PROPOSED PERFORMANCE AND LISTING CRITERIA FOR PROFESSIONAL RADON MEASUREMENT DEVICES

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Abstract

The recent commissioning of the Canadian National Radon Chamber at the Radiation Safety Institute of Canada, marked a major milestone for the Canadian National Radon Proficiency Program. The Canadian chamber will facilitate domestic radon measurement performance testing for C-NRPP listed radon professionals. It will also serve as the national radon chamber for professional radon measurement device testing to be used by manufacturers worldwide wishing to have their devices listed by C-NRPP for use in Canada.

This paper discusses proposed performance and listing criteria for manufacturers of professional radon measurement devices. In-chamber test proposals and performance requirements for alpha track and electret ion chamber devices are presented; as are "dynamic" tests and performance requirements for continuous radon monitors and electronic integrating devices.

Introduction

In late 2016, the Canadian – National Radon Proficiency Program (C-NRPP) began development of their "Professional Radon Measurement Device Listing" program in anticipation of commissioning of the Canadian National Radon Chamber. The initial goals were:

- Develop device performance specifications and technical specification sheet guidelines / content.
- Develop a Professional Radon Measurement Device Listing Implementation and Review Manual.

Extracts from the draft Manual follow.

Terms and Definitions

C-NRPP (Canadian – National Radon Proficiency Program) is an independent certification and accreditation program designed to establish guidelines for radon professionals and measurement device manufacturers serving the Canadian marketplace.

COV (Coefficient of Variation) - COV is defined as the ratio of the standard deviation of Identical Devices under test (SD or σ) at a mean value of radon concentration as measured in the reference radon chamber, divided by the mean value of radon concentration as measured by the individual Identical Devices under test (μD). For example, the mean value of radon concentration measured in the reference radon chamber = 220 Bq/m^3, three Identical Devices produce measurements of: 228, 235 and 225 Bq/m^3; therefore, $\sigma = 4.19$, and $\mu D = 229.33$, so $\sigma / \mu D = 4.19/229.33 = 0.02$ (device satisfies PASS criteria of COV ≤ 0.15).

CRM (Continuous Radon Monitor) – A CRM is an electronic radon measuring/monitoring device; for C-NRPP listing it must: a) have a measurement or dynamic range of 20 to 7,400 Bq/m^3 [0.5 to 200 pCi/L] (minimum), and b) be able to store reviewable and downloadable, date and time-stamped average radon concentration data in non-volatile memory. If applicable, it should have a battery power level indicator.

DME (Device Mean Error) – DME is based on the 1989 methodology established at the Canada Centre for Mineral and Energy Technology's (CANMET) National Radon/Thoron Test Facility, Elliot Lake, Ontario. Device Mean Error is defined as (the mean value of radon concentration, as measured by the Identical Devices under test (MD or μD), divided by the mean value of radon concentration as measured in the reference radon chamber (MC or μC) – 1); e.g., mean value of radon concentration measured in the reference radon chamber = 220 Bq/m^3 = μC, and mean value of radon concentration as measured by the Identical Devices under test = 246 Bq/m^3 = μD; therefore, $(\mu D/\mu C) - 1 = (246/220) - 1 = 0.12$ (device satisfies PASS criteria of DME being within $\pm$ 0.20 of radon reference chamber mean value radon concentration).

Dixon Criterion – A statistical method for dealing with outliers based on three or more measurements, and in the case of radon, made in nominally the same physical location, and during conditions of equivalent temporal, seasonal, and environmental conditions. See Appendix I.

EID (Electronic Integrating Device) – An EID is an electronic radon measuring/monitoring device; for C-NRPP listing it must: a) have a measurement or dynamic range of 20 to 3,700 Bq/m^3 [0.5 to 100 pCi/L] (minimum), and b) be able to store reviewable and downloadable, date and time-stamped average radon concentration data in non-volatile memory. If applicable, it should have a battery power level indicator.

EMI (ElectroMagnetic Interference) - A disruption in the normal operation of an electronic device due to induced electromagnetic behaviour or electromagnetic radiation generated by an external source.

ESD (ElectroStatic Discharge) - The transfer of electric charge between objects bearing different electrostatic potentials (voltages) as a result of direct contact or close proximity to one another.

Identical Devices - Devices produced by the same Manufacturer using the same production and quality control procedures, processes, component parts and sub-assemblies.

IMQP (Integrated Manufacturing and Quality Plan) Chart - A pictorial presentation of all manufacturing and QC steps involved (in sequence) from Receiving Inspection of components through to final QC Function Test of the TTU.

Individual Mean Errors (IMEs) - The mean value of radon concentration, as measured by the Identical Devices under test (MD or μD), divided by the mean value of radon concentration as measured in the reference radon chamber (MC or μC) – 1) at low and high Rn concentrations times 100, i.e., ((MD/MC) – 1) x 100. Equivalent to Device Mean Error.

Percent Non-Linearity - (for low to high Rn concentration) is the percent difference of the mean Individual Mean Errors (IMEs) for Identical Devices under test, e.g., mean IME (low radon conc.) = 0.18, mean IME (high radon conc.) = 0.15, therefore, (mean IME (low radon conc.) - mean IME (high radon conc.)) x 100 = (0.18 - 0.15) x 100 = 3% (device satisfies PASS criteria of percent non-linearity ≤ 15%).

QA (Quality Assurance) - A program which has been established to monitor and evaluate activities, including the establishment and adherence to Type Testing procedures, use of proper documentation, and implementation of a Quality Improvement Program, as required to ensure high standards of quality have been met.

QC (Quality Control) – An ongoing system of measurements conducted to ensure a testing device meets pre-established performance standards; these measurements include background radiation, response to known radon concentrations, and sound levels.

Reference Radon Calibration Chamber - A radon test facility (often called a "radon chamber") which provides a standard test atmosphere for radon concentration measurement and has been accepted by the listing agency. The chamber provides sufficient size, configuration, radon concentration range, and radon concentration controls that testing may be conducted in a radon-in-air atmosphere that is stable or can vary under controls (increasing or decreasing) with precision that exceeds the precision of the device being tested. In the context of this paper, the reference radon calibration chamber refers to the National Radon Chamber in Saskatoon, Saskatchewan, Canada; owned and operated by the Radiation Safety Institute of Canada.

SARA (Submit for Agency Review and Approval) Documents – Those Manufacturer's documents which have to be submitted to C-NRPP for listing compliance review and approval.

TTU (Type Test Unit) - A device provided by the manufacturer for type testing. The TTU is manufactured at the same facility, using the same personnel, procedures, equipment, and components/materials as the commercial units provided for homeowners at large.

Type Testing - A series of tests performed to qualify the design and performance of the device addressed by this protocol. Type Tests are performed on a single unit provided by the manufacturer for this purpose as being representative of the device to be qualified.

C-NRPP Specifications for Professional Radon Measurement Devices

The design specifications set forth in C-NRPPs proposed "Professional Radon Measurement Device Listing Requirements," are summarized as shown in Figure (1).

Figure (1): Specification Summary

SPECIFICATION SUMMARY CHART

AC Power Input – if applicable (electronic devices only): Voltage Frequency	 115 VAC ± 15VAC 60 Hz ± 3Hz
Ambient Temperature Range (all measurement device types)	10 – 30ºC (21°C typ.) 50 – 86°F (70°F typ.)
Relative Humidity (all measurement device types)	Up to 75% (non-condensing)
Pressure (all measurement device types)	101.325 kPa 1 atm or about 30" Hg
Electro-magnetic Interference (electronic measurement device types) - Electrostatic discharge (CEI IEC 61000-4-2), operator/user interference, 8kV contact - Cell phone interference (see Note 1), 5 call initiations at 60 second intervals 100 mm (about 4") from the face of the TTU (see Note 2), and repeated at a distance of 100 mm from the top horizontal surface of the TTU	≤ 20% error ≤ 20% error
Radon Measurement Accuracy (all measurement device types)	± 20% error

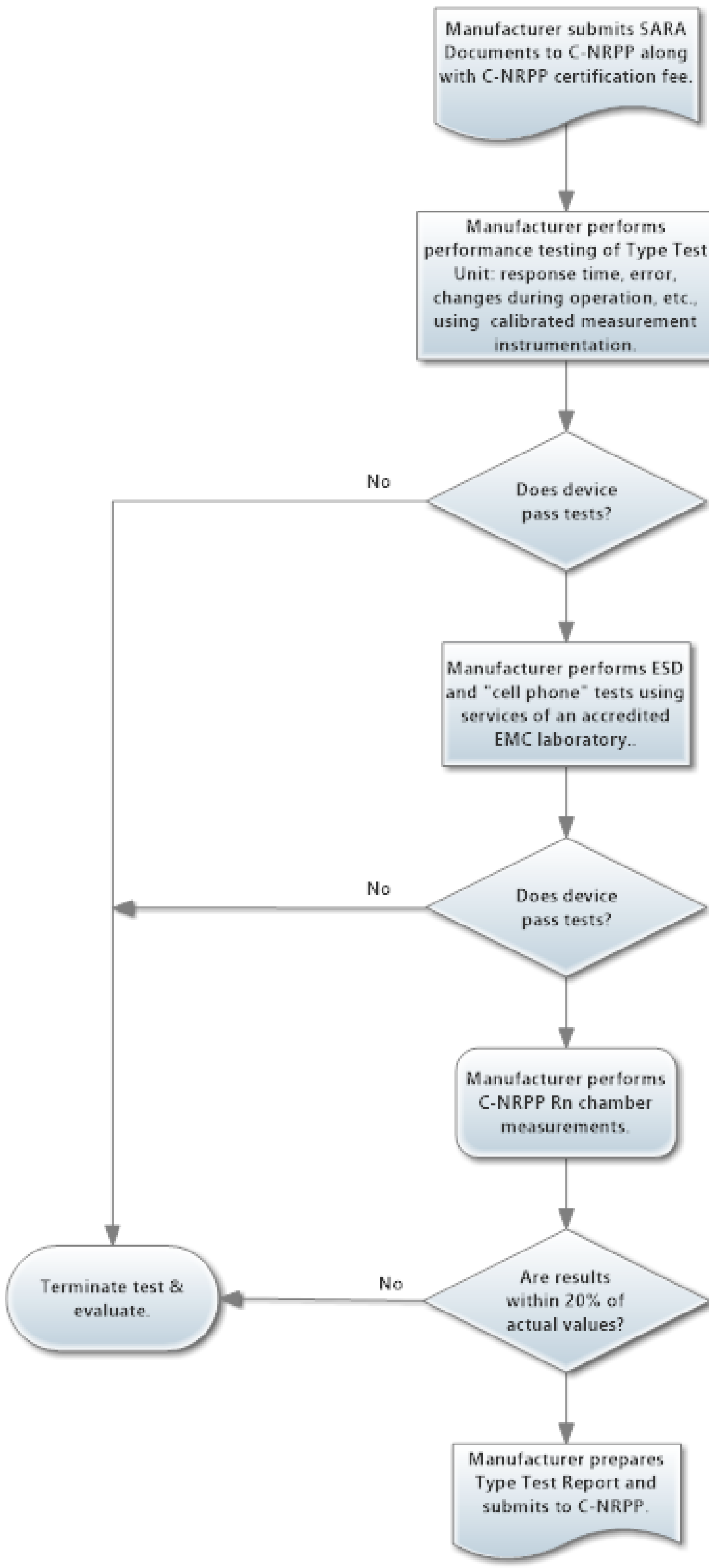
Notes:

1. Typical cell phone operating frequencies range from 850 MHz to 1.9 GHz.
2. TTU = "Type Test Unit."

The Listing Process

The Listing Process is presented graphically in Figure (2) which follows. Please check http://c-nrpp.ca for updated Listing Application Fees and Requirements. ***Note:*** *Manufacturer documentation submitted to C-NRPP in support of a Professional Radon Measurement Device listing application shall be maintained in confidence by C-NRPP as "Proprietary Information" specific to the providing Manufacturer ONLY. C-NRPP will execute a Non-Disclosure Agreement with the Manufacturer prior to the submission of any Manufacturer documents to C-NRPP.*

Figure (**2**): The Device Listing Sequence



The Manufacturer's QA Manual

The Professional Radon Measurement Device Manufacturer must submit a current copy of their Quality Assurance Manual along with their listing application, application fee, and other required SARA documents.

The QA Manual shall include:

- a statement of Management's quality policy and commitment to the quality assurance program as described therein,
- clearly defined areas of authority and responsibility pertaining to review and approval regarding document and design control,
- a list of the quality objectives,
- specifics regarding document and design control
    - document and part numbering scheme,
    - document generation and revision process,
    - document review and approval responsibilities,
    - preparation and control of the master document list or document status chart,
    - responsibilities for document control,
    - document storage and security,
- procedures addressing non-conformance and corrective action,
- a description of the process for internal audits.

The QA Manual shall also specify the requirements for:

- Manufacturing procedures,
- Quality Control procedures (including function test procedures, type test procedures, sampling plans, and receiving inspections, e.g., visual, dimensional, measurement of critical parameters and comparison to technical specifications such as capacitance and tolerance for capacitors),
- Commercial Dedication Plan - a method for validating the use of commercial off-the-shelf components for use in a professional radon measurement device,
- Disposition of rejects,
- Design specifications,
- Assembly drawings and schematics (as applicable),
- Operation manuals,
- Test reports and other documents pertaining to the Professional Radon Measurement Device.

SARA Documents

In addition to the QA Manual, the Professional Radon Measurement Device Manufacture has to provide C-NRPP with the following SARA Documents at time of listing application:

- General Assembly Drawing – see Figure (3)
    - usually presented as an "exploded view" or isometric view drawing which depicts the relationship of all component parts and sub-assemblies within the device, to one another
    - components and sub-assemblies usually numbered from left to right and from top to bottom using a numeric or alpha-numeric format
    - numbers used are cross-referenced to an associated Parts List (either appearing on the same sheet as the General Assembly or on a separate sheet of a multi-sheet drawing),
    - shall bear the signatures and date signed of the Preparer (the manufacturer's design authority), the Draftsperson, the Technical Check (independent cognizant design authority), Quality Assurance review and approval designate, and Engineering or Management approval designate,
    - shall also bear a title, document and revision number which must match the information appearing on the Document Status Chart (not submitted to C-NRPP).

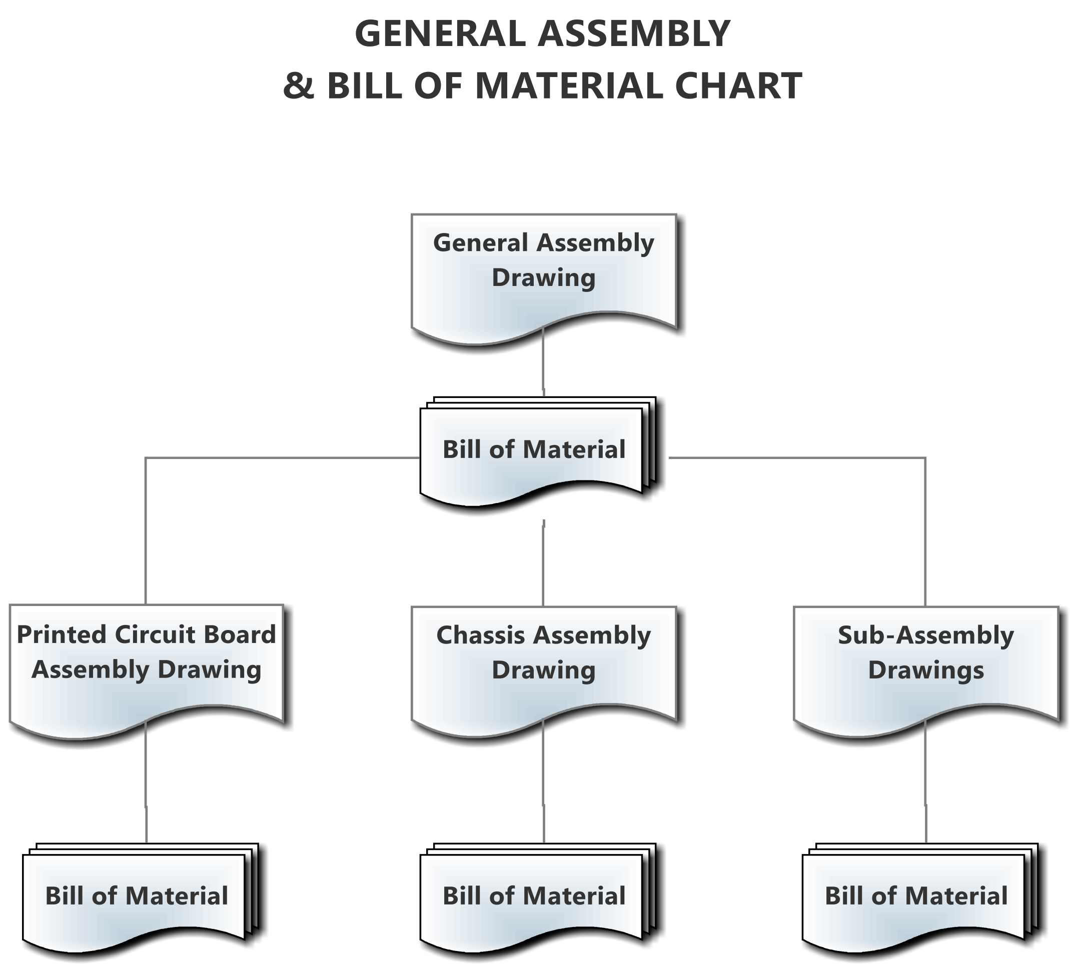


Figure (3): Typical CRM or EID General Assembly Drawing and Bills of Material Relationship

- Bills of Material (General Assembly, Printed Circuit Board(s), Sub-Assembly)
    - a comprehensive list of all parts/components/materials required to build an associated assembly. A Bill of Material for a complete product or device usually lists sub-assemblies as component parts of the main assembly or complete product.
    - shall bear the signatures and date signed of the Preparer (the manufacturer's design authority), Quality Assurance review and approval designate, and Engineering or Management approval designate,
    - shall bear a title, document and revision number, and list the assembly number it is associated with.
- Schematic(s)
    - a graphical representation of the electronic circuit associated with a specific printed circuit assembly,
    - components are represented by graphic symbols consistent with IEC 60617 - Graphical Symbols for Diagrams and/or IEEE STD 315- Graphic Symbols for Electrical and Electronics Diagrams,
    - shall have an associated Parts List (either appearing on the same sheet as the schematic or on a separate sheet of a large multi-sheet schematic),
    - shall bear the signatures and date signed of the Preparer (the manufacturer's design authority), the Draftsperson, the Technical Check (independent cognizant electronic design authority), Quality Assurance review and approval designate, and Engineering or Management approval designate,
    - shall also bear a title, and document and revision number.
- Inspection and Test Plan
    - a report-style document which typically contains: sections outlining document purpose, scope, references, integrated manufacturing and quality plan, sub-contracted services, characteristics to be inspected, test equipment identification and calibration records, jurisdiction and customer hold/witness points (if applicable), sampling plan, quality level, and workmanship standards.
- IMQP Chart
    - a pictorial presentation of all manufacturing and QC steps involved (in sequence) from Receiving Inspection of components through to final QC Function Test of the TTU. As shown in Figure (4), references to "(QC Procedures)" are usually a list from QC-1 to QC-*X (where X is the last procedure*). A related chart cross-references the QC numbers to the manufacturer's Quality Control procedures, e.g., QC-1 = Visual Inspection, QC Proc. No. XXX Rev. XX.

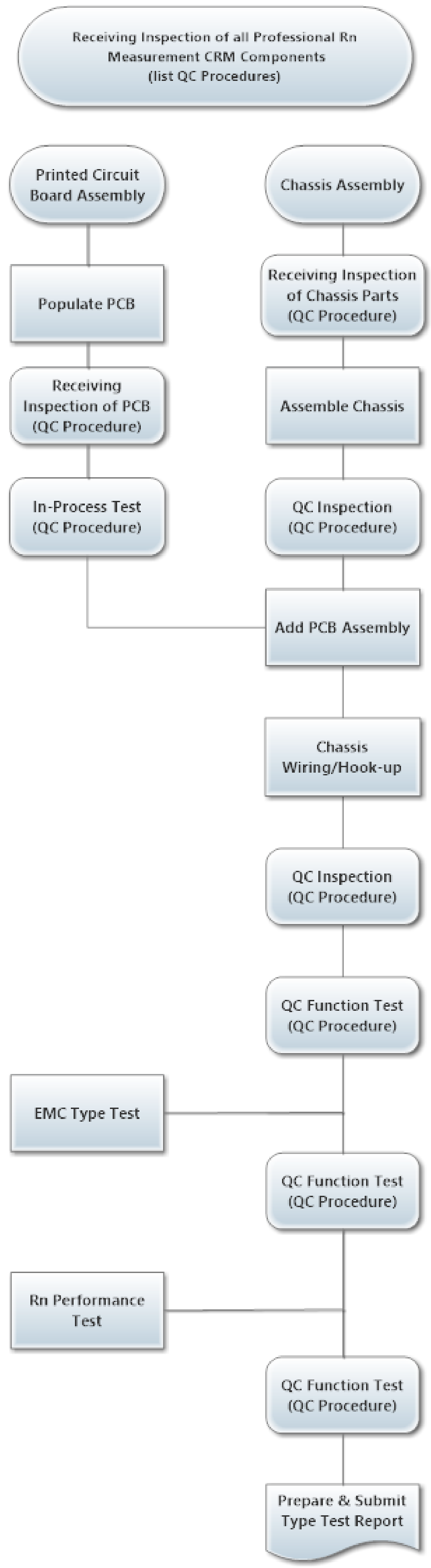


Figure (4): Typical IMQP Chart for CRMs

- Type Test Procedures
    - apply to tests specific to the Type Test Unit only,
    - shall be prepared for the: electrostatic discharge immunity test, electromagnetic immunity test (cell phone), and radon measurement accuracy performance test.
- User's Operation Manual
    - should provide the Radon Measurement Professional with all information required for the proper operation and maintenance of the professional radon measurement device,
    - should specify location requirements for the device; and provide calibration information specific to the professional radon measurement device.

On successful completion of C-NRPP Rn Chamber tests, the Professional Radon Measurement Device Manufacture has to provide C-NRPP with Technical and Performance Specifications for their device as per examples shown in Appendices II and III.

C-NRPP Site Audits

C-NRPP audits of the Manufacturer (if necessary) shall be conducted in accordance with C-NRPP's "The Implementation and Application Process for Professional Radon Measurement Device Manufacturers – Auditor's Guide and Checklist." Finding types are detailed below.

<u>Major Non-Compliance Finding</u>

Major Non-Compliance Findings are those findings that could likely result in the delivery of a defective or non-compliant Professional Radon Measurement Device to the Radon Measurement Professional. These findings include but are not limited to:

- missing or erroneous test records,
- use of unauthorized measurement or test equipment during device manufacture,
- undocumented testing,
- use of unapproved procedures, drawings or other documents,
- use of unapproved components or suppliers,
- missing documentation,
- occurrence of numerous minor non-compliance findings.

<u>Minor Non-Compliance Finding</u>

Minor Non-Compliance Findings are those findings that would have a minimal risk in the delivery of a defective or non-compliant professional radon measurement device to the Radon Measurement Professional. These findings include but are not limited to:

- use of a single piece of measurement or test equipment beyond its calibration due date,
- use of an obsolete drawing or procedure,
- use of an unapproved or partially approved document (drawing, procedure, etc.),
- sub-standard documentation.

The Canadian National Radon Chamber

The Canadian National Radon Chamber is a 12 m^3 [424 ft^3] walk-in type; allowing for the simultaneous exposure of over 100 radon monitors. Its design and operating ranges (Sandowski, 2017) are summarized in the following table:

Control System Element	Operating Range	Design Range
Chamber Rn Concentration	148 Bq/m^3 to 500 kBq/m^3 [4 pCi/L to 13,514 pCi/L]	52 Bq/m^3 to 500 kBq/m^3 [1.4 pCi/L to 13,514 pCi/L]
Injection Circuit Flow Rate	0 to 2 litres/minute [0 to 4.2 ft^3/hour]	0 to 10 litres/minute [0 to 21.2 ft^3/hour]
Exhaust Circuit Flow Rate	0 to 10 litres/minute [0 to 21.2 ft^3/hour]	0 to 20 litres/minute [0 to 42.4 ft^3/hour]
Rise Times	12 hours to 27 days	6.4 hours to 27 days

Note:
Stable radon concentrations can be maintained between the above-listed ranges. See Figure (5).

Typical (unmodified) environmental conditions inside the chamber (Sandowski, 2017) are as follows:

Environmental Parameter	Typical Test Condition
Temperature	18 – 22 °C [64 – 72 °F]
Relative Humidity	20 – 60%
Atmospheric Pressure	101 kPa (nominal) [1 atm (nominal)]
Ambient Gamma Dose Rate	340 nSv/h [0.034 mrem/h]

Note:
Typical environmental conditions would only apply to performance testing of C-NRPP listed devices for Radon Measurement/Mitigating Professionals.

In order to provide "worst case" test conditions to satisfy C-NRPP listing performance criteria for professional radon measurement devices, the following work-arounds have been proposed:

1. Test Condition: low radon concentration (< 200 Bq/m^3 [< 5 pCi/L]), high temperature, high humidity - place portable convection heater(s) and humidifier(s) in the chamber, establish target temperature 30°C (- 0°C / +5°C) [86°F (- 0°F / +9°F)] and target humidity (70% or best value, non-condensing), install detectors and run low radon concentration exposures.

2. Test Condition: high radon concentration (> 600 Bq/m^3 [> 16 pCi/L]), low temperature (20°C [68°F] typical), ambient humidity (55% typical), install detectors and run high radon concentration exposures.

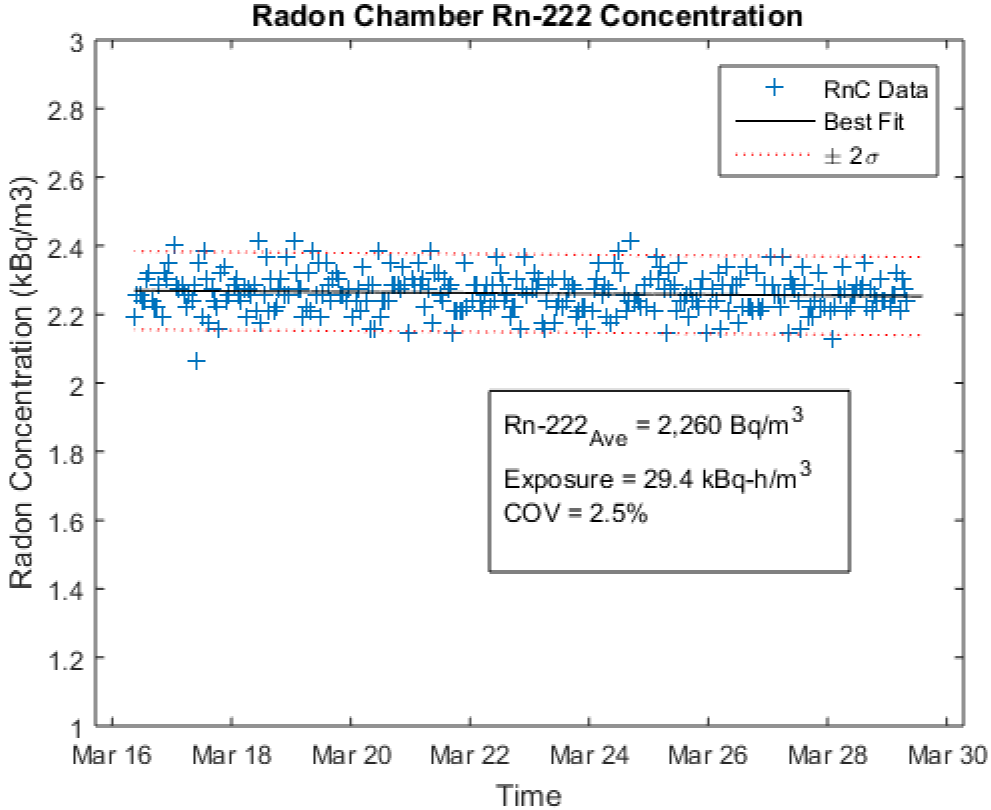


Figure (5): C-NRPP Rn Chamber Stability (2017)

C-NRPP Radon Chamber Test Protocols

The proposed C-NRPP radon chamber test protocols for professional radon measurement device listing purposes are summarized as follows:

1. Low Temperature Static Test (ATDs and EICs): Three identical devices shall be exposed (2 to 30 days exposure period) to high radon concentration (> 600 Bq/m^3 [> 16 pCi/L]), ambient temperature (20°C [68°F] typical), ambient humidity (55% typical).

   Acceptance Criteria: Device Mean Error for radon concentration shall be within ± 0.20 of chamber mean value radon concentration. Coefficient of Variation ≤ 0.15. ***Note:*** *The Dixon Criterion may be used in the event of a suspect reading from one of the devices.*

2. High Temperature Static Test (ATDs and EICs): Three identical devices shall be exposed (2 to 30 days exposure period) to low radon concentration (< 200 Bq/m^3 [< 5 pCi/L]), high temperature (30°C [86°F] typical), high humidity (70% or best value, non-condensing).

   Acceptance Criteria: Device Mean Error for radon concentration shall be within ± 0.20 of chamber mean value radon concentration. Coefficient of Variation ≤ 0.15. ***Note:*** *The Dixon Criterion may be used in the event of a suspect reading from one of the devices.*

3. % Non-Linearity (low to high radon concentration static tests for ATDs and EICs) shall be ≤ 15%.

4. Dynamic Test - Tracking Accuracy (EIDs): The Type Test Unit shall be exposed (48 hours total exposure period typical) to stable conditions of low radon concentration (< 200 Bq/m^3 [< 5 pCi/L]), high temperature (30°C [86°F]) typical, 70% nominal relative humidity (non-condensing); then the radon concentration increased to 1,000 Bq/m^3. Conditions will be allowed to stabilize and the high radon concentration benchmarked. Heater(s) and humidifier(s) shall be turned off and radon concentration in the chamber shall then be slowly increased to about 3,500 Bq/m^3 [95 pCi/L] and once there, allowed to drop down to ambient levels. The Tracking Accuracy test shall look at EID performance during the transient from 1,000 Bq/m^3 through to 3,500 Bq/m^3 and down to ambient. See Figure (6).

   Acceptance Criteria: Device Mean Error for radon concentration shall be within ± 0.20 of chamber mean value radon concentration. Coefficient of Variation shall be ≤ 0.15 for each of low and high radon concentrations. % Non-Linearity (low to high radon concentration) shall be ≤ 15%. Tracking Accuracy device reading shall be within ± 0.20 of chamber value (chamber value is defined as the mean radon concentration in the chamber during the period coinciding with the radon concentration averaging period of the device).

5. Dynamic Test - Tracking Accuracy (CRMs): The Type Test Unit shall be exposed (48 hours total exposure period typical) to stable conditions of low radon concentration (< 200 Bq/m^3 [< 5 pCi/L]), high temperature (30°C [86°F]) typical, 70% nominal relative humidity (non-condensing); then the radon concentration increased to 1,000 Bq/m^3. Conditions will be allowed to stabilize and the high radon concentration benchmarked. Heater(s) and humidifier(s) shall be turned off and radon concentration in the chamber shall then be slowly increased to about 7,000 Bq/m^3 [190 pCi/L] and once there, allowed to drop down to ambient levels. The Tracking Accuracy test shall look at EID performance during the transient from 1,000 Bq/m^3 through to 7,000 Bq/m^3 and down to ambient.

   Acceptance Criteria: Device Mean Error for radon concentration shall be within ± 0.20 of chamber mean value radon concentration. Coefficient of Variation shall be ≤ 0.15 for each of low and high radon concentrations. % Non-Linearity (low to high radon concentration) shall be ≤ 15%. Tracking Accuracy device reading shall be within ± 0.20 of chamber value (chamber value is defined as the mean radon concentration in the chamber during the period coinciding with the radon concentration averaging period of the device).

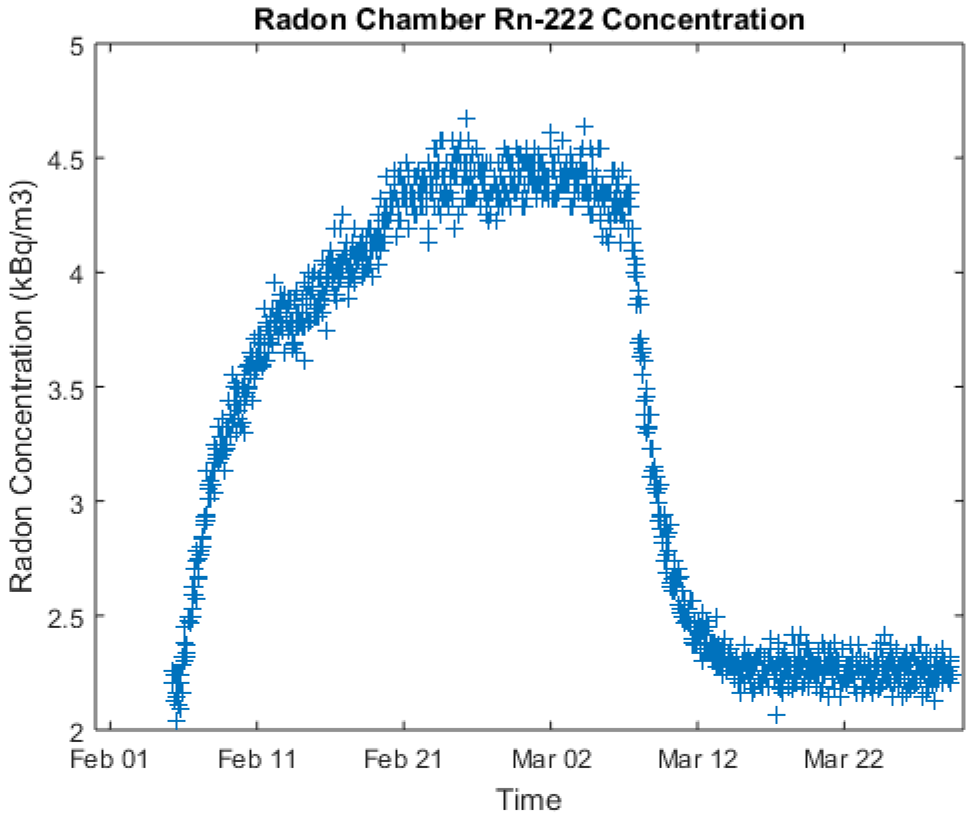


Figure (6): C-NRPP Radon Chamber Profile – Increasing/Decreasing Rn Concentration (2017)

Summary

The C-NRPP radon monitoring/measuring device listing program, represents an integrated device design qualification based on performance testing and C-NRPP review and approval of the Manufacturer's QA Manual, design and document control policies, and SARA documents.

Successful implementation of the program will:

- Provide all Professional Radon Measurement Device Manufacturers with a uniform set of performance and quality requirements for the Canadian marketplace.
- Ensure that radon measurement devices available to Radon Measurement Professionals comply with performance standards and quality assurance requirements set in forth C-NRPP's "Professional Radon Measurement Device Listing Implementation and Review Manual."
- Provide a resource and reference guide for both Radon Measurement Professionals and manufacturers of professional radon measurement devices.
- Provide Radon Measurement Professionals with a list of devices which comply with C-NRPP's requirements for professional radon measurement devices.
- Provide Radon Measurement Professionals with an on-line database of Technical Specifications for C-NRPP-Approved Professional Radon Measurement Devices.

Appendix I – Notes on the Use of the Dixon Criterion

In regards to the statistical treatment of multiple radon measurements (initial/screening and follow-ups, duplicates, etc.) made in nominally the same physical location, and during conditions of equivalent temporal, seasonal, and environmental conditions; it is expected that those measurements will follow a normal distribution (Lodge, 1990). Should one of the resulting measurements differ noticeably from the mean of all the measurements, use of the Dixon Criterion is recommended to validate retention or rejection of the questionable result.

For the cases of three, four, five, or six measurements, i.e., n = 3, 4, 5, or 6, the Dixon Criterion decision value at the 95% confidence level (one-sided test) is 0.941, 0.765, 0.642, and 0.560 respectively. See ASTM E178-08 for values > n = 6. If the smallest measurement is suspected to be markedly lower than the others, then the Dixon Criterion is: $(x_2 - x_1) / (x_n - x_1)$ where x_1 to x_n are the smallest to highest measurements respectively.

If the largest radon measurement is suspected to be markedly higher than the others, then the Dixon Criterion is: $(x_n - x_{n-1}) / (x_n - x_1)$ where again, x_1 to x_n are the smallest to highest measurements respectively.

In either case, if the Dixon Criterion is greater than the associated decision value, reject the associated measurement and use the mean of the remaining measurements as the measured radon concentration value.

Appendix II – Sample Technical Specifications

Alpha Track Detectors

Note: *C-NRPP recommends including a photo of the device and a brief written description which highlights features and applications/uses.*

DEVICE

Name:
Model No.:
Where Manufactured: Country of origin.

SENSOR

Film Type: e.g., Cr-39 or Kodalpha type LR115
Track Reading Area: e.g., 100 mm^2
Identification of Film: e.g., barcode, serial number
Processing Method: e.g., NaOH etching bath, electrochemical etching

CHAMBER (if applicable)

Internal Chamber Volume:

FILTER

Type / Material:
Dimensions (including thickness)**:**

MEASUREMENT

Measurement Range: Bq/m^3
Sensitivity: tracks/cm^2 per Bq-h/m^3
Track Counting Method: e.g., optical, CCD camera, digital image analysis
Lower Limit of Detection: Bq/m^3 days
% Detection Efficiency or Calibration Factor:
Maximum Minimum Detectable Rn Concentration: Bq/m^3 @ 90 days, @ 365 days
Device Mean Error (DME): report actual value as listed on C-NRPP Professional Radon Measurement Device Listing Program test results
Standard Deviation of Error:
Normal or Recommended Exposure Duration: e.g., range of days
Minimum Recommended Exposure Duration: e.g., days
Maximum Recommended Exposure Duration: e.g., days
% Uncertainty at Low ($\leq$ 200 Bq/m^3)**, Medium** (> 200 $\leq$ 600 Bq/m^3) **and High** (> 600 Bq/m^3) **Rn Concentrations:** (p*rovide % Uncertainty values for 90 and 365 days exposures at the cited indoor radon concentrations)*

QUALITY CONTROL

Internal (in-house) Test Results:
External Test Results: (cite nature of test, date of test, test facility, and specific test results)

STORAGE LIFE / RE-READABILITY

Storage Life of Processed Film:
Re-Readability: e.g., unlimited over storage life

OPERATING ENVIRONMENT

Temperature Range: °C
Relative Humidity: % RH non-condensing
Barometric Pressure: kPa

STORAGE ENVIRONMENT

Temperature Range: °C
Relative Humidity: % RH non-condensing

PHYSICAL

Dimensions:
Weight:
Tamper Prevention or Detection Method:

RESTRICTIONS / LIMITATIONS

Identify any factors or parameters that may impact measurement accuracy.

COMPLIANCE

List any ANSI, ISO or other recognized standards the device complies with (and provide proof of compliance to C-NRPP).

REFERENCES / EVALUATIONS

List published papers, peer-reviewed presentations, independent studies and research, etc.

Appendix II – Sample Technical Specifications (continued)

Electronic Integrating Devices

Note: *C-NRPP recommends including a photo of the device and a brief written description which highlights features and applications/uses.*

DEVICE

Name:
Model No.:
Where Manufactured: Country of origin.

SENSOR / CHAMBER

Detector Type: e.g., ionization chamber, passive diffusion chamber, Si diode
Chamber Volume *(if applicable)***:** total / active
Air Supply: e.g., passive, forced air fan

MEASUREMENT

Measurement Range: Bq/m^3
Measurement Intervals: e.g., 15, 30, 60 minutes
Sensitivity: cpm, cph or equivalent per Bq/m^3
Lower Limit of Detection: Bq/m^3 days
% Detection Efficiency, Calibration Factor or Equivalent:
Maximum Minimum Detectable Rn Concentration: Bq/m^3 @ 48 hours
Device Mean Error (DME): report actual value as listed on C-NRPP Professional Radon Measurement Device Listing Program test results
Standard Deviation of Error: based on C-NRPP Professional Radon Measurement Device Listing Program test results
Normal or Recommended Exposure Duration: e.g., hours, range of days
Maximum Recommended Exposure Duration: e.g., hours, days
% Uncertainty at Low ($\leq$ 200 Bq/m^3)**, Medium** (> 200 $\leq$ 600 Bq/m^3) **and High** (> 600 Bq/m^3) **Rn Concentrations:** (*Provide % Uncertainty values for 48 hour exposures at the cited indoor radon concentrations.)*

OPERATING ENVIRONMENT

Temperature Range: °C
Relative Humidity: % RH non-condensing
Barometric Pressure: kPa

STORAGE ENVIRONMENT

Temperature Range: °C
Relative Humidity: % RH non-condensing

PHYSICAL

Dimensions:
Weight:

ELECTRONICS

Response Time (10 to 90% total value)**:** seconds or minutes
Linearity:
Display: e.g., number of digits, type (LCD, LED, OLED, etc.)
User/Operator Controls:
I/O: e.g., USB, IR, Bluetooth
Power Supply:

DATA RECORD STORAGE

Radon Concentration Averaging Interval:
Maximum Number of Records Stored:

OTHER SENSORS *(as applicable)*

Barometric Pressure: range and typical error
Relative Humidity: range and typical error
Temperature: range and typical error
Tampering: sensor type and typical indication

RESTRICTIONS / LIMITATIONS

Identify any factors or parameters that may impact measurement accuracy.

COMPLIANCE ***(****Must meet Electromagnetic Compatibility requirements as per the C-NRPP Professional Radon Measurement Device Listing Implementation & Review Manual.)*

List any ANSI, ISO or other recognized standards the device complies with (and provide proof of compliance to C-NRPP).

REFERENCES / EVALUATIONS

List published papers, peer-reviewed presentations, independent studies and research, etc.

Appendix III – Sample Performance Specifications

Continuous Radon Monitors

Device Description / Theory of Operation:
Continuous radon monitors (CRMs) are electronic devices that detect and "count" alpha particles produced during the decay of radon (Rn-222) and/or its progeny polonium (Po-218, Po-214) within an internal ionization chamber or scintillation cell. In the context of these C-NRPP Performance Specifications, a CRM must: a) have a measurement or dynamic range of 20 to 7,400 *Bq/m^3 (minimum); and b) be able to store reviewable and downloadable, date and time-stamped average radon concentration data in non-volatile memory.*

CRMs can be based on a number of different technologies, including but not limited to:

- *Passive radon (Rn) diffusion ionization chamber, ion-implanted Si diode and alpha spectrometry,*
- *Active (an internal pump draws ambient air through a filtered inlet) Rn diffusion ionization chamber, ion-implanted Si diode and alpha spectrometry,*
- *Passive pulsed Rn diffusion ionization chamber, open grid ionization probe,*
- *Active or passive scintillation cell (Lucas type)coupled to a photomultiplier tube,*
- *Active (an internal forced air fan or pump draws ambient air through a filtered inlet) pulsed Rn diffusion ionization chamber, ion-implanted Si diode and alpha spectrometry,*
- *Passive Rn diffusion ionization chamber and diffused-junction photodiode.*

C-NRPP Recommended Application(s):

1. *Short term (48 to 96 hours) initial post-mitigation verification measurement (preferably made during the heating season).*
2. *Short term (48 hours) radon measurement for real estate transactions.*

MEASUREMENT

Listing Measurement Accuracy: Device Mean Error (DME) shall be within ± 0.20 of chamber value (48 hours (typ.) exposure) under worst case conditions of low temperature, low radon concentration (< 200 Bq/m^3), high humidity; and high temperature, high radon concentration (> 600 Bq/m^3), low humidity.
Tracking Accuracy: Device reading shall be within ± 0.20 of chamber value (chamber value is defined as the mean radon concentration in the chamber during the period coinciding with the radon concentration averaging period of the device.
Coefficient of Variation: ≤ 0.15 each for low and high radon concentration exposures
Percent Non-Linearity (low to high Rn concentration): ≤ 15%
Measurement or Dynamic Range: 20 to 7,400 Bq/m^3 (minimum)
Maximum Minimum Detectable Rn Concentration: ≤ 148 Bq/m^3 (for a 1 hour measurement)

NOTE: *AC power variation and loss effects (for those devices which are AC-powered with battery back-up) shall also be assessed during chamber testing.*

DATA STORAGE

Storage Interval: ≤ 60 minutes

Device must be able to store date and time-stamped average radon concentration *(radon concentration must be averaged over a period ≤ 60 minutes)* data in non-volatile memory. Data must be reviewable and downloadable.

OPERATING ENVIRONMENT

Temperature Range: 15 to 30°C (21°C typical)
Relative Humidity: up to 75% non-condensing
Barometric Pressure: 101.3 kPa

STORAGE ENVIRONMENT

Temperature Range: 15 to 30°C (21°C typical)
Relative Humidity: up to 75% non-condensing

Appendix III – Sample Performance Specifications (continued)

Electret Ionization Chambers

Device Description / Theory of Operation:
Electret ionization chambers (EICs) feature an electrostatically (+) charged polymer disc, i.e, an electret, housed within a conductive plastic ionization chamber. During exposure, radon-bearing air enters the chamber through filtered openings which preclude the entry of thoron. Once inside the chamber, the radon undergoes alpha decay, producing negatively charged ions (electrons) which get attracted to the electret. Each electron hitting the electret causes it to slightly discharge. After the exposure is complete, the potential remaining on the electret is measured using a non-contact surface potential reader. The drop in potential (from start to end of exposure) is used to calculate the radon concentration during the exposure.

EIC radon measurement sensitivity and exposure times are determined by the nature and thickness of the polymer used for the electrets, and by the volume of the ionization chamber.

C-NRPP Recommended Application(s):
1. *Long term (90 days to 1 year) indoor radon concentration measurement.*
2. *Short term (48 hours) real estate transaction measurement.*
3. *Short term (48 hours to 1 month) initial post-mitigation measurement (made during the heating season).*

MEASUREMENT (applies to each type combination of electret and ionization chamber)

Listing Measurement Accuracy: Device Mean Error (DME) shall be within ± 0.20 of chamber value (2 – 30 days exposure) under worst case conditions of low temperature, low radon concentration (< 200 Bq/m^3), high humidity; and high temperature, high radon concentration (> 600 Bq/m^3), low humidity

Coefficient of Variation: ≤ 0.15 each for low and high radon concentration exposures

Percent Non-Linearity (low to high Rn concentration): ≤ 15%

Minimum Detectable Exposure: *this parameter varies for each electret/ionization chamber combination (to be provided by manufacturer)*

Minimum Detectable Rn Concentration: ≤ 37 *Bq/m^3@ manufacturer's minimum recommended exposure period for the subject electret/ionization chamber combination*

OPERATING ENVIRONMENT

Temperature Range: 15 to 30°C (21°C typical)
Relative Humidity: up to 75% non-condensing
Barometric Pressure: 101.3 kPa

STORAGE ENVIRONMENT

Temperature Range: 15 to 30°C (21°C typical)
Relative Humidity: up to 75% non-condensing

References

1. ASTM E178-08, Standard Practice for Dealing With Outlying Observations, ASTM International, 2008.

2. CAN/CSA-ISO 9001 - 2008, Quality Assurance Model for Quality Assurance in Design, Development, Production, Installation and Servicing.

3. CEI IEC 61000-4-2, Electromagnetic Compatibility - Part 4-2: Testing and Measurement Techniques - Electrostatic Discharge Immunity Test.

4. C-NRPP Draft Document "Professional Radon Measurement Device Listing Requirements," 2017.

5. IEC 60617 - Graphical Symbols for Diagrams.

6. IEEE STD 315- Graphic Symbols for Electrical and Electronics Diagrams (including reference designation letters).

7. Lodge, J.P., Methods of Air Sampling and Analysis, 3rd ed., 1990, APCA ACS AIChE APWA ASME AOAG HPS ISA Intersociety Committee, 19.2.1:107.

8. Sandowski, J., Mavrichi, O., of Radiation Safety Institute of Canada, email to LaFontaine, M. re. Canadian National Radon Chamber, April 2017.