.67% @ 91 days

Expected Error

Less than 25% error for concentrations greater than 0.43 pCi/L (16.05 Bq/m^3) @ 30 days
Less than 10% error for concentrations greater than 1.46 pCi/L (54.15 Bq/m^3) @ 30 days
Less than 25% error for concentrations greater than 0.41 pCi/L (15.20 Bq/m^3) @ 91 days
Less than 10% error for concentrations greater than 1.19 pCi/L (43.86 Bq/m^3) @ 91 days

Response to Thoron

Less than 3%

Response to Gamma Radiation

0.60 pCi/L @ 5 µR/hr (accounted for via corrections in calculations)

Not Affected By (under normal conditions typically found in homes)

Temperature
Air Flow
Sunlight
Environmental Ions
Environmental Dust
Non-condensing Humidity (less than 100% relative humidity)
Magnetic fields (up to 10,000 Gauss)
Electric voltages (up to 5,000 volts)
Normal shocks while handling and shipping

L-OO Chamber

LMT-OO

Mid-Term Electret in L-OO Chamber

Mid-Term

Technical Specifications

Methodology & Purpose

True integrating electret ion chamber (53 ml) with on/off slide optimized for 91-day radon measurements.

Maximum Range

Approximately 7,289 pCi/L-Days (269,693 Bq/m^3-Days) with new electret.

Minimum Measurable Concentration

0.23 pCi/L (8.48 Bq/m^3) @ 30 days
0.20 pCi/L (7.53 Bq/m^3) @ 91 days
0.20 pCi/L (7.49 Bq/m^3) @ 120 days

Total Expected Error @ 4.0 pCi/L (148 Bq/m^3)

10.37% @ 30 days
6.29% @ 91 days
6.00% @ 120 days

Expected Error

Less than 25% error for concentrations greater than 0.69 pCi/L (25.50 Bq/m^3) @ 30 days
Less than 10% error for concentrations greater than 4.28 pCi/L (158.46 Bq/m^3) @ 30 days
Less than 25% error for concentrations greater than 0.43 pCi/L (15.81 Bq/m^3) @ 91 days
Less than 10% error for concentrations greater than 1.43 pCi/L (52.76 Bq/m^3) @ 91 days
Less than 25% error for concentrations greater than 0.42 pCi/L (15.50 Bq/m^3) @ 120 days
Less than 10% error for concentrations greater than 1.30 pCi/L (48.18 Bq/m^3) @ 120 days

Response to Thoron

Less than 3%

Response to Gamma Radiation

0.60 pCi/L @ 5 µR/hr (accounted for via corrections in calculations)

Not Affected By (under normal conditions typically found in homes)

Temperature, Air Flow, Sunlight
Environmental Ions & Environmental Dust
Non-condensing Humidity (less than 100% relative humidity)
Magnetic fields (up to 10,000 Gauss)
Electric voltages (up to 5,000 volts)
Normal shocks while handling and shipping

L-OO Chamber

LLT-OO

Long-Term Electret in L-OO Chamber

Long-Term

Technical Specifications

Methodology & Purpose

True integrating electret ion chamber (53 ml) with on/off slide optimized for long-term radon measurements.

Maximum Range

Approximately 26,475 pCi/L-Days (979,575 Bq/m^3-Days) with new electret.

Minimum Measurable Concentration

0.24 pCi/L (8.81 Bq/m^3) @ 91 days
0.20 pCi/L (7.51 Bq/m^3) @ 365 days

Total Expected Error @ 4.0 pCi/L (148 Bq/m^3)

11.65% @ 91 days
6.14% @ 365 days

Expected Error

Less than 25% error for concentrations greater than 0.83 pCi/L (30.61 Bq/m^3) @ 91 days
Less than 10% error for concentrations greater than 5.28 pCi/L (195.24 Bq/m^3) @ 91 days
Less than 25% error for concentrations greater than 0.42 pCi/L (15.61 Bq/m^3) @ 365 days
Less than 10% error for concentrations greater than 1.35 pCi/L (49.99 Bq/m^3) @ 365 days

Response to Thoron

Less than 3%

Response to Gamma Radiation

0.60 pCi/L @ 5 µR/hr (accounted for via corrections in calculations)

Not Affected By (under normal conditions typically found in homes)

Temperature
Air Flow
Sunlight
Environmental Ions
Environmental Dust
Non-condensing Humidity (less than 100% relative humidity)
Magnetic fields (up to 10,000 Gauss)
Electric voltages (up to 5,000 volts)
Normal shocks while handling and shipping

H Chamber

HST

Short-Term Electret in H Chamber

Short-Term

Technical Specifications

Methodology & Purpose

True integrating electret ion chamber (960 ml) optimized for highly sensitive short-term radon measurements spanning 1-2 days. Low dynamic range means that extra care needs to be taken to ensure the electret doesn't become depleted.

Maximum Range

Approximately 58 pCi/L-Days (2,146 Bq-m^3-Days) with new electret.

Minimum Measurable Concentration

0.21 pCi/L (7.88 Bq/m^3) @ 1 day
0.20 pCi/L (7.54 Bq/m^3) @ 2 days

Total Expected Error @ 4.0 pCi/L (148 Bq/m^3)

6.46% @ 1 day
5.82% @ 2 days

Expected Error

Less than 25% error for concentrations greater than 0.48 pCi/L (17.72 Bq/m^3) @ 1 day
Less than 10% error for concentrations greater than 1.69 pCi/L (62.61 Bq/m^3) @ 1 day
Less than 25% error for concentrations greater than 0.42 pCi/L (15.70 Bq/m^3) @ 2 days
Less than 10% error for concentrations greater than 1.29 pCi/L (47.57 Bq/m^3) @ 2 days

Response to Thoron

Less than 5%

Response to Gamma Radiation

0.35 pCi/L @ 5 µR/hr (accounted for via corrections in calculations)

Not Affected By (under normal conditions typically found in homes)

Temperature
Air Flow
Sunlight
Environmental Ions, Environmental Dust
Non-condensing Humidity (less than 100% relative humidity)
Magnetic fields (up to 10,000 Gauss)
Electric voltages (up to 5,000 volts)
Normal shocks while handling and shipping

H Chamber

HLT

Long-Term Electret in H Chamber

Long-Term

Technical Specifications

Methodology & Purpose

True integrating electret ion chamber (960 ml) optimized for short-term radon measurements spanning 7-14 days.

Maximum Range

Approximately 706 pCi/L-Days (26,122 Bq/m^3-Days) with new electret.

Minimum Measurable Concentration

0.24 pCi/L (8.84 Bq/m^3) @ 7 days
0.21 pCi/L (7.74 Bq/m^3) @ 14 days

Total Expected Error @ 4.0 pCi/L (148 Bq/m^3)

7.84% @ 7 days
6.23% @ 14 days

Expected Error

Less than 25% error for concentrations greater than 0.64 pCi/L (23.82 Bq/m^3) @ 7 days
Less than 10% error for concentrations greater than 2.62 pCi/L (96.88 Bq/m^3) @ 7 days
Less than 25% error for concentrations greater than 0.46 pCi/L (16.89 Bq/m^3) @ 14 days
Less than 10% error for concentrations greater than 1.54 pCi/L (56.95 Bq/m^3) @ 14 days

Response to Thoron

Less than 5%

Response to Gamma Radiation

0.35 pCi/L @ 5 µR/hr (accounted for via corrections in calculations)

Not Affected By (under normal conditions typically found in homes)

Temperature
Air Flow
Sunlight
Environmental Ions, Environmental Dust
Non-condensing Humidity (less than 100% relative humidity)
Magnetic fields (up to 10,000 Gauss)
Electric voltages (up to 5,000 volts)
Normal shocks while handling and shipping

Sample Test Report

ABC Radon Testing Company

555 Bismuth Blvd.
Frederick, MD 21704
(555) 555-5555

Radon Test Report

November 09, 2023
Batch #: 110923-1

Customer:
New Customer
123 Main Street
Frederick MD 21704

Test Site:
123 Main Street
Frederick MD 21704

E-PERM® Electret Ion Chambers were used for radon screening measurements that were conducted at the above referenced test site by: ABC Radon Testing Company

The Results are as follows:

Serial	Type	Location	Test Start Date		Test End Date		Results (pCi/L)
SAA001	SST	Basement	09-Nov-2023	12:00 PM	11-Nov-2023	12:53 PM	5.5
SAA002	SST	Basement	09-Nov-2023	12:00 PM	11-Nov-2023	12:53 PM	5.8
Average Radon Concentration in:			**Basement**				**5.6 pCi/L**
SAA003	SST	Game Room	09-Nov-2023	12:07 PM	11-Nov-2023	01:03 PM	3.3
Average Radon Concentration in:			**Game Room**				**3.3 pCi/L**
SAA004	SST	Upper Bedroom	09-Nov-2023	12:15 PM	11-Nov-2023	01:09 PM	1.1
Average Radon Concentration in:			**Upper Bedroom**				**1.1 pCi/L**

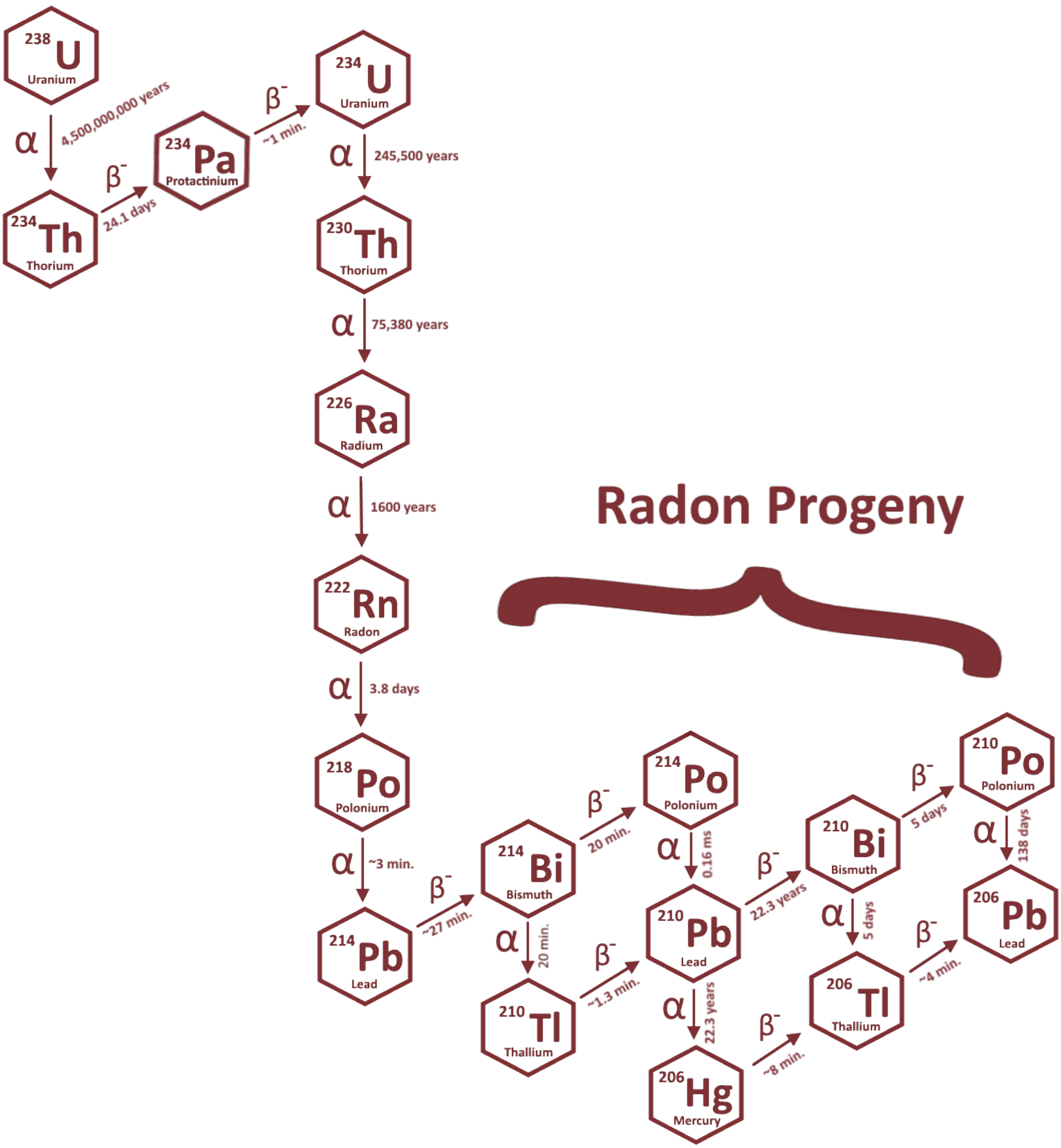
Deployed By: Radon Technician
Retrieved By: Radon Technician
Analyzed By: Radon Technician
Reader S/N: E0001 **Reader Calibration Due:** 02-Nov-24
Conditions: Requirements for Closed-Building Met
Tampering: None Observed
Weather: No Abnormal Weather Conditions
Vents: Not Applicable / Fan Not Applicable
Mitigation: No System Installed

Radon Health Risk Information

Radon is the second leading cause of lung cancer after smoking. The U.S. Environmental Protection Agency (EPA) and the Surgeon General strongly recommend that further action be taken when a home's radon test results are 4.0 pCi/L or greater. The national average indoor radon level is about 1.3 pCi/L. The higher the home's radon level, the greater the health risk to you and your family. Reducing your radon levels can be done easily, effectively and fairly inexpensively. Even homes with very high radon levels can be reduced below 4.0 pCi/L. Please refer to the EPA website at www.epa.gov/radon for further information to assist you in evaluating your test results or deciding if further action is needed.

Signature: Sample Signature Date: 07-Dec-2023

Radon Decay Chain



Estimated Background Gamma Table

State	µR/hr	nGy/hr		State	µR/hr	nGy/hr
Alabama	**6.5**	56.6		Montana	**8.6**	74.8
Alaska	**7.3**	63.5		Nebraska	**7.7**	67.0
Arizona	**8.0**	69.6		Nevada	**7.6**	66.1
Arkansas	**6.5**	56.6		New Hampshire	**7.4**	64.4
California	**6.6**	57.4		New Jersey	**7.1**	61.8
Colorado	**11.8**	102.7		New Mexico	**10.4**	90.5
Connecticut	**7.8**	67.9		New York	**7.3**	63.5
District of Columbia	**6.4**	55.7		North Carolina	**6.9**	60.0
Delaware	**6.1**	53.1		North Dakota	**7.8**	67.9
Florida	**5.3**	46.1		Ohio	**7.3**	63.5
Georgia	**7.0**	60.9		Oklahoma	**7.6**	66.1
Hawaii	**7.3**	63.5		Oregon	**7.4**	64.4
Idaho	**8.7**	75.7		Pennsylvania	**6.6**	57.4
Illinois	**7.1**	61.8		Rhode Island	**7.0**	60.9
Indiana	**7.4**	64.4		South Carolina	**6.7**	58.3
Iowa	**7.5**	65.3		South Dakota	**7.8**	67.9
Kansas	**7.7**	67.0		Tennessee	**6.9**	60.0
Kentucky	**7.3**	63.5		Texas	**6.1**	53.1
Louisiana	**5.4**	47.0		Utah	**9.3**	80.9
Maine	**7.5**	65.3		Vermont	**7.4**	64.4
Maryland	**6.2**	53.9		Virginia	**6.4**	55.7
Massachusetts	**7.3**	63.5		Washington	**7.4**	64.4
Michigan	**7.4**	64.4		West Virginia	**7.7**	67.0
Minnesota	**7.4**	64.4		Wisconsin	**7.5**	65.3
Mississippi	**5.4**	47.0		Wyoming	**10.4**	90.5
Missouri	**7.4**	64.4				
Province / Territory	**µR/hr**	**nGy/hr**		**Province / Territory**	**µR/hr**	**nGy/hr**
Alberta	8.6	**74.8**		Nunavut	7.6	**66.1**
British Columbia	8.0	**69.6**		Ontario	7.4	**64.4**
Manitoba	7.6	**66.1**		Prince Edward Island	7.5	**65.3**
New Brunswick	7.5	**65.3**		Quebec	7.5	**65.3**
Newfoundland & Labrador	7.5	**65.3**		Saskatchewan	8.2	**71.3**
Nova Scotia	7.5	**65.3**		Yukon	8.0	**69.6**
Northwest Territories	8.4	**73.1**				

Glossary

Term	Definition
Action Level	The environmental concentration threshold at which mitigation (or other appropriate remediatory action) is recommended. In the United States, the USEPA has set an action level of 4.0 pCi/L for radon gas and 0.016 WL for progeny. The USEPA recommends considering mitigation if the environmental concentration is between 2.0 and 4.0 pCi/L, and estimates that the average indoor radon concentration is approximately 1.3 pCi/L.
Blank	A blank is a quality assurance practice wherein an electret ion chamber is prepared for deployment normally, but left it in the closed position. Because it is left in the closed position, it will not lose voltage due to radon. Basically, this is a quality assurance practice to ensure that your analysis is capable of measuring the absence of radon. Blanks should comprise 5% (1 in 20) of your total detectors deployed.
Calibration Factor (CF)	A value that is derived from the specific E-PERM® configuration and the midpoint voltage of a specific exposure. After being calculated, the calibration factor represents a specific electret ion chamber's voltage loss per picocurie per liter (pCi/L) every 24 hours.
Chamber, H	A large ion chamber whose volume is 960 mL. It is almost exclusively employed for very short exposure periods, or in environments where low radon concentrations need to be measured accurately. It can also be modified into a flux monitor for outdoor radon flux measurements. Not affected by elevation.
Chamber, L	A small ion chamber whose volume is 58 mL. It is commonly used for longer exposure periods.
Chamber, L-OO	A small ion chamber whose volume is 53 mL. An on/off slide mechanism allows for this ion chamber to start and stop exposures easily. It is commonly used for longer exposure periods.
Chamber, S	A medium-sized ion chamber whose volume is 210 mL. A spring-loaded top allows for it to start and stop exposures easily. It is commonly used for shorter exposure periods lasting from a few days to several weeks.
Closed Building Conditions	The practice of ensuring that all doors, windows, and openings remain closed for a short-term radon test (defined as any test lasting fewer than 91 days). All short-term radon tests must maintain closed building conditions throughout the entirety of the radon test. For radon tests that are shorter than 96 hours, closed building conditions must be maintained 12 hours prior to beginning the test.

Desiccant	A canister whose job is to absorb the moisture in the air, thereby maintaining a very low humidity of a given environment. There is a desiccant in the SPER-1E voltage reader storage case. It should be checked every few months, and occasionally "recharged" by baking it at a low temperature for a few hours.
Duplicate	A duplicate is a quality assurance practice wherein an electret ion chamber is deployed simultaneously alongside another radon measurement device (i.e. in the same location with identical start and end dates/times). Duplicates measure precision, and should comprise 10% (1 in 10) of the total detectors deployed.
Dynamic Range	The total radon concentration that a specific electret ion chamber can measure throughout its lifetime (with a range spanning from 100 to 750 volts). As an electret's surface potential decreases, its dynamic range will also decrease. Dynamic range is typically expressed in pCi/L-Days (picocurie-per-liter days).
Electret	A Teflon® disk that has been electrically charged and processed so that it remains stable at a wide range of humidities and temperatures. When loaded onto an ion chamber, it will attract ions and lose voltage (which allows radon concentration to be measured). Rad Elec manufactures three distinct types of electrets, each with its own sensitivity.
Electret, LT	Long-Term Electret denoted with a red label and whose serials begin with the letter "L". These electrets are approximately 10x less sensitive than the short-term electrets, making them ideal for longer-term exposures and/or environments with large concentrations of ionizing radiation. Depending on the specific E-PERM® configuration, an LT Electret may be deployed from a few months to a year or longer. They can be paired with all of Rad Elec's ion chambers.
Electret, MT	Mid-Term Electret denoted with a burgundy label and whose serials begin with the letter "M". These electrets have a sensitivity roughly halfway between a long-term (LT) and short-term (ST) electret. It can currently *only* be paired with an L-OO chamber and used for radon tests lasting approximately three months up to around one year.
Electret, ST	Short-Term Electret denoted with a blue label and whose serials begin with the letter "S". These electrets are very sensitive, and can produce high-resolution characterization of an environment's ionizing radiation in a short exposure period, typically ranging from two to 90 days. They can be paired with all of Rad Elec's ion chambers.
Electret Ion Chamber (EIC)	A passive integrating ionization monitor consisting of a stable electret mounted inside an ion chamber that is constructed of electrically conducting plastic. As soon as you load an electret onto a chamber, it becomes an electret ion chamber. Synonymous with E-PERM®.

Electromagnetic Field (EMF)	A localized region of distinct electric and magnetic properties produced by the movement of electric charge. Occurs due to both natural (e.g. earth's magnetic field) and artificial (e.g. power grids) sources. The lower to middle frequencies (radio waves, WiFi signals, microwaves) are non-ionizing radiation, and do not affect electret ion chambers.
EIC	See **Electret Ion Chamber**.
E-PERM®	An acronym for Electret Passive Environmental Radon Monitor. See **Electret Ion Chamber**.
E-RPISU®	An acronym for Electret Radon Progeny Integrating Sampling Unit. It is an instrument manufactured by Rad Elec that is used to measure the radon concentration, radon progeny, and equilibrium ratio of a given environment.
Equilibrium Ratio (ER)	The ratio of progeny in an environment that can be inhaled. If the Equilibrium Ratio is 15%, this means that 15% of the environmental progeny is effectively "aerosolized" (attached to particulates in the air) and can be inhaled, whereas the remaining 85% has "plated out" in the environment by attaching to walls, furniture, filters, etc. ER is conveyed as a percentage; usually assumed to be between 40-50%.
Faraday Cage	An enclosure used to protect something against electromagnetic fields (EMFs). In the context of electret ion chambers, the ion chambers are constructed of electrically conductive plastic which protects the electret from external EMFs.
Final Voltage (FV)	An electret's surface charge as measured by a SPER-1E voltage reader *after* it is deployed for a specific radon test. Both the IV and FV values are needed in order to calculate the radon concentration.
Gamma (γ)	Background gamma (γ) is a highly penetrating form of electromagnetic, ionizing radiation that needs to be estimated or measured for electret ion chamber measurements.
H Chamber	See **Chamber, H**.
HLT	An E-PERM® configuration comprising a long-term (LT) electret loaded onto an H Chamber.
HST	An E-PERM® configuration comprising a short-term (ST) electret loaded onto an H Chamber.
Inherent Voltage Discharge (IVD)	The latent (or passive) voltage discharge rate for electrets, even when stored. This is a very small value, ranging from 0.022223 (LT) to 0.066667 (ST) volts per day. The IVD constants are factored into the EIC algorithms.
Initial Voltage (IV)	An electret's surface charge as measured by a SPER-1E voltage reader *before* it is deployed for a specific radon test. Both the IV and FV values are needed in order to calculate the radon concentration.

Ion Chamber	An ion chamber is constructed of electrically conductive plastic and serves as a well-defined volume for ionization to occur when it is paired with an electret. When an electret is loaded onto an ion chamber, it creates an **electret ion chamber**. As an ion chamber's volume increases, so does its sensitivity to radon. Rad Elec manufactures several different models of ion chambers.
Keeper Cap	A threaded lid that can be screwed onto electrets in order to store them for long periods of time. Every electret comes with its own keeper cap, although these caps are freely interchangeable between all electrets.
Lower Limit of Detection (LLD)	The mathematical limits of the detection methodology, below which the total uncertainty exceeds 50%. This is the lowest radon concentration that can be measured, and is usually around 0.2 pCi/L (~8 Bq/m^3) for the various E-PERM® configurations.
LLT	An E-PERM® configuration comprising a long-term (LT) electret loaded onto an L Chamber. Because it does not have an on/off mechanism, the electret must be loaded onto the L Chamber shortly before deployment.
LLT-OO	An E-PERM® configuration comprising a long-term (LT) electret loaded onto an L-OO Chamber. This is the least sensitive E-PERM® configuration, and is intended for extremely long radon tests (from 6 months to over a year).
LMT-OO	An E-PERM® configuration comprising a mid-term (MT) electret loaded onto an L-OO Chamber. This configuration is optimized for 91 day exposures.
LST	An E-PERM® configuration comprising a short-term (ST) electret loaded onto an L Chamber. Because it does not have an on/off mechanism, the electret must be loaded onto the L Chamber shortly before deployment.
LST-OO	An E-PERM® configuration comprising a short-term (ST) electret loaded onto an L-OO Chamber. This configuration is typically deployed for a few weeks up to a month.
LT	See **Electret, LT**.
L Chamber	See **Chamber, L**.
L-OO Chamber	See **Chamber, L-OO**.
Minimum Measurable Concentration (MMC)	The lowest radon concentration that can be measured within a certain uncertainty range (typically 10%, 25%, and 50%). At an uncertainty of 50%, this is synonymous with the **Lower Limit of Detection**.
Net Working Level	The net working level represents the radioactive decay product concentration after the background noise (such as from gamma and radon) has been subtracted out. This is the value that most accurately represents the progeny concentration in a given environment.

Plate Out	Radon progeny (which, unlike radon, are solids) can attach to physical objects in the environment. If the progeny attaches itself to walls, floors, furniture, or filters it is effectively "plated out" (and is no longer considered a health risk, as there is no chance of inhaling it into the lungs).
Progeny	The natural decay products of radon with a combined half-life of approximately 50 minutes; unlike radon, they are all solids. If they are inhaled, there is a significant chance they will become embedded in the lungs. The primary short-term health risks from radon progeny are Polonium-218 (with a half-life of approximately 3 minutes) and Polonium-214 (with a half-life of less than one second).
QA/QC	Quality Assurance and Quality Control. QA/QC is the practice of making sure that your radon testing business meets industry standards by conducting routine checks (such as deploying duplicates, field blanks, and spikes) and identifying any potential pitfalls. Quality Assurance tends to be more process-oriented (to prevent problems before they occur) whereas Quality Control tends to be more product-oriented (to identify and correct problems after they have happened).
Radon	An inert, noble, radioactive gas that is part of the uranium decay chain with a half-life of approximately 3.8 days; at terrestrial temperatures and pressures, it is notable for being the only gas in this otherwise solid decay chain. Radon is invisible and odorless, and cannot be detected without proper testing methods. It is the second leading cause for lung cancer after smoking.
Radon Concentration	The amount of radon present in an environment. In the United States it is usually measured in pCi/L (picoCuries per Liter), while the rest of the world measures it in Bq/m³ (Becquerels per cubic meter).
Reader	Nickname for the SPER-1E voltmeter, which is used to read electrets. See **SPER-1E**.
Reference Electrets	Low voltage electrets that are manufactured to be extremely stable. Two reference electrets are paired with a SPER-1E voltage reader. Because their voltages are certified, they can be used to ensure that the reader is functioning properly. They are exclusively for QA/QC purposes; they cannot be used to measure radon.
SLT	An E-PERM® configuration comprising a long-term (LT) electret loaded onto an S Chamber.
SPER-1E	The SPER-1E is the current generation of the Surface Potential Electret Reader. Commonly called a "reader", this instrument is a high-precision, non-contact voltmeter used to measure electret surface potential (voltage).

SST	An E-PERM® configuration comprising a short-term (ST) electret loaded onto an S Chamber.
ST	See **Electret, ST**.
S Chamber	See **Chamber, S**.
Surface Potential	The positive electric charge present on an electret's surface. This value typically ranges between 0 and 750, although Rad Elec recommends retiring electrets whose surface potentials have dropped below 100 volts. Also called **surface charge**.
Unattached Fraction	The amount of progeny (usually polonium-218) that has not attached to large particulates (such as dust) in the environment. It is highly diffusive, and has properties that make it distinct from the attached fraction.
Uncertainty	A range that represents the possible true values with a declared probability. With this in mind, the uncertainty range indicates the reliability of a specific measurement.
USEPA Guidance	The USEPA originally set a public threshold for radon progeny exposure at 0.02 WL (working levels), with a corresponding limit of 4.0 pCi/L for radon gas. This threshold assumed an equilibrium ratio of 50%. The USEPA later revised the guidance level to 0.016 WL (which assumes an equilibrium ratio of 40%) to more accurately reflect current models regarding the health effects attributable to radon gas.
Wire Mesh	The wire mesh filter (integrated into the progeny chamber filter head) is used when measuring the unattached fraction. When conducting a test of the unattached fraction, it is recommended to deploy a standard E-RPISU® (with the normal filter paper) alongside the wire mesh E-RPISU®.
Working Level (WL)	The unit used to show the concentration of radioactive decay products of radon in a given environment. This is distinct from the radon concentration!
Zeroing Electret	An electret with a stainless steel surface that does not have voltage. It should always read approximately zero volts. Alongside the reference electrets, the zeroing electret can be used to ensure that your SPER-1E voltage reader is operating properly.

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Please check out the Publications section on our website. There is a (figurative) ton of research papers and articles about electret ion chambers.

Afterword

If you've made it this far, thanks for reading our E-PERM® System User's Manual. This manual serves as our flagship document, and it's very important for us at Rad Elec to craft a guide that is well-organized and helpful. All of us are dedicated to listening to our customers' suggestions, so please contact us if you have any feedback to improve this manual and/or our equipment.

We hope that you find electret ion chambers to be an accurate, versatile, and highly scalable methodology for radon testing. If you'd like to learn more about the various applications and research behind electret ion chambers, we encourage you to visit the Publications section of our website.

Please contact us if you have any questions, concerns, or brilliant ideas!