

Health Canada

Protocols for Radon Measurements in Dwellings

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Section 1: Introduction

1.1 Scope and Summary

The intended audience for this document includes radon* survey planners and persons who intend to carry out radon measurements to identify dwellings for remedial action against radon. The scope is limited to guidance regarding measurement device placement, measurement duration, multiple measurements, and the interpretation of measurement results.

Section 1 of this document provides an overview of the Canadian Radon Guideline.

Section 2 of this document provides protocols for initial radon concentration measurements in dwellings intended to guide decisions on the need for remedial actions to reduce the radon concentration.

Section 3 of this document provides protocols for measuring radon for a real-estate transaction. These protocols were developed to deal with the time-sensitive nature of home sales and purchases, while still assuring the buyer that the measurement of radon concentrations in the building is valid.

Section 4 of this document provides general guidance on the implementation of these protocols and on the quality assurance planning needed to produce valid measurements.

1.2 Radon Guideline

The following guideline was adopted by the Federal-Provincial-Territorial Radiation Protection Committee on October 26, 2006:

“Remedial measures should be undertaken in a dwelling whenever the average annual radon concentration exceeds 200 Bq/m³ in the normal occupancy area.

The higher the radon concentration, the sooner remedial measures should be undertaken.

When remedial action is taken, the radon level should be reduced to a value as low as practicable.

The construction of new dwellings should employ techniques that will minimize radon entry and will facilitate post-construction radon removal, should this subsequently prove necessary.”

* The term "radon" refers to both Radon-222 and its decay products unless otherwise noted.

1.3 Measurement Duration

1.3.1 Long-term Measurements

Long-term measurements can range from 91 to 365 days (typically 3 to 6 months) to provide seasonal average radon concentration estimates. Once the measurement devices are installed, there are no requirements for the occupants to change their life-style during the measurement.

1.3.2 Short-term Measurements

Short-term measurements can range from 2 to 90 days but are typically 2 to 7 days. They are made under closed-building conditions to stabilize the radon concentrations and increase the validity of the annual radon concentration estimate. Closed-building conditions generally prevail during the cold season from October to April when the average daily temperature is low enough that windows are kept closed. In some houses, the most stable radon levels occur during late fall and early spring, when windows are kept closed but the house heating system (which causes some ventilation and circulation) is not used.

To provide closed-building conditions outside the cold season, the occupants may have to change their life-style for the duration of the measurement.

1.4 Measurement Locations

To provide a realistic estimate of the radon exposure of the occupants, all measurements should be made in the normal occupancy area of the lowest lived-in level of the dwelling.

Potential measurement locations for both long and short-term measurements include family rooms, living rooms, dens, playrooms and bedrooms. A lower level bedroom is preferred because people generally spend more time in their bedrooms than in any other room in the house. Similarly, if there are children in the home, lowest level bedrooms or other areas such as a playroom are preferred.

- The preferred device location is by an interior wall at least 50 cm from the floor and at least 10 cm from other objects. The optimal height is in the breathing zone – 0.8 to 2 metres from the floor.
- Measurements should not be made in kitchens or laundry rooms. Kitchen exhaust fan systems and airborne particles (caused by cooking) may affect some measurement devices.
- Measurements should not be made in bathrooms because relatively little time is spent in a bathroom, high humidity may affect some measurement devices, and use of an exhaust fan may temporarily alter radon concentrations.
- Measurements should not be made in closets, cupboards, sumps, crawl spaces or nooks within the foundation. Radon concentrations in these areas are not representative of the concentration in the occupied area of the house.

The location should not be in air currents caused by heating, ventilating and air conditioning vents, doors, fans and windows. Locations near heat, such as over radiators,

near fireplaces or in direct sunlight, should be avoided as some measurement devices may be affected.

1.5 Measurement Strategy

1.5.1 Initial Measurement

An initial measurement is required to determine whether the average radon concentration in a dwelling is high enough to justify additional measurements or remedial measures. It is common to see radon levels in a single house change by a factor of 2 to 3 over a one-day period, and variations from season to season can be even larger. The highest levels are usually during winter. A long-term measurement period will give a much better indication of the annual average radon concentration than measurements of shorter duration. For this reason, Health Canada recommends that the initial radon measurement in a dwelling be a long-term measurement. If the result is greater than 200 Bq/m³, then remedial action is recommended within the time frame suggested in the Guideline.

In some cases, however, a more rapid answer may be required, either as a screening measurement to confirm that radon levels are low or to decide on the need for further measurements. In these cases, short-term measurements lasting only a few days may provide sufficient information. The measurement conditions should be chosen to maximize the radon concentration (closed-building conditions). Wherever possible, short-term measurements should be made during the cold season (i.e. October to April) when radon levels are generally the highest.

1.5.2 Closed-building Conditions for Short-term Measurements

Closed-building conditions include:

- Windows on all levels and external doors should be kept closed, except during normal entry and exit, during the measurement period. Normal entry and exit include a brief opening and closing of a door, but external doors should not be left open for more than a few minutes.
- External-internal air exchange systems such as high-volume, whole-house and window fans should not be operated. However, attic fans intended to control attic temperature or humidity may be operated. Combustion or furnace makeup air supplies must not be closed.
- Normal operation of permanently installed energy recovery ventilators (also known as heat recovery ventilators or air-to-air heat exchangers) may continue during closed-building conditions. In houses where permanent radon mitigation systems have been installed, these systems should be functioning during the measurement period.
- Air conditioning systems that recycle interior air can be operated during the closed-building conditions.

In addition to maintaining closed-building conditions during the measurement, closed-building conditions are required for 12 hours prior to the start of the measurement for measurements lasting less than four days, and are recommended prior to measurements

lasting up to a week. When closed-building conditions are not the normal living conditions, the measurement conditions must be maintained rigorously to ensure the validity of the short-term measurement.

Short-term measurements lasting less than three days should not be conducted during severe storms or periods of unusually high winds. The rapid changes in barometric pressure associated with storms increase the chance of a large difference in the building interior and exterior air pressures, thus changing the rate of radon influx. A high wind increases the variability of radon concentration because of wind-induced differences in air pressure between the building interior and exterior. In either case, the radon concentration during the measurement may not be representative of the average concentration in the building. Weather predictions available on local news stations provide sufficient information to determine if these conditions are likely.

1.6 Interpretation of Initial Measurement Results

1.6.1 Long-term Measurements

If the long-term measurement result is below 200 Bq/m^3 , the average annual concentration in the dwelling is probably below 200 Bq/m^3 and further measurements are not necessary.

If the long-term measurement result is greater than 200 Bq/m^3 , then the average annual concentration in the dwelling is probably above 200 Bq/m^3 and remedial action is recommended.

1.6.2 Short-term Measurements

Since radon concentrations vary over time, it is suggested that the result of any short-term measurement be confirmed with a “follow-up” long-term measurement. The follow-up measurement should be made at the same location as the initial measurement.

If the initial short-term measurement result is below 200 Bq/m^3 , the average annual concentration in the dwelling is probably below 200 Bq/m^3 . However, since radon levels change over time, the homeowner may wish to confirm this with a long-term measurement.

If the initial short-term measurement result is greater than 200 Bq/m^3 , the average annual concentration may be above 200 Bq/m^3 , and a follow-up measurement with a long-term method is recommended.

If the initial short-term measurement is greater than 600 Bq/m^3 , the follow-up measurement may be made with a short-term method.

1.7 Interpretation of Follow-up Measurement Results

A single short-term measurement is not sufficient to base a decision to mitigate. A follow-up measurement is always necessary for mitigation decision-making regardless of the initial measurement result.

If the result of the long-term follow-up measurement is less than 200 Bq/m^3 , then remedial action is not necessary.

If the result of the long-term follow-up measurement is greater than 200 Bq/m³, then remedial action is recommended.

If a second short-term follow-up measurement result is greater than 200 Bq/m³, then remedial action is recommended.

1.8 Measurements in Public Buildings

Buildings with a high occupancy of long duration by the public, such as hospitals, long-term care residences, correctional facilities, schools and daycare centres are “public buildings” and the Radon Guideline applies.

Buildings where the occupants are employees are “workplaces”, and the exposure to radon is governed by the Canadian Guidelines for Management of Naturally Occurring Radioactive Materials (NORM).

Measurements in public buildings provide a different set of challenges from dwellings. Hospitals, long-term care residences and correctional facilities are occupied continually, and so a long-term measurement will give a good estimate of the radon exposure of the occupants. Schools and daycare centres are occupied only during the day, five days a week, and so require specific guidance.

Health Canada recommends that the initial radon measurement in a public building be a long-term measurement. If the result is greater than 200 Bq/m³, then remedial action is recommended within the time frame suggested in the Guideline.

In some cases, however, a more rapid answer may be required to decide on the need for further measurements. In these cases, short-term measurements lasting only a few days may provide sufficient information. Wherever possible, these short-term measurements should be made during the cold season (i.e. October to April) when radon levels are generally the highest.

1.8.1 Measurement Location in Public Buildings

Public buildings differ from houses in that the occupants are not involved in the measurement process. The choice of the measurement device location is constrained by the need for security so that the devices are not readily accessible by curious occupants. The buildings usually contain many rooms. (A room is the space enclosed by walls that reach the ceiling. A room subdivided by partitions can be treated as one room.)

To provide a defensible radon concentration estimate for the building, measurements should be made in the lowest-level occupied rooms of the building, preferably at the same time. If there are more than 25 rooms, the additional measurements can be made at the rate of one measurement per 200 m² floor area.

The device location should be selected so that there is a reasonable expectation that it will not be disturbed during the measurement period.

- The preferred device location is by an interior wall at a height above the reach of most people – 2.5 to 3 m from the floor.
- Measurements should not be made in bathrooms because relatively little time is spent in a bathroom.

- Measurements should not be made in closets, cupboards, sumps, crawl spaces, or nooks within the foundation. Radon concentrations in these areas are not representative of the concentration in the occupied area of the building.
- The device location should not be in air currents caused by heating, ventilating and air conditioning vents, doors, fans and windows. Locations near heat, such as over radiators, near fireplaces or in direct sunlight, should be avoided as some measurement devices may be affected.
- Measurements during the warm weather in buildings without central air conditioning are likely to give misleading results due to the very high likelihood that windows will be open during the measurement period.

1.8.2 Interpretation of Measurement Results in Public Buildings

2.6.2.1 Long-term Measurements

If the result of a long-term measurement in part of a public building is greater than 200 Bq/m³, then remedial action is recommended for that part within the time frame suggested in the Guideline.

2.6.2.2 Short-term Measurements

If the result of a short-term measurement in part of a public building is greater than 200 Bq/m³, a follow-up measurement with a long-term method is recommended. The follow-up measurement should be made at the same location as the initial measurement.

If the result of a short-term measurement in part of a public building is greater than 600 Bq/m³, the follow-up measurement may be made with a short-term method. The follow-up measurement should be made at the same location as the initial measurement.

If the result of a follow-up measurement in part of a public building is greater than 200 Bq/m³, then remedial action is recommended for that part within the time frame suggested in the Guideline.

1.9 Measurements in Schools and Daycare Centres

Schools and daycare centres are occupied only during the day, five days a week, and the heating and ventilation systems often operate differently when the school is not occupied. As this may affect the radon concentration, a representative estimate of student exposure requires measurements to be made only while the school is in session.

1.9.1 Measurement Location in Schools and Daycare Centres

To provide a defensible radon concentration estimate for the school, measurements should be made in the lowest-level occupied classrooms of the building, preferably at the same time. If there are more than 25 classrooms in this category, the additional measurements can be made at the rate of one measurement per 200 m² floor area.

The device location should be selected so that there is a reasonable expectation that it will not be disturbed during the measurement period.

- The preferred device location is by an interior wall at a height above the reach of most pupils – 2 to 3 m from the floor.
- Measurements should not be made in bathrooms, closets, cupboards, sumps, crawl spaces, or nooks within the foundation. Radon concentrations in these areas are not representative of the concentration in the occupied area of the building.
- The location should not be in air currents caused by heating, ventilating and air conditioning vents, doors, fans and windows. Locations near heat, such as over radiators, near fireplaces or in direct sunlight, should be avoided as some measurement devices may be affected.

Because of the cyclic occupancy of the building, a short-term measurement of 2 to 5 days during the cold weather months of October through April is suggested. The measurement should take place during the five days while the school is in session.

The short-term measurements should be done with the HVAC system operating at normal weekday settings, with the usual setback periods and with the building closed, except for normal entry and exit, starting at least 12 hours before the beginning of the measurement.

To ensure valid results, it is important that doors and windows be kept closed except for normal exit and entry. This minimizes the unpredictable impact on radon levels caused by air currents and air pressure changes from outside weather conditions.

To ensure cooperation of teachers and staff in maintaining closed-building conditions, it is recommended that the school principal talk to staff personally about the importance of keeping doors and windows closed during the measurement.

Measurements that include weekends or holidays may not provide results that reflect the exposure of pupils and teachers for the HVAC may operate differently on weekends, repair work may be in progress, and so forth. All these conditions can affect radon levels.

Measurements during the warm weather, in buildings without central air conditioning, is likely to give misleading results due to the very high likelihood that windows will be open during the measurement period.

1.9.2 Follow-up Measurements

It is expected that follow-up measurements will be made in the rooms with the highest measurements with an active continuous radon monitor that has the capability to integrate and record a new result at least hourly. This will indicate if the measured radon concentration is a realistic estimate of the concentration while the pupils are present.

1.9.3 Interpretation of School Measurement Results

If the result of these measurements in part of a school shows that the average radon concentration while occupied is greater than 200 Bq/m^3 , then remedial action is recommended for that part within the time frame suggested in the Guideline.

Section 2: Measurements for Real-Estate Transactions

2.1 Introduction

In areas of known high radon concentrations in dwellings, potential buyers (and their financiers) seek assurance that the dwelling has low radon concentrations, either naturally or because remedial work has been carried out. These real-estate transactions are expected to generate a significant proportion of radon measurements. As both buyer and seller hope to proceed expeditiously, the time constraints present radon measurement issues not encountered in the owner measurements discussed in Section 2.

These real-estate transaction protocols have been developed specifically to deal with the time-sensitive nature of home purchases and sales. They are intended to provide buyers, sellers, real-estate agents and measurement organizations with a common basis of understanding of the procedures for radon measurements and interpretation of the results.

If the dwelling has been measured for radon according to the protocols in Section 2, in advance of putting it on the market, the buyer may accept that result. However, many buyers will request an independent radon measurement. (Some home inspection companies may offer a radon measurement as part of a pre-purchase inspection package.)

As the owner may feel it advantageous that the measured radon concentrations in the dwelling are low, the faith that the purchaser may have in the measurement is highly dependent upon the assurance that the measurements are valid by methods to detect interference with the measurement device or the house conditions, plus quality control activities on the radon measurement devices.

2.1.1 Measurement Location for Real-Estate Transactions

Measurements made for a real-estate transaction should be performed in the lowest level of the dwelling that is suitable for occupancy. This includes a lower level that is not currently used, such as an unfinished basement that could be converted into a recreation room, bedroom, or playroom.

In the absence of a basement, potential measurement locations include lower level family rooms, living rooms, dens, playrooms, and bedrooms.

- A location should be selected where the device will not be disturbed during the measurement period.
- Measurements should not be made in kitchens, laundry rooms, or bathrooms.
- Measurements should not be made in closets, cupboards, sumps, crawl spaces, or nooks within the foundation. Radon concentrations in these areas are not representative of the concentration in the occupied area of the house.
- The preferred device location is by an interior wall at least 50 cm from the floor and at least 10 cm from other objects. The optimal height is in the breathing zone – 0.8 to 2 metres from the floor.
- The location should not be in air currents caused by heating, ventilating and air conditioning vents, doors, fans and windows. Locations near heat, such as over

radiators, near fireplaces or in direct sunlight, should be avoided as some measurement devices may be affected.

In the case of newly constructed and unoccupied dwellings, the radon measurement should be carried out after the following have been installed:

- all insulation,
- all exterior doors and hardware,
- all windows,
- fireplaces and fireplace dampers,
- all heating/cooling appliances (functioning and set to run at normal occupied temperatures),
- all ceiling coverings,
- all interior trim and coverings for exterior walls,
- all exterior siding, weatherproofing and caulking.

Structural openings to the exterior as a result of incomplete construction, structural defect, disrepair, or the like must be closed or repaired 12 hours prior to initiating a short-term measurement.

2.2 Options for Real-Estate Measurements

Based on US experience, two short-term measurement options are satisfactory and are described here. The availability of two options allows flexibility for the party carrying out the measurement. Each of these options will produce results that can be used to determine the need for remedial action.

2.2.1 Option 1: Passive Device Measurement

This option involves the use of two simultaneous 48 hour short-term measurements conducted with the same type of device placed side-by-side (<10 cm apart). The measurements are carried out under closed-building conditions as described in Section 2. If a radon reduction system is in place, make sure the system is in operation during the entire radon measurement. The same type of measurement device should be used for each measurement. Using different devices for the two measurements may increase the potential for differences between the two results.

2.2.1.1 Interpretation of Passive Device Measurement Results

Because radon measurements, like any measurements, usually do not produce identical results, there will usually be a difference between the two results. So that clients may have confidence in the results:

- If the higher result is twice or more than the lower result, then a re-measurement should be conducted.
- If the higher result is between 1.5 to 2 times greater than the lower result, a re-measurement is not necessary, but the source of the variability should be

investigated. The results of both measurements and the average of the two results should be reported to the client.

Both measurement results and the average result should be reported to the client. The results of the simultaneous measurements will fall into one of the two categories discussed below:

- Average of the two measurements is less than 200 Bq/m³ - remedial action is not necessary.
- Average of the two measurements is more than 200 Bq/m³ - remedial action is recommended within the time frame suggested in the Guideline.

2.2.2 Option 2: Active Device Measurement

This option requires an active continuous radon monitor that has the capability to integrate and record a new result hourly. The measurement is carried out under closed-building conditions as described in Section 2. If a radon reduction system is in place, make sure the system is in operation during the entire radon measurement. The minimum measurement period is 48 hours.

The first four hours of data from the continuous monitor may be discarded to allow for the monitor coming to equilibrium with its surroundings. There must be at least 44 consecutive hours of usable data to produce a valid average. The hourly results are averaged to produce the result that is reported to the client.

The approaches to increase the confidence in results obtained with active monitor devices include the use of device self-diagnostic features and data validation or verification procedures, such as check sources before and after each measurement, and use of spectrum readouts. Other features include (but are not limited to) the ability to check airflow rates and voltages before and after each measurement. Measurement companies should incorporate such checks into their routine instrument performance checks as part of their standard operating procedures.

Additional features that can increase confidence in measurement results are those that detect measurement interference; these features are discussed in Section 2.2.3 Measurement Interference. For example, a device that offers a variety of ways to detect tampering may deter, as well as detect, interference with the device's operation or proper closed-building measurement conditions. Potential tampering indicators include the ability of a device to record changes in temperature, humidity, or movement of or around the device during the measurement.

The reliability of any type of equipment, however, needs to be established and documented via a complete quality assurance program. This includes routine instrument performance checks prior to and after each measurement, annual calibrations, semi-annual instrument cross-checks, and frequent background and spiked measurements.

2.2.2.1 Interpretation of Active Device Measurement Results

Both the hour-by-hour measurement results and the average result over the effective measurement period should be reported to the client.

If the average is less than 200 Bq/m³ - remedial action is not necessary.

If the average is more than 200 Bq/m³ - remedial action is recommended within the time frame suggested in the Guideline.

2.2.3 Measurement Interference

The owner of a dwelling may have an interest in the measurement results being low to avoid hindering the sale of the dwelling, or incurring the added expense of having to install a mitigation system. The potential for measurement interference puts the professional radon measurer into the position of verifying that the equipment and the required measurement conditions have been maintained. A measurement result below the action guideline may be suspect if the measurer cannot verify that the necessary measurement conditions were maintained.

Interference with a radon measurement is defined as the altering of measurement conditions prior to or during the measurement to either change the radon or decay product concentrations in the measurement area, or to alter the performance of the measurement equipment with the intent of producing a low result. The following discussion reviews some of the types of measurement interferences and methods of detecting and preventing such interferences.

2.2.3.1 Influencing Measurement Area Concentration

The primary method of temporarily reducing radon levels is to ventilate the measurement area with outdoor air. Ventilation will slow down radon entry by reducing negative pressure in the measurement area and by diluting the radon concentration. Even small openings of a single window in the measurement area can have a large effect. Ventilating the floors above the measurement area has significantly less effect, unless the measurement area is connected with the ventilated room by an operating central air handling system.

2.2.3.2 Equipment Interference

The primary method of interfering with measurement equipment is to move the device to an area of low radon concentration. However, interfering with air sampling mechanisms of active monitors can maintain the radon concentration at the time of interference, or cause a large decrease in the reported concentration.

A passive detector could be turned off or sealed in its radon-proof transport container during most of its exposure period. Just covering a passive detector could cause the reported values to be much less than the true value. In addition, some passive detectors will read low under conditions of high heat or humidity.

2.2.4 Preventing Interference

Radon measurements conducted for a real-estate transaction must be performed using tamper-resistant measurement techniques. It is more advantageous for the measurer to take steps to prevent interference rather than to simply detect it.

Preventing interference can best be accomplished by:

- Educating the parties to a real-estate transaction about the necessary measurement conditions.

- Including in standard documentation for each measurement an agreement signed by the parties involved in the real-estate transaction listing the necessary measurement conditions and their agreement not to interfere with the conditions.
- The agreement should also state that the measurer may nullify the measurement results at their discretion if they believe the devices were interfered with.
- Informing the client that interference with the measurement conditions may increase the radon levels.
- Informing the client that interference-detecting techniques are in use and allow the documentation of the interference with a measurement.

Common equipment and techniques for detecting measurement interference and tampering are listed below:

- The ability to integrate and record radon measurements over intervals of an hour or less is an important tamper-detection feature. These monitors can indicate unusual concentration changes that can be indicators of measurement interference.
- Measuring other parameters that may provide additional indicators of equipment interference, such as a detector tilt or motion indicator, or a continuous recording of pump flow rate. Cages for passive monitors can be equipped with a movement indicator to deter handling.
- Measurement of CO₂ levels can indicate changes in the measurement area infiltration rate of outdoor air.
- Temperature and humidity readings may indicate changes in the infiltration rate of outdoor air.
- Instruments that do not allow occupants to view preliminary results (via a visible printer or screen) may reduce the incentive for interference.

Seals can aid in detecting and discouraging measurement interference and are especially important in the absence of other tamper-detection. It is advisable to use seals manufactured specifically for radon measurement and follow the manufacturer's installation instructions.

Seals can be placed between the detector and its support to verify that detectors have not been moved, or the detector has not been opened.

Seals should be placed on the lowest operable windows and non-primary exterior doors. A seal may be placed on the furnace control fan switch and on the thermostat.

Upon retrieval of the detector, the measurer should carefully inspect and record the following:

- Closed-building conditions are still being maintained;
- Changes in the detector placement;
- The condition of all seals; and
- Any abnormal variations in any of the measurements made.

Section 3: General Procedural Recommendations

This section outlines basic procedural recommendations for real-estate and non real-estate related radon measurements in homes.

3.1 Real-Estate Measurements

Section 3 provides protocols for real-estate measurements.

3.1.1 Initial Client Interview

Reasonable efforts should be made to determine whether the home is new or occupied, and who will be in charge of the home during the measurement period. Organizations that provide measurement services, or place or retrieve devices, should review the protocol options and the clients' needs, and inform clients of the buildings and measurement conditions necessary for conducting valid measurements. These organizations should use only those devices or methods for which they are proficient.

Measurement organizations should inform the client and other parties of the real-estate transaction of:

- The appropriate measurement recommendations as outlined in this document.
- The types of devices they will be using for the measurement.
- A statement of whether the device measures radon or radon decay products.

The results of radon decay product measurements should be reported in working levels (WL). The WL value should be converted to an equivalent radon concentration in the unit of Bq/m³ for comparison with the Radon Guideline using a 50% equilibrium ratio (unless the device measures the actual equilibrium ratio).

- Specific information on the minimum and maximum duration of exposure for the device.
- A description of closed-building conditions and a stated requirement that these conditions must be maintained 12 hours prior to and during all short-term measurements.
- Directions that the building's heating, ventilating, and air conditioning (HVAC) system and any existing mitigation system should be normally operated 24 hours prior to and during all measurements.
- A permanent radon reduction system should be fully operational for at least 24 hours prior to measurement to determine the mitigation system's effectiveness. The mitigation system is to be operated normally and continuously during the entire measurement.
- A written non-interference agreement, to be signed and returned by the occupants, confirming that they followed all instructions and did not interfere with the measurement device or building conditions.

3.1.2 Conditions for a Valid Measurement

Measurements should not be conducted if temporary radon reduction measures have been implemented. These include the introduction of unconditioned air into the home or closure of normally accessible areas of the home. In this case, the measurement organization should inform the client and other parties of the real-estate transaction that these conditions have been corrected.

If the measurer arrives at a property and finds windows or doors open, or suspects that closed-building conditions were not maintained for 12 hours prior to arrival, then the measurer should extend the measurement to account for this condition.

3.1.3 Anti-Interference Documentation

Measurement organizations should, in addition to providing written guidance, take steps to identify attempts to interfere with the measurement device or building conditions.

The signed non-interference agreement, a description of all non-interference controls employed, and a statement addressing any observed breaches of the non-interference agreement/controls should be made part of the permanent measurement documentation for each measurement.

3.2 Measurements by Clients

Measurement devices installed by the client must be accompanied by instructions for placing, retrieving and handling the device. These instructions should include specific information on the minimum and maximum length of time that the device must be exposed.

For short-term measurements, instructions on closed-building conditions must be included.

Documentation should be substantially the same as for real-estate measurements. The anti-interference agreement can be omitted.

3.3 Documentation

Measurement organizations should record sufficient information on each measurement in a permanent log to allow for future data comparisons, interpretations and reporting to clients.

Health Canada maintains a geographic database of radon measurements. The results of each measurement, the detector type, the start and finish dates and the postal code of the building should be forwarded to the Health Canada for each month that measurements are made.

3.3.1 Measurement Log

It is suggested that a measurement log be kept and maintained for five years with the following information:

- A copy of the final report, including the measurement results, and the statement outlining any recommendations concerning re-measurement or mitigation that was provided to the building occupant or agent.

- The address and postal code of the building measured.
- The locations of all measurement devices deployed. It is advisable to diagram the measurement area, noting the exact location of the detector.
- Start and stop times, and dates of the measurement period.
- A description of the device used, including its serial number if any.
- The name of the organization conducting the analysis.
- A description of any vents used in crawl spaces or in supplying air to combusive appliances.
- The name of the individual who conducted the measurement.
- A description of any variations from, or uncertainties about, standard measurement procedures, closed-building conditions or other factors that may affect the measurement result.
- A description of any non-interference controls used and copies of signed non-interference agreements.
- A record of any quality control procedures associated with the measurement, such as results of simultaneous or secondary measurements.

3.4 Quality Assurance in Radon Measurements

3.4.1 Quality Assurance Plans

All measurement organizations should develop, implement, revise periodically, and maintain a detailed quality assurance plan (QAP) appropriate to each device or method used. These plans should include written procedures for attaining quality assurance objectives, and a system for recording and monitoring the results of the quality assurance measurements described below.

Organizations that only use radon measurement devices analyzed by third parties still need to write and follow a QAP, and conduct quality control measurements.

3.4.2 Standard Operating Procedures

Organizations should have a written, device-specific standard operating procedure (SOP) in place for each radon measurement system they use. An SOP must include specific information describing how to operate and/or analyze a particular measurement device.

Organizations that analyze devices should develop their own SOP or adapt manufacturer-developed SOPs for their devices. Organizations that receive results from a laboratory should have a device-specific SOP for each brand/model/type of device they use.

3.4.3 Calibration Measurements

Calibration measurements are made in a known radon environment such as a calibration chamber to determine and verify the conversion factors used to derive the concentration results. Determination of these calibration factors is a necessary part of the analysis and is the responsibility of the analytical laboratory.

These calibration measurement procedures, including the frequency of measurements and the number of devices to be measured, are specified in the quality assurance programs operated by the device manufacturers and analysis laboratories. This data should be available to the device users for use in their quality assurance program.

Measurement providers are required to recalibrate active devices at least once every 12 months.

3.4.4 Known Exposure Measurements

Analysis laboratories for passive radon measurement devices should provide for the introduction of controls (devices exposed to known concentrations in a radon calibration chamber) into their measurement processes. Control devices should be labelled and submitted to the laboratory in the same manner as ordinary samples. The results of these measurements are used by quality assurance programs to monitor the accuracy of the entire measurement system. This data should be made available to the device users for their quality assurance program.

3.4.5 Background (Blank) Measurements

Analysis laboratories for passive radon measurement devices should measure routinely the apparent radon concentration of a statistically significant number of unexposed (blank) detectors from each batch to establish the laboratory background for the batch and the entire measurement system. This laboratory blank value is subtracted by the laboratory from the field sample results reported to the user. This data should be made available to the device users for their quality assurance program.

Background measurements are also required for active devices. Users must perform sufficient instrument background measurements to establish a reliable instrument background. Results should be recorded as part of the quality assurance program.

3.4.6 Field Controls

3.4.6.1 Field Blanks

Users of passive detectors should employ field blanks equal to approximately five percent of the detectors that are deployed. These blanks should be set aside from each detector shipment, kept sealed and in a low radon environment, labelled in the same manner as the field samples to preclude special processing, and returned to the analytical laboratory along with each shipment. These field blanks measure the background exposure that may accumulate during shipment and storage, and the results should be monitored and recorded for the quality assurance program.

3.4.6.2 Field Duplicates

Duplicate measurements provide a check on the quality of the measurement result and allow the user to make an estimate of the relative precision. Large precision errors may be caused by detector manufacture and/or improper data transcription or handling by suppliers, laboratories, or technicians performing placements. Precision error can be an important component of the overall error, so it is important that all users monitor precision.

Duplicate measurements should be side-by-side measurements (<10 cm apart) made in at least 10 percent of the total number of measurement locations. The locations selected for duplication should be distributed systematically throughout the entire population of samples.

Groups providing measurement services to homeowners can do this by providing two measurements instead of one to a random selection of purchasers, with the measurements made side-by-side. As with spiked samples introduced into the system as blind measurements, the precision of duplicate measurements should be monitored and recorded in the quality assurance program. If the precision estimated by the user is not within the precision expected of the measurement method, the problem should be reported to the analytical laboratory and the cause investigated.

3.4.7 Instrument Performance Checks

Proper functioning of analysis equipment and operator usage requires that the equipment and measurement system be subject to routine checks. Regular monitoring of equipment and operators is vital to ensure consistently accurate results. Performance checks of analysis equipment include the frequent use of an instrument check source. In addition, important components of the device (such as a pump and pump flow rate, battery, or electronics) should be checked prior to each measurement and the results noted in a log. Each user should develop methods for checking their measurement devices at least prior to each measurement, and for recording and reviewing the results of those checks.

3.4.8 Reporting Results

At a minimum, the client report should contain the following information:

- The dates of the measurement period and address of the building measured.
- A description of the device, its manufacturer, model or type, and the device identification (serial) number.
- The names of the organization and individual placing and retrieving the device, and the organization analyzing the device, if they are different.
- A statement concerning any observed tampering or deviations from the required measurement conditions.
- Diagnostic measurements should be reported as "for diagnostic purposes only."
- Measurements should be reported to the nearest 10 Bq/m³, e.g., a measurement of 433 Bq/m³ should be reported as 430 Bq/m³.
- Any radon decay product measurement should be converted to the equivalent radon concentration in Bq/m³ using a 50% equilibrium ratio (unless the actual equilibrium ratio is determined).

3.4.9 Recommendations for Remedial Action

Where average radon concentrations are greater than 200 Bq/m³, the measurement organization should inform consumers that Health Canada recommends remedial action in dwellings and also recommends that certified contractors be used to perform the work.

Dwellings should also be measured after remedial action to confirm that radon levels have been reduced.

3.5 Worker Safety

Individuals and organizations should comply with all applicable Occupational Health and Safety requirements and the Canadian Guidelines for Management of Naturally Occurring Radioactive Materials (NORM) relating to occupational worker exposure to radon.