AN ABSTRACT OF THE THESIS OF

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Title: AN INVESTIGATION OF THE DECAY CURVES FOR
RADON DAUGHTERS WITH ACTIVE COLLECTION OF
RADON ON ACTIVATED CHARCOAL

Abstract approved: Alfred J. Ervin

The focus of this investigation was to develop a rapid "on site active" collection technique for the concentration of radon on activated charcoal. The radon was adsorbed on the charcoal and its analysis was based on gamma spectroscopy, detecting primarily the decay daughters ^{214}Pb and ^{214}Bi. The results obtained were then used to relate the activity of radon (in secular equilibrium with its decay daughters) on the charcoal at a given time (t) to the initial activity of radon at the time of collection.

The decay curves for active and passive collection samples were analyzed over various time intervals for any deviations from the theoretically expected logarithmic decay curve using the computer spreadsheet QUATTRO.

Results obtained from the passive collection method indicated the expected linear decay curve for samples with moderately high activities. The active collection method gave numerically increased initial slopes during the interval of 250 - 5,000 minutes apparently due to radon gas transport. The portion of the decay curve past 20,000 minutes resulted in a slope slightly less than the theoretical slope probably due to the increasing effects of background variations and statistical variations of random decay.

Active collection was revealed to be a rapid method for determining radon concentrations with reasonable accuracy, provided the optimum portion of the decay curve (from 5,000 - 10,000 minutes) was used to determine original radon concentrations.

AN INVESTIGATION OF THE DECAY CURVES FOR RADON DAUGHTERS WITH ACTIVE COLLECTION OF RADON ON ACTIVATED CHARCOAL

A Thesis
Presented to
the Division of Physical Sciences
Emporia State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

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by
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A special thanks to my parents for their support and patience throughout my entire college career. Their willingness to enable my continued education will never be forgotten.

This paper was written in loving memory of
Chelise Michelle Mitchell.

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CHAPTER I

Introduction

Along with the growing concern the public has about the health effects of radon, a radioactive gas which quickly decays into a series of decay daughters which are generally accepted to be one of the leading causes of lung cancer (1-4), the scientific community is concerned with the quick and reliable detection of the gas. The alpha radiation from ^{222}Rn, ^{218}Po and ^{214}Po is believed to be the main cause of cancer. The significant gamma emitters in the decay chain are ^{214}Pb and ^{214}Bi, but as the more penetrating gamma radiation is less probable to react with matter and is of less concern. (See Appendix 2 for partial decay chain of radon.)

The two principal types of detection of radon utilize alpha or gamma radiation. The results obtained from alpha spectroscopy (using an etched track detector) are more time consuming, and less reproducible than those utilizing a charcoal adsorption detector analyzed by gamma spectroscopy (5).

One of the major factors differentiating alpha and gamma spectroscopy is the efficiency of detection associated with each. The efficiency of detection of gamma radiation is but slightly affected by the source on various separation media. Alpha radiation cannot be observed if separated from the detector by very thin media. By the use of a NaI(Tl) crystal in gamma spectroscopy, percent efficiencies in terms of amount of radon of around 100% can be obtained (6,7). This fact, along with the relatively short counting times with samples concentrated on charcoal or other adsorption media would indicate that analysis by gamma spectroscopy may be the method of choice when measuring radon levels. Gamma spectroscopy can be used for the quantitative analysis of radon daughters when the radon is concentrated on adsorbers. Radon is an alpha emitter, but the non-penetrating alpha radiation is difficult to detect and the radon is at low concentrations. Since the radon daughters are present in secular equilibrium with the parent radon, their concentration can be used to calculate the amount of radon present. When using gamma spectroscopy, the decay curve of radon's decay daughters (decaying with the half-life of radon due to secular equilibrium) is analyzed.

One problem with respect to the charcoal adsorption detectors is in reference to the temperature dependence on the adsorption capacity of the activated charcoal (5). Elevated temperatures facilitates transport of the radon gas from the activated charcoal and into the air. Another problem is the precision (only within 25%) of the values obtained from the charcoal adsorption technique (8). This lack of precision may be due to several contributing factors. Low concentrations of radon require long counting times and the variety of collection designs may not give true data in terms of units of activity per liter of air. The long time required to collect samples often necessitate their collection by non-technical staff (home owners), which adds to the difficulty of standardizing the method.

It becomes increasingly clear that some type of rapid "on site active" collection method would be preferable to the passive collection technique currently used by radon testing labs in which a small container of activated charcoal is allowed to sit for 2 to 5 days after which it is resealed and mailed for analysis. An active collection method of filtering the air for a short period of time followed by analysis at optimum conditions would eliminate some of the problems associated with the passive collection method. An active collection method would be faster and would help to ensure that the collection technique was the same for all samples and make it possible for samples to be analyzed at approximately the optimum time. The concentration would always be determined with the best possible conditions.

CHAPTER II

Experimental Section

Preliminary Preparation

In order to facilitate this investigation, it was necessary to concentrate the radon in a closed sample container. Three different sample containers were used, two being desiccators of known volume (approximately 2600 ml), and the third sample container being a 6000 ml Pyrex Erlenmeyer flask.

Uranium containing ore was placed in Containers #1 and #2 (see Figure 1 for sample setup) to generate radon and its decay daughters. A licensed radium source was placed in Container #3 (Figure 2) to generate radon and its decay daughters.

All sample containers were allowed to equilibrate or buildup for at least seven days before any testing was performed on the sample container. After seven days or more, the activity in the sample container would be approximately 75% of the maximum activity. The percent of the maximum activity could be calculated using the equation:

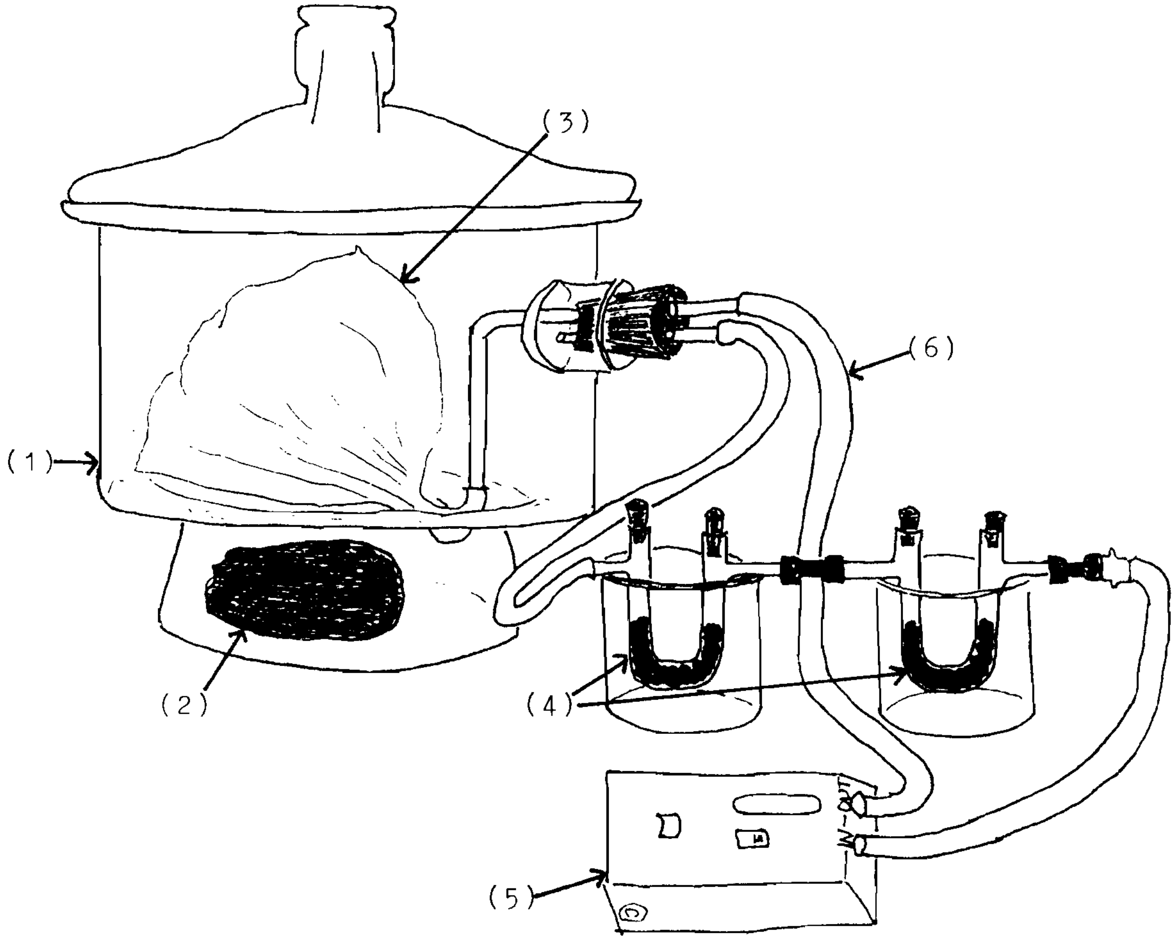


Figure 1. Sample radon concentration apparatus for containers #1 and #2.

(1) desiccator
(2) uranium ore (approximately 2600 mL)
(3) plastic bag
(4) u-shaped drying tubes containing charcoal
(5) portable air pump
(6) air outlet from pump

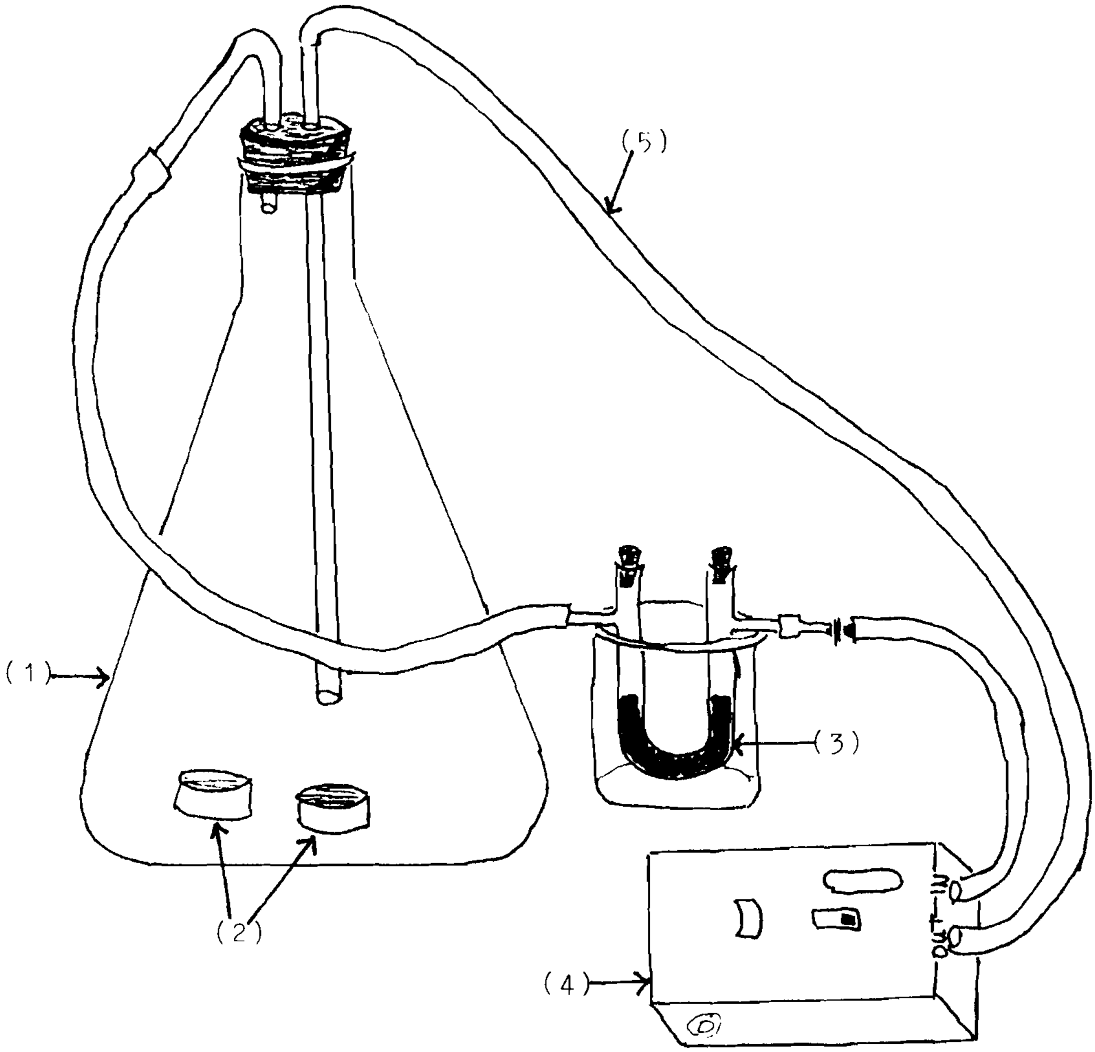


Figure 2. Sample radon concentration apparatus for container #3.

(1) Erlenmeyer flask (6000 mL)
(2) radium source
(3) u-shaped drying tube containing charcoal
(4) portable air pump
(5) air outlet from pump

$\%$ max. act. daughter = $(1 - e^{-Kt}) * 100$

where $K = \ln(2) / T_{1/2}$ (daughter)

and $T_{1/2}$ (daughter) $<< T_{1/2}$ parent nuclide

and act. (daughter) = $N * K = N_p * K_p (1 - e^{-Kt})$

where N_p and N represent the relative populations of the parent and decay daughter nuclides. K_p and K represent the decay constants of the parent and daughter radionuclides and (t) is the equilibration time (9).

The activated charcoal used for all collection techniques was 8 - 12 mesh coconut activated charcoal manufactured by Matheson Coleman and Bell. The activated charcoal was stored in an oven at 100 ° C until just prior to use, when it was removed from the oven and allowed to cool to room temperature.

Methods of Collection

In the passive collection technique, a petri dish containing approximately 5 - 6 grams of activated charcoal was placed in the sample container along with the radon source. Upon an elapsed buildup time of at least seven days, and directly following any active collection procedure (to be discussed shortly), the petri dish was removed from the sample container and approximately three grams (accurately weighed) of the 5- 6 grams of activated charcoal was placed in a 5.2 x 1.6 centimeter plastic sample vial with a screw cap and analyzed by gamma spectroscopy.

In order to carry out active collection of the radon, the three sample containers (see Figures 1 and 2) were arranged to pump air through a filter of activated charcoal and then return the air to the sealed sample container. The pump (Air-Check, Portable Air Sampling Pump, Model 222-3), was then attached in line with one or two U-shaped drying tubes containing approximately 3.0 grams of activated charcoal each. This amount of activated charcoal filled the U-tubes to one-half their total volume.

For all samples but one, a pumping time of 15 minutes was used. This pumping time resulted in approximately 1.150 Liters of air passing through the collection tubes. Immediately upon completing the pumping, all of the activated charcoal contained in both of the U-shaped drying tubes was poured into separate 5.2 x 1.6 cm plastic vials and sealed tightly with plastic screw caps.

Careful attention was taken when pouring the activated charcoal from the U-shaped drying tubes to ensure that the activated charcoal with the highest activity, (i.e. activated charcoal which comes in contact with the air from the sample container first), was placed in the plastic vial first, with the least active activated charcoal being placed in the sample vial last. This method of placing the activated charcoal in the sample vial was followed not only to ensure experimental consistency, but also to facilitate a higher count rate by placing the activated charcoal of highest activity closer to the detector.

Radon Sampling Methods

Three basic methods for the concentration of radon in the sample container were developed. Methods 2 and 3 were tried with the intent of increasing the activity which could be obtained from the sample container during active collection. The three methods used, and variations of those methods, are listed below:

1. The first trial of both sample containers #1 and #2 involved both passive and active collection. During the buildup period, a

petri dish containing activated charcoal was placed in the sample container with the radon source. When the active collection sample was collected, a portion of the passive collection sample was also collected for analysis.

2. The next approach was to increase the activity by removing the petri dish containing the activated charcoal from the sample container during buildup. Active collection was then carried out as in method one.

3. A third method developed to prevent dilution of the radon by return air entering the desiccator, involved attaching a deflated plastic bag to the air return glass tube inside the sample container, thereby letting the plastic bag expand inside the sample container as the return air, just filtered, fills the bag.

Two other variations of method number two were carried out to see if they would affect the shape of the observed decay curve. These variations involved the following changes:

1. A sample of approximately 3 grams activated charcoal (accurately weighed) was collected from sample container #1 using the second collection method described above. Immediately after the active collection was performed and the sample vial was sealed, the vial was placed in an oven at 100 ° C for 30 minutes. After removal from the oven, the sample was then counted in a similar manner to all other samples.

2. A sample of approximately 3 grams of activated charcoal (accurately weighed) was collected from sample container #3 with the only change being doubling of pumping time.

Spectroscopic Methods:

Once the activated charcoal sample had been prepared (from passive or active collection), and the 5.2 x 1.6 cm plastic sample vial had been sealed, the total gamma emissions were then counted as a function of time. A Quantum 8 Multichannel Pulse Height Analyzer designed by The Nucleus Inc. was connected to a Picker Nuclear deep well detector containing a 2" x 2" sodium iodide (thallium) crystal and used for the detection of the gamma emitting radon daughters, primarily ^{214}Pb and ^{214}Bi (10).

A counting time of five minutes was used for all samples, and the total counts from the Multichannel Analyzer were recorded as a function of the elapsed time from the sealing of the sample vial. This gave the total counts from channel 0 to channel 255 for all samples considered, and made it so the random statistics of radioactive decay was not a significant factor in uncertainty of results.

Initially up to 100 readings were taken over a period of 20 - 25 days to positively establish the shape of the decay curve of the radon daughters. After several trials had been performed and the decay curve was well established, the total number of readings was reduced to approximately thirty, and the period of analysis was reduced to roughly fourteen days. After fourteen days, the activity of the radon daughters in the sample vial had decreased to approximately 10% their initial activity.

Obtaining Decay Curves:

Decay curves were derived from the experimental information obtained from the Multichannel Analyzer by entering the data into the computer spreadsheet QUATTRO, a computer program distributed by Borland International Inc. The elapsed time and the total counts for each five minute activity reading were entered into columns. From this information, the computer then calculated the activity corrected for background as well as the natural logarithm of the corrected activity and displayed these values in separate columns. By utilizing the graphing capabilities of QUATTRO, the corrected activity as a function of time as well as the natural logarithm of the corrected activity as a function of time was calculated, plotted, and displayed as graphs.

CHAPTER III

Results Section

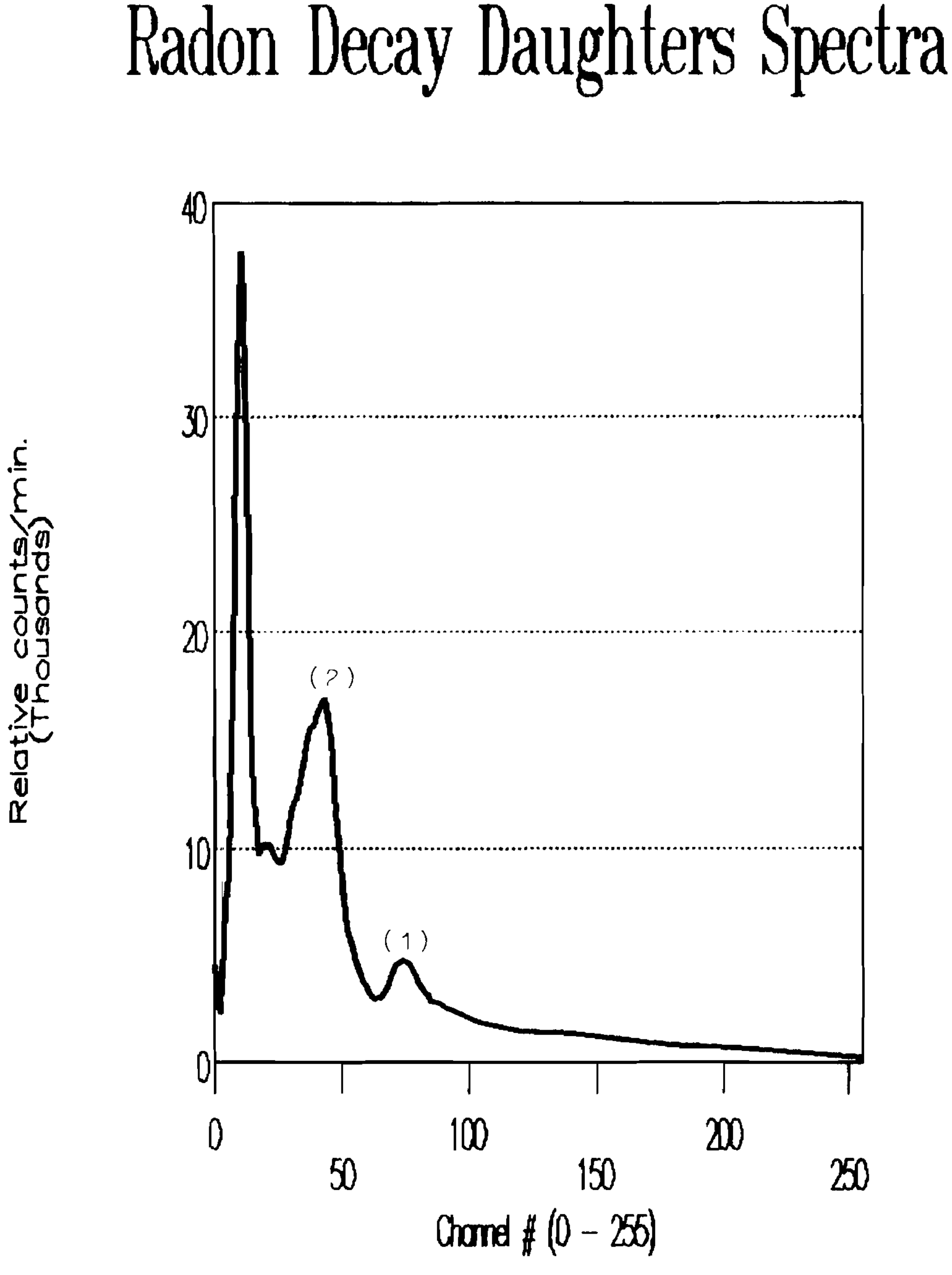
Radon Identification

Upon comparing the gamma spectrum obtained from the Multichannel Analyzer for all experimental runs (Figure 3) with a literature spectrum (10), it was easily determined that all of the experimental spectra obtained during this investigation were representative spectra for radon decay daughters. The 0.609 MeV peak associated with ^{214}Bi (peak 1) and the 0.352 MeV peak of ^{214}Pb (peak 2) were readily identified. The spectrum of sample container #3 (licensed radium source), being typical of all spectra, aided in the identification of the radon daughters. Since radium is in secular equilibrium (a limiting case of radioactive equilibrium in which the half-life of the parent radionuclide is many times greater than the half-life of the daughter radionuclide)(9) with radon, as well as radon being in secular equilibrium with its daughters. The spectra observed from the radium source should be that of the radon daughters, which are commonly used to evaluate radon levels when using gamma spectra.

Figure 3. Spectra observed for radon decay daughters from the Multichannel Pulse Height Analyzer. Relative counts per minute are plotted as a function of the channel number.

(1) ^{214}Bi channel 74 represents an energy of 0.609 MeV.

(2) ^{214}Pb channel 43 represents an energy of 0.352 MeV.



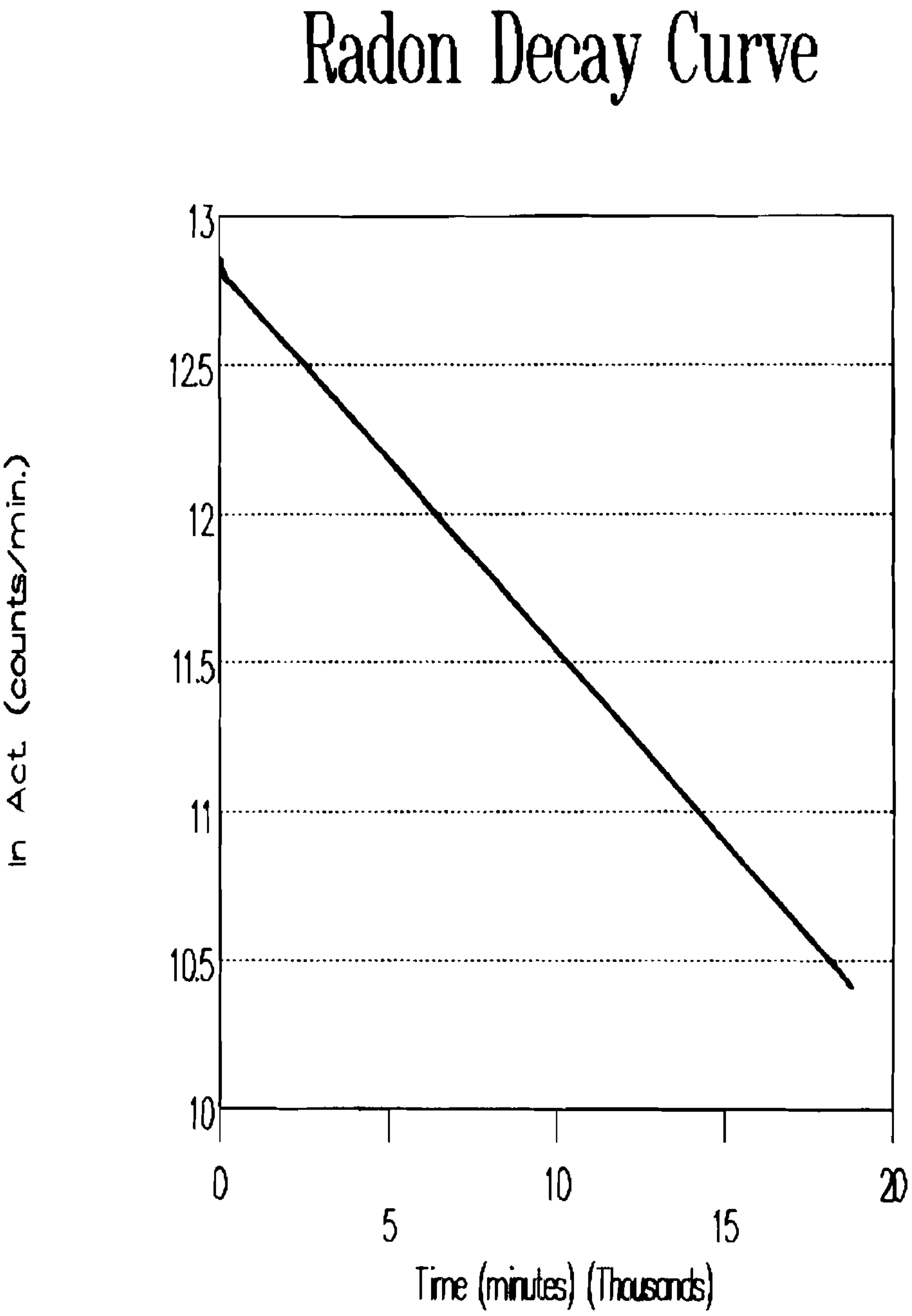
Passive Collection

Analysis of the activated charcoal samples from the passive collection technique yielded very high count rates, indicating that the activated charcoal was very efficient in adsorbing radon from the air.

A plot of the activity as a function of time for passive collection, Figure 4, gives the expected straight line typical for the decay of a pure radionuclide. The high degree of linearity associated with the passive collection technique, indicates secular equilibrium has been established.

As can be seen in Tables 1 and 2, the passive collection technique gives calculated half-life values which are relatively consistent with each other. Trial 1 in Table 1 (from sample container #1), gives an average half-life of 3.729 days with a standard deviation of 0.0154, whereas Trial 2 gives an average half-life of 3.744 days with a standard deviation of 0.00713. Trial 1 of Table 2 (from sample container #2) gives an average half-life of 3.866 days with a calculated standard deviation of 0.0893, whereas the results from Trial 2 give an average half-life of 3.801 days with a 0.0499 standard deviation.

Figure 4. The natural logarithm of the sample activity as a function of time for a typical radon sample collected by the passive collection method.



Active Collection

In the active collection samples, it was noted that it took approximately 250 minutes for radon to approach secular equilibrium with its decay daughters. Upon looking at the half-lives' of radon's daughters being 3.11 minutes, 26.8 minutes and 19.8 minutes, the time required to reach secular equilibrium becomes reasonable. This point is easily located on the buildup-decay curve for radon, being the peak maxima of the curve (see Figure 5).

After a few trials had been completed using two U-shaped drying tubes with approximately 3.0 grams (accurately weighed) of activated charcoal in each tube, it was observed that the activity of the second U-tube was essentially background radiation. Over 99.98% of the radon had been adsorbed in the first U-tube. When both the activities of the first and second U-tubes were plotted together as a function of time (see Figure 6), the activity of the second U-tube was essentially zero when compared to the high activity of the first U-tube. Upon completion of several experimental trials, the second U-tube was omitted from

Figure 5. The sample activity as a function of time for a typical radon sample collected by the active collection method.

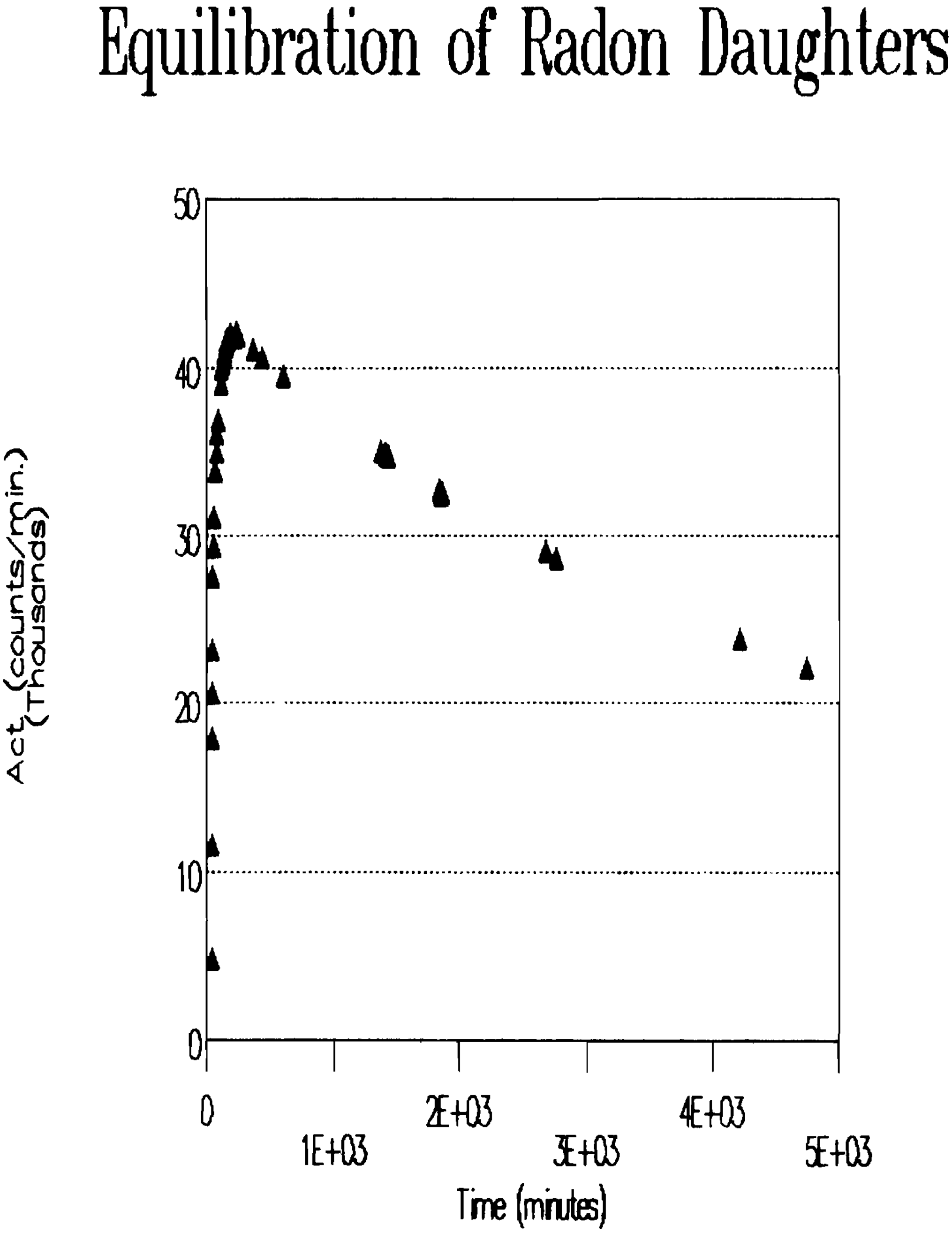
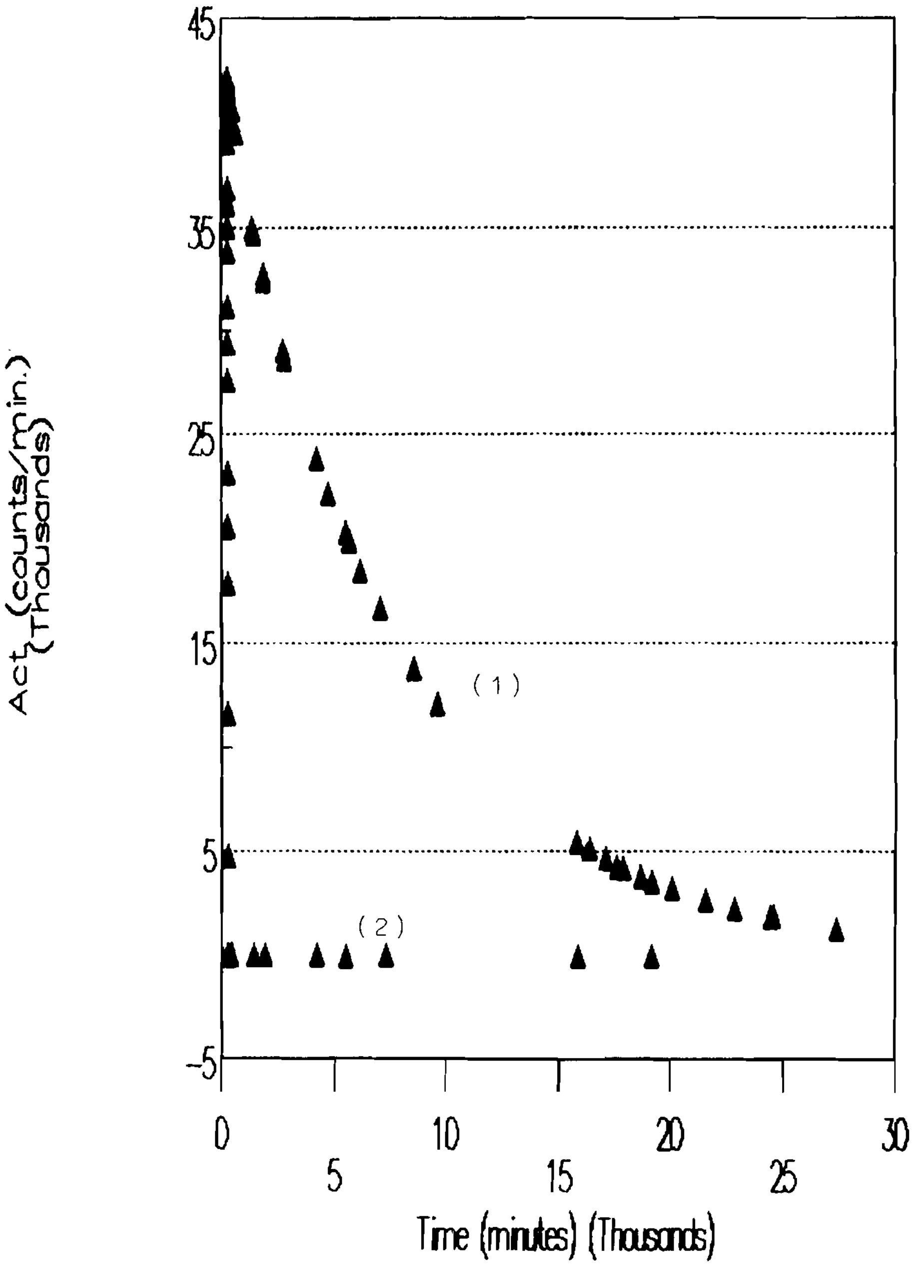


Figure 6. The sample activities of both u-tube #1 and u-tube #2 as a function of time for a typical radon sample collected by the active collection method.

(1) represents activity of u-tube #1

(2) represents activity of u-tube #2



the apparatus since the first U-tube adsorbed over 99.98% of the radon being filtered.

As mentioned earlier in the experimental section, once the decay curve had been well established, it was not necessary to take activity measurements as often as had been done initially. It was also observed from the decay curves that the portion of the curve of most interest was the portion from 0 - 20,000 minutes. The portion of the curve past 20,000 minutes, in several samples became uncertain due to the low level of activity of the sample. The half-life of radon is 5506 minutes, and when approximately four half-lives have elapsed, the activity is reduced to under 7% the initial activity. With the decrease in activity, the statistics of random decay and the uncertainty of background radiation began to affect the accuracy of the observed decay curve.

Concentration Techniques

The active collection runs when the petri dish containing activated charcoal was present in sample containers #1 and #2 gave moderately high activities for the sample ore used. By comparing Tables 1 and 3 as well as Tables 2 and 4, it was determined that the activities of the petri dish samples were around 700% the activities of the active collection samples when activated charcoal was also present in the sample containers.

The active collection experimental trials of the same containers (containers 1 and 2) after the petri dish of activated charcoal had been removed and the sample containers were allowed to equilibrate once again, increased by at least 400%, (as can be calculated by comparing Tables 3 and 5 as well as Tables 4 and 6), for samples which had approximately the same equilibration times.

Tables 7 and 8 represent data collected after the addition of a plastic bag attached to the air return of the sample containers. Upon comparing Tables 5 and 7 as well as Tables 6 and 8, it was noted that the activity increased an additional 20% as compared to the same sample containers analyzed with the air diluting the equilibrated radon. Only active collection samples with similar equilibration times and being from the same containers were compared.

Sample container #3 gave a low activity in the active collection sample collected from it (Table 9). This decrease in activity, was caused by the increased volume of the sample container as well as the lower activity of the source. Sample container #3 had a volume three times that of either sample containers 1 or 2, decreasing the percent of radon present which could be collected in the 15 minute pumping time. The volume of air pumped in 15 minutes would only be approximately 1150ml or one sixth the volume of sample container #3.

One of the two final procedural variations of active collection was to extend the pumping time of the sample container to 30 minutes. This was performed on sample container #3 with the only observable change being an increase in activity. The increase in activity was expected for the above sample, but there were no observable effects of increased pumping time on the typical variance of the half-life as calculated from the decay curve using different time intervals (Table 10). What was also unique, but easily explained, was that a pumping time twice as long did not double the activity. The activity for the 30 minute pumping time was only 61% greater than that of the 15 minute pumping sample. By understanding that the air being returned to the sample container was in effect diluting the concentration of the radon remaining in the container, failing to observe a doubling in the activity was accounted for. The failure of the increased pumping time to have any effect upon the typical variance of the calculated half-life is reasonable as the collection time was still a small percentage of the time required to establish secular equilibrium.

Sample container #1 was used for the second procedural variation. There was no change in the active collection method used (Method 2, page 11), but as soon as the sample vial was sealed, it was heated at 100°C for 30 minutes before analysis was performed. As was confirmed in an earlier experiment, by heating an open sample of radon adsorbed to activated charcoal, 98% of the radon was driven off the activated charcoal. Since the most active activated charcoal was on the bottom of the plastic sample vial, by heating the entire vial, transport of the radon gas within the vial might be facilitated. As can be seen from the calculated half-life results (Table 11), the results are typical of those for the two trials which were performed on sample container #1 that were not heated after collection (Table 5). This confirms that there is no easy method to equilibrate the radon inside the sample vial, since heating the sample would have quickly removed the radon from the charcoal. If the radon had re-equilibrated itself evenly, a linear natural logarithmic decay curve should have been observed.

Curve Analysis

All active collection trials displayed the same characteristics in terms of the linearity of the curves and the slopes associated with the different time intervals which were subjected to linear regression analysis.

Upon performing a linear least squares regression analysis on a selected portion of the decay curve, the y-intercept ("Constant" in regression output) was then used to calculate the initial activity (A zero) by taking the exponent of the y-intercept (e^x). The regression output also gives the slope (x-coefficient) of the line. This can be used to calculate the half-life of radon at various portions of the curve using the following equation:

$$T_{1/2} = -(\ln 2 / \text{slope}) * (1/1440) \text{ [in days]}$$

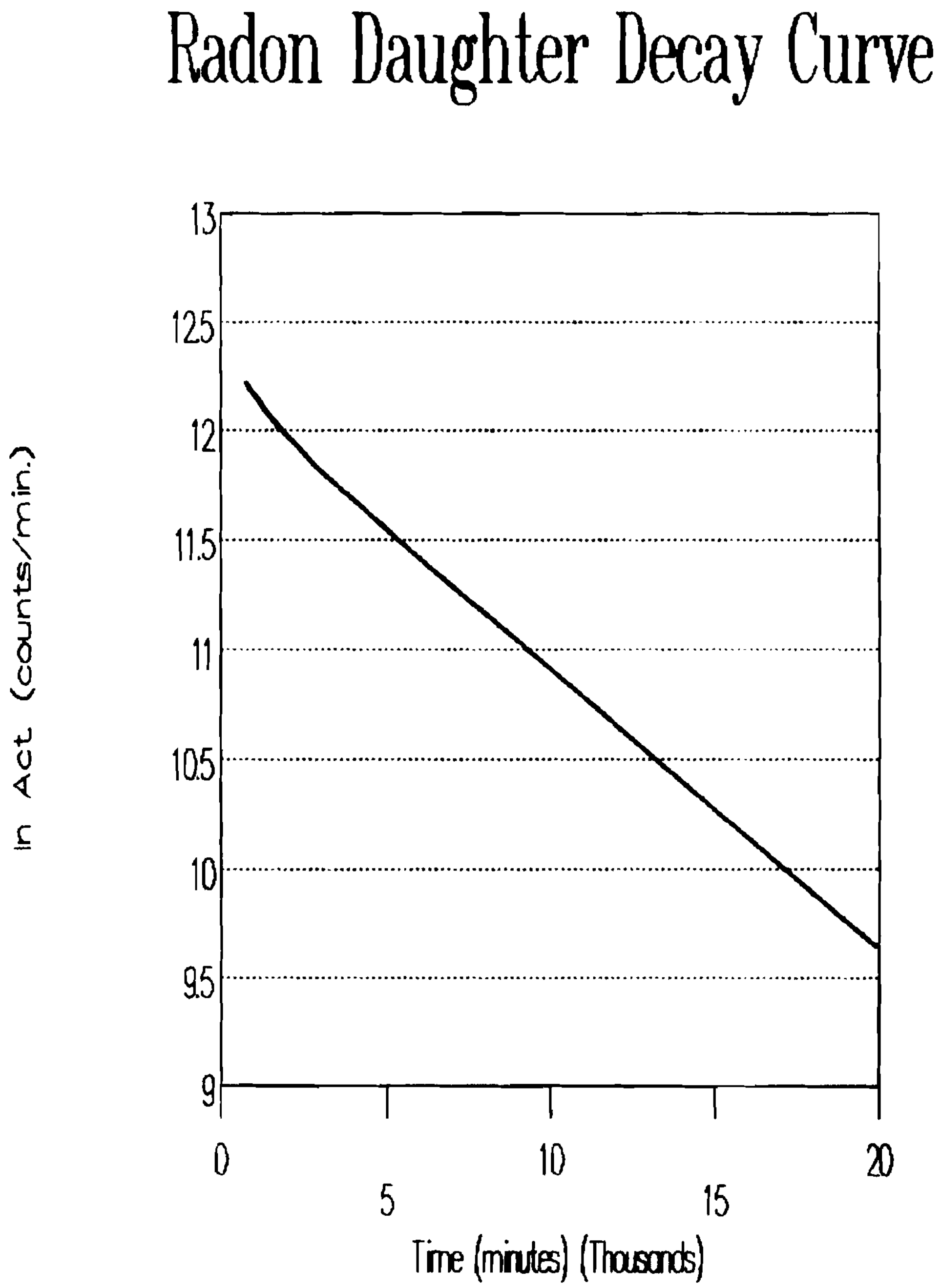
All of the above information was organized and calculated by the professional spreadsheet computer program QUATTRO described in the experimental section.

Upon examining the natural logarithmic decay curve, (Figure 7), it was found that over the time interval of approximately 0 - 5,000 minutes, for all data, the slope of the curve ranged from -1.43×10^{-4} to -1.66×10^{-4}, representing a half-life from 3.373 days to 2.899 days as compared to radon's accepted half-life of 3.824 days. This indicates a changing slope in the first few thousand minutes.

Analyzing the natural logarithmic decay curve for the approximate time interval of 10,000 - 20,000 minutes, it was observed that the slope varied from approximately -1.08×10^{-4} to -1.32×10^{-4}, representing half-life values from approximately 4.475 days to 3.654 days. The 4.475 day half-life for the upper boundary represents a sample with a very low activity. Although the deviation is not as large as the slope deviation of the initial portion of the curve, it was found that the decrease in activity after 10,000 minutes led to inaccurate slope determinations.

The most stable (linear) portion of the natural logarithmic decay curve turns out to be the approximate time interval of 5,000-15,000 minutes. This portion of the curve gives the best calculated half-life values and the slopes over this time interval have the lowest

Figure 7. The natural logarithm of the sample activity as a function of time for a typical radon sample collected by the active collection method.



values for the standard error of the slope, indicating a high degree of linearity.

CHAPTER IV

Discussion Section

This investigation was directed toward developing and determining the reliability of a rapid method for the concentration of radon. The radon was concentrated on charcoal and its analysis was based on gamma spectroscopy, making it possible to analyze the sample without separation from the concentration media.

The extremely high efficiency of the activated charcoal to adsorb radon gas was evident during the passive collection of radon. This adsorption efficiency was utilized to concentrate as much radon on the activated charcoal as possible. By developing a method which allowed relatively high concentrations of radon, statistical variation was not a significant source of error.

The primary focus of this investigation was to utilize gamma spectroscopy to analyze the decay curve for radon daughters in secular equilibrium with radon concentrated on charcoal. The results obtained were then used to relate the activity of the radon on the charcoal at a given time (t) to the initial activity of radon at the time of collection.

The passive collection of radon on activated charcoal was compared to the active collection method. The decay curves for the passive collection of radon were linear for the samples which had a moderate to high activity, but for samples of lesser activity, slight deviations from linearity were observed. These deviations for the passive collection samples of low activity are explained by the increased effects of both the statistics of random decay and the uncertainty of background activity.

The decay curves for the active collection samples were found to have very noticeable deviations from the theoretical curve. These deviations tended to indicate that the first portion of the natural logarithmic decay curve (from 0-5,000 minutes) generally had an increased numerical slope (resulting in a decreased calculated half-life) as compared to the middle portion of the curve (from 5,000- 15,000 minutes).

A reasonable explanation for the changes in the initial portion of the curve would be in terms of the deadsorption and transportation of the radon gas to another portion of the sample vial. Since the most active charcoal was placed towards the bottom of the sample vial, the radon gas deadsorbed from the charcoal on the bottom of the sample vial and readsorbed to the charcoal further up the sample vial, making the efficiency of detection decrease.

This phenomena of deadsorption and readsorption of the radon would explain the non-theoretical behavior of the first portion of the radon decay curve beyond changes based upon the half-life of radon and development of secular equilibrium with its decay daughters. This can be understood by realizing that increasing the distance between the gamma emitting radionuclides and the detector, the activity recorded by the Multichannel Analyzer would also be decreased. As the radionuclide is moved farther away from the detector, scattering of the radiation increases and fewer gamma emissions hit the NaI(Tl) crystal. The decrease in activity measured by the Multichannel Analyzer makes the slope different for the first portion of the decay curve than should be observed with theoretical radioactive decay.

The heating of the sample vial for 30 minutes before analyzing, was intended to speed the movement of the radon gas inside the sample vial before any activity measurements were taken. This sample gave similar results to those obtained when the sample vial was not heated. Although decreased temperatures tend to adsorb the radon more firmly, the increase in temperature had negligible effects as indicated by the results. This would indicate that temperature control in handling the samples was not critical in this investigation.

The theoretical slope of a line which would give the correct half-life for radon was calculated to be -1.25×10^{-4} by using the accepted half-life for radon (3.8235 days) and solving the equation on page 26 for the slope.

The portion of the natural logarithmic decay curve which gave experimental slopes closest to that of the theoretical slope was over the time interval of approximately 5,000 - 15,000 minutes. The calculated half-life values over this time interval generally ranged from 3.70 to 3.84 days and, as mentioned in the results section, have the lowest values for the standard error of the slope which indicates a high degree of linearity for the logarithmic plot.

One of the difficulties in obtaining accurate radon concentration values from passive collection of radon on an activated charcoal filter may be the assumption that the initial activity calculated for samples collected on charcoal depends only on the half-life of radon. The non-linear decay curve especially complicates measurements when low activities are being dealt with. It was clearly found in this investigation that the point at which the sample was analyzed would have a severe impact on the uncertainty of the calculated initial activity. These reasons, as well as failing to seal the sample container tightly before mailing it in, could be primary reasons for the inaccuracy in the results obtained from radon testing laboratories (8).

In order to determine how the initial activity was affected by taking measurements at different elapsed times, the initial activity was calculated using each individual datum point (time in minutes) as a reference to calculate the initial activity which would be represented by each elapsed time value. The following equation was used:

$$A(i) = \frac{\underline{(\mathrm{Activity})}}{e^{(-0.693*t)/T(1/2))}}$$

where Activity is the activity of the sample in counts per minute at elapsed time (t). T(1/2) is the half-life of radon in minutes. As can be seen from Figure 8, the passive collection system offers reasonably consistent results over a broad time interval for the calculation of the initial activity. In Figure 9 it can be seen that at relatively high activities

Figure 8. Initial activity calculated using each datum point. (passive collection)

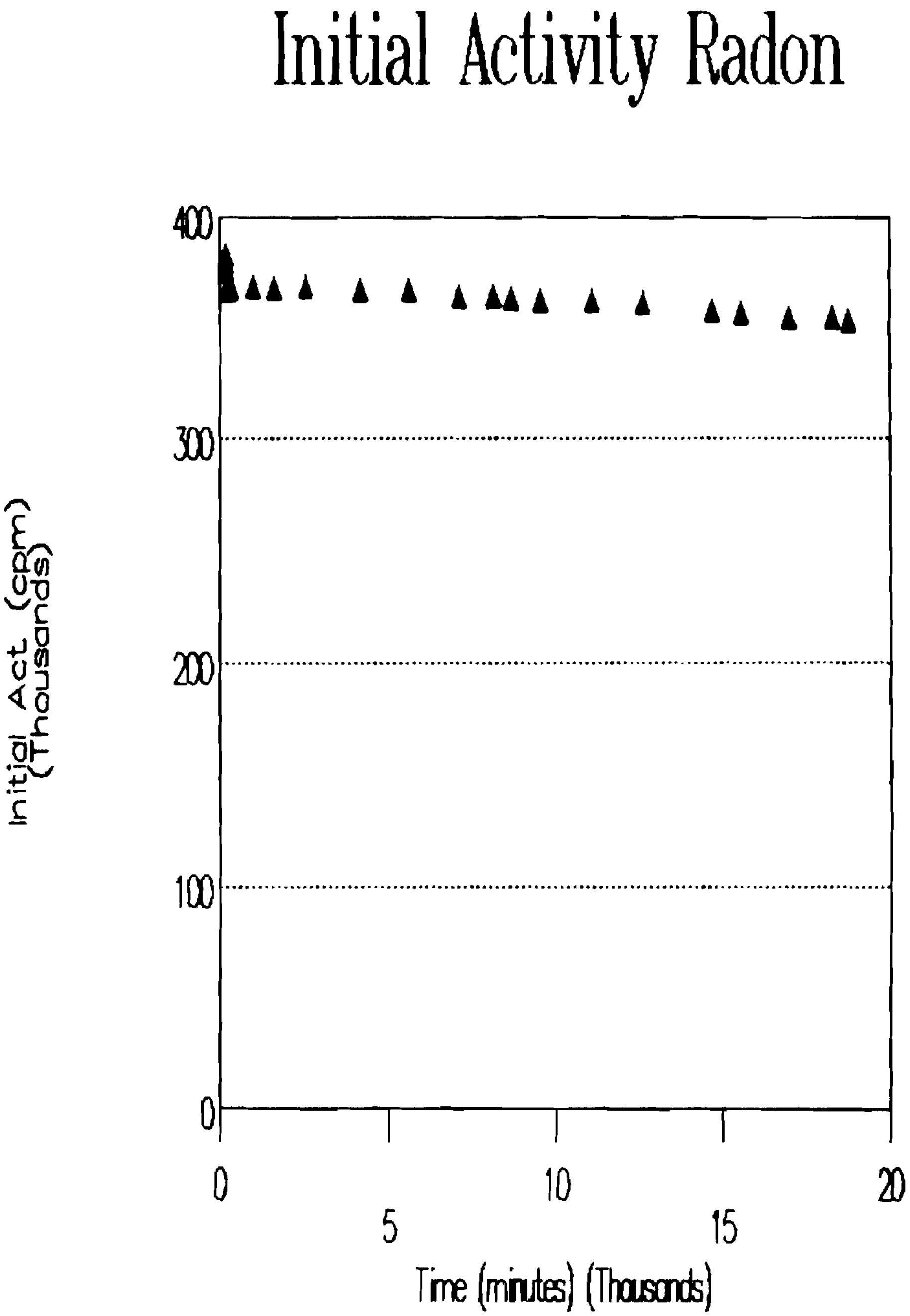
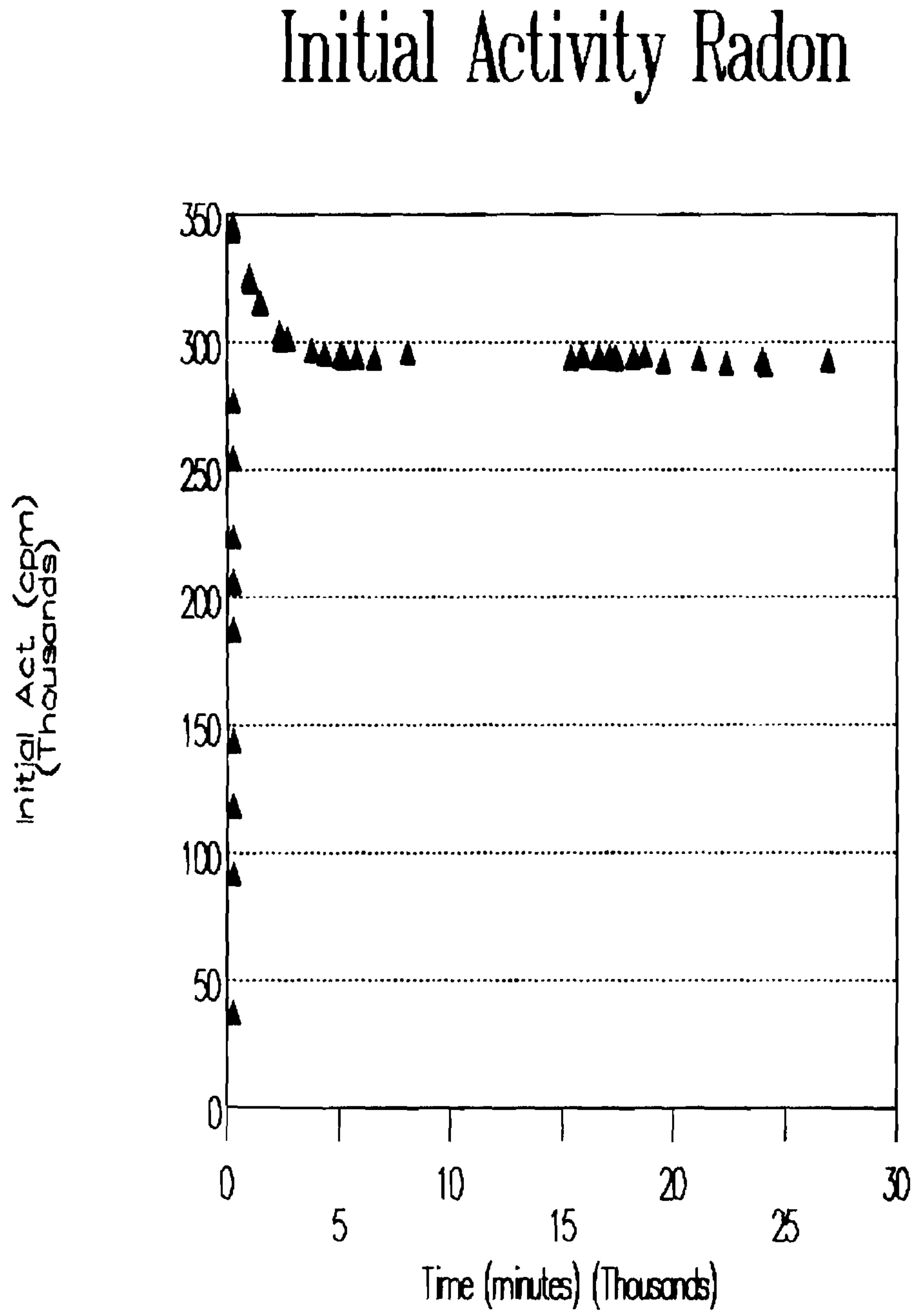


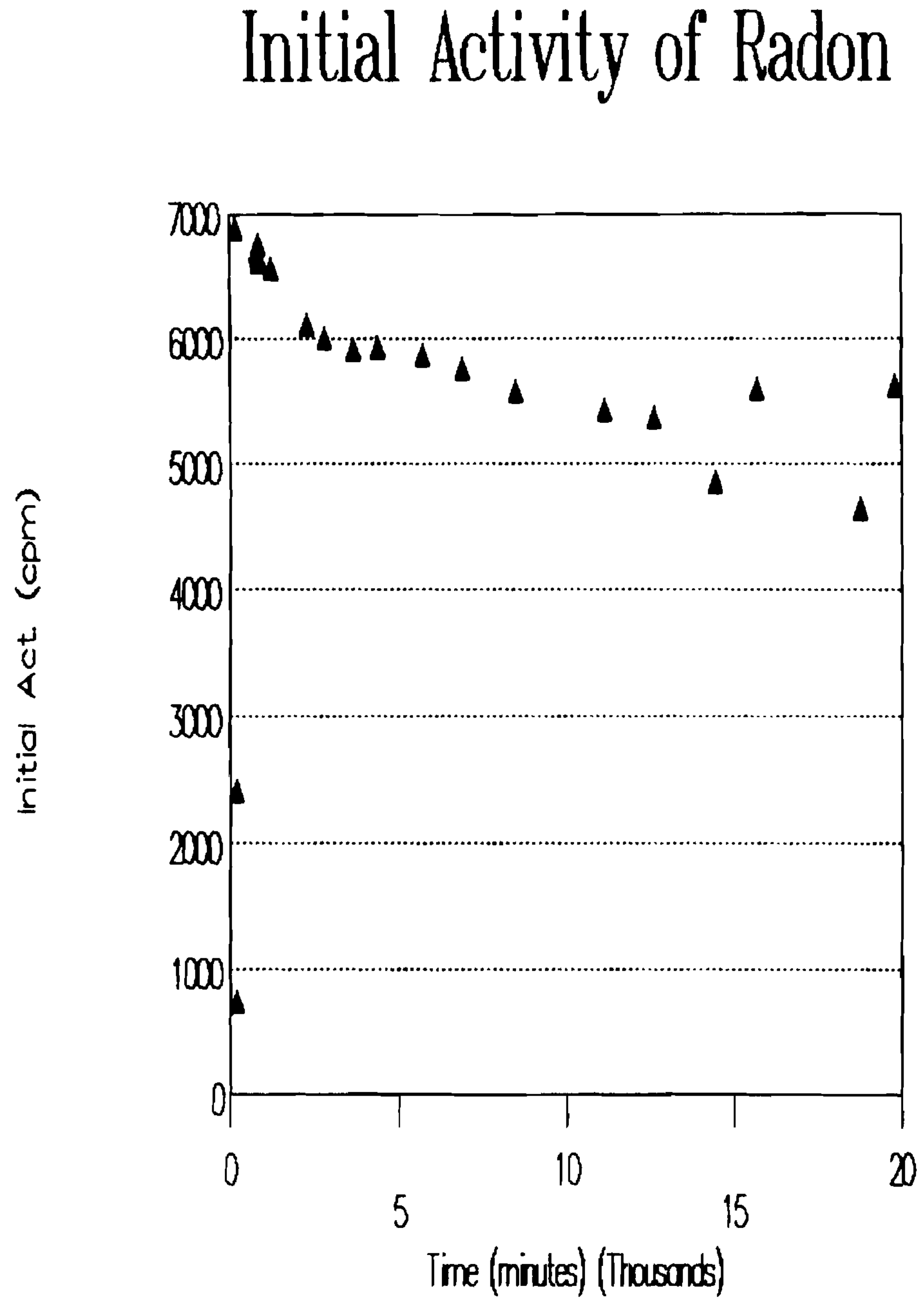
Figure 9. Initial activity calculated using
each datum point.
(active collection)



associated with the shorter sampling time, the active collection method is comparable in accuracy to the passive collection method. However, at lower activities, as can be seen in Figure 10, deviations are easily seen at greater elapsed times. Even with the samples of lower activity, reasonably consistent levels for the initial activity can be obtained within the optimum time interval (5,000 - 10,000 minutes) for the active collection method.

As revealed by this investigation, the method of active collection is a rapid method for determining radon concentrations with reasonable accuracy. By utilizing active collection, technical personnel could collect samples in a short time and take the sample for analysis approximately 3 days later. Investigation of the effects of various changes of experimental conditions upon radon levels in the environment may be quickly determined. The sensitivity of the method, may be increased by increasing the pumping rate or time and the counting time. Taking several measurements at the optimum elapsed time would also improve results.

Figure 10. Initial activity calculated using each datum point. (active collection)



CHAPTER V

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Appendix I

Passive and Active Collection Data Tables

TABLE I

Half-life calculated from passive collection of Radon on activated charcoal. *

TRIAL I

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
13-56094	-0.0001288642	1.16E-07	12.0823	0.016983	176716	3.735343
1169-41228	-0.0001287989	8.1E-08	12.08113	0.008814	176509	3.737238
11230-30315	-0.0001284745	2.05E-07	12.0767	0.006069	175729	3.746674
13-9751	-0.0001298797	3.61E-07	12.08499	0.005917	177192	3.706140
5794-30315	-0.0001283474	1.32E-07	12.07382	0.005856	175223	3.750385
1169-9751	-0.0001296891	3.31E-07	12.084	0.00401	177016	3.711586
20428-47183	-0.0001295721	5.11E-07	12.10556	0.024205	180875	3.714937
13-5794	-0.0001289989	6.71E-07	12.08356	0.006103	176938	3.731444

TRIAL II

9-18775	-0.0001287505	3.12E-07	12.82929	0.009266	372983	3.738642
4219-18775	-0.0001285678	1.38E-07	12.82707	0.00233	372157	3.743956
8722-18775	-0.0001288043	2.29E-07	12.83074	0.002407	373525	3.737081
4219-14718	-0.0001281809	2.26E-07	12.824	0.002132	371018	3.755257

* Container #1 sample from petri dish.

TABLE II

Half-life calculated from passive collection
of Radon on activated charcoal. *

TRIAL I

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
323-18317	-0.0001301346	6.91E-07	10.23334	0.028083	27815	3.698880
0-34102	-0.0001215687	9.94E-07	10.17244	0.090802	26172	3.959507
6-34102	-0.0001214776	1.01E-06	10.17065	0.091079	26125	3.962476
5467-26323	-0.0001240403	2.02E-06	10.16721	0.086512	26035	3.880612
3193-14169	-0.0001258478	2.91E-07	10.21714	0.005587	27368	3.824876
1322-10555	-0.0001244555	4.07E-07	10.20703	0.005619	27093	3.867665

TRIAL II

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
10-20157	-0.0001264216	5.36E-07	10.87535	0.017543	52857	3.807516
10-6972	-0.0001297988	2.17E-06	10.8817	0.018644	53194	3.708447
3115-12658	-0.0001266683	6.6E-07	10.86727	0.005957	52432	3.800098
3115-20157	-0.0001250143	4.01E-07	10.85579	0.007643	51834	3.850376
5916-17115	-0.0001254008	6.83E-07	10.85732	0.00715	51913	3.838509

* Container #2 sample from petri dish.

TABLE III

Half-life calculated from active collection of Radon on activated charcoal. *

TRIAL I

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
899-47192	-0.000139262	2.22E-06	10.00748	0.305152	22192	3.456447
899-19776	-0.000129887	4,97E-07	9.910302	0.02139	20137	3.705932
1156-19776	-0.000129374	4.14E-07	9.903591	0.017294	20002	3.720624
2312-47192	-0.000139723	2.51E-06	10.02193	0.32008	22515	3.445045
2312-19776	-0.000128338	2.76E-07	9.889604	0.010482	19724	3.750652
1156-9758	-0.000133054	1.09E-06	9.918765	0.015709	20308	3.617725
2312-9758	-0.000129631	6.14E-07	9.896248	0.007441	19856	3.713237
899-9758	-0.000134654	1.3E-06	9.928744	0.019828	20512	3.574721

TRIAL II

284-18769	-0.0001344252	1.99E-06	10.66022	0.049161	42626	3.580817
284-12647	-0.000141221	3.42E-06	10.69281	0.046926	44038	3.408502
4213-18769	-0.0001276695	6.3E-07	10.56841	0.010646	38887	3.770297
4213-12647	-0.0001281167	1.22E-06	10.57317	0.008922	39072	3.757138
8716-18769	-0.0001268889	1.04E-06	10.55684	0.010961	38439	3.793493

* Container #1 with petri dish present.

TABLE IV

Half-life calculated from active collection
of Radon on activated charcoal. *

TRIAL I

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
177-8251	-0.0001459886	2.56E-06	8.336534	0.032474	4174	3.297191
2772-14860	-0.0001288757	1.05E-06	8.251259	0.026127	3832	3.735012
177-14860	-0.0001339283	1.18E-06	8.302297	0.039672	4033	3.594103
319-14860	-0.0001330121	1.16E-06	8.293269	0.037342	3997	3.618860

TRIAL II

254-20151	-0.0001289042	3.08E-06	8.51027	0.084152	4966	3.734184
254-6966	-0.000160075	7.89E-06	8.607285	0.052502	5471	3.007041
4214-20151	-0.0001175221	2.52E-06	8.345528	0.042246	4211	4.095844
10248-20151	-0.0001075683	2.52E-06	8.184521	0.02364	3585	4.474853
3109-12652	-0.0001295081	4E-06	8.448839	0.036144	4670	3.716773

* Container #2 with petri dish present.

TABLE V

Half-life calculated from active collection
of Radon on activated charcoal. *

TRIAL I

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
8237-20963	-0.000127319	1.32E-07	12.32187	0.003479	224554	3.780677
5108-20963	-0.0001272867	1.05E-07	12.32136	0.003471	224440	3.781638
228-4009	-0.0001652484	1.8E-06	12.45149	0.009102	255630	2.912901

TRIAL II

773-19991	-0.0001318702	1.41E-06	12.24673	0.035663	208298	3.650197
773-8574	-0.0001427178	4.16E-06	12.28423	0.03315	216260	3.372754
2312-19991	-0.0001287313	3.98E-07	12.20377	0.00842	199540	3.739199

* Container #1 without petri dish.

TABLE VI

Half-life calculated from active collection of Radon on activated charcoal. *

TRIAL I

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
367-19159	-0.0001289357	4.47E-07	10.63581	0.015339	41598	3.733272
225-19159	-0.0001294858	5.12E-07	10.6432	0.018469	41907	3.717413
367-6187	-0.00013562	1.56E-06	10.65265	0.01198	42304	3.549271
367-15825	-0.0001303658	8.92E-07	10.64017	0.015242	41780	3.692319
237-15825	-0.0001311709	9.99E-07	10.64637	0.017836	42040	3.669655

TRIAL II

312-18726	-0.0001342744	2.09E-06	10.52528	0.051741	37245	3.584839
312-14673	-0.000139298	3.12E-06	10.55034	0.050014	38190	3.455556
312-9556	-0.0001477832	4.14E-06	10.58122	0.042474	39388	3.257150
5630-18726	-0.0001265719	7.37E-07	10.42021	0.011059	33530	3.802995
5630-14673	-0.0001270191	8.56E-07	10.42492	0.006728	33689	3.789603
4173-9556	-0.0001320721	6.8E-07	10.46313	0.003061	35001	3.644618

* Container #2 without petri dish.

TABLE VII

Half-life calculated from active collection of Radon on activated charcoal. *

TRIAL I

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
968-26962	-0.0001291891	5.7E-07	12.65229	0.02856	312477	3.725949
968-19629	-0.0001300828	8.21E-07	12.65623	0.029698	313710	3.700351
1463-19629	-0.0001280962	6.29E-07	12.62675	0.019637	304598	3.757738
968-5805	-0.0001483501	2.36E-06	12.69978	0.016241	327676	3.244704

TRIAL II

506-10258	-0.0001388772	3.93E-06	12.51593	0.036664	272647	3.466028
4684-10258	-0.0001268949	6.88E-07	12.4217	0.003017	248127	3.793312
1572-7185	-0.0001382011	3.77E-06	12.49197	0.01786	266192	3.482983
1572-10258	-0.0001333117	2.48E-06	12.47372	0.019335	261377	3.610727

* Container #1 without petri dish.
(Plastic bag attached to air return.)

TABLE VIII

Half-life calculated from active collection
of Radon on activated charcoal. *

TRIAL I

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
591-10310	-0.000139417	3.42E-06	10.69782	0.031796	44259	3.452606
4655-10310	-0.0001293215	7.4E-07	10.61863	0.003272	40890	3.722135
591-7103	-0.0001457534	5.07E-06	10.7162	0.029962	45080	3.302512

TRIAL II

821-19956	-0.0001322793	1.46E-06	10.55283	0.03823	38286	3.638908
821-8554	-0.0001443656	3.91E-06	10.59178	0.032437	39806	3.334258
2293-12679	-0.000129987	9.98E-07	10.50972	0.010382	36670	3.703079
3734-19956	-0.0001277415	3.39E-07	10.49001	0.006106	35955	3.768175
3734-12679	-0.0001284487	7.98E-07	10.49516	0.006591	36140	3.747427

* Container #2 without petri dish.
(Plastic bag attached to air return.)

TABLE IX

Half-life calculated from active collection of Radon on activated charcoal. *

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
830-19911	-0.0001394271	2.18E-06	8.771049	0.05726	6445	3.452358
830-8532	-0.0001489808	3.17E-06	8.803387	0.02679	6657	3.230968
2270-12663	-0.0001382069	7.13E-07	8.739156	0.007418	6243	3.482836
3694-19911	-0.0001354287	3.38E-06	8.715952	0.060772	6099	3.554284
3694-15726	-0.0001370789	3.39E-06	8.729619	0.042434	6183	3.511498
8532-19911	-0.0001317331	7.91E-06	8.656746	0.078913	5749	3.653994

* Container #3 without petri dish.

TABLE X

Half-life calculated from active collection
of Radon on activated charcoal. *

TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
278-20120	-0.000130992	1.86E-06	9.227253	0.050309	10171	3.674669
278-6876	-0.0001529488	5.49E-06	9.293442	0.034419	10867	3.147146
5820-12588	-0.0001269522	2.58E-06	9.143249	0.014967	9351	3.791601
5820-20120	-0.0001230333	1.17E-06	9.110596	0.016917	9051	3.912372
10194-20120	-0.0001207049	1.64E-06	9.072864	0.015377	8716	3.987843

* Container #3 without petri dish.
Sample pumped for 30 minutes.

TABLE XI

Half-life calculated from active collection
of Radon on activated charcoal. *

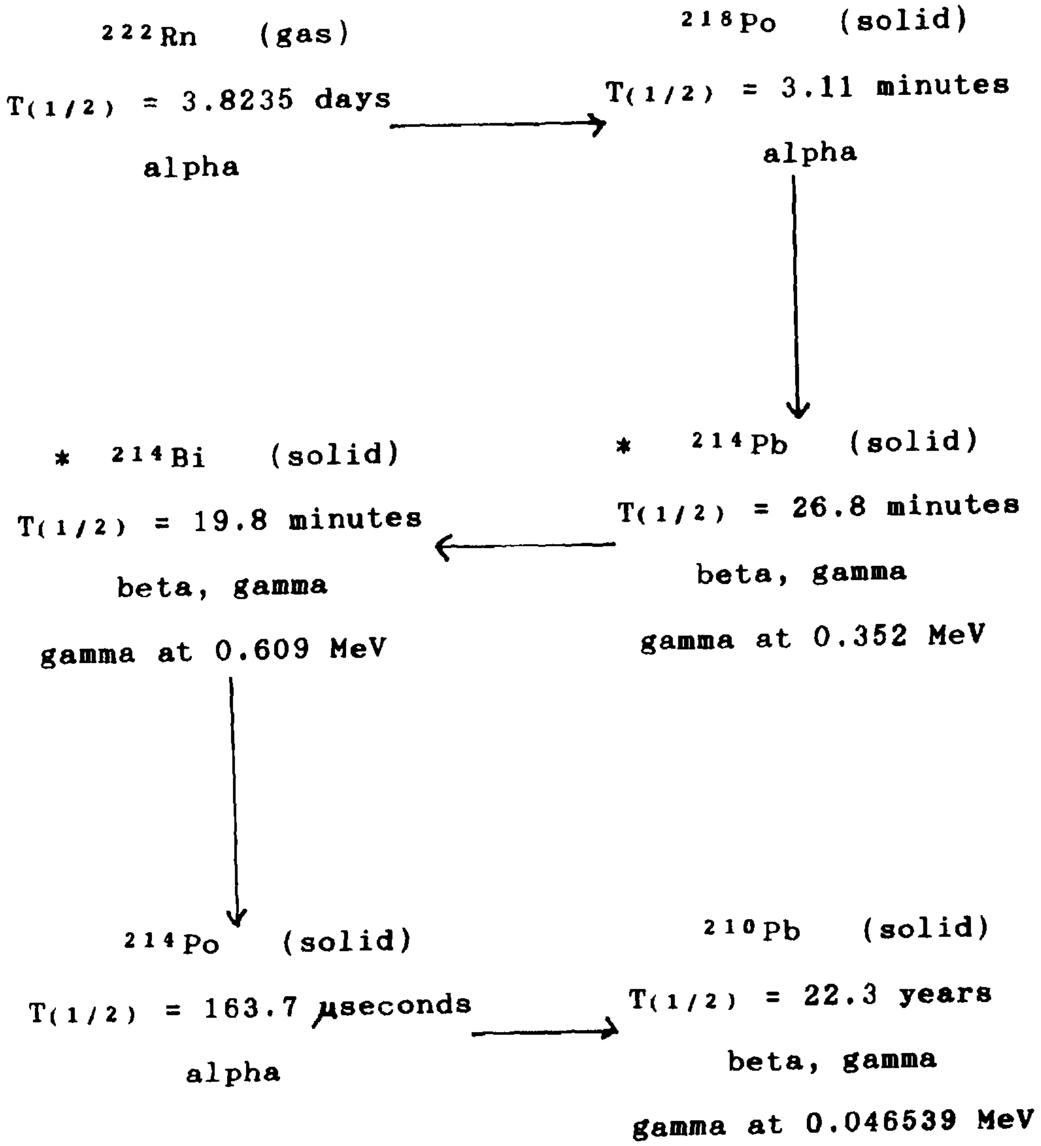
TIME INTERVAL (minutes)	Slope	std. err. of slope	Y intercept	std. err. intercept	A(zero) (e^x)	T 1/2 (days)
241-20143	-0.0001330411	1.03E-06	12.24899	0.040659	208770	3.618071
241-5857	-0.0001660253	4.01E-06	12.32685	0.024827	225674	2.899270
2503-6913	-0.0001376398	9.01E-07	12.23611	0.005033	206099	3.497187
5857-12621	-0.0001278715	2.22E-07	12.17643	0.001985	194158	3.764343
10231-20143	-0.0001266217	2.61E-07	12.16136	0.003137	191254	3.801499
7014-12621	-0.0001276401	3.76E-07	12.17377	0.002258	193644	3.771166
3054-11876	-0.0001299201	5.11E-07	12.19728	0.006694	198249	3.704987

* Container #1 without petri dish.
Sample heated for 30 minutes after collected.

Appendix II

Partial Radon Decay Chain

Partial Radon Decay Chain



* Principal decay daughters analyzed for with gamma spectroscopy.

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12/7/89
Date

AN INVESTIGATION OF THE DECAY CURVES FOR
RADON DAUGHTERS WITH ACTIVE COLLECTION OF
RADON ON ACTIVATED CHARCOAL

Jackie Gilbert
Signature of Graduate Office Staff Member

December 7, 1989
Date Received