Proceedings of the 2003 International Radon Symposium – Volume II
American Association of Radon Scientists and Technologists, Inc.
October 5 – 8, 2003

AN ADVANCED E-PERM SYSTEM FOR SIMULTANEOUS MEASUREMENT OF CONCENTRATIONS OF RADON GAS, RADON PROGENY, EQUILIBRIUM RATIO AND UNATTACHED RADON PROGENY

Kotrappa, Paul Ph.D.; Stieff, Rick & Lorin

Paul Kotrappa Ph.D.
Rick Stieff and Lorin Stieff
Rad Elec Inc. 5714-C Industry Lane
Frederick, MD 21704 USA
301-694-0011 Pkotrappa@aol.com

ABSTRACT

The detrimental effects of prolonged exposure to the decay products of radon, is well known and documented in the literature. The USEPA has set a primary standard for radon progeny exposure for the general public at 0.02 WL with a corresponding derived limit of 4 pCi/L for radon gas, assuming an equilibrium ratio of 50%. Because radon gas measurement is simpler and less expensive, more than 90 % of all the currently performed radon measurements in the US, measure radon gas and estimate the actual health risk via the assumed equilibrium factor for a residential structure. However, with increased concerns of radon related exposures in building with high air circulation rates (schools and commercial buildings) the 50% equilibrium ratio assumption may not allow for proper characterization of the true exposure from radon measurements. In these cases a more rigorous characterization by direct measurements of radon decay products may be useful follow-up measurement after initial radon measurements have identified a potential concern. This paper describes a configuration radon and radon decay product measurement devices that can simultaneously measure radon and its decay products as well as provide an indication of the relative ratio of attached to unattached decay products. This unique combination of devices has numerous applications for designers of complex remediation systems and environmental consultants who have the responsibility of providing cost effective and safe solutions.

Introduction

Radon is a radioactive gas known to cause lung cancer in human beings. It is also the largest contributor of the naturally occurring radiation dose to human beings. This is known to be the next only to smoking as causative agent of lung cancer.

Characterization of radon is important in evaluating and controlling the risk due to radon. Radon being a gas that is inhaled and exhaled, it does not contribute significant dose or risk to lungs. The decay products of radon are particulate radioactive elements, which can deposit in the airways of lungs, irradiate lung tissues and cause lung cancer. In USA, primary standard for homes is set in terms of radon progeny concentration as 0.02 WL, and the derived standard for radon gas as 4-pCi/L assuming equilibrium ratio of 50% . The assumption of 50% equilibrium ratio may not be correct in many cases, especially in large buildings/schools with high air circulation.

This is further based on the assumption that highly diffusive component of radon progeny often called as unattached fraction, is about 5% of the total progeny in air. This may not be so in some cases.

However, in homes or large buildings and schools, which have high radon concentration, high air circulation rate, it may be important to fully characterize radon and decay products before providing a cost effective and safe solution. Such characterization includes measurement of radon gas, total radon progeny, unattached fraction of radon progeny and equilibrium ratio.

E-PERM electret ion chambers (Ref 1 and 2) are passive integrating ionization chambers widely most widely used for measuring radon gas.

The purpose of this paper is to describe how the same technology is further adapted to measure other required parameters, namely: total radon progeny concentration, unattached fraction of radon progeny and equilibrium ratio.

Radon Gas Radon Concentration, Radon Progeny Concentration and Equilibrium Ratio

Atoms of radioactive radon gas decay by an emission of alpha particle, and transforms to Po-218 and in turn transforms to Po-214 by successive alpha emission.
In the room air, we have both radon and these two radioactive isotopes of Po, often called as radon progeny or radon decay products. These may stay free or attached to room aerosol. It is these radon progeny that get deposited in airways and cause primary inhalation risk. Radon gas itself does not cause much risk.

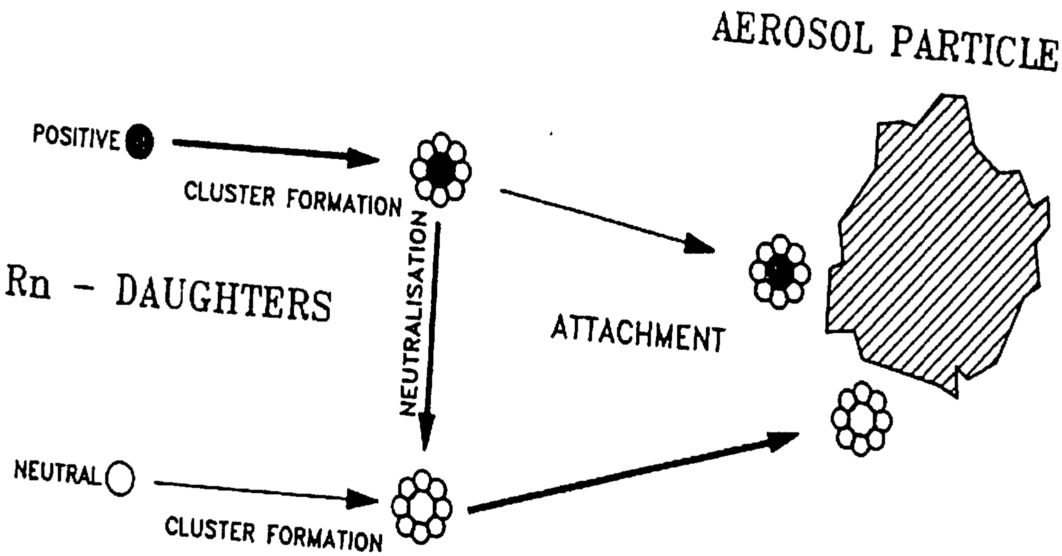
Based on the actual risk observed in uranium miners, USEPA has set the action limit as 0.02 WL. Because radon daughter products can get deposited in ventilation system or to the other surfaces, these do not reach equilibrium with radon. Based on some experimental data in typical homes, USEPA assumes that the equilibrium ratio as 50%. The action limit 0.02 WL corresponds to the derived radon concentration of 4 pCi/L when equilibrium ratio is 50%.

There are two methods of characterizing radon, either measure radon gas concentration or measure radon progeny concentration. USEPA action limit is 4 pCi/L for radon gas and 0.02 WL for radon progeny. Both measurements are acceptable, as long as USEPA (now NEHA or NRSB) listed devices and methods are used. These are equivalent to each other, only when equilibrium ratio is 50%.
Because radon gas measurement is simpler and considerably less expensive, most (>90%) measurements done to date are radon gas measurement. USEPA assumed 50% as the equilibrium factor and derived radon gas concentration of 4 pCi/L as the derived action limit. If this equilibrium ratio is different, the derived action limit for radon can be different. Example: Suppose measured equilibrium ratio in a home/office is 25 %, the derived action limit is 8 pCi/L (300 Bq/m3). This structure meets the standard even though radon concentration is twice the recommended action limit for radon gas. The mitigation is not required. It is possible to conclude this only if equilibrium ratio is measured. It is best to use radon progeny monitors and determine WL and compare with the action limit of 0.02 WL. The second best is to use radon monitors and compare the results with action limit of 4 pCi/L. If more accurate equilibrium ratio is available, radon concentration can be interpreted more accurately.

Radon Decay Products, Significance of Attached and Unattached Fraction

It is interesting to examine what happens immediately and subsequently after the formation of progeny.

When radon decays, the immediate radon progeny is a charged metallic ion of Po. Being a very small in size with almost atomic size, it starts moving around with high diffusivity. Some of these may pick up a free electron in the environment and become neutral. Some may remain charged. The final nature of this ion can be very different.



c processes of Rn decay

1. Highly reactive ion may become an aggregate with water molecule or other gaseous species.

2. Some of these may loose charge and neutralize in few seconds, others may take more time.

3. These will attach to the aerosol present in the room atmosphere. This attachment depends upon the dust load available in the room. Because of the relatively high abundance of small size particles in the atmosphere, the particle size of attached radon progeny is in the range of 0.5 micron or less. About 10 to 20% of these deposit in the upper part of the respiratory tract (T-B region) and smaller portion in the deep lung and most get exhaled. Such deposited radioactive progeny irradiate relatively small mass of T-B region causing lung cancer. This is the reason that most observed lung cancer cases in uranium mine exposures are in T-B region.

4. Some of these may not find aerosol or surfaces to deposit before being inhaled. Such decay products are termed as "unattached" decay products. Being a very small size with high diffusion coefficient, these deposit almost with 100 % efficiency in the T-B region.

Therefore, the risk of inhaling radon progeny depends upon not only on the total radon progeny concentration, but also on the unattached fraction of the total progeny. Table-1 illustrates this.

The USEPA has recommended the use of 0.02 WL as the action limit based on the unattached fraction of 5%. Assuming that, this combination provides the relative risk of 1.0, relative risks of different combination of the attached and unattached are given in the following Table-1.

Relative risk can go up by a large factor (6.42) when the unattached fraction goes to 50%.

We can work out an example to illustrate the significance.

Example: Let a filtration system reduces progeny concentration from 0.02 WL to 0.01 WL. This is less than acceptable level of 0.02.

If associated unattached radon progeny goes to 30%, then the effective progeny concentration considering the enhanced risk factor 0.0224. Therefore, **it is not below acceptable level.**

If the unattached fraction goes up to 50%, then the effective progeny concentration is 0.0642, considering the enhanced risk factors. Filtration system has enhanced the hazard by a factor of 3, compared no filtration.

When the radon reduction is achieved by filtration technique, the effective risk corrected levels may more than compensate the reduction in some cases.

Table-1

Mean Dose to T-B region per unit Exposure (BEIR IV (1988)

Unattached Fraction (%)	Attached (%)	Rad/WLM(range)	Mean Rad/WLM	Relative Risk Index
5	95	0.50 to 0.57	0.54	1.00
30	70	0.75 to 1.67	1.21	2.24
50	50	0.95 to 2.55	3.50	6.42

Rigorous and Complete Characterization

For evaluating more accurate inhalation risk, and to determine the best mode of providing the solution, rigorous characterization is necessary. This involves measuring concentration of radon, concentration of radon progeny, equilibrium ratio and unattached fraction of progeny. This is more important in large buildings and school system to provide a safe and economical solution.

An Advanced E-PERM System for Simultaneous Measurement of Concentrations of Radon Gas, Radon Progeny, Equilibrium Ratio and Unattached Radon Progeny

The system consists of separate components built into a single instrument carrying box.

Radon Monitor:

E-PERM® Radon monitors (Ref 1 and Ref 2) are listed by EPA and by NEHA/NRSB and are in use from the past 10 years and are known to provide accurate radon measurement in varying radon concentrations, varying humidities and temperatures. For an illustration of the quality. Please refer to a paper in the current conference (Ref 2) by Robert K.Lewis entitled "Short-term Electret Ion Chamber "Blind Test". This forms the first component of this system.

Radon Progeny Monitor 1

Radon Progeny monitor, known as E-RPISU® forms the second component of the system. This measures the total (unattached plus attached) radon progeny concentration in WL units and is listed by EPA/NEHA/NRSB.

The E-RPISU® (Ref 3) is basically composed of an air sampling pump, a flow meter and an electret ion chamber with an appropriate filter holder and an electret. The protocols applicable to other progeny monitors are applicable to this unit also.

An air-sampling pump (0.5 to 2 liters per minute) is used to collect the radon progeny for a known sampling time on a 3.5 cm^2 filter sampler mounted on the side of an electret ion chamber. The flow rate can be adjusted for a desired flow rate. Recommended flow rate is 0.5 to 1 liter per minute. And sampling duration 1 to 7 days. However, EPA protocol requires minimum of 2 days.

Please see Figure 1 for the schematic view of the monitoring head. The filter paper is mounted such that the progeny collected emit their radiation into the interior of the chamber. The alpha radiation emitted by the progeny collected on the filter ionizes air in the electret ion chamber. The ions are continuously collected by the electret, providing integrated alpha activity collected on the filter paper. The standard electrets and the readers used in E-PERM® System are usable with this unit. The initial and final readings of the electret, the flow rates and the duration sampling is used in appropriate equations to calculate progeny concentration in WL units. Software can be used for rapid calculation.

These monitors have sufficient sensitivity to provide results with better than 10% precision at 0.01 WL for a 2 day measurement when used with LT electrets. These provide better than 10 % precision at 0.001 WL, when used with ST Electrets.

Radon Progeny Monitor 2

Radon Progeny monitor, known as E-RPISU® forms the third component of the system. This measures the total (unattached plus attached) radon progeny concentration in WL units and is listed by EPA/NEHA/NRSB.

Wire mesh is used in the place of filter paper to determine the unattached progeny concentration.

One of the methods of measuring unattached decay products of radon is to sample air through a wire mesh.

Two E-RPISU units can be run together, one with the filter and the other with the mesh.

Calculate radon progeny concentration on both using the same procedure. The ratio of the result with mesh to that of filter gives the unattached fraction.

The wirescreen used for this purpose calculates to provide 92% sampling efficiency and comparable with the screen used for the purpose.
The collection efficiency of wire screens for RaA (First daughter of radon) can be theoretically calculated by the equation given by (Ref 4).

Fractional penetration P is given by the following equations:

$$P = 0.82e^{-0.233h} + 0.18e^{-16.7h}$$

$$E = 100\,(1 - p)$$

$$h = 100\frac{M^2\ d\,D}{V}$$

Where E is the collection efficiency in %
M is the mesh size in mesh/cm
d wire diameter in cm
D is the diffusion coefficient of Po-218 (assumed to be 0.06 cm^2 /cm
V is the linear velocity in cm/sec

M=47.24 ; V=12.2 ;d=0.009398 cm was used in the referenced paper and E calculates to be 92.59%.

The parameters of mesh used in E-PERM unattached radon progeny monitors are:

M=37; V=5.3 cm/sec at 1.0 LPM;d=010

Calculation of the collection efficiency of wire mesh for unattached progeny							
d	D	V	M	h	P	100*(1-P)	Reference
0.009398	0.06	12.2	47.24	10.31446	0.074146	92.58541	
0.01	0.06	5.3	37	15.49811	0.022159	97.7841	REI

Combined System

The combined system run simultaneously provides all the parameters necessary to fully characterize radon and radon progeny.

Conclusion

This device uses the same electrets and electret reader used with standard E-PERM Radon Measuring System. Current users can use this device with only a small additional cost and become an advanced laboratory, capable of measuring health risk related parameters.

References:

1. P.Kotrappa, J.C.Dempsey, R.W Ramsey, and L.R.Stieff "A Practical Passive Environmental radon Monitor for Indoor Radon Measurement" Health Physics p

2. Robert K. Lewis "Short Term electret Ion Chamber "Blind" testing Program Paper presented at 2003 International Radon Symposium, Nashville, conducted by AARST.

3. P.Kotrappa, J.C.Dempsey, L.R.Stieff, and R.W.Ramsey "An E-RPISU (Electret Radon Progeny Sampling Unit), A New Instrument for Measuring Radon Progeny Concentration in Air" Paper B-III-1, 1990 International Symposium on Radon and Radon Reduction Technology, conducted by USEPA, held in Atlanta, GA, Feb 1990

4. M. Raghavayya and J.H. Jones "A Wire Screen –Filter Paper Combination for the Measurement of Fractions of Unattached Daughters in Uranium Mines" Health Physics: 26: (417-429), 1974

E-RPISU™
(Electret-Radon Progeny Integrating Sampling Unit)
Schematic