

CHAPTER 32

The LSC Approach to Radon Counting in Air and Water

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INTRODUCTION

Various methods exist to monitor ^{222}Rn in air. There are seven commonly used types of detection: alpha track, activated charcoal adsorption, continuous radon monitoring, continuous working level monitoring, grab radon sampling, grab working level sampling, and radon progeny integrated sampling. Of these methods, the passive diffusion activated charcoal canister technique has been the method of choice when screening for radon. The liquid scintillation method is an improvement of the activated charcoal canister technique. Specially designed air detectors containing a small amount of activated charcoal and desiccant serve as the collection and counting vial. Because the liquid scintillation method offers the advantages of higher sensitivity, higher throughput, and shorter exposure times, interest in the method of measuring radon in air has increased.

Radon in water has been measured by both the Lucas cell^{1,2} and liquid scintillation methods.³ The liquid scintillation technique combines the advantages of minimal sample preparation time (1 min/sample), small sample sizes (10 mL), and high sensitivity (200 pCi/L).

This chapter will describe a liquid scintillation method for measuring radon in both air and water—the PICORAD™ system from Packard Instruments. Data comparing air measurements made with typical charcoal canisters and the liquid scintillation detectors will be presented.

RADON IN AIR USING LIQUID SCINTILLATION

The Detector

The PICORAD detectors are passive devices requiring no power. They are integrating detectors that determine the average radon concentration in the air they are placed.

The detector consists of a porous canister welded securely near the top of a plastic liquid scintillation vial. The porous canister contains a bed of a controlled weight of charcoal (1.3 g) and silica gel desiccant (0.9 g). The vial has a removable cap and an O-ring seal to prevent moisture or radon from entering the vial during storage and after exposure.

Exposure Procedure

To initiate the exposure, the vial is uncapped to allow radon laden air to diffuse into the charcoal. The nominal measurement time is 48 hr, at which point the radon accumulation has reached 95% saturation. A testing time of 24 hr is recommended in the summer when moisture problems can be severe. A 2 day exposure at 100% humidity will result in a 5% weight gain and a subsequent 10% loss of maximum counts. The radon accumulation reaches 80% of its saturation value in 24 hr. The rate of radon accumulation in the PICORAD detectors, empirically determined over a span of 9 hr to 5 days at room temperature, is shown in Figure 1. At the end of the exposure time, the detector is capped and sent to the laboratory for analysis.

Elution Procedure

In the laboratory, 10 cc of xylene based cocktail (InstaFlour™ Packard Instruments, Meriden, CT) is syringed or pipetted into the bottom of the detector, which is then recapped. With the cocktail below the charcoal canister, the desorption takes place through the vapor phase. Desorption is more than 80% complete after 3 hr (the time for full equilibrium of the decay product). The count rate reaches its maximum value in about 8 hr. The elution curve vs time, generated at room temperature, is shown in Figure 2. This curve is in good agreement with the elution curve determined by other investigators using a similar airborne radon detector of their own design.⁴

Analysis of Results

A calibration constant of 37 cpm (pCiL⁻¹)⁻¹ has been empirically determined at room temperature. Counts per minute corrected for background, are multiplied by the calibration constant and by correction factors for the decay of radon, for adsorption time, and for elution time. The calculations are part of a computer program licensed through Niton Corporation in Bedford, Massa-

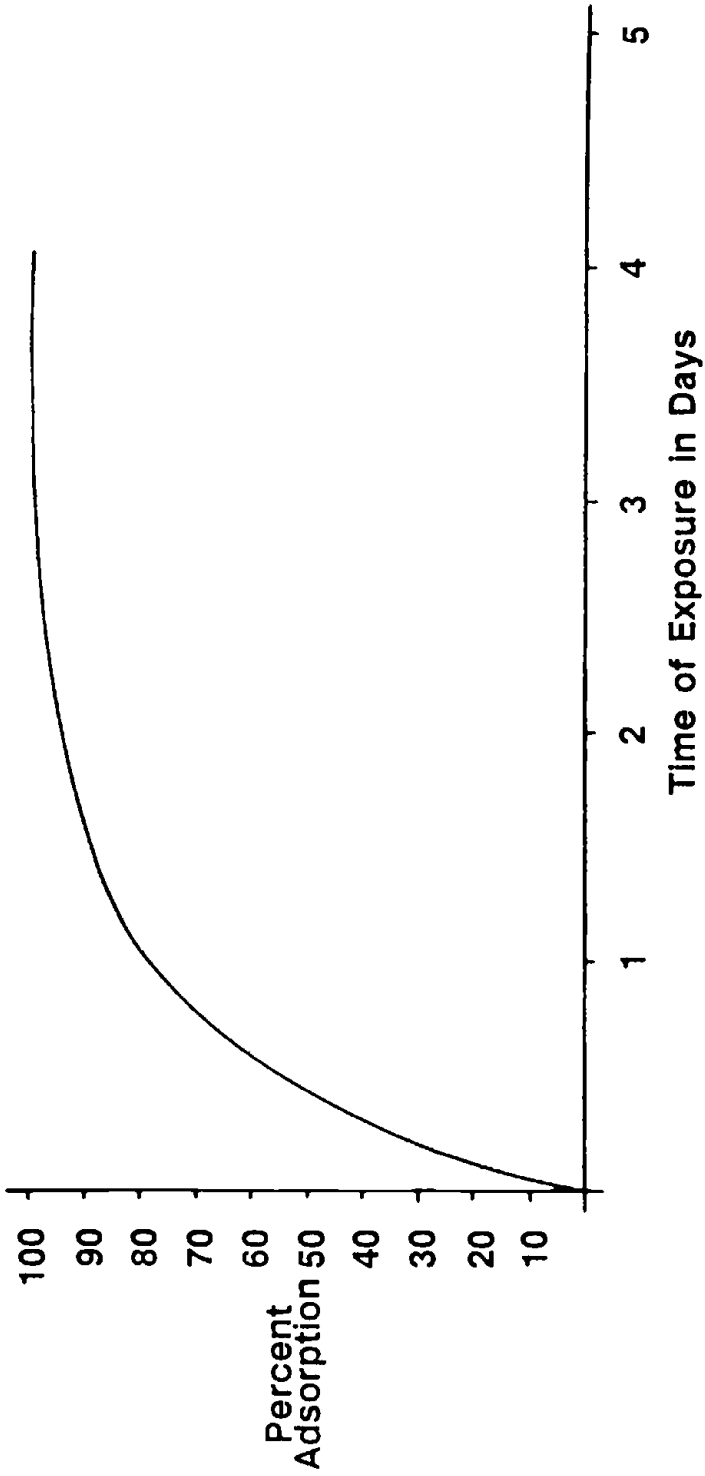


Figure 1. Adsorption of radon in air in PICO-RAD detectors.

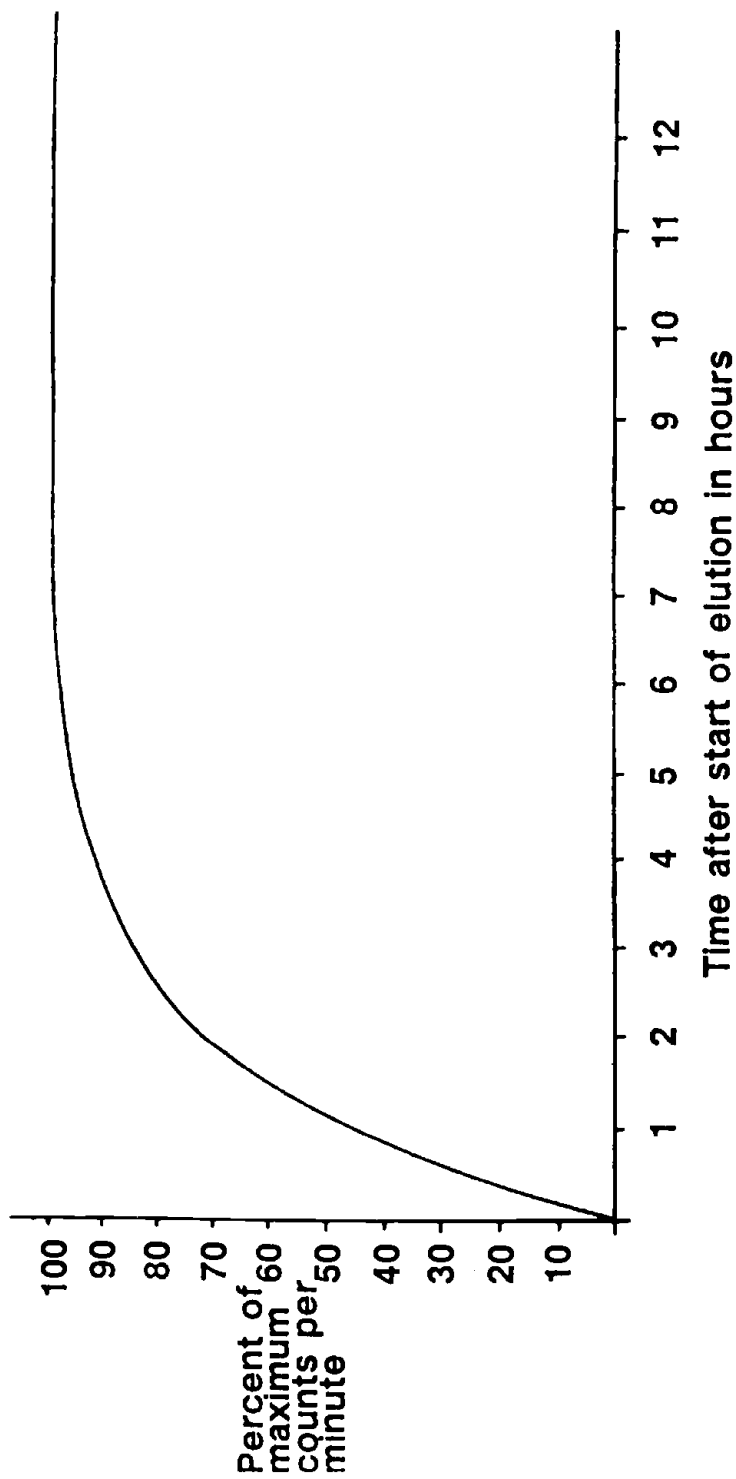


Figure 2. Desorption of radon from PICO-RAD detectors using a xylene based cocktail.

chusetts. The general form of the equation programmed into the computer is as follows:

$$I \text{ (pCi/l)} = K (N_1 - N_0) \frac{e^{(T_4 - T_2)/r_0}}{(1 - e^{-(T_2 - T_1)/r_1})^{-1} (1 - e^{-(T_4 - T_3)/r_2})^{-1}}$$

- where
- I = radon concentration in pCi/l
 - K = normalization constant that converts net cpm to pCi/l
 - N_1 = cpm obtained in the appropriate energy window of the LSC
 - N_0 = mean value of the background counts obtained from many background samples
 - r_0 = mean life of ^{222}Rn
 - r_1 = mean time for the adsorption of radon into the activated charcoal
 - r_2 = mean time for desorption of the radon out of the activated charcoal and into the liquid scintillation eluant
 - T_1 = exposure start time
 - T_2 = exposure end time
 - T_3 = time the elutant cocktail was placed in the detector
 - T_4 = analysis time

Comparisons with the Charcoal Canister Technique

A side by side study was performed to investigate the correlation of results obtained with the activated charcoal canister and the liquid scintillation method.

The charcoal canisters were obtained from Canberra Industries, Meriden, CT. The basic design and analysis of the canisters is the same as described by George.⁵ An individual container is 10.2 cm by 3.3 cm in dimension and contains 150–200 g of activated charcoal. The container has no diffusion barrier. The canisters were weighed before and after exposure to determine the moisture content and correct for humidity.

The liquid scintillation detectors are the PICORAD detectors described earlier. The study consisted of exposing both types of detectors at the same location in the basement of eight private homes.

Results

Figure 3 is a bar graph illustrating the results of side by side exposures done in eight private homes. From the graph, it is apparent that the liquid scintillation results compare favorably to those obtained by the activated charcoal canister method over a range of radon levels. This relationship is shown in Figure 4. The data plotted are the mean values of 2 to 6 individual determinations for each test. The individual results for tests number 7 and 8 are pre-

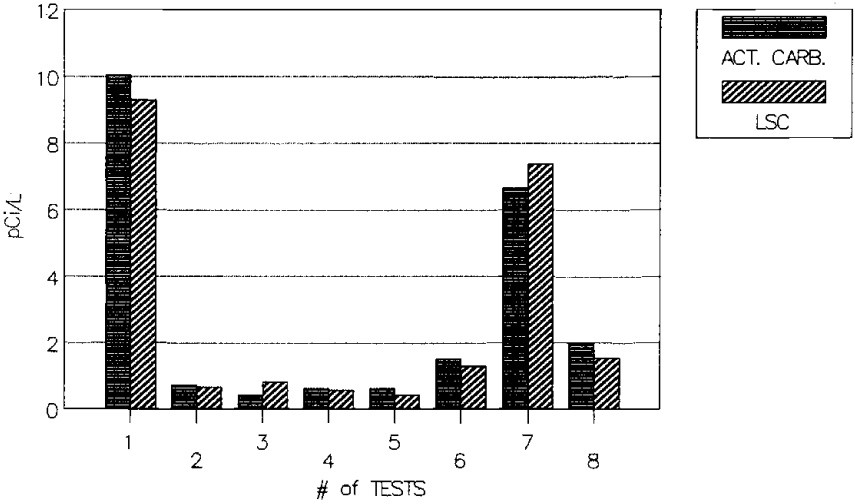


Figure 3. Method comparison of radon levels in eight private homes.

sented in Table 1. Six determinations with each method were made for these tests, because these were the homes found to have significant radon levels from an earlier screening. Student t tests were done to determine if the difference between the mean exposures for each method is significant. As reported in Table 1, the p values for test 7 and 8 indicate that in test 7, the mean values did not achieve a level of significance, while in test 8 they did. Even though the mean values for test 8 seem close, the standard errors around the means are

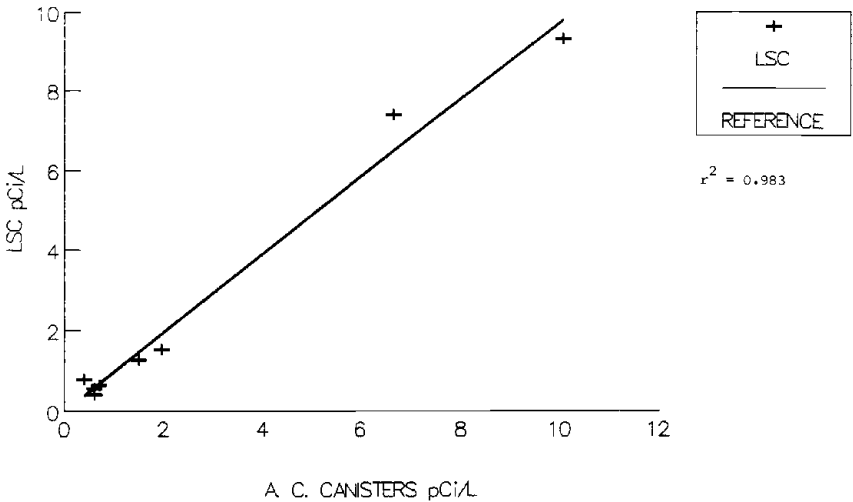


Figure 4. Relationship of radon measurements made with the activated charcoal and liquid scintillation methods.

Table 1. Individual Data and Statistics for Tests Numbered 7 and 8^a

Sample	Test 7		Test 8	
	A.C.	LSC	A.C.	LSC
1	7.0	8.9	1.9	1.8
2	6.8	6.4	2.3	1.6
3	6.3	6.8	1.7	1.2
4	7.1	8.1	2.0	1.5
5	6.5	7.3	2.0	1.5
6	6.2	6.8	1.9	1.6
Mean	6.65	7.38	1.97	1.53
S.D.	0.37	0.94	0.197	0.197
%CV	5.6	12.8	10.0	12.8
Student t	1.77 10 df p > 0.1		3.88 10 df p < 0.01	

^aRadon Levels pCi/L.

small, accounting for the level of significance achieved. Ideally, a t test run on a larger sample size would be more appropriate.

RADON IN WATER

The Collection Technique

The method of collection is important to insure against loss of radon from the water sample. The water collection procedure used here is based on EPA documents and individual test results. The collection technique is as follows:

If taking water from a faucet, remove the aerator and draw the water for five to ten minutes for the sample to be fresh. The water drawn should be a cold water sample since radon is less soluble in warm water. If taking water from a lake or stream, a direct sample can be taken. The recommended container is a standard EPA type water collection bottle with a volume of at least 20 mL. These vials have rubber-teflon plenums and prevent leakage of radon from the vial. Tests of radon leakage from water in such bottles indicate that the mean leakage time exceeds 3000 hr. The bottle should be filled such that a minimum amount of air is retained, preferably less than 1 cc, since radon prefers to be in air rather than water in the ratio of 4:1. As a result, a 1 cc bubble of air in a 20 mL bottle will yield an apparent radon concentration in the water which is 9% lower than the true concentration.

The Elution Procedure

The elution procedure for radon in water begins with a 20 mL syringe filled with 10 mL of Opti-Flour[®] O (Packard Instruments, Meriden, CT.). The cap of the water collection bottle is removed, and 10 mL of water is drawn into the syringe from the bottom of the bottle. The 20 mL mixture is then transferred to a liquid scintillation vial for counting. The syringe should be rinsed with "radon free" water between each test. The liquid scintillation vial is then shaken for approximately 5 sec (not critical) and set aside for equilibration of

the radon into the scintillation cocktail. A typical count rate vs time curve such as the one reported by Prichard³ is shown in Figure 5. As can be seen from the figure, a 3 hr equilibration time is appropriate. The elution will then be more than 95% complete.

Counting the Water Sample

Each decay of radon in the water will result in five detected counts: three alpha particles and two beta particles. The efficiency of counting the alphas and betas is close to 100%, with the lower level discriminator on the liquid scintillation counter set to 25 keV and upper value set to 900 keV. This value has been determined using a Bureau of Standards source of radium in water.

The number of pCi of radon in the water is calculated using the following formula:

$$\text{pCi/l} = (N - N_1) * 100 / (5 * 2.22 * 0.964) (D)$$

- where
- N = cpm obtained from the liquid scintillation counter
 - N₁ = background cpm
 - 100 = multiplication factor to give the concentration in pCi/l
 - 5 = number of counts per decay of radon
 - 2.22 = number of decays of radon per minute per pCi
 - 0.964 = correction factor applied for the radon in air vs water in the collection bottle
 - D = radon decay correction factor

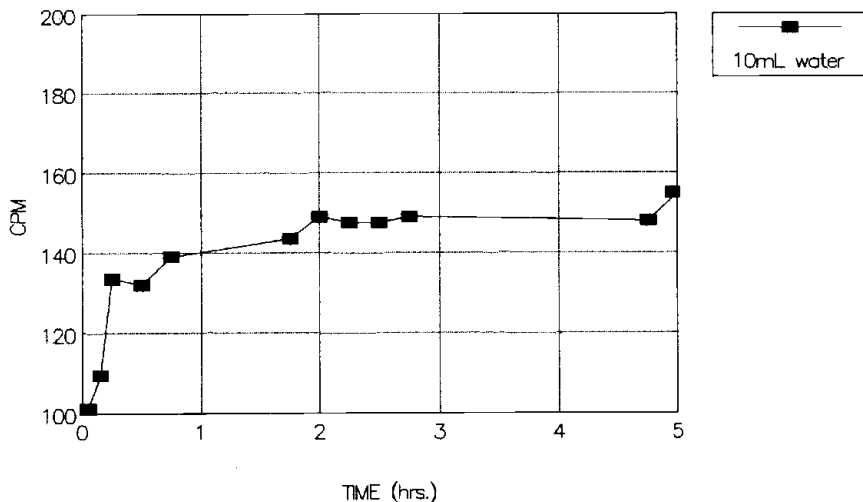


Figure 5. Count rate vs time for a 10 mL water sample in 10 mL of Opti-Fluor O.

A background sample can be prepared by from water drawn from a municipal source and either aerated for a number of hours, heated to 80°C for several hours, or allowed to stand idle for several months.

Comparisons with the Lucas Cell Method

A good correlation exists between the results obtained with the liquid scintillation and Lucas cell method. In early experiments, Prichard³ reported a 9.34 counts/min/pCi calibration factor from a plot of the relationship of the liquid scintillation count rate vs the Lucas cell results.

The predicted value, based on the relative solubilities of radon and the volumes of water, scintillation fluid, and air in the collection bottle, was 9.75 counts/min/pCi. This relationship is shown in Figure 6.

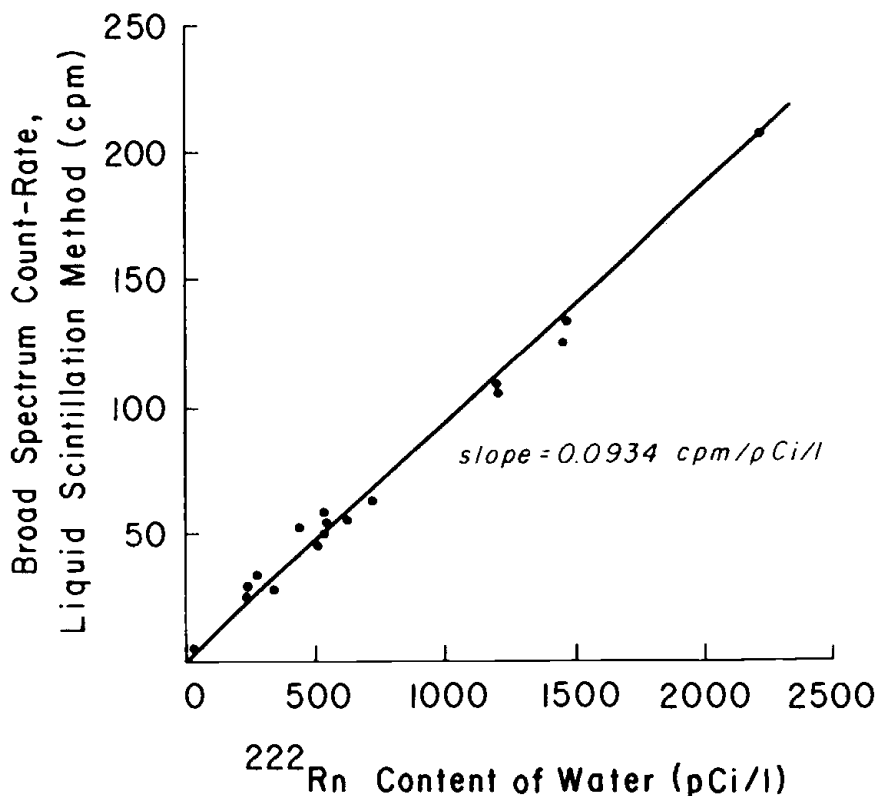


Figure 6. Count rate by liquid scintillation method vs ^{222}Rn content of water as determined by radon bubbler and Lucas cell. (This figure reproduced with the permission of Dr. Howard M. Prichard.)

Summary

The liquid scintillation method offers many desirable advantages for the measurement of radon: (1) Only one counting system is required to measure radon in both air and water. (2) The method is fast. A short exposure time of 24–48 hr for air measurements is ideal for short term screening. (3) The method is simple. Water samples can be counted directly while special air detectors serve both as a collection device and counting vial. (4) The method offers high throughput capabilities. Up to 200 samples can be counted and analyzed in a 24 hr period. (5) The method is accurate. It has passed EPA proficiency testing in rounds 4 and 5 and is currently a method listed by that agency for radon monitoring. (6) Measurements made with the liquid scintillation method show good correlation with established procedures for quantitating radon in air and water.

REFERENCES

1. Lucas, H.F. "Improved Low Level Alpha Scintillation Counter for Radon," *Rev. Sci. Instrum.*, 28:680 (1957).
2. Lucas, H.F. "A Fast and Accurate Survey Technique for Both Radon-222 and Radium-226," in *The Natural Radiation Environment* J.A.S. Adams and W.M. Lowder, Eds. (Chicago: University of Chicago Press, 1964), p. 315.
3. Prichard, H.M. and T.F. Gesell. "Rapid Measurements of ²²²Rn Concentrations in Water with a Commercial Liquid Scintillation Counter," *Health Physics*, 33:577–581 (1977).
4. Schroeder, M.C., U. Vanags, and C.T. Hess. "An Activated Charcoal-Based, Liquid Scintillation Analyzed Airborne Rn Detector," *Health Physics*, 57(1):43–49 (1989).
5. George, A.C. "Passive, Integrated Measurement of Indoor Radon Using Activated Carbon," *Health Physics*, 46(4):867–872 (1984).