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RADON MIGRATION THROUGH MULTI-STORIED PERSONAL CARE BOARDING HOMES

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ABSTRACT

The purpose of this indoor radon study was to test radon levels in personal care boarding homes located within the City and County of Denver and then evaluate the test data, and suggest control alternatives. The main emphases in the evaluation of the test data were on the seasonal variability of radon measurements, comparative radon concentrations across three radon measurement technology types, and a vertical profile of radon levels in these multistoried buildings without regard to occupancy. The tests were conducted for a twelve-month period and also concurrently during the spring and fall seasons of that same period. The three detection devices employed in this study were: charcoal canisters (CC) with a seven day exposure period, alpha track detectors (ATD) with three and twelve month exposure periods, and a direct reading instrument. One ATD was left in place at each of the selected locations, in each of the buildings, to measure radon concentrations at those locations for the three-month period of February, March and April 1991. Collectively these are referred to as the "spring" ATD. These same locations were also used to measure radon concentrations for the three- month period of August, September, and October 1991: referred to as the "fall" ATD. These same locations were again used to measure radon concentrations for the twelve-month period of February 1991, to February 1992. The CC were placed midway through the three-month ATD testing period for both the spring and fall seasons. The direct reading instrument was used to measure radon concentrations in the locations used for all of the ATD and CC. Two sanitarians conducted this survey with one direct reading instrument. Half of the direct reading measurements were taken while setting the CC in each of the sampling locations and the other half of the measurements were taken while retrieving the CC in each of the sampling locations. It was expected that the twelve-month ATD reported radon concentrations would be an approximate average of the spring and fall ATD because the spring would simulate the "closed house" testing period when the doors and windows were closed and outside ventilation was at a minimum and the fall would simulate the "open house" testing period, where the windows and doors are open and the outside ventilation was at a maximum. This same assumption would have been used if we had tested during the winter "closed house" testing period and summer "open house" testing period. The highest concentrations of radon are typically found in the lowest levels of buildings. However, in this study, these expected patterns did not always occur. At least one of the radon detection devices reported a higher level on floors other than the lowest level. Mitigation techniques such as sealing crawl space entry doors, installing polyethylene sheeting over exposed dirt and filling all cracks and holes in foundation slabs and retaining walls were suggested for those buildings with radon concentrations exceeding EPA guidelines. In some instances passive or mechanical ventilation was suggested to dilute radon gas concentrations or to balance the pressure in the lowest level of the facility.

BACKGROUND

The Environmental Protection Agency has released the following information in the "Radon Technology for Mitigators" course workbook:

1. The only known health risk associated with exposure to radon and radon decay products is an increased risk of contracting lung cancer.
2. External exposure to radon and its decay products poses very little threat because an alpha particle can be stopped by an inch of air or by the body's outermost layer of dead skin. If radon is swallowed into the body, the liquids in the gastrointestinal tract will stop the alpha particles from damaging the surrounding tissues.
3. Smoking is the greatest risk factor for lung cancer in the United States. The combination of radon exposure and smoking appears to result in a multiplicative risk.

4. Health professionals agree that this risk increases with higher concentrations and longer exposure times.

Radon is a colorless, odorless, and tasteless gas produced by the normal decay of uranium and radium. Radon 222 is the most prevalent isotope. It has a half-life of 3.8 days and emits alpha and gamma radiation. Radon is an inert gas which is not chemically bound or attached to other materials. Radon can move easily through all gas permeable materials.

Radon gas concentration is expressed in units of picoCuries per liter (pCi/l) in this report. One pCi/l is 2.2 radioactive disintegrations per minute within a one liter volume.

SCOPE AND METHODOLOGY

Charcoal Canisters

Activated carbon CC were used in this study to adsorb radon by molecular diffusion over a period of 2-7 days. Each canister has an airtight cover or enclosure which is removed at the beginning and sealed at the end of a measurement period. The CC are circular in design, 6-10 centimeters in diameter and approximately 2.5 centimeters deep. The canister is filled with 25-100 grams of activated charcoal. One side of the container is fitted with a screen that keeps the charcoal in but allows air to diffuse into the charcoal.

Radon in the air will be adsorbed onto the charcoal and will subsequently decay, depositing decay products in the charcoal. After the sampling period, the laboratory will analyze the canister by placing it directly on a gamma detector. It is necessary to account for the reduced sensitivity of the charcoal due to adsorbed water. This is done by weighing each canister when it is prepared and then reweighing it when it is returned to the laboratory for analysis.

Advantages of the CC include: low cost; passivity; convenience; unobtrusiveness; simplicity of use; and relatively short measurement periods. Disadvantages of CC include: measurements are biased toward the last 12-24 hours; sensitivity to temperature and humidity; sensitivity to airflow extremes; and limitation to a few days of sampling.

Alpha Track Detectors

Alpha track detectors (ATD) consist of a piece of Kodak cellulose nitrate film positioned in a relatively small container with a filter. An ATD samples passively by diffusion when removed from its sealed pouch. The filter allows radon gas to enter. Alpha particles emitted by the radon decay products in air strike the film and produce submicroscopic damage tracks. Analysis is accomplished by placing the film in a caustic solution that accentuates the damage tracks so they can be counted using a microscope or an automated counting system. The number of tracks per unit area are correlated to the radon concentration in air, through a conversion factor derived from calibration measurements.

Advantages of ATD include: low cost; passivity; convenience; simplicity of use; and their ability to measure average radon concentration over long periods. Disadvantages of ATD include: their inability to measure short-term concentrations; relatively large precision error at low concentrations; and the fact that sampling conditions during the measurement period could affect results.

Direct Reading Devices

A continuous radon monitor measures radon gas concentrations by allowing ambient inside air laden with radon to diffuse through a filter into the detection chamber. As the radon gas decays, the alpha particles are counted by using a solid state silicon detector to sense alpha decays. This unit will display the current radon concentration in pCi/l.

Advantages of the continuous radon monitor include: portability; on-site availability of results; relatively short measurement times; and flexible measurement duration. Disadvantages include: the cost of the instrument; bulkiness and weight of the instrument; regular calibration requirements; the requirement for trained personnel for accurate operation and; the sampling conditions during measurement period which may affect the results.

REPORTED RADON CONCENTRATION COMPARISONS

In order to compare the reported radon concentrations for the various testing methods, an average of each of the testing technologies was calculated. The individual reported concentrations and the average for each floor for the various tech types can be found in Appendix B. In addition, there are graphs depicting the reported radon concentrations for the various testing methods for each building in this appendix.

The results are as follows (averages):

The lowest concentration of radon gas (0.2pCi/l) was recorded with the direct reading instrument followed by a CC reported concentration of 1.4pCi/l and an ATD reported concentration of 2.8pCi/l.

The average for the ATD was calculated for both the 12- month and three-month periods. The average reported radon concentration for the three-month ATD for both spring and fall was 3.2pCi/l. The average reported radon concentration for the 12-month ATD was 2.1pCi/l.

For the reasons indicated below, measurement errors appear responsible for a significant portion of the wide variation in the reported radon concentrations. These errors may be due to the following factors:

1. Inexperience of the operators with the direct reading instrument.
2. Uncontrollable weather conditions while using the direct reading instrument.
3. Laboratory errors, either in the preparation of the testing device or in the assessment of the radon concentration.

Assessment of Laboratory Errors: Duplicates, Blanks, and Spikes

In anticipation that laboratory errors could occur and in order to help explain results which may be counter-intuitive, the investigators arranged for duplicate test canisters to be placed in identical locations to better determine the accuracy of the final results. In addition, "blanks" (with zero radon levels) and "spikes" (with a known level of radon) were employed to further determine possible laboratory error. These were submitted to the laboratory for the seasonal and annual ATD and CC. The reported results are presented below.

Duplicates

The data presented below are the differences between two individual cannisters placed at identical sites. A result is 0.0, indicates no difference in reported radon levels between two devices simultaneously placed at the same location.

Charcoal Canisters

Spring (pCi/l)	Fall (pCi/l)
0.0	0.0
0.0	0.2
0.0	0.3
0.0	0.3
0.1	0.3
0.2	0.3
0.4	0.4
0.5	0.4
0.8	1.5
3.3	1.5
	6.5

The mean difference between the spring charcoal canisters was 1.1 pCi/l with a standard deviation was 2.0. The fall charcoal canister's mean difference was 0.5 pCi/l with a standard deviation of 0.5. The widest difference between the submitted sets of duplicates was 6.5pCi/l.

Alpha Track Detectors

Spring (pCi/l)	Fall (pCi/l)	12 Month (pCi/l)
0.4	0.1	0.3
0.8	0.8	0.4
0.9	0.8	0.4
1.4	1.0	0.5
1.6	1.3	0.7
	1.6	1.4
	2.4	4.1
	3.7	5.1
	3.8	5.2

The mean difference between the spring alpha track duplicate detectors was 1.8 pCi/l with a standard deviation of 1.2. The mean difference between the fall alpha track detectors was 2.2 pCi/l with a standard deviation of 2.0. The 12-month alpha track detectors mean difference was 0.5 pCi/l and the standard deviation was 0.2.

The results of the 12-month duplicates showed less variation than the three-month ATD. The widest difference between the submitted sets of duplicates was 0.7 pCi/l and the mean was 0.5 pCi/l.

Blanks

As a further check on the accuracy of the lab analyses, blanks, which were not exposed to radon, were sent to the lab. The laboratory should have reported readings of 0.0 pCi/l on all of these. The actural reported lab results were as follows:

Charcoal Canisters
(pCi/l)

0.0	0.3	0.0	0.6	0.0	0.7	0.0	1.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1

The mean error for the blank charcoal canisters was 0.1 pCi/l with a standard deviation of 0.3.

Alpha Track Detectors
(pCi/l)

0.0	0.0	0.0	0.0	0.1	0.4	0.8	1.5	1.2	1.4	1.4	1.8

The mean error for the blank ATDs was 1.4 pCi/l with a standard deviation of 0.3.The blank ATD were reported to have a measurable level of radon for 76% of the detectors.

Spikes

Charcoal Canisters

Some charcoal cannisters were exposed to a known concentration of 10.2 pCi/l of radon by the U.S. EPA and then sent to the lab to determine the accuracy of their analysis. The fall canisters suffered from an excessive lapse in time before they were analyzed and therefore the values reported below may not have significance. However, the spring canisters did not experience this same problem so the laboratory results reported for these canisters are valid. As one can see, the reported values are significantly below the 10.2 pCi/l exposure level. The mean laboratory error for the spiked spring canisters was 3.6 pCi/l with a standard deviation of 0.5. Due to the delays in obtaining laboratory analysis of the fall canisters, their differences from the known exposure concentration levels were not analyzed.

Spring (pCi/l)	Fall (pCi/l)
6.1	2.2
6.3	2.7
6.5	2.9
6.6	3.0
7.0	3.2
7.4	3.5
	3.7

Alpha Track Detectors

The spiked ATD were all exposed to 99.1 pCi/l for four days by the EPA facility. The fall and spring spikes were submitted to the laboratory with the actual four-day exposure time reported to the lab. The "12-month" ATD spikes (which were actually exposed for four days) were submitted to the lab with a reported 365-day exposure time. This longer exposure time should have caused the lab to report a radon concentration of 2.2 pCi/l.

The lab results spiked ATD submitted in the spring ranged from 24.7 pCi/l below the actual exposure level to 33.1 pCi/l above the actual exposure level (a range of 57.8 pCi/l). The spring alpha track detector's mean concentration was 104.3 pCi/l and the standard deviation was 25.9. The spiked ATD submitted in the fall were reported by the lab to have exposure levels ranging from 12.6 pCi/l below the actual exposure level to 108.2 pCi/l above the actual exposure level (a range of 120.8 pCi/l). The fall alpha track detector's mean concentration was 128.1 pCi/l and the standard deviation was 37.8. These extensive variations indicate that either the laboratory and/or the devices are not accurate for a short testing period at elevated concentrations. The spiked ATD submitted with a reported 365-day exposure were more accurate ranging from 0.3 pCi/l below the actual exposure level to 1.1 pCi/l above the actual exposure level (a range of 2.4 pCi/l). The 12-month alpha track detector's mean concentration was 1.6 pCi/l and the standard deviation was 0.9. This would indicate that the longer the exposure time, the more credible the laboratory results and/or device become. The lab results are summarized here:

Spring (pCi/l)	Fall (pCi/l)	12 Month (pCi/l)
74.4	86.5	0.8
95.5	88.1	0.8
115.2	116.3	1.0
132.2	123.4	1.1
	125.0	1.3
	136.9	1.8
	141.1	1.8
	207.3	2.9
		3.2

The ATD were received from the laboratory in a sealed foil package. The ATD were removed from this package and immediately placed in the location for the testing period. Some of the detectors were manufactured with a piece of tape around the center seam of the detector, others had no tape. The laboratory did not run these ATD for our first testing period because they felt the ATD may have been tampered with. Subsequently, the ATD were submitted to the laboratory with instructions that all of the ATD were to be read and the results included in the report. The lack of this tape around the ATD may have altered the results by allowing more radon gas into the detector.

Based on this assessment of laboratory error, the CC readings of radon gas detected seem to be more accurate than the ATD readings.

Implications of Laboratory Results

The laboratory errors in the reported levels of radon concentration for duplicates, blanks, and spikes may have raise serious questions about the validity of the reported concentrations of radon in all of the testing that was conducted in this study. This report is based on the reported results from the laboratory. Even on a relative basis, the reported laboratory results may not be comparable and therefore of questionable value. The reported data presented below should be viewed with these defects in mind.

SEASONAL VARIABILITY

Seasonal variability is important in conducting radon measurements because this factor can vastly influence the concentration levels. This is primarily due to the differences in ventilation a building experiences resulting from the open or closed condition of the windows and whether or not the heating/cooling system is operating. Generally, one would expect that direct outside ventilation would tend to lower interior radon levels so measurements taken in the summer would tend to be lower than in the winter, for example.

The seasonality tests included: a spring test period (February, March and April); and a fall test period (August, September, and October).

The CC were set during the months of March and September for seven days. The direct reading instrument was read while either setting or retrieving the CC.

Comparing the three detection devices, one might assume that the spring readings would have the highest concentrations of radon since February, March, and April typically have cool, wet weather, therefore outside/inside air exchange in the buildings is normally kept to a minimum, which causes any radon infiltrating into the buildings to accumulate. One must keep in mine that all the measurements presented in this report are "reported" levels from the laboratory and appear to involve inaccuracies due to laboratory technique, handling, timing of lab analysis or other factors. This will be discussed further below.

<u>Results and Analysis of Seasonality</u>

FALL ATD: Comparison of the various radon technology types indicates that the fall ATD levels had higher average concentrations than the other two radon technology types 92% of the time. This might be explained, in part, due to increased infiltration at the lower building levels. This increased infiltration may be due to the "chimney effect" which might act to actually pull radon from the substrate under buildings into a building thereby increasing the flux of radon through a building. If at the same time, this increased radon tended to concentrate in pockets in certain parts of the buildings, this would help to explain the higher fall concentrations. If so, this finding would tend to refute the notion that closed buildings tend to have higher concentrations than open or externally ventilated buildings.

As a technology category, the ATD reported concentrations of radon showed higher results than the CC 84.6% of the time across all seasons.

The spring charcoal cannisters had a higher reported average concentrations of radon than the fall CC in seven of the buildings. This finding tends to be counter to that from the ATDs where the fall readings were higher and may be explained, in part, by the vertical pull and chimney effect throughout the buildings. However, this finding is consistent with most other results from other studies. If the data are correct, one might surmise that they say something about the detection devices, since that is the only variable. The buildings and locations are constants as well as the seasonality. Therefore, something about the nature of the detection devices may explain this difference and their ability to accurately "read" radon concentrations. The opposing findings may also be the result of laboratory processing error. Possibly either the ATDs or CCs were incorrectly read. The study team is unable to determine the cause of this difference.

The direct reading results were below all other test results in nine of the buildings for all testing periods. The spring testing period for the sniffer was very humid with rain on most of the days. This was the first experience for the operators to use the sniffer. This lack of experience and the high humidity levels may have affected the results for spring. The results for fall were a little higher but still below the other testing technologies. It is possible that these instruments are not calibrated accurately or that direct readings do not provide a good approximation of radon levels. Since radon exposure is not an acute health problem at low levels, testing with such a device may only be useful as a screening device.

The 12-month ATD reported radon concentrations were more closely aligned with the averages for the CC which may indicate that the longer the ATD is exposed the more accurate the results will become. The laboratory assessment of the 12-month ATD and the CC also supports this possible conclusion.

The graphs located in the appendices will help illustrate seasonal variability.

VERTICAL PROFILE OF RADON CONCENTRATIONS

The buildings that were chosen for this survey all had three or more floors. The measurement devices were placed in two separate locations on each of the three lowest floors.

Theoretically, radon concentrations should decrease floor by floor as one moves higher above the ground level. In this study, the buildings had reported radon concentrations which increased for one or more of the measurement devices as the test location moved higher within the building.

The increase in reported radon concentration occurred between the second floor and the third floor in two of the buildings and between the first and second floors in one of the buildings. The remaining 10 buildings showed no particular pattern.

The highest concentration of radon gas was located on the lowest floor for two of the buildings for all of the radon technology types. An elevated concentration of radon was on the top (third) floor for one building with the fall ATD and the fall direct reading instrument. The middle floor had an elevated level of radon concentration for six of the buildings.

BUILDING-RELATED FACTORS

There were 13 personal care boarding homes selected to monitor the vertical profile of radon, seasonal variability, and comparative radon concentrations across three radon measurement technology types. One laboratory provided both the charcoal canisters and the alpha track detectors utilized for this survey. The laboratory proficiency and the device reproducibility was tested by submitting duplicates, blanks, and spikes as controls.

Along with these three main topic areas, we also documented the facility structural foundations, heating, ventilating, and air conditioning (HVAC) systems, possible radon migration routes, and suggested radon mitigation techniques when the levels of radon gas were reported to be above the Environmental Protection Agency (EPA) recommended guideline for indoor air exposure.

The sampling was sometimes conducted in areas that were not normally utilized by the residents of the buildings. This protocol does not conform to the EPA recommended guideline, but the study was to determine radon levels in such buildings irrespective of occupancy. Therefore, sampling was conducted on the lowest area of the building, including a crawl space, basement, garden level, or living area. An attempt was made to include buildings with a variety of construction foundations. For the buildings selected, four had full basements, three had a partial crawl space with either a garden level or a partial basement, two had a partial basement with a slab, two had garden levels, one had a slab foundations and one had a full crawl space.

The HVAC systems were varied. Some buildings had a central HVAC system, others had air conditioning for the hallways and common areas, while others had no air conditioners.

The buildings that were above the 4pCi/l concentration as an average for one or more measurement device were given mitigation suggestions. Of the facilities surveyed, five buildings were given suggested mitigation techniques. There was a hot water radiator (radiant) heating system in all of the buildings that were given mitigation techniques. These five buildings also had a crawl space and/or a partial or full basement. Air conditioning was provided in two of these five buildings.

Additional information on the individual buildings is located in the appendices.

FINDINGS AND CONCLUSIONS

Since there is considerable uncertainty regarding the accuracy of the laboratory results, the reported radon levels and any findings regarding seasonality and or stratification must be viewed with a commensurate level of uncertainty. However, it may be that on a relative basis the data are comparable and therefore drawing conclusions may be appropriate--assuming the suggested laboratory error is consistent across all tech types. Disregarding the suspected laboratory error, the findings are as follows.

The seasonal variability of radon measurements indicated that the fall alpha track detector levels were higher than all other measurement technology types. This could be due to the wind and indoor air movement causing infiltration of more radon gas into the facility even with the "open house" conditions. Alternatively, this could also indicate the lack of precision in the production of the alpha track detectors and the lack of precision in the analysis of the alpha track detectors.

The comparative radon concentrations across the three _radon measurement technology types indicated that the charcoal canisters had more reproducible results, the blanks were reported to have no exposure to radon gas in most cases, and the spikes were within 0.5 standard deviations. The reported ATD results did not have the same reproducibility. Most of the blanks were reported to have a level of exposure to radon gas. The spikes that were submitted with a 365 day exposure had reported radon concentrations with a standard deviation of 0.9. This would indicate that the longer the exposure for the alpha track detectors the more reliable the results may become. The direct reading instrument was the third measurement device and the limitations with this instrument seem to be the operator and weather conditions. With more practice and selecting days with lower humidity, the results may be adequate.

The vertical profile of radon levels in multistory buildings indicated that radon gas will flow and concentrate throughout the facility. We could not find any pattern to the flow of radon through the buildings. Some of this migration may be due to the results we obtained from the alpha track detectors which may not be accurate.