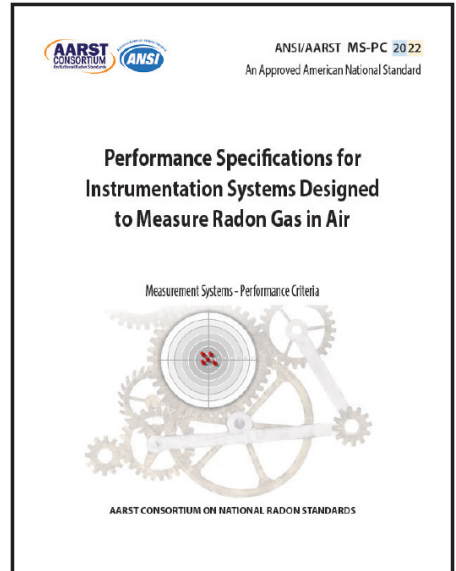# 2024 Public Review of MS-PC 2022

Consistent with plans relative to our continuous maintenance program, the latest publication of ANSI/AARST MS-PC 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-PC 2022
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-PC 2022*

• **Name:**   Affiliation:

• **Clause or Subclause**:

• **Comment/Recommendation**:

• **Substantiating Statements**:

Repeat the four bullet items above for each comment.

Intellectual rights

AARST Consortium on National Standards

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."

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MS-PC

Performance Specifications for Instrumentation Systems Designed to Measure Radon Gas in Air

1. SCOPE

This standard specifies minimum performance criteria and testing procedures for instruments and/or systems designed to quantify the concentration of ^{222}Rn gas in air. These are consistent with general performance criteria 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. Also included is a description of documentation necessary for demonstration of compliance with this standard.

Limitations: This standard addresses performance criteria for radiological and environmental parameters only. This standard does not address *calibration* or other quality assurance requirements for the use of the instruments and/or systems, or the measurement of other isotopes of *radon* such as ^{220}Rn and ^{219}Rn or *progeny* of any *radon* isotope. This edition of the standard does not address interference from isotopes of *radon* other than ^{222}Rn, grab sampling methods, mechanical and electrical issues related to the devices, or performance criteria for laboratory equipment that might be used to analyze devices, such as a gamma-ray spectroscopy system for analyzing a charcoal canister. Sampling periods of less than 1 hour in duration are explicitly excluded from performance testing procedures in this standard. Although the performance criteria could be adopted for use in a certification program, the decisions of such a program are beyond the scope of this standard.

2. SIGNIFICANCE OF USE

This standard provides guidance to *manufacturers* and/or laboratories regarding minimum performance criteria for their instruments or measurement systems with the associated tests that they should perform, or have performed by a third party, to demonstrate compliance with the standard. Such tests are conducted in a *Standard Test Atmosphere for Radon (STAR)* as defined in Section 4. Tests conducted under conditions other than the controlled conditions of a *STAR* are insufficient to determine whether the requirements of this standard have been met.

3. APPLICATION

3.1 Mandatory Conventions

The terms "shall" and "required" indicate provisions herein that are mandatory for compliance with this standard. The terms "note–", "informative", "should" and "recommended" indicate provisions that are considered to be helpful or good practice but that do not contain a mandatory requirement.

3.2 Conversion Conventions

Conversions are rounded to no more than three significant figures. For example, 4.0 pCi/L is converted to 148 Bq/m^3 and not rounded to 150 Bq/m^3. However, if a conversion results in more than three significant figures, only three significant figures are used. For example, 1500 pCi-d/L is converted to 1.33×10^6 Bq-h/m^3.

4.   DEFINITIONS & ABBREVIATIONS

Terms not defined herein shall have their ordinary meaning within the context of their use. Ordinary meaning shall be defined in "Webster's Eleventh New Collegiate Dictionary."

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.

As Constant as Practicable. This term is defined by agreement between the provider of the device(s) and the operator of the *STAR*, taking into consideration the inherent function of the device(s) and the design limitations and operational requirements of the *STAR*.

Atmosphere. Gas intended to be monitored or sampled for *radon*.

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. Similarly, a single plastic melt is sold to laboratories who manufacture many ATDs where detectors from each plastic melt are considered a batch.

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 measurement environment, 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.

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).

Response Function. That factor or combination of factors or functions that represent the relationship between the method's response and the concentration to which it is responding. The *response function* 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). Therefore, in all cases *response function* is based on method response divided by the concentration to which it is responding. Note that *response function* has been commonly expressed as the calibration factor, however *response function* includes all factors that are used to relate the response to the concentration.

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*).

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 4 pCi/L (148 Bq/m^3) for a 1-hour measurement, and

(3) has a *response function* of at least 2 counts per hour per pCi/L or 37 Bq/m^3 (0.054 counts per hour [cph] per Bq/m^3).

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*.

Electronic Integrating Device (EID). An electronic *radon* measuring device that (1) does not meet the specifications of the definition of a *CRM* in this standard, and (2) displays or otherwise provides results only for time periods at least as long as those for which it has demonstrated compliance with the performance requirements of this standard.

EPA. The U.S. Environmental Protection Agency.

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]   (1)

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

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

Integrating Device. A device that records or registers information that is directly related to the integral of *radon* concentration over time within the operating range of the device.

Lower Limit of Detection (LLD$_{CT}$), Counting Technology Methods. 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 Curie (1968) is used.

LLD$_{CT}$ = 2.71/t$_s$ + 3.29(R$_b$/t$_b$ + R$_b$/t$_s$)$^{\frac{1}{2}}$ (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, Noncounting Technology Methods (LLD$_{NCT}$). 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:

Uncertainty in net voltage loss = $\sqrt{s_{vi}^2 + s_{vf}^2}$ (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 $\sqrt{2} * s_v^2$

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 or the familiar (4)

LLD$_{NCT}$= 4.65* s_v^2 (5)

Manufacturer. Individual or organization engaged in the design, manufacture or sale of commercial instrumentation.

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.

Minimum Detectable Concentration (MDC). The concentration derived from the *LLD* by applying the response functions that are used to convert the sample net count rate to *radon* concentration or integrated concentration. For a *CRM*, the *LLD* is divided by the *response function* to obtain the MDC. For charcoal devices, the response functions include factors that take into account such parameters as the adsorbed moisture, the duration of the measurement, the system counting *response function*, and radioactive decay.

NIST. National Institute of Standards and Technology.

Performance Test. A Performance Test, or *blind* performance test, is a *blind* spike in which the *radon* concentration 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 absolute 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.

Precision. A measure of mutual agreement among individual measurements of the same property, under prescribed and similar conditions. Precision may be expressed as variance, relative percent difference, coefficient of variation, or a similar statistic that expresses the spread of the measurements from one another.

Progeny. One or more radionuclides that occur in the decay chain from a specified parent radionuclide.

Provider. *Manufacturer*, laboratory or other entity that submits devices for test in a *STAR* for the purpose of demonstrating compliance with the performance requirements of this standard.

Quality Assurance (QA). A management program which has been established to monitor, evaluate/audit, support and improve activities, including: the establishment and adherence to *quality control* and associated inspection and test procedures, use of proper documentation, and implementation of a Quality Improvement Program, as required to ensure high standards of service and product quality have been met.

Quality Assurance Plan (QAP). A formal document describing in comprehensive detail the *quality system*, including responsibility for data validity, *quality assurance* policies, *quality control* 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 actions*, 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 actions*; 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 Control (QC). An ongoing system of activities designed to measure and control the quality of a product or service to ensure it meets pre-established performance standards and the needs of users.

Quality Improvement Program. A dynamic process practiced by the person(s) responsible for quality control within an organization to ensure its Quality Control procedures comply with the evolving requirements of normative standards and industry guidelines.

Radon. The specific isotope radon-222 (^{222}Rn).

Representative. Devices that are from the same lot, *batch*, model number or other identifying characteristics and are identical in operation and configuration to such devices made available to consumers.

Sample Standard Deviation. The estimate of the standard deviation of a distribution, given by *s*, calculated by the square root of the sum of the squares of the deviations about the mean divided by one less than the sample size.

Short-Lived Radon Progeny . The following specific radionuclides in the ^{222}Rn decay chain: ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po.

Short-Lived Thoron Progeny. The following specific radionuclides in the ^{220}Rn decay chain: ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po and ^{208}Tl.

Significant change. A measurement system change requiring retesting for conformance to this standard includes:

1. A change in the detection mechanism and/or geometry that results in a change in the operating characteristics of the instrument in the field or the laboratory analysis of the device;
2. Changes in recommended measurement durations;
3. Expansion of the *manufacturer's* 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.

Spike. Spikes are devices or materials that are deployed in a STAR to known radon concentrations for duration or integrated concentrations normally encountered in field measurements. 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 test period.

Standard Test Atmosphere for Radon (STAR). A standard test *atmosphere* for *radon* (often called a "*radon* chamber"), sufficient in size and configuration, *radon* concentration range, and *radon* concentration controls such that:

1. At least five simultaneous and independent measurements of *radon* concentration can be conducted at the high and/or low limits of the ranges of *radon* concentration (e.g., in pCi/L) or integrated concentration (e.g., in pCi-h/L or pCi-d/L), during which time the conditions in the STAR are *as constant as practicable*;

2. the performance of the devices being tested is their function for measuring *radon* concentration;

3. temperature, relative humidity and *radon* concentration are recorded hourly or more frequently by devices with annual *NIST*-traceable *calibrations* (or *traceable* as defined below) and documented uncertainty estimates;

4. barometric pressure in the STAR at local conditions during tests is recorded or otherwise available and included in reports;

5. temperature and relative humidity are controlled to within the limits of this standard for the particular test being conducted;

6. the background gamma radiation at the location of the STAR (μR/h or nGy/h) is measured inside the chamber, if the chamber configuration allows;

7. the uncertainty of the average *radon* concentration during the test period is calculated using methods recommended by *NIST* (NIST TN-1297), published and reported with each test;

8. the STAR is operated under a documented quality management system consistent with recognized international standards such as ISO 9001.

Thoron. The specific isotope radon-220.

Traceable. For the purpose of this standard, the response of an instrument or system can be related, or traced, with an unbroken chain of documentation and associated estimates of uncertainty, to a standard maintained by NIST or a similar internationally recognized reference facility. Radon concentration traceability requires that the *radon* concentration used as a working standard was derived from a certified *NIST* radium-226 standard. Note: These working standards of *radon* are usually constructed by bubbling nitrogen, *aged air* or other gas through a vessel containing a certified radium solution (Ra-226 in weak acid). By strict definition, any sealed ampoule that was purchased from *NIST* and is opened is no longer *NIST*-traceable. With careful handling, however, such a solution can be transferred to another vessel while retaining its quality. At present, *NIST* produces Standard Reference Material (SRM) Ra-226 solutions that may be used to produce working laboratory standards for *radon*. There is no SRM for *radon*. General procedures for producing these working standards are described by the National Council on Radiation Protection and Measurements (NCRP; see NCRP 1988) and others (e.g., Sensintaffar 1990). Traceability for *radon* may be achieved through interlaboratory comparisons with a facility using standards as described above.

5.   UNIT ABBREVIATIONS & CONVERSIONS

The units used in this standard, abbreviations of those units, and some conversions between traditional units and those of the International System of Units (SI) are listed in Table 5.1.

Table 5.1 Unit abbreviations and conversions

Unit & Abbreviation	Conversion
becquerel (Bq) – a unit of activity	1 Bq = 1 disintegration per second = 27 pCi
becquerel per cubic meter (Bq/m^3) – a unit of activity concentration	1 Bq/m^3 = 0.027 pCi/L
becquerel-hours per cubic meter (Bq-h/m^3) – a unit of integrated concentration	1 Bq-h/m^3 = 0.00113 pCi-d/L
counts per hour (cph) – a unit of rate of observed counts	1 cph = 0.0167 cpm
counts per minute (cpm) – a unit of rate of observed counts	1 cpm = 60 cph
curie (Ci) – a unit of activity	1 Ci = 3.7x10^{10} Bq
hour (h) – a unit of time	1 h = 60 min
liter (L) – a unit of volume	1 L = 1,000 cm^3
minute (min) – a unit of time	1 min = 0.0167 h
picocurie (pCi) – a unit of activity	1 pCi = 0.037 Bq
picocuries per liter (pCi/L) – a unit of activity concentration	1 pCi/L = 37 Bq/m^3
picocurie-days per liter (pCi-d/L) – a unit of integrated concentration	1 pCi-d/L = 888 Bq-h/m^3

6. CLASSIFICATION OF INSTRUMENT SYSTEMS

Informative—The minimum performance criteria and testing requirements specified in this standard are consistent for all methods, with the exception of two additional requirements for *continuous radon monitors* used for measurements of 1-hour in duration.

6.1 Continuous Radon Monitors

To comply with this standard, a *Continuous Radon Monitor (CRM)* shall be 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 4 pCi/L (148 Bq/m^3) for a 1-hour measurement, and

(3) has a *response function* of at least 2 counts per hour per pCi/L or per 37 Bq/m^3 (0.054 counts per hour [cph] per Bq/m^3).

Note—Results with less uncertainty in the accuracy of hourly data are obtained with larger *response functions*.

Electronic *radon* measuring devices that do not provide hourly radon concentration values, or otherwise do not meet these requirements shall be classified as *Electronic Integrating Device (EID)* in accordance with Section 6.2.3.

Described below are three types of *CRMs* that differ by the mechanism used to detect radiation from *radon* and/or its *progeny*. This standard does not exclude devices with detection mechanisms that may vary from those described here, provided that the device meets all of the requirements for being classified as a *CRM*.

Informative—Measurements made during short time periods, such as 1 hour, are not independently sufficient for determining if there is need for remedial action, or mitigation, of a residence or building. Such measurements of short duration may be used to supplement measurements of longer duration by helping to judge whether or not there was some unusual occurrence (for example, a severe weather disturbance, tampering, instrument malfunction, etc.) during the measurement period that would invalidate the overall measurement. CRM requirements herein for *MDC* and *response function* are to ensure that 1-hour measurements provide results that are usable for such tasks.

Note—Continuous *radon* monitors may be affected by the temperature and relative humidity of the surrounding air. For example, some devices require that a desiccant be used so that the air coming into the monitor is very dry. If effects of temperature and humidity on the response of the device are significant according to the device manufacturer, then some method to eliminate or compensate for the effects would be needed to meet requirements in Section 7.

6.1.1 Scintillation Cells

Informative—This type of *CRM* uses a combination of a scintillation cell and a photomultiplier tube as the detection mechanism. Depending on the design of the scintillation cell, air containing *radon* is continuously pumped through the scintillation cell, or *radon* passively diffuses into the cell. The interior surface of the cell is coated with zinc sulfide (ZnS). Alpha particles emitted by *radon* and its short-lived *progeny*, ^{218}Po and ^{214}Po, strike the ZnS coating and cause it to scintillate; i.e., emit weak flashes of light. The photomultiplier tube detects the flashes of light, converts them to electronic signals, and amplifies those signals so that they can be detected as electrical pulses. The pulses are further processed by an electronics circuit and are counted using a scaler. The number of counts detected over a specific period of time is then converted to an average *radon* concentration through a *calibration factor*. The *calibration* is achieved by exposing the *CRM* to a reference *radon* concentration in a *STAR*.

6.1.2 Ion Chambers

Informative—This type of *CRM* uses an ion chamber, as described below, to detect emissions of alpha particles from *radon* and in some cases also from two short-lived *progeny* of *radon*, ^{218}Po and ^{214}Po. The ion chamber typically consists of a metal cage or cylinder defining the sensing volume with an electrode through the center. An electrical potential is applied between the cage or cylinder and the center electrode. When alpha particles travel through the air in the sensing volume, they strip electrons from molecules of gas and thus create negatively charged electrons and positively charged ions. The electrons are collected on the positively charged electrode, and the positively charged ions are collected on the negatively charged electrode. An electronics circuit detects the resulting electrical signals, shapes and amplifies the pulses, and counts them using a scaler. Depending on the design of the monitor, *radon* passively diffuses into the sensing volume, or a pump or blower is used to bring air containing *radon* into the sensing volume. The number of counts detected over a specific period of time is converted to an average *radon* concentration through a *response function* that is determined by exposing the instrument to a reference *radon* concentration in a *STAR*.

6.1.3 Solid-state Detectors

Informative—This type of *CRM* uses a solid-state detector to detect alpha particles primarily from ^{218}Po and ^{214}Po, and to a lesser extent from *radon* itself. Alpha particles striking the surface of the detector create electrical pulses. An electronics circuit detects the pulses, shapes them and counts them using a scaler. Depending on the design of the monitor, *radon* passively diffuses into the sensing volume or a pump or blower is used to bring air containing *radon* into the sensing volume. Depending on the type of detector, it may be possible to perform alpha spectroscopy; i.e., measure the energy of the alpha particle and thus identify the specific nuclide from which the alpha particle was emitted. The number of counts detected over a specific period of time is converted to an average *radon* concentration through a *response function* that is determined by exposing the instrument to a reference *radon* concentration in a *STAR*.

6.2 Integrating Methods

Described below are three types of *integrating devices* that differ by the mechanism used to detect radiation from *radon* and/or its *progeny*. This standard does not exclude devices with detection mechanisms that may vary from those described here.

Informative—This class of device stores a signal that continuously updates in such forms as an increasing number of counts or latent tracks, or a decreasing electrical charge, during the measurement period. Some devices are later processed or read out to produce a response that is directly related to the integral of the *radon* concentration over the measurement duration, enabling the calculation of the average concentration during the measurement period. Electronic devices in this class may produce measurements in real time or store data to be read out at a later time. Depending on the specific design, an *integrating device* may be used for a measurement duration as short as 2 days or as long as 1 year.

Note—Some devices in this class may be affected by the temperature and relative humidity of the surrounding air. If effects of temperature and humidity on the response of the device are significant, then some method is needed to eliminate or compensate for the effects to meet requirements in Section 7.

6.2.1 Electret Ion Chambers

Informative—This type of device uses an ion chamber made of an electrically conductive plastic with an electret as the detecting mechanism. The surface voltage of the positively charged electret is measured before and after deployment. During the measurement, *radon* passively diffuses into the ion chamber and subsequently decays. The decay of *radon* and its short-lived *progeny* ionizes the air inside the chamber. Negative ions are attracted to the electret and discharge it. Relative to the duration of the measurement, the average *radon* concentration during the measurement can be calculated using *response functions* determined

through tests of devices in a *STAR*. Electrets of different sensitivities and chambers of different sizes can be used in combination to measure a range of values of *radon* concentrations over time periods ranging from 2 days to 1 year.

Note—Ambient gamma rays also ionize air inside the chamber, therefore, the effect of ambient gamma radiation must be taken into account to meet requirements in Section 7.

6.2.2 Alpha-track Detectors

Informative—This type of device utilizes a piece of plastic, typically of either allyl diglycol carbonate or cellulose nitrate, inside a container typically made of electrically conducting plastic. *Radon* diffuses passively into the container 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 the use of 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 *response function*, determined through tests of devices in a *STAR*, is used to convert the track density to a value of integrated concentration in the unit of pCi-d/L, Bq-d/m^3 or Bq-h/m^3. The average *radon* concentration during the measurement is determined by dividing the integrated concentration by the duration of the measurement.

6.2.3 Electronic Integrating Devices

To comply with this standard:

(1) an electronic *radon* measuring device that does not provide hourly radon concentration values, or otherwise does not meet the requirements in Section 6.1 for being classified as a *CRM*, is an *Electronic Integrating Device (EID),*

(2) such a device shall only begin displaying average *radon* concentration measurements after a time period for which the device has demonstrated compliance with the performance requirements of this standard; and

(3) *EIDs* in compliance with this standard shall comply with the requirements for *MDC*, *precision* and *accuracy* as described in Section 7.

Informative—An *EID* typically utilizes one of the mechanisms described in Subsections 6.1.1 through 6.1.3 to detect alpha particles emitted from *radon* and/or two of its *progeny*, ^{218}Po and ^{214}Po. The detector and associated electronics record the number of alpha particles detected as counts, and the number of counts over a given period of time is converted to a *radon* concentration through a *response function* determined by tests of the device in a *STAR*.

6.3 Charcoal Adsorption Device (CAD) Methods

Described below are two types of charcoal adsorption devices that differ by the mechanism used to detect radiation from *radon* and/or its *progeny*. This standard does not exclude devices with detection mechanisms that may vary from those described here or devices that use an adsorbing material different from activated charcoal.

Informative—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 material, the measurement duration 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 measurement period if there are no large changes in *radon* concentration or the environment (e.g., temperature, humidity) during the measurement. Because of the half-life of *radon* and the time it takes for *radon* to adsorb, they are typically limited to measurement durations between 2 and 7 days. *Calibration* of a charcoal adsorption system

is accomplished through tests of *representative* sets of devices in a *STAR* for various time periods and different values of temperature and humidity.

6.3.1 *Gamma-ray Spectroscopy*

Informative—This type of charcoal adsorption device bases the detection and quantification of the adsorbed radon on gamma-ray spectroscopy, where gamma rays from two short-lived *progeny* of *radon*, ^{214}Pb and ^{214}Bi, are detected. This is often done using a sodium iodide detector and a multichannel analyzer system. Depending on the *manufacturer* or laboratory, the device may be in such forms as metal canisters, paper pouches or trays containing activated charcoal.

Note—Observed counts from ambient gamma radiation in the energy ranges analyzed would need to be subtracted from the gross counts to meet requirements in Section 7.

6.3.2 *Liquid Scintillation Spectroscopy*

Informative—This type of charcoal adsorption device uses liquid scintillation spectroscopy to detect alpha particles emitted by ^{222}Rn, ^{218}Po and ^{214}Po, and possibly also beta particles emitted by ^{214}Pb and ^{214}Bi, to quantify the adsorbed *radon*. The device is typically in the form of a small vial or cartridge containing activated charcoal.

7. PERFORMANCE & TESTING CRITERIA

The following criteria requirements in Section 7 shall be applicable to all types of *radon* devices or systems within the scope of this standard.

Due to the diversity of technologies addressed within this standard and the natural limitations of each technology, the *provider* shall stipulate limits upon test procedures (e.g., ranges of durations, concentrations, and integrated concentrations) that are consistent with literature published for consumers who will use the device(s).

7.1 Accuracy & Precision (Total Error)

7.1.1 Criteria

Each device shall demonstrate an *Individual Percent Error (IPE)* within 0 ± 25% when tested in a *STAR* (defined in Section 4) for the shortest duration recommended by the *provider* at:

(1) a *radon* concentration in the range of 6 – 15 pCi/L (222 – 555 Bq/m³);

(2) a temperature in the range of 65 – 75°F (18 – 24°C); and

(3) a relative humidity in the range of 10 – 55%, with *radon* concentration, temperature and relative humidity held *as constant as practicable* (defined in Section 4).

The *precision* of the devices shall be assessed using the CV of the set of five devices which shall be less than or equal to 15%.

7.1.2 Test for Accuracy & Precision (Total Error)

The test for accuracy & precision (total error) shall be conducted using the following procedure:

(1) A set of at least five *representative* devices is placed in a *STAR* for the minimum period of time recommended for use by the *provider* and under the conditions stated in Subsection 7.1.1. The *radon* concentration, temperature and relative humidity held *as constant as practicable* in the ranges stated in that subsection during the test period.

Note—See the definition of "*as constant as practicable*" in Section 4.

(2) If appropriate, such as for long-term detectors, the devices are permitted to be exposed to an integrated *radon* concentration in pCi-d/L (or Bq-h/m³) equal to the minimum time specified by the *provider* times a *radon* concentration in the range specified in Subsection 7.1.1. The conditions in the *STAR* are permitted to vary outside of the ranges specified in Subsection 7.1.1 for durations longer than approximately 1 week.

Informative—For example, if the minimum measurement duration for the device type is 10 days, then the integrated concentration should be in the range of 60-150 pCi-d/L (53 – 133 kBq-h/m⁻³).

7.2 Minimum Detectable Concentration or Integrated Concentration

Device *providers* shall calculate and report MDCs specific to minimum measurement durations and typical processing. It is incumbent on the *provider* (or *manufacturer*) to provide such statistics in at least the level of detail as described in Table 8.1.

7.2.1 Criteria

The device shall have an MDC of no greater than 1 pCi/L (37 Bq/m³) for the minimum measurement period recommended by the *provider* and when using the procedures recommended by the *provider*. This criterion shall apply to a measurement of at least 2 days in duration.

As discussed in Section 6.1, an additional criterion shall apply to 1-hour measurements made with *CRMs*. For 1-hour measurements, the MDC shall be no greater than 4 pCi/L (148 Bq/m³).

7.2.2 Test for Minimum Detectable Concentration

The basis for the MDC assessment shall be the count rate of an appropriate set of *blanks* or the background of a *representative continuous radon monitor* when measuring nitrogen or *aged air* for a time period sufficient to produce a reliable estimate of device response to an atmosphere free of *radon*.

For devices that measure counts, the MDC shall be calculated using the LLD_{CT} equation as defined in Section 4, derived specifically for methods that use counting technology. For devices that measure something other than counts, such as a drop in voltage on an electret, the background response and its variability shall be determined using the alternate LLD_{NCT} equation as defined in Section 4.

Informative—For example, the EPA requires that the MDC for ozone be calculated from the variability (measured by the *sample standard deviation*) of the ozone analyzer's response to ozone-free air (40 CFR 53.23).

7.3 Proportionality

The test for proportionality is the difference between the averages of the *IPEs* from the two sets of tests in the *STAR*.

7.3.1 Criteria

The difference between the average *IPE* of a set of five devices exposed at a non-zero low concentration (or integrated concentration) and the average *IPE* of a set of five devices exposed at a high concentration (or integrated concentration) shall be in the range of 0 ± 15%.

As in Section 7.1, the *IPE* of each individual measurement shall be in the range of 0 ± 25%, and the CV of each set of measurements shall be no greater than 15%.

7.3.2 Test for Proportionality

A set of at least five devices shall be deployed in a *STAR* under the same conditions as described in Section 7.1 for the test at a low concentration or integrated concentration. The results from the test in Section 7.1 are permitted to be used for the set of devices exposed to a low concentration (or integrated concentration).

For the test at a high concentration, a set of at least five devices shall be deployed in a *STAR* under the same conditions, to the extent practicable, of temperature and relative humidity used for the test at low concentration. The *radon* concentration shall be in the range of 30 – 60 pCi/L (1110 – 2220 Bq/m³), or at least three times the low concentration range, whichever is greater.

Where an integrated concentration test is more appropriate, the high integrated concentration test (pCi-d/L or Bq-h/m³) shall be to a value of the concentrations listed in the paragraph above (30 – 60 pCi/L or 1110 – 2220 Bq/m³) multiplied by the minimum duration recommended by the *provider* or at least three times the low integrated concentration in which the devices were tested, whichever is greater, taking into account the limitations of the *STAR*.

Informative example: The average of the *IPE* values from the test at a low concentration (or integrated concentration) might be 5%, indicating that the devices exposed to the lower concentrations are *biased* high compared to the *STAR*; and the average of the *IPE* values from the test at high concentration (or integrated concentration) might be −5%, indicating that the devices exposed to the higher concentration are *biased* low compared to the *STAR*. The difference between the two values is 10% [i.e., 5% – (– 5%)] and therefore the proportionality criterion is met in this example.

7.4 Temperature

To ensure that test results adequately represent a device's performance in a range of environments, a relatively tight control on humidity is required in the *STAR* used for testing the effects of temperature.

Informative—Radon measuring devices are typically calibrated at a temperature of approximately 70°F (21°C). If a temperature different from the *calibration* condition but within the range of temperatures generally found in indoor environments causes the *radon* measurement of the device to be substantially *biased*, then some manner of adjusting for this effect should be incorporated into the method.

7.4.1 Criteria for Effect of Temperature

Each individual device shall demonstrate an *IPE* within the range of 0 ± 25% when tested in a *STAR* for a duration of time at least as long as the minimum recommended by the *provider* and in two conditions:

(1) a relative humidity of 10 – 25% and temperature of 60 ± 5°F (16 ± 3°C), and

(2) a relative humidity of 10 – 25% and temperature of 80 ± 5°F (27 ± 3°C).

The CV for each set of five devices shall be less than or equal to 15%.

7.4.2 Test for Effect of Temperature

The test for effect of temperature shall be conducted using the following procedure:

(1) Two sets of at least five devices are exposed in a *STAR* under the conditions specified in Subsection 7.4.1.

(2) The *radon* concentration should be greater than 10 pCi/L (370 Bq/m^3) so that the measurement uncertainty due to the *radon* concentration itself is not large.

(3) If appropriate, the devices are exposed to an integrated concentration of at least 10 pCi/L (370 Bq/m^3) times the minimum measurement period recommended by the *provider*. The relative humidity should be kept *as constant as practicable* to a value in the range of 10 – 25%.

(4) As far as practicable, the *radon* concentration and relative humidity shall be the same during the two tests.

7.5 Humidity

*Informative—*Many *radon*-measuring devices are affected by the humidity in the surrounding air. If the measurements from a device are affected substantially over the range of relative humidity generally found in indoor environments, then some manner of adjusting for this effect should be incorporated into the method.

7.5.1 Criteria for the Effect of Humidity

Each individual device shall demonstrate an *IPE* value within the range of 0 ± 25% when tested in a *STAR* for a duration of time at least as long as the minimum recommended by the *provider* and at a temperature in the range of 65 – 75°F (18 – 24°C) and values of relative humidity within the ranges of 15 – 25% and 70 – 80%. The CV value for each set of five devices shall be less than or equal to 15%.

7.5.2 Test for Effect of Humidity

The test for effect of humidity shall be conducted using the following procedure:

(1) Two sets of at least five devices are exposed in a *STAR* under the conditions specified in Subsection 7.5.1.

(2) The *radon* concentration should be greater than 10 pCi/L (370 Bq/m^3) so that the measurement uncertainty due to the *radon* concentration itself is not large.

(3) If appropriate, the devices are exposed to an integrated concentration of at least 10 pCi/L (370 Bq/m^3) times the minimum measurement duration recommended by the *provider*.

(4) To the extent practicable, the *radon* concentration and temperature shall be the same during the two tests.

7.6 Compliance

The ranges of environmental conditions specified in this standard are typical of indoor environments. In order for a device or measurement system to meet this standard's specifications, all requirements in this Section 7 shall be met.

7.6.1 *Star Facilities*

Demonstrations of compliance with performance criteria required in Section 7 shall be conducted in a test chamber meeting the definition of a *STAR* as defined in Section 4. Results of testing in a *STAR* conducted for purposes other than compliance with this standard are permitted to partially or fully suffice to demonstrate compliance with this standard.

Tests conducted under conditions other than the controlled conditions of a *STAR* shall be insufficient to determine whether the requirements of this standard have been met.

Exception: When climate conditions local to a STAR render it not practicable to achieve timely verification of meeting criteria associated with the highest or lowest ranges specified for humidity, evidence obtained by other statistically valid means in other chambers shall be an acceptable substitute for demonstration of compliance.

8. DOCUMENTATION

To meet the requirements of this standard, the manufacturer shall have available upon request a report covering the tests performed on the device model demonstrating the attainment of the performance requirements of this standard. The report shall list the requirements and corresponding test results described in this standard, with the STAR information where the tests were performed and a description of how the system used to determine the average radon concentration from the STAR is traceable as defined in Section 4. At a minimum, the *provider's* (*manufacturer's* or distributor's) report of tests shall cover, as appropriate, the information listed in Table 8.1, with:

- ranges of radon concentration and measurement duration for which the device meets this standard's requirements;
- effects of other types of radiation;
- suggested method(s) of calibration;
- effects of temperature, pressure and humidity, and shocks inherent to the vibrations associated with the operation of hand-held or hand-carried equipment, including the results of the tests specifically listed in this standard;
- effects of radio frequency, electrostatics, electromagnetic interference and microwaves;
- elevation of the chamber;
- background gamma rate and RH in the chamber during each test;
- air velocity in the chamber, if air velocity affects the response function of the device being tested;
- personnel responsible for the test results; and
- summary of or reference to the quality assurance/quality control requirements for the chamber.

In addition to these, the manufacturer shall document any other factors that affect the performance metrics.

Documentation of results of testing in a STAR shall include the information in the sample report shown in Table 8.1. Formatting and order of information is permitted to be different from that shown in the sample report, but all of the information shall be included in order to provide the test report that shall be made available to demonstrate compliance with the requirements of this standard.

STAR Information, including name, location and elevation:

Conditions during test:

Air velocity at the location of the devices being tested, if air velocity affects the response function of those devices being tested

Approximate ambient gamma radiation exposure rate _____ (µR/h or nGy/h)

Hourly chamber conditions, including radon concentrations, and a report providing the description of the derivation of the uncertainty of average radon concentrations or integrated radon concentrations for the durations used in these tests are provided as an attachment to this summary report. The derivation of the uncertainty estimates should be consistent with NIST Technical Note 1297 and include the original data used for the derivation.

Device Information:

Manufacturer: _____ Model Name: _____

Provider (sent by): _____ Photos of devices as provided to the STAR facility are attached.

Description of any operations necessary to start/stop test: _____

Serial numbers of the devices: _____ (photos also attached, if appropriate)

Test Results:

Accuracy (Total Error) and Precision (Sec. 7.1) **Requirements:** Each Individual Percent Error (IPE) = 0 ± 25% and CV ≤ 15% for each set of five devices when exposed for the shortest duration specified for use by the provider.

Temperature _____ range 65 – 75°F (18 – 24°C)

Rn Conc _____ range 6 – 15 pCi/L (222 – 555 Bq/m³)

RH _____ range 10 – 55%

Serial number	Date-time start	Date-time end	Temp	RH	Device result	STAR conc	IPE	CV

Proportionality (Sec. 7.3) **Requirements:** Each IPE = 0 ± 25% and CV ≤ 15% for each set of five devices, and the difference between the average IPE (low concentration) and the average IPE(high concentration) must be between −15% and +15%. Note that a test in either a high radon concentration or a high *integrated* radon concentration is required (not both).

Low Concentration Test:

Temperature _____ range 65 − 75°F (18 − 24°C)

Rn Conc _____ range 6 − 15 pCi/L (222 − 555 Bq/m³)

RH _____ range 10 − 55%

Serial number	Date-time start	Date-time end	Temp	RH	Device result	STAR conc	IPE	CV

High Concentration Test:

Temperature _____ range 65 − 75°F (18 − 24°C)

Rn Conc _____ range 30 − 60 pCi/L (1110 − 2220 Bq/m³) or at least 3 times the low concentration, whichever is greater.

RH _____ range 10 − 55%

Serial number	Date-time start	Date-time end	Temp	RH	Device result	STAR conc	IPE	CV

High Integrated Concentration Test:

Temperature _____ range 65 – 75°F (18 – 24°C)

Integrated Rn Conc (units of pCi-d/L, Bq-d/m³, or Bq-h/m³) _____ integrated concentration of approximately 30 – 60 pCi/L (1110 – 2220 Bq/m³) *multiplied by the minimum duration* recommended by the provider or at least three times the low integrated concentration in which the devices were tested, whichever is greater, taking into account the limitations of the STAR.

RH _____ range 10 – 55%

Serial number	Date-time start	Date-time end	Temp	RH	Device result	STAR conc	IPE	CV

Temperature Group (low) (Sec. 7.4) Requirements: Each IPE = 0 ± 25% and CV ≤ 15% for each set of five devices.

Temperature _____ range 60 ± 5°F (16 ± 3°C)

Rn Conc _____ ≥ 10 pCi/L (370 Bq/m³)

RH _____ range 10 – 25%

Serial number	Date-time start	Date-time end	Temp	RH	Device result	STAR conc	IPE	CV

Temperature Group (high) (Sec. 7.4) Requirements: Each IPE = 0 ± 25% and CV ≤ 15% for each set of five devices.

Temperature _____ range 80 ± 5°F (27 ± 3°C)

Rn Conc _____ ≥ 10 pCi/L (370 Bq/m³)

RH _____ range 10 – 25%

Serial number	Date-time start	Date-time end	Temp	RH	Device result	STAR conc	IPE	CV

Relative Humidity Group (low) (Sec. 7.5) Requirements: Each IPE = 0 ± 25% and CV ≤ 15% for each set of five devices.

Temperature _____ range 65 – 75°F (18 – 24°C)

Rn Conc _____ ≥ 10 pCi/L (370 Bq/m³)

RH _____ range 15 – 25%

Serial number	Date-time start	Date-time end	Temp	RH	Device result	STAR conc	IPE	CV

Relative Humidity Group (high) (Sec. 7.5) **Requirements:** Each IPE = 0 ± 25% and CV ≤ 15% for each set of five devices.

Temperature _____ range 65 – 75°F (18 – 24°C)

Rn Conc _____ ≥ 10 pCi/L (370 Bq/m³)

RH _____ range 70 – 80%

Serial number	Date-time start	Date-time end	Temp	RH	Device result	STAR conc	IPE	CV

Minimum Detectable Concentration (Sec. 7.2) **Requirement:** ≤ 1 pCi/L (37 Bq/m³) for measurements of 2 days or longer; for integrated concentrations <=1 pCi/L (37 Bq/m³) multiplied by the minimum measurement period, and for individual 1-hour measurements the MDC shall be no greater than 4 pCi/L (148 Bq/m³). Tests to determine MDC are run outside the STAR(s) and the individual device results, including test durations and the complete calculations, are provided in this report. Calculations are performed using the algorithms in Section 4. The MDC is: _____ (units) for the measurement duration of _____ .
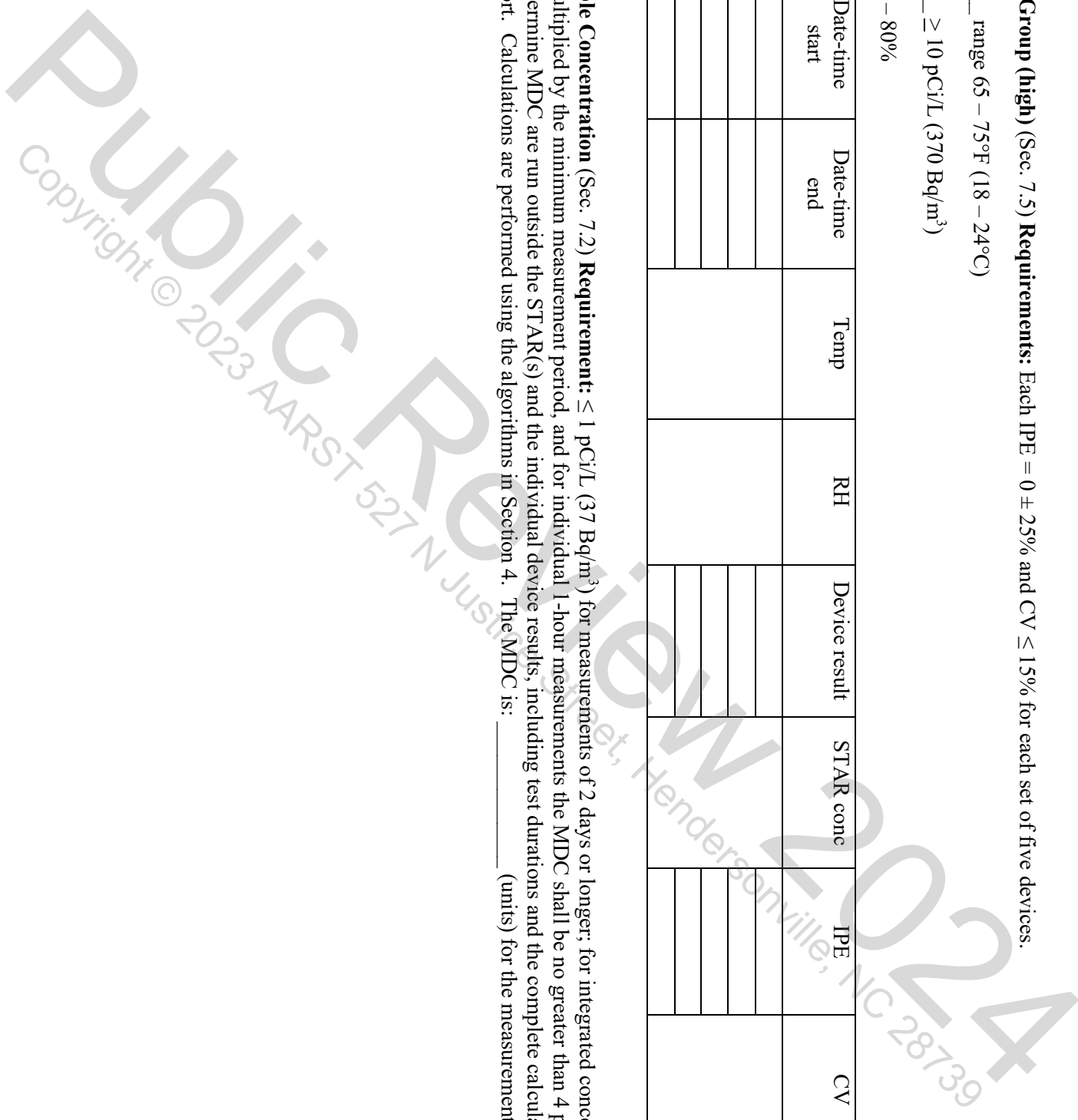
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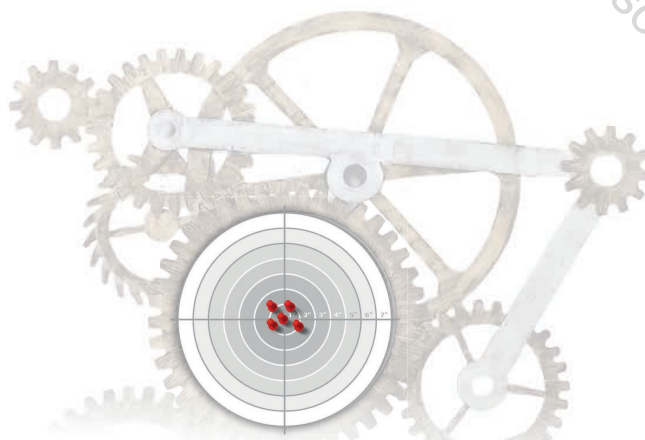
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Deep appreciation is expressed for contributions of time and wisdom provided by the following experts.

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