A NOVEL APPROACH FOR AUTOMATION OF RADON MEASUREMENTS USING ACTIVATED CHARCOAL

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ABSTRACT

A "new" method for measuring typical household radon concentrations has been developed. Screened containers holding under ten grams of activated charcoal have been successfully used in conjunction with an automated gamma ray spectrometer to determine radon concentrations. Liquid scintillation was not necessary. This method has been tested and calibrated for exposure time, decay time, temperature, and humidity at East Stroudsburg University. Additional exposures were made at Bowser Morner's Radon Calibration Laboratory. Our calculations of the radon concentrations were within 5% of the actual values. An intercomparison study with Prosser Laboratories' charcoal canisters in northeastern Pennsylvania also yielded good results. We anticipate that this method will be economically competitive with other methods and will allow many radon testing facilities to significantly automate their measurements and remove the need for cocktails.

INTRODUCTION

Reader's Note

The introduction of this paper contains the motivation for this work. Section 2 describes a feasibility study which determined numerous parameters of the vials to be used in this work. Section 3 describes the initial calibration of the system using East Stroudsburg University's radon chamber, while section 4 contains the results of the intercomparison study with Prosser Laboratories' charcoal canisters. Section 5 contains the quality assurance analyses performed via Bowser Morner's radon chamber. The last sections contain conclusions, acknowledgments, references, and figures.

Radon Detection Methods

Numerous detection techniques are currently used including pulse ionization chambers, electret ionization chambers, scintillation detectors with zinc-sulfide, alpha particle spectrometers, diffused junction detectors, gamma ray spectrometers using scintillation crystals, and the etching

of nuclear tracks in solid-state materials (George 1996). Most of these techniques can be classified as either grab-sampling methods, continuous monitors, or integrating monitors (Nazaroff & Nero 1988).

Currently the different methods are competitive in terms of price, accuracy, and turn-around time for results. Arguably the least expensive and most popular short-term tests use activated charcoal as a passive device for periods from two to seven days. The ability of activated charcoal to adsorb gases is well known and its ability to adsorb radon has been known since 1906 (Rutherford 1906). Typical passive detectors use between 25 and 200 g of activated charcoal as an adsorbent for radon gas. Collected gas is then analyzed with a NaI(Tl) crystal that detects gamma radiation emitted by radon progeny. The lowest level of detection (LLD) for this method is often 0.1 to 0.2 pCi/L and acceptable charcoal detection devices are accurate within the EPA's recommended range of 25%. This test costs the consumer from $10 to $30 and a typical waiting period of seven to ten days after sending the collector to the laboratory for analysis. Laboratory start-up costs include $15K to $30K for the detection equipment and about $1 for each collector (George 1996). A related use of activated charcoal detectors requires desorption of the radon into a scintillation cocktail followed by liquid scintillation counting techniques (Nazaroff & Nero 1988, George 1996). Although this technique only uses 1 to 2 g of charcoal, it requires more handling and increased health and flammability risks (Freifelder 1982, Hawkins & Steiner 1992).

Any industry, including the radon detection industry, that requires a repetitive process can possibly benefit from automation (Cohen & Cohen 1983). Connecticut's State Department of Health distributed 2000 short-term charcoal cartridges as part of a grant from the EPA in 1986 for a statewide radon screening program (Graves 1987). Key Technology, a leading manufacturer of radon-detection devices, sold 30,000 kits in 1994 (*Consumer Reports* 1995). These are two of many examples that would require individual handling and analysis by technicians. As of 1994, the EPA estimates that over 10 million homes in the U. S. have been screened for radon and approximately 1 million of these have needed mitigation. Approximately 85% of the residential buildings in the U. S. have not been tested and the EPA is recommending that all homes be tested in real estate transactions (George 1996).

The medical industry has been using automation for many years to analyze radioactive samples. The Beckman Gamma 8000 and Gamma 9000 Counting Systems have the intended purpose of use during *in vitro* diagnostic radioassay and radioimmunoassay procedures that count gamma ray emissions by gamma scintillation techniques (Price 1979). Both Beckman Instruments and Packard Instruments currently produce automated liquid scintillation counters to test water samples for radon concentrations (Cothern & Rebers 1990). Since charcoal canisters are typically analyzed by detection of gamma rays by scintillation counters, the following question arose: Could currently available automated counting systems be effectively used to measure average household radon levels without the use of scintillation cocktails?

We have been investigating this question by using Beckman's Gamma 8500 counting System to detect gamma rays emitted from radon adsorbed to 9.0 g of activated charcoal held in 20 ml vials. Excellent agreement was found between our calculations and levels reported for

exposures at Bowser-Morner's Radon Calibration Laboratory. An intercomparison study with Prosser Laboratories, Inc. also yielded good results. As a result of this research, we have applied for a provisional patent for our method.

GENERAL MATERIALS AND METHODS

Beckman Gamma 8500 Counting System

The central focus of this study involved the use of the Beckman Gamma 8500 Counting System. This system uses a microprocessor to control delivery and detection of gamma radiation from up to 300 samples loaded on a conveyor belt. It can be operated in either manual or autocount modes. Samples are lowered by an elevator to two possible positions in front of a gamma ray detector using an inorganic scintillating material coupled to a photomultiplier tube and various electronic systems. A three inch diameter, three inch long cylinder of a sodium iodide crystal doped with approximately 0.1% thallium is used as the scintillating material. Up to two channels are available for counting different energies. Various counting programs (which can be modified) manipulate the data before the results are printed. Quantities such as count time, number of counts, counts per minute, sample position, two-sigma uncertainty percentage, and scanned energy range can be calculated and printed.

Sample diameters must be less than 1.1 inches and sample heights must be less than six inches. Sample column heights less than 1.5 inches should be counted in the high elevator position and heights greater than this should be in the low position for optimum sample geometry and therefore better counting efficiencies. Since the crystal diameter is three inches, sample heights of greater than three inches will be subject to decreased counting efficiencies. Small 20 ml vials (one-inch diameter, 2.375 inch height) and large 40 ml vials (one-inch diameter, 3.875 inch height) manufactured by Industrial Glassware were used in this investigation. For maximum counting efficiency these vials should therefore be placed in the low elevator position. Since the 40 ml vials are taller than the crystal they were subject to a decreased counting efficiency.

Trials were counted using both the manual and autocount modes. Library Program #7 was found to be a useful program with a few alterations. A sample print-out and brief description of a modified program used for this investigation is shown in figure 1 for the autocount mode.

If an initial background check was made and entered as the BKG for channel 1, the machine would print the net CPM. This option was exploited for the intercomparison study with Prosser Laboratories and to analyze vials exposed at Bowser Morner Laboratories. In these two cases, the PST was set to a maximum of four hours in order to detect low radon concentrations.

Radon Chamber

Radon gas for East Stroudsburg University's radon chamber was provided by pumping air using either the building's compressor or a Wave Castle Air Aquarium Pump at a flow rate of 1.0 L/min through a Dwyer flow meter. This air was then passed through a W. A. Hammond Drierite Company desiccant and into a Pylon Radon source (Model 1025, serial number A-184, maximum

output of 0.764 Bq/min). Next the radon gas was directed into a sealed rectangular plastic chamber of approximate dimensions 60 cm by 40 cm by 30 cm high via a diffusive tube mounted in the upper left side. An exhaust tube allowed air to vent from the lower right side of the chamber through a window located above the back of the chamber. Concentration of the chamber was monitored by continuously pumping air at a flow rate of 0.5 L/min from the center of the chamber through an Omega flow meter, a piece of filter paper, a Pylon Lucas Cell (model 300A, serial number 159) mounted to a Pylon AB-5 radiation monitor, and back into the chamber. The monitor was set in the continuous sampling mode generally for one hour intervals and was interfaced with a Pylon Model PPT-1 Portable Printer to tabulate the results. Some of the results were downloaded to a computer and exported into EXCEL using the Pylon Model CI-55 Computer Interface Accessory.

A small door in the front of the chamber allowed access for placement and removal of vials and other instruments. An analog meter was placed inside the chamber to monitor temperature and relative humidity. Continuous sampling of the temperature was periodically done with a Pasco Temperature Probe placed inside the chamber and interfaced to a computer using Pasco's Science Workshop interface. To raise the temperature of the chamber above ambient levels, 100 W and 200 W light bulbs were placed in the chamber. To lower the temperature below ambient levels, blocks of ice were placed on top of the chamber. Pumping the intake air through a desiccant generally kept the relative humidity at low levels. To raise the relative humidity, a beaker of water was placed in the chamber. Background levels of Lucas Cells and the room were checked.

Flow rates, internal temperatures, and internal relative humidities were recorded on a regular basis. Due to inconsistencies of the compressors, intake flow was found to vary from 0.8 to 1.2 L/min. The internal pump of the Pylon Monitor was set at a flow rate was 0.5 L/min and radon concentrations in the chamber were varied from 12 to 22 pCi/L depending on the trial. Small fluctuations in the radon level were present for most trials as shown in figure 2.

Continuous monitoring and recording of temperature was done for two weeks using a Pasco Temperature Probe interfaced to a computer using Pasco's Science Workshop interface. During the calibration phase of this project, relative humidity was varied from 7% to 55% and temperature was varied from 60^0 F to 110^0 F.

Activated Charcoal Vials

During the feasibility study, small and large glass vials (described previously) were numbered and masses were measured. Due to the penetrating ability of gamma rays, the vials were numbered directly on their sides with ink with no concern for absorption. Two sets of caps, one closed-top and a second equipped with Whatman #1 filter paper covering an open top, were correspondingly numbered and masses were measured. A diffusion barrier was initially used to extend the integration time for radon collection (Prichard and Marien 1985, Cohen & Nason 1986, George and Weber 1990). The activated charcoal was baked for seven hours in a 225^0 F oven to vaporize adsorbents, in particular, the radon progeny and water (George 1984). Immediately after baking, 9.0 g of charcoal was measured into the small vials and 16.5 g of

charcoal was measured into the large vials. Vials were immediately sealed with the closed-top caps. Charcoal column heights of 1.5" and 2.75" were topped by an air space of 0.75" for the small and large vials respectively.

After being used in a trial, masses of the vials were remeasured. Before reusing the vials, they were uncapped and baked for approximately twelve hours in an oven set at a temperature range between 225^0 and 250^0 F. Again, vials were immediately resealed and masses were remeasured. A few control vials were labeled and used as background checks. These were identical to other vials but remained sealed and were not placed in the radon chamber. Vials were given a background check after baking as a quality control measure. As expected gamma counting of these baked vials showed a return to background levels.

A piece of filter paper was used as a diffusion barrier between the air in the radon chamber and the activated charcoal in the vials during the first six trials of the feasibility study. Immediately prior to exposure sealed caps were replaced with filtered open-top caps. Immediately following removal, filtered-caps were replaced with sealed caps. The last trial used unfiltered open-top caps that were replaced by sealed caps before and after exposure.

For the calibration phase and intercomparison studies, essentially open-faced 20 ml vials containing 9.0 g of activated charcoal were used. Fine mesh screens were fastened with GE - Silicone II - Household Glue and Seal. This glue has a temperature rating of 400^0 F so it can be safely baked in an oven with the vials following exposures. The shape of the mouth of the vial, in conjunction with additional restrictions of the glue along the edge of the screen, may allow the collector to behave as if a simple diffusion barrier is present (Prichard & Marien 1985). Polypropylene closed-top lids were screwed onto the numbered vials. Some of these lids were teflon-lined.

FEASIBILITY STUDY

Methods

To determine the feasibility of this method, a total of seven trials were initially conducted during a span of two-and-a-half months. (See figure 3). Comparisons were made between 20 and 40 ml vials, upright and prone vials, and vials with and without diffusion barriers. Detection efficiencies were determined for each configuration. Time required to reach saturation was determined for vials with and without diffusion barriers. To check for an air-tight seal of the vials following closure, the decay rate was determined and compared with that of radon gas.

Results of initial trials determined the nature of later trials. The original intention was to run the necessary trials to determine an optimum configuration for the charcoal vials. If this optimum configuration seemed viable, particular trials were to be run in order to calibrate for the effects of exposure time, time out of the chamber, temperature, and relative humidity. Since the larger vials did not provide an increased yield, the fourth trial again used the smaller vials placed on their sides. Ambiguous data from the fifth trial led to another attempt to compare small

upright and sideways vials for the sixth trial. In an attempt to gain an increased counting efficiency, the seventh trial was run without a diffusion barrier. Since there was only minimal gain in efficiency using sideways vials, it was decided to place these open vials in an upright position for sake of simplicity.

Results and Conclusions of the Feasibility Study

As indicated in figures 4 and 5, the larger vials used in trial #3 did not result in an increased detection ability. On the contrary the results were actually the worst of the seven trials. A plausible explanation is that since the larger vials were taller than the scintillation crystal, any advantage gained by an increase in radon adsorption was canceled by a decrease in counting efficiency with the Beckman machine. Vials placed sideways were expected to produce a higher yield than those standing upright but once again this did not seem to be the case. Although trial #6 did show a slightly higher yield for the sideways orientation, trial #5 indicated no gain. The best results were obtained in trials #5 and #7. This last trial used small upright vials without a diffusion barrier resulting in an increased gamma emission by several counts per minute per picocurie per liter compared to most other trials, all of which used filter paper as a diffusion barrier. The resultant counting time required to reach the two-sigma confidence level with a 10% uncertainty would be 188 minutes to detect a level of 1.0 pCi/L, 50.7 minutes to detect a level of 2.0 pCi/L, and only 14.5 minutes to detect the EPA's action limit of 4.0 pCi/L.

As figure 6 indicates, checks for the saturation points of vials with and without diffusion barriers yielded approximately the same result of four to five days. The vials without the barrier simply collected more radon. When the last vial from trial #7 was removed on day five, it did show a slight increase in activity but this was probably due to a statistical variation.

Although the original purpose of trial #4 was to determine the saturation point of the vials, data was also gathered to calibrate against time out of the chamber. As indicated on figure 7, the effective half-life of the sample was slightly less than four days which compares favorably with the 3.82 day half-life of radon. As expected, the exposure time did not appear to effect the slope of the line.

ESU CALIBRATION PHASE

Methods

The orientation and construction of the vials chosen for the calibration phase were previously described. From 7/10/97 through 8/30/97, several tests were conducted at a variety of humidity levels, temperatures, exposure times, and decay times to calibrate for these effects. Quadruplicate measurements (four different vials) were made for the calibrations involving temperature and humidity. Duplicate and quadruplicate measurements were made for calibration of exposure time. Temperature was varied from approximately 19^0 to 27^0 C. Relative humidity was varied from roughly 7% to 55%. Exposure time was varied from one to seven days. Decay time following exposure was varied from zero to four days. Figures 8, 9, and 10 provide additional details regarding specific exposures.

Results and Conclusions of the Calibration Phase

As shown in figure 8, counting yield was found to decrease linearly with increasing temperature. Increased humidity levels also decreased the counting yield. As shown in figure 9, a linear fit was chosen as a first-order approximation. Radon adsorption as a function of time is analogous to charging a capacitor. In this case, figure 10 shows that our vials have an integration time constant that is sufficient to allow for integration periods between 2 and 7 days. Decay time was again found to be 3.8 days.

After testing for these factors an algorithm to allow for efficient calculation of radon concentrations was determined.

INTERCOMPARISON STUDY WITH PROSSER LABORATORIES

Methods

Two ESU vials were simultaneously deployed with two charcoal canisters from Prosser Laboratories in nine different locations including eight homes and ESU's radon chamber. This would allow an intercomparison of the duplicate measurements to check for variability. Participants were given the vials and canisters with the standard instructions from Prosser Laboratories concerning test procedures. Following exposure, most of the canisters were collected and returned to Prosser Laboratories on a Friday afternoon where they waited until Monday for analysis. The ESU vials were placed in the Beckman Gamma 8500 Counting System and a program was run that allowed for automated counting overnight and calculation of the net count rate. Decay time was therefore kept under one day

Exposure times chosen by the participants ranged between 2.00 and 5.38 days. Temperatures were reported ranging from 60^0 to 70^0 F. Most of the exposures were made in basements or cellars of the homes.

Results and Conclusions of the Intercomparison Study

Radon concentrations found ranged from approximately 1 to 60 pCi/L. Count times required to measure these levels at the two sigma confidence level with a 10% uncertainty ranged from 5 to 57 minutes. Total time required for the automated counting of the 18 vials was approximately 12 hours yielding an average count time of 40 minutes. Mass gains ranged from 0.0 to 0.5 g indicating relative humidites ranging from approximately 20% to 87%. Using our initial algorithm, our calculations were found to be 5.3% higher on average than Prosser's. The precision value of the ESU vial duplicates was typically 1%.

This intercomparison study indicates that use of our method yields values which are both accurate and precise. Figure 11 provides a synopsis of this study.

CALIBRATION AND QUALITY ASSURANCE CHECKS VIA BOWSER MORNER LABORATORIES

Methods

Five sets of quadruplicate exposures were made at Bowser-Morner's Radon Calibration Laboratory. This chamber is similar to those used by the U.S. EPA radon facilities. Similar to the EPA, radon gas is generated by a radium-226 standard source. Bowser Morner is a commercial source of radon calibration in the United States.

Vials were sent and returned using United Parcel Service's 2nd Day Air Delivery. Exposure times ranged from 2.00 to 6.00 days. Temperature was held fairly constant at 70^0 F. Radon chamber concentrations were held constant for individual exposures and ranged from 9.6 to 113.1 pCi/L. Lower concentrations were not available during this study. Decay times ranged from approximately 2.3 to 3.2 days. Mass gains ranged from 0.0 to 0.5 g. Gamma rays were counted in the same manner described for the intercomparison study with Prosser Laboratories.

Results and Conclusions of QA Checks

With a calibration factor of 1.14 our algorithm yields excellent agreement with the measurements made at Bowser Morner Laboratories. On average our measurements of the radon concentrations were 2.1% lower than those reported in the Bowser Morner chamber. Once again there was good reproducibility amongst quadruplicate measurements as indicated in figure 12. Count times required to measure these radon concentrations at the two sigma confidence with a 10% uncertainty ranged from 4 to 36 minutes. Based on the mass gains, relative humidites were calculated to be between 20% and 70%. Although this is a fairly wide spread, 80% of our calculations were within 10% of the reported relative humidities. Figure 12 provides a synopsis of the exposures at Bowser Morner Laboratories.

CONCLUDING REMARKS

Results of this study indicate that the technique of an automated gamma counter using open faced vials containing only activated charcoal produces results that easily satisfy the accuracy and precision requirements of industry and government protocols. Furthermore, it eliminates all the problems associated with scintillating cocktails and greatly reduces the manpower needed by laboratories using charcoal canisters.

ACKNOWLEDGMENTS

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FIGURES

PROG 7	USER 1	(Loads a general counting program for user #1.)
CNT CH 1	1 TIMES	(Channel one is used to count the sample once.)
CSS	1 TIMES	(The set of samples is counted once.)
E R	2.0	(An energy range from 0 to 2 MeV will be counted.)
ELV	0	(Elevator is in the low position.)
CALC	1	(Results will be converted to CPM.)
PST	15.00 MIN	(Each sample will be counted for 15 minutes max.)
CH 1	.00 2 SIGMA %	(By setting to 0, count time will not be reduced.)
	.0 LSR	(By setting to 0, samples will not be rejected.)
	.0 BKG	(By setting to 0, background is not subtracted.)
	.00 2 SIGMA B	(By setting to 0, count time will not be reduced.)
	10 LL	(Lower limit for channel set as low as possible.)
	1000 UL	(Upper limit for channel set as high as possible.)

Fig. 1. Sample program for the Beckman Gamma 8500 Counting System

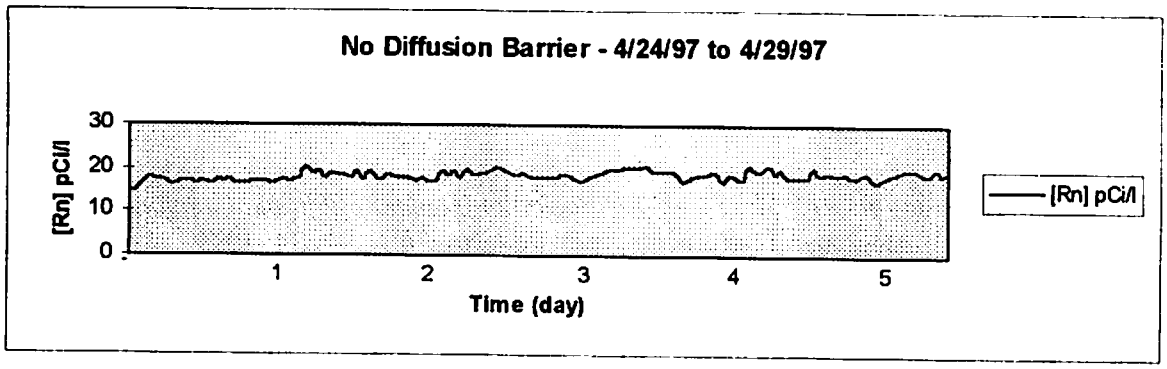


Fig. 2. Typical radon concentration of East Stroudsburg University's radon chamber for this study.

Trial Summary			Ave [Rn] in chamber
Trial #	Date- 1997	Description	(pCi/L)
1	2/15 - 2/17	5 small, on side	16.80
2	2/17 - 2/19	5 small, on side, repeated	12.14
3	2/20 - 2/22	5 large, on side	13.16
4	3/5 - 3/12	14 small, side, sat. pt.	16.32
5	3/28 - 4/1	4 up vs. 4 on side, small	21.16
6	4/20 - 4/22	8 up vs. 8 on side, small	18.39
7	4/24 - 4/29	19 up, open, small, sat. pt.	18.33

Fig. 3. Summary of trials run during the initial feasibility study.

	Ave [Rn] in chamber		Yield
Trial #	(pCi/L)	Net CPM	CPM/pCi/L
1	16.80	356	21.2
2	12.14	294	24.2
3	13.16	258	19.6
4	16.32	396	24.3
5u	21.16	546	25.8
5s	21.16	543	25.7
6u	18.39	380	20.7
6s	18.39	391	21.3
7	18.33	473	25.8

Fig. 4. Summary of counting yields following a 48-hour exposure and a 3-hour wait-time for the trials indicated in figure 3.

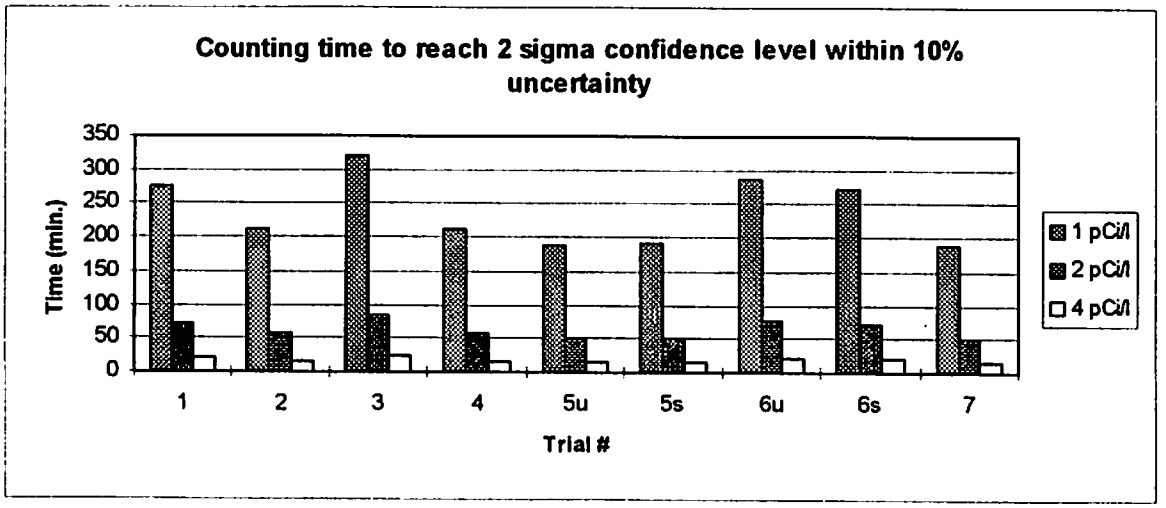


Fig. 5. Counting time required to determine [Rn] levels having a two sigma confidence level for two-day exposures for trials indicated in figure 3.

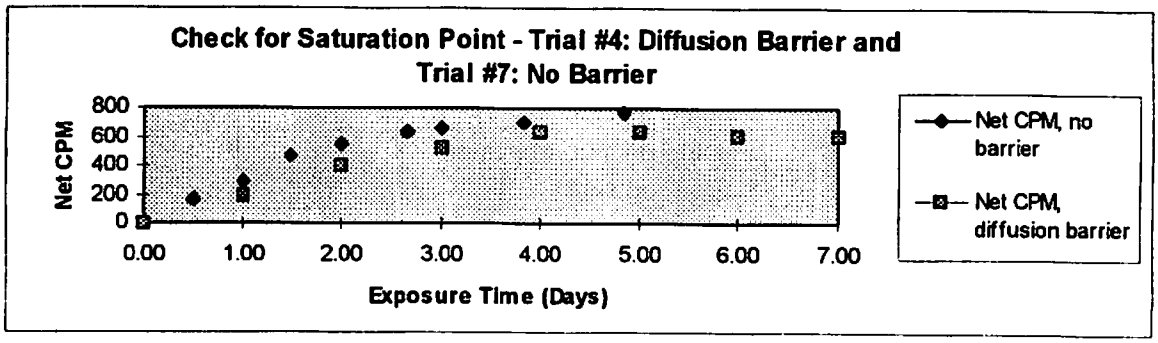


Fig. 6 Net count rate as a function of exposure time is shown for vials with and without diffusion barriers for trials #4 and #7 indicated in figure 3.

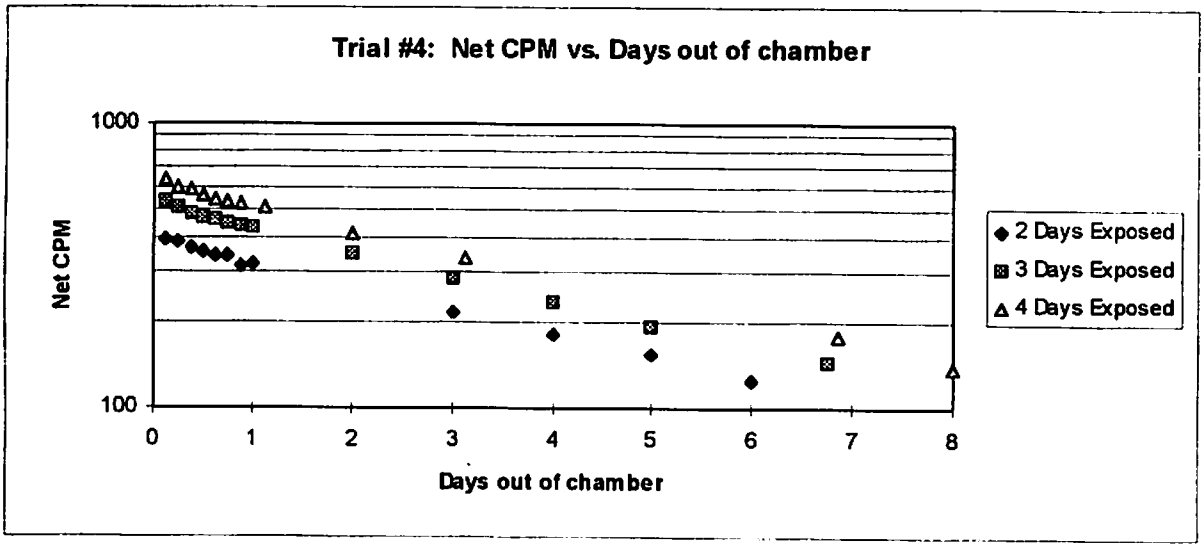
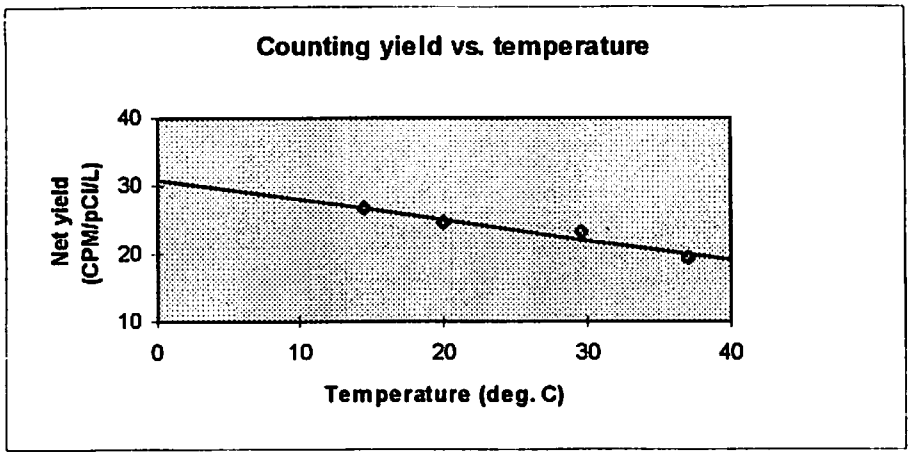
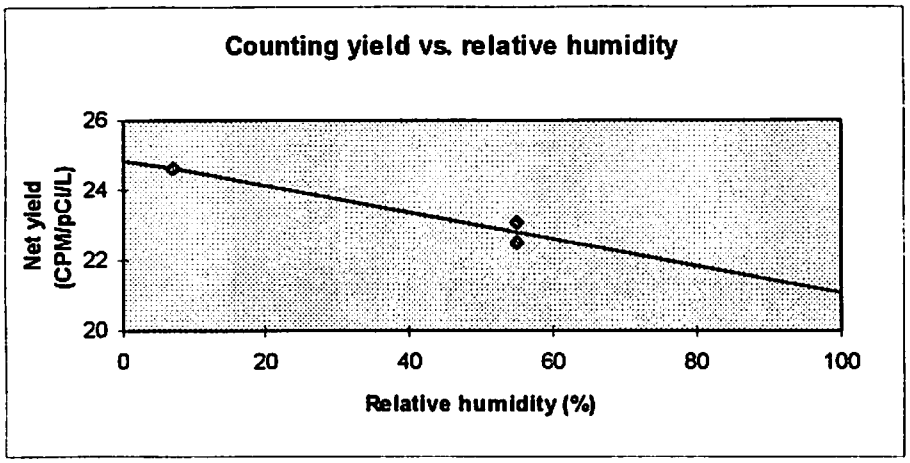


Fig. 7. Net count rate plotted on semilog axes as a function of time out of the chamber for several different exposure times for trial #4 indicated in figure 3.





Figs. 8. & 9. Linear regressions of net yield as a function of temperature and net yield as a function of relative humidity. These curves specifically were used in the determination of calibration coefficients.

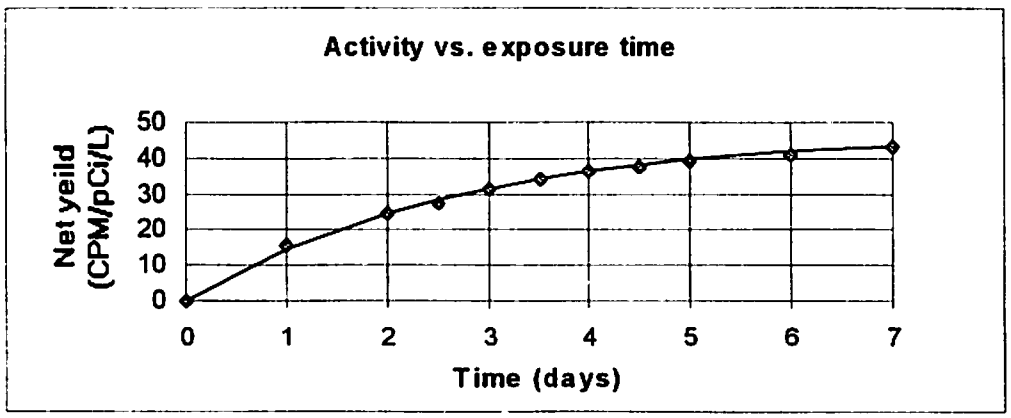


Fig. 10. Net yield as a function of exposure time. This curve specifically was used in the determination of one of the calibration coefficients.

Two vials were simultaneously deployed with two canisters from Prosser Laboratories in nine houses in PA.										
			Mass		Net count	Count	Decay	ESU	Prosser	
	Exp. time	Temp.	gain	RH	rate	time	time	[Rn]	[Rn]	ave.
Vial	(days)	(F)	(g)	%	(CPM)	(min)	(days)	(pCi/l)	(pCi/l)	% diff.
1	4.63	60	0.3	52.4	30.9	57	0.51	1.0	1.2	
2	4.63	60	0.2	41.6	31.2	57	0.55	1.0	1.1	15.1
3	3.00	65	0.3	70.0	20.6	59	1.17	0.9	0.9	
4	3.00	65	0.4	86.7	21.3	59	1.21	1.0	1.2	12.0
5	2.48	68	0.1	40.2	316.1	26	0.39	12.6	13	
6	2.48	68	0.2	60.3	315.5	26	0.40	12.9	14.7	8.0
7	5.38	60	0.5	66.4	1791	5	0.50	54.6	57.8	
8	5.38	60	0.5	66.4	1775	5	0.50	54.2	41.1	-10.1
9	2.16	65	0.2	66.2	57.6	52	1.34	3.1	2	
10	2.16	65	0.2	66.2	55.2	53	1.38	3.0	1.9	-57.4
13	3.00	60	0.3	69.9	78.6	49	0.87	3.3	3	
14	3.00	60	0.2	53.3	82	47	0.90	3.4	3.7	-0.3
15	2.98	70	0.1	36.8	607	17	0.66	22.4	18.8	
16	2.98	70	0	20.0	600.1	17	0.67	21.7	21.5	-9.5
17	2.71	67	0.2	56.9	483.9	20	0.79	20.2	18.2	
18	2.71	67	0.2	56.9	460.9	20	0.80	19.3	19.2	-5.4
									average	-5.3

Fig. 11. Fall 1997 Intercomparison Study with Prosser Laboratories. All measurements were made as duplicate values. For example, vials 1 and 2 were exposed as a duplicate measurement. The Prosser canisters were also exposed as duplicates.

Bowser Morner Report						ESU Measurements and Results							
						Mass		Net count	Count	Decay			% diff.
	Exp.	[Rn]	T	RH		gain	RH	rate	time	time	[Rn]		with BM
Vial	(day)	(pCi/l)	(^{0}F)	(%)		(g)	(%)	(CPM)	(min)	(days)	(pCi/l)		report
1	2	112.6	70.1	50.7		0.2	70.00	1548.9	0:06	2.42	120.2		-6.8
2	2	112.6	70.1	50.7		0	20.00	1477.8	0:06	2.43	106.9		5.1
3	2	112.6	70.1	50.7		0.1	45.00	1508.7	0:06	2.43	113.2		-0.6
4	2	112.6	70.1	50.7		0.1	45.00	1569.7	0:06	2.44	118.8		-5.5
										ave	114.8		-1.9
5	6	113.1	70.1	50.7		0.4	53.33	2382.5	0:04	2.37	105.0		6.8
6	6	113.1	70.1	50.7		0.4	53.33	2424.7	0:04	2.37	106.9		5.1
7	6	113.1	70.1	50.7		0.4	53.33	2379.22	0:04	2.37	104.9		6.8
8	6	113.1	70.1	50.7		0.5	61.67	2427.53	0:04	2.38	106.6		5.3
										ave	105.8		6.0
9	2	10.2	71	50.7		0.1	45.00	139.6	0:35	2.32	10.2		-0.1
10	2	10.2	71	50.7		0.1	45.00	128.8	0:36	2.39	9.6		6.4
11	2	10.2	71	50.7		0.1	45.00	142.1	0:34	2.34	10.4		-2.4
12	2	10.2	71	50.7		0.1	45.00	139.9	0:34	2.37	10.3		-1.2
										ave	10.1		0.7
13	5	9.6	70	50.6		0.4	60.00	194.2	0:29	2.39	9.2		4.4
14	5	9.6	70	50.6		0.3	50.00	187.3	0:30	2.44	8.8		8.3
15	5	9.6	70	50.6		0.3	50.00	191.2	0:30	2.46	9.0		6.0
16	5	9.6	70	50.6		0.3	50.00	192.8	0:21	2.48	9.1		4.9
										ave	9.0		5.9
17	3	23.7	70	50		0.3	70.00	357.1	0:20	3.17	24.8		-4.6
18	3	23.7	70	50		0.2	53.33	348.6	0:20	3.19	23.7		0.0
19	3	23.7	70	50		0.3	70.00	335.4	0:20	3.20	23.4		1.3
20	3	23.7	70	50		0.2	53.33	335.7	0:20	3.22	22.9		3.2
										ave	23.7		0.0
										overall average			2.1

Fig. 12. Summary of Exposures at Bowser Morner Laboratories' Radon Chamber from 3/98 through 4/98. ESU vials were exposed as quadruplicates.