AN EVALUATION OF THE SCREENING MEASUREMENT AS AN INDICATOR OF AVERAGE ANNUAL INDOOR RADON EXPOSURE

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NOTE: LE RÉSUMÉ EN FRANÇAIS SUIT IMMÉDIATEMENT LE RÉSUMÉ EN ANGLAIS.

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Executive Summary

A study was conducted during the period 1994-1995, to evaluate the radon screening measurement as an indicator of average annual indoor radon exposure. Data for the study was obtained from 24 single family detached homes from across the province of Ontario. Short-term (4 day) radon screening measurements were made in the basement and main living areas of each household, during each season: summer, fall, winter and spring. In addition to the screening measurements, a long-term (annual) radon measurement was made in the main living area of each home. All short-term and long-term measurements were made with electret ion chambers.

Using the annual measurement as the reference for each home, results of the current study indicated that a screening measurement made in any season had a 50-50 chance of under or over-estimating the average annual indoor radon exposure. No correlation between the short-term screening measurement and long-term annual radon measurement was found.

The study also demonstrated:

- *Guidelines or action levels based on annual radon exposure should not be used as the criteria for short-term screening measurements. A scaled criteria based on both the annual exposure level guideline and duration of screening measurement period should be developed and implemented.*
- *Instantaneous or grab sample readings should not be used as a basis for estimating annual indoor radon exposure.*
- *Peak radon values may occur in any season, though winter exhibits the highest number.*
- *Indoor radon levels can be extremely variable within the same community. Confounding factors include: house construction - nature of underlying fill material, proximity to and nature of bedrock, presence of exposed earth (sump pits, crawl spaces), condition of foundation, etc.; house location - urban versus rural; lifestyles - ventilation type and frequency of use, nature and usage of depressurizing devices, e.g., basement fireplaces, clothes dryers.*
- *Electret ion chambers are easy to deploy by the homeowner, and are small enough to facilitate postal delivery.*

Résumé

Une étude a été menée en 1994 et 1995 afin d'évaluer les mesures de dépistage du radon en tant qu'indicateur de l'exposition au radon moyenne annuelle à l'intérieur. Les données qui ont servi à l'étude ont été recueillies dans 24 maisons individuelles isolées situées un peu partout dans la province de l'Ontario. Des mesures de dépistage du radon ont été prises durant quatre jours au sous-sol et dans les principales pièces de séjour de chaque maison pour les quatre saisons de la période d'étude, soit l'été, l'automne, l'hiver et le printemps. Outre ces mesures de dépistage, le radon a été mesuré durant toute une année dans la principale pièce de séjour de chaque foyer. Toutes les mesures à court et à long terme ont été effectuées au moyen de chambres d'ionisation à électret.

Les mesures recueillies sur un an ayant servi de référence pour chaque maison, les résultats de la présente étude indiquent qu'une mesure de dépistage réalisée à n'importe quelle saison avait une chance sur deux de surestimer ou de sous-estimer l'exposition au radon annuelle moyenne à l'intérieur. Aucune corrélation n'a pu être établie entre les mesures de dépistage du radon prises à court terme et celles étalées sur une année.

L'étude a également montré ceci :

- Des directives ou des niveaux d'intervention qui seraient fondés sur une exposition annuelle au radon ne devraient pas être utilisés comme critères pour les mesures de dépistage à court terme. Il faudrait élaborer et mettre en place des critères proportionnés fondés à la fois sur les niveaux d'exposition annuelle et la durée de la période de mesure de dépistage.
- Des mesures portant sur des échantillons ponctuels ou pris au hasard ne devraient pas être utilisées à l'appui d'une estimation de l'exposition annuelle au radon à l'intérieur.
- Des concentrations de radon de pointe peuvent se produire en toute saison, mais ces pointes sont plus fréquentes en hiver.
- Les concentrations de radon à l'intérieur peuvent varier énormément au sein d'une même collectivité. Les facteurs confusionnels sont la construction de la maison (nature du remblai sous-jacent, proximité et nature du substratum rocheux, sol à découvert [puisard ou vide sanitaire], état des fondations, etc.), l'emplacement de la maison (ville ou campagne), le mode de vie (type d'installation de ventilation et fréquence d'utilisation, nature et emploi des appareils entraînant une dépressurisation comme un poêle à bois ou une sécheuse au sous-sol).
  Les chambres d'ionisation à électret sont faciles à utiliser par le propriétaire-occupant et sont suffisamment petites pour être expédiées par la poste.

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Abstract

A study was conducted during the period 1994-1995, to evaluate the radon screening measurement as an indicator of average annual indoor radon exposure. Data for the study was obtained from 24 single family detached homes from across the province of Ontario. Short-term (4 day) radon screening measurements were made in the basement and main living areas of each household, during each season: summer, fall, winter and spring. In addition to the screening measurements, a long-term (annual) radon measurement was made in the main living area of each home. Short-term and long-term measurements were made with electret ion chambers.

Using the annual measurement as the reference for each home, results of the current study indicated that a screening measurement made in any season had a 50-50 chance of under or over-estimating the average annual indoor radon exposure. No correlation between the short-term screening measurement and long-term annual radon measurement was found.

Introduction

Radon

Naturally occurring uranium is present to some degree in most rocks and soils; in North America the average concentration is 1 part per million (Lafavore, 1987). Radon, an inert, radioactive gas, is part of the radioactive decay chain of uranium. It has no odour, colour or taste. Radon accounts for more than 50 percent of the background radiation that Canadians are exposed to (Townsend, 1989), and represents the most common source of background radiation in the world (Thomas, 1989).

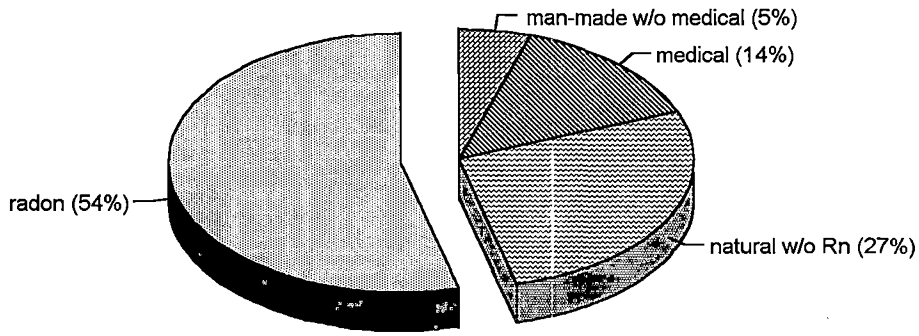


Figure 1 *- Background Radiation Sources*

The carcinogenic potential of radon is realized when radon and its decay products are breathed in (Krewski et al., 1989). As radon decays, it produces a number of electrically charged decay products or daughters, two of these, polonium 218 and polonium 214 are responsible for about 94% of the alpha radiation associated with radon. When inhaled, the radon decay products attach themselves to the lung tissue and can produce cell damage when they themselves decay. Health risk varies with exposure levels.

Most radon entering the home will do so at points of the house in direct contact with the underlying soil; entry points include:

- cracks in the floor slab or foundation wall
- penetrations in the floor slab/walls, e.g., (sewer, natural gas, water, electrical)
- exposed soil (root cellars, crawl spaces)
- sumps & drains
- slab to wall joints
- hollow support posts
- hollow block walls.

Since the air pressure inside a house is usually lower than that outside the house, even a crack smaller than a pin head in width, can produce soil gas flow that brings radon into the structure (Lafavore, 1987). Radon is readily soluble in water, so a wet basement may also be a radioactive one (Cothern et al., 1987). ***Note:*** *Even if radon is not present in the water, the water itself is an indicator of porosity or cracks in the building's foundation.* Other sources of radon in buildings include the water supply (if the water comes from wells) or the natural gas supply (rare).

The amount of radon entering a home depends on a number of factors:

- the nature of the soil beneath the house, damp clay can insulate the house from radon entry, whereas, dry cracked clay, sand or glacial till can allow radon to move rapidly from the soil into the foundation
- the condition of the building and number of cracks or openings in the foundation
- weather — wind, temperature, barometric pressure (drops in pressure result in more radon being released from the ground); season — radon levels are generally higher in cold months (building is closed, also, the presence of frost, snow and ice can block radon's release into the air from the surface of the outdoor soil); and lifestyles — the frequency of operation of fireplaces, dryers, exhaust fans, etc., that increase depressurization of the indoor air.

Measurement

Currently, the only way to determine the amount of radon present in a house is to measure it directly. In Canada and the United States, a phased measurement program is advocated; both countries recommend one or more short-term screening measurements, followed by a confirming long-term measurement (if required).

The Canadian federal government defines a screening test as a radon measurement made in the basement (or lowest level of a house) and capable of producing a result in a few days (Health and Welfare Canada, 1989). It recognizes that the screening measurement does not provide a reliable estimate of annual radon exposure, and recommends a six-month long exposure be made in the living area of the house (no preference as to which six months).

The province of Manitoba recommends 2-day to several week long screening measurements be made in the lowest livable level of the house. It too recognizes that the screening measurement does not provide a reliable estimate of annual radon exposure, and recommends a three-month long exposure (under closed-house conditions) be made in at least two lived-in areas of the house. The long-term test is to be considered if the screening measurement is about 150 Bq/m^3 to 800 Bq/m^3, and made if the screening measurement is about 800 Bq/m^3 or greater (Government of Manitoba, 1989.)

British Columbia dispenses with the screening measurement; recommending instead a long-term measurement made during a minimum of 3 heating months. The stated preference is a 6 to 12 month exposure (Province of British Columbia, 1989).

Experimental Design

Households

The project started with 28 single family detached homes with basements, selected at random from across the province of Ontario. Homeowners were solicited by telephone to participate in the research project. Follow-up was by way of confirming letter.

Initial communities in the study included: Arthur, Ayr, Balmertown, Bancroft, Brampton, Cambridge, Conestogo, Deep River, Glen Morris, Guelph, Hamilton, Kanata, Kenora, Kingston, Kitchener, Lively, Mount Brydges, Onaping, Pembroke, Richmond Hill, St. George, Stratford, Waterdown and Waterloo. ***Note:*** *Homeowners in Ayr, Balmertown, Brampton, Conestogo, Kanata, Kingston and Lively did not return monitors after the initial seasonal measurement (despite several follow-up calls and letters). The household in Kenora elected to drop out of the program (they felt the questionnaire was too involved) and returned all materials. Some of the non-respondents were replaced by alternate homeowners in Dowling, Pembroke, Timmins and Willowdale.*

The 24 homeowners who did participate in the study were from the communities of: Arthur, Bancroft, Cambridge, Deep River, Dowling, Glen Morris, Guelph, Hamilton, Kitchener, Mount Brydges, Onaping, Pembroke, Richmond Hill, St. George, Stratford, Timmins, Waterdown, Willowdale and Waterloo (see Figure 2).

Information pertaining to specifics of each house tested, e.g., house size, age, construction and heating method was obtained by questionnaire (see sample in Appendix II). Householders were also asked to sketch details of their basement floor plan, including: floor area and basement height; the location of drains, floor cracks, sumps and furnace; and indicate the location of the short-term monitor.

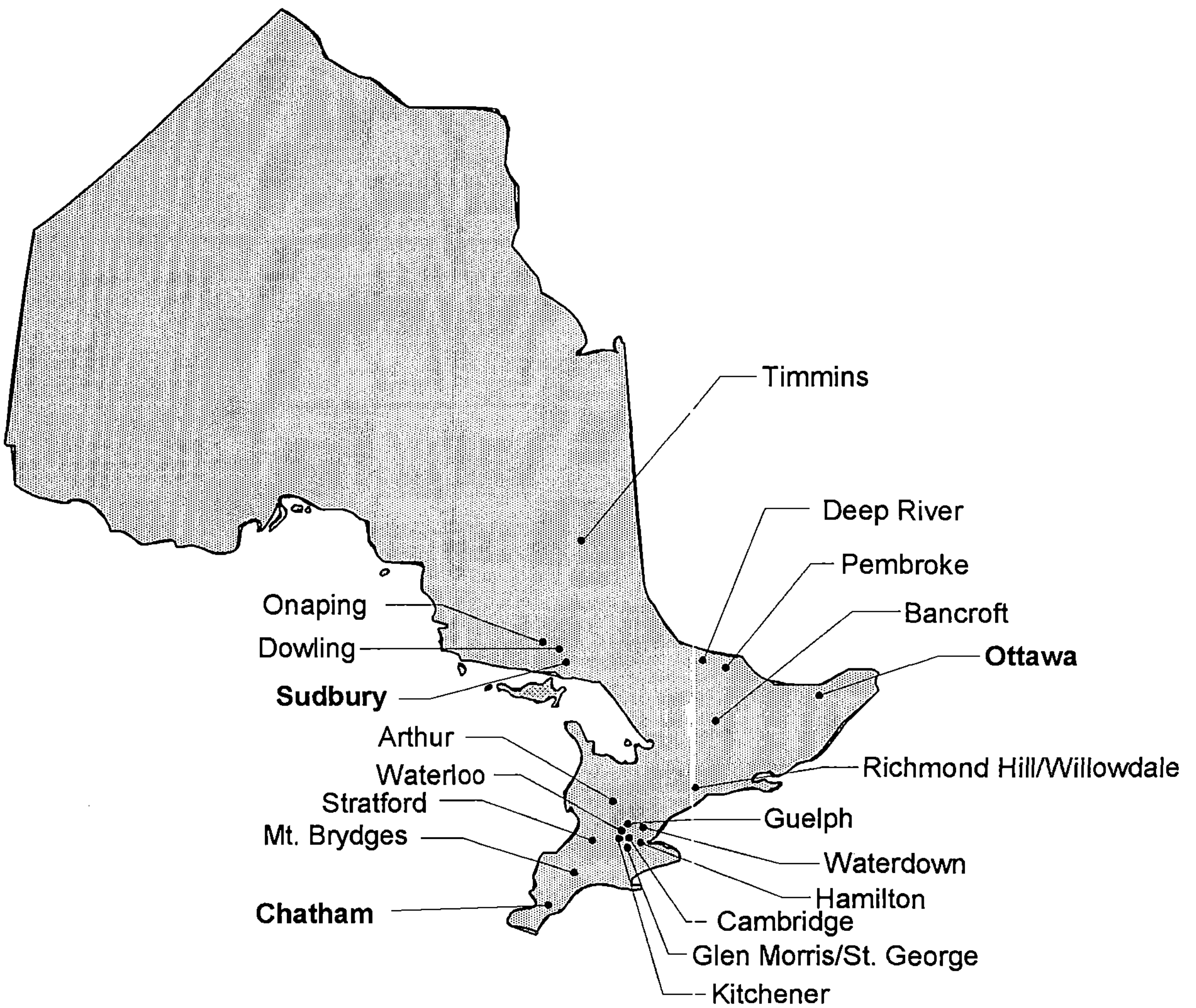


Figure 2 *- Participating Communities (bold entries for reference only)*

Radon Monitoring

The first deployment of long-term (annual) and short-term (seasonal) radon monitors, took place in the summer of 1994. The monitors used for both measurements were E-PERMs® (Electret - Passive Environmental Radon Monitor) produced by Rad Elec Inc., Frederick, Maryland.

E-PERMs® or electret ion chambers (EICs), were chosen because the EIC method provides a true integrated measurement of the average radon concentration during the exposure period. The electret ion chamber is not affected by varying temperatures, air pressure changes or humidity (Summers et al., 1990), however, environmental gamma radiation makes a small contribution to the voltage drop on the electret and must be measured separately and corrected for. The EIC can be adapted to monitor a variety of ionizing radiations, see Appendix III for calculational methods.

The short-term monitors consisted of a charged dielectric disc — the electret (polytetraflouroetheylene Teflon for short-term electrets) housed in a type-S ionization chamber (210 ml air volume, conductive plastic canister). The exposed surface of the electret is positive (surface potential is typically in the range of 200 to 750 volts), the surface bonded to the base, and the plastic canister, are negative. See Figure 3.

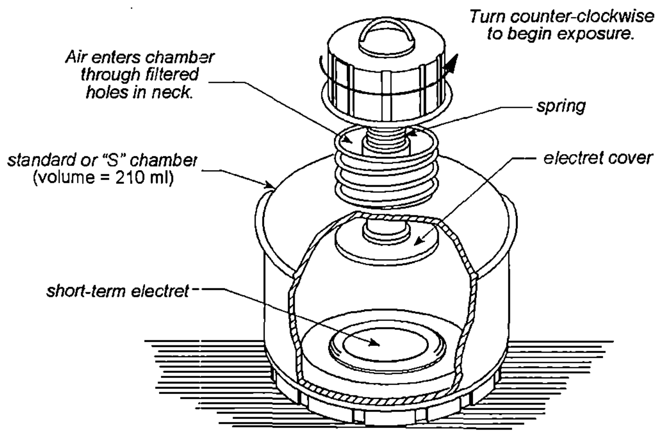


***Figure 3** - The Short-term Monitor*

The operating principle of the short-term EIC is as follows: The electret ion chamber is activated or turned "ON" by unscrewing its spring loaded cap. This allows airborne radon to diffuse into the monitor through filtered holes in the neck of the chamber. These same filtered holes exclude the entry of radon progeny and other environmental ions (Kotrappa et al., 1990). The electret loses electrostatic potential in direct response to negative ions generated inside the chamber by the decay of radon and its radioactive daughters. The exposure is stopped by screwing down the cap — this action pushes the electret cover down over the electret, effectively sealing it from ions inside the chamber. Once the exposure has stopped, no further voltage drop occurs on the electret. The LLD (LLD is defined as the lowest (radon) level detectable ±50%) for short-term electret ion chambers (210 ml air volume) is as follows (Rad Elec Inc, 1993):

2 day exposure LLD = 9.3 Bq/m^3
4 day exposure LLD = 7.9 Bq/m^3
7 day exposure LLD = 5.9 Bq/m^3.

Short-term EICs were exposed in the basement and main living level of each house tested, for a period of four days during each season (summer, fall, winter and spring). At the start of each season, homeowners received two, sealed short-term electret ion chambers containing pre-measured short-term electrets. They were instructed to establish closed-house conditions (EPA, 1993) for at least 12 hours before starting the measurement; and to maintain those conditions for the duration of the short-term measurement. ***Note:*** *Homeowners were allowed to use furnaces and air conditioners (provided they were only recirculating interior air) as they normally would.* The EICs were deployed at least 75 cm above the floor or below the ceiling, and at least 10 cm away from other objects. Vents, exterior doors and windows were avoided. See Appendix I for the short-term test protocol.

The long-term monitors consisted of a long-term electret (tetrafluoroethylene Teflon) housed in a type-L ionization chamber (50 ml air volume, conductive plastic canister). Unlike the type-S chamber, the type-L chamber does not have an ON/OFF mechanism.

The LLD for long-term electret ion chambers (50 ml air volume) is as follows:

90 day exposure LLD = 11.1 Bq/m^3
365 day exposure LLD = 7.0 Bq/m^3.

Homeowners received a pre-measured and capped long-term electret, and a type-L chamber. The long-term test protocol instructed them to quickly remove the cap and install the electret into the chamber to begin the long-term measurement. The long-term EICs were deployed on the main living level of the house. They were positioned at least 75 cm above the floor or below the ceiling, and about 30 cm away from the main floor short-term EIC. See Figure 4 and Appendix I.

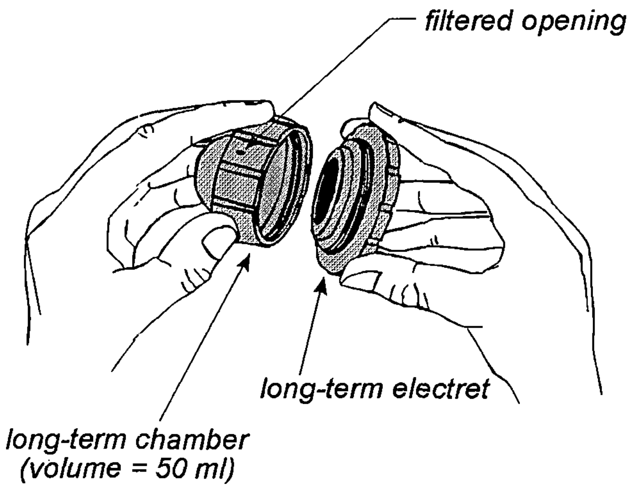


Figure 4 *- The Long-term Monitor*

Results

Exposed electret ion chambers were returned via Canada Post to LaFontaine Consulting Services for analysis. Homeowners were instructed to return the long-term monitors with the fourth and last pair of seasonal short-term monitors. The long-term electrets were left in the 50 ml chambers for transit — it was assumed that the electret voltage drop produced by radon exposure during the mail delivery period would have an insignificant impact on the final results, i.e.,

$$\Delta V_{365\ days} >> \Delta V_{mail}.$$

Summary Statistics

Test Period	Location	N	geometric mean	arithmetic mean	standard deviation	minimum	maximum
summer	basement	24	168.0	227.6	189.3	62.9	847.3
	main	24	105.0	162.8	162.7	18.5	647.5
fall	basement	23	150.3	201.2	200.9	40.7	936.1
	main	23	123.9	166.3	154.8	29.6	680.8
winter	basement	24	191.3	242.4	216.2	66.6	1028.6
	main	24	144.1	194.1	181.4	33.3	817.7
spring	basement	23	149.6	201.2	204.7	48.1	917.6
	main	23	116.1	151.5	149.9	37.0	714.1
annual	main	24	196.3	247.6	212.9	77.7	895.4

Notes:
1) means, standard deviation, minimum and maximum values have units of Bq/m^3.
2) the standard deviation is the sample standard deviation, i.e., the square root of the sample variance.
3) for the houses studied, the occurrence of maximum radon levels was as follows:

Basement — spring 4.5%, summer 36.4%, fall 13.6% and winter 45.5%
Main — spring 18.2%, summer 18.2%, fall 18.2% and winter 45.4%.

Summer/Annual Summary

house #	basement (B) Bq/m³	main (M) Bq/m³	annual (A) Bq/m³	B/M	B/A	M/A
1	259.0	307.1	240.5	0.84	1.08	1.28
2	181.3	506.9	843.6	0.36	0.21	0.60
3	281.2	162.8	222.0	1.73	1.27	0.73
4	77.7	170.2	166.5	0.46	0.47	1.02
5	325.6	55.5	199.8	5.87	1.63	0.28
6	133.2	111.0	451.4	1.20	0.30	0.25
7	114.7	166.5	96.2	0.69	1.19	1.73
8	62.9	92.5	96.2	0.68	0.65	0.96
9	617.9	440.3	229.4	1.40	2.69	1.92
10	111.0	55.5	185.0	2.00	0.60	0.30
11	388.5	40.7	177.6	9.55	2.19	0.23
12	151.7	29.6	114.7	5.13	1.32	0.26
13	122.1	96.2	107.3	1.27	1.14	0.90
14	77.7	103.6	140.6	0.75	0.55	0.74
15	292.3	136.9	266.4	2.14	1.10	0.51
16	199.8	125.8	173.9	1.59	1.15	0.72
17	111.0	59.2	155.4	1.88	0.71	0.38
18	281.2	77.7	388.5	3.62	0.72	0.20
19	395.9	296.0	325.6	1.34	1.22	0.91
20	210.9	99.9	159.1	2.11	1.33	0.63
21	66.6	18.5	107.3	3.60	0.62	0.17
22	847.3	647.5	895.4	1.31	0.95	0.72
23	85.1	66.6	122.1	1.28	0.70	0.55
24	66.6	40.7	77.7	1.64	0.86	0.52
			mean	2.18	1.03	0.69
			count	24	24	24
			min.	0.36	0.21	0.17
			max.	9.55	2.69	1.92

Note: *Houses 2 and 9 were both in Pembroke yet the annual radon concentration in house #2 was 3.7 times greater than that measured in house #9.*

Fall/Annual Summary

house #	basement (B) Bq/m³	main (M) Bq/m³	annual (A) Bq/m³	B/M	B/A	M/A
1	151.7	118.4	240.5	1.28	0.63	0.49
2	192.4	107.3	843.6	1.79	0.23	0.13
3	66.6	51.8	222.0	1.29	0.30	0.23
4	107.3	125.8	166.5	0.85	0.64	0.76
5	192.4	173.9	199.8	1.11	0.96	0.87
6	599.4	484.7	451.4	1.24	1.33	1.07
7	62.9	81.4	96.2	0.77	0.65	0.85
8	144.3	48.1	96.2	3.00	1.50	0.50
9	333.0	262.7	229.4	1.27	1.45	1.15
10	40.7	29.6	185.0	1.38	0.22	0.16
11	***	***	177.6	***	***	***
12	144.3	107.3	114.7	1.34	1.26	0.94
13	99.9	88.8	107.3	1.13	0.93	0.83
14	162.8	366.3	140.6	0.44	1.16	2.61
15	262.7	233.1	266.4	1.13	0.99	0.88
16	107.3	129.5	173.9	0.83	0.62	0.74
17	151.7	129.5	155.4	1.17	0.98	0.83
18	74.0	66.6	388.5	1.11	0.19	0.17
19	155.4	166.5	325.6	0.93	0.48	0.51
20	111.0	70.3	159.1	1.58	0.70	0.44
21	92.5	70.3	107.3	1.32	0.86	0.66
22	936.1	680.8	895.4	1.38	1.05	0.76
23	333.0	144.3	122.1	2.31	2.73	1.18
24	107.3	88.8	77.7	1.21	1.38	1.14
			mean	1.30	0.92	0.78
			count	23	23	23
			min.	0.44	0.19	0.13
			max.	3.00	2.73	2.61

Note: *Personal schedule of household #11 prevented timely deployment of the fall short-term monitors.*

The summer/annual and fall/annual summary tables show a mean basement screening : annual radon measurement ratio of 1.03 for the summer, and 0.92 for the fall. Mean basement screening : main floor screening radon measurements for the same two seasons was 2.18 for the summer and 1.30 for the fall.

Results of the annual radon measurement (column 4 on all summary tables) are summarized as follows:

- 8/24 or 33.3% of the measurements were less than the U.S. EPA action level of 148 Bq/m^3 (4 pCi/L)
- 16/24 or 66.7% of the measurements exceeded the U.S. EPA action level of 148 Bq/m^3 (4 pCi/L)
- 2/24 or 8.3% of the measurements exceeded the "recommended" Canadian guideline of 800 Bq/m^3
- 22/24 or 91.7% of the measurements were less than the "recommended" Canadian guideline of 800 Bq/m^3.

Figure 5 is a graph of the summer basement radon measurement vs. the annual living area radon measurement for each house. The spread in the data is expected due to the small sample size and diverse geologies of the test localities.

Linear regression analysis produced a slope (annual Rn : summer basement Rn) = 1.0 ± 0.30. The value of the coefficient of determination ($r^2 = 0.335$) indicates that for the study data, 33.5% of the variability in annual radon concentrations is explained by the variability in summer radon screening measurements. The remaining 66.5% is unexplained.

Figure 6 shows the graph of the fall basement radon measurement vs. the annual living area radon measurement for each house. Linear regression analysis produced a slope (annual Rn : fall basement Rn) = 1.0 ± 0.24. The value of the coefficient of determination ($r^2 = 0.444$) indicates that for the study data, 44.4% of the variability in annual radon concentrations is explained by the variability in fall radon screening measurements; 55.6% is unexplained.

The frequency distribution histograms in Figures 7 and 8, show the percent occurrence for the basement/annual radon measurement ratios.

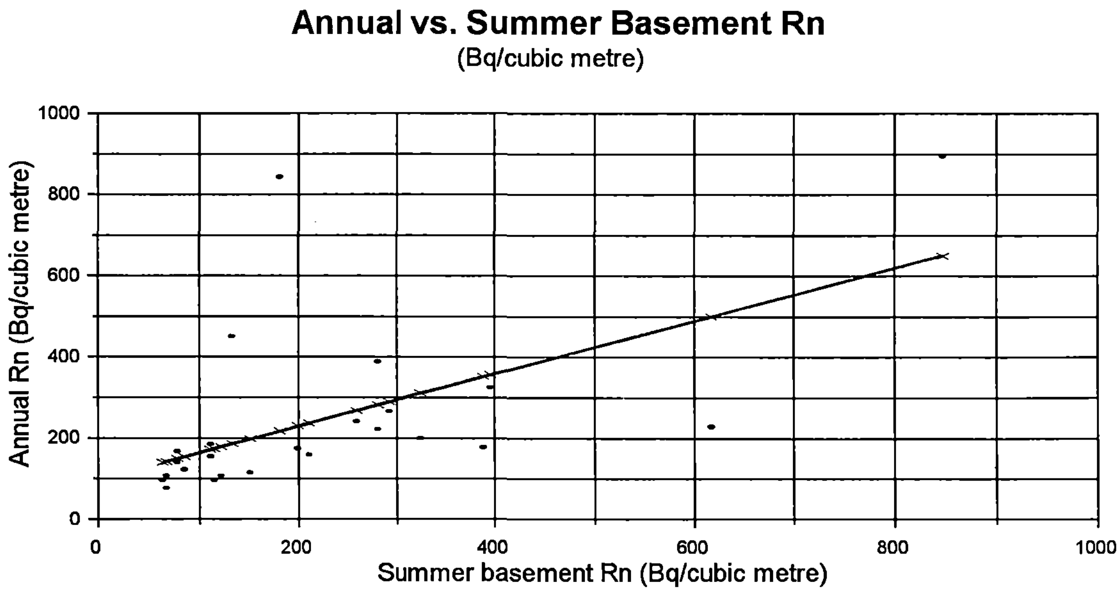
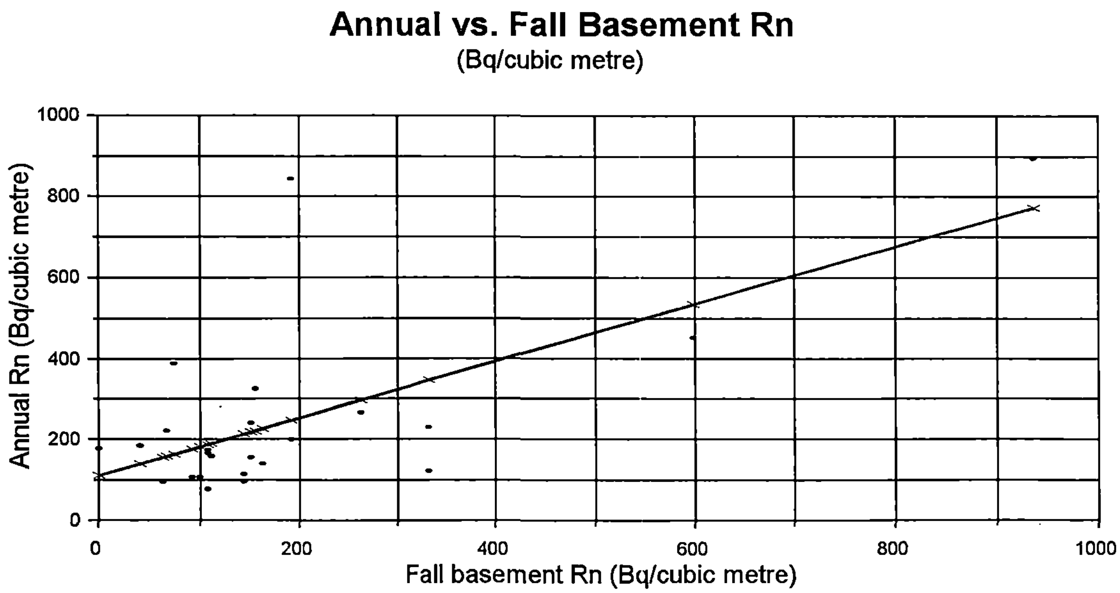


Figure 5



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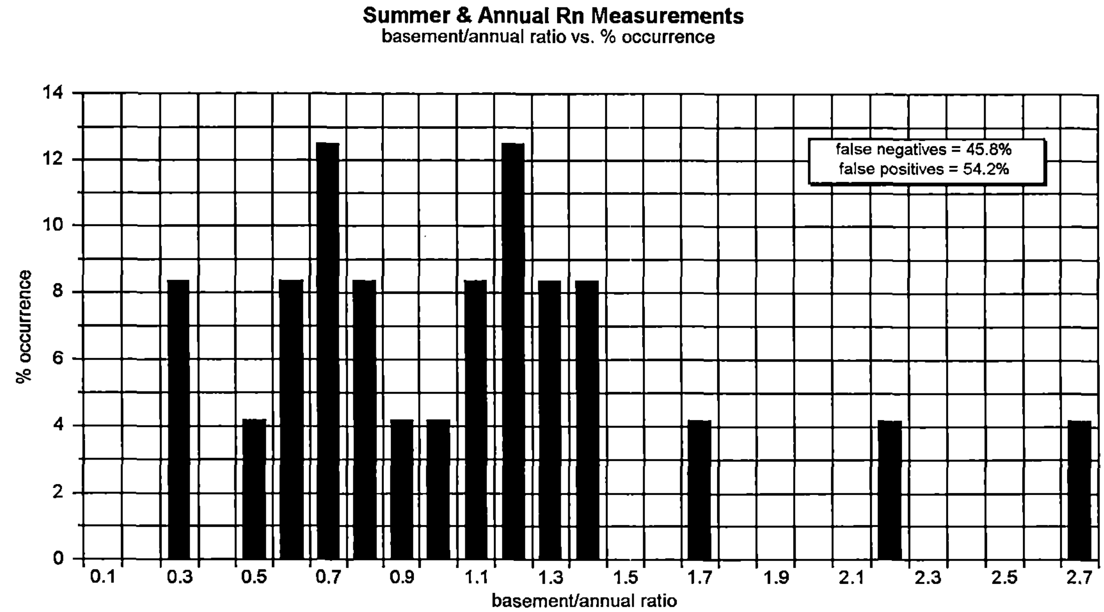

Figure 7

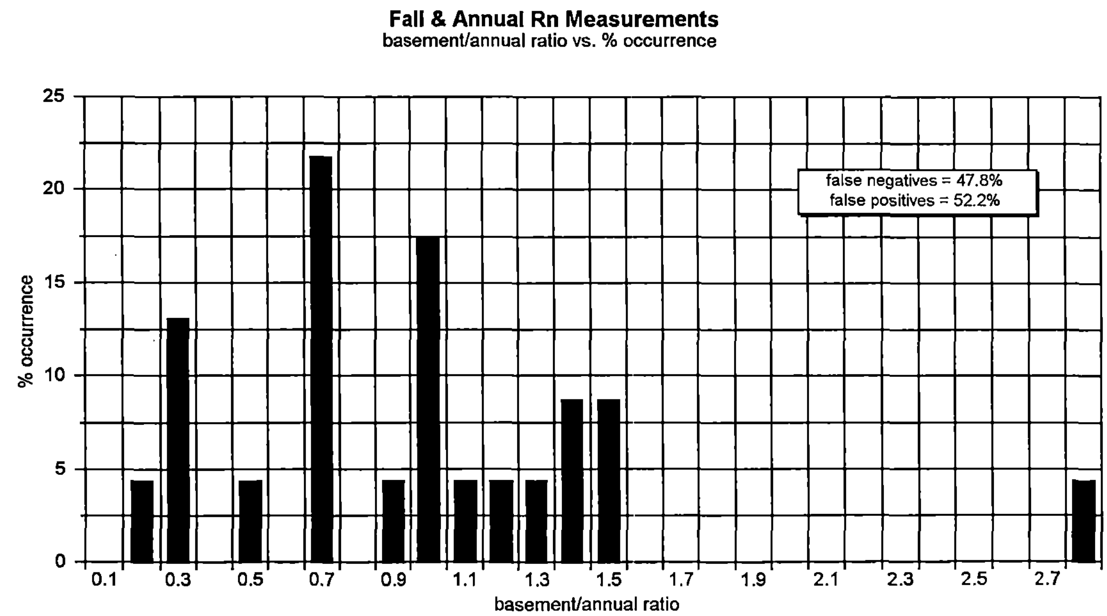

Figure 8

Winter/Annual Summary

house #	basement (B) Bq/m^3	main (M) Bq/m^3	annual (A) Bq/m^3	B/M	B/A	M/A
1	218.3	233.1	240.5	0.94	0.91	0.97
2	270.1	92.5	843.6	2.92	0.32	0.11
3	173.9	111.0	222.0	1.57	0.78	0.50
4	214.6	218.3	166.5	0.98	1.29	1.31
5	236.8	192.4	199.8	1.23	1.19	0.96
6	732.6	621.6	451.4	1.18	1.62	1.38
7	66.6	55.5	96.2	1.20	0.69	0.58
8	85.1	33.3	96.2	2.56	0.88	0.35
9	281.2	199.8	229.4	1.41	1.23	0.87
10	151.7	140.6	185.0	1.08	0.82	0.76
11	103.6	40.7	177.6	2.55	0.58	0.23
12	129.5	103.6	114.7	1.25	1.13	0.90
13	111.0	99.9	107.3	1.11	1.03	0.93
14	251.6	244.2	140.6	1.03	1.79	1.74
15	273.8	162.8	266.4	1.68	1.03	0.61
16	155.4	185.0	173.9	0.84	0.89	1.06
17	203.5	192.4	155.4	1.06	1.31	1.24
18	399.6	358.9	388.5	1.11	1.03	0.92
19	177.6	203.5	325.6	0.87	0.55	0.63
20	229.4	111.0	159.1	2.07	1.44	0.70
21	77.7	66.6	107.3	1.17	0.72	0.62
22	1028.6	817.7	895.4	1.26	1.15	0.91
23	129.5	81.4	122.1	1.59	1.06	0.67
24	114.7	92.5	77.7	1.24	1.48	1.19
			mean	1.41	1.04	0.84
			count	24	24	24
			min.	0.84	0.32	0.11
			max.	2.92	1.79	1.74

Spring/Annual Summary

house #	basement (B) Bq/m^3	main (M) Bq/m^3	annual (A) Bq/m^3	B/M	B/A	M/A
1	185.0	114.7	240.5	1.61	0.77	0.48
2	148.0	107.3	843.6	1.38	0.18	0.13
3	236.8	199.8	222.0	1.19	1.07	0.90
4	129.5	151.7	166.5	0.85	0.78	0.91
5	233.1	173.9	199.8	1.34	1.17	0.87
6	677.1	451.4	451.4	1.50	1.50	1.00
7	81.4	74.0	96.2	1.10	0.85	0.77
8	92.5	66.6	96.2	1.39	0.96	0.69
9	321.9	185.0	229.4	1.74	1.40	0.81
10	48.1	37.0	185.0	1.30	0.26	0.20
11	85.1	81.4	177.6	1.05	0.48	0.46
12	144.3	96.2	114.7	1.50	1.26	0.84
13	62.9	66.6	107.3	0.94	0.59	0.62
14	92.5	148.0	140.6	0.63	0.66	1.05
15	299.7	125.8	266.4	2.38	1.13	0.47
16	173.9	222.0	173.9	0.78	1.00	1.28
17	170.2	107.3	155.4	1.59	1.10	0.69
18	107.3	55.5	388.5	1.93	0.28	0.14
19	***	***	325.6	***	***	***
20	151.7	77.7	159.1	1.95	0.95	0.49
21	85.1	85.1	107.3	1.00	0.79	0.79
22	917.6	714.1	895.4	1.28	1.02	0.80
23	99.9	74.0	122.1	1.35	0.82	0.61
24	85.1	70.3	77.7	1.21	1.10	0.90
			mean	1.35	0.87	0.69
			count	23	23	23
			min.	0.63	0.18	0.13
			max.	2.38	1.50	1.28

Note: *Personal schedule of household #19 prevented timely deployment of the spring short-term monitors.*

The winter/annual and spring/annual summary tables show a mean basement screening : annual radon measurement ratio of 1.04 for the winter, and 0.87 for the spring. Mean basement screening : main floor screening radon measurements for the same two seasons was 1.41 for the winter and 1.35 for the spring.

In Figure 9, the winter basement radon measurement vs. the annual living area radon measurement for each house is graphed. Here, linear regression analysis produced a slope (annual Rn : winter basement Rn) = 1.0 ± 0.18. The value of the coefficient of determination (r^2 = 0.594) indicates that for the study data, 59.4% of the variability in annual radon concentrations is explained by the variability in winter radon screening measurements. The remaining 40.6% must be explained by other factors.

Figure 10 is a graph of the spring basement radon measurement vs. the annual living area radon measurement for each house. Linear regression analysis produced a slope (annual Rn : spring basement Rn) = 1.0 ± 0.25. The value of the coefficient of determination (r^2 = 0.425) indicates that for the study data, 42.5% of the variability in annual radon concentrations is explained by the variability in spring radon screening measurements; 57.5% is unexplained.

The frequency distribution histograms in Figures 11 and 12, show the percent occurrence for the basement/annual radon measurement ratios.

The false positives and false negatives (referenced to the annual measurement) for each season, are tabled as follows:

Season	False Negatives	False Positives
summer	45.8%	54.2%
fall	47.8%	52.2%
winter	37.5%	62.5%
spring	47.8%	52.2%

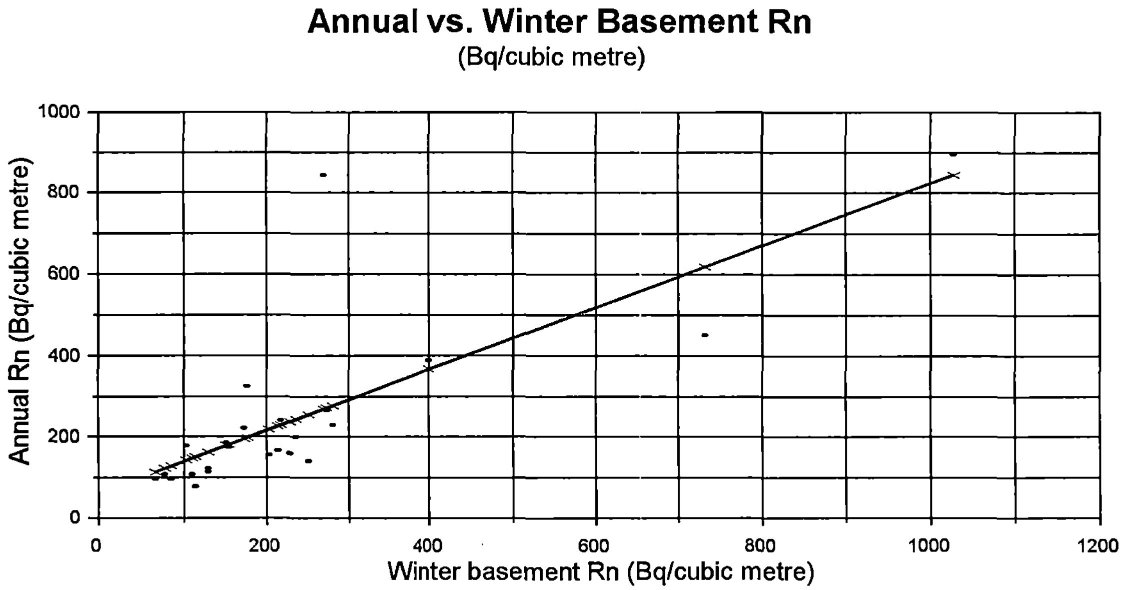

Figure 9

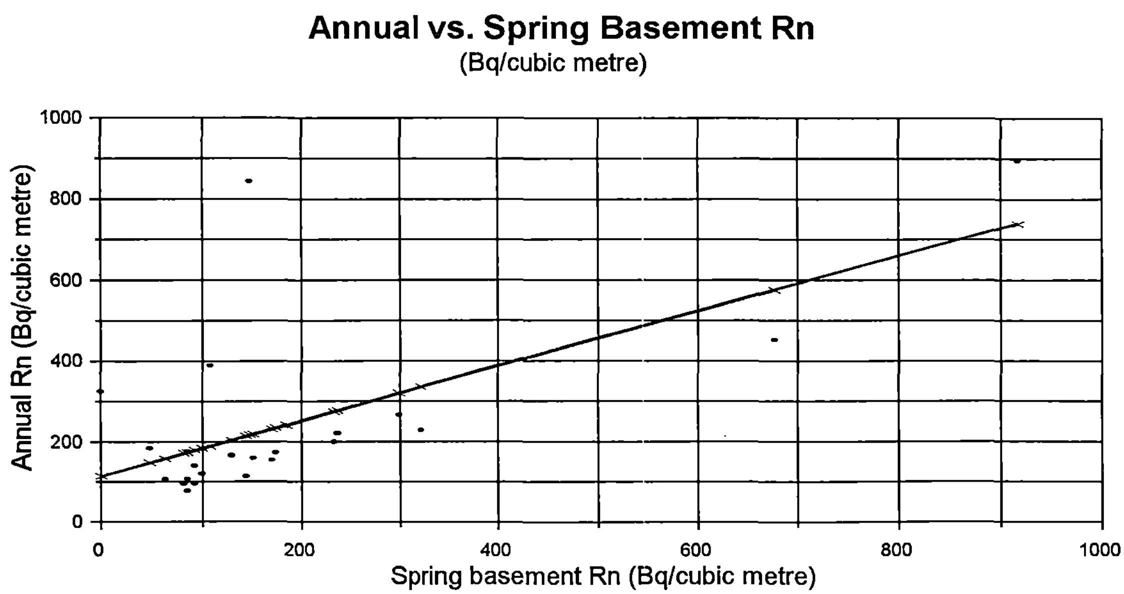

Figure 10

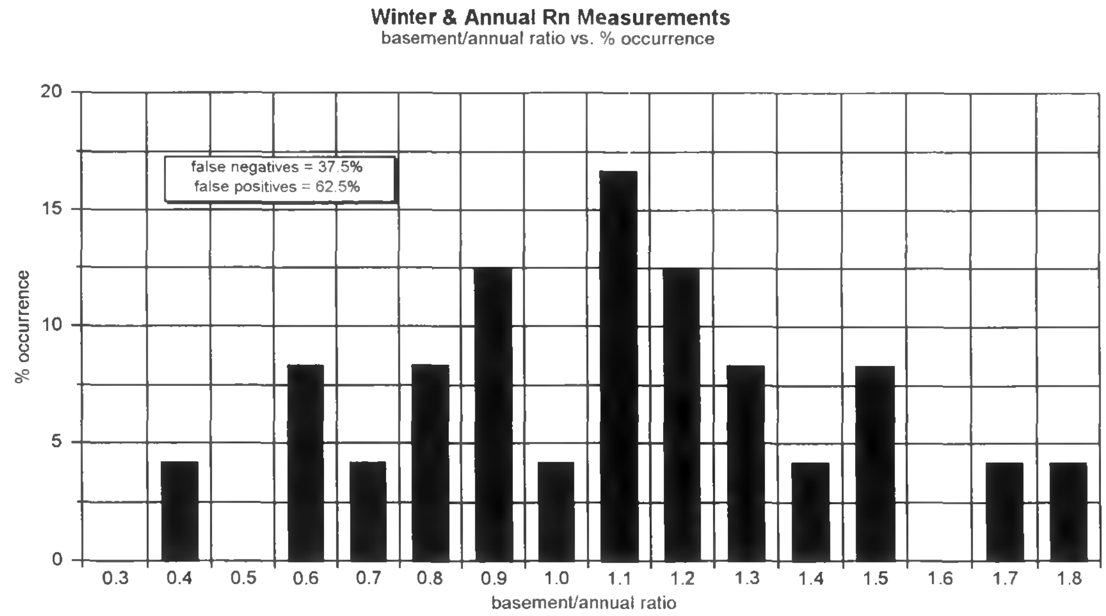

Figure 11

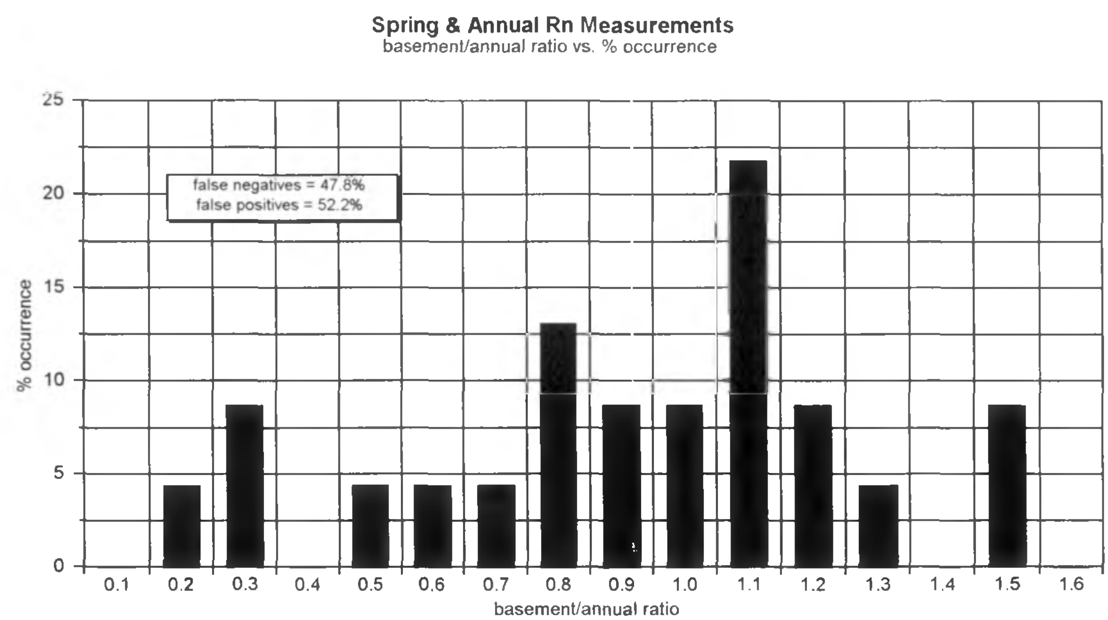

Figure 12

Conclusions

A study was conducted to evaluate the radon screening measurement as an indicator of average annual indoor radon exposure. Data for the study was obtained from 24 single family detached homes from across the province of Ontario.

The study indicates:

1) The short-term screening measurement is not an accurate indicator of annual indoor radon exposure. Regardless of season, there exists a 50-50 chance that the screening measurement will actually be a false negative or false positive.

2) Guidelines or action levels based on annual radon exposure should not be used as the criteria for short-term screening measurements. A scaled criteria based on both the annual exposure level and duration of screening measurement period should be implemented.

3) Instantaneous or grab sample readings should not be used as a basis for estimating annual indoor radon exposure.

4) Peak radon values may occur in any season, though winter exhibits the highest number.

5) Indoor radon levels can be extremely variable within the same community. Confounding factors include: house construction - nature of underlying fill material, proximity to and nature of bedrock, presence of exposed earth (sump pits, crawl spaces), condition of foundation, etc.; house location - urban versus rural; lifestyles - ventilation type and frequency of use, nature and usage of depressurizing devices, e.g., basement fireplaces, clothes dryers.

6) Electret ion chambers are easy to deploy by the homeowner, and are small enough to facilitate postal delivery.

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Appendix I - Test Protocols

Instructions for Exposing Short Term Electret Ion Chambers

1.0 SCREENING MEASUREMENTS

1.1 The screening measurement is a 4 day test. It provides a quick measure of the radon level in a house or building. The test provides information to determine whether follow-up testing is required.

2.0 DESCRIPTION

2.1 The electret ion chamber consists of a charged dielectric disc - the electret, housed in a conductive plastic canister. The exposed surface of the electret is positive, the surface bonded to the base, and the plastic canister, are negative.

2.2 The electret ion chamber works by collecting radon gas and losing electrostatic potential in direct response to ions generated inside the chamber by the decay of radon and its radioactive daughters. The decrease in electrostatic potential is measured by the test laboratory and is used to calculate the radon concentration. This method results in an integrated measurement of the radon concentration during the exposure. The electret ion chamber is not affected by temperature fluctuations, air pressure changes or humidity during exposure.

3.0 SCOPE

3.1 These instructions apply to short term electret ion chambers (EICs).

4.0 PROCEDURE

4.1 Maintain Closed House Conditions

a) Ventilation systems (other than a furnace) which interact with outside air should not be operated for a period at least 12 hours before, and during the test. Such systems include: fans, air conditioners, range hoods, attic fans and clothes driers. Air conditioning systems that recycle interior air may be operated.

b) Keep all doors to the outside and windows closed (except for normal exit and entry) at least 12 hours before the test and for the duration of the test.

4.2 Test at the Lowest Habitable Level & Main Living Level of the House

a) Perform one of the screening tests at the lowest level of the house which could possibly be inhabited, i.e., an unfinished basement. DO NOT TEST in crawl spaces, fruit cellars or laundry rooms.

b) **Perform the second screening test on the main living level of the house - locate the screening EIC about 12" away from the long term EIC.**

c) **DO NOT TEST** in rooms where water or fumes may be present. Included in this category are: kitchens, washrooms and laundry rooms.

d) **DO NOT TEST** near sumps, drains or sewers.

e) **DO NOT TEST** near oil, gas or other fuel tanks.

4.3 Avoid Drafts

a) **DO NOT TEST** near exterior walls, doors or windows.

b) **AVOID** heating, ventilation and air conditioning vents.

4.4 Test at a Central Location

a) Position the EIC at least 75 cm (30 inches) above the floor or below the ceiling, and at least 10 cm (4 inches) away from other objects.

b) Locate the EIC near the middle of the room if possible.

c) **DO NOT PLACE** the EIC in a closet, cupboard or drawer.

d) **DO NOT PLACE** the EIC in direct sunlight.

4.5 Avoid Severe Weather Conditions

a) **DO NOT PERFORM** short term measurements if severe weather conditions, i.e., rapid barometric pressure changes, strong winds and storms are predicted.

4.6 Exposure

a) Start the exposure by unscrewing the cap of the canister in the direction indicated on Figure 1. Once unscrewed, a spring beneath the cap will raise the cap and connecting stem to the ON position. **DO NOT remove the electret from the base of the canister!**

b) Record the time of day (**use the 24 hour clock or indicate a.m. or p.m.**) and date the detector was turned ON, on the data form.

c) Stop the exposure by pushing down on the canister's cap and screwing it back in place. Record the time of day and date the detector was turned OFF, on the data form.

4.7 Return EICs

a) Fill in your name, address and phone number in the spaces provided on the data form. Complete one form for each screening measurement.

b) Identify where in the house the EIC was exposed, e.g., rec room - basement.

c) Fill in the remaining information on the data form.

d) Place both EICs and completed data forms in the shipping box, attach return postage and address stickers, and mail to the laboratory.

RESULTS WILL BE SENT TO YOU IMMEDIATELY UPON ANALYSIS.

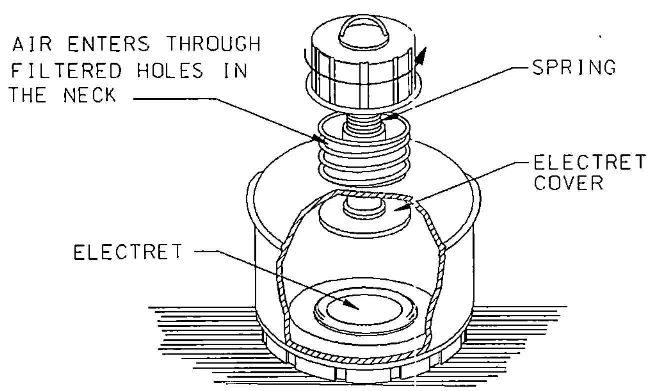


FIGURE 1 - Electret Ion Chamber "ON"

RETURN TO:

LaFontaine Consulting Services
106 Krug Street
Kitchener, Ontario
N2H 2X9

Electret Data Form

Return this form with the exposed electret.

Electret I.D. Number ____________________ *(e.g., SA1234 — see barcode on base of device)*

Chamber Type: ☐ standard

Name: ____________________

Street: ____________________

City: ____________________ Province: ____________

Postal Code ____________ Phone ____________

Exposure Start date:____________ time:____________

Exposure Stop date:____________ time:____________

Room where canister was exposed (e.g., bedroom - basement):____________________

Approximately how many hours was the heating system operating during the screening measurement?:__________

Appendix II - Questionnaire

Radon Questionnaire

The following information will be used to interpret your radon test results. Please send this completed form back with the first pair of exposed short term radon monitors. YOUR NAME, ADDRESS AND ANY PERSONAL INFORMATION WILL BE HELD IN CONFIDENCE.

Date ______________

Name ______________________________________

Street ______________________________________

City ______________________________________

Postal Code ___________________ Phone No. _________________

OCCUPANT INFORMATION

1. Are you the original occupant? ______
2. How long have you lived at this address? _______
3. How long do you intend to live at this address? _______
4. Number of household occupants __________
5. Do any occupants smoke? _______
6. Indicate ages of occupants who smoke ____________________________

7. List occupants ages in the following chart. Also, indicate the approximate amount of time per week, each occupant spends in the basement and main living area.

Occupant	Age (years)	Time in Basement (hours)	Time on Main Living Area (hours)
1			
2			
3			
4			
5			
6			
7			
8			

GENERAL HOUSE INFORMATION

8. Approximate age of house ______________

9. Approximate area of the house (including basement) in square feet ___________

10. What is your water supply?

municipal ___ private well ___ other _________________

11. Describe the location of your house

urban ___ suburban ___ rural ___

12. Indicate soil type around house.

sand ____ wet clay ____ dry clay ____ loam ____ rock ____

13. Is your house sheltered from wind? Indicate those that apply.

front: _____ trees/hedges/fences/walls _________
distance from house (feet) _________

side: _____ trees/hedges/fences/walls _________
distance from house (feet) _________
other buildings _______________
distance from house (feet) _________

side: _____ trees/hedges/fences/walls _________
distance from house (feet) _________
other buildings _______________
distance from house (feet) _________

back: _____ trees/hedges/fences/walls _________
distance from house (feet) _________
other buildings _______________
distance from house (feet) _________

HEATING/VENTILATION SYSTEM INFORMATION

14. What type of heating system do you have?

Type	Primary	Secondary	Location	Vent Location		Notes
				ceiling	floor	
oil						
forced air gas						
electric - forced air						
electric - baseboard						
heat pump						
woodstove - fireplace						
other						

15. Indicate door type on woodstoves/fireplaces.

none ___ metal screen ___ glass ___ airtight glass ___ metal ___

airtight metal ___ other ____________________

16. What type of ventilation system do you have?

Type	Location	Location of Vents		Notes
		ceiling	floor	
windows only		n/a	n/a	
window fans		n/a	n/a	
room air conditioners		n/a	n/a	
central air				
heat pump				
air-to-air heat exchanger				
other				

17. Does furnace fan run continuously? __________________

ENERGY EFFICIENCY/SEALING

18. Describe the exterior of your home.

brick/stone ___ stucco ___ metal siding ___ vinyl siding ___ wood ___

other ____________________

19. Describe your windows.

Type	Number
all windows	
single pane	
double pane	
triple pane	
other	

20. Describe your exterior doors.

Type	Location e.g., front, back, side	Number
wood door only		
wood door + screen door		
insulated metal door only		
insulated metal door + screen door		
other		

21. Describe the insulation used in your home.

Type	Attic (thickness in inches)	Walls (thickness in inches)
air space		
batt		
styrafoam		
cellulose		
other		

22. How would you rate the thermal efficiency of your home?

poor (drafty) _____ average _____ good (few drafts, low heating costs) _____

BASEMENT INFORMATION

23. Describe the basement

foundation wall type ______________________________

foundation floor type ______________________________

finished yes ____ no ____

bedrooms yes ____ no ____ , apartment yes ____ no ____

sub-floor yes ____ no ____

24. How many floor drains ______

drain diameter(s) ______________________________

drain cover type(s) ______________________________

25. Provide the following for the sump:

sump dimensions (length, width, depth) ____________________

sump cover type ________________________

is sump normally wet ____ dry ____

26. Are there cracks in the foundation: walls _____ floor _____

27. Indicate support post type

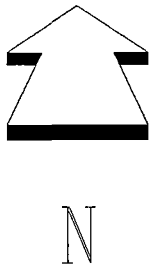
hollow metal post ____ metal beam ____ hollow block pillar ____

concrete pillar ____ brick pillar ____ wood pillar ____

28. Basement dimensions (in feet)

length ______ width _____ height _____

Please sketch details of your basement floor plan below. Include the location of any floor drains, sumps & sump pits, French drains, and any cracks in the floor.



BASEMENT FLOOR PLAN

Appendix III - *Calculations*

[redacted]

Radon Concentration

As discussed earlier, the electret ion chamber works by collecting radon gas and losing electrostatic potential in direct response to ions generated inside the chamber by the decay of radon and its radioactive daughters. The decrease in electrostatic potential was measured at LaFontaine Consulting Services and used to calculate the radon concentration according to the following equation (Rad Elec Inc. 1993):

$$C_{Rn} = (\Delta V/CF \times T) - BG$$

where:

C_{Rn} = average radon concentration in Bq/m^3

ΔV = electret voltage before exposure (V_i) - voltage after exposure (V_f)

CF = calibration factor in units of V per Bq/m^3 d

$= 0.04222 + 0.0000349 \times (V_i + V_f)/2$

[green labelled short-term electret in 210 ml S-chamber]

$= 0.04589 + 0.0000155 \times (V_i + V_f)/2$

[blue labelled short-term electret in 210 ml S-chamber]

$= 0.00064401 + 0.0000003027 \times (V_i + V_f)/2$

[red labelled long-term electret in 50 ml L-chamber]

T = exposure period in days (d)

= number of hours of exposure/24

BG = correction for environmental gamma radiation

(Gamma dose rate values for the Ontario communities studied, were derived from Environmental Health Directorate, 1988. The numbers used to calculate indoor radon concentrations were: a) northern Ontario [Dowling, Onaping, Timmins] = 0.07 μSv/h; b) central Ontario/upper Ottawa Valley [Bancroft, Deep River, Pembroke] = 0.08 μSv/h; c) Toronto/Hamilton vicinity [Hamilton, Richmond Hill, Waterdown, Willowdale] = 0.06 μSv/h; d) southwestern Ontario [Arthur, Cambridge, Glen Morris, Guelph, Kitchener, Mount Bridges, St. George, Stratford, Waterloo] = 0.07 μSv/h.)

= 321.9 Bq/m^3 equivalent per μSv/h gamma (Rad Elec Inc., 1993).