# Residential Indoor Radon Testing

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# Introduction

Radon is a known carcinogen, and is estimated to cause up to 10% of all lung cancers in Canada[1,2,3]. It is a radioactive gas that is produced by the decay of uranium. Radon is naturally occurring, and emanates from soil and rocks. It percolates up through soil into buildings, and if it is not evacuated there can be much higher exposure levels indoors than outdoors[4]. Fortunately, high radon levels can be easily tested for, allowing for mitigation. Health Canada's guideline for the acceptable level of indoor radon in a normal living area has recently been changed from 800 Bq/m$^3$ to 200 Bq/m$^3$.[5]

In order to evaluate the relative risk of radon exposure among residents of communities throughout the country, Health Canada has prepared a preliminary radon map of Canada[6]. This provides a spatial map of historical indoor radon levels across Canada, using health regions as the basic geographic unit.

# Mechanisms of radon entry into the home

As radon is a gas, it is able to diffuse through the soil and other materials around the foundation of a home. Homes tend to operate under a negative pressure, meaning that the air pressure inside the home is lower than the air pressure outside[7]. This negative pressure comes about from:

- The stack effect, by which the upward flow of warm air inside the home creates a positive pressure area at the top of the home and a negative pressure area at the bottom[7,8].
- A vacuum effect caused by air vented to the outside by exhaust fans, clothes dryers, etc.[7].
- A downwind draft effect, which is caused by wind blowing past a home[9,10,11].

This negative pressure differential tends to be strongest in basements and during the heating season[7]. It acts as a vacuum that pulls radon-rich air into the lower areas of the home through any dirt floor areas or unsealed sumps or cracks, fissures, or pores in the building materials[7]. Although numerous factors can influence the radon entry diffusion/convection mechanism (e.g. atmospheric pressure, indoor-outdoor-temperature differentials, humidity, rainfall, and atmospheric pressure) in homes having natural ventilation, the predominant factors influencing radon entry are the indoor-outdoor differential pressure and in some cases the wind velocity[9,10].

# Testing methods

As radon has no odour, colour, or taste, tests must be carried out to detect its presence and levels[12,13]. Testing homes and buildings for radon can be done to determine if levels are high enough that remediation should be carried out, or to ensure that they are low enough that it is not required. Testing is straightforward and inexpensive, costing approximately $50 to $100 per test[13]. Radon tests can be conducted using a do-it-yourself kit or by a professional. At present there is no Canadian certification program for radon testing companies, however Health Canada is currently working on developing such a program[14].

## *Types of detectors*

Radon is present in the atmosphere in extremely low quantities, and can only be detected by its radioactivity[15]. Three principal types of radon-testing devices are available for home testing:

- Passive alpha-track detectors contain a plastic sheet of film onto which the alpha particles produced from radon and radon progeny etch lines as they pass through the monitor. These etched lines are then analyzed in a laboratory and the radon concentration is quantified[16].

Most alpha-track detectors are only suitable for long-term (3-12 months) tests, however some detectors are available for short-term testing (7-10 days)[15,17].

- Activated charcoal canister detectors are filled with charcoal which adsorbs radon at a known rate. After exposure to air in the home for a specific period of time, it is sent to a laboratory that measures the gamma rays emitted by the adsorbed radon and progeny[16]. These are only suitable for short-term tests (2-7 days) due to radon having a radioactive half-life of only 3.8 days[15].
- Electret ion chambers contain a positively charged "electret" disc inside an electrically conducting plastic chamber. This is contained within a case that is designed to exclude radon daughter products already present in the environment being monitored[15]. These detectors use ionization for quantification by measurement of the overall decrease in electret charge resulting from radon-related ionization[16,17]. Electrets and their chambers are generally designed for short- (1-7 days) or longer-term (1-12 months) test periods[18]. Electrets respond to alpha radiation from radon and its decay products, as well as to natural background gamma radiation. Corrections for the latter contribution must be made[15,19,20].

    - In the case of the Rad Elec E-PERM model, background gamma levels are not separately measured, and estimates of these levels must be used in calculating radon levels[19]. Errors in the estimated levels used can cause significant errors in calculated radon levels[15,20].

    - The RTCA Ra-Dome model involves a dual chamber system. One chamber measures the discharge contribution of the radon, radon progeny, and gamma background, and the second chamber measures only the gamma background contribution. This allows for an accurate correction of the background gamma contribution, which is particularly important for long-term (12 month) tests[19].

In addition, low cost electronic continuous "digital radon detectors" are now available for purchase over the Internet. Field testing of these has been carried out[21], and the results were systematically higher than the true radon levels. Some detectors appeared to have their sensitivities significantly miscalibrated. For this type of monitor there is the potential for electromagnetic interference from other electronic devices in the dwelling to cause large errors in results.

Advantages and disadvantages of these types of detectors are summarized in Appendix A. A list of radon detector suppliers is given in Appendix B. Additional suppliers may be found in your community's Yellow Pages.

## *Temporality of indoor radon levels*

Seasonal variations in indoor radon levels have been consistently documented in radon surveys[22,23,24]. Tests conducted in the winter months tend to give higher results than the annual average, and conversely tests conducted in summer months produce lower results[22].

Diurnal patterns in outdoor[25] and indoor radon levels also occur[23,24,26,27], and are largely attributed to temperature and negative pressure changes within a dwelling. It is not unusual for radon levels to fluctuate by a factor of 2-3 over a 24-hour period[5].

Dwelling occupancy patterns influence radon levels. Canadian lifestyle patterns typically follow a 7-day pattern. Such lifestyles often result in cyclical weekly variations in indoor radon levels[15].

## *Weather factors influencing radon levels*

Numerous studies have found that meteorological factors can affect indoor radon levels. Outdoor temperature variations have been found to be the most important factor affecting both monthly and

3-day mean radon levels[28]. Storms involving marked drops in barometric pressure can significantly affect indoor radon levels during short-term (7 days) tests.

## *Test duration*

As outlined above, radon levels fluctuate on a daily, weekly, and annual basis. Radon levels are generally highest in the winter and in the late night/early morning hours. In order to capture the day-to-day variations and the average of seasonal variation, and to obtain an accurate representation of mean annual indoor radon levels, the optimum testing period is 12 months[23]. In considering if remediation should be carried out, only the results of such long-term tests should be relied upon.

However, under some circumstances, e.g. real estate transactions, evaluation of new homes built with radon reduction measures, or in geographic areas having low radon levels, short-term tests can be useful for screening purposes. Short-term controlled tests can only be used to give an indication of radon levels being very low, medium, or very high[29]. Owners need to be aware that in a significant percentage of cases the results of such short-term tests will be inconclusive[30], even when carried out under the controlled conditions described below. Therefore, all short-term tests should be followed up with 12-month tests for confirmation.

Short-term tests typically range from 48 hours to 3 months in duration, and long-term tests generally range from more than 3 months to 1 year.

- Short-term tests lasting 2 - 7 days can be conducted using charcoal canisters, short-term electrets[18,31], or short-term alpha-track detectors[15]. Those lasting from 1 week to 3 months can be done using long-term electrets[18], and alpha-track detectors can be used for tests lasting 3 months[18].
- Long-term tests can be conducted using alpha-track detectors or long-term electrets[18].

Although controlled tests have found charcoal canister, alpha-track, and electret detectors to all produce reasonably accurate short-term results, electret results have the greatest precision[17,32]. For 12-month tests, alpha-track detectors have been demonstrated to give acceptable results[33]. In the case of electrets, correction for background gamma radiation is required, and to allow long-term (12 months) tests to be accurate, this should be measured rather than just estimated[16,34].

## *Measurement device location and number of monitors*

As radon is denser than air, radon concentrations are consistently higher in basements than in upper level floors[22,35]. For this reason, measured levels are often a function of the test location. To provide test results that adequately represent radon levels in normal occupancy areas, which are any part of the home where a person is likely to spend several hours (4 or more) per day[36], tests should ideally be carried out in these locations. On average, the most time people spend in their dwelling is in their bedroom, at night[29], when indoor radon levels are also generally at their highest.

For a one-storey dwelling (e.g. bungalow), if the main living room and all bedrooms are on the main floor, then one monitor should be sufficient, unless significant time is also spent in some area of the basement. Monitor placement point(s) should then be the main bedroom, and if applicable the basement area used. For a two-storey dwelling where the bedrooms are on the second floor, one monitor location should be the main bedroom. A second monitor location should be the main living room or the lowest level normal occupancy area (e.g. a basement playroom or den)[29].

Monitors should be placed at a location away from dwelling occupants and should be left undisturbed during the testing period, but they should not be placed in small enclosed areas such as closets or cupboards.

The optimal location for detector placement is by an interior wall. Ideally, each detector should be placed at a height of 0.8 - 2.0 meters (3 - 6.5 feet) above the ground, in the general breathing zone. To allow normal airflow around the detector(s) they should be placed at least 20 inches (50 cm) above the ground and at least 8 inches (20 cm) below the ceiling[14].

Testing in the bathroom or kitchen should be avoided as humidity and temperature variations can interfere with monitor performance. To avoid fluctuations in temperature, monitors should not be placed within 3 feet (90 cm) of exterior doors or windows, or 1 foot (30 cm) of exterior walls having no windows[48]. Similarly they should not be placed near heaters, fireplaces, or in direct sunlight. Monitors should not be placed near fans or heating vents, as increased airflow can lead to misleading test results[14]. They should also not be placed on or near electronic devices such as stereos, speakers, computers, or televisions[37].

For short-term tests, only one monitor is needed at each monitor location (if more than one). For 12-month testing using electrets, it is recommended that two be placed side-by-side at each testing location[38]. This is because electrets can accidentally discharge if not handled properly. Using two detectors at each location could avoid having to repeat a 12-month test, if something were to go wrong.

### *Controlled short-term measurement conditions*

Short-term testing carried out following the controlled conditions described below can be used as a preliminary screen when time constraints prevent long-term testing. The controlled conditions are designed to elevate the indoor radon to its highest levels. Thus, if a short-term test is carried out under such conditions and the results show levels to be well below 200 $Bq/m^3$, it is likely that the mean annual average indoor radon level is below the 200 $Bq/m^3$ acceptable level. Regardless, a 12-month test should be subsequently carried out for confirmation.

Short-term testing should be conducted from October through April, when homes are closed up, indoor heating is in use, and radon levels are likely at their highest. The dwelling should also be occupied during the testing period. All of this is done to allow a conservative estimate of the annual average radon levels.

As there are significant diurnal as well as weekly patterns in radon levels, short-term measurements of radon levels should ideally be carried out for time periods that are multiples of 24 hours and 7 days (e.g. a short-term test should be carried out for a minimum of 7 days and the total test length should be 168 ± 2 hours)[15,39]. A somewhat longer test could be carried out for 28 days (vs. 30 days or “one month”).

For tests lasting 7 days, closed-building conditions (other than normal use of doors for entrance and exit) should commence 12 hours before testing begins, and continue throughout the length of testing. Fans or other machines that bring in air from outside should not be used. Heating and air-conditioning system fans that re-circulate indoor air may be operated. Fans that are part of a radon-reduction system should be run during the test[37].

Short-term testing lasting 7 days should not commence during or just before forecast extreme weather conditions (e.g. severe storms with high winds or rapid changes in barometric pressure).

Once testing is complete, detectors can be sent back to the supplier for analysis. Expedited delivery methods should be used to ensure that the test results can be measured within the required time frame. In the case of electrets, the professional (or homeowner) carrying out the testing will usually measure both the start and end of test voltages on-site.

# Interpreting radon test results

## *Weighted average results*

If more than one detector was used, the combined results need to be considered. As more time is generally spent in the bedroom (at night, when radon levels are at their diurnal maximum), this measure is given greater weight. The weighted average indoor radon level can be calculated by applying a weight of 0.55 to the bedroom reading and 0.45 to the main living (or other) area reading, as is done in the UK National Radiological Protection Board (NRPB) protocol[15].

If the weighted average of long-term (12 months) test result(s) is above 200 $Bq/m^3$, homeowners should consider remediation.

# Summary

- Long-term radon testing over the course of 12 months provides the most accurate estimate of average annual indoor radon levels.
    - Alpha-track or electret detectors are recommended for such long-term tests.
- Short-term testing can be used for preliminary crude screening of the effectiveness of radon remediation/prevention work already undertaken, or of the possible need for remediation of real estate being purchased.
    - Regardless, long-term testing should be subsequently carried out for confirmation.

## Useful resources

A. Health Canada. It's your health. Radon. [Online]. 2007 Jun 08 [cited 2008 Jun 30]; Available from: URL: http://www.hc-sc.gc.ca/iyh-vsv/environ/radon_e.html

B. BC Centre for Disease Control. Radon – Why the concern? [Online]. 2007 Sep 26 [cited 2008 Jun 30]; Available from: URL: http://www.bccdc.org/content.php?item=69

C. Canada Mortgage and Housing Corporation (CMHC) and Health Canada. Radon: a guide for Canadian homeowners. [Online]. 2007 [cited 2008 Jun 30]; Available from: URL: https://www03.cmhc-schl.gc.ca/b2c/b2c/init.do?language=en&shop=Z01EN&areaID=0000000016&productID=00000000160000000036

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## Appendix A: Advantages and disadvantages of the principal types of passive radon detectors[16]

| | Electret Chambers | Passive Alpha-Track Detectors | Digital Radon Detectors[21,40] | Activated Charcoal Canisters |
|---|---|---|---|---|
| Test duration | - Various models are available that are suitable for ranges of 2 days to 12 months (or more) | - Models are available for long-term testing (3 to 12 months or more) and for short-term (10 days)[15] | - Single model can be used for short-term (7 days average) or long-term (up to 5 years) tests | - 2 to 7 days |
| Advantages | - Detectors give a true integrated measure of exposure[18]<br><br>- For short-term (3 to 4 days) tests, electret chambers have recently been found to give more accurate and precise results than active charcoal canisters[31]<br><br>- Electrets are reported to be insensitive to temperature[42]<br><br>- Detector voltage can be measured at the start and end of the test period by an independent testing company<br><br>- Electret detectors may be reused a number of times 10-25)[20,44], before requiring a recharge | - Low cost<br><br>- Detectors give a true integrated measure of exposure[18]<br><br>- Detectors are not sensitive to background beta or gamma radiation, so no correction factor is required for these[15,16]<br><br>- Most detectors do not appear to be affected by normal indoor temperature and humidity ranges[43] | - Low cost<br><br>- Two display options: short-term average reading or long-term average reading<br><br>- Audible alarm sounds if either the short-term average or long-term average reading exceeds 4 pCi/L (148 Bq/$m^3$) | - Low cost<br><br>- Suitable for short-term screening texts under controlled conditions |

| | Electret Chambers | Passive Alpha-Track Detectors | Digital Radon Detectors[21,40] | Activated Charcoal Canisters |
|---|---|---|---|---|
| Disadvantages | - Detectors respond to natural background gamma radiation, and correction for this is required<br><br>- Detectors may be accidentally discharged if dropped or handled improperly; this translates into a falsely elevated radon level reading[16,19,41]<br><br>- Electrets have been reported to be sensitive to humidity[42], but recent studies have conflicted with this[20,46], so the role of humidity and electrets is currently unclear<br><br>- Results require correction for the altitude at which testing took place[47] | - Detectors must be sent to a laboratory for analysis<br><br>- Prompt analysis is required, within 7 days of end of test<br><br>- Results require correction for the altitude at which testing took place (due to the increase in alpha particle range with increasing altitude)<br><br>- When detectors are used for periods of longer than 3 months, aging can reduce sensitivity; for 12-month tests this has been measured to be by 23%; sensitivity corrections are thus required for tests longer than 3 months[30] | - The detector must be plugged into a 120VAC power outlet<br><br>- Display reports radon levels in pCi/L not Bq/m$^3$<br><br>- Detectors should not be placed on granite, metal, or slate surfaces[40]<br><br>- Detectors must be kept free of dust to ensure air vents are not blocked[40]<br><br>- Field testing has recently been carried out[21], and the results were systematically higher than the true radon levels; some monitors appeared to have their sensitivities significantly miscalibrated<br><br>- For this type of monitor there is the potential for electromagnetic interference from other electronic devices in the dwelling to cause large errors in results[21]<br><br>- Detectors should not be placed near computers, televisions, or any other electronic equipment[40] | - Detectors are only useful for short-term tests, which provide less reliable results than long-term tests; maximum time of use is only 7 days, as radon has a radioactive half-life of 3.8 days[29]<br><br>- Detectors must be sent to a laboratory for analysis<br><br>- Prompt analysis is required, no more than 7 days after end of test<br><br>- Detectors are sensitive to temperature and humidity[45]<br><br>- Due to the adsorption/desorption process that occurs after adsorption, these detectors do not provide a true integration of the exposure[43]<br><br>- Due to the radon decay that occurs after adsorption (half-life 3.8 days), the weight of the final 4 days of exposure is much larger than the weight of any earlier days[15]; also, because of this decay, analysis at the end of the test period must be carried out within 7 days, but ideally it should be sooner (e.g. 2 days)<br><br>- Airborne particulates from cooking or from smoke can interfere with measurements[15] |

## Appendix B: Radon detector suppliers in Canada and the United States

### Canadian Companies

**Bubble Technology Industries**
Radiation Services Div
Hwy 17, PO Box 100
Chalk River, ON KOJ 1J0
Tel: 613-589-2456
Fax: 613-589-2763
Email: services@bubbletech.ca
Website: http://www.bubbletech.ca/
Cost: $49.95 (plus GST/S&H)

**Canadian Radon Testing Products Inc**
Grant MacDonald
639 Burning Bush Rd
Waterloo, ON N2V 2C4
Tel: 866-461-3999
Email: sales@canadianradontesting.com
WebSite: http://www.canadianradontesting.com

**Fine Homes Design**
Peter Chataway (Mitigation Consultant)
368 Cadder Ave
Kelowna, BC V1Y 5N1
Tel: 250-763-1334
Fax: 250-763-1334
Cost: $45.00 (plus GST/S&H) - also includes information package

**LEX Scientific Inc**
Saul Bravo
204-2 Quebec St
Guelph, ON N1H 2T3
Tel: 519-824-7082
Fax: 519-824-5784
Email: admin@lexscientific.com
Website: http://www.lexscientific.com

**Lynch Building Inspection Service**
Nelson Office:
803 Silica St
Nelson, BC V1L 4N5
Tel: 250-352-2300
Toll Free: 1-877-352-2300
Fax: 250-352-2309
Email: steve@lynchinspection.com
Castlegar/Trail Office:
940 Columbia Rd
Castlegar, BC V1N 4K5
Tel/Fax: 250-359-8044
Email: bill@lynchinspection.com

**PRO-LAB®, Inc**
40 Hanlan Rd, Unit 45
Vaughan ON  L4L 3P6
Toll Free: 1.800.427.0550
Tel: 905.663.7036
Email: info@prolabinc.com
WebSite: http://www.prolabinc.com/products.asp?kit=radongas

Radon Test Kits from this company are available in Home Depot, Wal-Mart, Zeller's, Office Depot, TSC Stores, Home Hardware, Lowes, Canadian Tire Corp, and Rona.
Cost - $9.99 + taxes for short-term at all stores listed (plus $30.00 analysis fee when you mail the detectors into PRO-LAB).

## US Companies

**Home Radon Test**
77 West Broad St
Bethlehem, PA 18018
Tel: 610-868-2642
Email: info@homeradontest.com
Website: http://www.homeradontest.com/
Cost: $29.99 US LT 100 (long-term single detector)

**Landauer Corporate Office**
2 Science Rd
Glenwood, IL 60425-1586
Tel: 708-755-7000
Toll Free: 1-800-323-8830
Fax: 708-755-7016
Email: custserv@landauerinc.com
Website: http://www.landauerinc.com
Cost: $24.95 US (plus taxes/S&H)

**PRO-LAB®, Inc.**
1675 N. Commerce Pkwy
Weston, FL 33326
info@prolabinc.com
http://www.prolabinc.com/products.asp?kit=radongas
Tel: 954-384-4446
Toll Free: 1-800-427-0550

Radon test kits from this company also available at US stores including: Home Depot, Lowe's, Menards, Ace Hardware, True Value, Do It Best, Kroger, Fred Meyer, Giant Eagle, and CVS.
Cost: $10 + tax for short-term test at most stores listed (plus $30 analysis fee when you mail the detectors into Pro-Lab) or $35 + tax for long-term radon test (includes analysis).

**Sun Nuclear Corporation**
425-A Pineda Court
Melbourne, FL 32940
Tel: 1+ 321 259-6862
Fax: 1+ 321 259-7979
Web: www.sunnuclear.com
Starting cost for a continuous radon detector: $595.00 US

Note: All prices shown are approximate and subject to change. Contact the businesses directly to receive current prices.

If you have information about other suppliers that you would like us to include in our list, please contact us at http://www.ncceh.ca/en/contact_us.

The National Collaborating Centre for Environmental Health includes this list of suppliers for information only, and neither endorses the products nor accepts any responsibility for them.

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