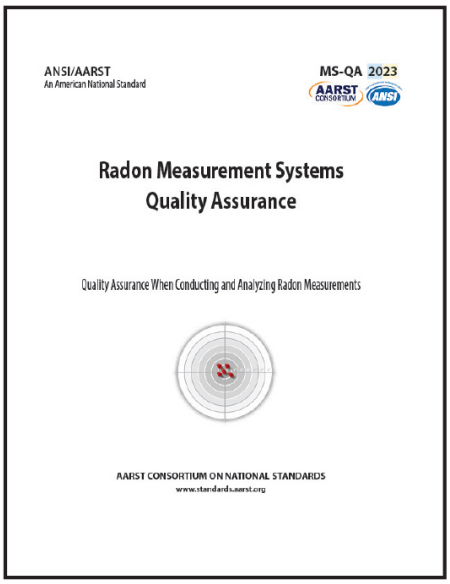
2024 Public Review of MS-QA 2023

Consistent with plans relative to our continuous maintenance program, the latest publication of ANSI/AARST MS-QA is being published for public review. Processes are still underway for repopulating the standing QA committee tasked with review and update of this standard. This public review is intended to gather comments that will lead to improvements in upcoming publications.

ANSI/AARST standards are available for review and for purchase at www.standards.aarst.org. A link to ensure you receive future public review notices can be found at www.standards.aarst.org/public-review.



2024 Public Review: MS-QA 2023

COMMENT DEADLINE: **October 7th, 2024**

REQUESTED PROCESS AND FORM FOR FORMAL PUBLIC REVIEW COMMENTS

Submittals (MS Word preferred) may be attached by email to StandardsAssist@gmail.com

1) Do not submit marked-up or highlighted copies of the entire document.

2) If a new provision is proposed, text of the proposed provision must be submitted in writing. If modification of a provision is proposed, the proposed text must be submitted utilizing the strikeout/underline format.

3) For substantiating statements: Be brief. Provide abstract of lengthy substantiation. (If appropriate, full text may be enclosed for project committee reference.)

REQUESTED FORMAT

Public Reviewed Item and Its Date: *MS-QA 2023*

- **Name:** Affiliation:
- **Clause or Subclause**:
- **Comment/Recommendation**:
- **Substantiating Statements**:

Repeat the four bullet items above for each comment.

Intellectual rights

NOTE: Commenters that choose to submit comments shall be deemed to have done so at their sole discretion and acceptance that work product resulting from comments and other participation shall be wholly owned by the publisher (AARST), to include all national and international publishing and intellectual rights associated with the work product creation and publication.

AARST Consortium on National Standards

Website: www.standards.aarst.org Email: StandardsAssist@gmail.com

527 N Justice Street, Hendersonville, NC 28739

The Consortium Consensus Process

The consensus process developed for the AARST Consortium on National Radon Standards and as accredited to meet essential requirements for American National Standards by the American National Standards Institute (ANSI) has been applied throughout the process of approving this document.

Continuous Maintenance

This standard is under continuous maintenance by the AARST Consortium on National Standards for which the Executive Stakeholder Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard.

User Tools: User tools are posted online (www.standards.aarst.org/public-review) as they become available (such as templates for field notices, inspection forms, interpretations and approved addenda updates across time).

Notices

Notice of right to appeal: Bylaws for the AARST Consortium on National Standards are available at www.standards.aarst.org/public-review. Section 2.1 of Operating Procedures for Appeals (Appendix B) states, "Persons or representatives who have materially affected interests and who have been or will be adversely affected by any substantive or procedural action or inaction by AARST Consortium on National Standards committee(s), committee participant(s), or AARST have the right to appeal; (3.1) Appeals shall first be directed to the committee responsible for the action or inaction."

Radon Measurement Systems Quality Assurance

MS-QA Contents

MS-QA 2023

Radon Measurement Systems Quality Assurance

1 SCOPE

This standard of practice specifies minimum requirements for *quality systems* designed to quantify the concentration of ^{222}Rn gas in air by *qualified* professionals (QPs) and laboratories, whose data are intended to be used to determine the need for, or success of, radon mitigation. This standard is applicable to the wide variety of radon measurement devices used for indoor measurements, primarily in residential environments or buildings not associated with the possession or handling of radioactive materials.

1.1 Limitations

1.1.1 These requirements do not directly apply to the measurements made by non-trained individuals such as homeowners because such measurements fall outside of a cohesive *quality system*.

1.1.2 These requirements apply to measurements made to determine the need for remedial action and may not be applicable to special studies conducted by researchers or scientists investigating radon phenomena.

1.1.3 Adherence to this standard does not guarantee or supersede compliance with the applicable codes or regulations of any federal, state, or local agency with jurisdiction. Such jurisdictions may require additional practices.

1.1.4 This edition of the standard does not address interference from radon isotopes other than ^{222}Rn, radon decay product measurements, grab sampling methods, or radon dynamics or diagnostic measurements. Although the performance criteria could be adopted for use in a certification program, the specifications for such a program are beyond the scope of this standard.

1.1.5 This standard uses definitions and terms consistent with ANSI/AARST MS-PC including total uncertainty, imprecision and, importantly, *minimum detectable concentration*. However, the performance criteria limits specified in MS-PC are outside the scope of this standard; this standard provides criteria for *quality systems* used by QPs working in homes, schools, laboratories and workplaces.

1.1.6 This standard specifies requirements for *quality systems*, but not all specific procedures (such as compensating for various possible contributions to background) are specifically addressed. Such procedures are left to the implementation of the *qualified professional (QP)*, as long as (a) the procedures are included in the documentation that is part of the quality system including a *Quality Assurance Plan (QAP)*; (b) the *quality control (QC)* and other operations described in this standard are routinely conducted and documented; and (c) the other provisions of this standard are met.

1.2 Applicability

1.2.1 *Adoption and Use*

These standards of practice can be adopted as requirements for contractual relationships or adopted as recommendations or requirements of an authority or jurisdiction.

1.2.2 *Provisions Which Are Not Mandatory*

The terms "Note–" and "Informative advisory—" indicate provisions considered helpful or good practice, but which do not contain a mandatory requirement.

2 DEFINITIONS

Accuracy: The degree of agreement between the observed value *(X)* and the *conventionally true value (T)* of the quantity being measured. The degree of agreement is often expressed as the difference between *X* and *T*: *(X − T)*, or as a percentage relative to *T*: (100 [*X − T*] / *T*).

Aged Air: Air that has been stored and isolated for at least 30 days before use to allow the radon in it to decay to an insignificant concentration.

Alpha Track Detector (ATD): Radon detector constructed from a piece of plastic, typically of either allyl diglycol carbonate or cellulose nitrate, inside a chamber usually made of electrically conducting plastic. Radon diffuses passively into the chamber, where it subsequently decays. Alpha particles emitted from radon and two of its short-lived progeny, ^{218}Po and ^{214}Po, strike the plastic detector and create damaged volumes or "latent tracks." The plastic is etched in a caustic solution, which produces tracks that are visible with a microscope because the latent tracks are more soluble than the surrounding undamaged material in such a solution.

The plastic is scanned and the track density is determined in terms of tracks/mm^2. A *calibration factor*, determined through exposures of devices in a *STAR*, is used to convert the track density to a value of integrated concentration in the unit of Bq-h/m^3 or pCi-days/liter. The average radon concentration during the exposure is determined by dividing the integrated concentration by the length of time of the exposure.

As constant as practicable: This term is defined by agreement between the provider of the device(s) and the operator of the standard test *atmosphere for radon (STAR)* and considers the inherent function of the device(s) and the design limitations and operational requirements of the *STAR*.

Audit: As defined by the U.S. EPA, an audit is a systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives (U.S. EPA 2002).

Batch: The set of material that is considered to be homogenous regarding characteristics that determine the *calibration* relationship. For example, activated carbon is prepared and sold in batches, which are then used by laboratories to construct devices with that carbon; a single plastic melt is sold to laboratories who manufacture many ATDs from that batch.

Note—For *quality control* efforts in the field, conducting *spikes* relative to each batch of manufactured products or lots of products purchased on a specific date can be a useful verification of quality.

Bias: Systematic or persistent distortion of a measurement process that causes errors in one direction. Bias is determined by measuring the positive or negative difference from the *conventionally true value*, often as a percentage of the *conventionally true value*.

Blanks: A type of *quality control (QC)* check that quantifies detector response due to factors other than the measurement itself. Blanks are devices deployed to measure effects on the measurement result from anything other than the environment tested, i.e., effects caused during storage, shipping, handling and transport. The purpose of blanks for *in-control* operations is to verify and document the lack of influence of factors encountered outside the measured environment; their records are necessary to support data validity.

Blind: A type of *performance test* of the analytical capability of a method in which a sample is not identified as a *performance test* to the analyst.

Note—When QC detectors are processed at an analysis laboratory, best practices dictate that they should be treated and labeled as other routinely returned detectors and should not to be identified as QC detectors. As sometimes required by state regulators or as part of coordinated QC efforts with the laboratory, it may be acceptable to identify QC detectors to the analyst.

Calibration: To adjust or determine or both, the response or reading of an instrument or device relative to a series of *conventionally true values* (U.S. DOE 2011).

Calibration Factor: That factor or function that represents the relationship between the method's response and the concentration to which it is responding. The *calibration* relationship is the ratio of "rise," or the response (dependent variable represented on the vertical axis), to the "run" of the concentration being analyzed (independent variable represented on the horizontal axis). In all cases the calibration factor is based on measurement system response divided by the concentration or integrated concentration to which it is responding.

Charcoal Adsorption Device (CAD) Methods:
This class of device employs a material such as activated charcoal that adsorbs radon from the air. The amount of radon adsorbed depends on the design of the device, the type of charcoal, the exposure time and the radon concentration, temperature and relative humidity in the surrounding air. This class of device can provide an accurate representation of the average radon concentration during the exposure period if there are no large changes in radon concentration or the environment (e.g., temperature, humidity) during the exposure. Because of the half-life of radon and the time it takes for radon to adsorb, they are typically limited to exposure durations from 2 to 7 days. *Calibration* of a charcoal adsorption system is accomplished through exposures of representative sets of devices in a *STAR* for various time periods and different temperatures and humidities.

Coefficient of Variation (CV): The sample standard deviation(s) of a set of measurements expressed as a percentage of the arithmetic mean of the measurements; CV = 100 (s/mean).

Collocated: Two or more detectors or instruments that are operated simultaneously while located side by side, separated by a distance that is large enough to preclude the air sampled by any of the devices from being affected by any of the other devices but small enough so that all devices measure air that is equally representative of the general area in which the devices are located (U.S. EPA 2017).

Comparison Checks: *Collocated*, simultaneous measurements conducted for the purpose of assessing and monitoring measurement reliability. Comparison checks include but are not limited to *duplicate* measurements that are defined as *collocated*, simultaneous measurements using measurement devices of the same manufacturer, model, and most recent *calibration* date and facility.

Continuous Radon Monitor (CRM): An electronic device that (1) is capable of automatically recording a retrievable time series of numeric measurements of radon concentration averaged over time intervals of 1 hour or less; (2) has a *minimum detectable concentration (MDC)* of no greater than 148 Bq/m^3 (4 pCi/L) for a 1-hour measurement; and (3) has a *calibration factor* of at least 2 counts per hour per 37 Bq/m^3 (0.054 counts per hour [cph] per Bq/m^3 or 2 cph per pCi/L).

Conventionally True Value: The best estimate of the value of a quantity determined by a primary or secondary standard, or by a reference instrument that has been calibrated against a primary or secondary standard. For the purpose of this standard, the average radon concentration value reported by the facility that exposes a device in a *STAR* is considered to be the conventionally true value.

Corrective Action: Actions taken to identify and eliminate root causes of a problem thus preventing their recurrence.
Note—It is important to recognize that some failed QC results, especially those near the limits, may occur solely by chance and not be due to a correctible problem. In such cases, repeated QC checks will be within limits, and no corrective action is needed. Corrective action may include communicating with instrument providers, the analysis laboratory and shippers (as relevant) to find and fix the cause of poor measurement performance, as

well as thorough documentation of the problem, the solution and preventive action. Failed QC checks may indicate a problem with already-completed measurements, and corrective action in that case may include retesting environments where previous measurements are not defensible. Corrective action records document how the results of QC checks were used to validate or invalidate measurements already conducted with that measurement system.

Data Validation: Valid data are produced when a measurement system, including storage, field deployment, transport, analysis, and reporting, are operating *"in-control"* and within QC limits, and *in-control* QC checks demonstrate stable operation both before and after a set of validated data.

Duplicate Measurements: *Collocated*, simultaneous measurements conducted with instruments or devices that are identical (including manufacturer, model, and, for continuous monitors, the same most recent *calibration* facility and schedule) for the purpose of assessing and monitoring the measurement system imprecision. (See ***Comparison Check*** for a different category of QC measurements that do not require the use of identical devices.)

Electret Ion Chamber (EIC) Method: This type of device uses an ion chamber made of, or lined with, an electrically conductive material with an electret as the detecting mechanism. The surface voltage of the positively charged electret is measured before and after the exposure to radon. During the exposure, radon passively diffuses into the ion chamber and subsequently decays. The radon decay and its short-lived progeny ionize the air inside the chamber. Electrons are attracted to the electret and discharge it. From the surface voltage of the electret measured before and after the exposure, and the duration of the exposure, the average radon concentration during the exposure can be calculated using *calibration factors* determined through exposures of devices in a *STAR*. Ambient gamma rays also ionize air inside the chamber, and the effects of ambient gamma radiation must be taken into account. Different electret sensitivities and chamber sizes can be used in combination to measure a range of radon concentration ranging from 2 days to 1 year. The EIC QA requirements apply to all combinations of electrets and chambers used to measure radon concentration in ambient air.

In-Control: A measurement system that produces repeatable and stable QC results, including background, instrument stability tests and *comparison checks* for CRMs; *duplicates*, *spikes,* and *blanks* for other methods; and the method-specific checks described in this standard.

Note—The QC limits presented in this standard of practice are derived from industry experience and results that are applicable to categories of methods. Each measurement system can develop more restrictive limits than those presented here based on their QC results, which must in all cases be derived by using a method described in the companion handbook (or another statistically defensible control limit generation algorithm) and documented. Until a measurement system derives limits from its own QC results, the limits presented in this standard can be applied to determine data validity.

Individual Percent Error (IPE): The degree from which a single measured value (X) deviates from the *conventionally true value* (T). The IPE is calculated using the following equation:

$$IPE = [100 (X - T) / T] \quad (1)$$

where X = Measured value (Bq/m^3, pCi/L, pCi-d/L, Bq-d/m^3, or Bq-h/m^3)

T = *Conventionally true value* (in the same unit as X)

Laboratory Control Sample: A sample of material or a device that has been exposed to a known concentration or infused with known activities of radioanalytes, which is then used in routine procedures to track changes in different components of laboratory operations. Laboratory control samples may be laboratory standards, which are usually defined as an uncontaminated sample matrix that is spiked with known amounts of analytes from a source that is independent from the *calibration* standards.

Lower Limit of Detection, Counting Technology (LLD_{CT}) Methods (CRM, ATD and CAD): The smallest net count rate at which there is 95% confidence that a signal above background is detected (true positive). The *blank* count rate *and* blank counting time are determined by counting a *blank* sample in the laboratory. For this standard, and for devices that rely on independent event counting technology, this equation by Currie (1968) is used.

$$LLD_{CT} = 2.71/t_s + 3.29(R_b/t_b + R_b/t_s)^{1/2} \quad (2)$$

where LLD_{CT} = Lower Limit of Detection (cpm) for counting technology methods
t_s = Sample counting time (min), or for ATDs, the area of sample scanned (mm^2)
R_b = Background or blank count rate (cpm), or for ATDs, the blank sample track density (tracks/mm^2)
t_b = Background or blank counting time (min), or for ATDs, the area of blank sample scanned (mm^2)

Note—The LLD for ATD counting systems can use the same formula by using the areas of the plastic counted for *blanks* and field exposed detectors as surrogates for the background and sample counting times. For CRMs, the sample counting time is the time spent making a radon measurement; the background count rate and counting time are determined when measuring an atmosphere free of radon, such as nitrogen or aged air. For CADs, the sample counting time is the time spent counting the sample in the laboratory.

Lower Limit of Detection, Non-Counting Technology (LLD_{NCT}) Methods: The EIC method does not count detected radioactive decay events, but the LLD for such methods is calculated to provide the same assurance: the smallest signal at which there is 95% confidence that a signal above background is detected (true positive). EIC methods use the difference between the two voltage measurements (final subtracted from initial with the uncertainty in each voltage determination being independent of both the concentration and one another). Therefore, the combined variance is given by the sum of the variances in both the initial and final voltage, which follows the traditional root-sum-of-the-squares of sample standard deviations of both measurements. Assuming that both voltage determinations have equal variances, and using the square of sample standard deviation as the variance, results in the combined standard uncertainty in the net voltage of:

$$\text{Uncertainty in net voltage loss} = \sqrt{s_{vi}^2 + s_{vf}^2} \quad (3)$$

If both voltage determinations are assumed to have equal variances (s_v^2), then the uncertainty in net voltage loss given by the combined uncertainty of the two analyses is given by $\sqrt{2} * s_v$.
If the mean background voltage loss m_b is zero, as there should be zero voltage loss in EICs stored with the sensitive plastic prevented from discharge using a "keeper cap," this reduces to:

$$LLD_{NCT} = 3.29*\sqrt{2} * s_v^2 \text{ or the familiar} \quad (4)$$

$$LLD_{NCT} = 4.65* s_v^2 \quad (5)$$

Matrix Spike: A routine detector that has been exposed to or infused with a known amount of target analyte so that when analyzed the results include any *bias* that is introduced by the materials used in, or the configuration of, the routine detector.

Measurement Method: The combination of air sample collection system design, detector technology and analysis procedure, including software, used in the instrumentation to make radon measurements.

Measurement System: All the components that are involved in the measurement of ^{222}Rn concentration and that are part of the *quality system*, including all personnel and equipment associated with providing measurement results.

MDC (Minimum Detectable Concentration): The lowest concentration that is detectable at an established confidence (95% at minimum). The MDC is derived from the LLD by applying the same factors that are used to convert the net signal to radon concentration or integrated concentration. For a CRM, the MDC is calculated from the LLD using the CRM *calibration factor*. For CAD methods, the MDC is calculated from the LLD using factors that consider parameters such as the adsorbed moisture, the duration of the exposure, the system counting *calibration factor* and radioactive decay.

MS-PC: ANSI/AARST MS-PC *(Performance Specifications for Instrumentation Systems Designed to Measure Radon Gas in Air)* specifies that each measurement system demonstrate that when tested in a *STAR* for the shortest duration recommended by the provider:

An individual *Relative Percent Error* (RPE, also known as *Individual Percent Error*, or *IPE*) < ± 25% and a CV of a set of five < 15% in the following tests;

- for the temperature test, in a relative humidity of 10–25% and
  - a temperature of 60 ± 5°F, and
  - a temperature of 80 ± 5°F;
- for the relative humidity test, in a temperature of 65–75°F and
  - relative humidity of 15–25%, and
  - relative humidity of 70–80%.

That standard further specifies that:

- the conditions in the *STAR* may vary outside these ranges for duration exposures longer than approximately 1 week, and
- the *MDC* must be **≤** 1 pCi/L (37 Bq/m^3), for the minimum measurement period recommended by the provider (at least 48 hours), and that for 1-hour *CRM* measurements, the *MDC* shall be ≤ 4 pCi/L (150 Bq/m^3), (1-hour measurements are not used in decisions on the need for mitigation), and
- measurement systems must demonstrate sufficient proportionality so that the difference between the average *RPE* (also known as the IPE) of a set of five devices exposed at a non-zero low concentration and the average *RPE* of a set of five devices exposed at a high concentration (or integrated concentration) shall be in the range of 0 ± 15%.

Performance Test: A Performance Test, or blind performance test, is a *blind spike* in which the radon reported by the device user or laboratory is compared by an independent party, such as a chamber or proficiency program, to the established chamber concentration in which the device was exposed. Performance Test criteria historically includes an IRE of no more than 25%. Independent verification is a demonstration of quality that is valuable to third parties such as certification bodies (State or private) and consumers.

Qualified Professional (QP): An individual who has demonstrated a minimum degree of appropriate technical knowledge and training specific to radon measurement in indoor environments: (a) as established in certification requirements of a national program that is compliant with requirements in normative Appendix A; and (b) as required by local statute, state licensure or certification programs that evaluate individuals for radon specific technical knowledge and skills.

Quality Assurance Plan (QAP): A formal document describing in comprehensive detail the *quality system*, including responsibility for data validity, QA policies, QC procedures and other technical activities that need to be implemented to ensure that the results of the work conducted will satisfy the stated performance criteria. The QAP must define objectives (e.g., QC limits at various stages of the operations) and the responsibilities and authorities of personnel, especially regarding data quality and *corrective action*, including an individual

responsible for the implementation of the quality policies, who is usually known as a QA Manager or Officer. A QAP will include at least the following elements: (1) organization and responsibilities, including accountability for sufficient training of personnel and QC measurements and their documentation; (2) measurement, data review and reporting procedures; (3) systems for ensuring measurement device and data custody tracking; (4) analytical procedures; (5) assessments (audits) and corrective action; and (6) QA reporting that is used to improve quality over time. All six elements are to be documented in a QAP and associated standard operating procedures.

Quality System: Quality objectives, policies, organizational authority, responsibilities, accountability and implementation of an organization for ensuring the stated quality in its work processes and services. (ISO 9000:2000, 2.2.3) The quality system is documented in a QAP and is periodically reviewed and documented in accordance with changes and improvements in the measurement system (ANSI/ASQC 1994; U.S. EPA 2002).

QC (Quality Control): The technical activities that measure the attributes and performance of a process, item or service against defined standards to verify that they meet established specifications.

QC Interval: The interval of time necessary to gather at least approximately 20 of each type of QC check is defined as the QC interval. For example, a laboratory analyzing 500 devices each month can use approximately 3-month QC intervals for *spikes* and may use shorter intervals for *laboratory control samples* and background QC intervals as those QC checks are made more frequently. QC intervals are more fully described in Section 7.7.

RPD (Relative Percent Difference): A statistic used to evaluate the difference between two measurements when there is no evidence to support one being more accurate than the other. As with RPE, the RPD normalizes the difference between two measurements by dividing by the best estimate of the true value, which in this case is the mean of the two results. The difference is normalized (compared as a fraction) to the mean of the two results as there is no reason to assume that one measurement is more accurate than the other, and over time a set of RPD values can be used as an estimate of imprecision.

$$RPD = [(A - B) / mean] * 100 \quad (6)$$

where A = the larger result,
B = the smaller result, and
mean = the average of the two results.

Informative advisory—It is important to record whether one measurement is consistently greater or less than the other (as applicable to the method being used), as that may indicate a systematic *calibration* or background problem that can be corrected.

Note—A 10% CV for two measurements corresponds to a 14% RPD.

RPE (Relative Percent Error): A statistic used to evaluate the difference between a measurement and the *conventionally true value*, which may be a more recently calibrated CRM or a chamber concentration. The RPE is the degree from which a single measured value (X) deviates from the *conventionally true value (T)* and is sometimes called IPE. The RPE is used as an estimate of total error, combining both imprecision and bias, and RPE statistics gathered over time can be used to estimate and correct system biases.

$$RPE = [100 (X - T) / T] \quad (7)$$

where X = Measured value (Bq/m^3, pCi/L, Bq-h/m^3, or pCi-d/L)
T = *Conventionally true value* (in the same unit as X)

Significant Type Difference: Each measurement system uses *calibration factors* and algorithms to calculate the measured radon concentration from the measured and reported parameters. A significant type difference is defined as the difference between systems that requires type-specific *calibration factors* and/or algorithms to meet the requirements of *MS-PC*. Significant type differences include:

- Any factor that results in a difference in the efficiency of the detection mechanism (e.g., a change in a charcoal *batch* that is significant enough to warrant a change in the *calibration factors*, or a difference between diffusion barrier materials or design that affects radon adsorption);
- Changes in recommended measurement durations that require changes in *calibration factors* or algorithms;
- Expansion of the manufacturers' recommended range of temperature, pressure, relative humidity or radon concentration within which it should be used.

Note—Manufacturers periodically change device user interfaces, software, internal electrical components and instrument housings; such changes do not generally change the method's response characteristics and are not considered a significant change. In addition, determinations of significant change may require the evaluation of type-test data and be evaluated on a case-by-case basis rather than as categorical assessments.

Spike: Spikes are devices or materials that are exposed in a *STAR* to known radon concentrations for duration or integrated exposures normally encountered in field measurements, and which are recommended by the manufacturer and agreed to between the supplier of the devices and the exposure facility; temperatures between 60–80°F; and relative humidities between 10–75%. Spikes are submitted *blind* to the analyst and are not for *calibration* purposes but are necessary to verify and document the *accuracy* of the continued measurement system. In some cases, spikes can be used as *laboratory control samples*. Typical spiking operations disclose the radon concentration to the sender of the device. However, for a *blind spike*, the radon concentration is withheld until after the client reports the radon value back to the chamber for independent verification.

Results of spikes are assessed using the *RPE* statistic (also known by *IPE*, see definition), which is the degree from which each single measured value (spike) deviates from the chamber's average concentration during the exposure period.

Standard Test Atmosphere for Radon (STAR): A standard test atmosphere for radon, often called a "radon chamber" and termed STAR by ISO/IEC standards, including the standard for generating reference radon atmospheres (IEC 61577-4 2009). The STAR is defined as being sufficient in size and configuration and radon concentration range and controls such that:

1. At least three simultaneous and independent radon concentration measurements can be conducted at the high and/or low limits of radon concentration ranges (e.g., in pCi/L) or integrated concentration (e.g., in pCi-d/L), during which time the conditions in the STAR are *as constant as practicable*.
2. Devices are being tested for their ability to measure radon concentration.
3. Temperature, relative humidity, and radon concentration are recorded hourly or more frequently by devices with NIST-*traceable* annual *calibrations* (*traceable* as defined in this standard) and documented uncertainty estimates. If the devices being exposed are documented to have insignificant response to changes in temperature or relative humidity (see below), hourly monitoring of these parameters is not necessary but is recommended, and only the average temperature and relative humidity during exposures must be documented.
4. Barometric pressure in the STAR at local conditions is recorded or otherwise available and included in exposure reports.

5. Temperature and relative humidity are controlled to this standard's limits for the particular operation being conducted.
6. The uncertainty of the average radon concentration during the exposure period is calculated using methods recommended by NIST (JCGM 2008; Taylor and Kuyatt 1994), published and reported with each exposure, and the one-sigma total uncertainty of the average radon concentration during any duration of 48 hours or longer is less than 8%.
7. The STAR is operated under a documented quality management system, which is consistent with recognized international standards such as ISO 9001 (ISO 2015).

When the term "STAR" is used within this standard, it refers to accredited chambers known as Secondary or Certified Reference Chambers and tertiary chambers such as manufacturer or laboratory chambers that are equipped specifically for calibrating a specific device or method device. Those that are tertiary chambers are only required to track hourly temperature and relative humidity (RH) environmental conditions when conducting *spikes* or *calibrations* if the integrated measurement results are affected by hourly shifts in either environmental condition. Such chambers are, however, required to track hourly radon concentrations and verify agreement no less than annually by intercomparison with a Secondary or Certified Reference Chamber STAR.

Traceability: Property of the measurement result that can be related to stated references, usually national or international standards, through an unbroken chain of comparisons, each of with their own stated uncertainties. The concept is often expressed by the adjective "traceable." The unbroken chain of comparisons is called a traceability chain (JCGM 2008b; ISO/IEC 17025; ANSI N42.22 1995).

3 REQUIREMENTS FOR ALL METHODS

Informative Advisory—It is important to recognize that usually quality assurance (QA) practices result not in the identification of out-of-control processes, but in the continued documentation of stable, within-limits operations. Only with such documentation can the validity of measurement results be defended.

3.1 Quality Assurance Required

Each *qualified professional* (QP) and analysis service provider shall be responsible for developing, documenting, and implementing their own procedures for defensible *quality control* (QC*)* processes and assessments within the context of their operation's quality management system. The requirements herein include minimum QC requirements that must be included in an annually reviewed and updated *quality assurance plan* (QAP).

3.1.1 *QC Checks*

QC checks are to be conducted, recorded, and evaluated using time sequence control charts so that processes can be reviewed for internal quality improvement with documentation available to credentialing authorities subject to confidentiality agreements.

Note—Examples of time sequence control charts are provided in the MS-QA Companion Guidance.

3.1.2 *Training*

All radon measurement methods have specific advantages and limitations, and each device type and configuration have unique procedures for use, along with critical device-specific QC control procedures. Therefore, QAP-documented, device-specific training is required to perform measurements in accordance with this standard. A record of training, e.g., certificate(s) or similar, must be maintained by the trainee and, if applicable, by the trainee's organization.

3.1.3 *Chain of Custody*

As with the transport of any sample or device to be analyzed, chain-of-custody procedures are to be implemented with documentation of times, conditions, locations, and personnel. The exact test location including building address, room and floor and all other factors relevant to the analysis or interpretation are to be recorded, stored, and relayed to the analyst as appropriate.

3.1.4 *Data Validation*

Measurement results are defensible as valid when they are bracketed in time by applicable within-limit QC results. The record of QC checks shall be part of the *quality system* documentation and available to auditors or other credentialing authorities, subject to confidentiality agreements. Valid data produced by *continuous radon monitors* must similarly be bracketed in time by documented, within-limits QC checks, and those that record automatic instrument checks, data flagging and reporting for unusual results provide increased assurance for data validity.

3.1.5 *Reporting*

When opinions and interpretations are included, the laboratory or field professional's report shall document the basis upon which the opinions and interpretations have been made. Opinions and interpretations, including initials and date, shall be clearly marked as such in a test report.

3.1.6 *Quality System*

Every QP is to operate within a *quality system*, which is documented in a QAP, as defined in this standard. Documentation shall be available to auditors and credentialing authorities, subject to confidentiality agreements.

3.2 Approved Devices and Qualified Laboratories

Conformance with this standard requires the use of devices approved through a Device Evaluation Program and laboratories certified or accredited by a laboratory approval program that meets requirements:

a) as required by local jurisdictions that have a program for evaluating and approving devices; or

b) as established by a national certification or listing program, such as the National Radon Proficiency Program (NRPP), the National Radon Safety Board (NRSB), or an equivalent program that verifies compliance with the most current version of ANSI/AARST *MS-PC* (Performance Specifications for Instrumentation Systems Designed to Measure Radon Gas in Air).

Note—Identification of two existing bodies that have a program for evaluating and listing devices that meet specified quality requirements is not an endorsement of either program.

3.3 Validation of Performance

3.3.1 *Laboratories and Analytical Services*

Performance tests are one critical verification of *traceability* between the recognized authority for radon concentration and field measurement results and are a component of *quality systems* described by international consensus standards such as ISO/IEC 17025. *Blind* performance or proficiency tests are important validations of the entire quality assurance program and are to be conducted in *standard test atmosphere for radon (STAR)* environments.

3.3.2 *Field Operations—Blind Blanks and Spikes*

Informative advisory—When field *blanks* and field spikes are processed at an independent analysis laboratory, they should be treated and labeled as other returned detectors and are not to be identified as *blanks* or *spikes* to the analyst because the objective of field QC is to monitor the stability of field operations and procedures. If there are more restrictive requirements, including those by credentialing authorities that may require the demonstration of a minimum proportion of QC detectors and chain of custody, then that authority supersedes this standard.

3.4 Measurement System Calibrations and Evaluations

To comply with this standard, measurement devices cannot be used or marketed for use outside the ranges of temperature, relative humidity and atmospheric pressure or integrated radon concentrations greater than or less than those for which the specific device type has been:

a) evaluated for capacity to achieve stable, *in-control* response or readings within warning and control limits established herein, which may include using the physical principles of the device and theoretical extrapolations based on the device design, and

b) calibrated to support expectations of *in-control* response or readings within warning and control limits established herein across the ranges of temperature, relative humidity, atmospheric pressure, and integrated radon concentrations specified for use in product instructions.

If results are reported for exposures conducted outside the ranges specified for use in product instructions, a caveat is to be included in the report with a description of concerns that were observed by the QP or in accordance with the analyst's quality policies.

If there are documented evaluations, such as from the manufacturer, demonstrating the lack of effect of an interference such as temperature or relative humidity, and such evaluation reports are available to auditors or other credentialing authorities (subject to confidentiality agreements), then *calibration* for these devices does not need to include exposures in different magnitudes of these interferences.

Calibration is conducted by exposing a set of identical devices in a standard radon test atmosphere as defined in this standard. Because different methods are affected by different interferences and durations, *calibration* procedures will be agreed upon between the supplier of the device and the calibration facility.

Informative advisory—Complete measurement system calibration should be performed before initial use or following maintenance, repair or any other changes that could affect performance (ASTM D7282 2006).

3.5 Default Minimum Criteria for Warning and Control Limits—Duplicates and Spikes

In all cases, warning and control limits shall be equal to or more stringent than the minimums provided in this standard. When applying more stringent minimums, default warning and control limits shall be updated using the results of QC checks following statistically defensible control limit generation algorithms, such as described in the MS-QA Companion Guidance Section B.

3.5.1 *Duplicate and Comparison Check Target for Imprecision*

Note—The default interim limits presented in this standard were derived assuming a conservative "*in-control*" target for imprecision that is demonstrated by the average *relative percent difference (RPD)* of *duplicate* and *comparison checks* being not greater than:

a) 14% in an environment with a radon concentration ≥ 4 pCi/L (150 Bq/m^3), and
b) 25% in an environment with a radon concentration between 2 and 4 pCi/L (75-150 Bq/m^3).

3.5.2 *Warning and Control Limits for Duplicate and Comparison Checks*

Minimum warning and control limits required in this standard are:

a) In an environment with a radon concentration ≥ 4 pCi/L (150 Bq/m^3)
   — The warning limit is reached when a *duplicate* pair or *comparison check* exhibits an RPD ≥ 28%.
   — The control limit is reached when a duplicate pair or comparison check exhibits an RPD ≥ 36%;
b) In an environment with a radon concentration between 2 and 4 pCi/L (75-150 Bq/m^3)
   — The warning limit is reached when a *duplicate* pair or *comparison check* exhibits an RPD ≥ 50%.
   — The control limit is reached when a *duplicate* pair or *comparison check* exhibits an RPD ≥ 67%; and
c) If the average of a *duplicate* pair or *comparison check* is less than 2 pCi/L(75 Bq/m^3), the warning limit is reached when there is a difference between the two results of more than 1.0 pCi/L (37 Bq/m^3).

3.5.3 *Spike Target for Measurement System Accuracy*

Note—The default interim warning and control limits presented here for *spikes* were derived assuming in-control operations produce a distribution of spike results centered on zero, with a sample standard deviation of 10%.

3.5.4 *Warning and Control Limits for Spikes*

Any single *spike* result exhibiting a *relative percent error (RPE)* (or *individual percent error* [*IPE*]) outside the range of 0 ± 20% has exceeded the warning limit, and any single spike result outside the range of 0 ± 30% has exceeded the control limit.

3.5.5 *Informative Background for Understanding Warning and Control Limits*

Limits in this standard are based upon a conservative estimate of industry performance. Most systems will exhibit smaller imprecision and bias errors. Limits generated based on actual *RPD* and *RPE* performance of a stable and in-control system, the warning limit is expected to be exceeded by chance 5% of the time, and the control limit is expected to be exceeded by chance 1% of the time; therefore, investigation after a failed check may not lead to *corrective* action. However, if more than 5% of QC checks fall outside warning limits or more than 1% fall outside control limits, an investigation should result in either corrective action or, when applying more stringent limits, regeneration of the limits that reflect actual *in-control* operations.

4 CONTINUOUS RADON MONITORS (CRM) QC

All the requirements described in Section 3 apply to each individual CRM instrument. Field operations for using CRM devices require QC procedures that include:

1. Instrument Checks
2. *Comparison Checks*, and
3. *Calibrations*

Records of within-limit QC check results at frequencies described in this standard are required to defend the data validity.

4.1 CRM Instrument Checks

Standard operating procedures are to include checks of instrument functionality at the beginning of each test conducted.

Informative advisory—The instrument checks, that include review of instrument warning indicators, should comply with manufacturer instructions and user procedures. For example, some CRM designs include automatic generators of electronic pulses resulting in a signal that would be produced by radon decay products in the detection chamber. These generators can serve as both instrument checks and as a QC measure.

4.2 CRM Comparison Check Requirements

Note—*Comparison checks* are *collocated*, simultaneous measurements conducted for at least 48 hours to verify and document the continued stable and *in-control* operation of a CRM by comparing a result to another radon measurement device not necessarily of the same method category. The purpose of both a *comparison check* and a *duplicate* are to verify and document that there have been no increases in the measurement system imprecision since the last passing QC check or calibration.

4.2.1 *CRM Comparison Checks—Frequency and Procedure*

Comparison checks are to be made with approximately every tenth measurement (i.e., 10%), so that the checks are distributed across the range of conditions, operators and usage patterns experienced by the radon measurement provider.

CRMs used in a *comparison check* are to be operated in the manner that they are typically deployed in the normal course of business. The results of *comparison checks* shall be recorded and analyzed so that the QP better understands the expected imprecision during routine, stable operations (e.g., *"in-control"* conditions).

Informative advisory—It is recommended that routine procedures for beginning chain of custody of CRMs when they are received, either new or from recalibration, include a *comparison check* with another CRM. This practice can identify malfunctions or damage during shipping and handling.

4.2.2 *CRM Comparison Check—Statistic*

The test statistic for a *comparison* check and a duplicate is the *RPD*, which represents imprecision as a percentile of the best estimate of the known concentration. Note that the RPD is always positive, as the smaller measurement result is subtracted from the greater measurement result. The average of the two devices is used in the denominator because neither *comparison checks*, nor *duplicates* can assume that either result is more reliable.

Informative advisory—If repeated checks are made with the same CRMs, it is important to document whether one CRM is producing results that are consistently greater than or less than the comparison CRM, as that indicates potential bias error and warrants investigation.

4.2.3 *CRM Comparison Check—Warning and Control Limits*

In all cases, warning and control limits shall be equal to or more stringent than:

a) If the average of the two measurements is ≥ 4.0 pCi/L, the default interim QC limits for the CRM are based upon an *"in-control"* expected deviation of an *RPD* of up to 14%.
   - The warning limit indicating a potential problem requiring investigation is triggered when an *RPD* > 28.0%.
   - The control limit indicating a potentially serious problem is triggered when an *RPD* > 36%, and if the control limit is reached the measurement system shall be subject to corrective action and probable recalibration.

b) If the average of the two measurements is ≤ 4 pCi/L (150 Bq/m^3), but ≥ 2 pCi/L (75 Bq/m^3), the QC limits are based on an *"in-control"* expected deviation an *RPD* of up to 25%.
   - The warning limit indicating a potential problem requiring investigation is triggered when an *RPD* > 50%.
   - The control limit indicating a potentially serious problem is triggered when an *RPD* > 67%.

c) If the average of the two measurements is less than 2 pCi/L, the warning limit is reached when there is a difference between the two results of more than 1.0 pCi/L (37 Bq/m^3).

Note—These minimum requirements are presented for those who do not yet have sufficient QC data to develop more stringent limits specific to their measurement systems in accordance with the guidance in the MS-QA Companion Guidance Section B or another statistically defensible control limit generation algorithm, as informed by their field experience.

Table 4.1: Criterion for CRM Comparison Checks (Duplicates if identical systems)

Average Concentration	*Warning Limit RPD*	*Control Limit RPD*
≥ 4.0 pCi/L (≥ 150 Bq/m^3)	28.0%	36.0%
< 4.0 and ≥ 2.0 pCi/L (< 148 and ≥ 75 Bq/m^3)	50.0%	67.0%
< 2.0 pCi/L (< 75 Bq/m^3)	Absolute value of the difference between the results is > 1.0 pCi/L (37 Bq/m^3)	

4.3 CRM Calibration

4.3.1 *CRM Calibration—Frequency and CRM Calibration System (Chamber)*

Each CRM is to be calibrated at least annually in a calibration facility that meets the requirements of a *standard test atmosphere for radon* as defined in this standard.

4.3.2 *CRM Calibration—Exposure Duration*

Calibration durations shall be 24 hours or longer, starting after the radon and decay product concentrations in the detection volume of the instrument have reached equilibrium and the device has reached count-rate equilibrium (typically 4 hours after the device exposure begins and as indicated by the operating instructions) and for a duration consistent with the manufacturer's instructions. Sufficient counts need to be accrued during the *calibration* exposure to ensure that the uncertainty due to few counts (i.e., counting statistics) are not the largest component of uncertainty.

4.3.3 *CRM Calibration—Exposure Conditions*

The calibration concentration is to be between 10 and 80 pCi/L.

Note—Additional *calibration* concentrations outside this range may be included in *calibration* operations.

The CRM being calibrated is to have a proportional response to radon concentrations in the range of environmental conditions and radon concentrations to which it is exposed during routine use; this proportional response is assumed by the *calibration* facility. CRMs that meet the proportionality requirements of ANSI/AARST MS-PC meet this requirement.

As described in Section 3.4, if a CRM manufacturer has documented the lack of effect of temperature or relative humidity on radon concentration in reports available to credentialing authorities (subject to confidentiality agreements), then calibration requirements do not need to include exposures to different temperatures and relative humidities; however, the average temperature, relative humidity and barometric pressure must be recorded during the *calibration* exposure.

4.3.4 *CRM Calibration—Components and Authority*

CRM *calibration* shall include the following components, all of which are to be documented:

- Verification of the "as received" status.
- Device readiness evaluation and operating parameters check, such as replacing batteries and verifying voltages and currents for some methods.
- Background assessments, using aged air or nitrogen, for at least 24 hours (including an initial 4 hours to bring the CRM to equilibrium) or as agreed upon between the *calibration* facility and the CRM provider, such as for 16 hours.

  Informative advisory—The optimal ratio for background-to-*calibration* time is a common calculation in radioanalysis (e.g., Wang and Willis 1965) and should be used as guidance for whether longer background counting times are needed.
- Adjustment of device response, if necessary, including a second exposure if needed to verify that the adjustment was successful according to the device manufacturer's instructions.

The calibrating facility is responsible to have obtained written authority from the manufacturer or the provider to conduct the calibration, because *calibrations* may often include adjusting the device response, replacing parts or other procedures indicated by the manufacturer.

4.3.5 *CRM Calibration—Documentation*

For instruments that produce radon concentration values that are retrieved and reported by the field measurement provider, *calibration* stickers that are visible on the outside of the CRM must include the facility and date of calibration, due date for recalibration and serial number. If there are factors that are required for the user to calculate concentration, these must be included on the sticker.

Note—These may include instrument background value as assessed (or assumed, if necessary) in units applicable to the method (count rate or concentration), and *calibration factor* (response/concentration).

Exception: If instruments offer field results accessible only by the manufacturer or approved third parties, a calibration sticker shall provide field measurement providers with all relevant information that is required by state or other relevant credentialing authorities.

Calibration facilities shall provide a *calibration* certificate or statement with the calibrated CRM that contains the same information that is on the *calibration* sticker plus the conditions to which the monitor was exposed, average radon concentration, environmental conditions (temperature, relative humidity, barometric pressure) and duration of exposure.

5 QC FOR FIELD OPERATIONS USING EIC, ALPHA TRACK DETECTORS (ATD), and CHARCOAL ADSORPTION DEVICES (CAD) METHODS

This section applies to the field measurement operations of EICs, ATDs and CADs, but does not include their analyses.

The purpose of QC procedures is to provide documentation of validity and to ensure measurement results are defensible; the results of QC checks must be recorded, evaluated, and used to maintain and improve measurement quality.

Field operations for these methods require QC checks, including:

1. Detector condition checks
2. *Blanks*
3. *Spikes*
4. *Duplicates*

5.1 Field Operations (EIC, ATD, CAD)—Required Detector Condition Checks

Standard operating procedures are to include checks for the integrity of the detector and package at the beginning of each test before it is opened and at the end of each test when it is closed.

Any concerns are to be logged and relayed to the QP responsible for data validation of test results, to include:

a) For CAD methods: poor closure of the charcoal container; damaged packaging; loose stickers, tape, lids and caps; or other conditions that may affect measurement;

b) For ATD methods: poor closure of the ATD, damaged packaging, loose closure of a sticker or cap, or other conditions that may affect measurement; and

c) For EIC methods: poor closure of the chambers, a loose cap or spring or debris on the electret surface, evidence of mechanical shock, or other conditions that may affect measurement.

5.2 Field Operations (EIC, ATD, CAD)—Required Blanks

Informative advisory—Blanks are devices deployed to verify and document the absence of effects on the measurement result from sources other than the air being tested, and their records are important components of defensible data. It is vitally important to deploy *blanks* in a timely manner because an investigation of any failed *blank* may result in invalidating all recent field measurements or entire inventories of stored detectors due to interferences introduced during storage or shipping.

5.2.1 *Field Operation Blanks—Frequency and Procedures*

Users of EIC, ATD, and CAD detectors are responsible for setting aside at least 5% of the number of measurements or a maximum required of 25 per month to be used as blanks. If using detectors with different configurations, even when from the same manufacturer, the same requirement applies for each different configuration, including differences in both the design of the detector as well as the type and source of the sensitive material used in the CADs and ATDs

(Note—Section 7.4 (Lab Quality Control of Detector Materials) describes quality tracking for laboratories.)

Procedures related to detector packaging and shipping, such as opening and immediately closing detectors, shall be done in conformance with manufacturer recommendations for handling *blanks*.

Informative advisory—When *blanks* are processed at an independent analysis laboratory, the deployment period represented to an independent analysis laboratory should be consistent with that of other deployed detectors or as stated by the manufacturer as the optimal deployment period for that detector.

5.2.2 *Field Operation Blanks—Distribution*

Blanks are to be distributed among all the environments where the devices are handled, stored and transported. Therefore, careful logging of location and time for all detectors used as *blanks* is required.

a) Field *Blanks*

A portion of the required 5% blanks shall be field *blanks* with additional *blanks* dedicated, if and where deemed necessary, to other evaluations such as for storage, office or trip *blanks*. Field *blanks* verify that there have been no unexpected influences during all conditions within the chain of custody. Therefore, field *blanks* are to be handled and placed exactly as the routine devices used for testing, except that the *blanks* are not used to measure radon concentration. Each field *blank* is to be carried through all steps in the measurement process, which, depending on the configuration of the device and seal, may include opening and immediately resealing the detector and may include doing so in the environment being tested.

b) Office/Storage *Blanks*

Office *blanks* verify that there were no influencing factors that occurred during storage or in-office handling. If CAD or ATD inventories are stored in a low-radon environment, RH extremes are recorded, and this information is documented and available upon request to auditors, then office *blanks* need not be used, as long as this is consistent with the manufacturer's directions. Otherwise, CAD and ATD users who cannot store devices in a monitored environment are responsible for setting aside at least approximately 5% of their devices (or as directed by the QA manager) as storage blanks.

c) Lab-Transit Blanks

Transit (or "trip") *blanks* verify and document the lack of influences during shipping.

Informative advisory—Measurement providers should follow manufacturer's instructions regarding how to conduct each type of *blank*.

5.2.3 *Control Limits for Field Operation Blanks*

The evaluation is to identify any detectable concentration or signal that is above the measurement systems *minimum detectable concentration* (*MDC*). If *blank* results indicate concentrations greater than the *MDC*, as presented in Table 5.2, then an investigation shall be conducted in consultation with the analysis laboratory.

Table 5.2 Control Limits for Blanks

Method	*Control Limit*	*Action*
CAD and ATD methods	> MDC	Investigate, document and, if necessary, take corrective action
EIC Methods	≥ 2 volts, or as recommended by the manufacturer for that configuration	

5.3 Field Operations (EIC, ATD, CAD)—Required Spikes

Spikes provide evidence of a continued accurate measurement system operation by comparing reported spike analyses results to a recognized reference authority for radon concentration. Documentation of within-limit *spikes* is necessary to support the validity of measurements. *Spikes* should be labeled and treated as other returned detectors and are not to be identified as *spikes* to the analyst.

5.3.1 *Field Operations Spikes—Frequency and Procedures*

Users of CAD, ATD and EIC methods are responsible for setting aside at least 3% of the devices deployed for field measurements as *spikes*, arranging for and interpreting their results with six per month being the necessary maximum and no less than three per year.

If using detectors of different configurations, even if from the same manufacturer, the same requirements apply for each different configuration, which includes both the design of the detector as well as the type and source of the charcoal or alpha track sensitive material. In addition, any project involving more than about 100 measurements shall include at least 3 *spikes*.

5.3.2 *Field Operation Spikes (EIC, ATD, CAD)—Statistic*

Results of *spikes* are assessed using the statistic of *RPE* (also known as IPE; see Definitions), which represents the percentage by which each single measured value (*spike*) deviates from the chamber's average concentration during the exposure period.

5.3.3 *Field Operation Spikes—Warning and Control Limits*

Any single *spike* result exhibiting an RPE outside the range of 0 ± 20% has exceeded the warning limit, and any *spike* result outside the range of 0 ± 30% has exceeded the control limit.

5.4 Field Operations (EIC, ATD, CAD)—Required Duplicates

Informative advisory—Deploying field *duplicates* provides evidence that field transport and handling procedures do not introduce unacceptable errors into the measurement system. These QC checks are very important because they can indicate changes in the system, differences between field operatives' procedures or other contributors to imprecision that occurred during field operations.

5.4.1 *Field Operation Duplicates—Frequency and Procedures*

Field operation *duplicates* are to be deployed in approximately one in 10 measurements, or 10% the time. Large projects involving more than 20 measurements are to include some *duplicates*.

Conducting duplicates is to include exposing identical, *collocated devices* (see Definitions) simultaneously for at least 48 hours, submitting them for analysis without identification as *duplicates* (*blind*) and then comparing the two results. The results of each *duplicate* pair are to be recorded and plotted on control charts for evaluation.

Field operation *duplicates* are to be distributed among different environments, operators, and projects so that the *duplicate* data reflects the range of environments tested. *Duplicates* are to be deployed in environments greater than 4 pCi/L (150 Bq/m^3), when feasible, because the results from higher concentrations will provide more information for assessing and tracking precision error.

5.4.2 *Field Operation Duplicates—Statistic*

The test statistic for *duplicates* is the *RPD*, which represents imprecision as a percentile of the best-known concentration estimate. Note that the *RPD* is always positive, as the smaller measurement result is subtracted from the larger measurement result. The average of the two detectors is used in the denominator because the best estimate of the true concentration is the average of the results; the *RPD* therefore represents the imprecision as a percentage of the best true concentration estimate.

5.4.3 *Field Operation Duplicates—Warning and Control Limits*

Each measurement system can develop more restrictive limits than those presented here based on its QC results, which are to be derived in all cases using the method described in Section 3.5 (or another statistically defensible control limit generation algorithm) and documented. Until a measurement system derives such limits from its own QC results, the limits warning and control limits shall be equal to or more stringent than the minimums presented in Table 5.4 as described in Section 3.5.

Table 5.4: Criteria for Duplicates Using ATD, CAD and EIC Methods

Average of the two devices	*Warning Limit RPD*	*Control Limit RPD*
≥ 4.0 pCi/L (≥ 150 Bq/m^3)	28.0%	36.0%
< 4.0 and ≥ 2.0 pCi/L (< 148 and ≥ 75 Bq/m^3)	50.0%	67.0%
< 2.0 pCi/L (< 75 Bq/m^3)	Absolute value of the difference between the results is > 1.0 pCi/L (37 Bq/m^3)	

If any *duplicate* pair result exceeds these criteria, which may happen even in a small percentage of perfectly operating, *in-control* operations (especially at low radon concentrations), then an investigation in consultation with the analyst or analysis laboratory is required as described in Section 3.5.

5.5 EIC Field Operations—Additional Requirements for Electret Ion Chambers

Analysis of EIC detectors requires additional information to ensure that the voltage loss is due only to the radon in the air being tested. Information to be logged and relayed to the EIC analyst includes:

a) Log and Report Test Location Elevation.
The elevation at the measurement location is to be accurately logged and relayed to the EIC analyst; and

b) Log and Report Potential Gamma Interference and Exact Test Location.
If there is anecdotal or other information about radioactivity in building components—natural stone (such as rock collections, granite counter tops, stone hearths, or slate pool tables) or exposed bedrock in or near the building—this information is to be logged and relayed to the analyst or analysis laboratory for consideration and retention in records for that test location.

6 ANALYSIS OF EICs

6.1 QA Required

The analysis service provider or laboratory shall be responsible for developing, documenting and implementing its own procedures for defensible QC processes and assessments within the context of its own operation's quality management system. QC records are to be maintained and retained so that QC processes can be reviewed for internal QC improvement and available if needed to auditors or credentialing authorities, subject to confidentiality agreements.

Results of QC checks are to be recorded, evaluated, and used to improve quality performance when using the EIC method. QC checks that are required when using EIC methods include both:

a) QC checks conducted during field operations in accordance with Section 5; and

b) Additional QC requirements conducted in association with analysis that include:
   1. Detector condition (including maintenance, storage, and transport)
   2. Verification of acceptable analysis environment

6.1.1 *EIC Operations and Responsibilities*

Ensuring that QC checks are conducted, including field operation QC checks for detector condition, blanks, spikes and duplicates, is the responsibility of:

a) the QP when engaged in both field operations and detector analyses, or

b) the analyst when field operations are conducted by other individuals.

These responsibilities include adequate training for individuals for each task required in the EIC chain of custody including both field operations and detector analysis.

6.2 *Informative* Description of the EIC Method

The EIC detector consists of:

a) an ion chamber made of an electrically conductive plastic, and

b) an electret as the detecting mechanism. The electret is typically an electrically charged disk that is housed in an electrically conductive plastic holder. The surface voltage of the electret is positively charged and, when attached to the ion chamber, ionization that results from the decay of radon and its decay products within the chamber reduces the voltage of the electret.

EIC analysis entails measuring the electret surface voltage both before and after field deployment by a special surface voltage measurement device. The loss of surface voltage, duration of the exposure, elevation, ambient gamma exposure rate and configuration-specific *calibration factors* are used to calculate the average radon concentration.

6.3 EIC Analysis QC—Condition of Detectors

Standard operating procedures are to include checks for the integrity of the chambers and the electrets during storage, transport and immediately before and at the end of each measurement.

6.3.1 *EIC Analysis—Visual Inspections of Detectors*

Visual inspections are to include checking the condition and cleanliness of the outside or inside of the chamber, chamber closure, loose cap or spring and debris on the electret surface or other conditions that may affect the measurement. Any concerns encountered are to be logged and relayed to the QP responsible for *data validation* of test results and measurement system maintenance.

6.3.2 *EIC Analysis—Detector Transport and Storage*

Informative advisory—Electret surfaces should be exposed to a minimum of air volume except when the electrets are used to measure radon concentrations or are being analyzed, and the period of exposure to air when assembling or analyzing electrets is to be as brief as possible.

6.3.3 *EIC Analysis—Timely Transport or Shipping for Analyses*

Transport, shipping and handling must be arranged so that the initial pre-test surface voltage is measured not more than 7 days prior to the beginning of the exposure, and the final surface voltage is measured not more than 7 days after the end of exposure. Exceptions to these durations are acceptable if agreed upon between the analyst and the manufacturer.

6.3.4 *EIC Analysis—Electret Voltage Drift*

All new electrets are to be inspected and their voltage measured upon receipt. Any electrets with initial voltage that is less than manufacturer's specifications are to be returned to the manufacturer. For the voltage drift evaluation:

a) The initial voltage and the serial number of each new electret are to be recorded in QA logs, and at least 5% of all new electrets (including 5% of each electret type) shall be randomly chosen for voltage drift tests.

b) All electret surfaces are to be kept covered with protective caps or other mechanisms to minimize exposure to air during the voltage drift tests.

c) The voltage drift of each of the electrets used for short-term testing should be measured over a period of at least 4 weeks and are to exhibit an average voltage drop of no more than 6 volts per month or as specified by the manufacturer.

d) The voltage drift of the electrets used for long-term testing should be measured over a period of at least 3 months and are to exhibit voltage loss of no more than 4 volts per month or as specified by the manufacturer.

e) Any voltage loss measured in these electrets of more than the limits specified above is to be investigated and corrective action taken in collaboration with the manufacturer.
Note—Such *corrective action* may include invalidation of measurements already conducted with electrets of the type that exhibited voltage drift.

6.4 EIC Analysis QC—The Electret Voltage Reader

6.4.1 *EIC Analysis—Annual Calibrations of Voltage Readers*

Calibration of the EIC analysis system includes *calibration* of both the voltage reader and the reference electrets used with every analysis session. The surface voltage reader is to be calibrated annually by the manufacturer (or a manufacturer-approved calibrator) and have a *calibration* certificate and a sticker visible indicating the date of the last calibration and the next *calibration* due date. The reader and electrets shall be from the same manufacturer.

6.4.2 *EIC Analysis—Storage of Voltage Readers*

Readers are to be stored in an enclosure (i.e., a sealed protective case) that includes a humidity reduction device such as desiccant, which is changed at least every year and as necessary.

6.4.3 *EIC Analysis—Checking Stability of Voltage Readers Prior to Analysis Session*

The EIC analyst is to check the reader's stable operation using the reference electret(s) and record the reader's response at least once during each analysis session, with results logged and available for review.

QC procedures for the analysis are to include using at least one reference electret, and preferably two, which are used as a QC check for repeatability of the surface voltage reader.

Note—Use of reference electrets are not a *calibration* of the reader, but rather a verification of the continued stability of the reader's response.

Informative advisory—It is recommended that the reader's response to the reference electret(s) be verified at the end of any analysis session that results in radon concentration results that are greater than an action limit or otherwise unexpected for the location. Such good business practices protect the analyst in the event of questions about the data.

6.4.4 *EIC Analysis—Control Limits for Voltage Reader Stability*

Informative advisory—If after three attempts, the voltage reading on reference electrets differs by more than the manufacturer's limits for the difference from the electret's specified value, the reader's operation is suspect and the analyst should begin collaboration with the manufacturer to investigate and conduct *corrective actions* if needed. Results from that reader from that point and earlier until the last passing reference electret reading will be suspect and may be invalidated.

6.4.5 *EIC Analysis—Annual Verification of Reference Electrets*

The continued applicability of reference electrets voltage is to be verified at least annually by the manufacturer.

6.5 EIC Analysis—Interferences

6.5.1 *EIC—Analysis Environment (including both the reader and the EIC itself)*

The electret surface voltage and its measurement are affected by several critical factors, which are to be documented, kept within limits and consistent between voltage measurements. For the analysis environment:

a) Electret surface voltage measurements used for reported radon measurements are to be made in a stable indoor environment in which the % RH is less than 60%. These conditions are to be measured and recorded at least once during each analysis session. Temperature and RH must be measured and documented, and the initial and final voltage readings must be conducted in RH environments not differing by more than 10%, or within tolerances established by the device manufacturer;

b) The EIC detectors and the reader are to be equilibrated to the temperature in the analysis environment prior to measuring surface voltage. This may require waiting at least 60 minutes (or until a consistent, stable voltage is obtained, consistent with manufacturer recommendations) prior to measuring the surface voltage; and

c) Both the pre-test and post-test surface voltage are to be measured in the same physical location to help ensure the repeatability of other factors that may affect surface voltage, including the background gamma exposure rate in the analysis environment.

6.5.2 *EIC Analysis—Control of the Consistency of Equipment and Procedures*

The procedures used to conduct the readings are to be as reproducible as possible.

a) Reader readiness checks are to be conducted prior to analyzing detectors including battery, dust checks and other pre-operational checks recommended by the manufacturer.
Informative advisory—Compressed gas is to be used, if necessary, to blow dust off the electret or reader surface. A technician's breath should never be used to remove dust.

b) The pre-test and final surface voltage are to be measured using the same reader and preferably conducted by the same technician.

c) The surface voltage is to be measured immediately after opening the device and exposing the electret surface.
Informative advisory—If the EIC cannot be analyzed immediately, it should not be opened and should be stored in a low background radiation area until it can be read.

d) The alignment of the electrets in the reader is to be consistent (e.g., serial numbers horizontal or otherwise consistent between readings).

e) Surface voltage measurements for each electret are to be conducted at least three times. A measurement is not complete until at least three identical voltages are displayed, and this repeatable surface voltage is used as the test result.
Informative advisory—If it is not possible to obtain three consecutive identical voltage readings, the manufacturer should be contacted for how to investigate a possible problem in the measurement system.

6.6 EIC Analysis—Required Calibration Factors

Electrets of different sensitivities and chambers of different sizes can be used in combination to measure a range of radon concentrations over time periods from 2 days to 1 year. The formula required for converting voltage loss to radon concentration depends on the difference between the initial and final surface voltage, duration, *calibration factors* specific to the size of the ionization chamber and electret thickness, and, for some configurations, elevation (air pressure) corrections. Elevation correction factors account for alpha ionization path length inside the chamber and should be applied using algorithms and software that are available from the manufacturer.

6.6.1 *Reported Test Results and Calibration Factors for Each EIC configuration*

The final reportable test results shall be derived from using the calibration factor that is established by the EIC manufacturer for specific EIC configurations. Each combination of chamber size and electret voltage, such as short- or long-term use electrets, requires that the analyst apply the correct *calibration factor* to the EIC configuration according to the manufacturer.

6.6.2 *Reported Test Results and Calibration Factor Adjustments for Elevation and Gamma*

The final reportable test results shall include *calibration factor* adjustments established by the EIC manufacturer that account for elevation of the location tested and ambient gamma radiation.

Note—The *calibration* relationship for EIC measurement systems includes subtraction of that proportion of voltage loss due to ionization caused by the ambient background gamma exposure rate (ion formation by gamma radiation). The vast majority of testing is done in locations where there is no information leading the technician to suspect that there is increased gamma exposure rate, and in these cases the state-wide average gamma exposure rates published by a relevant federal agency (Bogen and Smith 1981; Mauro and Briggs 2005; Oakley 1972) or supplied by the manufacturer can be used.

6.7 EIC Analysis—Verifying System Calibration and In-Control Operations

Voltage reader *calibration* and field operation *blanks*, *spikes* and *duplicates* are required for maintaining in-control operations. Because spikes assess sources of error in the entire field/laboratory measurement system, continued *calibration* verification for EIC measurement systems is achieved using *spikes* with 3% of all tests conducted and with 6 per month and no fewer than 3 per year the maximum necessary.

7 LABORATORY REQUIREMENTS FOR ALL METHODS

7.1 Minimum General Requirements

The requirements in this section and Section 3 apply to laboratory analysis for all methods, including requirements for QA, QC checks, training, chain of custody, *data validation*, reporting, *quality systems*, approved devices and qualified laboratories, measurement system *calibration* and default minimum control limits. All of the requirements in this section and in Section 3 apply to charcoal adsorption devices (analyzed with gamma counting or liquid scintillation analysis) and alpha track devices. Responses for both devices depend on the material used in the detectors as well as the particular device model configuration; *calibrations* and QC checks are to be specific to both materials and configurations.

7.2 Laboratory Specific QA

Laboratories shall be responsible for developing, documenting, and implementing procedures for defensible QC processes and assessments that include a full *calibration* conducted specifically for each laboratory, device configuration/material and analysis system configuration, and for monitoring data imprecision and *bias* that results from the *quality system* measurement process, including shipping.

QC records are to be maintained and retained so that QC processes can be reviewed for internal improvement and are available to auditors and credentialing authorities, subject to confidentiality agreements.

The requirements herein are minimum requirements for procedures to be included in a *Quality Assurance Plan* with QC checks logged in QC records. Most analysis laboratories will have additional QC procedures to meet their *quality system's* requirements.

7.3 Responsibilities

Ensuring adequate QC within the laboratory is the responsibility of laboratory management, with duties often assigned to quality managers. Adequate QA includes verification and documentation of:

a) sufficient training of individuals responsible for laboratory operations;

b) verifying that the detection media quality as well as the materials used (charcoal or alpha-sensitive plastic, scintillant, etc.) meet the QAP requirements;

c) continued applicability of the *calibration factors* and functions (curves);

d) QC operations conducted at required frequencies, with results within warning and control limits or appropriate investigative and *corrective actions* taken, as needed;

e) maintenance of equipment and system; and

f) quality policies as specified in a QAP, revised as operations change, and records of all QC checks, which are available to auditors or credentialing authorities, subject to confidentiality agreements.

7.4 Lab QC of Detector Materials

Detector response is dependent on the *batch*-specific properties of activated charcoal or alpha-sensitive plastic, which is used when assembling the detector. It is the responsibility of the laboratory to:

a) ensure the detector material background properties and response to radon concentrations (sensitivity) are known and consistent within the limits set by the laboratory;

b) track which detectors are made from specific materials so that the correct *calibration* functions (curves) are applied as well as aid in investigations of imprecision, failed *spikes*, *blanks* or other QC results, such as successions of *blanks* greater than the *MDC*; and

c) determine shelf life beyond which the laboratory can no longer warrant the detector to be reliable.

Laboratories who assemble detectors are responsible for testing the homogeneity of the *batch* using standard sampling techniques, tracking which detectors were constructed from which *batch*, and setting limits on the ranges of the characteristics that affect their use as detectors (e.g., background and response to radon exposure) so that the requirements in this standard are met.

7.5 Calibration

To operate within the requirements of this standard, a radon measurement analysis laboratory shall develop and document operating procedures and *calibration* relationships specific to the laboratory, analysis equipment, and detector material and configuration.

7.5.1 *Calibration Chamber*

The *calibration* system chamber must meet the requirements of a standard test atmosphere for radon, as defined in this standard.

7.5.2 *Exposures*

The requirements of Section 3.4 (Measurement System Calibrations and Evaluations) apply to all methods, including those detector characteristics that require calibration exposures to include exposures of sets of devices to different environmental conditions.

If the device configuration is affected by temperature and relative humidity, as are charcoal adsorption methods, *calibration* exposures are to expose at least five, and preferably more, devices at a time in an exposure *calibration* chamber to combinations of three parameters. These include separate exposures to environments of:

a) three different relative humidity ranges, including an RH less than 30%, an RH between 40% and 60%, and an RH greater than 60%;
b) two different temperatures, including one greater than 70° F; and
c) at least three different durations/integrated concentrations.

(Note—These combinations result in a total of up to 18 separate exposure sets of at least five devices in each set.)

Full *calibration* is to include using the resulting corrected count rates in nonlinear regression analyses to generate interpolated functions (curves), which best represent the relationship between counts and the radon concentration to which the device was exposed.

Informative advisory—The use of tabular-only *calibration factor* "lookup" values is discouraged, because computer algorithms can be used to arrive at interpolated correction factors specific to, for example, the duration and change the specific CAD mass.

7.6 Initial and Ongoing Warning / Control Limits for Laboratory Assessments of Bias and Imprecision

Note—Laboratories assess components of error in their operations using various QC checks as part of their routine operations. For example, conducting a second analysis of the same device assesses imprecision due to the analysis system only. Other checks assess imprecision of the entire laboratory system, such as with lab *duplicates* exposed to a concentration greater than the *MDC*. Other checks assess *bias*, such as a *laboratory control sample* that is used to verify and document that no drift has occurred in the analysis system electronics, or a laboratory control *matrix spike* device is introduced in the beginning of the lab custody to assess total error in laboratory operations.

Informative advisory—QA managers must be vigilant and imaginative in assessing these results as well as inserting QC checks into other operations as investigative tools.

7.6.1 *Minimum Warning and Control Limits*

The limits presented in this standard of practice are the basic minimums, and it is expected that labs will develop their own limits based on at least 20 different types of QC checks and then develop, document and periodically evaluate their own limits specific to their operations using the methods referenced in Section 3.5 or other statistically defensible control limit generation algorithms.

7.7 Establishment of In-Control Operations

Informative advisory—Because recalibration can entail a large set of chamber exposures (at least five of each unique parameter combination or as consistent with the requirements in Section 7.5), it is important to keep all factors as consistent as possible to allow stable, *in-control* operations without having to generate new *calibration factors*.

7.7.1 *Adequate Statistics Required*

This standard does not dictate specifics for the triggers that mandate recalibration but does supply the following principles that shall be incorporated into the laboratory's QAP:

a) At least approximately 20 valid QC checks of each type used by the laboratory to monitor stability (at minimum, 20 lab spikes, 20 lab *blanks* and 20 *laboratory control samples*, as relevant) are necessary to establish adequate statistics to determine *in-control* operations.

(*Informative advisory*—An optional type of QC check, lab *duplicates* or recounts, is recommended for at least periodic assessments of imprecision components due to laboratory activities.); and

b) Determination of stability.
The determination of calibration function stability shall be based on at least the variability and mean for:

1. background as determined using matrix blanks,
2. the RPE for laboratory *spikes*, and
3. *laboratory control samples* (such as *matrix spikes*) during every analysis session.

7.7.2 *QC Interval and Continued Assessment of In-Control Operations*

The *QC interval* is defined as the shortest interval of time needed to gather at least 20 of each type of QC check necessary for the laboratory's *quality system*.

After *calibrations in-control* operations are established, an initial pool of QC results is to be collected and analyzed, which will produce control charts with QC limits. These QC limits are used as a baseline against which future QC results will be compared and demonstrate the validity of measurements made during the time periods when QC results are within limits.

The data needed for continued assessment and documentation of stable *calibration* functions shall include:

a) At least approximately 20 QC checks of each type used by the laboratory to monitor system performance that are charted, evaluated statistically, and used to characterize the *in-control* distribution (variability and mean) of each QC check type.

b) At least approximately 20 QC checks of each type from subsequent *QC intervals*, which are charted, evaluated statistically, and compared with the mean and variability of the initial post-*calibration*, *in-control* set of QC results.

c) An ongoing analysis of QC results demonstrating that there are no statistically significant (probability >5%) changes in the mean or the variability of the current set of QC check results when compared to both the:

1. results from the most recent *QC interval*, and

2. the initial post-*calibration* QC results.

Laboratories are permitted to use a rolling assessment "look-back" period after the initial *in-control* limits are set or other systems designed to ensure that their operations are in control and that analysis results are accurate. Such QC records and analyses are to be available to auditors and credentialing authorities, subject to confidentiality agreements.

7.7.3 *Minimum Intervals between Calibrations*

As *batches* of sensitive material, equipment and all the details involved in device analyses change over time, warning and control limits are to be recalculated based on changes in QC results.

The same *calibration* functions can be used by CAD and ATD analysis laboratories for up to 5 years if:

1. No new materials are used in the device or new instrumentation introduced, including counters, shielding, electronics, charcoal, plastic, containers, etc.; and
2. There is documentation, including QC data, demonstrating that there has been no statistically significant (5%) change in the population (mean and variability) for each type of QC check. This is done by comparing the current QC results to the most recent *QC interval* and the initial post-*calibration* population of QC checks.

7.7.4 *Use of Calibration Factors Beyond Any 12-Month Period*

Tests for both changes in the mean and the variability shall be conducted and documented to validate the continued use of the *calibration factors* beyond 12 months.

A two-tailed F-test (Snedecor and Cochran, 1983), as well as other methods, can be used to test if the variances of two populations are equal, and these results will indicate whether the equal-variability t-test is appropriate. An unpaired two-sample t-test (Snedecor and Cochran, 1989), among others, can be used to determine if two population means are equal.

If these analyses demonstrate that there is less than a 5% probability that the most recent set of QC checks come from a different population of QC checks (based on a comparison of both mean and variability) than either the original post-*calibration* set or the set from the most recent QC interval, the calibration period is permitted to extended beyond 12 months. The results of such analyses are to be available to auditors for review and determination of acceptability.

7.8 Laboratory Spikes

Note—Lab *spikes* assess sources of error in the entire laboratory measurement system relative to a recognized reference radon concentration. These laboratory QC checks are independent of *calibration* operations and are designed to measure and track variability within the entire laboratory's *quality system*. To do this, *spikes* are handled and analyzed just as routine detectors. These QC checks are in addition to *laboratory control samples* that track variability of equipment performance or internal processes.

7.8.1 *Analysis Laboratory—Spike Frequency*

Laboratory *spikes* are to be conducted with at least three laboratory spikes per every 100 devices processed, or a maximum necessary of six per month. If a laboratory analyzes different configurations, the same requirements apply for each different configuration, which includes both the detector design as well as the type and source of the charcoal or alpha track-detection plastic. The definition of *significant type difference* can be used to determine the need for sample *spikes* for devices with different characteristics.

7.9 Analysis Laboratory—Duplicates or Recounts (Best Practice)

Note—The fourth type of laboratory-specific QC measurement that may be tracked and analyzed using control charts with probability-based limits is laboratory *duplicates* (side-by-side exposures), which assess imprecision in the entire laboratory system and recounts of the same exposed device, which assess imprecision only in the analysis operation. In either case, the results can be tracked using the *RPD* of the pairs.

Informative advisory—If possible, laboratory *duplicates* should be exposed in an area with a radon concentration large enough to produce adequate counts or signal. If the distribution of *RPD* values (mean and sample standard deviation) of lab *duplicates* and recounts is similar to the distribution of *RPD* from field *duplicates*, then documentation will provide evidence that laboratory processes do not add significant variability.

7.9.1 *Minimum Warning and Control Limits—Duplicates or Recounts*

Until a laboratory generates at least 20 laboratory *duplicates* or recounts, the criteria in Table 7.1 can be used as interim default values.

Note—As referenced in Section 3.5, these limits were derived using the chi square function, when precision error is a constant function of the mean.

Table 7.1: Temporary Default Criteria for Lab Duplicates/Recounts

Average of the two devices	*Warning Limit RPD*	*Control Limit RPD*
≥ 4.0 pCi/L (≥ 150 Bq/m^3)	28.0%	36.0%
< 4.0 and ≥ 2.0 pCi/L (<148 and ≥ 75 Bq/m^3)	50.0%	67.0%
< 2.0 pCi/L (< 75 Bq/m^3)	Absolute value of the difference between the results is > 1.0 pCi/L (37 Bq/m^3)	

8 LAB QA FOR CHARCOAL ADSORPTION DEVICES—GAMMA SPECTROSCOPY METHODS

This section applies to the gamma counting method of analyzing charcoal adsorption devices. All requirements in Sections 3 and 7 apply to this method, including laboratory-specific QA/QC training, chain of custody, *data validation*, reporting, *calibration*, warning and control limits, responsibilities, QC of detector material and minimum intervals between system calibrations.

8.1 CAD / Gamma Spectroscopy—Standard Counting Configurations

Note—Common systems for analyzing activated carbon adsorption detectors include:

- 3" by 3" NaI (Tl) or other gamma-ray detector and photomultiplier,
- At least 5 cm of lead shielding that completely surrounds each detector,
- High-voltage power supply,
- Pre-amplifier and amplifier,
- Single- or multi-channel analyzer and scaler,
- Timing system,
- Standard counting configurations, placement jigs and procedures to standardize the counting geometry as much as possible and
- Gravimetric scale that measures the device mass before and after exposure.

8.1.1 *Equipment Maintenance*

All system components are to be routinely maintained and verified for functionality when operating to analyze detectors. Concerns are to be logged and relayed to the quality manager or persons responsible for *data validation* of test results.

8.1.2 *Gravimetric Scale Requirements*

The measurement error of the scale, as listed on the scale manufacturer documentation, shall not exceed 0.01 g, and the scale shall be recalibrated at least annually in accordance with manufacturer recommendations.

In addition, at least one documented counting session-specific QC check is to be conducted with at least one standard weight, compared to tolerance limits, repeated when outside the limits, documented as part of each counting session QC log and *corrective action* implemented when warranted.

Note—Section 18.6.7 of the Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP) (U.S. EPA et al. 2004) provides guidance on control, *calibration* and maintenance of *calibration* instruments that are used for mass measurements.

8.2 CAD / Gamma Spectroscopy—QC of Detector Materials

Gamma emitters in the energy region of interest that are inherent in the unexposed charcoal can vary from *batch* to *batch*. It is the laboratory's responsibility to measure and track the background and efficiency associated with different *batches* using device serial numbers. The background count rate from one or a set of background counts on each counter is to be subtracted from the gross counts of exposed devices prior to applying the *calibration* relationship described in Section 8.3. This information aids staff and users of these detectors during investigations of imprecision, failed spikes or failed *blanks* with successive results higher than the *MDC*. Finally, variability in background counts is necessary to determine the *MDC*.

Concerns regarding the integrity of closure for detector packaging are to be logged and relayed to staff who are responsible for the integrity of detectors.

8.3 CAD / Gamma Spectroscopy—Calibration Relationship

Note—The equation originally published by George (1984) can be used, as well as others, to calculate the radon concentration from the net count rate as shown below in equation 8:

$$C = NCR / (CF * t_e * \varepsilon * DF) \quad (8)$$

where C = Rn concentration (pCi/L)

NCR = net count rate (cpm), including the subtraction of configuration- and counter-specific background count rate

CF = *calibration factor* (L/min), specific to configuration

t_e = exposure time (min)

ε = continued *calibration* verification check (cpm/pCi) which is often kept as unity and tracked separately (see Section 8.5.1)

DF = decay factor (unitless)

- DF corrects for radon decay between the device sealing and its analysis;
- ε, the continuing *calibration* verification, sometimes known as the daily instrument check, is determined by counting a sealed, laboratory standard QC sample (standard can or device containing radon in equilibrium with a known activity of ^{226}Ra or containing other radionuclide such as ^{230}Th with gamma emission rates of between 1,000–10,000 counts per minute in the energy region of interest) of the same geometry as the devices to which ε is applied; and
- CF determined from the *calibration* functions (curves) that incorporate both moisture gain, as change of mass before and after exposure, as well as the duration of exposure.

8.4 CAD / Gamma Spectroscopy—Establishment and Maintenance of In-Control Operations

Determining *calibration* function stability shall be based on, and continually assessed, using the variability and mean of (a) analysis session background counts, (b) laboratory QC standards for session efficiency and (c) at a frequency of at least 3%, RPE for laboratory spikes. Results of counting session backgrounds and laboratory QC standards shall be recorded during every analysis session and compared to warning and control limits derived from previous responses. As presented in Section 7.7, adequate statistics are obtained after at least 20 of each type of QC check that are used for monitoring system performance.

8.4.1 *Batch Specific Calibration Relationships*

Activated carbon used in detectors is prepared in *batches*, with variation in efficiency and background between *batches*. Laboratories are to develop *batch*-specific *calibration factors* and background characterizations (through *STAR* exposures) and monitor within-*batch* variations in both.

8.5 CAD / Gamma Spectroscopy—Analysis Session Quality Assurance

The session-to-session and between-counter variability of analysis system components, including gamma counting systems and associated electronics, shall be controlled and documented each day when analyses are performed. *In-control* operation of counting systems is to be verified through consistent use of QC checks specific to each device configuration and detector. The following checks are to be repeated daily or at least once during each counting session for each device configuration analyzed (Definitions—*Significant Type Difference*), and each counting system used.

8.5.1 *CAD / Gamma Spectroscopy—Continuing Calibration Verification Using Laboratory Control Devices*

Counter response can fluctuate over time, and a laboratory standard QC device (*matrix spike*) is to be analyzed at the beginning of each counting session to determine the stability of the counting system, ε,

for that counter, that session and for the set of devices corresponding to the configuration of the laboratory standard QC device.

Laboratory standard QC devices, also known as *matrix spikes* in this context, are devices that have been impregnated with a gamma emitter, preferably ^{226}Ra, and are sealed so that radon is in equilibrium with ^{226}Ra inside the device, which provides a benchmark indicator of individual counter response fluctuations. Use of radionuclides other than ^{226}Ra may require adjustment for decay over time and must be evaluated for applicability to the energy region of interest. The results of one or more continuing *calibration* verifications using one or more laboratory standard QC device results are to be incorporated into the *calibration* relationship described in Section 8.3.

In addition to being used in the algorithm to generate radon concentrations from the NCR, counting efficiencies are to be tracked and analyzed using statistically based control chart limits that have been generated from previous QC standard results for each configuration. Records of the continuing *calibration* verifications are necessary for documenting the counting system stability.

8.5.2 *CAD / Gamma Spectroscopy—Characterization of the Background Count Rate (Lab Blanks)*

Characterization of the background count rate within the energy range (region of interest [ROI]) for each counting system requires measuring the count rate from unexposed, sealed devices that are dedicated solely for use as background devices, and which may be assigned a specific detector.

The gamma emitters in the ROI that are inherent in the unexposed charcoal may vary from *batch* to *batch*, and it is the laboratory's responsibility to measure and track the background associated with different sets of device serial numbers. The background count rate from one or more background counts on each counter is to be subtracted from the gross counts of exposed devices prior to applying the *calibration* relationship.

8.5.2.1 Initial Calibration—Background Checks

Note—At the initial *calibration*, background counts should be repeated as many times as necessary to demonstrate that the background counts do not vary more than would be expected due to Poisson counting statistics alone.

8.5.2.2 Routine Operations—Background Checks

During routine operations, background count rates are to be counted to measure counting-session-specific background, as well as differences between counters. At least one background count for a duration sufficient to acquire enough counts (i.e., 400) to reduce the error—due to assumed Poisson counting statistics alone—to 5% is to be conducted each counting session on each counter.

9 LAB QA FOR CHARCOAL ADSORPTION DEVICES—LIQUID SCINTILLATION METHOD

This section applies to the method of analyzing charcoal adsorption devices using liquid scintillation (alpha/beta counting) analysis. For this method, all requirements in Sections 3 and 7 apply, including laboratory-specific QA/QC training, chain of custody, *data validation*, reporting, *calibration*, warning and control limits, responsibilities, QC of detector material and minimum intervals between system *calibrations*.

Note—Liquid scintillation (LS) counts the alpha- and beta-particle emissions from radon and its decay products that have adsorbed onto activated carbon. In this method, a container of activated carbon is exposed during the measurement, sealed, and sent to a lab, where a liquid medium capable of converting the kinetic energy of radioactive alpha and beta emissions into light energy is added to the container and mixed. The liquid medium includes several components (thus termed a "cocktail"), including a solvent and phosphor(s). When dissolved in the solvent, molecules of phosphor convert the absorbed energy from radiations emitted by radon decay products into light. After sufficient time is allowed for the elution process of desorbing the radon into the fluid, the container is analyzed in an automated, shielded, light-sealed counter using photomultiplier tubes, generally in a coincidence-counting pair to ensure that light counted is from radioactive emissions and not chemiluminescence. With every counting session, appropriate background and laboratory standards are also counted; the net count rate from the sample is proportional to the radon concentration to which the activated carbon was exposed.

9.1 CAD / LS—Standard Counting Configurations

Note 1—LS counters can be automated machines capable of counting hundreds of vials in one counting session. Because the vials are placed in size-appropriate wells, configuration can be standardized. Each counter consists of a mechanism to move the vials into position and two photomultiplier tubes with associated coincidence counting software. Counting generally is conducted for as long as is necessary to obtain adequate counts.

Note 2—Depending on the mass of charcoal used and other factors, some systems for analyzing activated carbon adsorption detectors via LS analysis may include a gravimetric scale, which is used to measure the mass of the device before and after exposure and is used with exposure duration to determine the appropriate *calibration factor* (CF) for each device's change in mass.

9.2 CAD / LS—QC of Detector Materials

Because this method uses activated carbon, the requirements for assuring the homogeneity and stability of the carbon (*batch* testing) are the same for this method as for carbon analyzed using gamma counting (Section 8.2).

Informative advisory—Because the charcoal mass used in LS counting is generally small (e.g., 2 grams), the requirements for within-*batch* testing are critical.

The liquid mixture (cocktail) is composed of several components and must also be standardized. This may be done by the cocktail manufacturer, in which certificates of uniformity that are supported by test results should be obtained so that the consistency of relevant cocktail characteristics is documented. In addition, cocktails degrade over time, and users are responsible to follow manufacturer's recommendations regarding shelf life and use cocktails in laboratory standards and *blanks*.

9.3 CAD / LS—Calibration Relationship

LS counting efficiency depends on several factors including the degree of quenching in the sample/cocktail mixture. Chemical quenching reduces the number of photons generated by the radioactive decay, and color quenching absorbs light in the wavelength range emitted by the scintillator, which reduces the number of

photons that reach the photomultiplier tubes. The degree of quenching is dependent on the scintillator fluid used and is to be determined during each counting session for the samples being counted. Quenching can be determined for each sample using features built into many liquid scintillation counters.

Each LS Counter is to be calibrated to the range of energies that it will detect, such as the commonly used *calibrations* based on laboratory exposures of the charcoal devices to ^{222}Rn. Where required by the manufacturer, LS counters used for this application must be calibrated using ^{226}Ra. Subsequent counter stability checks must be made with the laboratory standards that are recommended by the LS counter manufacturer and are usually made with Tritium (^{3}H) or ^{14}C.

Note—The activity can be calculated as shown below in equation 9:

$$C = NCR / (CF * t_e * \varepsilon * DF) \quad (9)$$

where C = Rn concentration (pCi/L)

NCR = net count rate (cpm), including the subtraction of configuration- and counter-specific background count rate

CF = calibration factor (L/min), specific to configuration

ε = continuing calibration verification (cpm/pCi), which is often kept as unity (see Section 9.5)

t_e = exposure time (min)

DF = decay factor correcting for decay between device sealing and analysis (unitless)

- DF corrects for radon decay between the device sealing and its analysis;
- CF is determined from the calibration functions (curves) that incorporate both moisture gain (if incorporated), as change of mass before and after exposure, as well as the duration of exposure.

9.4 CAD / LS—Establishment and Maintenance of In-Control Operations

Conducted in accordance with the requirements in Section 7.7, laboratories are to use results from at least 20 lab *spikes*, 20 lab *blanks* and 20 laboratory standard device counts to establish and monitor system stability. In addition to these categories of QC devices, the laboratory shall evaluate lab *duplicates* or recounts of the same device (with decay corrections) as part of investigations and periodic evaluation of system stability.

Calibration function stability shall be based on the distribution (variability and mean at minimum) characterization of results from (a) counting session backgrounds, (b) laboratory standard QC devices and (c) the *RPE* for laboratory *spikes*.

Note—Interferences include static electricity, which can be released as a burst of light from the cocktail. Static electricity counts can be reduced by using glass instead of plastic vials and wiping vials with antistatic sheets.

9.5 CAD / LS—Analysis Session Quality Assurance

Continuing *calibration* verifications are required to determine the background and counter response by counting at least two laboratory standard QC devices and *blanks*. *Blanks* are also to be counted, recorded and assessed during each counting session.

LS counter operations include automatic instrument stability checks that are to be part of every counting session to ensure consistent responses that are within the limits.

Informative advisory—Laboratory standard QC devices should consist of a standard solution containing a known emission rate such as known for ^{226}Ra, ^{3}H and ^{14}C to verify counter stability and apply normalization factors that are specific to that counting session, as necessary.

10 LAB QA FOR ALPHA TRACK DETECTOR (ATD) METHODS

This section applies to the method of counting tracks in alpha-sensitive material. For this method, all requirements in Sections 3 and 7 apply, including laboratory-specific QA/QC training, chain of custody, *quality systems*, *data validation*, reporting, *calibration*, warning and control limits, responsibilities, QC of detector material and minimum intervals between system calibrations.

This standard presents limits on QC results that are applicable to all configurations and are defined by the combination of chamber, plastic and the etching and counting process.

10.1 ATD Laboratory—Standard Counting Configurations

Note 1— Detectors. This type of radon measurement method uses a piece of plastic, typically of either allyl diglycol carbonate or cellulose nitrate, inside an electrically conducting plastic chamber. Radon diffuses passively into the chamber, where it subsequently decays. Alpha particles emitted from radon and two of its short-lived progeny, ^{218}Po and ^{214}Po, strike the plastic detector and create damaged volumes or "latent tracks." The plastic is etched in a caustic solution, which produces tracks that are visible with a microscope, as the latent tracks are more soluble than the surrounding undamaged material in such a solution.

Note 2— Analysis. ATD analysis uses a microscope or computer optic system to determine the track density in tracks/mm^2. A *calibration* factor, determined through device exposures in a *STAR*, is used to convert the track density to a value of integrated concentration in Bq-h/m^3 or pCi-d/L. After subtracting the background track density that is appropriate to the *batch* of plastic, the average radon concentration during the exposure is determined by dividing the integrated concentration by the length of the exposure time. Each ATD configuration is associated with different exposure periods, such as 90–365 days, with some ATD configurations effective for time periods as short as 10 days.

10.2 ATD Laboratory—QC of ATD Materials

10.2.1 *Alpha-Sensitive Plastic and Etchant*

Laboratories are to measure background track density and its variability in at least 5% of the detectors made from each *batch*. Background track density is used in the algorithm (1) to generate radon concentration from the exposed detector counts from the same batch, and (2) to generate the *lower limit of detection* (from background within-*batch* variability), which is then translated to *MDC* using the *calibration* relationship.

In addition to being used in the algorithm to generate radon concentration from the track density, the variability in background tracks is to be tracked and analyzed using control charts as a QC measure to identify changes in the measurement system.

Some laboratories arrange for testing and certification (e.g., ASTM STP 643 [ASTM International 1978]) to assess plastic components used in the detectors. Etchant characteristics are to be within QAP-specified limits and may be purchased as certified to be within those limits. Limits on the range and variability of material characteristics can be set by the laboratory if the results of the QC tests, including chamber-exposed *spikes* conducted at a rate of 3% of the tests conducted, meet the *lower limit of detection*, imprecision, total error and proportionality requirements of the ANSI/AARST MS-PC standard.

10.2.2 *ATD Laboratory—Storage of Alpha-sensitive Materials*

Because any radon exposure can cause tracks, shipping and handling procedures are to provide as little air exposure as possible except to the environment being tested. Especially for configurations that allow shorter term exposures, background track accrual and the variability in background (tracks accrued in all

the processes other than the actual exposure) shall be thoroughly characterized, limited, documented and monitored by the analysis laboratory.

10.2.3 *ATD Laboratory—Shelf Life*

Note—Shelf life varies for different device types. Because of the accrual of background, the effects of aging and possible changes to alpha sensitivity, the ATD laboratory should determine and publish, including in instructions to consumers, the time period after which the laboratory can no longer warrant the detector to be reliable.

10.3 ATD Laboratory—Calibration Relationship

Note—The plastic material's sensitivity to alpha particles, the material/analysis system's background and aging effects on the plastic are critical parameters for this method. Although the principle of this method is based on the number of tracks in the plastic being proportional to the time-integrated radon concentration to which the plastic was exposed, the phenomenon of overlapping tracks makes the *calibration* relationship nonlinear for higher exposures.

10.3.1 *Batch-specific Calibration Factors*

To maintain performance within the requirements for lower limits of detection, imprecision, total error and proportionality of ANSI/AARST MS-PC, *batch*-specific *calibration factors* are necessary. Each *batch calibration* must assess the effect of at least three factors (sensitivity, background, and aging) on track density over the range of integrated concentrations to which the *calibration* relationships apply, including the nonlinear relationships for overlapping tracks. The assessment includes characterizing the sample frequency distribution (means and sample standard deviations at a minimum) that are taken from the *batch* regarding:

- sensitivity of the plastic to alpha particles from a range of directions and within the appropriate energy range,
- background track density of the plastic as processed, and
- effect of aging (fading) on the plastic in terms of both sensitivity and background.

Calibration characterizations are made by exposing sets of devices in a *STAR* and are to be conducted when there is a change in the supply of track-sensitive material, device configuration, handling and etching procedures, etchant or counting systems, or as part of an investigation due to failing QC results.

It is the manufacturer's responsibility to track QC results from different configurations and batches to monitor factors that apply to different batches of alpha-sensitive material.

Note—Assessing the effects of aging on background track density and sensitivity should be conducted at least annually to generate factors that can compensate for background increases in older plastic.

10.4 ATD Laboratory—Establishment of In-Control Operations

This standard presents the following principles that shall be incorporated into the laboratory's QAP while allowing for flexibility in implementation and the derivation of limits that are specific to each laboratory and analysis system. Conducted in accordance with Section 7.7, ATD analysis laboratories are to use limits from at least 20 independent determinations of different laboratory QC checks to monitor system performance. Although terminology and sampling procedures to meet these requirements may vary (e.g., counting tracks in 20 areas and counting tracks in 20 separate samples can both be used to characterize the distribution of track counts), basic requirements include the characterization (mean and sample standard deviation at minimum) and continued monitoring and documentation of processes and materials used during analyses and handling procedures.

Informative advisory—These characterizations should take place at the inception of operations and on an ongoing basis, with documentation available to auditors from credentialing authorities who operate under confidentiality agreements.

10.5 ATD Laboratory—Ongoing In-Control Operations

Verification of the processing and analysis system's (etchant and conditions of the etching process, microscopes, light sources, software, device configurations, recording systems, etc.) stability shall be performed as part of each component's operation.

Note—These checks can be performed by analyzing a specific set of QC detectors or plastic samples that were exposed to a known radon concentration (greater than the detection limit), and which have been designated as laboratory QC samples. *Batch*-specific QC samples should be available to verify and document *in-control* analysis operations for detectors that are associated with different *batches* of detectors, as detectors from different *batches* may be returned for analysis during the same analysis session. The mean and variability of these QC samples are used to derive laboratory limits to assess when the system operations deviate from *in-control* operations.

10.5.1 *ATD Laboratory—Development and Monitoring Control limits*

At least 20 determinations are required for the development of control limits consistent with the guidance in Section 7.7. Processes to be monitored include the stability of at least:

a) the etching materials, equipment, sensors and procedures by including at least one laboratory QC sample of material or device (laboratory *spike*) with each etching process;
b) the analysis equipment and procedures by including at least one laboratory QC device (laboratory *spike*) with each counting session; and
c) appropriate background subtractions using an ongoing assessment of a background specific to *batch* and configuration.

10.5.2 *ATD Laboratory—Laboratory QC Samples in Etching and Counting Processes*

ATD analysis is to include counting control detectors with known track densities as part of every laboratory process and with each analysis session. Control samples are obtained by exposing plastic or assembled devices in known radon concentrations (spikes). Characterizing the distribution of *laboratory control samples* (at minimum, variability and mean) is necessary to develop limits for (a) background track densities and (b) RPE of laboratory QC samples.

Laboratory QC samples are designed to:

(a) measure and track variability within the entire laboratory's *quality system*, and
(b) document the degree of agreement to concentrations in a *STAR*.

Laboratory QC samples shall be taken from different sheets of alpha-sensitive material to measure the variability of material and analysis system responses within and between *batches*.

10.5.3 *ATD Laboratory—Laboratory Duplicates or Recounts*

Note—As a best practice, laboratory duplicates and recounts can provide estimates of imprecision in different portions of the lab processes. Recounts of the same detector area assess analysis system variability and are often conducted as part of investigations after failed QC checks. As with other QC checks, continued performance within limits provides evidence of the limited imprecision caused by laboratory handling.

ANNEX A (NORMATIVE)

National Certification/Listing Programs

For private sector certifications of qualified measurement professionals, this standard requires a national program that evaluates and lists qualified individuals, training courses and other products or services, such as laboratory services, integral to achieving public health goals intended by this standard. Programs meeting the purpose, need and requirements of this standard are those with policies as established in a), b) and c) of this normative Appendix A.

a) Programs with published policies that:
   1. require persons to undergo education and an impartial examination process prior to granting personal certification or certificates of educational achievement; and
   2. require surveillance of continued competence, not less than as demonstrated by continuing education on standards updates, compliance and other related technical knowledge and skills, prior to granting recertification or renewed certificates or listings; and
   3. require, for the certification of radon measurement laboratories, initial demonstration and scheduled ongoing surveillance of compliance with ANSI/AARST MS-QA (Radon Measurement Systems Quality Assurance).

b) Programs that:
   1. have a written policy and means for receiving and adjudicating complaints against individuals or companies who have been granted a credential; and
   2. have publicly published educational and examination requirements for each credential or listing available online where readily accessible for consumers of credentialed services.

c) Programs that include educational prerequisites as follow:
   1. Qualified Radon Measurement Professional—Homes
      Certifications granted that qualify individuals as proficient in conducting radon measurements in existing homes are to include:
      a. no less than 16 hours education prior to granting certification that focuses on tasks required in ANSI/AARST MAH (Protocol for Conducting Measurements of Radon and Radon Decay Products in Homes); and
      b. biennial recertifications after completing continuing education requirements and any other program surveillance activities.
   2. Qualified Radon Measurement Professional—Multifamily and Commercial
      Listing or certification credentials granted that qualify individuals as proficient in placement, retrieval, and analysis (as applicable) of *radon* detectors and to design, plan, and implement quality procedures when conducting *radon* measurements in multifamily, school, commercial and mixed-use buildings are to include:
      a. current certification as a qualified radon measurement professional in homes; and
      b. additional education and processes approved by the program relative to tasks required in the most current version of this standard ANSI/AARST MA-MFLB (Protocol for Conducting Measurements of Radon and Radon Decay Products in Multifamily, School, Commercial and Multi-Use Buildings) prior to granting this advanced level certification or listing and recertifications or relisting.

Informative Note 1—The National Radon Proficiency Program (NRPP), the National Radon Safety Board (NRSB), or equivalent programs that also meet requirements of a), b) and c) of this normative **Appendix A** meet the requirements of this standard.

Note—identification of existing certification bodies is not an endorsement of their programs.

Informative Note 2—The purpose of requirements in this Appendix A is to ensure contractors have an appropriate degree of technical, engineering, and scientific knowledge to protect occupants by providing reliable measurements of *radon gas* present in indoor air.

ANNEX B (INFORMATIVE)

Referenced Publications

ANSI Standard N42.22: 1995 *Traceability of Radioactive Sources to NIST and Associated Instrument Quality Control.* (American National Standards Institute)

ANSI/AARST Standard MS-PC: 2015. *Performance Specifications for Instrumentation Systems Designed to Measure Radon Gas in Air.* (AARST Consortium on National Standards)

ANSI/ASQC Standard E4-1994A 1994. *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs.* (American Society for Quality Control)

ASTM Standard D3648: 2014. *Standard Practices for the Measurement of Radioactivity.* (ASTM International)

ASTM Standard D7282: 2006. *Standard Practice for Set-up, Calibration, and Quality Control of Instruments Used for Radioactivity Measurements.* (ASTM International)

ASTM Standard STP643: 1978. *Quantitative Surface Analysis of Materials*. (ASTM International)

Bogen, K.T. and A.S. Goldin. (ORP/SEPD-80-12): 1981. *Population Exposures to External Natural Radiation Background in the United States.* (U.S. Environmental Protection Agency)

Currie, L.A. 1968. *Limits for Qualitative Detection and Quantitative Determination: Application to Radiochemistry.* (Analytical Chemistry 40: 586.)

George, A.C. 1984. *Passive, Integrated Measurement of Indoor Radon Using Activated Carbon.* (Health Physics 46 (4): 867–872)

IEC Standard 61577-4: 2009. R*adiation Protection Instrumentation—Radon and Radon Decay Product Measuring Instruments Part 4: Equipment for the Production of Reference Atmospheres Containing Radon Isotopes and Their Decay Products (STAR).* (International Electrotechnical Commission)

ISO/IEC 17025: 2017 General *Requirements for the Competence of Testing and Calibration Laboratories.* (International Organization for Standardization - International Electrotechnical Commission)

ISO 9000: 2000. *Quality management systems - Fundamentals and vocabulary.* (International Organization for Standardization)

ISO 9001: 2015. Quality Management Systems: Requirements. (International Organization for Standardization)

ISO 11665-4: 2012. *Measurement of Radioactivity in the Environment—Air: Radon-222—Part 4: Integrated measurement Method for Determining Average Activity Concentration Using Passive Sampling and Delayed Analysis.* (International Organization for Standardization)

ISO 11665-5: 2012. *Measurement of Radioactivity in the Environment–Air: Radon-222—Part 5: Continuous Measurement Method of the Activity Concentration.* (International Organization for Standardization)

JCGM 100:2008. *Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement.* (Joint Committee for Guides in Metrology)

JCGM 200:2008. *International Vocabulary of Metrology—Basic and General Concepts and Associated Terms (VIM), Third Edition.* (Joint Committee for Guides in Metrology)

Mauro, J. and N.M. Briggs. 2005. *Assessment of Variations in Radiation Exposure in the United States.* (Nuclear Regulatory Commission)

NIST 2018: SOP 1. *Recommended Standard Operating Procedure for Calibration Certificate Preparation.* (National Institute of Standards and Technology)

Oakley, D.T. (ORP/SID–72-1): 1972. *Natural Radiation Exposure in the United States.* (U.S. Environmental Protection Agency. Thesis submitted to the Harvard School of Public Health, Boston, on June 30, 1973.)

Snedecor, George W. and Cochran, William G.: *1983. F-Test for Equality of Two Variances; and 1989. Two-Sample T-Test for Equal Means* (Statistical Methods, Eighth Edition, Iowa State University Press)

Taylor, B.N. and C.E. Kuyatt (NIST TN-1297): *1994. Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results.* (National Institute of Standards and Technology)

U.S. DOE (10 C.F.R. §835.2): 2011. *Occupational Radiation Protection: "Definitions."*

U.S. EPA (40 CFR 50 Appendix L sec. 8.3.7): 2006. *Reference Method for the Determination of Fine Particulate Matter as PM2.5 in the Atmosphere*.

U.S. EPA (40 C.F.R. §53.1.2017). *Ambient Air Monitoring Reference and Equivalent Methods: "Definitions"*

U.S. EPA (600/R-04/003): *2012 Quality Management Plan for the Environmental Assessment and Innovation Division*.

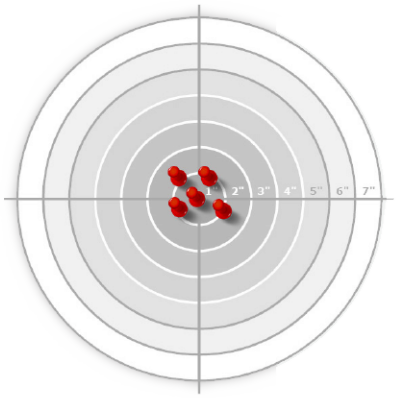
U.S. EPA (EPA-240-R-02-009): *2002. Guidance for Quality Assurance Project Plans*, EPA QA/G-5.

U.S. EPA et al. (EPA-402-B-04-001C; NUREG-1576; NTIS PB2004-105421): *2004. Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP).* (U.S. EPA, U.S. Department of Defense, U.S. Department of Energy, U.S. Department of Homeland Security, U.S. Nuclear Regulatory Commission, U.S. Food and Drug Administration, U.S. Geological Survey, and National Institute of Standards and Technology.)

U.S. EPA (600/R-04/003): *2012 Quality Management Plan for the Environmental Assessment and Innovation Division.*

C. H. Wang and David L. Willis: *1965 Radiotracer Methodology in Biological Science.* (Prentice-Hall, N.J.)

Zeeb H. and F. Shannoun, eds. 2009. W*HO Handbook on Indoor Radon: A Public Health Perspective.* (World Health Organization Press)



QA Committee Consensus Body Members

Deep appreciation is expressed for contributions of time and wisdom provided by the following experts.

Non-voting Chair: Melinda Ronca-Battista (AZ)

Non-voting Assistance Team: Gary Hodgden (KS)

Stakeholder Group	Delegate	Affiliation
(Educators)	Brian Hanson (KS)	Midwest University Radon Consortium (MURC)
(Educators alternate)	Jim Burkhart (CO)	Western Regional Training Center
(Non-Regulated States)	Clay Harwick (KY)	Kentucky Dept. of Environmental Protection
(Regulated States)	Dan Hylland (MN)	Minnesota Department of Health
(Regulated States alternate)	Ryan Fox (PA)	Pennsylvania Dept. of Environmental Protection
(Federal EPA)	Tommy Bowles (DC)	U.S. Environmental Protection Agency (EPA)
(Proficiency Program)	Shawn Price (NC)	National Radon Proficiency Program (NRPP)
(Proficiency Prog. alternate)	Bill Angell (MN)	National Radon Proficiency Program (NRPP)
(Mitigation Prof.)	Leo Moorman (CO)	Professional Service Provider
(Mitigation Prof. alternate)	Terry Howell (GA)	Professional Service Provider
(Measurement Prof.)	Tamara Linde (OR))	Professional Service Provider
(Measurement Prof. alternate)	Rick Welke (IA)	Professional Service Provider
(Building Inspectors)	Nate Burden (PA)	Professional Service Provider
(Chambers)	David Wilson (TN)	Oak Ridge National Laboratory
(Charcoal Lab)	David Grammer (NJ)	RAdata Inc.
(Charcoal Lab alternate)	Carlos Avery (MD)	Envirolabs
(Alpha Track Lab)	Tryggve Ronnqvist (SE)	Radonova
(Electret Manufacturer)	Lorin Stieff (MD)	Rad Elec, Inc.
(Scientist)	Michael LaFontaine (CN)	Physics Solutions Inc.
(Scientist alternate)	Mike Kitto (NY)	New York Department of Health (retired)
(Environmental Cons.)	Myca Bruno (NC)	Professional Service Provider

Assist Team: Joanna Mandecki, Nanci Hermberger and Denise Bleiler.

MS-QA
Companion Guidance

Radon Measurement Systems Quality Assurance

This "Companion Guidance" publication includes informational content only and is not part of the standard. It is intended only to supplement an understanding of standards content and application. There are no required practices in this content and the content has not met due all process requirements to be deemed an American National Standard.

AARST CONSORTIUM ON NATIONAL STANDARDS

Section A

Example of Time Sequence Control Charts

This example spreadsheet is provided to illustrate how easy it is to implement automation for what was once laborious data entry and calculations on paper charts.

While still referred to as "control charts", common computer programs can make it easy to watch out for quality control problems.

Spreadsheet or Database Tracking Across Time for
Duplicate and Crosscheck *QC* measurements

	A	B	C	D	E	F	G
	Data Entry - Test Result A	**Data Entry - Test Result B**	**Average of the Two Results**	**RPD**	**Expressed as a Percentage**	Avg of all RPDs	new COV
1	10	8	9	0.222	22.2%	7%	5%
2	9	10	9.5	0.105	10.5%	Looking at totals for collected data of interest across time.	
3	29	30	29.5	0.034	3.4%		
4	8	8	8	0.000	0.0%		
5	11	12	11.5	0.087	8.7%		
6	9	9	9	0.000	0.0%		
7	6	6	6	0.000	0.0%		
8	12	12	12	0.000	0.0%		
9	13	13	13	0.000	0.0%		
10	14	14	14	0.000	0.0%		
11	15	15	15	0.000	0.0%		
12	45	46	45.5	0.022	2.2%		
13	22	23	22.5	0.044	4.4%		
14	45	46	45.5	0.022	2.2%		
15	77	78	77.5	0.013	1.3%		
16	99	100	99.5	0.010	1.0%		
17	88	89	88.5	0.011	1.1%		
18	100	200	150	0.667	66.7%		

The Calculations Across Each Row						
data entry	data entry	**AVERAGE (A:B)**	**ABS(A-B) ÷ Average**	*format as %*	AVERAGE (RDP data)	Avg RDPs ÷ 1.414

Spreadsheet calculations are:

=AVERAGE(A:B)	=ABS(A-B)/C	=AVERAGE(D1:D18)	=F1/1.414
Range averaged is 2 data points: A and B	Absolute value of A minus B, divided by their average	RDP range averaged, as chosen to evaluate	Average of RDPs divided by the square root of 2

Note—Virtually all QC data can be tracked and automated this way to provide instant access for ongoing review of quality status.

Section B

Development of Quality System-Specific Performance Criteria

The limits in MS-QA are based upon a conservative estimate of industry performance. Most measurement systems will exhibit smaller imprecision and bias errors. It is possible to use more restrictive limits that can be more helpful. To make the control charts useful for specific measurement systems, the default warning and control limits can be updated using the results of QC checks following statistically defensible control limit generation algorithms.

One way to set the "in control" precision error level is to initially use a level prescribed in MS-QA that is recognized by industry and EPA as a goal for precision. It is based on a 10 percent COV (corresponding to a 14 percent RPD). After at least 20 pairs of measurements are plotted, it will become apparent whether the 10 percent COV (or 14 percent RPD) is appropriate for your system. If it is not, a new control chart should be prepared so that the warning and control limits are set at the correct probability limits for your system.

It can be shown (Iglewicz and Myers 1970, EPA 600/9-76-005; U.S. EPA 1984) that when the expected precision is a constant function of the mean, control limits can be expressed in terms of the COV.

COV=S/Xm;

where S is the variance or the square of the standard deviation, and

Xm is the mean or average of the two measurements.

One method for obtaining percentiles for the distribution of the COV is to apply a chi-squared (X2) test:

$X2_{n-1} \approx B[(n-1)COV_n^2/(n+(n-1)COV_n^2)]$ (Equation 1)

where: $B = n[1 + (1/COV^2)]$;

COV_n = the observed COV of the nth pair (the pair that is to be evaluated); and

COV = the "in control" COV (e.g., 10 percent at levels greater than 4 pCi/L).

For duplicates, where n=2, Equation 1 becomes

$X2 = [2 + (2/COV^2)][COV_n^2/(2 + COV_n^2)]$ (Equation 2)

To illustrate using the chi-squared (X2) test, we will use example data provided in the MS-QA Companion Guidance Section A for *Time Sequence Control Charts*.

1st One calculates "B": B = n[1 + (1/COV2)]

Using the example data that produced a "COV" based on a series of duplicates, this spreadsheet formula "2*(1+(1/(COV*COV))) = B" produced a "B" value of 847.8063125.

2nd For calculating the *warning level*, use chi-squared=3.84

This spreadsheet formula "SQRT((2*3.84)/("B"-3.84))" using chi-squared=3.84 produced the value 0.09539334 as a COV. This value times 1.414 converted to an RDP warning level of 13%

3rd For calculating the *control limit*, use chi-squared=6.64

This similar formula "SQRT((2*6.64)/("B"-6.64))" using chi-squared=6.64 produced the value 0.12564873 as a COV. This value times 1.414 converted to an RDP *control limit* of 18%

Section C

Understanding Statistical Counting Errors for Various CRM Instruments Relative to Detector Sensitivity for Counts Per Hour (cph)

The below table illustrates uncertainty in statistical counting (inherent to all detector designs) that varies with different commonly used models of Continuous Radon Monitors (CRM) and Electronic Integrating Devices (EID). Uncertainty regarding statistical counting for different detector sensitivities (in terms of counts per hour) is illustrated for various time periods of exposure relative to different radon concentrations.

This information can aid understanding the trustworthiness of an hourly reading (and the average for a group of hourly readings) relative to the radon concentration being measured.

Key (potential counting error)
- Red is ≥ 14%
- Orange is ≥ 10%
- Light orange is ≥ 6%
- Yellow is less than 6%

	Detector Sensitivity 2 cph/pCi/L		Detector Sensitivity 8 cph/pCi/L		Detector Sensitivity 16 cph/pCi/L	
	At 4 pCi/L Potential % error	**At 8 pCi/L** Potential % error	**At 4 pCi/L** Potential % error	**At 8 pCi/L** Potential % error	**At 4 pCi/L** Potential % error	**At 8 pCi/L** Potential % error
any **1 hr** period	35.4	17.7	17.7	8.8	12.5	6.3
any **4 hr** period	17.7	8.8	8.8	4.4	6.3	3.1
any **8 hr** period	12.5	6.3	6.3	3.1	4.4	2.2
any **12 hr** period	10.2	5.1	5.1	2.6	3.6	1.8
any **24 hr** period	7.2	3.6	3.6	1.8	2.6	1.3
any **36 hr** period	5.9	2.9	2.9	1.5	2.1	1
any **48 hr** period	5.1	2.6	2.6	1.3	1.8	0.9

Advisory

These values do not intend to represent that test results across any specific time duration will exhibit error exactly as shown, nor do they represent all potential errors and confounding factors.

Section D

Example Template for Quality Assurance Plan Manuals

Background—This template is a compilation of essential practices commonly associated with quality assurance programs as identified in the International Standards Organization "ISO 9001 - Quality Assurance".

Advisory To Read Before Reviewing This Template:

This template (rendered in a commonly used 12 point font) is not a complete Quality Assurance Plan until amended to reflect operations for an individual organization. Each topic needs to be reviewed and, as applicable, amended to match each organization's structure and operation.

In addition, a completed Quality Assurance Plan does not, in itself, fulfill requirements. Quality Control is an ongoing process. It requires tracking quality and comparing observed results to your quality policy and objectives.

Per the definition of a QA plan in MS-QA:

The QAP must define objectives (e.g., QC limits at various stages of the operations) and the responsibilities and authorities of personnel, especially regarding data quality and corrective action, who are responsible for the implementation of the quality policies.

Quality management will include at least the following elements:

(1) organization and responsibilities, including accountability for sufficient training of personnel and QC measurements and their documentation;

(2) measurement, data review and reporting procedures;

(3) systems for ensuring measurement device and data custody tracking;

(4) analytical procedures;

(5) assessments (internal audits) and corrective action; and

(6) QA reporting that is reviewed at regular intervals to improve quality over time.

All six elements are to be documented in a QAP and associated standard operating procedures.

Availability of Templates

It is the intent that text versions of field operation templates (such as this QA plan manual and field notices) will be made publicly available online. Among other locations for access, these will be posted in "User Tools" when available on each standards committee website that can be linked to from https://standards.aarst.org/public-review/

Field Services — Radon Measurement Quality Assurance Plan

Business Name: _____

_____

Address: _____

_____

_____

Phone: _____

Owner of the Business: _____

_____

Measurement Personnel:

Name(s)	Certification ID#
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

QAP Approval Date: _____

Signature of Quality Assurance Manager:

X_____

Title Page

Staff working under this plan

Latest Revision Date

Signature

Table of Contents

Table of Contents

SECTION 1: BUSINESS MANAGEMENT

1.1 **Statement of Commitment**

Our organization resolves to conduct activities in a manner that complies with the quality assurance plan set forth herein.

Commit to your QAP

1.2 **Commitment to Annual Review**

This QAP is reviewed and approved on an annual basis. A written report is also maintained that includes: audit findings; written assessment of whether or not quality goals are being reached; and suggestions to improve the program due to changes such as in technology, quality concepts and standards or regulations.

Commit to timely review of processes and policy

Distribution List

This report reflects current operations, and therefore is often updated and revised. The QA Manager/Officer has responsibility for incorporating changes and ensuring that the changes are reviewed and approved by the management, as indicated by their dated signature(s) on the signature page.

Identify who is copied after each major revision

After significant revisions, revised copies of this QAP are distributed to the following key personnel:

(X) QA Manager/Officer (X) Person(s) ultimately responsible (e.g., President)
( ) Field manager(s) ( ) Office oversight/manager
( ) Installers ( ) Procurement manager
( ) State or regulatory agencies, where required.

1.3 **Description of the Business and Work**

Our organization provides radon measurement services primarily for:
( ) Home owners or in relation to home sales ( ) Multifamily buildings
( ) Schools ( ) Large Buildings ( ) Other _____

State your general scope

1.4 Management and Organization

The names of individuals in our organization are listed below where (X) indicates all those authorized to stop inadequate quality or unsafe work

Names of Individuals	Responsibilities
(X) ___John Doe_____	QA Manager/Officer (Measurement)
( ) _____	QA Manager/Officer (Mitigation)
(X) _____	Ultimate responsibility (e.g., President)
( ) _____	Office Manager
( ) _____	Procurement Manager
( ) _____	Office oversight
(X) _____	Field supervisor
( ) _____	Measurement staff
(X) _____	Other staff member
( ) _____	Other staff member

Identify "who" is responsible for QA duties and "who" is authorized to stop unsafe or inadequate work.

1.5 Personnel Qualifications and Training

Commit to training

Our organization resolves to establish training and qualification requirements for staff and to maintain evidence of all training for the duration of employment and to retain such records for five years past the end of employment.

- All staff members are to be qualified for their apportioned task.
- Measurement tasks are to be conducted by individuals who have obtained training, skills and knowledge for conducting radon measurements, as demonstrated by certification for radon measurement services.
- All uncertified staff laborers work under the responsible charge of a certified staff member.

Identify chain of authority

1.6 Procurement of Items and Services

Commit to organize resources

To assure resources and materials are available to fulfill quality goals: Written procedures instruct field staff in providing timely notice of procurement needs to staff responsible for procurement duties and budget ramifications.

Examples of procurement needs when conducting radon measurements include calibration of testing instruments, test device purchases based on written technical and quality specifications and notices, signs, non-interference agreements and other equipment or paperwork for daily needs.

1.7 Documents and Records

Commit to responsible handling of records

Our organization resolves to control documents and records storing records so that they are legible, retrievable, protected from fire, water, theft, and deterioration. Computer software commonly associated with business management is employed and customized for needs related to radon services. Project records are retained for no less than 6 years and, as applicable, staff radon exposure records are retained for no less than 20 years.

1.8 **Planning**

Our organization resolves that: Efficient use of technology, personnel, and materials requires our commitment to planning; The elements of this quality program serve as the basic structure of staff quality commitments; and planning is to be considered an opportunity to ensure functions that are consistent with and fulfill specified requirements of quality goals and procedures.

Commit to planning

1.9 **Suggestions and Complaints**

Our organization commits to a timely and professional process for accepting, assessing, and responding to suggestions and complaints. Records of suggestions or complaints are evaluated during routine review of the QAP for determining how alternative resolutions are considered and implemented.

Your complaint policy

1.10 **Corrective Actions**

Records of corrective actions are to be included in routine internal assessments of the QAP and evaluated for how the proposed remedies were implemented and how their effectiveness is verified.

Response to quality problems

1.11 **Standard Operating Procedures (SOP)**

Our organization resolves to standardize relevant aspects of services provided in written procedures.

Commit to standardized procedures

1.12 **Calibration**

Our organization resolves to control quality for instruments and test equipment employed in conjunction with radon measurement services to include, among other quality checks, the use calibrated test equipment and laboratory services who demonstrate calibration when achieving and maintaining certifications.

Commit to calibration

1.13 **Worker Protection Plan**

Our organization resolves to maintain a worker protection program

Commit to worker safety

1.14 **Other**

_____

_____

_____

SECTION 2: MEASUREMENT SERVICES

2.1 QUALITY POLICY FOR MEASUREMENT SERVICES

a) **Measurement Quality:** Our organization resolves to conduct measurements that are in compliance with approved standards including standards for quality control as prescribed in ANSI/AARST MS-QA.

b) **Measurement Quality Objectives:** Our organization resolves to consistently produce, to the extent possible, reliable radon measurements to determine if radon mitigation is necessary in order to protect current and future occupants.

Two levels of quality commitment

2.2 STANDARDS OF PRACTICE

Our organization resolves to comply with NRPP recognized standards of practice when providing radon measurement and/or mitigation services, except as superseded by local statutes. ***Our Measurement Standard Specifications:***

Commit to standards

For measurement of single family homes:

(X) ANSI/AARST MAH: *Protocol for Conducting Measurements of Radon and Radon Decay Products in Homes*

( ) EPA: *Protocols for Radon and Radon Decay Product Measurements in Homes (EPA 402-R-93-003, June 1993).*

For measurement of multifamily buildings:

(X) ANSI/AARST: *Protocol for Conducting Measurements of Radon and Radon Decay Products in Multifamily Buildings*

For measurement of schools and large buildings:

(X) ANSI/AARST: *Protocol for Conducting Measurements of Radon and Radon Decay Products in Schools and Large Buildings*

For quality assurance of measurement devices or systems:

(X) ANSI/AARST MS-QA: *Radon Measurement Systems Quality Assurance*

List standards that all staff working under this plan are to abide by.

2.3 JOBSITE STANDARD OPERATING PROCEDURES (SOP)

Our organization resolves to collect and retain evidence of quality control.

The following practices are standard practice for our organization. Deviations from these specifications and site specific information are tracked and retained for review on jobsite tracking sheets (Appendix 2-B and 2-B)

Jobsite SOPs

2.3.1 Test Devices

All test devices used for deciding if mitigation is warranted are to be devices that are listed for having proven to meet minimum quality requirements by one of the following authorities:

Test Device Quality

a) the National Radon Proficiency Program (NRPP); the National Radon Safety Board (NRSB); or
b) as required by local statutes for jurisdictions that have a program for evaluating and approving devices.

Instrument Calibration and Laboratories: All measurement instruments such as continuous monitors are to be calibrated annually. All laboratories that analyze detectors are to be listed for having proven to meet minimum quality requirements by one of the following authorities:

a) the National Radon Proficiency Program (NRPP); the National Radon Safety Board (NRSB); or
b) as required by local statutes for jurisdictions that have a program for evaluating and approving devices.

Tracking: Devices, calibrations and laboratories that may change from time to time are shown in Appendix 2-I.

Tracking logs should be shown in Appendices

2.3.2 Onsite Personnel

Staff members conducting onsite radon measurement activities are individually trained and certified for radon measurement services.

Tracking: Individuals that may change from time to time along with evidence of applicable training and certification numbers are shown in Appendix 2-J.

Tracking logs should be shown in Appendices

2.3.3 Initial Contact with the Client

Initial testing activities are to include determining the purpose of the test and whether the building is new, occupied, and who will be responsible for closed-building conditions prior to and during the measurement period.

Closed-building protocols: Communications to clients or parties responsible for the property include essential elements required for compliance with closed-building protocols. Information about required test conditions are to be communicated when practicable to the person responsible for the home prior to when the pre-test 12-hour closed-building requirements are to be initiated.

Report distribution: Information from the client regarding their choices for where reports are sent and who is authorized to receive reports should be obtained when practicable.

Tracking: Information collected on initial contact with a confirmed client is to be recorded on test project tracking sheets and maintained in records.

Call Sheet Form should be shown in Appendices

2.3.4 Test Locations and Protocol Options

Test locations are to comply with the standards of practice listed in Section 2.2 as appropriate for the building or situation.

Onsite Tracking: Information is to be recorded by the onsite technician(s) for the exact location and serial number of each test device. Information

Job Site Form should be shown in Appendices

recorded is to provide an indication of which floor, room and location within the room where the test is conducted.

2.3.5 **Chain of Custody**

Chain-of-custody procedures and records are to be maintained to help verify responsible practices.

Onsite Tracking: Technicians are document for each test event where they were the person responsible for onsite activities. This record should be made by way of initialing tracking sheets next to the date of the testing event.

Job Site Form should be shown in Appendices

2.3.6 **Instrument/Detector QC Checks**

Onsite technicians are to conduct checks of instrument functionality and checks for the integrity of the any detector or detector packaging at the beginning and at the end of each test.

Onsite Tracking: Information is to be recorded by the staff technician for each incident where instrument functionality appears to be impaired or damaged is observed to detectors or their packaging. In addition, the technician should additionally bring concerns observed to the attention of the QA manager.

Job Site Form should be shown in Appendices

2.3.6 **Building Investigations**

To attempt verification of required test conditions, the following procedures are to be employed:

a) Inform the person responsible for building operation of the required test conditions.
b) Post notification of a Radon Test in Progress in conspicuous locations stating the required conditions of the test.
c) Request a signature on a noninterference agreement and note in the report if this document was not signed.
d) Conduct visual inspections.

Inspection policies

Visual inspections of the dwelling that evaluate observed conditions and document deviations from protocol and temporary conditions that might affect the test result are conducted by a Certified measurement professional:

i. Upon detector placement to help ensure all closed-building conditions and other protocol requirements are met; and
ii. Upon detector retrieval of the detector(s) to help verify that:
    1. Closed-building conditions and other protocol requirements are still being maintained;
    2. Detector placement has not changed; and
    3. Tamper seals, if present, have not been broken.

Onsite Tracking: The onsite technician is to document each incident where deviations from protocol and temporary conditions might affect the test result. This information along with any other quality concerns such as observations relative to noninterference controls or unsigned noninterference agreements

Job Site Form should be shown in Appendices

are to be brought to the attention of the QA manager or person responsible for approving the release of measurement reports.

2.3.7 **Radon Systems**

Where a mitigation system or efforts to mitigate radon are observed, the onsite technician is to record general description of the mitigation system observed and whether it appeared to be operating. The onsite technician should also record a description of any temporary radon mitigation strategies that are not permanent installations.

Job Site Form should be shown in Appendices

2.3.8 **Collocated (side-by-side) Duplicate/Comparison QC Checks**

Onsite Tracking: The onsite technician is to document the location and serial numbers of collocated (side-by-side) devices, including duplicate or comparison QA check devices.

Job Site Form should be shown in Appendices

2.3.9 **Blank QC Checks**

Onsite Tracking: The onsite technician is to document the location and serial numbers of blank detectors placed in the field.

2.3.10 **Weather**

Onsite or Office Tracking: The onsite technician or designated staff member is to document a description of weather conditions during the test to include the range of outdoor temperatures, precipitation, wind and any storms or high winds that are unusually severe for the location being tested.

Job Site Form should be shown in Appendices

2.3.11 **Health information**

Onsite technicians that describe radon risk in writing or verbally are to provide health risk information in accordance with the EPA's Citizens Guide; EPA's Home Buyers and Sellers Guide, and in accordance with State Radon Program requirements as applicable.

Office Tracking: Evidence of training (classroom and annual staff review) is to be documented and confusion or complaints by clients should be reviewed to add consistency to clarity on information provided by all technicians.

Staff Review no less than yearly

2.4 **DEVICE QUALITY CONTROL**

Our organization resolves to control quality by collecting, analyzing and retaining evidence of quality control for each device/detector model or type.

2.4.3 **All Devices — Duplicate/Comparison QC Checks**

Duplicates or crosschecks are deployed at a rate of 10% of all measurement locations. Evaluations verify that there have been no increases in the measurement system imprecision since the last passing QC check or calibration.

Corrective Action*:* If these evaluations indicate the *relative percent difference* between the two devices have exceeded established warning and control limits, an investigation to identify the cause may be warranted and could

Maintain ongoing log of "Dupe" QC checks

include repeating the measurements. If analysis reveals repeated results at a rate that is outside established control limits, corrective action is required.

2.4.2 **Passive Detector Blank QC Checks**

Blanks are detectors that are not exposed or left open for measuring the air in a room. Blanks are conducted and processed at a rate of 5% of test locations or a maximum required of 25 per month for each detector type or model. Blank detectors placed in the field and those processed for evaluation of storage or shipping are to be identified in records. Evaluations are made to verify the absence of effects on test results from sources other than the air being tested.

Corrective Action: If analysis of blanks reveal measurements that exceed minimum detectable concentration limits for the measurement system, investigation to identify the cause and corrective action is required and could include repeating measurements previously conducted.

Maintain ongoing log of "Blank" QC checks and any corrective actions

2.4.3 **Passive Detector Storage**

Storage locations are to be monitored for high radon concentrations, high humidity or extreme temperatures and blanks are also used to ensure against the potential of introducing detector error.

Maintain log of storage location QC checks

2.4.4 **Passive Detector Spike QC Checks**

Spikes are conducted in coordination with an approved radon chamber at a rate of than 3% of the devices deployed for field measurements with six per month being the necessary maximum and no less than three per year for each detector type or model. Evaluations are made to provide evidence of a continued accurate measurement system operation by comparing reported spike analyses results to approved radon chamber results that correlate to a recognized reference authority for radon concentration.

***Corrective Action*:** If analysis of spike reveal measurements that exceed acceptable limits for disagreeing with an approved radon, investigation to identify the cause and corrective action is required and could include repeating measurements previously conducted.

Maintain ongoing log of "Spike" QC checks and any corrective actions

2.5 **QUALITY CONTROL IN REPORTING MEASUREMENT RESULTS**

Our organization resolves to control quality of reported measurement results.

Quality Control of Test Reports

2.5.1 **Personnel**

Staff members authorized for oversight and release of radon measurement reports are to be individually certified for radon measurement services.

2.5.2 **Data Validation**

Valid data must be bracketed in time by documented, within-limits QC checks, and instrument checks, data flagging and reporting for unusual results.

2.5.4 **Standards Compliance**

Reports are to contain all content required by the standard associated with the test project.

Quality Control of Test Reports

2.5.4 **Opinions**

When opinions and interpretations are included, the laboratory or field professional's report shall document the basis upon which the opinions and interpretations have been made. Opinions and interpretations, including initials and date, shall be clearly marked as such in a test report.

2.6 ONGOING ASSESSMENTS, OVERSIGHT AND RESPONSE (MEASUREMENT)

Quality Management (Internal Audits)

2.6.1 **Ongoing Evaluation**

Evaluation for achieving successful quality for both the measurement quality and the objective of health protection is an ongoing process. Ongoing evaluation allows timely response to the cause of failed quality. The cause of failed quality can include a poor process needing improvement or poor practices conducted.

Evidence of failed quality can also come in the form of customer suggestions and complaints. Customer complaints are responded to immediately or in a timely manner.

2.6.3 **Corrective Action**

Failure of quality control within the defined limits of this QA plan is to result in timely action to identify, correct and document the problem. Corrective actions are quickly communicated to staff.

2.6.2 **Quality Assurance Audits and Reports**

The QA Officer audits operations on an ongoing basis and is responsible to convene staff meetings no less than yearly to review operational actions and results with the goal of improving existing quality procedures. Changes in procedures are written and distributed to management and affected staff.

2.6.4 **Training for Quality Assurance**

Training plans for new staff and the plans for retraining when procedures change are regularly reviewed. Adequate training is given high priority, since the implementation of this QA plan is dependent upon the staff's understanding of its requirements.

2.7 CORRECTION, REVIEW AND VERIFICATION OF EFFECTIVENESS

Corrective actions and changes to procedures are monitored and reviewed no less than annually to verify that corrections have achieved the desired quality improvements.

EXAMPLE LIST OF APPENDIX CONTENT

Appendix 2-A

Call Sheet Forms

Reserve a section for your call sheet and field tracking forms.

Appendix 2-B

Jobsite Forms

Reserve a section for your QC tracking forms/methods.

Appendix 2-C

Complaint or Suggestion Form

Reserved a section for your complaint forms

Appendix 2-D

Corrective Action - Investigation Form

Reserved a section for your investigation forms

Appendix 2-E

Client Contracts

Reserved a section for contracts used by your organization

Appendix 2-F

Our System Labels and Occupant Notices

Reserved a section for labels and notices used by your organization

Appendix 2-G

Worker Safety Plan, Yearly Review and Technician Acknowledgment Form

Reserved a section for worker safety and tracking forms for technician training

Suggestion for tracking QC, staff members, test devices and laboratory choices:

Because changes occur in a fluent manner, those records need to be readily available on virtually a daily basis.

Appendix 2-H

Staff Records

Reserved a section for all staff members working under this QA plan

Name _____ Certification Number(s) _____
Qualifications/Radon Education _____
Other _____

Name _____ Certification Number(s) _____
Qualifications/Radon Education _____

Appendix 2-I

Test Device Records

Reserved a section for tracking all test devices and laboratories.

Monitors currently employed:

Model_____ Serial# _____ Cal ____ Model_____ Serial# _____ Cal ____
Model_____ Serial# _____ Cal ____ Model_____ Serial# _____ Cal ____
Model_____ Serial# _____ Cal ____ Model_____ Serial# _____ Cal ____
Model_____ Serial# _____ Cal ____ Model_____ Serial# _____ Cal ____

Laboratories and detectors currently employed:

Detector Model _____ Lab _____
Detector Model _____ Lab _____
Detector Model _____ Lab _____

Appendix 2-J

Quality Control Tracking Sheets/Methods

Reserve a section for your QC tracking forms/methods.

- Duplicate/Crosschecks
- Blanks
- Spikes

SECTION 3: MITIGATION SERVICES?

If providing mitigation services:
Repeat essential components of Section 2 for quality policy statements associated with mitigation to include standards observed and standard operating procedures specific to mitigation practices.

Closing Advisory
Evidence of Quality Control That Auditors Look For

Field—Analytical Services (all device types individually accounted for):

Continuous Monitors:

[ ] Evidence of annual calibration for each device employed, including background;
[ ] Evidence of duplicate or comparison measurements
[ ] Evidence of tracking relative percent difference
[ ] Evidence of control actions for maintenance and subsequent to indications of device failure or inaccuracy

Electrets:

[ ] Evidence of annual re-certification of reference electrets and calibration of reader(s).
[ ] Evidence of duplicate or comparison measurements
[ ] Evidence of tracking relative percent difference
[ ] Evidence of measurements and/or correction for background gamma radiation
[ ] Evidence of checking electret voltage stability on stored devices (e.g. monthly)
[ ] Evidence of control actions for maintenance and subsequent to indications of device failure or inaccuracy.

Field—Passive Measurement Services (all non-analytical device types individually accounted for):

[ ] Written operating procedures for monitoring storage locations to ensure against the potential of introducing detector error such as can occur from high radon concentrations, high humidity or extreme temperatures.
[ ] Written operating procedures for inventory control to include considerations for: maximum shelf-life allowances; first in is in first out rotation; order date, date of receipt and quantity
[ ] Evidence of duplicate measurements and comparison measurements
[ ] Evidence of tracking relative percent difference
[ ] Evidence of measurements for background and unexpected influences (blanks)
[ ] Evidence of exposures to known concentrations (spikes)
[ ] Evidence of control actions subsequent to indications of device failure or inaccuracy.

ANSI/AARST MS-QA 2023

Radon Measurement Systems Quality Assurance