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An Extended Study on the Correlation between ^{210}Pb in Household Dust and Indoor Radon Concentration

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Abstract

Radon and its progeny have been identified as the second leading cause of lung cancer after tobacco smoking. Radon decays to a long-lived isotope, ^{210}Pb, with a half-life of about 22 years. Measuring concentrations of ^{210}Pb in household dust could be an alternative method of determining indoor radon levels. A previous study conducted in 2008 demonstrated that ^{210}Pb concentrations in household dust correlate reasonably well to radon concentrations in homes. To confirm the viability of this retrospective method, a field experiment was repeated in 2010 to further study the correlation between ^{210}Pb in household dust and indoor radon concentration. The results showed that ^{210}Pb is a reasonably good indicator of long-term radon exposure indoors when dust samples collected are representative of household dust in a house.

Keywords: radon-222, indoor radon, lead-210, household dust

1. Introduction

Radon is a naturally occurring radioactive gas generated by the decay of uranium bearing minerals in rocks and soils. Radon and its progeny have been identified as the second leading cause of lung cancer after tobacco smoking (WHO, 2005, 2009). The main health risk associated with long-term, elevated exposure to radon is an increased risk of developing lung cancer. The level of risk depends on the concentration of radon and the length of exposure. Based on new scientific information, the Canadian radon guideline was lowered from 800 to 200 Bq/m^3 in June 2007 (Health Canada, 2007a). It is recommended that remedial measures should be undertaken in a dwelling whenever the average annual radon concentration exceeds 200 Bq/m^3 in the normal occupancy area.

Since radon levels in a home can vary significantly over time, a long-term measurement period (3 to 12 months) will give a much better indication of the annual average radon concentration compared to short-term tests (Health Canada, 2008). Although detectors for long-term radon testing are commercially available, many homeowners wish to know radon levels much sooner. Alternative methods to quickly estimate long-term indoor radon concentrations are therefore being explored.

Radon decays with a half-life of about 3.8 days to its progeny as shown in Figure 1. Among its progeny, ^{210}Pb is a long-lived isotope with a half-life of about 22 years. Most of the radon decay products attach to airborne dust particles. The dust inventory of long-lived radon progeny in the indoor environment provides an indirect means to quantify long-term total deposition of ^{210}Pb, and thus is an indicator of long-term indoor radon concentration. Household dusts were therefore collected from 111 homes where long-term radon concentrations were determined for the same period in 2008 (Chen et al., 2009). The study demonstrated that measuring the concentration of ^{210}Pb in household dust is a viable alternative method to estimate indoor radon levels. With lessons learnt in the first study and to further investigate the feasibility of this retrospective method in residential homes, the study of the correlation between ^{210}Pb in household dust and indoor radon concentration has been carried out in 2010. A summary of the study is reported here.

2. Methods

To study the correlation, radon concentrations and concentrations of ^{210}Pb in household dust accumulated over the radon test period are required. Indoor radon measurements, dust sample collection and determination of ^{210}Pb in the dust samples were described in the previous publication (Chen et al., 2009). A brief summary with some special aspects for the second study is given here.

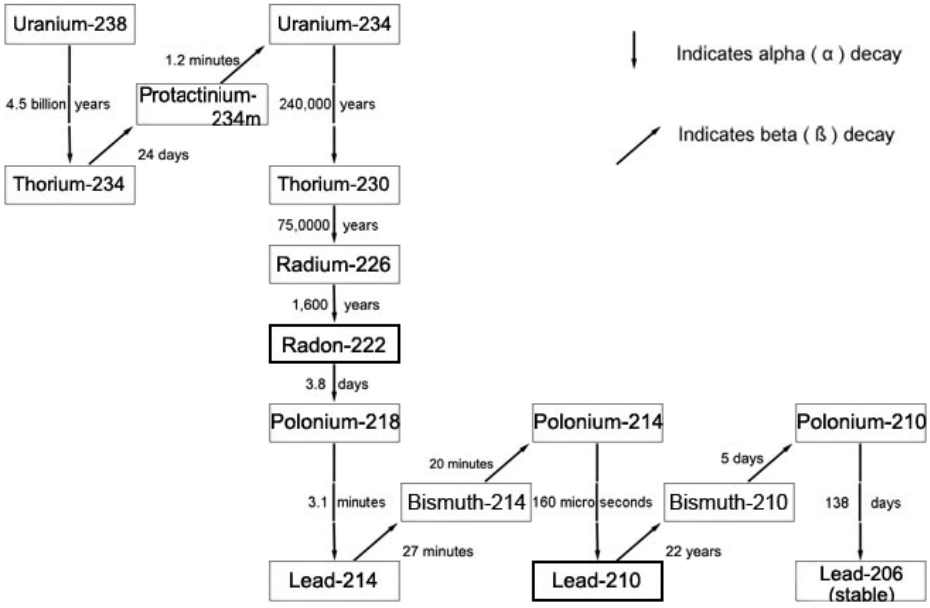

Figure 1. Decay scheme of ^{238}U (Health Canada, 2007b)

2.1 Radon Measurements

As in the first study, the present study followed Health Canada's recommendation that the radon testing performed in a home be a long-term measurement (Health Canada, 2007b), i.e., 3 months or longer. Therefore, all radon measurements in this study began in February and ended in June 2010. To determine the concentrations of radon, passive integrated radon-thoron discriminative detectors (commercially available RADUET) were used. RADUET detectors were placed on the lowest floor of 110 private homes randomly distributed in two Canadian cities, 45 in Fredericton and 65 in Halifax. Details of detector characteristics and radon measurements were given in a previous publication (Chen et al., 2011).

2.2 Dust Sample Collection

The survey was designed to collect household dust in vacuum bags during the test period. Participants were asked to change their vacuum bags at the beginning of the test, to ensure that the bags could be used for the entire test period. From the lessons learnt in the first study that many participants only gave a small portion of the dust, all participants were encouraged to provide entire dust sample collected during the test period.

2.3 Dust Sample Preparation and Analysis

Dust samples were first sieved to 100 μm to remove the large objects. All sieved samples were contained in PVC vials (60 mm in diameter and 55 mm in height), and then analyzed for the levels of ^{210}Pb by counting on a Gamma Analyst Integrated Gamma Spectrometer (GAM-AN2) coupled with a BEGe detector (BE5030) (Canberra Industries Inc.). Details of ^{210}Pb measurements and calibration were described in the previous publication (Chen et al., 2009).

The BEGe detector is a germanium detector, which has proper efficiency and resolution in the 46.5keV region for determination of ^{210}Pb activity concentration in the dust samples. The gamma-spectrum was collected by placing the dust sample right on the top of the BEGe detector. Spectrum analysis was performed with the Genie2K spectrometry software, version 1.4 (Canberra Industries Inc.). The ^{210}Pb activity of each sample was calculated with the area and yield of the 46.5 keV peak, the counting time, and the estimated efficiency:

$$A = \frac{N}{\varepsilon \cdot p \cdot t}$$

where A is the ^{210}Pb activity (in Bq), t is the counting time (in s), ε the counting efficiency, p is the emission probability or yield of the 46.5 keV photon, and N is the number of net counts under the peak.

3. Results

Among 110 participants, RADUET detectors were returned for analysis from 109 homes while dust samples

were provided from 66 homes. A study of correlation between ^{210}Pb and ^{222}Rn concentrations can then be performed in a total of 66 homes, 26 in Fredericton and 40 in Halifax. Even though a special instruction was given at the beginning of the study to collect the entire vacuum bag used during the test period for household cleaning, many of dust samples received were still in small quantities, much less than expected. A few participants even provided white dirt (possibly from dry-wall collected in house renovation) instead of real household dust. To prepare for analysis by gamma counting, fine dust was obtained by sieving to 100 μm. The weights of those fine dust samples varied from 2.3 g to 98.2 g. Twelve out of the sixty-six samples had less than 10 g fine dust.

Activity concentrations of ^{210}Pb were determined by counting the 46.5 keV peak. The initial counting time was set to 8 hours for all samples. The uncertainty for the 46.5 keV peak area was calculated for each sample. Re-counting was then conducted for those samples where the uncertainty for the 46.5 keV peak area was greater than 15%. The re-counting time varied from 12 to 48 hours depending on the initial uncertainty of the individual sample. Activity concentrations of ^{210}Pb were determined in the unit of Bq/g.

The correlation between ^{210}Pb and ^{222}Rn concentrations was studied by linear regression. The correlation coefficient R^2 is a measure of the correlation, i.e. linear dependence between ^{210}Pb and ^{222}Rn concentrations. The coefficient ranges from 0 to 1 with 0 for no correlation at all and 1 for a perfect prediction of radon concentration from observed ^{210}Pb concentration in dust.

Figure 2 presents the paired values of ^{210}Pb and ^{222}Rn concentrations in all 66 individual homes. ^{210}Pb was chosen to plot against ^{222}Rn because it is a long-lived progeny of ^{222}Rn and its concentration depends on the radon level in the air. A linear regression revealed a R^2 of 0.09 indicating practically no correlation. If considering only dust samples of 10 g and more, the correlation coefficient improved to 0.25, as shown in Figure 3.

For dust samples with more than 10 g in fine dust weight, it is of interest to see whether the correlations could be different for samples from different cities. Twenty-five dust samples from Fredericton contained more than 10 g. The ^{210}Pb and ^{222}Rn concentrations in those 25 homes showed absolutely no correlation, as shown in Figure 4. Twenty-nine dust samples from Halifax contained more than 10 g. The ^{210}Pb and ^{222}Rn concentrations in those Halifax homes showed a promising R^2 of 0.69, as shown in Figure 5. However, one can see that the promising correlation coefficient mainly results from a single data point (0.48 Bq/g of ^{210}Pb in a home with a radon concentration of 2341 Bq/m^3). When this data point is removed from the linear regression, the correlation coefficient drops from 0.69 to 0.19.

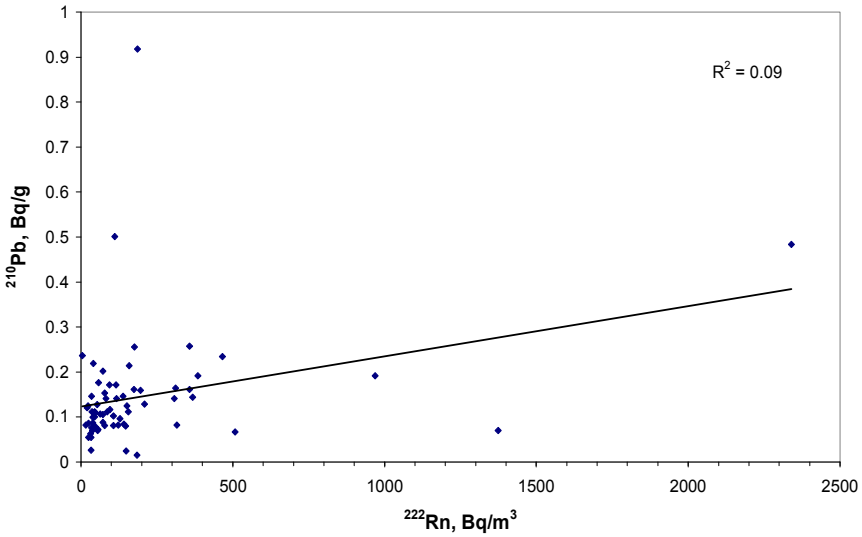

Figure 2. ^{210}Pb in dust versus indoor ^{222}Rn concentration, and linear fit through all 66 data points available in this study

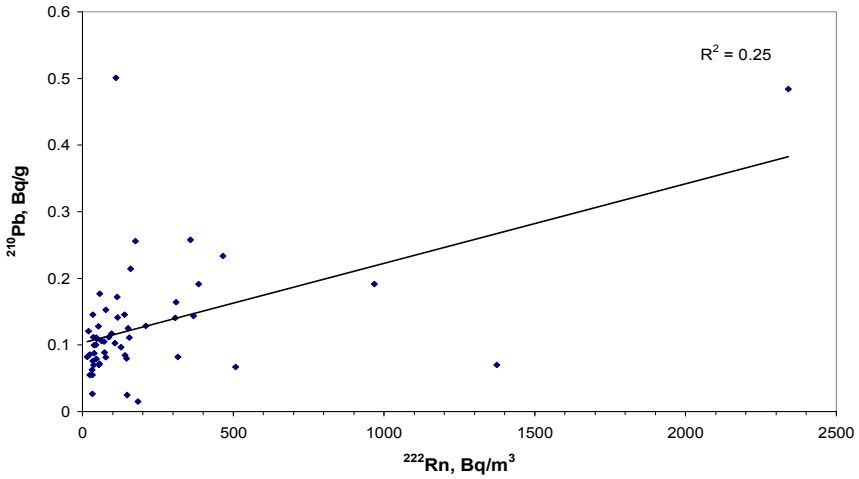

Figure 3. ^{210}Pb in dust versus indoor ^{222}Rn concentration for 54 dust samples of 10 g and more

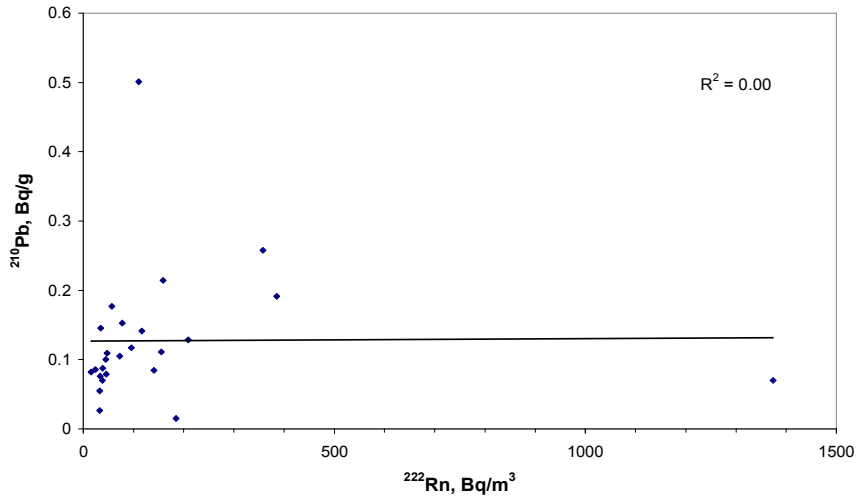

Figure 4. ^{210}Pb in dust versus indoor ^{222}Rn concentration for 25 dust samples of 10 g and more from Fredericton

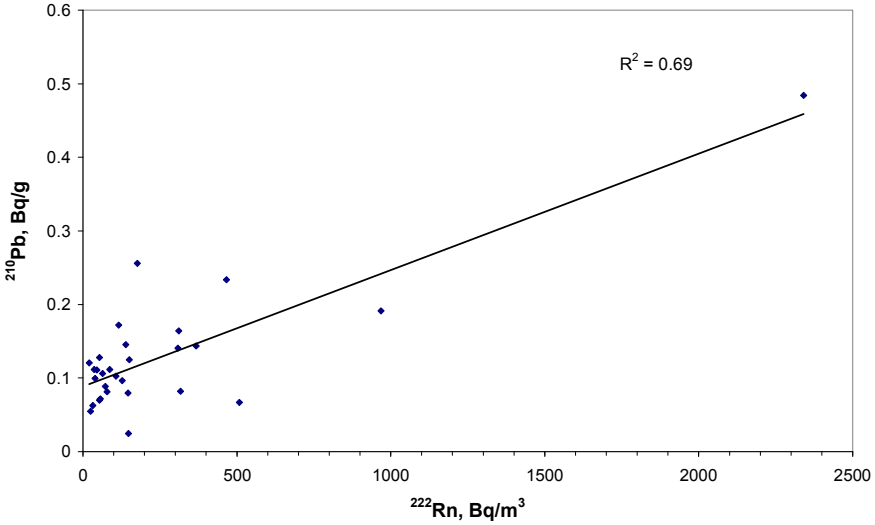

Figure 5. ^{210}Pb in dust versus indoor ^{222}Rn concentration for 29 dust samples of 10 g and more from Halifax

4. Discussion

Compared to the previous study, a similar correlation coefficient is observed among samples from the city of Halifax. A rather promising correlation coefficient of $R^2 = 0.69$ indicates that theoretically speaking, ^{210}Pb is a reasonably good indicator of long-term radon exposure indoors, when experimental conditions are well controlled and many uncertainty factors can be eliminated or reduced in the determination of both ^{210}Pb and ^{222}Rn concentrations.

However, this study was designed to estimate or predict indoor radon concentration by measuring ^{210}Pb in household dust. In the real world, the predictive power of this retrospective method could vanish if non-representative dust samples were provided. This may be the case for the few samples from Fredericton where the sample size was already limited for such correlation analysis.

In principle, the correlation coefficient, R^2, should not depend on geographic location. To make this method a practical and viable tool for quick estimation of long-term indoor radon concentration, it is important to make sure, before performing the analysis, that the sample is representative household dust collected in the past several months and from most surfaces in a house. Only dust representing indoor dust deposition over several months can be used to reasonably estimate the long-term indoor radon exposure condition.

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