

**The Effects of Moisture Gain on Activated
Charcoal When Measuring Radon Concentrations
in Air by Liquid Scintillation Methods**

An Honors Thesis (HONRS 499) Submitted to the Honors College for
Partial Completion of the Honors Program and the Degree of
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by

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Thesis Abstract

A presentation of the results of this investigation was given at the first annual Argonne Undergraduate Symposium at Argonne National Laboratory on November 2, 1990, and the following abstract was included in the anthology of papers presented at the conference.

The Effects of Moisture Gain in Activated Charcoal When Measuring Radon Concentrations in Air by Liquid Scintillation Methods, M.D. Reese*, D.R. Ober, D. Govaer, Department of Physics and Astronomy, Ball State University, Muncie, IN 47306.

Because of the high counting efficiency and automation, liquid scintillation detectors provide an attractive method for determining radon concentrations in air. In this study, a two-gram quantity of activated charcoal was placed in a vial and used to measure radon in air, no desiccant was included in the vial. A series of 48-hour measurements were made with standard canisters and vials, each containing activated charcoal. The canisters were then analyzed in the traditional method using sodium iodide detectors. In the analysis of the vials, 10 ml of scintillation fluid was added to each. After approximately ten hours, the samples were counted in a liquid scintillation system. A comparison of the results indicated a good linear relationship between the results obtained by standard canister methods and an adjusted counts per minute of the vials. The results also indicated that it is possible to apply water correction factors to the vials in a similar manner as is done in the canister method, thereby obtaining similar concentration results in both methods.

Acknowledgements

I would like to thank Dr. David Ober and Dr. David Govaer for giving me the opportunity to become involved with this project, and I am happy that the results seem to be very promising for the future. I would especially like to thank Dr. Ober for his undying support and encouragement, especially during the week prior to my presentation of our results at Argonne National Laboratory. I believe we have also set some form of departmental record for completing a thesis with actual time to spare before my graduation! Thanks also go to the Dept. of Biology, and particularly Dr. Alice Bennett, for the use of the Beckman liquid scintillation system.

Finally, I would also like to extend my thanks, albeit at a long distance, to Benjamin Koltenbah, who graciously sacrificed part of his 1989 Christmas break to help me analyze what seemed at the time to be an enormous amount of data.

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The Effects of Moisture Gain on Activated Charcoal When Measuring Radon Concentrations in Air by Liquid Scintillation Methods

I. Introduction

The measurement of radon concentrations in indoor air has become an area of intense interest in the past few years. The harmful effects of prolonged radiation exposure have been well documented¹, therefore, when the Environmental Protection Agency (EPA) released the results of its first national radon study, many people became extremely concerned. The EPA's study indicated that 25% of the homes that they tested had levels above their chosen 4.00 pCi/l *action level*². It was believed that homes above this level provided an unnecessarily high risk of lung cancer for the occupants, and it was consequently recommended that everyone should have his/her home tested for radon.

A very popular, reliable, and cost effective method of screening for radon is by exposing activated charcoal canisters, and then counting the gamma-ray radiation associated with radon decay products using sodium iodide (NaI) detectors³; however, since very few NaI crystal scintillation systems are automated, there is a considerable amount of time and labor involved in the

analysis of the canisters by this method. The canisters typically used in this method contain 75 grams of activated charcoal, which increases the shipping and handling costs, thereby increasing the entire cost of the process. In contrast, the automation and high efficiency of liquid scintillation systems utilizing lightweight vials containing one or two grams of activated charcoal makes liquid scintillation an attractive method for analyzing large quantities of radon tests at low cost. Current measurements using this method employ vials that contain a desiccant pack which reduces the moisture uptake of the charcoal; excessive water uptake effects the efficiency of the detector ⁴.

Kits utilizing a desiccant can cost as much as \$2.50 per vial ⁵. Therefore, in order to reduce expenses in testing for radon, the question was asked whether or not a procedure could be developed to determine radon concentrations by liquid scintillation where one did not use a desiccant, but corrected for moisture uptake in a manner similar to that when using the 75-gram canisters and NaI detector methods.

If a liquid scintillation method utilizing a desiccant-free vial could be devised, then the question was also asked about the effect that water gain would have on the two grams of activated charcoal in the vials. The analysis of the 75-gram canisters according to EPA protocol contains a correction

factor which takes humidity levels into account, but no such factor currently existed for the vials. Consequently, it was decided to determine a relationship between canister and vial water gains, and thereby produce correction factors for the two-gram activated charcoal vials for use in the liquid scintillation method.

The current investigation was therefore undertaken to compare the radon concentrations obtained with the canister/Nal method and those obtained with the vial liquid scintillation method. This paper will first give descriptions of radon concentration analyses by the 75-gram canister technique and the 2-gram vial technique. Next, a description will be given of the results obtained from comparing the two methods with and without mass gain considerations in the 2-gram vials. Finally, some conclusions will be drawn and some suggestions will be offered for investigating the 2-gram vial technique in the future.

II. Detection of Radon and its Daughter Products

A. Radon/Daughter Decay Processes

Radon is a naturally occurring inert gas produced from the radioactive decay of uranium-238. If radon enters a home, school, or other building where people live, work, or spend a great deal of time, over a period of years, the possibility then exists for the people to inhale the gas and/or its daughter products. Unfortunately, when further decays occur in the lungs, the damage over a period of years can be sufficient to induce lung cancer⁶. Therefore, every attempt should be made to reduce radon levels in homes, schools, and the workplace.

Uranium-238 is an alpha-emitter which begins a decay chain of alpha and beta emissions, eventually producing radon-222, as shown in Fig. 1.

Unfortunately, the damage to the lungs does not end here. Radon is itself an alpha emitter, as shown in Fig. 2; and it too is just the beginning of a series of alpha, beta, and gamma emitters, known as *daughter products*, which eventually decay to ^{206}Pb , a stable isotope of lead. When the daughter products of radon attach to particles in the air, the potential exists for the particulate matter to attach in the lungs and cause damage during the decay process.

Uranium-238 Decay Chain

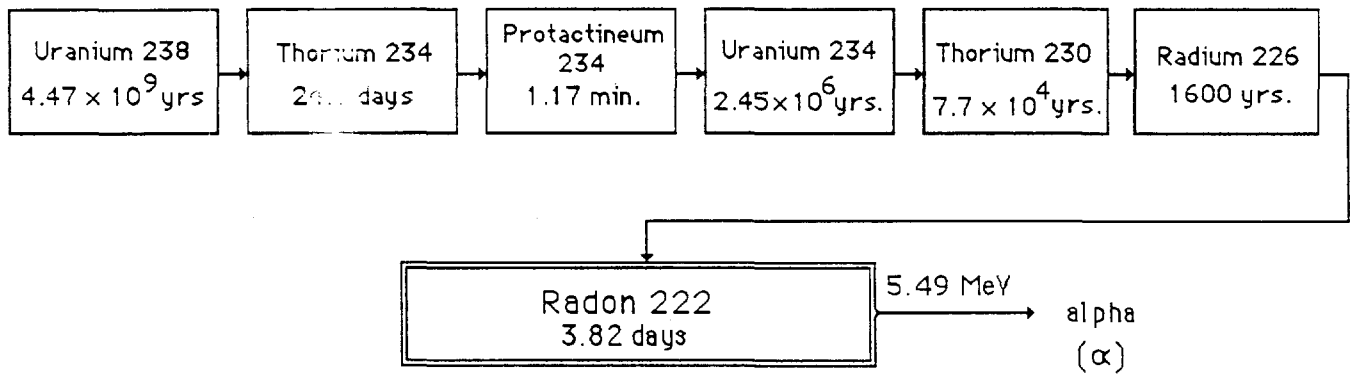


Fig. 1 The uranium-238 decay chain to radon-222.

Radon-222 Decay Chain

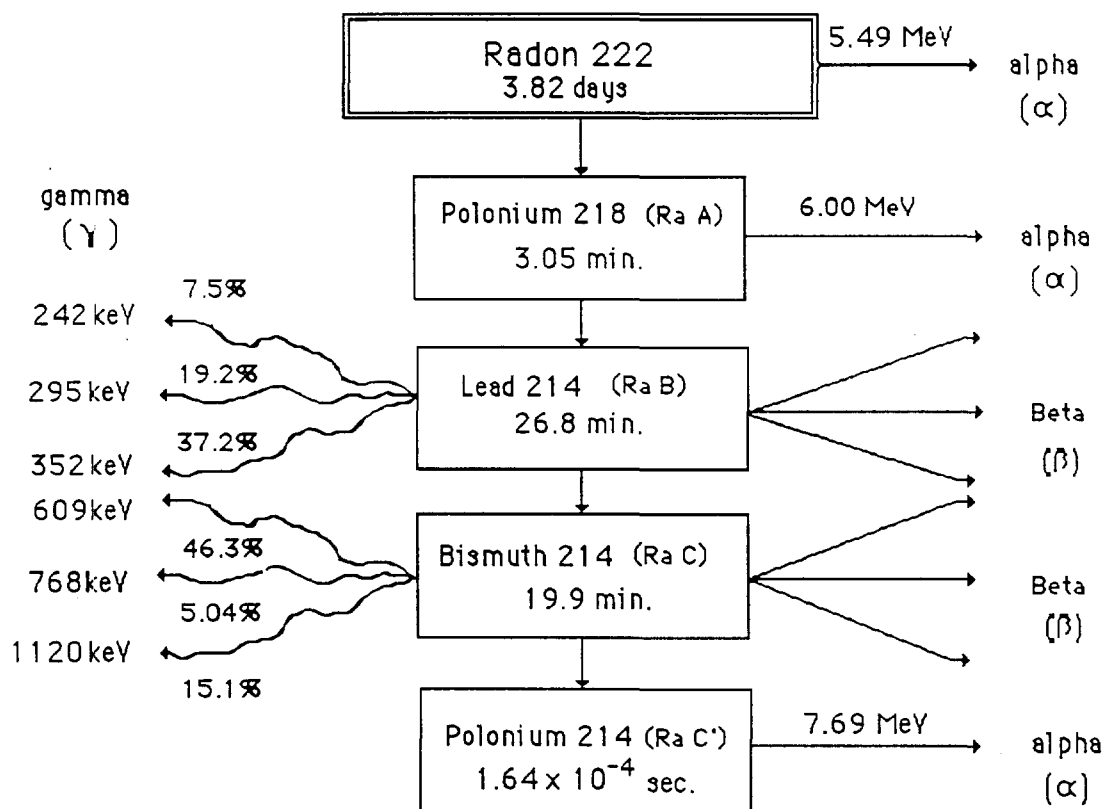


Fig. 2 The radioactive decay of radon-222 and its daughters.

B. General Detection Methods

The same emission particles which cause damage in the lungs also can be detected, thereby verifying the presence of the elements of interest, particularly radon. A NaI crystal scintillation spectrometer is the most common instrument used for measuring gamma radiation. Two daughter products of radon (^{214}Pb and ^{214}Bi) are gamma emitters, as shown in Fig. 2. If the characteristic gamma rays of these daughters are detected, then it is known by this indirect evidence that radon itself is present. As incoming gamma-ray radiation strikes any material, any of the three interaction processes are likely to occur – the photoelectric effect, Compton effect, or pair production. In a simple spectrometer system, energy is released in the form of light flashes, or scintillations, as radiation interacts with the scintillator material. These photons strike a photocathode, releasing photoelectrons, which are subsequently multiplied, amplified, and eventually counted as voltage pulses by a single channel or multichannel analyzer. The most common variety of scintillator material is thallium-doped sodium iodide (NaI(Tl)). Sodium iodide crystals do not offer the best spectral resolution, however, they are relatively inexpensive and serve well in the simple radiation screening measurements used in radon analysis ⁷.

If radon and its daughter products only emitted gamma radiation, crystal scintillators would be the only logical choice; however, Fig. 2 shows that polonium-218, polonium-214, and radon-222 are all alpha emitters, and both lead-214 and bismuth-214 are beta emitters. Because of the low penetration abilities of alpha and beta particles, NaI crystal scintillators are seldom used for measuring alpha or beta radiation. For this reason, liquid scintillation systems which incorporate the sample directly in the scintillator material are used. In this case, alpha or beta particles are emitted by the sample directly into a scintillation fluid. The small flashes of light which are released are detected by two phototubes. Because the sample pulses are comparable in size to the background radiation pulses (quite small), the amplified pulses are fed into a coincidence circuit designed to discriminate against the "background noise" signals. These output pulses are then fed into three scalars which are set at three different energy window settings typically associated with ^3H , ^{14}C , and ^{32}P radiations ⁸.

The scintillator material used in the process of liquid scintillation is obviously a fluid. A suitable scintillation fluid must consist of three parts. The *primary fluor* converts the alpha or beta energy to light energy. The component known as the *secondary fluor* is used to shift the light energy to a

wavelength which the phototubes can detect with more efficiency. Finally, an inexpensive, yet suitable solvent is used as a "filler", since only small quantities of the fluors are necessary to produce high efficiency results⁹. Scintillation fluids based on toluene or mineral oil are quite common, relatively inexpensive, and produce impressive counting results.

C. Charcoal Canister Detection Method

As noted earlier, a popular method of radon screening is by the activated charcoal canister method. For this study, four-inch metal charcoal canisters manufactured by F & J Specialty Products, Miami Springs, Florida, were used to absorb the radon in the air. The canisters contained 75 grams of an 8 x 16 mesh Calgon Corp. Type PCB activated charcoal, which was covered with a wire mesh screen. The canisters were exposed for 48 hours and then resealed to allow the radon and its daughters to reach equilibrium.

To measure the gamma-ray radiation from the canisters, a sodium iodide (NaI(Tl)) spectrometer system was used. This system consisted of a sodium iodide scintillation crystal, photomultiplier tube, high voltage source, preamplifier, linear amplifier, and a multichannel analyzer. A block diagram of this set-up is shown in Fig. 3.

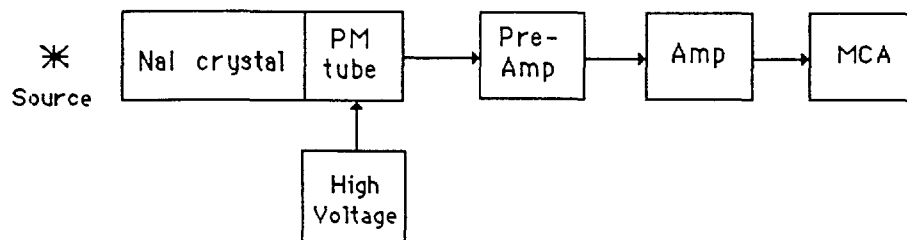


Fig 3. Block diagram of an NaI spectrometer system to measure gamma radiation.

The system was calibrated with a 7.3-kBq standard radium sample (in a similar canister as the samples) for a one-minute period, and background measurements were taken for the detector for a ten-minute period. The counting periods were chosen to achieve suitable statistical accuracy. A typical sodium iodide spectrum of radon daughter products is shown in Fig. 4 with the labeled gamma-ray photopeaks from the decays of the two radon daughters (Ra B and Ra C); in all analyses an integral sum of counts was taken which included the 295-, 352-, and 609-keV gamma-ray photopeaks. The canisters were each counted for a ten-minute period. This information and the mass gain measurement due to water moisture uptake were used to arrive at a final concentration in pCi/l using Eq. 1 :

$$Rn \text{ (pCi/l)} = \frac{\text{Net CPM}}{(T_{\text{exp}})(E)(CF)(DF)} \quad (1)$$

where Net CPM = Total counts - Background counts

T_{exp} = Canister Exposure Time

E = Detector Efficiency

CF = Humidity Factor

DF = Radioactive Decay Factor given by $e^{-(\ln 2/T_{1/2})}$

$T_{1/2}$ = Half-life of radon-222 (3.8 days)

The process of system calibration, background measurement, sample measurement, and sample analysis required approximately 30 minutes to complete for one round of canisters. Obviously, the amount of time necessary to complete larger numbers of canisters depends on the number of detectors available and the capability of the multichannel analyzer, but in general, the process is time-consuming for any large volume of tests. In actual practice in this investigation, a four-detector system was used for the canister analyses. After initial calibrations were completed, approximately 20 canisters per hour could be analyzed.

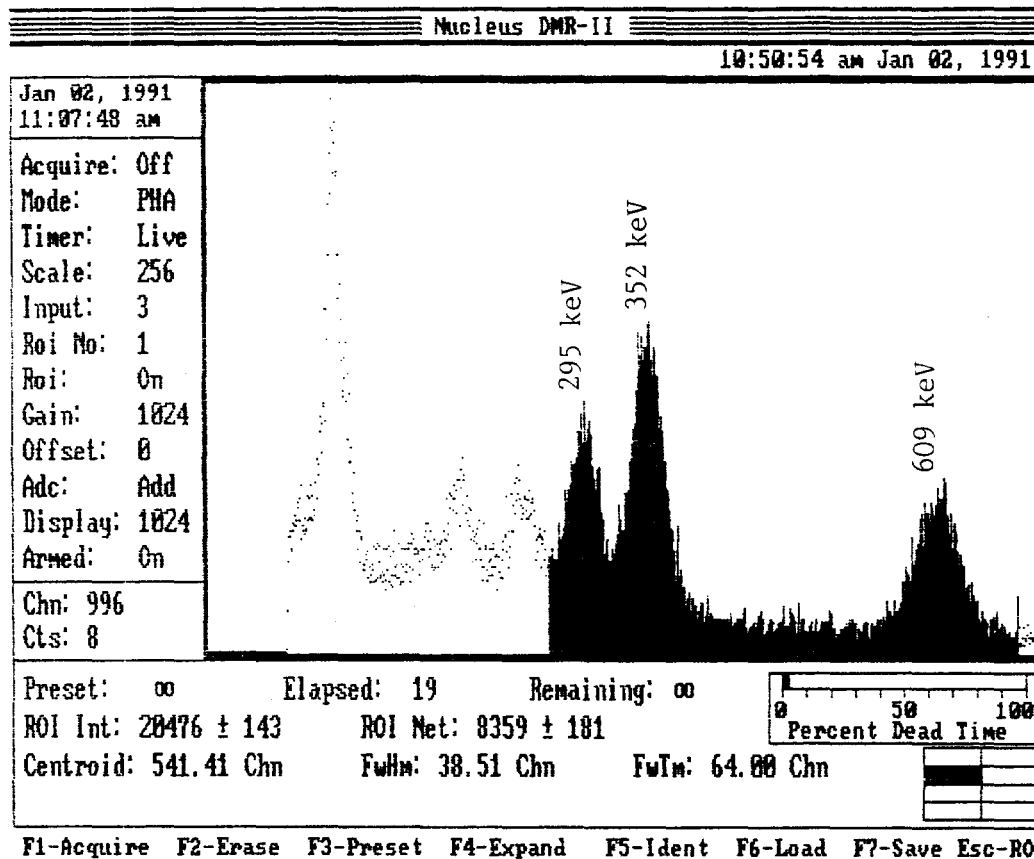


Fig. 4 A portion of a gamma-ray spectrum associated with the decay of radon daughters. The darkened region of interest shows the three gamma-ray photopeaks and the region of energy used to determine radon concentrations by the canister method.

D. Liquid Scintillation Vial Detection Method

Because of the excessive time and labor involved in analysis by the canister method, a method utilizing a liquid scintillation system can be used as an alternative, as outlined by Schroeder, Vanags, and Hess in their paper. The purpose of their investigation was to develop an inexpensive detector for measuring radon in indoor air utilizing liquid scintillation techniques.

Although their paper dealt briefly with the effects of humidity on activated charcoal, Schroeder, Vanags, and Hess chose to use a desiccant pack to reduce moisture uptake in the charcoal, and they consequently did not determine humidity correction factors. The results of their study indicated that liquid scintillation is a viable method for radon detection in air. In addition, desiccant cartridges included in the vial performed well at temperatures below 21 °C and relative humidity levels below 50%; however, Schroeder admitted that it would be "desirable to determine rough moisture correction factors" ¹⁰, particularly for those situations not ideal for the use of a desiccant.

For this current study, 20-ml glass vials with 3/4" diameters were used. The same charcoal was used in the vials as was used in the 75-gram canisters, however, only two grams were placed in the vials. Analogous to

the canister measurements, the vials were exposed for 48 hours and then sealed with their plastic screw-type caps. Next, 10 ml of high efficiency mineral oil scintillator PSS-007H (manufactured by Biotechnology Systems-DuPont) was added to each vial, and then each vial of charcoal was allowed to reach an equilibrium in its build-up of activity in the scintillator fluid. Ten hours was determined as the minimum time needed for the activity to reach a stable, equilibrium level inside a vial. A description of this determination will be given in the next section. After the build-up period, the vials were counted with a Beckman 3801-Liquid Scintillation system for ten-minute periods. Energy spectra for tritium, carbon-14, and radon-222 obtained with the Beckman 3801 are shown in Fig. 5. One can observe the wide distribution of energies characteristic of beta decays of the radon daughters, and the two peaks in the radon "window" are evidence of the three alpha emissions of radon and two of its daughters (^{218}Po and ^{214}Po) with energies of 5.49, 6.00, and 7.69-MeV, respectively. For each round of vial tests, a duplicate, unexposed charcoal vial was used to obtain background counts for the series.

The net counts from a sample minus the background count was then adjusted for exposure time and delay time using Eq. 2 :

$$\text{Adj. CPM} = \frac{\text{Net CPM}}{1 - e^{-\left(\frac{0.693}{T_{1/2}}\right)t_{\text{ex}}}} \times \frac{e^{\left(\frac{0.693}{T_{1/2}}\right)t_{\text{d}}}}{\text{CF}} \quad (2)$$

where Net CPM = Total counts - Background counts

t_{ex} = Vial exposure time

t_{d} = delay time from midpoint of exposure to start of count time

$T_{1/2}$ = Half-life of radon-222 (3.8 days)

CF = Humidity factor (0.1025 for no correction)

Doped Source Spectra
Liquid Scintillation System

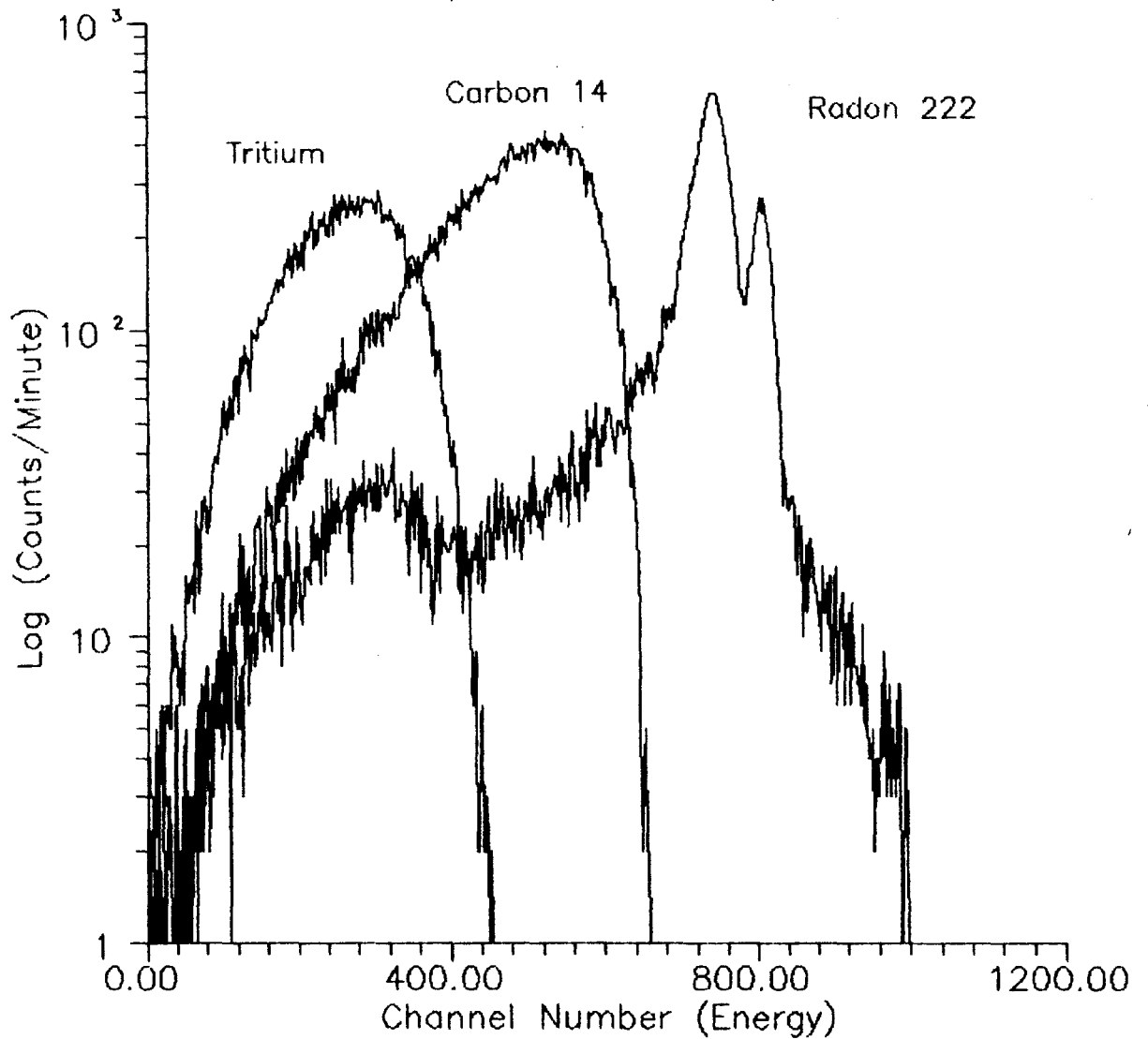


Fig. 5 An energy spectrum of tritium, carbon-14, and radon-222 obtained with a Beckman 3801-liquid scintillation system.

III. Experimental Considerations

A. Establishment of Radioactive Buildup

After scintillation fluid is introduced into a vial, a period of time exists when the activity of the sample must be permitted to build up to an equilibrium level and reach a reasonable level of stability. This equilibrium level is the result of two separate effects which occur because of the introduction of the scintillation fluid, each taking a certain amount of time to complete. To begin, the radon gas which was adsorbed by the activated charcoal is chemically released into the scintillation fluid. Next, as each particle radioactively decays in the fluid, daughter products are formed, which in turn decay into more daughter products (see Fig. 2). The relative amounts of each daughter product in the vial are under constant change over several hours because of the continuous radioactive decay process, and therefore, the total count rate will be inconsistent over the same time period. Consequently, in order to insure a stable count rates during the counting period, the radon gas must be given enough time to be released from the charcoal *and* to achieve relative radioactive equilibrium with its daughter products inside the vial.

The time necessary for this buildup was determined by experiment, as

shown in Fig. 6. Two vials were exposed for 48 hours and then sealed; 10 ml of mineral oil scintillator fluid was then added to each vial. Next, each vial was counted for 10-minute periods every one or two hours for 24 hours beginning immediately after the scintillation fluid was added. This data was corrected for the radioactive decay of radon-222 and plotted as a function of time in Fig. 6 (see Appendix A). The graph clearly shows that until the ten-hour mark, the activity of the sample continued to steadily increase. Error bars were added (due to counting statistics only), but were sufficiently small to indicate that the graph is an accurate description of the process as it is shown. Consequently, it was concluded that samples counted before at least ten hours of build-up of the activity would produce erroneously low count rates, and thereby yield erroneously low radon levels.

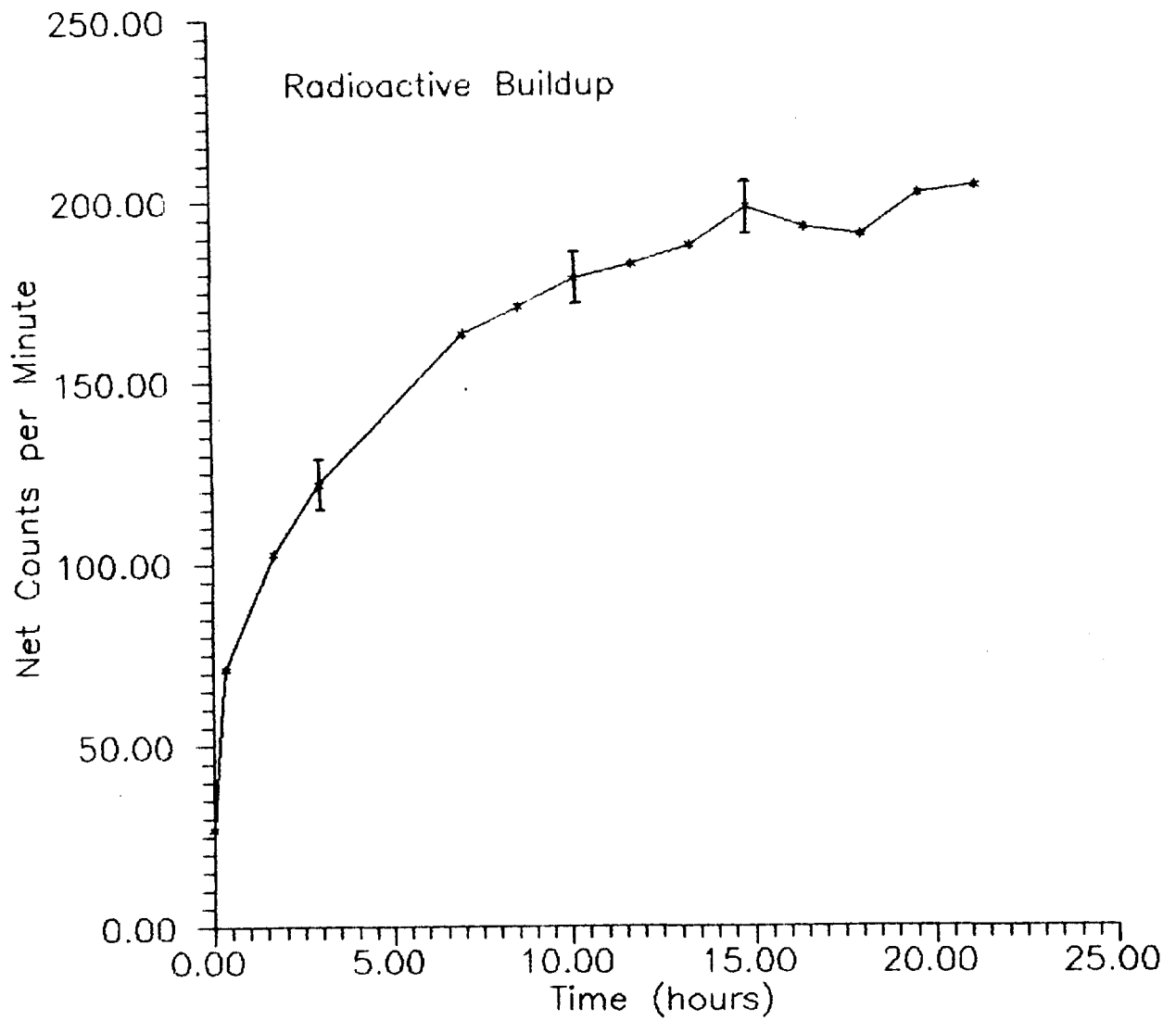


Fig. 6 A graph depicting the results of liquid scintillation analyses as a function of time, thus demonstrating the build-up of radioactivity in charcoal vials.

B. Experimental Details - Vial/Canister Analysis

In this investigation, approximately 200 pairs of vials and canisters were exposed side by side for 48 hours in varying radon concentration environments, ranging from near outdoor levels to 16 pCi/l. The concentrations for the canisters and radon half-life adjusted counts for the vials were both obtained using the previously described methods of counting and analysis (see Appendix B). Radon concentrations/adjusted CPM values for each canister/vial pair were then plotted on a graph, as shown in Fig. 7. A visual inspection of the data indicated that a linear relationship existed, so regression analysis was performed and yielded Eq. 3 :

$$Y = 0.0111 * X - 0.01066 \quad (3)$$

where Y = canister pCi/l

 X = vial adjusted CPM

Error bars (due to counting statistics only) are shown; the statistical uncertainty in the Y-intercept was sufficiently large to indicate that the y intercept was essentially zero, as one might expect. Obviously, a zero concentration result with the canisters should yield a zero concentration result with the vials. Uncertainties with the intercept from the regression analysis indicated this to be true also (see Appendix C).

This data was plotted assuming zero moisture gain for the vials; the next procedure was to consider analyses which incorporated a moisture gain correction.

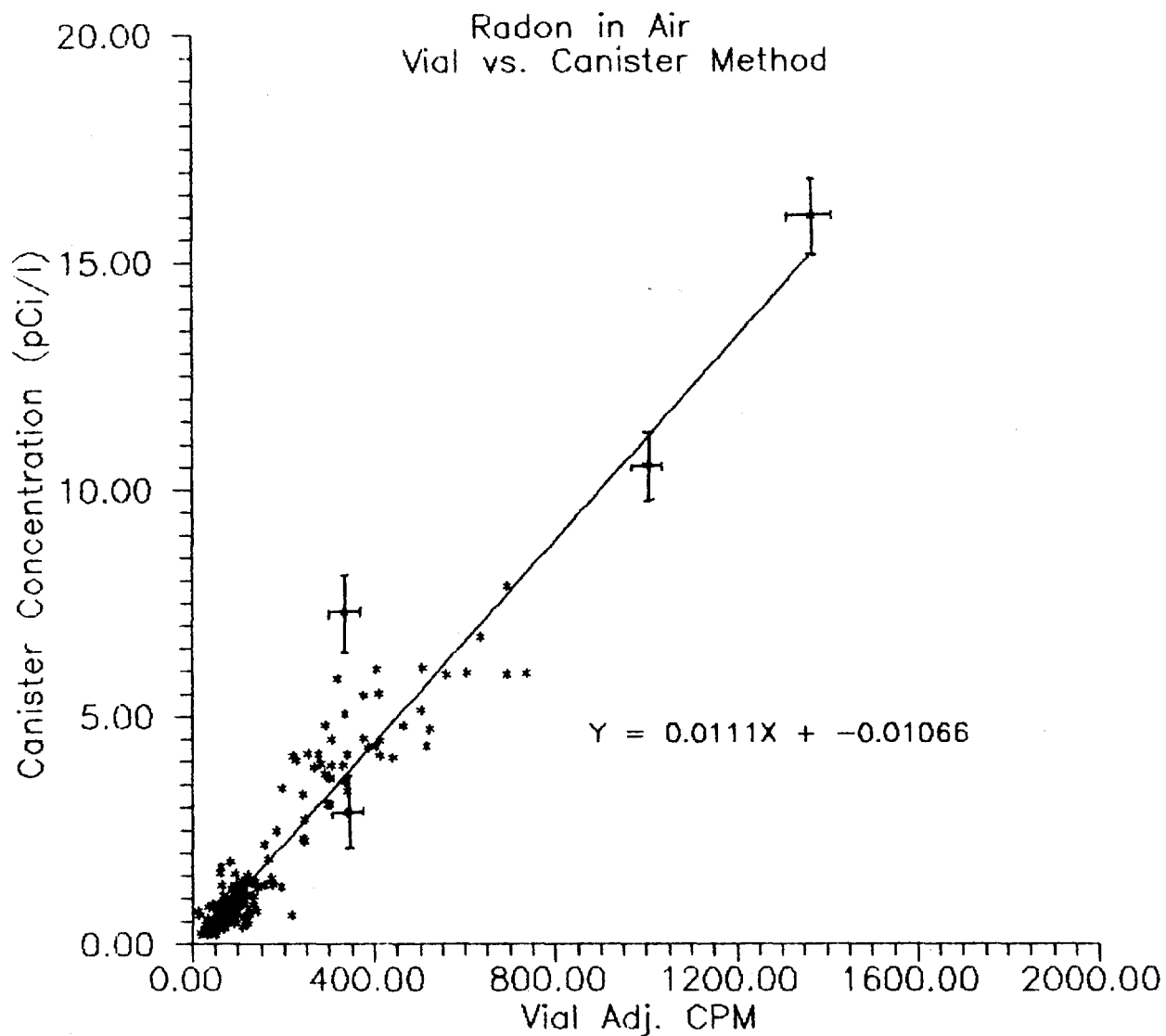


Fig. 7 A comparison of radon concentrations (pCi/l) by the canister method to results obtained by liquid scintillation (vial adjusted counts per minute). No corrections were made for vial moisture content.

C. Determination of Humidity Correction Factors

A series of canister/vial measurements of radon concentration was performed where the masses of each canister and vial were carefully measured before and after a 48-hour exposure (see Appendix D). The resulting mass gains were analyzed to determine whether there was a simple relationship between the canister and vial moisture gains. The resulting data, as shown in Fig. 8, did not appear to reveal a simple linear relationship, however, it was determined that Eq. 4 provided a good representation of the relationship of water moisture gain in the two containers. The line associated with this equation is shown in Fig. 8.

$$\text{delM}(c) = 19.039 * \text{delM}(v)^{0.674} \quad (4)$$

where, $\text{delM}(c)$ = canister water moisture gain

$\text{delM}(v)$ = vial water moisture gain

The EPA's empirical moisture gain Correction Factor (CF) curve for 75-gram canisters is shown in Fig. 9. The curve shows the humidity correction factors for 2-day exposures as a function of water gain. The curve in Fig. 10, along with the associated equation shown, is used to calculate correction factors for exposure times other than two days for 20%, 50%, and 80% humidity levels. This study only considered two-day exposures, as

shown by the vertical line in Fig. 10. From these curves (Fig. 9 and Fig. 10) and Eq. 4 given in Fig. 8 , a new Correction Factor curve was developed for the 2-gram vials by converting the moisture gain values to equivalent CF values (see Appendix E). This new CF curve for 2-gram charcoal vials is shown in Fig. 11. An average CF was computed for each of the humidity levels shown on the graph. These levels, along with their respective vial moisture gains and humidity correction factors are given in Table I below.

Table I

Humidity Level	Moisture Gain (g)	CF (l/min)
20%	0.00-0.01	0.106
50%	0.01-0.099	0.907
80%	0.099+	0.076

Table I. Average humidity correction factors for low, medium, and high humidity levels.

The new water moisture correction factors were then applied to the previous vial adjusted counts values to produce a new "corrected" curve of vial CPM vs. canister radon concentrations, as shown in Fig. 12. As one would expect, the slope of the line did change slightly from the previous uncorrected curve (Fig. 7).

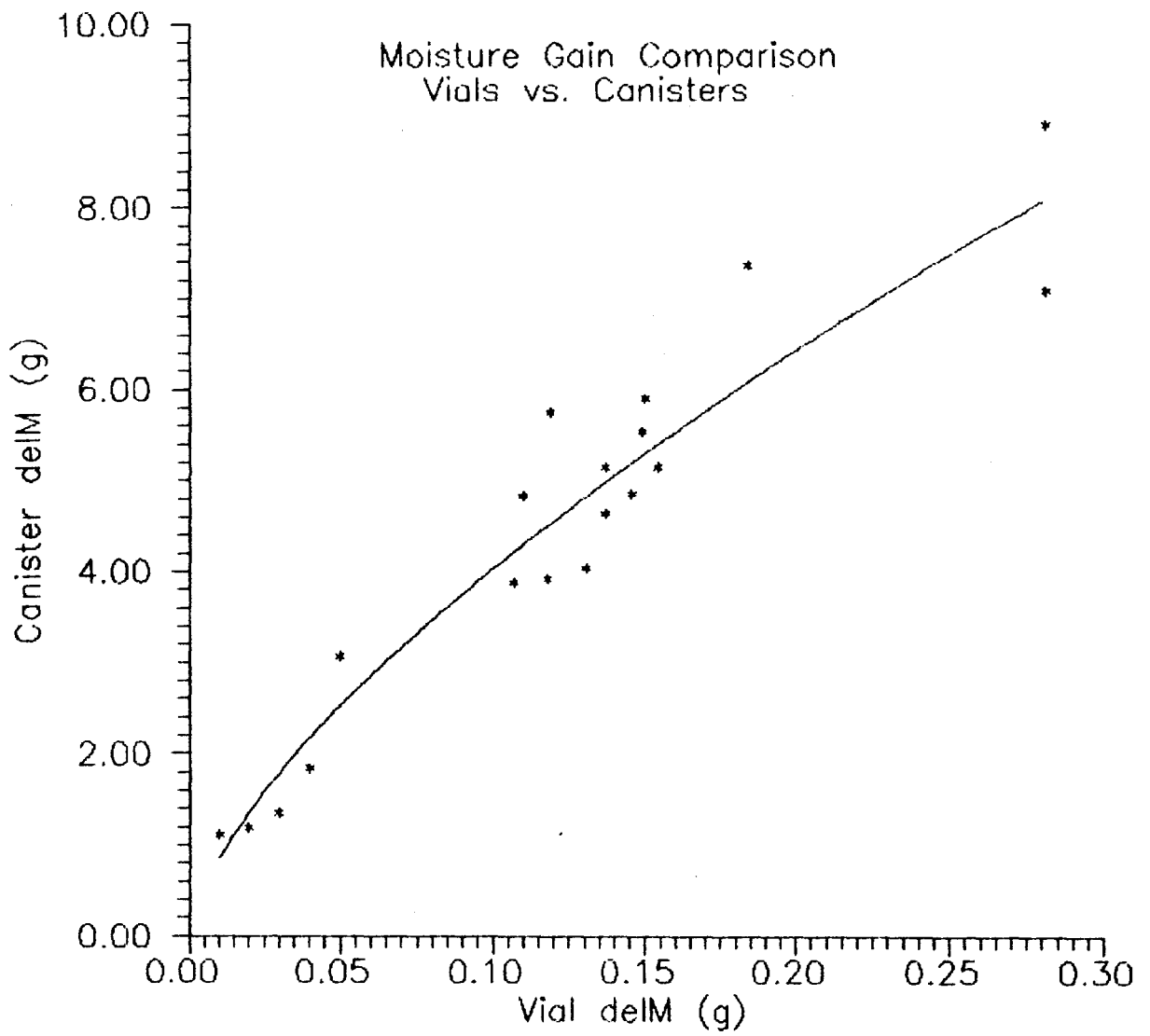


Fig. 8 Comparison of moisture gain by activated charcoal in canisters and vials.

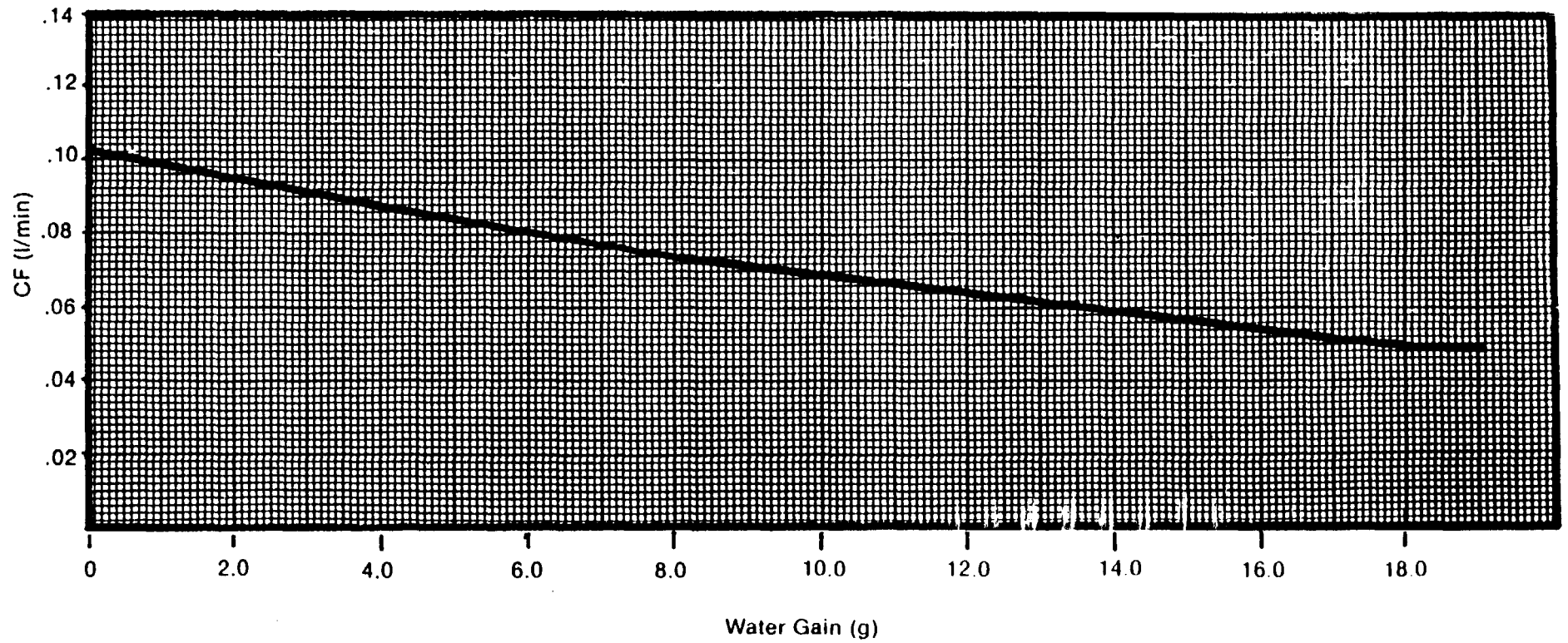
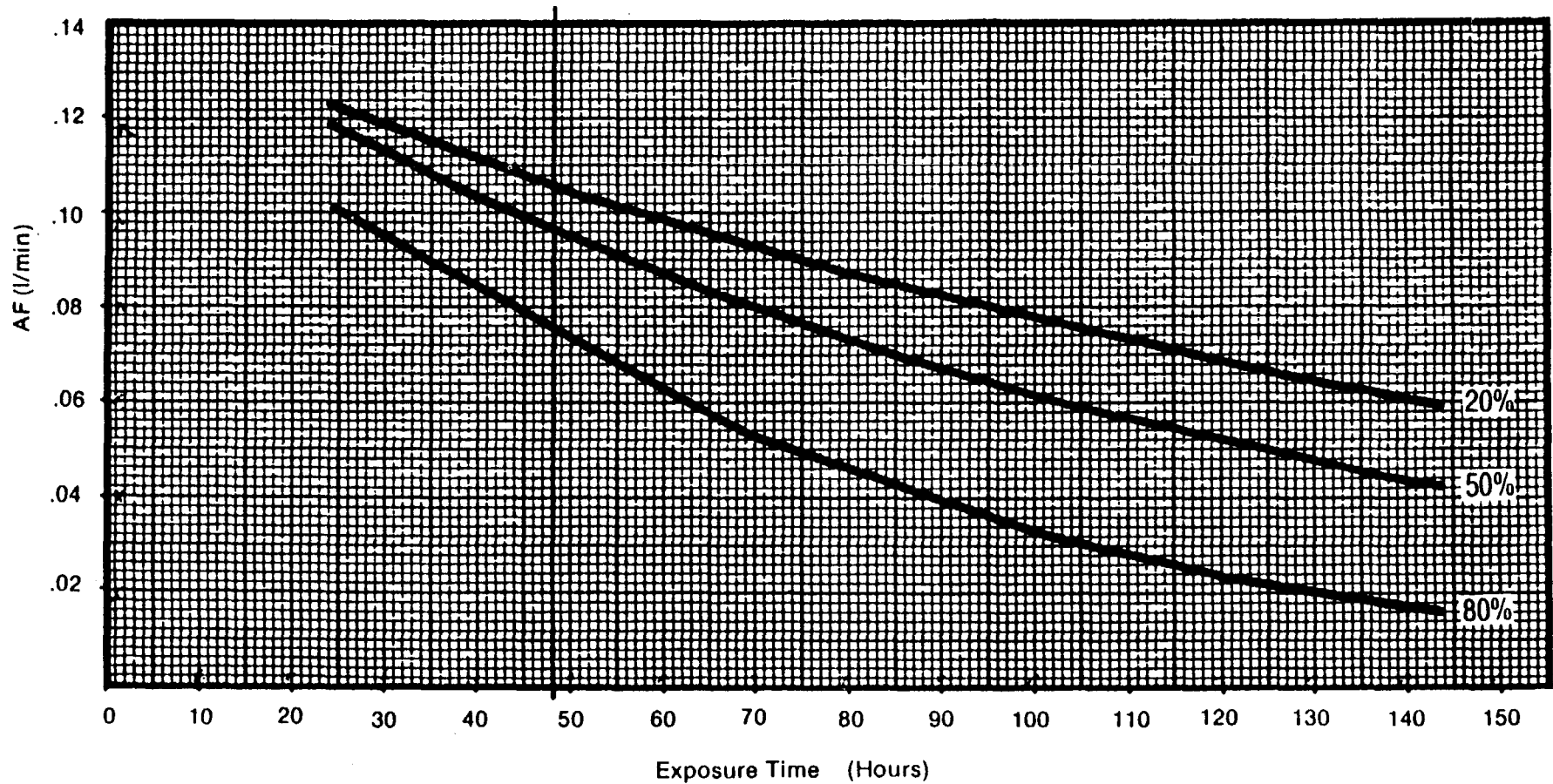


Fig. 9. EPA experimentally determined correction factors (CF) for two-day exposures as a function of water gain¹¹.



$$\text{Final CF used} = \text{Initial CF} \times \frac{\text{AF for actual exposure time}}{\text{AF for 2 day (48 hr) exposure time}}$$

Fig. 10 EPA experimentally determined adjustment factors (AF) for low, medium, or high humidity levels¹².

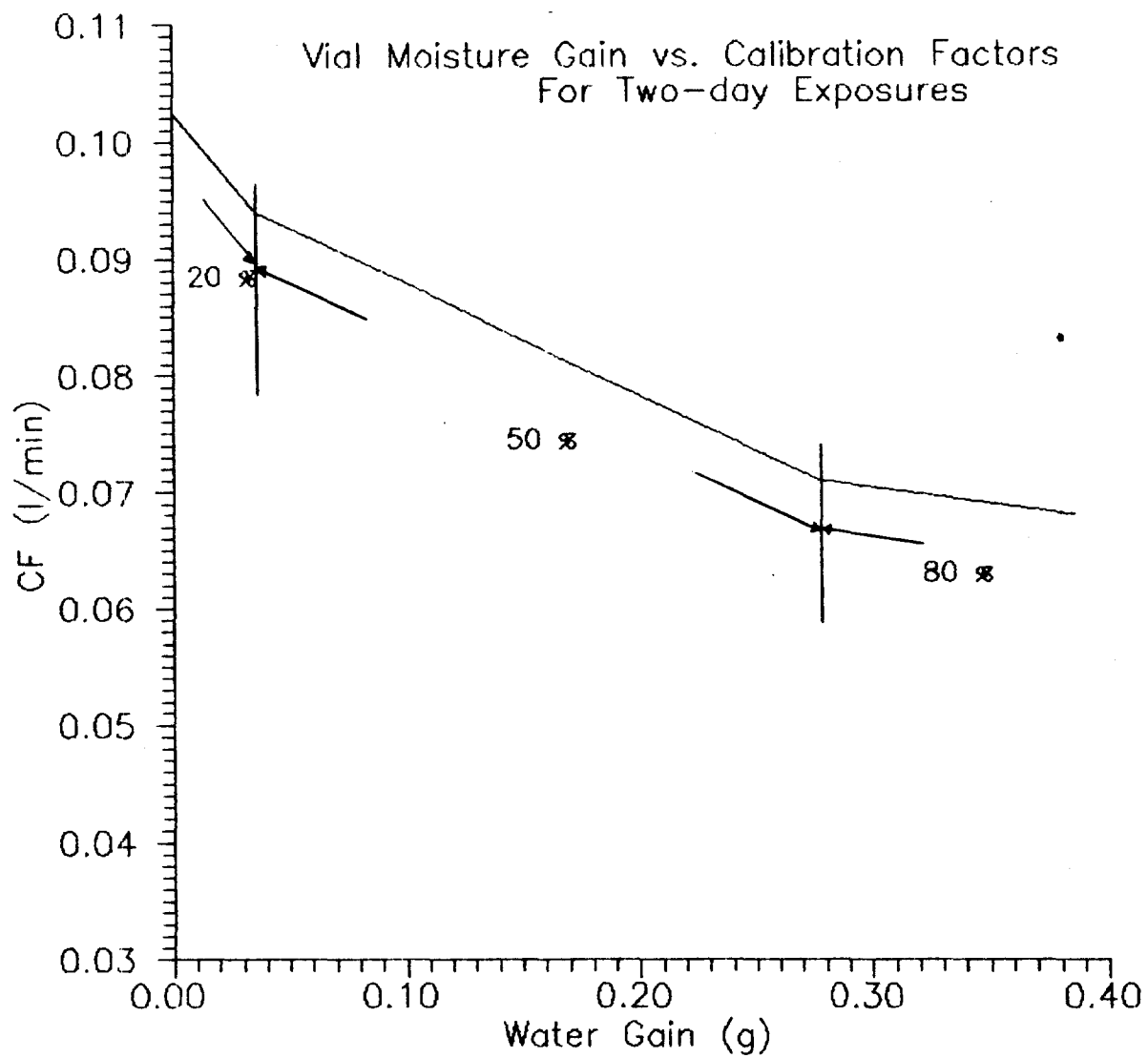


Fig. 11 Experimentally determined correction factors (CF) for two-day exposures of activated charcoal vials for low, medium, and high humidity levels.

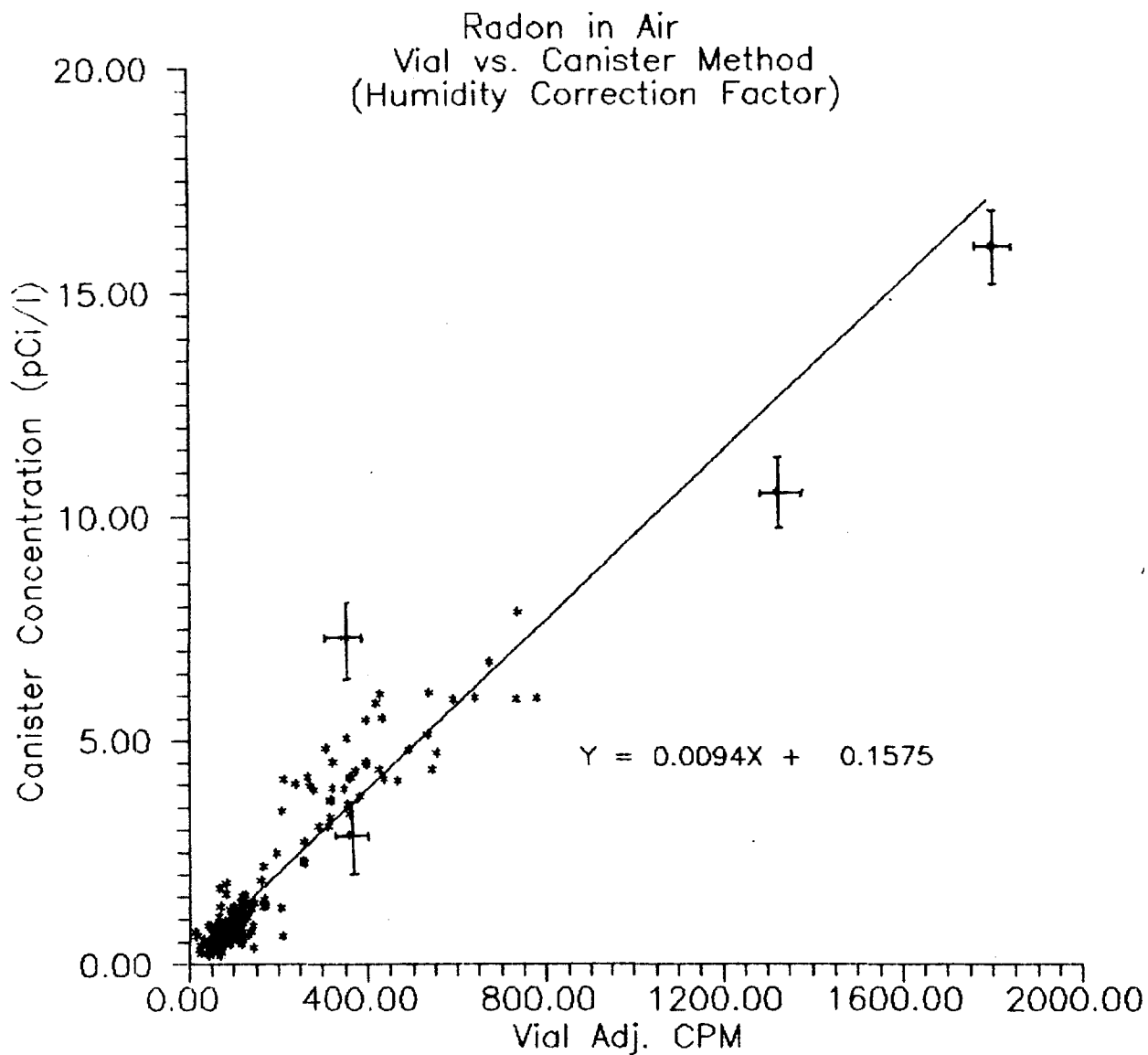


Fig. 12 Comparison of radon concentrations (pCi/l) by the canister method to results obtained by liquid scintillation (vial adjusted counts per minute). Corrections were made for vial moisture content.

iv. Experimental Results

An additional stage of the investigation was to determine whether the newly obtained moisture corrected curve for the vials (Fig. 12) could reproduce the results obtained by the canisters with reasonable accuracy and consistency. Sixteen pairs of canisters and vials were exposed, sealed, and eventually analyzed exactly as before. These samples had been exposed at relatively high (8-10 pCi/l) and low (~1.5 pCi/l) radon concentration levels. The results by the canister method were obtained exactly as before. The results by the vial method were obtained using counts corrected for moisture, and then corrected using the equations obtained from the regression analysis to express the results in pCi/l. Table II shows that the results for the corrected values are easily within an error ± 0.5 pCi/l (at low concentrations) or within 25% (at higher concentrations), which are acceptable ranges (according to EPA protocol) in screening measurements of this type¹³. It is also important to note that the mass gains were successfully predicted to within 0.04 g (Table III), which predicted the proper humidity level, and therefore the proper humidity correction factor in every case. Consequently, it is concluded that the 2-gram charcoal vial analyses are able to successfully reproduce the 75-gram canister results.

Table II
Radon Canister and Vial Comparison
(Radon Concentration in pCi/l)

ID#	Canister	Vial	Vial(CF)	Vial Diff.	Vial(CF) Diff.
1	9.06	9.71	9.54	0.63	0.46
2	7.53	8.37	7.98	0.84	0.45
3	8.20	9.80	9.52	1.60	1.32
4	10.15	10.35	10.26	0.20	0.11
5	9.06	9.59	9.31	0.53	0.25
6	8.85	8.77	8.72	-0.08	-0.13
7	8.42	7.81	7.62	-0.61	-0.80
8	8.06	7.69	7.43	-0.37	-0.63
9	8.00	7.64	7.45	-0.36	-0.55
10	9.87	9.82	9.54	-0.05	-0.33
11	1.51	1.72	1.88	0.21	0.37
12	1.25	1.22	1.39	-0.03	0.14
13	1.23	1.55	1.70	0.32	0.47
14	1.21	1.08	1.23	-0.13	0.02
15	1.19	1.10	1.28	-0.09	0.09
16	1.59	1.58	1.79	-0.01	0.20

Table II. A comparison of the determination of radon concentrations by the canister method to concentrations predicted from two-gram vial measurements; no moisture corrections were used to obtain *Vial* results, while moisture corrections were used to obtain *Vial(CF)* results.

Table III
Radon Canister and Vial Comparison
 Moisture Gain (g)

ID#	Canister	Vial	Predicted Vial	Diff.
1	3.51	0.062	0.081	0.019
2	3.26	0.059	0.073	0.014
3	3.36	0.077	0.076	-0.001
4	3.44	0.084	0.079	-0.005
5	3.36	0.081	0.076	-0.005
6	2.92	0.090	0.062	-0.028
7	2.03	0.073	0.036	-0.037
8	2.64	0.059	0.053	-0.006
9	3.06	0.065	0.066	0.001
10	1.77	0.071	0.029	-0.042
11	4.56	0.109	0.119	0.010
12	4.06	0.108	0.101	-0.007
13	3.63	0.106	0.086	-0.020
14	3.84	0.101	0.093	-0.008
15	4.99	0.117	0.137	0.020
16	4.68	0.129	0.125	-0.004

Table III. A comparison of canister moisture gains to actual vial moisture gains and predicted vial moisture gains using Eq. 4.

v. Conclusions and Closing Comments

It has been shown that two-day screening measurements for radon concentrations can be reliably made with two grams of activated charcoal in 20-ml liquid scintillation vials (with no desiccant) and subsequent counting by liquid scintillation methods. In addition, the humidity correction (CF) factors empirically developed by the EPA for 75-gram canisters can be used (with a slight modification) to correct for moisture gain in the vials, thus eliminating the need for a desiccant, and the extra labor and cost involved with the use of a desiccant. In commercial kits, this could reduce expenses from as much as \$2.50 per vial to just a few cents per vial (which includes the nominal cost of the charcoal).

Liquid scintillation counting is a highly efficient and automated method; less charcoal is needed to acquire the same results as with the 75-gram canisters, and the vials can be run continuously without constant human supervision. Overall the vial method without a desiccant cartridge can provide a cost-effective, reliable, and less-labor intensive method for determining radon concentrations in air screening measurements.

In future studies, it is suggested that investigations be carried out using less expensive types of scintillation fluid. It would also be worthwhile to

study a wider range of humidity levels, thus seeing the true usefulness for the humidity correction factors. Finally, it would be very worthwhile to determine water moisture correction factors for any exposure time period (one to seven days) and extend the results for the 48-hour exposure time in this investigation to the one-to-seven-day data provided by the EPA in canister measurements.

This author understands from personal experience the large amount of time and effort which must be spent in the preparation and analysis of any radon measurements using a large quantity of the conventional charcoal canisters. It is therefore concluded that the liquid scintillation method (without desiccant packs) can serve to eliminate "canister labor," and yet provide reliable radon concentration results at lower costs.

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Appendix A

This appendix includes the experimental data associated with the radioactive buildup presented in Fig. 6.

Equilibrium Curve Data

(see Fig. 6)

Time (hrs.)	Raw CPM	Tdel(hrs.)	Corrected CPM
0.54	82.90	5.59	86.48
1.05	113.00	6.90	119.06
3.10	137.80	8.15	146.56
7.51	182.94	12.60	201.24
9.08	200.54	14.10	223.11
10.66	203.16	15.70	228.78
12.23	207.30	17.28	236.25
13.81	213.16	18.86	245.85
15.39	212.50	20.44	248.04
16.97	224.60	22.00	265.27
18.54	216.90	23.60	259.30
20.12	223.04	25.17	269.83
21.69	218.17	26.74	267.09

Appendix B

This appendix includes the database information obtained during this study. Following is a list of entries making up the spreadsheet/database : vial ID#'s, canister ID#'s, vial net counts per minute, vial exposure time (T_{exp}), vial delay time (T_{del}), vial initial mass [$M(i)$], vial final mass [$M(f)$], canister mass gain [$\Delta M(c)$], vial mass gain [$\Delta M(v)$], vial adjusted counts per minute, moisture correction factor, vial adjusted counts per minute (humidity corrected), and canister concentration (pCi/l).

Study of vials vs. canisters
Marty Reese -- Data file

Vial #	Can #	Net CPM	Temp	Tdel	M(i)	M(f)	delM(v)	delM(c)	Adj CPM	Conc.(c)	CF	CF-CPM
1	1	6.8	41.1	13.6	19.02	19.17	0.14	4.02	28.12	0.19	0.078	36.16
2	2	13.2	48.0	27.8	18.66	18.81	0.15	5.9	53.41	0.21	0.078	68.48
3	3	9.2	48.0	16.4	18.86	18.99	0.18	4.65	34.28	0.21	0.078	43.95
4	4	4.8	48.0	30.0	18.63	18.82	0.19	4.77	19.30	0.26	0.078	24.74
5	5	7.9	48.2	97.4				6.67	54.54	0.28	0.078	69.92
6	6	11.2	48.8	31.6	18.97	18.98	0.01	0.63	46.08	0.28	0.106	43.47
7	7	10.2	48.0	25.2	18.66	18.81	0.28	8.9	40.61	0.3	0.078	52.07
8	8	17.1	48.8	35.2	18.32	18.32	0	0.75	72.29	0.34	0.106	68.20
9	9	14.3	48.8	36.0	18.82	18.80	-0.02	0.78	60.82	0.34	0.106	57.38
10	10	12.5	47.2	43.7	18.42	18.43	0.01	0.64	57.94	0.36	0.106	54.66
11	11	30.7	51.0	20.5	18.86	18.97	0.18	7.36	111.92	0.38	0.078	143.48
12	12	14.7	46.3	40.1	17.98	18.00	0.02	0.95	67.37	0.39	0.106	63.56
13	13	11.2	48.0	46.4	18.19	18.06	-0.13	0.73	52.25	0.40	0.097	53.86
14	14	13.8	46.2	43.3	18.34	18.33	-0.01	0.74	64.92	0.40	0.106	61.24
15	15	15.8	48.8	34.2	17.6	17.58	-0.02	0.79	66.29	0.40	0.106	62.54
16	16	12.0	48.8	34.3	19.13	19.07	-0.06	0.61	50.39	0.40	0.106	47.54
17	17	15.7	60.1	61.4				3.41	68.35	0.40	0.106	64.48
18	18	6.0	48.0	46.0	18.22	18.18	-0.04	0.74	27.91	0.43	0.106	26.33
19	19	14.5	45.5	43.9	17.92	17.94	0.02	0.73	69.40	0.44	0.106	65.47
20	20	10.4	48.8	33.4	17.95	17.95	0.00	0.69	43.37	0.45	0.106	40.92
21	21	22.9	48.8	34.7	18.87	18.87	0.00	0.84	96.45	0.46	0.106	90.99
22	22	25.8	45.4	44.8	18.44	18.44	0.00	0.77	124.56	0.46	0.106	117.51
23	23	11.9	48.8	31.3	19.37	19.37	0.00	0.65	48.85	0.48	0.106	46.08
24	24	14.6	48.8	34.9	19.88	19.87	-0.01	0.69	61.58	0.51	0.097	63.49
25	25	10.5	48.8	36.7	18.92	18.90	-0.02	0.75	44.90	0.52	0.106	42.36
26	26	19.6	48.8	33.8	18.64	18.64	0.00	0.93	81.99	0.53	0.106	77.35
27	27	15.9	46.0	46.1	18.65	18.66	0.01	0.8	76.67	0.54	0.106	72.33
28	28	18.4	45.5	44.2	18.86	18.85	-0.01	0.7	88.27	0.55	0.097	91.00
29	29	20.0	47.5	37.9	19.19	19.21	0.02	1.26	88.25	0.55	0.097	90.98
30	30	7.2	48.0	45.9	19.08	19.09	0.01	0.82	33.46	0.56	0.106	31.57
31	31	16.7	48.0	46.3	18.57	18.58	0.01	1	77.85	0.56	0.078	99.80
32	32	12.8	46.3	43.3	18.20	18.25	0.05	3.07	60.10	0.57	0.097	61.96
33	33	21.9	46.8	15.6	18.53	18.64	0.15	5.53	82.80	0.57	0.097	85.36
34	34	17.8	47.0	31.3	18.47	18.24	-0.23	1.64	75.38	0.57	0.097	77.71
35	35	21.7	48.4	37.5	19.13	19.15	0.02	1.09	93.99	0.58	0.097	96.90
36	36	26.6	47.1	34.0	18.08	18.08	0.00	1.27	114.77	0.60	0.097	118.32
37	37	15.8	48.8	31.1	18.76	18.77	0.01	0.8	64.76	0.60	0.097	66.76
38	38	19.0	45.5	36.1	18.29	18.32	0.03	1.39	85.73	0.60	0.097	88.38
39	39	19.8	46.8	16.4	18.71	18.85	0.28	4.83	75.33	0.61	0.078	96.58
40	40	19.5	48.8	38.1	19.06	19.06	0.00	0.85	84.27	0.62	0.106	79.50
41	41	16.7	48.8	35.1	18.44	18.07	-0.37	0.7	70.55	0.63	0.106	66.56
42	42	22.2	48.0	31.3	18.10	18.08	-0.02	1.06	92.38	0.64	0.097	95.24
43	43	14.7	48.8	30.6	18.22	18.21	-0.01	0.74	60.02	0.64	0.097	61.88
44	44	3.7	48.8	36.9	18.09	18.08	-0.01	0.74	15.84	0.64	0.106	14.95
45	45	49.3	47.8	40.8	19.33	19.34	0.01	0.85	215.81	0.64	0.106	203.59
46	46	19.4	47.0	43.7	17.65	17.66	0.01	1.15	90.24	0.64	0.097	93.03
47	47	15.7	51.0	19.7	19.34	19.47	0.14	5.15	56.85	0.65	0.097	72.98
48	48	28.1	45.8	37.1	17.68	17.58	-0.10	1.2	127.05	0.66	0.097	130.98
49	49	21.3	47.5	43.2	18.94	18.93	-0.01	0.67	97.83	0.66	0.106	92.30
50	50	20.2	46.2	42.7	18.33	18.31	-0.02	0.78	94.59	0.66	0.106	89.24
51	51	19.5	46.6	35.2	18.60	18.60	0.00	1.04	85.66	0.67	0.097	88.31

Vial #	Can #	Net CPM	Temp	Tdel	M(i)	M(f)	delM(v)	delM(c)	Adj CPM	Conc. (c)	CF	CF-CPM
52	52	23.5	48.8	34.0	18.40	18.40	0.00	0.79	98.45	0.70	0.106	92.88
53	53	17.3	46.1	46.2	18.37	18.37	0.00	0.78	83.34	0.70	0.106	78.62
54	54	21.1	48.0	39.8	18.50	18.52	0.02	1.25	93.64	0.71	0.097	96.53
55	55	19.7	48.0	36.4	18.66	18.62	-0.04	1.38	85.20	0.72	0.097	87.84
56	56	20.7	44.8	40.5	18.75	18.76	0.01	1.35	97.82	0.72	0.097	100.85
57	57	17.3	48.0	13.5	18.51	18.54	0.03	0.92	62.92	0.73	0.097	64.87
58	58	16.3	45.9	31.6	18.36	18.36	0.00	1.41	70.57	0.73	0.097	72.75
59	59	18.3	47.9	32.1	18.14	18.15	0.01	1.28	76.75	0.73	0.097	79.12
60	60	2.8	45.5	44.0	18.51	18.5	-0.01	0.72	13.41	0.73	0.106	12.65
61	61	28.0	47.0	38.7	18.06	18.07	0.01	0.84	125.40	0.73	0.097	129.28
62	62	31.5	47.3	42.2	19.00	19.00	0.00	0.81	144.10	0.73	0.097	148.55
63	63	16.1	46.2	42.6	18.01	17.6	-0.41	0.79	75.34	0.74	0.106	71.07
64	64	16.4	48.8	32.5	18.86	18.86	0.00	0.76	67.93	0.74	0.106	64.09
65	65	19.6	48.8	39.4	18.45	18.44	-0.01	0.73	85.54	0.76	0.106	80.70
66	66	14.3	48.8	33.1	18.68	18.62	-0.06	0.64	59.50	0.76	0.106	56.14
67	67	19.8	45.8	33.7	18.13	18.13	0.00	0.98	87.25	0.77	0.097	89.95
68	68	18.7	48.0	43.8	19.36	19.35	-0.01	0.93	85.54	0.77	0.097	88.18
69	69	19.5	48.8	37.2	18.60	18.59	-0.01	0.83	83.70	0.78	0.097	86.29
70	70	13.4	48.8	31.1	19.14	19.08	-0.06	0.73	54.92	0.79	0.106	51.81
71	71	12.6	46.1	45.9	18.40	18.39	-0.01	0.86	60.56	0.81	0.097	62.43
72	72	12.7	61.7	9.9				4.4	36.71	0.82	0.078	47.06
73	73	23.0	45.8	33.9	18.53	18.56	0.03	1.16	101.50	0.82	0.097	104.64
74	74	18.5	47.1	45.2	18.5	18.52	0.02	0.79	86.88	0.83	0.106	81.96
75	75	10.6	46.2	43.2	17.69	17.71	0.02	0.93	49.83	0.84	0.097	51.37
76	76	17.3	43.8	34.2	18.77	18.77	0.00	1.42	79.45	0.84	0.097	81.90
77	77	25.2	48.8	30.3	18.10	18.09	-0.01	1.13	102.66	0.85	0.097	105.84
78	78	15.1	48.0	43.9	18.41	18.42	0.01	0.59	69.12	0.85	0.106	65.21
79	79	14.0	48.0	31.9	18.59	18.59	0.00	1.1	58.52	0.85	0.097	60.33
80	80	8.5	51.0	63.2				4.99	43.02	0.85	0.078	55.15
81	81	10.7	47.7	36.3	18.37	17.49	-0.88	1.37	46.48	0.86	0.097	47.92
82	82	31.5	47.1	35.6	17.14	17.14	0.00	1.11	137.56	0.87	0.097	141.82
83	83	21.3	48.2	36.7	18.40	18.41	0.01	0.94	92.02	0.87	0.097	94.86
84	84	17.9	45.5	45.3	18.10	18.11	0.01	0.79	86.59	0.87	0.106	81.69
85	85	10.3	47.8	32.0	20.25	20.27	0.02	0.85	43.24	0.87	0.097	44.58
86	86	17.5	47.8	31.1	17.75	17.68	-0.07	1.14	72.97	0.88	0.097	75.22
87	87	25.2	48.0	37.9	18.08	18.09	0.01	1.28	110.24	0.89	0.097	113.64
88	88	25.8	48.0	37.1	18.31	18.35	0.04	2.07	112.18	0.89	0.097	115.65
89	89	18.3	46.1	43.0	17.98	17.98	0.00	0.92	86.05	0.89	0.097	88.71
90	90	21.5	48.0	43.6	18.87	18.86	-0.01	0.89	98.19	0.90	0.097	101.23
91	91	26.0	47.3	36.6	17.59	17.62	0.03	1.17	114.00	0.92	0.097	117.53
92	92	17.0	48.0	31.7	17.97	17.92	-0.05	2.95	70.96	0.92	0.097	73.15
93	93	22.9	47.2	44.6	19.24	19.25	0.01	0.72	106.86	0.95	0.106	100.82
94	94	22.2	47.3	34.5	18.11	18.13	0.02	1.29	95.81	0.95	0.097	98.77
95	95	19.3	48.0	41.4	18.25	18.27	0.02	1.07	86.69	0.97	0.097	89.37
96	96	16.8	44.2	34.3	17.87	17.82	-0.05	1.29	76.62	0.97	0.097	78.99
97	97	21.9	47.2	43.9	19.14	19.15	0.01	2.24	101.66	0.97	0.097	104.80
98	98	25.6	45.8	35.8	19.25	19.25	0.00	0.97	114.61	0.98	0.098	116.95

Vial #	Can #	Net CPM	Temp	Tdel	M(i)	M(f)	delM(v)	delM(c)	Adj CPM	Conc. (c)	CF	CF-CPM
99	99	24.7	47.8	33.3	18.41	18.41	0.00	1.5	104.71	1.02	0.097	107.95
100	100	30.8	48.0	38.7	19.04	19.03	-0.01	0.81	135.55	1.05	0.098	138.32
101	101	15.6	47.9	40.1	18.40	18.42	0.02	0.96	69.51	1.06	0.098	70.92
102	102	25.5	48.3	35.3	18.21	18.22	0.01	1.16	108.81	1.09	0.098	111.03
103	103	22.7	48.0	36.2	18.96	18.98	0.02	1.16	98.03	1.09	0.098	100.03
104	104	22.4	45.8	36.0	18.29	18.31	0.02	1.08	100.44	1.11	0.097	103.54
105	105	29.1	48.2	30.3	18.34	18.35	0.01	1.16	119.77	1.11	0.097	123.47
106	106	23.1	48.0	41.2	17.93	17.95	0.02	1.28	103.60	1.11	0.097	106.81
107	107	22.2	48.6	33.3	18.62	18.58	-0.04	1.08	92.83	1.13	0.097	95.70
108	108	25.6	47.9	39.7	17.84	17.85	0.01	1.24	113.72	1.15	0.097	117.23
109	109	30.2	48.5	14.8	18.86	18.98	0.11	3.88	109.83	1.16	0.097	113.23
110	110	26.4	48.0	35.2	18.40	18.38	-0.02	1.05	113.15	1.16	0.097	116.65
111	111	20.3	47.5	40.2	18.28	18.29	0.01	1.94	91.15	1.18	0.097	93.97
112	112	25.3	47.9	39.1	18.60	18.61	0.01	1.41	111.88	1.21	0.097	115.34
113	113	26.5	49.0	28.7	19.22	19.37	0.11	8.9	106.30	1.23	0.097	109.59
114	114	31.9	46.7	40.5	18.38	18.36	-0.02	0.67	145.55	1.23	0.097	150.05
115	115	21.4	47.7	29.3	18.12	17.99	-0.13	1.63	88.17	1.24	0.097	90.90
116	116	43.1	46.9	42.5	18.71	18.74	0.03	1.38	199.01	1.26	0.097	205.17
117	117	15.6	48.0	35.8	18.45	18.38	-0.07	1.44	67.17	1.29	0.097	69.24
118	118	36.2	47.7	39.3	18.28	18.29	0.01	1.11	160.87	1.30	0.097	165.85
119	119	20.1	44.7	42.7	17.99	18.01	0.02	1.3	96.76	1.30	0.097	99.76
120	120	39.2	47.1	41.9	18.22	18.23	0.01	0.99	179.55	1.31	0.098	183.21
121	121	28.8	47.9	32.4	18.72	18.73	0.01	1.26	121.06	1.35	0.097	124.80
122	122	31.0	48.0	36.4	18.63	18.51	-0.12	1.29	134.08	1.36	0.097	138.22
123	123	31.1	48.0	42.3	19.21	19.24	0.03	1.62	140.65	1.37	0.097	145.00
124	124	30.2	46.8	33.5	18.54	18.55	0.01	0.33	130.50	1.38	0.106	123.11
125	125	27.1	48.0	42.7	18.37	18.38	0.01	1.48	122.93	1.38	0.097	126.73
126	126	30.4	48.5	13.9	19.35	19.47	0.11	3.92	109.95	1.39	0.097	113.35
127	127	37.7	47.0	45.0	19.11	19.12	0.01	0.86	177.09	1.45	0.097	182.56
128	128	28.1	47.0	37.6	17.84	17.83	-0.01	0.73	124.81	1.53	0.106	117.74
129	129	24.4	49	27.8	18.20	18.48	0.15	5.15	97.05	1.55	0.099	98.03
130	130	20.3	61.3	19.7				4.21	63.55	1.57	0.078	81.47
131	131	14.3	48.0	42.1	18.58	18.59	0.01	1.61	64.57	1.70	0.097	66.57
132	132	19.3	47.8	40.8	18.45	17.98	-0.47	0.85	86.60	1.82	0.097	89.28
133	133	38.9	48.9	39.2	18.77	18.75	-0.02	0.83	169.22	1.87	0.097	174.46
134	134	24.7	44	81				3.55	160.75	2.19	0.078	206.09
135	135	53.9	46.7	42.8	18.47	18.48	0.01	1.03	250.34	2.26	0.097	258.08
136	136	53.4	47.2	44.1	17.75	17.78	0.03	1.37	248.25	2.32	0.097	255.93
137	137	41.5	47.1	40.7	18.68	18.68	0.00	1.48	188.36	2.49	0.097	194.19
138	138	53.9	46.3	42.1	19.49	19.51	0.15	1.36	250.81	2.74	0.097	258.56
139	139	84.2	48.8	32.1	18.41	18.43	0.02	1.15	347.72	2.90	0.097	358.47
140	140	65.1	46.5	45.3	18.49	18.48	-0.01	0.35	309.23	3.08	0.106	291.73
141	141	75.2	48.8	28.9	18.99	19	0.01	1.27	303.13	3.08	0.097	312.50
142	142	52.8	46	41.7				4.63	246.28	3.28	0.078	315.74
143	143	74.9	46.0	41.4	19.05	19.05	0.00	1.21	348.57	3.36	0.097	359.35
144	144	50	48.8	29.0	18.89	18.89	0.00	1.17	201.70	3.42	0.097	207.94
145	145	77.8	47.0	36.9	19.13	19.14	0.01	1.32	343.73	3.58	0.097	354.36
146	146	69.5	48.2	39.7	18.72	18.73	0.01	1.32	307.13	3.64	0.097	316.63
147	147	72.1	47.0	32.1	18.79	18.81	0.02	1.36	307.18	3.67	0.097	316.68

Vial #	Can #	Net CPM	Texp	Tdel	M(i)	M(f)	delM(v)	delM(c)	Adj CPM	Conc. (c)	CF	CF-CPM
148	148	77.6	48.9	39.1	19.04	19.04	0.00	1.09	337.32	3.92	0.097	347.75
149	149	68.0	48.8	35.2	17.89	17.90	0.01	0.89	287.48	3.97	0.097	296.37
150	150	55.1	47.0	30.4	19.03	19.04	0.01	1.20	231.75	4.03	0.097	238.92
151	151	101.5	48.5	41.3	18.50	18.51	0.01	1.19	451.68	4.10	0.106	426.11
152	152	51.5	48.5	39.0	18.41	18.42	0.01	0.83	225.22	4.13	0.097	232.19
153	153	98.3	49.0	38.0	18.98	18.97	-0.01	1.12	423.05	4.14	0.097	436.13
154	154	78.6	47.0	36.7	18.16	18.19	0.03	1.61	346.74	4.17	0.097	357.46
155	155	58.7	48.3	39.2	18.95	18.94	-0.01	1.00	257.98	4.18	0.097	265.96
156	156	57.7	48.0	52.9				10.90	282.50	4.18	0.078	362.18
157	157	91.3	48.8	38.5	17.66	17.66	0.00	0.92	395.75	4.32	0.106	373.35
158	158	98.9	48.5	32.7	18.91	18.94	0.03	1.21	412.38	4.35	0.097	425.14
159	159	123.5	48.6	36.0	19.17	19.18	0.01	1.18	527.08	4.35	0.098	537.83
160	160	95.2	48.6	40.6	18.18	18.19	0.01	0.94	420.69	4.47	0.106	396.87
161	161	73.7	48.8	35.5	18.35	18.37	0.02	1.23	312.29	4.50	0.097	321.95
162	162	89.4	48.5	36.5	19.44	19.43	-0.01	1.21	383.64	4.52	0.097	395.51
163	163	119.1	48.8	43.4	18.43	18.45	0.02	1.29	535.74	4.72	0.097	552.31
164	164	114.8	48.5	32.1	18.32	18.35	0.03	1.33	476.51	4.80	0.097	491.25
165	165	70.3	47.0	31.5	18.86	18.87	0.01	1.72	298.16	4.81	0.096	310.58
166	166	84.6	48.6	29.2	18.09	18.11	0.02	1.10	342.95	5.06	0.098	349.95
167	167	115.3	47.1	39.1	18.28	18.29	0.01	1.36	517.04	5.14	0.097	533.03
168	168	90.3	47.0	31.7	18.31	18.33	0.02	1.51	383.56	5.47	0.097	395.42
169	169	98.2	47.0	32.2	18.91	18.93	0.02	1.31	418.70	5.50	0.097	431.65
170	170	50.8	46.2	83.8				4.05	324.95	5.84	0.078	416.60
171	171	126.9	47.0	39.6	18.77	18.79	0.02	1.80	572.22	5.92	0.097	589.92
172	172	150.2	46.3	44.4	19.14	19.18	0.04	1.88	711.18	5.93	0.097	733.17
173	173	169.3	48.8	42.3	18.34	18.35	0.01	1.30	755.25	5.95	0.097	778.60
174	174	144.0	48.5	36.8	19.09	19.08	-0.01	1.50	619.35	5.96	0.097	638.51
175	175	91.9	46.9	39.2	18.38	18.40	0.02	1.50	413.88	6.04	0.097	426.68
176	176	76.6	50.1	100.3				3.59	519.04	6.07	0.097	535.09
177	177	148.2	46.6	35.3	19.17	19.20	0.03	1.02	651.50	6.76	0.097	671.65
178	178	73.4	46.4	41.8	18.13	18.16	0.03	1.67	340.16	7.30	0.097	350.68
179	179	157.4	46.9	39.8	18.24	18.27	0.03	1.87	712.09	7.87	0.097	734.12
180	180	143.9	48.0	102.9				5.03	1029.16	10.54	0.078	1319.44
181	181	254.6	48.5	69.4				4.76	1401.67	15.99	0.078	1797.01

Appendix C

Presented in this appendix are the linear regression analyses performed on "uncorrected" vial/canister data (see Fig. 7) and "corrected" vial/canister data (see Fig. 12).

The results of the regression analysis for the data given in Fig. 7 and in Fig. 12 are given here in tabular form.

The variables are identified as follows :

Constant : Y-axis intercept
Std. Err of Y EST : Error of predicted Y values from X- values
R squared : Coefficient of determination
X Coeff. : Slope of computed regression line
Std. Err of Coef. : Standard Error of computed slope

Vial and Canister Data (Zero Mass Gain)

Regression Output :

Constant	-0.010660
Std Err of Y Est	0.643468
R Squared	0.907957
No. of Observations	188
Degrees of Freedom	186
X Coefficient(s)	0.011110
Std Err of Coef.	0.000259

Vial and Canister Data (Mass Gain Consideration)

Regression Output :

Constant	0.157502
Std Err of Y Est	0.657666
R Squared	0.903850
No. of Observations	188
Degrees of Freedom	186
X Coefficient(s)	0.009442
Std Err of Coef.	0.000226

Appendix D

Presented in this appendix are the experimentally determined moisture gains of the activated charcoal canisters and the two-gram vials. This data was presented graphically in Fig. 8.

Mass Gain Data
(see Fig. 8)

Canister (g)	Vial (g)
7.08	0.281
5.75	0.119
4.04	0.131
5.54	0.149
4.83	0.110
4.86	0.146
4.64	0.137
5.15	0.154
8.90	0.281
5.15	0.137
7.36	0.184
5.90	0.150
3.92	0.118
3.88	0.107
1.15	0.010
1.20	0.020
1.36	0.030
1.84	0.040
3.70	0.050

Appendix E

The following table presents the humidity correction factors for the two-gram vials. These results were obtained using the EPA canister CF factors (see Fig. 9) and the experimentally determined mass gain relation for the canisters and the two-gram vials (see Fig. 8).

Conversion from Canister to Vial CF factors
(see Fig. 11)

$\text{delM}_{\text{canister}}(\text{g})$	CF(l/min)	$\text{delM}_{\text{vial}}(\text{g})$
0.00	0.1025	0.0000
2.00	0.0940	0.0353
4.00	0.0880	0.0988
6.00	0.0800	0.1803
8.00	0.0710	0.2763
10.00	0.0680	0.3847
12.00	0.0640	0.5042
14.00	0.0580	0.6337
16.00	0.0540	0.7726
18.00	0.0480	0.9201