E-PERM® SYSTEM
USER'S MANUAL

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(VERSION 3.3.1)

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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, low-cost E-PERMs® have gained acceptance with over 1,500 home inspectors throughout the USA and used in over 30 countries worldwide.

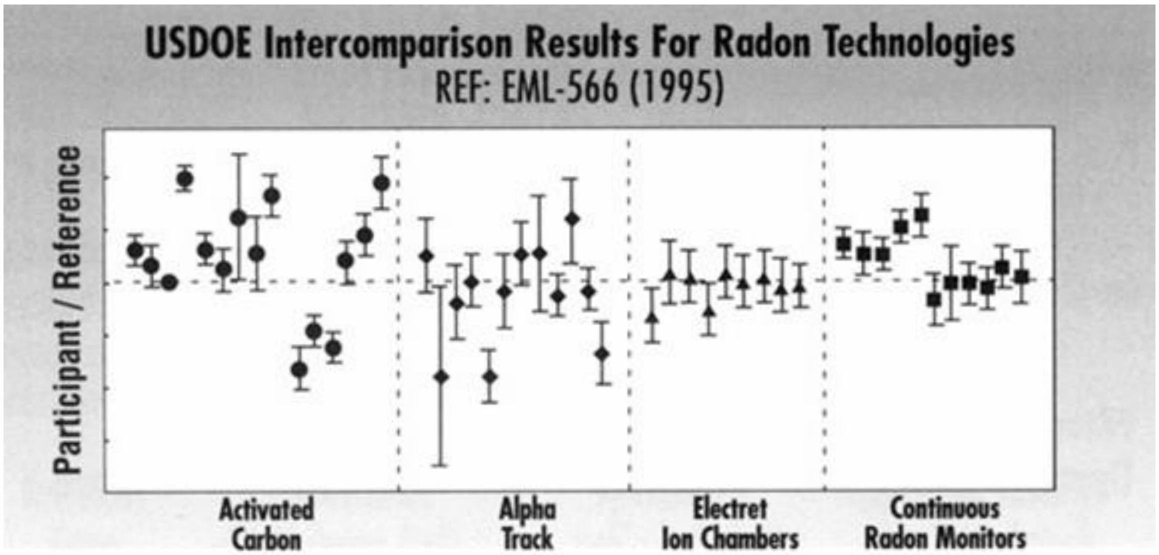
An E-PERM®, also known as an Electret Ion Chamber (EIC), is a passive integrating ionization monitor consisting of a very stable electret mounted inside a small chamber made of electrically conducting plastic. The electret, a charged Teflon® disk, serves as both the source for ion collection and as the 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. The reduction in charge 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 user friendly SPER-1 Electret Voltage Reader. The results are calculated and a Radon Test Report is generated using the WinSper or Radon Report Manager Software.

The basic components of the E-PERM® System consist of the electret voltage reader, chambers, electrets and calculation/analysis tools. There are chambers of different sizes and electrets of different sensitivities to meet a wide range of monitoring situations. Typically, more sensitive electrets, referred to as ST Electrets, are used for short-term measurements, and LT Electrets (long-term electrets) which are less sensitive are used for measurements of a longer duration.

Visit our web site at www.radelec.com to view a streaming video that demonstrates how easy the equipment is to use and how quickly the calculations and reports can be generated. Simply click on the Home Inspector in the top right hand corner of the Home page to watch the video. You can also find technical documents under the Publications/Resources link explaining the theory behind electret ion chambers and provide a number of inter-comparisons of our electret technology with other methods of measuring radon gas.

Performance of E-PERMS®

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



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

Relative Performance of Different Detectors in the USEPA RMP program during 1991-1997 (EPA 402-F-93-003-1)

Detector Type	Activated Carbon	Alpha Track	E-PERM® Short Term	E-PERM® Long Term	Continuous Radon Monitor	Liquid Scintillation-Activated Charcoal
Number of detectors tested	1164	113	2206	1083	670	216
Device Pass Rate (%)	81.1	64.2	92.3	89.0	85.9	80.0
Program %	21	2.6	35	17.8	11.4	3.9

CONCLUSIONS: The E-PERM® constitutes more than 50 % of the detectors that went to RPP for testing and had the highest pass rate. There have been several inter-comparison tests published in national as well as international journals, where these detectors stand out among the passive detectors.

Quality Audit Report by USEPA

On December 9, 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 onsite visit at Rad Elec. Below are **relevant extracts** from their five page report issued May 20, 1998:

> USEPA
> Office of Radiation and Indoor Air
> NARAL
> 540 South Morris Avenue
> Montgomery, AL 36115-2601
>
> National Radon Proficiency Program
> Analytical Measurement Services
>
> May 20. 1998
>
> **Extracts**:
>
> 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.**

(Full five-page report may be requested.)

Basic Components of the E-PERM® System

The E-PERM® system consists of four components: (1) an electrostatically charged Teflon® disk which collects ions, called an electret; (2) an ion chamber made of conductive plastic into which an electret can be loaded, (3) a reader to read the surface potential (voltage) of the electret, and (4) software to calculate radon concentrations. These components are needed to make an indoor radon measurement. E-PERM®s (which include an electret and chamber) are sometimes referred to (as well as the software used to calculate the radon concentration and generate a report) by their generic name, Electret Ion Chambers, which the EPA has designated the acronym "EIC" or "EC" method in reference to Rad Elec's E-PERM® system.

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, which can be downloaded from our website.

An Electret Passive Environmental ^{222}Rn Monitor Based on Ionization Measurement
P. Kotrappa, J. C. Dempsey, J. R. Hickey, L. R. Stieff
Health Physics. 54(1):47-56, January 1988

A Practical E-PERM® (Electret Passive Environmental Radon Monitor) System for Indoor ^{222}Rn Measurement
P. Kotrappa, J. C. Dempsey, R. W. Ramsey, L. R. Stieff
Health Physics. 58(4):461-467, April 1990.

I. The Electrets

The electret used in the E-PERM® System is a disk of Teflon® which has been electrically charged and processed by special procedures so that the charge on the electret remains stable even at high humidity or low/high temperatures. The electret disk is secured in a holder that can be screwed into an E-PERM® chamber. The electret produces an electrostatic field within the chamber capable of attracting ions of the opposite sign generated by the decay of radon and its daughter products within the chamber. The surface charge is neutralized by the collection of ions and the surface voltage of the electret decreases in proportion to the radon concentration and the exposure time.

Rad Elec manufactures different types of electrets with different characteristics, which are identified by different colored labels. Short-term (ST) electrets have a high sensitivity, are used principally for short-term measurements, and are identified by blue labels. Long-term electrets are less sensitive, used principally for long-term measurements, and are identified by red labels. A bar code number affixed to the back of the electret holder identifies each electret by a unique serial number.

New electrets come with 700 – 780 volts which allows for 500 usable volts. Electrets showing a reading of less than 100 V should not be used for measurements because the weaker electrostatic field is not as consistent in collecting the ions efficiently. They can be exchanged for new electrets through Rad Elec's replacement program at a lower price than the original purchase price of the electret.

The electret surface should never be touched. Touching or allowing something to touch the electret surface will cause instability issues and voltage loss.

An electret comes in a holder with a screw cap, which is also known as the electret "keeper" cap. The keeper cap can be removed by unscrewing it from the electret before use. It is important to store the cap in a clean zip lock bag or the Tyvek bag that the electrets were originally received in. If there is dust or any other particles in the cap, the electret surface will attract the dust or particles to its surface. This will render the electret surface "unclean", which may then cause the electret to discharge more than what is expected.

It is important to keep the surface of the electret clean. The electret surface and the keeper caps should be routinely blown off using industrial grade nitrogen. The use of a regulator and blow gun attached to a nitrogen tank is recommended to blow off the electret. This process does not change the surface charge.

Electrets should be read in a controlled environment such as in an office or laboratory. The initial and final readings should be read at the same temperature (within ± 5 degrees). If the electrets are cold or warm when received from the field, allow them to return to room temperature before taking the reading.

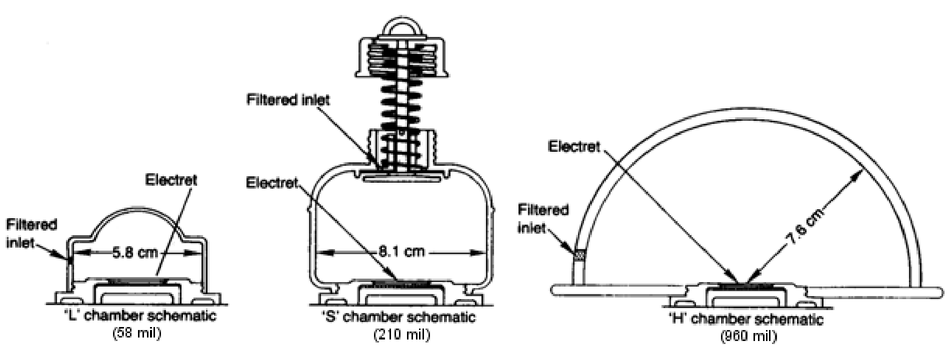
Keep the electret clean, do not touch the electret surface, and read the initial and final readings at similar temperatures.

II. The Chambers

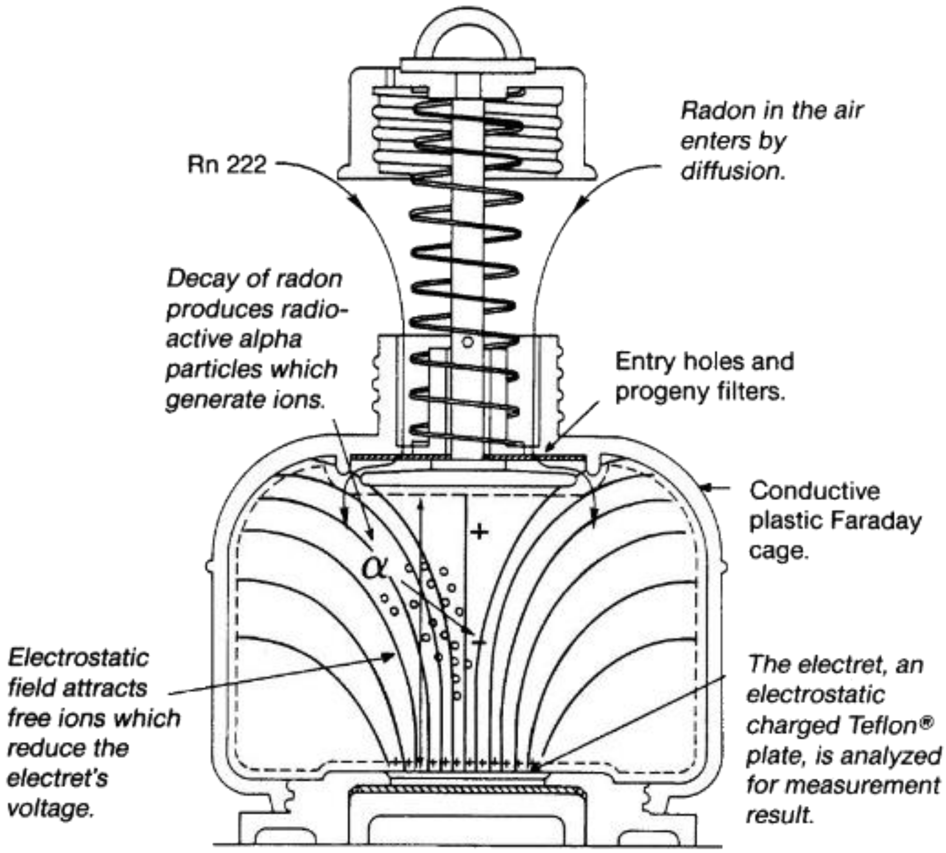
When an electret is fitted with the chamber, it is called an electret ion chamber and referred to as an E-PERM®. The electret serves both as a source of electric field helping ion collection and it also serves as a sensor. As ions are collected, the surface voltage of the electret decreases in proportion to the radon concentration and the exposure time. The decrease in voltage is measured by using an electret voltage reader, known as a SPER-1 Reader.

Radon is an inert radioactive gas. As radon diffuses into the 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 occurs in the fixed volume of an electrically conducting chamber, the negative ions are drawn towards the surface of the positively charged electret. The electret carries a positive charge and hence collects negative ions from the air, while the positive ions go to the wall of an electrically conducting chamber and are neutralized. Rad Elec manufactures different types of chambers. The base of the E-PERM® chamber is threaded on the bottom to screw in the electret. Two types of ion chambers (the "S" and “L-OO” chambers) include an on/off mechanism for covering and uncovering the electret.

Rad Elec manufactures chambers that have different volumes to be used for a range of measurement options. The S Chamber (210 mL) is used primarily for 2-7 day measurements and features an “ON/OFF” mechanism. The L Chamber (61 mL) is used primarily for long term measurements. A version of the L Chamber, referred to as an L-OO, also has a mechanism that allows the chamber to be “opened” and “closed”. An H Chamber (960 mL) is used primarily for measurements of a shorter duration, and can be modified for “flux” measurements.



PRINCIPLE OPERATION OF THE ELECTRET ION CHAMBER



This diagram illustrates the principle operation of an E-PERM® radon detector**.**

Only radon gas (not the radon progeny present in the air) diffuses through the filtered inlet into the chamber volume until the concentration of radon inside the chamber is the same as that inside the room. Radiation emitted by the decay of radon and the progeny formed inside the chamber ionizes in the air. The positively charged electret attracts the negative ions (anions) generated by the radiation in the chamber resulting in a net decrease of the electret voltage. Positive ions (cations) go to the wall of the chamber and dissipate. The voltage decrease of the electret is proportional to the radon concentration and the time of the exposure. The drop in voltage of the electret is a measure of the product of the radon concentration and the exposure time. The radon concentration is reported as either pCi/L or Bq/m^3.

S CHAMBER

The standard or S chamber is a 210 mL volume chamber with an "ON/OFF" mechanism. When a short-term (ST) electret is loaded into the S chamber, the E-PERM® configuration is called a "SST" E-PERM®. When a long-term (LT) electret is loaded into the S-chamber, the E-PERM® configuration is called an "SLT" E-PERM®.

The "SST" E-PERM® configuration is used for making short term measurements, typically 2-7 days. The "SLT" E-PERM® configuration is used for making longer measurements, approximately 30-120 days.

Refer to the section "How to Calculate Radon Concentrations" in this manual for calculating radon with the SST and SLT configurations.

S Chamber (210 ml)

The left picture shows the S chamber in the "**OFF**" or closed position. When the top is screwed all the way down, the chamber can serve as a keeper for the electret - either for extended storage or shipment. Failure to fully secure the cap will permit ions to reach the surface of the electret resulting in excessive voltage losses during storage or shipment. The right picture shows the S chamber in the "**ON**" or open position. When the top cap is unscrewed, a spring under the cap lifts and holds the cover away from the electret leaving the electret open to the chamber volume. The electrostatic field, which emanates from the electret, can then fill the chamber and attract the negative ions generated by radon and the radon decay products.

The interior of the chamber should be inspected before every use to make sure the filter is not loose and it is free of dust and fibers before it is loaded with an electret. Gently tap the chamber on a table to check for loose filters. The chamber should be blown out with nitrogen to remove dirt/dust particles. When they are not in use, store the chambers in the zip lock bags they were shipped in to avoid dust accumulation. If the filter comes loose, send the chamber back to Rad Elec for repair.

NEHA/NRPP Device Codes:	8212-25	Rad Elec E-perm SST (S Chamber w/ ST electret)
	8211-25	Rad Elec E-perm SLT (S Chamber w/ LT electret)
NRSB Device Codes:	51203 ES	Rad Elec E-perm SST (S Chamber w/ ST electret)
	51202 EL	Rad Elec E-perm SLT (S Chamber w/ LT electret)

L CHAMBER

The low volume or L Chamber is a 61 mL small volume chamber. This lower cost chamber does not have an "on/off" mechanism. When loaded with a long-term electret, the E-PERM® configuration is called an "LLT" E-PERM®.

The LLT E-PERM® is used for making long-duration measurements, typically for 91-365 days. Because of the absence of the "ON/OFF" mechanism, the LLT E-PERM® must be deployed as soon as possible after measuring 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 chamber and put in its “keeper cap”. The total non-exposure delay time (i.e., the sum of delay time before the exposure and the delay time between the end of the exposure to the time of measurement) should be less than 5% of the exposure period. This will assure that the background radiation picked up during the delay periods (e.g., during transit if shipped) is negligible compared to the much longer exposure period.

Refer to the section “How to Calculate Radon Concentrations” in this manual for calculating radon with the LLT configuration. Remember when using L chambers, an appropriate elevation correction factor needs to be applied when testing at elevations more than 200 feet above sea level.

The interior of the chamber should be inspected before every use. It should be free of dust or fibers before it is loaded with an electret. The chambers are supplied in zip lock plastic bags. When they are not in use, it is recommended that they be stored in these bags to avoid dust accumulation. If dust is found inside a chamber, it can be blown out.

NEHA/NRPP Device Code: 8210-25 Rad Elec E-perm® LLT (L-Chamber w/ LT electret)

NRSB Device Code: 51201 EL Rad Elec E-perm® LLT (L-Chamber w/ LT electret)

L-OO CHAMBER

The low volume chamber with an "ON/OFF" mechanism is a 58 mL small volume chamber, known as the L-OO Chamber. When loaded with a long-term electret, the E-PERM® configuration is called a "LLT-OO" E-PERM®. When it is loaded with a short-term electret, it becomes an "LST-OO" E-PERM®.

The L-OO E-PERM® has benefits of both the L and S Chambers. This L-OO Chamber is used for making <u>long-duration measurements</u>, typically for 91-365 days, just as the L Chamber when configured with an LT electret. When the L-OO Chamber is configured with an ST electret, it is typically used for making radon measurements for approximately 30-91 days. Having a slide mechanism gives the L-OO Chamber the same capability to be turned on and off, just like the S chamber.

To use the on/off mechanism place the electret into the bottom of the L-OO Chamber. Pull the slide mechanism in the OFF position (Fig 2.) with the hole to the side of the chamber. Place a clip into the side hole to keep the chamber in the OFF position until ready to start the test. To start the test, remove the clip, pull the slide so that the hole is now between the chamber and the electret. The hole will not be seen (Fig. 1). Use a 4" wire-tie to secure the slide in the "ON" position. To stop the test, cut off the wire-tie and pull the slide back to the OFF position and secure with the clip.

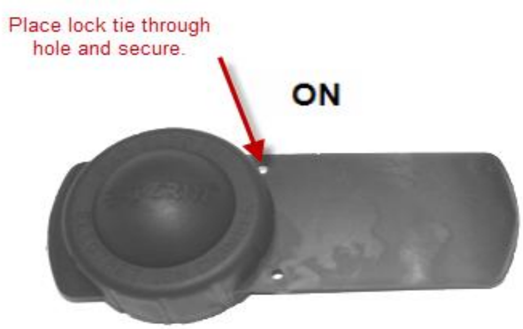


Fig. 1

Fig. 2

Refer to the section "How to Calculate Radon Concentrations" in this manual for calculating radon with the LLT-OO and LST-OO.

The interior of the chamber should be inspected before every use. It should be free of dust or fibers before it is loaded with an electret. The chambers are supplied in zip lock plastic bags. When they are not in use, it is recommended that they be stored in these bags to avoid dust accumulation. If dust is found inside a chamber, it can be blown out.

NEHA/NRPP Device Code: 8230-25 Rad Elec E-perm® LST-OO (L-OO Chamber w/ ST electret)
NEHA/NRPP Device Code: 8234-25 Rad Elec E-perm® LLT-OO (L-OO Chamber w/ LT electret)

H CHAMBER

The high-volume or H Chamber is a 960 mL volume chamber. When this chamber is loaded with a short-term electret, the configuration is called an "HST" E-PERM®. This configuration is designed to make accurate measurements of low levels of radon in exposure periods as short as one day. It is ideally suited for making quick measurements. It is a very accurate measurement of the extremely low concentrations often found in houses after mitigation. Standard versions of these chambers do not have the "ON/OFF" mechanism. The electret should be loaded into the chamber just before placing the E-PERM® for measurement. At the end of the exposure, the electret should be removed immediately from the chamber and loaded into the keeper cap or read with a SPER-1 Reader. If the electret is put into its keeper cap, it can be measured later in the laboratory. The electret should not be left in the chamber when not in use.

Refer to the section "How to Calculate Radon Concentrations" in this manual for calculating radon with the HST configuration. Note: <u>No corrections are necessary due to elevation for H Chamber calculations.</u>

The interior of the chamber should be inspected before every use. It should be free of dust or fibers before it is loaded with an electret. The chambers are supplied in zip lock plastic bags. When they are not in use, it is recommended that they be stored in these bags to avoid dust accumulation. If dust is found inside a chamber, it can be blown out using nitrogen.

NEHA/NRPP Device Code: 8227- 25 Rad Elec E-perm HST (H Chamber w/ ST electret)

III. The Electret Reader

The SPER (**S**urface **P**otential **E**lectret **R**eader) readers are a family of readers used for measuring the voltage of an electret. Included in the SPER Reader family are the SPER-1, SPER-1A, SPER-1E, and the SPER-2. The SPER-1E is Rad Elec's latest model and contains new hardware and software enhancements to provide higher sensitivity and more reliable operation. (For pictures of the different models of the SPER Readers, please refer to page 33 in this manual.) The change in the surface voltage of an electret during a known exposure period is a measure of the time-integrated concentration of radon in the E-PERM® chamber during that period.

The SPER readers are high-precision, non-contact voltmeters. They should be handled with care. Each reader comes with a cushioned carrying case. When not in use, the reader should be stored in its case. The carrying case holds a desiccant canister located in the bottom of the case to keep the reader dry. It should be periodically inspected and re-dried when necessary. The desiccant can be seen through a window in the top of the canister. The desiccant crystals are dark blue when dry, and pink or white when wet. If pink, the desiccant canister should be removed from the reader case and baked for about one-half hour (or until it turns dark blue) in an oven at 350^{o} F. Allow the desiccant to cool to room temperature before placing back in the reader case. Proper care of the desiccant ensures that the instrument is stored in a relatively dry environment as required for its proper operation.

Calibration of the readers is recommended annually along with the re-certification of the reference electrets (see Reference Electrets in the next section of this manual). Rad Elec will do routine maintenance on the Reader, change the battery, calibrate the Reader, issue a Reader Calibration Certificate and certify the Reference Electret Set. There is a charge for this service. Please use the Reader Calibration form on Rad Elec's website (www.radelec.com) when sending a Reader in for calibration. Readers seldom need to be calibrated more than once a year. However, the voltage response should be checked on a weekly basis for stability using the Reference Electrets.

To read the surface voltage of an electret using a "SPER1 series" reader follow the below instructions. **Note: SPER-1 and SPER-A readers have the shutter handle on the side where the SPER1-E has a top pull handle. SPER-1E is pictured below.**

1. Place the electret face down into the circular receptacle on top of the reader.

2. Rotate the electret so that the serial number is upright from your point of view and the bar code is exactly parallel to the name "Rad Elec Inc" on the reader.

3. Make certain that the electret rests on the lower edge of the receptacle. The best way to do this is to slide the electret toward to the bottom of the reader as far as it will go.

4. If the reader is not currently on, turn it on by pulling the shutter handle with a slow but steady motion down to the lower limit and return it slowly back to the closed position. This turns on the reader. If using a SPER1-E model, the display will show some diagnostic information during power-up including the battery condition and temperature in Fahrenheit. When the message "READY" is displayed, the unit is ready for use. On older models, numbers will appear. If an error message is displayed, it is necessary that corrective action be taken. (See the FAQ section in the back of this manual or the SPER1-E Users Manual for diagnosing problems.)

5. Pull the shutter handle again and hold it down until the voltage reading is displayed. The voltage will be displayed in the middle of the display. On the newer model reader, the battery condition will be pictured to the left and the number in the upper right corner indicates the time it takes to pull the shutter open (in milliseconds). If it is pulled too quickly or too slowly, an appropriate message will be displayed and it is necessary to repeat this step.

6. After leaving the shutter closed for several seconds, repeat step 5 and read the voltage again. If this new value is different, repeat step 5 until a minimum of two successive readings are the same. This repeated value is the correct electret voltage reading.

7. Remove the electret from the reader and protect it either by storing it in its “keeper cap” or by installing it in an appropriate chamber that has an On/Off mechanism.

8. If additional electrets are to be read at this time, repeat steps 1, 2, 3, 5, and 6 to obtain the desired readings. This may be repeated as often as necessary.

9. The reader will automatically turn off within a few minutes of inactivity.

10. Return the reader to its carrying case and close the cover to allow the desiccant to maintain the low humidity environment recommended by the manufacturer.

Reference Electrets

The Reference Electrets are for the quality assurance of the Reader. Rad Elec recommends the use of two highly stabilized "reference" electrets and a blank or "zeroing" electret to assure reader accuracy. The "zeroing" electret's surface is a stainless steel disc that carries no charge. The zero electret is for checking that the reader zeroes, and should be within ± 3 volts of 0. A "reference" electret is a very stable, low charged electret for checking the reader's accuracy. They are not to be used for radon testing. The reference electrets should read within ± 3 volts of the certified readings issued on a certificate at the time of calibration.

The reference electrets are re-certified each time the reader is calibrated. Therefore, always send the reference electrets back with the reader to the manufacturer at the time of calibration for re-certification.

A weekly record of all three Standards should be maintained and used as part of your Quality Assurance/Quality Control Plan. Record the voltage readings of the reference and zeroing electrets as you would a regular electret. Always keep the reference electrets in their protective "keeper cap" when not being read. If the weekly readings remain constant within acceptable limits, you can be confident that your reader is functioning correctly.

When checking the reference electrets, if one electret deviates **significantly** from the certified reading and the other reference electret does not deviate significantly, then you can assume the reader is still functioning properly. Most likely, the one reference electret has discharged due to either being touched or dust and fibers have gotten on the surface. Blow the electret off with nitrogen and watch carefully until the electret becomes stable again. If the either reference electret drops below 210 volts, it should be exchanged for a new reference electret.

If both electrets deviate more than ± 3 volts of the certified reading, the reader may need to be calibrated or repaired. Contact the manufacturer for advice.

The reference electrets should not be used for a calibration check. These electrets provide only **one point of reference** for the reader and should not be construed as a method of calibration. During the calibration of a reader, the reader is calibrated over the entire voltage range.

How to Perform a Short Term Radon Measurement Using SST and SLT E-PERM® Configurations

DO NOT TOUCH THE SURFACE OF THE ELECTRET AT ANY TIME!!!

- **It is recommended that the user purchases and views the DVD entitled "Becoming Proficient with E-PERM® Measurement Devices"**
- Practice by performing a radon test in your home and generating a Radon Test Report**.**

You will need (2) ST or LT Electrets, (2) S Chambers, (1) Tamper Resistant Twin Box, (1) - 4" Lock Tie, (1) – 15" Lock Tie, SPER-1 Reader, (1) Sheet of Tamper Indicating Tape, and the WinSper® or Radon Report Manager software installed on the hard drive of your computer.

Example Using a SPER-1E Reader

1. Remove the "Keeper Cap" from the electret and place it face down on to the circular receptacle on top of the SPER-1 reader.
2. Rotate the electret so that the serial number is upright from your point of view and the bar code is exactly parallel to the name "Rad Elec Inc" on the reader.
3. Make certain that the electret rests on the lower edge of the receptacle. The best way to do this is to slide the electret toward to the bottom of the reader as far as it will go. Do not press down on the electret or touch the edge of the electret while taking the reading.
4. If the reader is not currently on, turn it on by pulling the shutter handle with a slow but steady motion down to the lower limit and return it slowly back to the closed position. This turns on the reader. The display will show some diagnostic information during power-up. When the message "READY" is displayed, the unit is ready for use.
5. Pull the shutter handle again and hold it until the voltage reading is displayed. Gently release the handle.

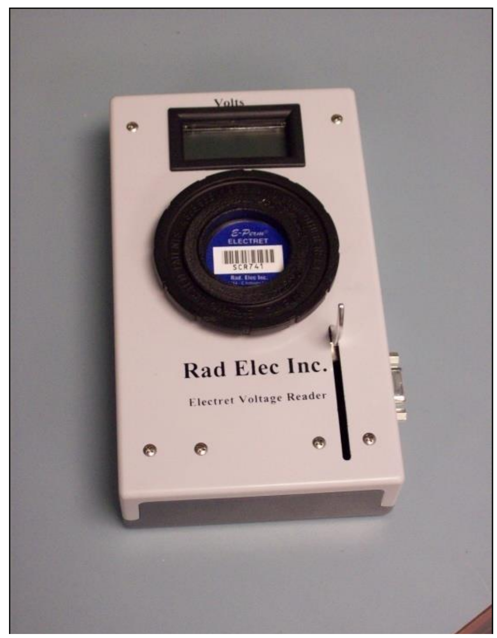


Figure 1: Placing the electret

6. After leaving the shutter closed for several seconds, repeat step 5 and read the voltage again. If this new value is different, repeat step 5 until a minimum of two successive readings are the same. This repeated value is the correct electret voltage reading and should be recorded in the WinSper Software Program as the Initial Voltage Reading.

7. Remove the electret from the reader and screw it into the bottom of the S Chamber. Once the electret has been loaded into the S Chamber, it is referred to as an E-PERM®.

8. Repeat steps 1 – 7 to read the second (duplicate) electret.

9. Place both of the E-PERM®s into the Tamper Resistant Twin Box.

10. Take the Twin Box with the two E-PERM®s to the lowest livable level of your home. Make sure the chambers are pushed all the way to the bottom of the Twin Box. Unscrew the spring loaded tops of both E-PERM®s and close the lid of the Twin Box. Record the Start Date and Time of the test.

11. Secure the lid of the Twin Box using a 4” lock tie that is threaded through the two small holes on the front of the box. (It will now be necessary to “snip” the lock tie in order to open the lid of the Twin Box.)

12. Take the 15” Lock Tie, thread it through the “strap” on the top of the Twin Box, and secure the box to an immovable object. Tamper indicating tape may also be used.

13. At the conclusion of the test remove the Twin Box from the immovable object by cutting the 15” Lock Tie (not the “strap” handle!!!). Then snip the 4” Lock Tie to open the lid of the Twin Box. Immediately close the top of the S Chamber to the “OFF” position. This will stop the test. Record the End Date and Time of the test.

14. When ready to read the final voltage of the electrets, remove the E-PERM®s from the Twin Box and carefully unscrew the electrets from the S Chambers. Do not touch the electret surface at anytime. Always hold the electret around its edge only. Repeat steps 1 -7 to obtain the Final Voltage Readings.

15. Enter the information (start date and time, end date and time, initial voltage, final voltage, etc) into the WinSper or Radon Report Manager program, calculate the results, and print the Radon Test Report. Please refer to the WinSper or Radon

Report Manager User's Manual for instructions on how to enter data and generate reports.

IV. Analysis Tools

Rad Elec Inc. can provide the user with several different tools for calculating the actual radon concentration and reduce the probability of making mistakes. The WinSper and Radon Report Manager Software provides one way to quickly and easily calculate the radon concentration and generate a Radon Test Report when deploying one or two (duplicates) E-PERM®s per test location. The user can also purchase a pre-programmed hand-held Casio to calculate the results out in the field. Rad Elec also provides an Excel Template for the various chamber/electret configurations that may be used for large scale measurement programs and for specialized uses, such as radon in water calculations. A "Quick Calculator" is also available on our website (www.radelec.com) and is often used as a backup if any of the other "tools" are not functioning or are inaccessible. The next section will provide instructions on how to manually calculate the radon concentration.

No matter which method is used the following data must be gathered and recorded to calculate the radon concentration in addition to the E-PERM® configuration being used:

Initial voltage: the voltage reading of the electret immediately prior to deploying the test
Start Date of the Test: the date the test began
Start Time of the Test: the exact time the test started
End Date of the Test: the date the test was stopped
End Time of the Test: the exact time the test was stopped
Final voltage: the voltage reading of the electret immediately after the test is stopped
Elevation: the elevation of the test location (not needed when using H chambers)
Background gamma: the gamma background of the test location – see chart in back of manual for average state background gamma or Canadian province. Also, dosimeters may be used to calculate the background gamma

Calculating Radon Concentrations

If not using the pre-packaged software program or Excel spreadsheets, you can calculate the radon concentration manually. Several steps and different equations are required to convert the two-electret voltage readings (initial and final voltages) and the exposure period into a radon concentration value. *****Note:** Pay special attention to the chamber and electret combination, calibration factor, exposure period, elevation, and background gamma level when doing your calculations. Always double check your work using analysis tools provided by Rad Elec to ensure accurate results are reported.

Step 1: Look up the Constants (A, B, and G) for a specific E-PERM® configuration

The table below consists of Calibration Constants (A and B) and the gamma conversion Constant (G). The A and B calibration constants depend upon the particular E-PERM® configuration. The gamma conversion depends upon the type of chamber. Find the Constants A, B and G based upon the E-PERM® configuration you are using.

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
HST**	7.2954	0.004293	0.07
HLT**	0.60795	0.000358	0.07
LST-OO	0.074671	0.037557	0.12
LLT-OO	0.011965	0.002079	0.12
LMT-OO	0.013497	0.012499	0.12

* configuration not approved as "listed device"

** configuration uses linear calibration factor, not logarithmic.

Step 2: Look up the Background Gamma level (BG) and Elevation where the test was conducted

Example: Frederick, MD

- The approximate elevation for Frederick, MD is 300 feet (found on Google).
- The background gamma level (taking into account building shielding) for Maryland is 6.2 µR/Hr (table found on the last page of this manual and on www.radelec.com).

BG is the environmental gamma background radiation given in units of radon concentration equivalent (pCi/L). The environmental gamma background radiation can be measured or estimated from the listing of average gamma radiation levels in each state as published by the EPA. BG values for each state in the USA and each Canadian province are listed on the last page of this manual. Those in Canada may use the BG corrections, which are shown in nGy/Hr, and convert them to μR/hr by dividing the nGy/Hr value by 8.7.

Step 3: Calculate the Number of Days (D) of the testing period

Calculate the exposure period in units of days. For example: If exposure period is 2 days and 3.5 hours, then

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

Step 4: Calculate the Calibration Factor (CF)

The calibration factor (CF) is defined as the decrease in electret voltage when a specific electret and chamber are exposed for one day at a concentration of 1 pCi/L of radon. The CF for E-PERM®s is logarithmically related to the electret voltage over a range of approximately 100 V to 750 V, and a self-correcting formula is used to develop the actual calibration factor appropriate to the average voltage during the exposure. Please note that the HST and HLT configurations still use the old linear calibration factor, also listed below.

$$CF = A + \left(B \times \ln\left(\frac{IV+FV}{2} \right) \right)$$ (for SST, SLT, LST, LLT, LST-OO, LLT-OO, LMT-OO)

$$CF = A + \left(B \times \left(\frac{IV+FV}{2} \right) \right)$$ (only for HST & HLT)

- **CF** the calibration factor
- **A** the Constant A for a particular E-PERM® configuration (see prior table)
- **B** the Constant B for a particular E-PERM® configuration (see prior table)
- **I** the initial electret voltage
- **F** the final electret voltage
- **ln** the natural logarithm (in this context, of the midpoint voltage)

Step 5: Calculate the Elevation Correction Factor (Elev CF)

The Elevation Correction Factor (**Elev CF**) depends upon the type of chamber being used. Follow the formula for the particular chamber type being used (S, L or L-OO, or

H). **For H Chambers, there is no elevation correction factor, because elevation does not affect the H Chamber.**

S Chamber Elevation Correction Factor (Elev CF) in feet**:**

IF Elevation ≤ 4000, then Elev CF = 1.0

IF Elevation >4000, then use the following formula:

$$ElevCF = 0.79 + \left(\frac{6 \times Elevation(ft.)}{100{,}000}\right)$$

L Chamber (and L-OO Chamber) Elevation Correction Factor (Elev CF):

IF Elevation ≤ 200, then **Elev CF = 1.0**

IF Elevation >200, then use the following formula:

$$ElevCF = 1.005 + \left(\frac{4.5526 \times Elevation(ft.)}{100{,}000}\right)$$

- **Elev CF** the elevation correction factor for S, L, and L-OO chambers
- **Elevation** the elevation (in feet) where the radon test was conducted

Step 6: Calculate the Radon Concentration (RnC)

$$\text{RnC} = \left(\left(\frac{(\text{I} - \text{F}) - (\text{IVD} \times \text{D})}{\text{CF} \times \text{D}}\right) - (\text{BG} \times \text{G})\right) \text{x (Elev CF)}$$

Note for H chamber configurations: the formula is slightly different because there is no Elevation Correction Factor (Elev CF). Therefore, **do not** multiply the radon concentration by the Elev CF at the end of the formula.

- **RnC** the radon concentration in units of pCi/L
- **I** the initial electret voltage
- **F** the final electret voltage
- **D** the exposure period in units of days
- **CF** the calibration factor
- **BG** the background gamma (listed by state in the back of this manual)

- **G** the gamma conversion constant (see prior table for G)
- **Elev CF** the correction factor dependent upon the elevation where the test was conducted and the type of chamber used
- **IVD** Inherent Voltage Discharge of electret. This value is 0.066667 for short-term electrets and 0.022223 for long-term electrets, and represents the inherent voltage discharge per day of the electret.

Example Calculation: SST E-PERM® (S Chamber with ST Electret)

The initial voltage reading is 751 volts, and the final voltage reading is 719 volts. The SST is exposed in a home in Frederick, MD (USA) for a period of 3 days and 8 hours. What is the average radon concentration?

Step 1: Look up the A, B, and G Constants for this particular E-PERM® configuration (obtained from table listed in prior section of this manual)

E-PERM® configuration	Constant A	Constant B	Constant G
SST	0.314473	0.260619	0.087

Step 2: Look up the State background gamma level (BG) and elevation where the test was conducted

Example: Frederick, MD

- The approximate elevation for Frederick, MD is 300 feet (found on Google).
- The State background gamma level for Maryland is 6.2 µR/hr (found on the last page of this manual, and on our website at www.radelec.com).

Step 3: Calculate the number of days (D) the test was conducted

Exposure period was 3 days and 8 hours, therefore

$$D = 3 + \frac{8}{24} = 3.\overline{333}$$

Step 4: Calculate the Calibration Factor (CF)

So, we know that:
A = 0.314473 (A constant from table)
B = 0.260619 (B constant from table)
I = 751 (initial volts)
F = 719 (final volts)

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

$$\text{CF} = 0.314473 + \left(0.260619 \times \ln\left(\frac{751 + 719}{2} \right) \right) = 2.0345$$

Step 5: Calculate the Elevation Correction Factor (Elev CF)

Since an S Chamber's Elevation Correction Factor (Elev CF) is based on if the elevation is ≤ 4000 feet or > 4000 feet, for an elevation in Frederick, MD of 300 feet, the following condition would apply:

IF Elevation ≤ 4000, then Elev CF = 1.0

Step 6: Calculate the radon concentration (RnC)

We know now that:

IV = 751
FV = 719
D = 3.333
CF = 2.0345
BG = 6.2
G = 0.087
Elev CF = 1

$$\text{RnC} = \left(\left(\frac{(\text{IV - FV}) - (0.066667 \times D}{CF \times D} \right) - (BG \times G) \right) \times (Elev\ \text{CF})$$

$$\text{RnC} = \left(\left(\frac{(751 - 719) - (0.066667 \times 3.333}{2.0345 \times 3.333} \right) - (6.2 \times 0.087) \right) \times (1.0)$$

RnC = 4.1 pCi/L

If needing to report the radon concentration in International Units (SI units), convert pCi/L to Bq/m^3 by multiplying the pCi/L result by 37.

Example: 4.1 pCi/L x 37 = 152 Bq/m^3

Dynamic Range and Error Analysis

Introduction

The basis for the estimation of these parameters for several E-PERM® configurations is described in a paper by Kotrappa, et al, in Health Physics (58:461-467, 1990). However, it is useful to have an elementary knowledge of these factors for proper understanding of the E-PERM® System.

Dynamic Range

The various E-PERM® calibration factors given in this manual are applicable over the electret voltage range of approximately 100 volts to 750 volts. This is because ion collection by electrets with voltages less than 100 Volts becomes less efficient and ion multiplication can occur with electrets well above 750 volts. Thus 100 volts to 750 volts is the useful voltage range of electrets for radon measurement. This voltage range establishes the dynamic range of integrated radon concentration (expressed in pCi/L-days) which each type of E-PERM® can measure. Example: For a short-term electret in an S Chamber, this 100 volt to 750 volt range limitation translates to a limitation of about 340 pCi/L-days. This means that the voltage would fall from 750 V to 100 V if exposed for one day to approximately 340 pCi/L or for 10 days to approximately 34 pCi/L. Similarly, a long-term electret in an S Chamber has a pCi/L-days limitation of approximately 3,970, and a long-term electret in an L Chamber has a pCi/L-days limitation of approximately 21,240. These are called Dynamic Ranges (DR).

In actual practice, the Dynamic Range is less because of the voltage loss caused by background gamma radiation – the higher the background gamma radiation, the greater the voltage loss. Background gamma is typically measured in micro Roentgens per hour (µR/hr), and a background of 10.0 µR/hr will result in approximately 2 volts per day (24 hours) in an SST E-PERM® and approximately 0.2 volts per day in an SLT E-PERM®.

Methods of Estimating Errors

Sources of Error

There are three sources of error in EIC radon monitors.

1. Error component No. 1 (E1): The error associated with the system component imperfections, which includes uncertainty in chamber volumes, electret thickness and other component parameters. This has been experimentally measured to be about 5%. (Health Physics Journal 58:461, 1990).

2. Error component No. 2 (E2): The error in the electret voltage reading. There can be an uncertainty of as much as 1 volt in both the initial and final readings, the error in the difference of the two readings is 1.4 volts, which is the square root of the sum of the squares of the two 1 volt errors. The percent error is then:

$$\frac{100x1.4}{(I-F)}$$

3. Error component No.3 (E3): Error due to uncertainty in the gamma background. The maximum error introduced by using the EPA-listed state average background values (available from Rad Elec) to correct measurements made in various locations within a state can introduce an error of about 0.1 to 0.2 pCi/L. Using the precise gamma level at the site can minimize this error component. Even if the gamma level is ± 20% off of the state average level; e.g., 8 to 12 µR/hr when the state average is 10µR/hr, the error introduced is only about 0.2 pCi/L.

4. There are no significant errors due to temperature, humidity, air draft and concentration variations. Precise corrections are available for elevation variations.

5. Total Error (ET): The total error is the square root of the sum of the squares of individual error components listed above.

Example of an Error Calculation:

$$ET = \sqrt{E1^2 + E2^2 + E3^2}$$

Assume that an S Chamber loaded with a ST electret was exposed for 5 days.
I = 700 volts and F = 645 (I and F are initial and final electret voltages respectively).

$$ET = \sqrt{5^2 + 2.5^2 + 2.27^2} = 6.0\%$$

The radon concentration is 4.4 pCi/L. The error is determined as follows:
From the above components, it can be seen that the error depends upon the type of E-PERM® device and the measurement period. The following table gives the lowest concentrations, which can be determined at 50%, 25%, and 10% error levels for various EIC types and exposure periods. The level that can be measured with 50% error is also defined as minimum detectable level. The final column lists calculated maximum error values at the EPA action level of 4.0 pCi/L.

Minimum Measurable Concentrations and Concentrations at Stated Accuracy **(Rev 2017)**

EIC	Exposure	MMC* AT 50%	MMC* AT 25%	MMC* AT 10%	Error (%)
Type	(Days)	(pCi/L)	(pCi/L)	(pCi/L)	4.0 pCi/L
SST	2 7	0.3 0.2	0.8 0.4	3.6 1.4	9.3 6.0
SLT	30 120	0.2 0.2	0.5 0.4	2.4 1.2	7.8 5.8
LST	30 120	0.2 0.2	0.4 0.4	1.4 1.2	6.1 5.6
LLT	91 365	0.2 0.2	0.5 0.4	2.9 1.2	8.8 5.8
LST-OO	91 365	0.2 0.2	0.4 0.4	1.2 1.2	5.7 5.6
LMT-OO	30 91 180	0.2 0.2 0.2	0.7 0.4 0.4	4.3 1.4 1.3	10.4 6.3 6.0
LLT-OO	91 365	0.2 0.2	0.5 0.4	3.7 1.2	9.7 5.9
HST	1 2	0.2 0.2	0.5 0.4	1.7 1.3	6.5 5.8
HLT	7 14	0.2 0.2	0.6 0.5	2.6 1.5	7.8 6.2

* = MMC (minimum measurable concentration at stated error)

MMC at 50 % error is also called as minimum detectable level.

This table is based on a midpoint voltage of 450 volts and 10 μR/hr gamma background.

Dynamic Range of Different E-PERM® Configurations **(Rev 2011)**

E-PERM® Type	Chamber Volume	Dynamic Range (pCi/L-days)
HST	960	58
HLT	960	706
SST	210	342
SLT	210	3,970
LST-OO	58	2,151
LMT-OO	58	7,289
LLT-OO	58	26,475
LLT	61	21,240
LST	61	1,753

Effects of Environmental Parameters

In order to use the E-PERM® successfully in different environments, it is important to understand the effects of certain environmental parameters on the performance of the System. The effects (or absence of effects) caused by: (1) temperature, (2) relative humidity, (3) correcting E-PERM® results for elevation, (4) presence of ions in the room, (5) electric fields in the room, (6) air draft, (7) gamma radiation sources, (8) thoron in air and (9) external dust.

Temperature

E-PERM® measurements are not affected by the usual temperature variations found in homes or the environment. In fact, E-PERM®s have been used successfully by the U.S. EPA to make ambient radon measurements through all seasons of the year in all fifty (50) States. These and other controlled tests have proven that the effect of temperature on the accuracy of E-PERM® radon measurements is negligible. However, you should be aware of a secondary effect of temperature, which can occur during the reading of an electret. Due to the different expansion coefficients of Teflon and the conducting plastic holder material, the Teflon® electret surface tends to concave or convex slightly when the temperature is changed substantially. This causes the electret surface to move slightly closer to or away from the sensor during reading which results in a small (few volts) change in the voltage value. The reading difference can be as high as 2 V for each 10^{o} F temperature change. This effect is easily eliminated by taking both the initial and final readings at the same (room) temperature; i.e., if the electrets are warmer or colder when they arrive for the reading, simply wait one or two hours for the electret to return to room temperature before taking the reading.

A substantial change in temperature of the reader also affects the electret voltage reading by approximately 1 V per 10^{o} F. Accordingly, it is good practice to make sure the reader is at room temperature before taking a reading.

THE ELECTRETS AND READER SHOULD BE AT THE SAME ROOM TEMPERATURE WHEN TAKING THE INITIAL AND FINAL READINGS.

Relative Humidity

Even the highest relative humidity levels found in homes or in the environment do not affect E-PERM® radon measurements. In fact, E-PERM®s are routinely used for making radon-in-water measurements under conditions of 100% relative humidity.

HOWEVER, THE READER MUST BE KEPT DRY TO GIVE PROPER VOLTAGE READINGS.

Correcting E-PERM® Results for Elevations

Like any other ionization chambers, E-PERM®s are affected by the ambient pressure, relative to the pressure at which the calibration was done. In our efforts to make E-PERM® radon measurements with as much accuracy as possible, careful experiments were conducted to quantify this effect. Results are published in the following paper:

Elevation Correction Factors For E-PERM® Radon Monitors
P. Kotrappa, L. R. Stieff
Health Physics. 62(1):82-86, January 1992.

Rad Elec has included an elevation correction factor into the formula to minimize the effect that elevation has on the chambers. The elevation correction factor depends upon the type of chamber being used (S, L, or H). For H Chambers, there is no elevation correction factor, because elevation does not affect the H Chamber. Refer to page 22 of this manual for information on how to calculate the elevation correction factor.

The elevation correction factor is taken into account when using Rad Elec's software programs, calculation templates, and hand-held pre-programmed Casio's if the input data contains the elevation at which the test was conducted.

Presence of Ions in the Room

There are always some ions in every room. A large number of ions can be present if an ion generator is operating or burning, or an open flame is burning. Ambient room ions are stopped completely by the E-PERM® filter. This was confirmed by measuring radon in a room with and without an ion generator in operation. The filter also stops all radon progeny. Only gases like radon can enter the E-PERM® chamber.

External Electric Fields

External electric fields in the room have no effect on the performance of an E-PERM®. The E-PERM® chamber is made of electrically conductive plastic, which shields out all external electric fields from the E-PERM® chamber.

Air Drafts

EPA protocols recognize that open-faced charcoal canisters are sensitive to air drafts at the measurement site. However, air drafts have no effect on the ability of E-PERM®s to detect the average radon concentration, even in a stream of flowing air. This has been confirmed by careful measurements inside and immediately outside of a tunnel in which the airflow was significantly high.

Gamma Radiation

E-PERM®s are sensitive to ions produced by penetrating and ionizing radiation, such as X-rays or gamma radiation, as well as ions produced by radon inside the chamber.

Natural background radiation is the only source of gamma radiation at most measurement sites. Rad Elec provides a list of average correction factors by state (and province) to correct for this natural background. These correction factors are based on a compilation of the average background radiation by state. This compilation was taken from the EPA Report "*Population Exposure to External Natural Radiation Background in the USA*" ORP/SEPD-80-12 by Kenneth T. Bogen and Abrahm S. Smith 1981. Of course, the background gamma varies some within any state, but the error which these in-state variations may introduce errors in radon measurements is minimal; i.e., 0.1 to 0.2 pCi/L.

If some other source (other than the normal environmental background) is suspected at a site, it can be easily measured and corrected for; e.g., it can be measured accurately by an E-PERM® sealed in a radon-proof bag. (Contact Rad Elec for details.)

Thoron in Air

Thoron is another isotope of radon with a short half-life. Thoron is usually present in small concentrations in homes. E-PERM®s are designed to have less than 10% response to thoron. Therefore, for all practical purposes, it can be stated that the E-PERM®s measure only radon.

External Dust

External dust does not influence the performance of the E-PERM®, since dust particles are filtered out during the passive diffusion through the filter. However, it is a good practice to wipe clean the dust deposited on the external surfaces before taking the electret out for measurement. Otherwise, there is a possibility of dust falling on the electrets during the process of unscrewing the electret out of the chamber.

FREQUENTLY ASKED QUESTIONS

READERS

1. How do I store the reader and the E-PERM®s when not in use?

A carrying case is provided with each reader. It contains a desiccant, which should be checked periodically to see if it needs to be dried. Follow the instructions for drying, which come with the carrying case. We recommend storing the reader in its carrying case at all times when not in use to keep it dry and free of dust and dirt. Proper storage of the reader is especially important during highly humid days.

E-PERM®s should be stored at room temperature away from dust or dirt. The electrets should be kept in their keeper caps and stored in the Tyvek® bags in which they are shipped. The chambers should be stored in the plastic bags in which they were shipped.

2. What do I do if a series of voltage readings are not reproducible?

This happens occasionally during periods of very high humidity if the reader is not kept in a dry environment: e.g., it is not kept in its case. Also, always make sure that the electret receptacle is clean. Use a soft cloth and rubbing alcohol to clean the receptacle, and then it blow off with nitrogen to make sure that all lint is removed. Always keep the reader at room temperature and make sure the electrets are at the same room temperature when read.

3. How do I know that my reader is functioning properly?

To see that your reader is functioning properly, read the "reference" electrets as per the instructions. If one electret deviates significantly from the reference reading and the other tracks the reference reading, the reader is OK. If both electrets deviate more than accepted values, the Reader may need calibration. Contact Rad Elec. However, the reference electrets should not be used for a calibration check. These electrets provide only **one point of reference** for the reader and should not be construed as a method of calibration. During the calibration of a reader, the reader is calibrated over the entire voltage range.

In addition to the above, you should check to see if the reader indicates "zero" when no charge is present. A zeroing electret is used for this purpose, and the electret should read ± 3 volts of 0. However, if the zero reading is more than ± 3 volts from 0 it is recommended that you send your reader to the manufacturer for evaluation. This zero check should be carried out weekly along with the reference electret readings and the results recorded as part of your quality assurance program.

4. How often should I change the batteries in the reader?

If the battery is low, a "low bat" indication shows on the display panel of the reader and the battery should be changed. The batteries are also changed when the reader is shipped to the manufacturer for calibration.

5. How often should my reader be calibrated?

Your reader should be calibrated at least once a year. It is also important to send with the reader the set of reference electrets for re-certification. There is a charge for the calibration plus shipping and handling. The date of calibration is listed on the back of the reader and a calibration certificate and reference electret certification will be issued. At the time of calibration if additional services are required the manufacturer will contact the customer.

"Reference" electrets are used as part of your quality assurance program and a record of your weekly readings should be maintained. If your weekly readings remain essentially constant, you can be confident that your reader is functioning properly. Sometimes a low battery will produce different readings. Try replacing the battery and checking the reference electrets again. If both reference electrets are deviating more than ± 3 volts of the certified readings, it is recommended that you send your reader in for evaluation.

6. My Reader doesn't look like the one shown in this manual, what do the other versions of the SPER Readers look like?

The SPER-2 Microprocessor Electret Reader.

The SPER-1 Electret Reader.

The SPER-1 A Electret Reader.

Diagnosing Problems with the Reader

1. **Readings will not reproduce or they fluctuate**

   This malfunction can happen occasionally on very humid summer days or when moisture condenses inside the reader: e.g., as when a cold reader is brought into a warm, damp room. Avoid leaving the reader in a hot or cold car and then performing measurements. It is recommended that the reader be used in air conditioned rooms with a relative humidity of less than 75%. The reader should also be kept in its carrying case and the desiccant checked frequently. The electret receptacle may become dirty which may not allow good contact with the reader. Clean the electret receptacle on the reader. Dab a bit of rubbing alcohol onto a Q-tip and wipe around the receptacle, cleaning any debris off of the surface. Blow off the receptacle with nitrogen to make sure no lint or fibers were left behind. Do not open the shutter and expose the interior while cleaning the receptacle. Always read the electrets at room temperature.

2. **"LO BAT" appears on the display**

   This display is a warning to change the batteries. It is recommended that you always replace the batteries with new alkaline batteries.

3. **The voltage of a "reference" electret is more than ±3 V different than its certified voltage value**

   If only one electret deviates significantly from the reference readings and the other reference electret tracks the reference readings consistently, the reader is OK. If both electrets deviate more than the accepted value of ± 3 volts, the reader may need calibration. Please refer to the "Reference Electrets" section in this manual for more information. You may also try replacing the batteries with fresh ones, and see if that makes a difference.

4. **No display shows on the digital panel meter**

   Pulling the shutter handle should turn on the reader, if the reader doesn't turn on the batteries may be low. Try replacing the batteries with brand new alkaline batteries. If still there is no display, return the reader to Rad Elec for servicing.

5. **The reader does not turn off after two minutes**

   This symptom indicates a defect in the auto off switch. The reader should be sent to Rad Elec for servicing. Otherwise, the battery will not last long.

6. **The SPER-1 reader makes a high-pitched "whistling" sound**

   This sound indicates that the slide has not moved all the way up to its proper "OFF" position, usually because the metal-to-metal slide rail is binding the slide movement. The reader will stay on and run the batteries down if this sound persists. Try moving the slide back and forth, this will usually free it and allow the slide to return to its' proper "off" position. If the problem persists, remove the battery and send the reader to Rad Elec for repair.

ELECTRETS

1. Since the electrets basically look the same when covered, how do I identify the short-term from the long-term electrets?

There is a label on the bottom of the electret- blue labeled electrets are short term (ST) electrets, and red labeled electrets are long term (LT) electrets. Additionally, each electret has a unique bar code. If the label starts with letter S, it is a short term (ST) electret. If the label starts with letter L, it is a long term (LT) electret.

2. How do I know that my electrets are of good quality?

Rad Elec has a very thorough QA/QC Program. Each electret goes through a rigorous processing procedure to test for stability. To insure correct calibration, a statistically significant number of electrets are checked in our NRSB accredited Radon Test Chamber. The Electret Quality Certificate is provided to the user with Rad Elec's QA information on each electret.

In addition to Rad Elec's QA/QC program, the user should conduct additional tests as required by the user's specific QA/QC Plan. ST electrets should not discharge more than 6 volts per month measured over one month and LT electrets should not discharge more than 4 volts per month measured over a 3 month period.

3. Is the electret shock resistant?

Yes, the electret is shock resistant as long as it is tightly in its keeper cap. A moderate mechanical shock (i.e. dropping it from a table onto a carpet floor) will not change the electret reading; however violent shocks should be avoided. If the electret receives a violent shock or jolt, measure the voltage again before using.

4. Would I get an electric shock if I touch the actual electret surface?

No, you will not receive a shock, but you will discharge the voltage on the electret. Even though the surface voltage of a new electret is about 700-780 V, it can never give a shock because of the extremely high resistance of the material (for this same reason you cannot draw current from an electret). However, touching the electret will cause the voltage to drop and make the electret unstable. Most likely the voltage will drop to a negative number. The electret will become unusable.

5. What do I do with electrets that have less than 100 V (volts)?

Electrets showing a reading of less than 100 V should not be used for measurements because the weaker electrostatic field is not as consistent in collecting the ions efficiently. They can be exchanged for new electrets through Rad Elec's replacement program at a lower price than the original purchase price of the electret.

6. What do I do if I drop an open electret during a measurement?

It is possible that the electret surface may come in contact with something due to the fall, or debris (dirt or fibers) may have been deposited on the surface of the electret. If so, there could be a substantial change in the electret voltage. Clean off any dust or small particles by blowing the electret surface with nitrogen. Then measure and record the voltage for two to three weeks at weekly intervals. If you are satisfied that it remains stable; i.e., no more than a change of 4 to 6 volt per month, it can be reused.

7. Can I store the electrets in the E-PERM® chambers (in the "OFF" position) or should I store them in the caps? What is their shelf life?

The electrets can be stored in S chambers and the L-OO chambers as long as the chambers are in the "OFF" position. The electrets can also be stored in their "keeper" caps. The same small but finite volume of air above the electret surface in either storage mode causes the electrets to lose a small amount of voltage during storage (less than 4 to 6 V per month for short-term electrets and less than 2 to 3 V per month for long-term electrets). For this reason, it is always a good procedure to measure your electrets as near to deployment time as is possible. Never store an electret in a chamber that is not equipped with an "ON/OFF" mechanism or in a chamber that is not in the "OFF" position. There is no shelf life and electrets that are many years old can be still used, provided that their voltage is above 100 volts.

8. I know I should not use electrets below 100 volts; what should I do if my final reading comes out to be less than 100 volts?

When electrets deplete to 100 volts or less, they should be exchanged for new electrets through Rad Elec's replacement program. Due to the characteristic of an electret, as the voltage depletes the electrostatic field becomes weaker and does not collect the ions as efficiently. With our current logarithmic calibration factors, the midpoints voltages for nearly all configurations (apart from the HST and HLT) can have midpoint voltages as low as 50. This means that the lowest deployment (initial) voltage should never drop below 100. When using an electret in either an HST or HLT configuration, you must switch configurations or retire the electret when it drops below 200 volts, as these configurations still rely on our older linear calibration factor equations.

If the final reading is zero volts, report the result as above that value. For example, if the result was 2.3 pCi/L, then report the result as >2.3 pCi/L.

If the final voltage reading is negative, then the electret surface was probably touched and the results are invalid.

E-PERM® CHAMBERS

1. Does the foil wrapped around label on the S chamber serve a particular purpose? Can it be removed and replaced?

The foil wrapped around label not only serves as a label but also holds the top and bottom portions of the S chamber together. DO NOT REMOVE THIS LABEL. If you wish to identify your company on the label, you can do so by placing an additional small label in the blank space available in its center panel. The information on the right end of the label is required by the EPA to be exhibited.

2. How can I prevent someone from tampering with the top of the S Chamber?

First, S chambers can be deployed with a tamper proof box which can be secured with lock-ties. Or you can feed a lock-tie through the neck of the S chamber to prevent someone from closing the chamber. You will notice that there is a hole in the stem of the top of the S-chamber. Simply insert the tie through this hole and "lock" it. This, in effect, makes the top of the E-PERM® tamper proof. To prevent someone from unscrewing the electret, tamper tape may be used. The tape will leave a void mark if removed. Tamper Indicating Tape is available from Rad Elec.

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

Usual problems can be:

- The detachment of the progeny filter: This can be repaired by the manufacturer for a minimal charge.
- Electrets not fitting into the bottom of the chamber: If the electret will not securely close in the bottom of the chamber, the threads have worn out and the chamber will need to be replaced.
- Top screw does not tighten and/or pops up by itself: The top threads of the chamber have worn out and the chamber will need to be replaced.

Rad Elec will replace S Chambers through a trade-in program if they cannot be repaired.

RANGE and SENSITIVITY

1. What is the sensitivity of E-PERM®s?

There is no unique answer. Since E-PERM®s are true integrators, these can be used for any length of time to achieve the sensitivity needed. If you wish to measure 4.0 pCi/L in 2 days, the error involved is 8.6%. If you measure the same concentration over 7 days, the error is 6.4%. If you need to measure low concentration with high sensitivity, the E-PERM®S have to be used for a longer period. If you use an SLT for 90 days, your error of measuring 4.0 pCi/L is 6.7%. Please refer to the "Dynamic Range and Error Analysis" section of this manual for more information.

2. What is the lowest level of detection (LLD) or minimum measurable concentration (MMC)?

Again, there is no unique number. Based on the definition of MMC (minimum measurable concentration), it is the radon concentration that can be measured with 50% error. If an SST E-PERM® is used for 2 days, the MMC is 0.25 pCi/L and if it is used for 7 days the MMC is 0.16 pCi/L. Please refer to the "Dynamic Range and Error Analysis" section of this manual for more information.

3. Is there a unique exposure time limit for E-PERM®s?

No, however the USEPA testing protocols for short term measurements require a minimum of 48 hours. Please refer to the "Dynamic Range and Error Analysis" section of this manual for more information on the typical time frame of radon measurements with regard to specific E-PERM® configurations.

Please be aware that the SST E-PERM® can be used for long term measurements if the radon concentration is low and that the SLT E-PERM® can be used for short term measurements if the radon concentration is high.

4. Can SST E-PERM®s be used for long term measurements?

Yes but only if there are low levels of radon. Normally long term testing should be done with long term electrets and/or L chambers. The USEPA actually used SST E-PERM®s to measure ambient radon concentrations by exposing them for 90 days.

Incidentally, the 0.4 pCi/L which is listed as the national average ambient level in the Citizen's Guide was determined by using SST E-PERM®s. E-PERM®s are one of the few devices that can measure radon at low concentrations in ambient outdoor environments covering a wide range of temperatures and humidities.

5. Can SLT E-PERM®s be used for short-term measurements?

Yes. SLT E-PERM®s can be used for measuring radon concentrations in as little as 2 days, when concentrations are above 50 pCi/L. Such radon concentrations are not uncommon in some regions in Pennsylvania and Canada.

ENVIRONMENTAL PARAMETERS

1. **I understand that E-PERM®s respond to gamma and X-rays. Can I place an E-PERM® close to a television?**

   Radiation emitted by television sets (or monitors) is regulated by the Federal government. Television sets (or monitors) have not been found to emit measurable levels of ionizing radiation, and therefore there is no "measurable" effect upon E-PERM® detectors.

2. **I understand that E-PERM®S respond to gamma and X-rays; Can I take these through airport security check stations?**

   As long as the E-PERM®s are in the "OFF" position or if electrets are in their keeper caps, there is no measurable effect. E-PERM®s have been transported all across the world without any measurable effect. However, it is important that the E-PERM®s are fully in the "**OFF**" position.

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

   Yes, however the USEPA testing protocols require that the thermostat be set at "normal" settings. When E-PERM®s are returned to the office or laboratory for reading, the user should wait until the E-PERM®s reach room temperature before taking a final reading. It is important to remember that the initial and final electret readings should be taken at the same temperature.

4. **Can I make an E-PERM® measurement in an unusually high dust area, such as in a furniture factory or in a paper processing area?**

   Radon measurements can be made in these types of areas, however Rad Elec recommends enclosing E-PERM®s in Tyvek bags, which allow radon gas to penetrate the bag while stopping dust and other small particles.

5. **I understand that E-PERM®s are ionization chambers that detect ionizing radiation. Can I use E-PERM®s in an area where an ion generator is being used?**

   Yes. The E-PERM®s have filtered inlets which stop ions generated in a room from getting inside the chamber. It is important to follow USEPA testing protocols regarding fans, humidifiers, and other filtration appliances.

6. **I understand that E-PERM®s are affected by the environmental background gamma radiation. Can I use E-PERM®s when there can be high background gamma due to the presence of external radiation sources?**

   If it is suspected that the area may have external radioactive sources, you need to measure the background gamma radiation level using a calibrated meter in units of micro R/h and apply it to the background correction formula. It is possible to co-locate an E-PERM® sealed in a Mylar bag that not only provides background subtraction but also determines the gamma radiation level quantitatively. Contact Rad Elec for more information.

7. What is a false positive reading and a false negative reading? Why does the EPA believe that false negative readings are especially undesirable? Do E-PERM®s give many false negative readings?

A false positive reading means a reading is higher than the true value. A false negative reading means that a reading is lower than the true value. A false positive measurement errs on the safer side with respect to health while a false negative measurement error misleads the homeowner on the dangerous side; i.e., the family will be receiving a higher dose than the measurement indicates. This is the reason why the EPA considers a false negative reading undesirable. With the E-PERM® System, the most common handling errors committed -- such as touching or getting dust or dirt on the electret -- all tend to discharge the electret, resulting in an erroneous low second voltage read-out. This is true because the electrets carry a positive polarity, and any friction charges accidentally induced on the electret are always negative. If an E-PERM® reading is erroneous because of a handling mistake, it will almost always result in a false positive rather than a false negative radon concentration value. This is an important advantage of E-PERM®s.

8. What is the difference between a detector that is a true integrator and a detector that is not a true integrator?

"True integrating" radon detectors respond to changes in radon concentration during the measurement period. True integrating devices can be exposed for longer periods if radon concentrations are low and can be exposed for a shorter period if radon concentrations are higher. Also, true integrating devices are not biased by varying radon concentrations. Examples of devices that are true integrators are E-PERM®s, Alpha Tracks, and Continuous Radon Monitors.

Examples of devices that are not true integrators are charcoal canisters and Liquid Scintillation vials. These are devices that adsorb and de-adsorb radon and thus do not give a true integrated measurement over the exposure period.

TECHNICAL SPECIFICATIONS

ELECTRETS

- The electret is a Teflon® disk that is electrically charged and stabilized by Rad Elec's proprietary processes. It is mounted in an electrically conducting plastic holder and covered by a keeper cap.
- Initial charge: 700 to 780 volts
- An electret should not be deployed below 100 volts.
- ST electret voltage loss when stored in keeper cap should not exceed 6 volts per month when measured over a one month.
- LT electrets voltage loss when stored in keeper cap should not exceed 4 volts per month when measured over a 3 month period.

  (Note: Discharge can be higher if electret surface is not clean)
- Usable: In all E-PERM® applications.

CHAMBERS

All of the chambers are made of electrically conducting plastic and can be re-used indefinitely. Electrets can be screwed into these chambers.

- S Chamber: 210 mL volume with on/off mechanism
- L Chamber: 61 mL volume
- H Chamber: 960 mL volume
- L-OO Chamber: 58 mL volume with on/off mechanism

SPER-1 READER

- The SPER-1 Reader (all models) is an ultra-high impedance, non-contact electric field sensor that works on the principle of electrometer with shutter on/off mechanism.
- Range: 0 to ± 2000 volts
- Resolution: ± 1 volt
- Adjustments: zero and calibration
- Requires annual servicing and calibration

REFERENCE ELECTRETS

- Reference electrets are highly stabilized electrets that have been "certified" to a known voltage by the manufacturer. These detectors are used to verify that the SPER-1 Reader is functioning properly.

PERFORMANCE

- E-PERM®s when used in accordance with the recommended procedures are expected to give better than +/- 10% accuracy.

Selected List of Publications

(Most of these publications can be found on the Rad Elec website at www.radelec.com under the "Publications/Resources" tab)

Radon in Air

An Electret Passive Environmental ^{222}Rn Monitor Based on Ionization Measurement
P. Kotrappa, J. C. Dempsey, J. R. Hickey, L. R. Stieff
Health Physics. 54(1):47-56, January 1988

A Practical E-PERM® (Electret Passive Environmental Radon Monitor) System for Indoor ^{222}Rn Measurement
P. Kotrappa, J. C. Dempsey, R. W. Ramsey, L. R. Stieff
Health Physics. 58(4):461-467, April 1990.

Elevation Correction Factors For E-PERM® Radon Monitors
P. Kotrappa, L. R. Stieff
Health Physics. 62(1):82-86, January 1992.

An advanced E-PERM® system for simultaneous measurement of concentration of radon, radon progeny, equilibrium factors and unattached radon progeny
P. Kotrappa and Lorin Stieff
Proceedings of the 2003 International Symposium-Vol II, AARST Oct, 2003

"Radon in Indoor Air in Nevada (measurements done with electret ion chambers)"
J. G. Price et al
Health Physics 66(4); 433-438(1994)

Field Comparison of commercially available short term radon monitors
K. Sun, M. Madzon, D.W. Field and R.W. Field
Health Physics 91:221-226 (2006)

Influence of Environmental Changes on Integrating Radon Detectors: Results of Inter-Comparison Exercise
A. Vargas and X. Ortera
Radiation Protection Dosimetry 1-6, Oct 2005

Radon in Water

Electret Ion Chamber Radon Monitors Measure Dissolved ^{222}Rn in Water
P. Kotrappa, W. A. Jesters
Health Physics. 64(4):397-405, April 1993.

Thoron

"Measurement of Thoron Using Electret Ion Chambers"
Kotrappa, P., Stieff, L.R., and Bigu, J.,
1994 International Radon Symposium IIIP-2. 1-7(1994)
US National Ambient Radon Study

"Radon in indoor air in Nevada (measurements done with electret ion chambers)"
J. G. Price et al
Health Physics 66(4); 433-438(1994)

"National ambient radon study Proceedings of International Symp. On radon and radon protection"
Hopper R.D., et al
Philadelphia, PA 1991 (EPA reviewed paper)

EPA technical support document for the 1992 citizen's Guide to Radon
Hopper R. D.
EPA-400-R-92-011 Appendix A Radon Concentration in ambient air (measured using Rad Elec Electret ion chambers)

Radon Inter-Comparison Publications, containing results of E-PERM® radon monitors

Department of Energy, Environmental Measurement Laboratory Reports containing results for electret ion chambers

EML-527 (1990)
EML-536 (1991)
EML-554 (1993)
EML-566 (Feb 1995)
EML-577 (Dec 1995)

"Inter-comparison of radon and decay product measurements in an underground mine and EPA radon laboratory; A study organized by the IAEA international metrology program"
G. Budd, R. Hopper, E. Braganza et al
Health Physics 75(5): 465-474; 1998

Radon Flux

"Passive E-PERM® Radon Flux Monitors For Measuring Undisturbed Radon Flux From The Ground"
Kotrappa, P., Stieff, L.R., and Bigu, J.
1996 International Radon Symposium II-1.6(1996)

"**A preliminary comparison of radon flux measurements using large area activated charcoal canister (LAACC) and Electret ion chambers (EIC)"**
Jack Rechcigl et al
1996 International Radon Symposium, Florida Hosted by AARST

Additional Applications for Electrets and Chambers

Call Rad Elec if you are interested in any of the following applications.

1. Instant radon measurement.
2. Measurement of radon in water.
3. Electret radon sniffer for mitigation diagnostics.
4. Environmental gamma radiation measurement.
5. Radon emanating Ra-226 concentration from soil.
6. Personnel dosimeter radon monitor.
7. Measurement of undisturbed radon flux from the ground, uranium mill tailings, and phosphate stacks.
8. Modified E-PERM® for passive measurement of thoron.
9. Modified E-PERM® for passive measurement of airborne tritium.
10. Tritium concentration in water, tritium contamination on surfaces.
11. Modified E-PERM® for passive measurement of beta radiation.
12. Modified EPERM® for passive measurement of alpha radiation from contaminated surface.
13. A calibration system for integrating radon monitors (E-PERM®S) using the NIST Radon Emanation Standard.
14. Modified E-PERM® for passive measurement of Uranium and Plutonium contamination in soils.
15. Measurement of radon emanation from Granite Countertops.
16. Measurement of radon emanation from Building Materials.
17. Measurement of radon progeny concentration in air, using E-RPISU (Electret Radon Progeny Integrating Sampling Unit).
18. Electrets for measuring ion concentration in air.
19. Glove box radon test chamber traceable to NIST radon emanation standard.

GAMMA TABLE TAKING INTO ACCOUNT BUILDING SHIELDING

Taken from EPA Report "Population Exposure to External Natural Radiation Background in the USA" ORP/SEPD-80-12 by Kenneth T. Bogen and Abrahm S. Smith 1981

	State	AV uR/Hr
AL	Alabama	6.5
AK	Alaska	7.3
AR	Arkansas	6.5
AZ	Arizona	8.0
CA	California	6.6
CO	Colorado	11.8
CT	Connecticut	7.8
DC	Washington, DC	6.4
DE	Delaware	6.1
FL	Florida	5.3
GA	Georgia	7.0
HI	Hawaii	7.3
IA	Iowa	7.5
ID	Idaho	8.7
IL	Illinois	7.1
IN	Indiana	7.4
KS	Kansas	7.7
KY	Kentucky	7.3
LA	Louisiana	5.4
MA	Massachusetts	7.3
MD	Maryland	6.2
ME	Maine	7.5
MI	Michigan	7.4
MN	Minnesota	7.4
MO	Missouri	7.4
MS	Mississippi	5.4
MT	Montana	8.6
NC	North Carolina	6.9
ND	North Dakota	7.8
NE	Nebraska	7.7
NH	New Hampshire	7.4
NJ	New Jersey	7.1
NM	New Mexico	10.4
NV	Nevada	7.6

	State	AV uR/Hr
NY	New York	7.3
OH	Ohio	7.3
OK	Oklahoma	7.6
OR	Oregon	7.4
PA	Pennsylvania	6.6
RI	Rhode Island	7.0
SC	South Carolina	6.7
SD	South Dakota	7.8
TN	Tennessee	6.9
TX	Texas	6.1
UT	Utah	9.3
VA	Virginia	6.4
VT	Vermont	7.4
WA	Washington	7.4
WI	Wisconsin	7.5
WV	West Virginia	7.7
WY	Wyoming	10.4

Canadian Provinces and Territories		AV nGy/Hr
AB	Alberta	74.8
BC	British Columbia	69.6
MB	Manitoba	66.1
NB	New Brunswick	65.3
NL	Newfoundland & Labrador	65.3
NS	Nova Scotia	65.3
NT	Northwest Territories	73.1
NU	Nunavut	66.1
ON	Ontario	64.4
PE	Prince Edward Island	65.3
QC	Quebec	65.3
SK	Saskatchewan	71.3
YT	Yukon	69.6

(end)