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American National Standard for Performance Specification for Tritium Monitors

Accredited by the American National Standards Institute

Sponsored by the
National Committee on Radiation Instrumentation, N42

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American National Standards Institute

Secretariat

The Institute of Electrical and Electronics Engineers, Inc.

Approved 25 September 2002

American National Standards Institute

Abstract: The performance requirements for tritium monitors used for monitoring airborne tritium radioactivity are provided in this standard. It also provides test methods for establishing a monitor's performance characteristics.

Keywords: airborne tritium, monitors, radioactivity, tritium

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Introduction

(This introduction is not part of ANSI N42.30-2002, American National Standard for Performance Specification for Tritium Monitors.)

This standard is the responsibility of the Accredited American Standards Committee on Radiation Instrumentation, N42. Committee N42 delegated the development of this standard to Subcommittee N42.RPI. Drafts were reviewed by Committee N42, Subcommittee N42.RPI, and other interested parties; and the comments were utilized in producing the standard as finally approved. This standard was approved on N42 letter ballot of 25 September 2002.

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American National Standard for Performance Specification for Tritium Monitors

1. Scope

This standard provides the performance requirements for tritium monitors used for monitoring airborne tritium radioactivity.

This standard also provides a set of test methods that can be used to establish a monitor's performance characteristics.

Tritium monitors addressed by this standard are used for

- The determination of the average airborne tritium concentration in a work area and measurement of its variation as a function of time
- The activation of a warning signal when either a predetermined high concentration and/or exposure of airborne tritium at a given location is exceeded

This standard specifies general, radiation, chemical, electrical, mechanical, physical, and environmental performance requirements and test procedures. For equipment accepted for use prior to the issuance of this standard, meeting the stated requirements is at the discretion of the user.

2. Definitions

2.1 acceptance tests: A contractual test to prove to the purchaser that an instrument meets conditions of its specification.

2.2 coefficient of variation (V): The standard deviation expressed as a percentage of the mean by

$$V(\%) = \frac{\sigma}{\bar{x}} \times 100$$

2.3 conventionally true activity: The commonly accepted best estimate of the value of a quantity. This and its associated uncertainty will normally be determined by a national or transfer standard, or by a reference instrument calibrated against a national or transfer standard, or by measurement quality assurance with a national laboratory or qualified secondary laboratory.

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2.4 effective range of measurement: The range of measurement within which the accuracy requirements of this standard are met.

2.5 least significant digit (LSD): The least significant digit displayed on the lowest range or decade of a digital display.

2.6 minimum detectable activity (MDA): A term used to indicate the ability of a particular monitor to discern between the radioactivity associated with the radionuclide content of a sample of interest and background radiation with a particular degree of statistical confidence (taken from NCRP 87-1987 [B11][1]). For this standard, MDA is the point where there is a 95% probability that the observed response is not produced by background alone.

2.7 qualification tests: Tests performed to verify that the requirements of a specification are fulfilled. These tests are subdivided into type tests and routine tests.

2.8 reference reading: The monitor's response while operating under normal laboratory conditions.

2.9 reproducibility: The degree of agreement between repeated measurements of the same property.

2.10 response time: The time taken to indicate an instantaneous change from 10% to 90% of the conventionally true activity at the rated nominal flow rate.

2.11 routine tests: Tests that each individual instrument is subjected to, during or after manufacture, to ascertain whether it complies with certain criteria.

2.12 tritium: The hydrogen isotope with one proton and two neutrons in the nucleus (^{3}H or T).

2.13 tritium-in-air: Tritium of any chemical form in a gas form. For example: HTO-, T2O-, DTO-, HT- DT-, and T2-in-air are all considered to be tritium-in-air.

2.14 type tests: Evaluation or measurement of all identified performance characteristics of a representative sample of production model instruments. (ANSI N42.17C-1989 [B3])

3. General test information

Test procedures addressed by this standard, except where otherwise specified, are considered type tests. Any, or all, may be considered as acceptance tests by agreement between manufacturer and the user. The stated requirements are minimum requirements and may be extended for any particular monitor or function depending on the requirements of the user. Standard test conditions are defined in Table 1.

Table 1—Reference conditions and standard test conditions

Influence quantity	Reference conditions	Standard test conditions
Reference radioactive source	Air labeled with tritium in form appropriate to instrument under test	Air labeled with tritium in form appropriate to instrument under test
Warm-up time	Specified by the manufacturer	Specified by the manufacturer
Ambient temperature	20 °C	18 °C to 22 °C

[1]The numbers in brackets correspond to the numbers in the bibliography in Annex B.

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Table 1—Reference conditions and standard test conditions *(continued)*

Influence quantity	Reference conditions	Standard test conditions
Relative humidity	65%	50% to 75%
Atmospheric pressure	101.3 kPa	96 kPa to 106 kPa
Power supply voltage	Nominal supply voltage U_N	$U_N \pm 1\%$
Ambient gamma radiation	Absorbed dose rate air less than 20 µrad/h at the detector position	Absorbed dose rate air less than 25 µrad/h at the detector position
Magnetic induction of external origin	Negligible	Less than twice the value of the induction of the earth's magnetic field
Electromagnetic field of external origin	Negligible	Less than the smallest value which causes interference
Sampling flow rate	Adjustment to the nominal flow	Adjusted to nominal flow ± 5%
Contamination by radioactive materials	Negligible	Effect on detector less than or equal to that produced by the background noise of the ambient gamma radiation

Tests are classified according to whether they are performed under standard test conditions or under other conditions.

3.1 Tests performed under standard test conditions

Tests performed under standard test conditions are listed in Table 2 that indicates, for each characteristic, the specific requirement and the clause where the corresponding test method is described.

Table 2—Tests performed under standard test conditions

Characteristic under test	Requirement	Method of test clause
Power supply	Stated in 4.12	5.1
Alarms	Visual locally. Fail-safe contacts for digital outputs to remote alarms. Shall activate a local light that flashes until acknowledged and remains activated in a steady-on state until the alarm condition is corrected. The audible alarm has a local-acknowledge (silence) switch and is at least 10 dB to 15 dB above background noise level (not exceeding 85 dB at ≤ 3 m) at a frequency of 500 Hz to 3000 Hz. It shall not be a bell and shall not exceed 85 dB at ≤ 3 m.	5.2
Warm-up time	Shall be stated by the manufacturer.	5.3

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Table 2—Tests performed under standard test conditions *(continued)*

Characteristic under test	Requirement	Method of test clause
Zero drift	After the monitor has been in operation for the manufacturer's stated warm-up time, the electronic zero position shall not drift by more than ± 1% [± 1 least significant digit (LSD)] of full scale of the most sensitive decade over 8 h of continuous operation.	5.4
Accuracy	Tritium-in-air response shall be ≤ ± 20% (± 1 LSD) of the conventionally true value reading under nominal laboratory conditions (corrected for temperature and atmospheric pressure).	6.1
Response time	Shall be specified by the manufacturer or the facility, as appropriate. Shall be as short as practicable and consistent with the measurement technique employed.	6.2
Minimum detectable activity (MDA)	Shall be stated by the manufacturer. Shall be able to measure levels as low as 5 $\mu Ci/m^3$ ($\mu Bq/m^3$) within 1 min and be within the effective range of measurement.	6.3
Coefficient of variation (V)	For linear scales, 10% for any radioactivity level exceeding the level corresponding to one-third of the scale maximum on the most sensitive range. For nonlinear scales, 20% for any radioactivity level exceeding three times the level corresponding to the lowest significant graduation on the scale. For digital display, 10% for any radioactivity level exceeding the level corresponding to the least significant decade.	6.4
Overload test	The monitor shall continue to operate when exposed to levels of tritium that are greater than the range maximum. Digital readouts shall indicate that radiation levels exceed the upper limit of the monitor. When the radiation level is reduced, the instrument shall return to the pre-exposure reading within 5 min.	6.5
Self-decontamination (purge)	The detector shall be designed to reduce the retention of tritium.	6.6

3.2 Tests performed with variation of influence quantities

These tests are intended to determine the effects of variations in influence quantities. Conditions are given in Table 3 with the range of variation of each influence quantity and limits of consequent variation in the response of the monitor.

The range of variations of influence quantities indicated in Table 3 defines a nominal operating range where the variation in indication shall remain within the limits stated. In order to test the effect of variation in any one of the influence quantities listed in Table 3, all other influence quantities shall be maintained within the limits for standard test conditions given in Table 1 unless otherwise specified in the test procedure concerned.

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Table 3—Tests performed with variation of the influence quantities related to measuring devices and protection against ambient radiation and other radioactive gases

Influence quantity	Range of values of influence quantity	Limit of variation of indication	Method of test
Tritium in form other than the form for which assembly is designed (selective equipment only)	As specified by the manufacturer	As specified by the manufacturer	7.1
Other radioactive gases	As specified by the manufacturer	As specified by the manufacturer	7.2
Response to ambient gamma radiation	For compensation monitors only	The steady-state response shall not change by more than ± 15% (± 1 LSD) when subjected to an external gamma radiation field.	7.3
Mechanical shocks	Portable monitors should be able to withstand, without damage, mechanical shocks from all directions.	300 m/s^{-2} (≈ 30 g) at a time interval of 13 m/s, semi-sinusoidal.	7.4
Ambient temperature	+2 °C to +50 °C	± 15% (± 1 LSD)	7.6
Relative humidity	Up to 93% (± 3%) at 30 °C ± 2 °C	± 15% (± 1 LSD)	7.7
Atmospheric pressure	Specified by the manufacturer	Specified by the manufacturer	7.8
Radio frequency fields	80 MHz to 1000 MHz at 10 V/m	± 15% (± 1 LSD)	7.9
Conducted radio frequency fields	150 kHz to 80 MHz at 140 dB (μV).	± 15% (± 1 LSD)	7.10
Magnetic fields	10 Gauss in two orthogonal orientations	± 15% (± 1 LSD)	7.11
Control and measurement of airflow	The nominal flow rate and the range of adjustment shall be stated by the manufacturer.	The flow rate after 24 h shall not differ more than ± 10% from the nominal flow rate.	8.1

Other aspects of the performance of the assembly need to be tested with variation of influence quantities only if it is considered that the routine test specified will not give a representative indication.

3.3 Statistical fluctuations

For any test involving the use of radiation, if the magnitude of the statistical fluctuations of the indication arising from the random nature of radiation alone is a significant fraction of variation of the indication permitted in the test, then sufficient readings shall be taken to ensure that the mean value of such readings may be estimated with sufficient precision to demonstrate compliance with the test in question.

The interval between such readings shall be long enough to ensure that the readings are statistically independent. This interval should be based on the method of indication or other means used by the monitor to display the reading. Refer to Appendix A for additional information.

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3.4 Reference test source

Tests should be performed with tritium, although equivalent gamma (^{137}Cs preferred) fields or electrical simulation can be used for responses that require relatively high activities.

More than one reference activity will be required in order to cover the complete effective range of the monitor. The relative (gamma or current) activities used shall be such that an appropriate radiation response is obtained in each range (for linear-scaled monitors) or each decade (for logarithmic-scaled monitors).

4. General criteria

4.1 Classification of equipment

Various tritium monitor designs are available with many monitors being of a special design to meet the specific needs of the user. This standard classifies tritium monitors based on the following operational and usage requirements; primary power source, system interface (output), and measurement range:

— *Low-range* tritium monitors include monitors that have a range, R, of $0 < R \leq 1000$ μCi/m^3 (μBq/m^3).
— *High-range* monitors have a range of $0 < R \leq X$, where X is the maximum response of the monitor as stated by the manufacturer.
— *Installed* tritium monitors typically have outputs that interface the monitor with a centralized radiation monitoring system to initiate alarms or indicate operating faults. Installed monitors operate using line power primarily and may have battery backup.
— *Portable* monitors could also have the ability to interface with a centralized system, but use battery power primarily. They can also use line power through an internal or external converter and are typically carried from location to location for use.

4.1.1 Effective range of measurement

4.1.1.1 Discussion

It is well known that measurements obtained from low levels of radiation are random. The randomness is primarily caused by the radiation level as well as a monitor's ability to collect enough information within an acceptable time interval. The manufacturer is required to state the overall response range of the monitor. It should be from the lowest to highest displayed reading. Unfortunately, this response range is typically not possible with radiation-measuring devices. The point at which the monitor's response becomes more random than what is acceptable is effectively the lowest response or the lowest point of the effective range of measurement. This point can also be loosely called *minimum detectable activity* (MDA). At this point, it would be difficult to discern between the randomness of the ambient radiation and an actual increase in activity.

See 6.3 for information about how to determine the MDA for tritium monitors.

4.1.1.2 Requirements

For analog meters, the effective range of measurement should be from 10% of the maximum reading of the lowest range or decade to 100% of the monitor's stated response range.

For digitally scaled assemblies, the effective range should be from the start of the second least significant digit (LSD) to the full range of indication available [i.e., if the stated response range was 0 to 1000 μCi/m^3 (μBq/m^3), the effective range of measurement is 2 μCi/m^3 (μBq/m^3) to 1000 μCi/m^3 (μBq/m^3)].

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4.2 Measurement principle

A wide range of measuring techniques are available for measuring tritium-in-air levels. These techniques include flow-through ionization chambers and gas-flow proportional counters with a range of compensation techniques for minimizing the response to background gamma radiation or other radioactive gas. Inlet filters should be incorporated to minimize the response to radioactivity from aerosols or particulates present. Water vapor traps may be used either to eliminate tritiated water vapor prior to the detector assembly (in equipment measuring tritiated water vapor selectively by difference techniques) or to concentrate the tritium in a medium that is subsequently passed through a detector assembly. The choice of technique in any particular situation will be influenced by the particular circumstances at the facility concerned.

4.3 Equipment description

Tritium monitor components may be grouped into two assemblies, which may be associated or separated according to the monitoring and operating requirements. These two assemblies are the sampling and detection assembly and the control and measurement assembly.

4.3.1 Sampling and detection assembly

The sampling and detection assembly includes, where applicable, some or all of the following components:

- Sampling and exhaust tubes
- Inlet filter
- Tritiated water vapor trap
- Facilities for drawing samples for laboratory analysis or for calibration tests with radioactive gases
- Air/counting gas mixing devices (for proportional counters)
- Radiation detector
- Electronic measuring components including electronic background compensation device
- Ambient gamma radiation shielding or compensation device
- Humidity controls (i.e., heat trace) to minimize condensation
- Air/flow rate monitoring and control devices
- Air pump

4.3.2 Control and measurement assembly

The control and measurement assembly includes, where applicable, the following components:

- Electrical control and supply components
- Signal measurement circuitry
- Display and/or recording components
- Warning signals and alarm components

4.4 Ease of decontamination

The monitor shall be designed to limit external and internal contamination. The sampling and detection assembly shall have smooth, nonporous surfaces. In-line filtering media shall be available to prevent the ingress of particulate contamination into the chamber. The external surface of the monitor shall be made from material that will allow easy decontamination. Filtering or trapping devices shall be easy to dismantle and decontaminate.

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4.5 Operating noise level

Operating noise is typically caused by the air pump. The manufacturer shall select components and design the monitor in such a way that the resulting acoustic noise level satisfies the requirements of the user. In any case, the noise level shall not impede the ability of the user to hear the alarm.

4.6 Mass and dimensions

As far as possible, an attempt shall be made to minimize the mass and dimensions of the equipment, particularly for portable monitors. The mass and dimensions shall be specified by the manufacturer.

4.7 Units of readout

The units of readout shall be based on the requirements of the user. As a minimum, the display shall have the capability to indicate radioactivity in becquerels and have the capability to display volume in cubic centimeters, cubic meters, or liters. Other values such as MPC or DAC should be available depending on the user's requirements. The activity units may be permanently indicated as an exterior marking near the display.

4.8 Markings

All instrument controls, displays, and adjustments, both internal and external, shall be identified as to function.

4.8.1 Exterior markings

External markings shall be easily readable and remain permanently affixed under normal conditions of use. The following markings shall appear on the exterior of the monitor:

- Instrument type
- Manufacturer and model number
- Unique serial number
- Control functions
- Chamber location
- Check source placement position
- Power requirements
- Readout units, when applicable

4.9 Alarm threshold

Monitors shall be equipped with audible and visual alarms. Alarm thresholds shall be adjustable to any point within the range of the monitor.

4.10 Alarm capabilities

The overall alarm and indication capabilities shall be appropriate to the use and location of the monitor. Portable monitors may not require extensive alarm output capabilities whereas installed monitors typically do require many outputs for connection to a central radiation monitoring system.

All alarm circuits shall give visual indication locally on the monitor and also operate outputs for use with an external alarm. Local alarms shall be audible with a local-acknowledge (silence) switch. Means to acknowledge an alarm remotely should be available. Audible alarms shall be at least 10 dB to 15 dB above the back-

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ground noise level at a frequency of 500 Hz to 3000 Hz, should be compatible with the user's requirement for alarm sounds, and shall not exceed 85 dB at distances ≤ 3 m. Provision should be made to allow internal deactivation of the audible alarm feature. All alarm functions shall be provided with test facilities to allow checking of alarm operation.

In the case of adjustable alarms, it shall be possible to check an alarm's operation over the range of adjustment, with indication of the actual alarm operation point. Alarm circuits shall be able to hold the alarm signal until reset by a reset control or to autoreset when the alarm state no longer exists. The two modes of operation shall be available by simple modification on all equipment. The alarm capabilities in 4.10.1 and 4.10.2 shall normally be provided.

4.10.1 High radioactivity alarm

The high radioactivity alarm shall have an adjustable threshold (set point) that is within ± 5% of the indicated reading when activated. The alarm shall activate a light and output device. The alarm light shall remain on after the audible alarm is acknowledged.

The actual alarm set point shall not deviate from the indicated set point level by more than ± 5%. The user shall have the ability to select whether the alarm is latching or nonlatching. Nonlatching alarms shall automatically extinguish within 30 s after the measured radioactivity level returns to a level that is below the alarm set point.

4.10.2 Failure alarms

Failure alarms shall be available for as many electronic circuit or mechanical device faults as practical. Wherever practicable, separate indication of the source of the fault shall be given.

a) *Low airflow alarm*. The low airflow alarm shall have an adjustable set point that is within ± 5% of the maximum flow rate value and shall activate a light and output. The alarm shall be activated from no or out-of-tolerance airflow or from out-of-tolerance differential pressure.
b) *Power failure alarm***.** The monitor shall have the ability to issue an alarm upon loss of power. This alarm shall be fail-safe, opening a contact or other equivalent action upon loss of power.
c) *Trouble alarms***.** Trouble alarms shall be activated from loss of high voltage or no radiation response or from the failure of any component or circuit that would affect the ability of the monitor to function correctly. Trouble alarms shall include a light and an output for remote indication and shall be distinguishable from the high radioactivity alarm.

4.11 Protection of switches and controls

Switches and controls, especially zero, shall be protected from inadvertent operation. The zero control should not be operable while the monitor is performing a measurement, unless it is used as compensation for changes in ambient gamma radiation levels. If the zero control is used for gamma compensation, precautions shall be in place to prevent its use when increases in response are caused by increases in tritium levels.

4.12 Power supply

4.12.1 Requirements for ac-powered monitors

Tritium monitors are expected to operate when exposed to line voltage variations from 102 V to 132 V (117 V ± 15%) ac. The monitor's response shall remain within ± 15% of the response obtained at 117 V. The measured flow rate shall also be unaffected by the change in line voltage.

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Tritium monitors shall remain operational when exposed to a 100 kHz Ring Wave and to a 1.2/50 μs–8/20 μs Combination Wave at 2.5 kV using the criteria stated in IEEE Std C62.41™-1991 [B10]. The monitor should remain operational, and no alarms shall be activated. The response shall be within ± 15% of the reference value obtained prior to the test.

4.12.2 Requirements for battery-powered monitors

4.12.2.1 General

Facilities shall be provided to check the battery condition under maximum load. The minimum battery check indication shall be clearly marked on the monitor. A low-battery indication shall be available that activates before the operation of the monitor is affected.

Batteries may be connected in any desired manner, but shall be individually replaceable; the correct polarity shall be clearly indicated on the assembly.

4.12.2.2 Primary batteries

When power is supplied by primary batteries, their capacity shall be such that, after 16 h of intermittent use (periods of use of 4 h at most, separated by intervals of at least 1 h) or 8 h of continuous use, the indication of the assembly shall not differ from the initial indication by more than 10%.

4.12.2.3 Secondary batteries

When power is supplied by secondary batteries, their capacity shall be such that, after 8 h of continuous use, the indication of the assembly does not differ by more than 10% from the initial value.

Secondary batteries shall be rechargeable from line power in 16 h. The use of a device that switches off the charger when a complete charge is obtained is recommended.

4.13 Function indicators

The following indications shall be provided, except where agreed to the contrary between the manufacturer and the user:

- Power on
- Air pump on or airflow acceptable
- Detector bias supply on (only as needed)
- System normal (no alarms activated)

4.14 Remote indication capabilities

If the monitor will interface with a centralized radiation monitoring system, the following outputs shall be available to permit remote indication on one or more of the following display devices:

- Continuous log or linear output for 4 mA to 20 mA and/or 0 to 10 V dc. The signal**,** converted to an activity value, shall be within ± 5% of reading displayed.
- Printer.
- Computer with standard RS-232 or other suitable digital interface.

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4.15 Setup and maintenance requirements

In addition to an instruction and maintenance manual, all monitors shall be provided with easily accessible test points to facilitate setup and fault location. Where necessary, maintenance aids (e.g., extension printed wiring boards, jumper leads, special maintenance tools) shall be available.

4.16 Overload protection

Where practicable, a thermal or electromechanical device (e.g., fuse or circuit breaker) shall be included in the power circuit so that, if the current exceeds twice its rated value for more than 1 s, the supply is automatically disconnected and cannot be re-established except by manual intervention.

4.17 Ambient radiation

Because ambient gamma radiation can be measured using tritium monitors, shielding and/or compensation detectors should be available. For example, it should be noted that, for an ionization-chamber tritium monitor with a 1 L chamber, the amount of current required to produce a reading of 90 $\mu Ci/m^3$ ($\mu Bq/m^3$) is roughly equivalent to a gamma background radiation level of about 1 mR/hr.

The limitations of any ambient radiation reduction device shall be known by the user and should be stated by the manufacturer.

4.17.1 Shielding

Shielding shall result in nearly identical attenuation of radiation in all directions as seen from the sensitive volume of the detector, taking into account the structural materials of the detection assembly, including its support, and the angular response of the detector. Shield material shall be easily removable; this requirement may further require that the shield be constructed from several elements. Each element should not exceed 15 kg and shall not exceed 40 kg. An eye for handling by a crane shall be included, as necessary.

4.17.2 Compensation ionization chambers

Compensation ionization chambers are typically identical to the tritium measurement chambers. Their response is used to compensate the total response because they respond only to the ambient radiation fields. Compensation chambers shall be chosen and located to give the best practicable compensation, taking into account the possible range of the gamma energies and the direction of the irradiation.

4.18 Radon effects

The monitor should have the ability to compensate for radon. This is typically done electronically using direct signal discrimination. Direct signal discrimination typically uses pulse-measuring techniques, such as rise-time or pulse height discrimination to correct the tritium response.

4.19 Air circuit

The air circuit shall be designed to minimize the possibility of leaks.

4.19.1 Sampling and exhaust pipes

The following characteristics shall be taken into account and should be subject to agreement between the user and the manufacturer:

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— Characteristics of internal surfaces
— Inner diameter of ducts (pressure drop and deposition effects)
— Nature of materials used (including their electrostatic effects and chemical corrosion)
— The overall pumping system time constant (volume exchange rate)

4.19.2 Inlet filters

High-efficiency particulate filters should be placed in a filter carrier at the inlet of the sampling circuit in order to remove any dust or aerosols from the air, including those with attached radon daughters. In order to maintain the specified performance of the assembly, the manufacturer shall provide information regarding the useful filter lifetime in terms of total running time or total installed lifetime, under specified conditions.

4.19.3 Tritiated water vapor trap

If a tritium monitor uses a water vapor trap, it should be designed in a manner that limits the resuspension of the adsorbent (if used). The manufacturer shall provide information regarding its useful lifetime in terms of total running time or total installed lifetime, under specified conditions.

4.19.4 Flow control and measurement devices

The flow-rate control device shall have a nominal flow-rate adjustment range to allow for variations in the intrinsic characteristics of the air pump and any filters used. The flow-rate meter shall be a direct reading type. Rotameters, or other equivalent devices, shall be used as a minimum to measure the airflow. If the monitor provides an integrated activity measurement, the airflow rate should be measured using a mass-flow sensor.

Flow alarms shall be provided for warning of any excessive change of flow. Whatever the actual measurement conditions, the flow rate shall be expressed in unit volume per unit time (e.g., cubic meters per hour).

4.19.5 Humidity controls

If the monitor is supplied with a means to minimize condensation (i.e., heat trace), indication about the heating circuit's functionality [i.e., lamp, light-emitting display (LED), or equivalent] shall be available. Ground-fault interrupter circuitry shall be included for any external controls.

4.20 Detector

All practicable steps shall be taken to limit the particulate contamination of the detector so that such contamination will not affect the measurement. Access to the detector and adjacent surfaces should be made as convenient as practicable for the purpose of decontamination.

5. Electronic criteria

5.1 Power supply

5.1.1 Requirements

The power supply requirements are stated in 4.12.

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5.1.2 Test methods for line-powered monitors

5.1.2.1 Supply voltage

Connect the monitor to a variable power supply set to 117 V ac. If the pump flow rate is not displayed, use an independent flow-measuring device to obtain the flow rate.

With the monitor exposed to a gamma radiation source of sufficient intensity to produce an equivalent tritium response that is approximately midscale on the range being tested, reduce the supply voltage in 5 V increments obtaining a sufficient number of readings at each increment until reaching 102 V. Perform the same technique from 117 V to 132 V.

5.1.2.2 Line noise test

With the monitor exposed to a gamma radiation source of sufficient intensity to produce an equivalent tritium response that is approximately midscale on the range being tested, apply each power line disturbance listed in Table 4 and observe the monitor's response.

Table 4—Line noise test parameters

Disturbance	Waveform	
	100 kHz Ring Wave	Combination Wave
Number of pulses	10	10
Peak amplitude	2.5 kV	2.5 kV
Pulse repetition time	1 min	1 min

When complete, re-evaluate the monitor to determine whether there are any post-test effects. Determine whether the post-test response remained within ± 15% of the reference value obtained prior to the test, and document whether any alarms were activated during subjugation.

5.1.3 Test methods for battery-powered monitors

New primary, or fully charged secondary, batteries of the type indicated by the manufacturer shall be used for this test.

Expose the monitor to an appropriate source (gamma preferred) to give a reading of approximately two-thirds of full-scale deflection on the least sensitive scale range.

Note the initial response. Leave the equipment operating for at least 8 h while continuously recording the monitor's output using a data logger, chart recorder, or equivalent recording device. Compare the initial response with the final response after 8 h have elapsed.

5.2 Alarms

5.2.1 Requirement

The alarm requirements are stated in 4.10.

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5.2.2 Test method

5.2.2.1 Remote outputs, when required

Verify that remote outputs are available for high radioactivity, low airflow, power failure (inop), normal, and trouble, and a remote acknowledge switch (if appropriate).

5.2.2.2 Audible alarm

Verify that the audible alarm has a local-acknowledge (silence) switch and is at least 10 dB to 15 dB above background noise level (not exceeding 85 dB at ≤ 3 m) at a frequency of 500 Hz to 3000 Hz. Verify that the alarm can be deactivated.

5.2.2.3 High radioactivity alarm

Verify that the alarm is adjustable over the response range. Verify that the alarm operates as expected by exposing the monitor to a gamma field of high enough intensity to activate the alarm.

Verify that the remote indicator functions properly, and that the alarm activates at a point within ± 5% of the set point. Verify that the high radioactivity alarm light activates. After acknowledging the alarm, verify that the audible alarm is silenced and that the high radioactivity alarm light remains on.

If nonlatching operation is required, verify that the alarm clears within 30 s and the high radioactivity light returns to a dim state after the field is reduced. Without changing the alarm set point, perform an alarm verification each day for the next 3 days, and verify that the alarm activation level remains within ± 5% (± 1 LSD) over that period.

5.2.2.4 Low airflow alarm

Verify that the alarm is adjustable to enable a set point range of –100% to +100% of the recommended flow rate. Reduce the airflow and verify that the alarm is initiated both locally and remotely. Verify that the activation point is within ± 5% of the set point.

5.2.2.5 Power failure alarm

With the monitor operating normally, remove the power and verify that the output activates.

5.2.2.6 Trouble alarm

Verify that the monitor has the capability to alarm for the following conditions:

— Loss of high voltage or no radioactivity, or
— The failure of any component or circuit that would affect the ability of the monitor to function correctly.

NOTE—This alarm shall sound different from the high radioactivity alarm and be indicated locally on the monitor and remotely.

5.3 Warm-up

5.3.1 Requirements

The manufacturer shall state the monitor’s warm-up time. The warm-up time should not exceed 10 min.

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5.3.2 Test method

Switch on the monitor and activate a recording device (e.g., video, chart recorder) to begin collecting data. Starting at time zero and at 10 min intervals, record the monitor's response for 1 h. After the first 10 min measurement, artificially increase the monitor's response through the zero control or with a gamma source. Record the response at 1 h intervals for 24 h.

Review the results and document the time required for the monitor to reach a stable state and the overall stability of the monitor for the duration of the test.

5.4 Zero drift

5.4.1 Requirements

The electronic zero shall not drift by more than ± 1% (± 1 LSD) of full scale of the most sensitive decade over 8 h of continuous operation.

5.4.2 Test method

With the pump off, switch the monitor on and let it stabilize. After the required warm-up time, activate the electronic zero and adjust as needed to zero the monitor. Release the zero control and allow the monitor to stabilize. Record the initial response. Continue to record the response at hourly intervals for 8 h. The final reading shall be within ± 1% (± 1 LSD) of the initial reading.

5.5 Air pump

5.5.1 Requirements

Where an air pump is an integral part of the monitor, the following requirements shall be met:

a) The air pump shall be placed downstream from any filter or measuring unit and be capable of continuous operation between scheduled maintenance operations. The frequency of maintenance operations shall generally be not more than once every 6 mo depending on use.
b) Air pumps shall be capable of withstanding the variation of pressure induced by normal operating conditions so that there shall not be a variation of nominal airflow of more than 20%.
c) The air pump shall be fitted with appropriate safety devices to protect it against any abnormal temperature or pressure increase. The operation of any such safety device shall be indicated to the user by a suitable failure alarm.
d) The air pump shall be capable of providing the flow rate needed to meet the user's required response time.

6. Radiation response

6.1 Accuracy

6.1.1 Requirements

The response to tritium shall be within ± 20% of the conventionally true value reading under nominal laboratory conditions (corrected for temperature and atmospheric pressure). When testing with gamma or electrical sources, the monitor's reading shall be within ± 10% of the equivalent tritium concentration.

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6.1.2 Test method

6.1.2.1 Type tests performed with radioactive sources

For monitors with linear scales, the type test shall be performed with a radioactive source on at least one point on each range, e.g., at about 25% of the lowest range, 75% of the highest range, and about 50% of the other ranges.

For monitors with nonlinear scales, the source test shall be performed on at least one point at approximately the middle of each decade, except the for the highest decade where it should be at about 75%.

6.1.2.2 Type tests performed electronically

For analog displays, tests with electronic test equipment shall be performed at about 25%, 50%, and 75% of each range. For digital displays, tests with electronic test units shall be performed at about 25% and 75% of the scale of the measuring system.

6.1.3 Routine tests

Routine tests shall be performed on all monitors. The type of test depends on the type of monitor and user requirements.

6.1.3.1 Routine tests with a gamma source

For analog monitors provided with linear scales, the test shall be performed at one point on each range between 50% and 75% of scale maximum. For monitors with a single logarithmic range, the test shall be performed for one value in each decade. For digital monitors, the test shall be performed at one point from 50% to 75% of the scale or range of interest.

6.1.3.2 Routine tests with electronic equipment

For analog monitors, the routine test shall be performed at approximately 25% of maximum reading or 50% of the second most sensitive decade of measurement (whichever is lower). For monitors provided with linear scales, the test shall be performed at one point on each range between 50% and 75% of scale maximum. For monitors with a single logarithmic range, the test shall be performed for one value in each decade. For digital monitors, the electronic test shall be performed at one point from 50% to 75% of the scale or range of interest.

6.2 Response time

6.2.1 Requirements

The response time shall be as short as practicable, consistent with the measurement technique employed and the requirements of the user. The response time is usually determined by physical considerations, such as the time required for the gas to pass from the inlet to the measuring detector and the time to change the gas in the measuring volume, rather than by electronic considerations.

6.2.2 Test method

NOTE—The use of a two-way valve, one way allowing air to be circulated through the assembly, the other allowing tritium-in-air, is recommended.

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Following the monitor's technical manual, prepare the monitor to perform a tritium measurement. Record the tritium activity value (the activity chosen should be equivalent to 50% of the most sensitive decade), ambient background (as indicated by the tritium monitor after electronic zeroing), and the flow rate (which should be set to the nominal value). Expose the monitor to the tritium activity; and after the response has stabilized, record the monitor's reading as the reference reading.

Allow the monitor to purge and after the response has stabilized, re-expose the monitor and record the time required for the response to go from 10% to 90% of the reference reading.

While flushing the monitor, record the time required for the response to go from the exposed reading to within 10% of the reference reading.

Repeat this process at least four additional times, and calculate and record the mean response times for increasing and decreasing activities.

6.3 MDA

6.3.1 Requirements

The MDA shall be stated by the manufacturer based on the gamma background at the test location. The ambient background in the test area should be stable to ensure that the MDA is determined properly.

6.3.2 Test method

Purge the monitor with dry nitrogen. Switch the pump off, and plug the inlet and outlet of the monitor in order to prevent ambient air from entering the chambers. Allow the monitor to stabilize. Using the appropriate controls, zero the electrometer, and then allow the reading to stabilize.

Record at least 20 readings at 1 min (or greater) intervals. Calculate the average background reading and its standard deviation. Calculate and record the MDA (95% confidence interval) using the following equation:

$$MDA = 4.66 \times \sigma_b$$

where

σ_b is the standard deviation of the background.

6.4 Coefficient of variation (V)

6.4.1 Requirements

6.4.1.1 Linear scales

For linear scales, the V shall be ± 10% for any radioactivity level exceeding the level corresponding to one-third of the scale maximum on the most sensitive range.

6.4.1.2 Nonlinear scales

For nonlinear scales, the V shall be ± 20% for any radioactivity level exceeding three times the level corresponding to the lowest significant graduation on the scale.

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6.4.1.3 Digital display

For digital display, the V shall be ± 10% (± 1 LSD) for any radioactivity level exceeding the level corresponding to the least significant decade of reading.

6.4.2 Test method

Expose the detector to an appropriate radioactive source providing an indication between one-third and one-half of scale maximum on the most sensitive range (linear scale) or decade (logarithmic scale). Record the response and remove the radiation field.

Expose the monitor to the same field again and record the response. Repeat this process eight additional times for a total of ten readings. The time interval between each exposure shall be long enough to ensure that the readings are independent from one another. Determine the mean, standard deviation, and V from the set of readings taken. The V shall be within the limits stated in 6.4.1.

6.5 Overload test

6.5.1 Requirements

The monitor shall continue to operate when exposed to levels of tritium that are greater than the range maximum. Digital readouts shall indicate that radiation levels exceed the upper limit of the monitor. When the radiation level is reduced, the instrument shall return to the pre-exposure reading within 5 min.

6.5.2 Test method

Expose the monitor to a gamma field that is equivalent to two times the maximum value of the effective range of measurement.

Continue exposing the monitor for 10 min at the nominal flow rate and verify that the indication of the measurement assembly stays at its maximum value.

Remove or reduce the exposure and verify that the response returns to the pre-overload value within 5 min.

6.6 Self-decontamination (purge)

6.6.1 Requirement

The detector shall be designed to reduce the retention of tritium.

6.6.2 Test method

Inject tritium at a level that is at least twice the full-scale radioactivity of the most commonly used range. On wide range monitors, the value chosen should be based on the potential radioactivity levels expected by the user. After at least 15 min, the system will be allowed to purge with clean air at the nominal flow rate. Record the time required for the unit to reach the pretest value. Repeat this test four additional times. There should be no substantial increase between the reading taken at the completion of the first exposure and the reading taken upon completion of the last exposure.

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7. Response to different physical parameters

7.1 Chemical forms of tritium

7.1.1 Requirements

If the monitor is designed to measure a specific chemical form of airborne tritium, its performance when exposed to other chemical forms shall be specified by the manufacturer. The monitor shall not respond to other forms by more than the specified amount.

7.1.2 Test method

The method of test shall be described by the manufacturer and be performed in consultation with the user. The forms of tritium selected should be based on the user's requirements. The monitor will be exposed to each required form and the response recorded.

7.2 Response to radioactive gas other than tritium

7.2.1 General

Tritium monitors will typically respond to any radioactive gas that enters the detector volume. Some monitors may incorporate compensation devices that use gating, rise time, or pulse shape discrimination to reduce the response to other radioactive gases.

7.2.2 Requirements

The response of the monitor to other radioactive gases shall be stated by the manufacturer, as appropriate. The equipment shall not respond to such gases by more than the specified amount.

7.2.3 Test method

The method of test shall be described by the manufacturer and be performed in consultation with the user. The selection of test gases should be based on the user's requirements. The monitor will be exposed to each gas and the response recorded.

7.3 Ambient gamma radiation compensation

7.3.1 Requirement

If the monitor has the ability to compensate for ambient background radiation, the reliability of the method used shall be evaluated. The method's limitations shall be determined by evaluating the angular and field intensity dependence. The compensating technique is considered operational up to a level where the response exceeds ± 15% (± 1 LSD) of the reference response obtained without the radiation field present.

7.3.2 Test method

With the tritium monitor measuring a known activity of tritium, expose the monitor to a known gamma field. The gamma field intensity shall be based on the intensity at the center of the monitor, and all parts of the monitor shall be within the field.

The test shall be performed in two orientations as a minimum. The first orientation will have the monitor perpendicular to the incident radiation and the second, parallel to the incident radiation.

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7.4 Mechanical shocks

Portable monitors should be able to withstand, without damage, mechanical shocks from all directions at an acceleration of 300 m/s^{-2} (≈ 30 g) at a time interval of 13 m/s, the shape of the shock being semi-sinusoidal.

7.5 Sealing

In cases where a monitor is likely to be used in exceptionally damp conditions (e.g., out of doors), gaskets or other similar material or techniques shall be used to protect the monitor against the ingress of moisture.

7.6 Ambient temperature

7.6.1 Requirements

The monitor shall remain operational when exposed to temperatures from +2 °C to +50 °C. Its response shall not vary by more than ± 15% (± 1 LSD) compared to the reference response obtained at 20 °C ± 2 °C. Temperature changes shall be at a rate not to exceed 10 °C/h. The monitor shall be operated at the extreme temperatures for a minimum of 24 h prior to collecting data. It is recommended that this test be carried out in a environmental chamber. It is not generally necessary to control the humidity of the air in the chamber unless the equipment is particularly sensitive to change of humidity, but it is recommended that the relative humidity levels be held below 75%.

7.6.2 Test method

Expose the monitor to a gamma radiation source of sufficient intensity to produce an equivalent tritium response that is approximately midscale on the range being tested. The temperature shall be maintained at each of its extreme values for at least 24 h. The indication of the assembly shall be measured during the last 30 min of this period and compared with the reading under standard test conditions. Responses shall be corrected for changes in atmospheric pressure as necessary.

7.7 Relative humidity

The test in 7.7.2 evaluates the monitor for susceptibility to high humidity. Flow-through ionization-chamber tritium monitors can also be susceptible to low relative humidity. This susceptibility has been observed by an increase in response when relative humidity levels become very low (< 10%).

7.7.1 Requirements

The monitor shall be capable of operating when exposed to 93% (± 3%) relative humidity at 30 °C ± 2 °C for a minimum of 96 h. Responses shall be within ± 15% (± 1 LSD) of the reference values obtained at 30 °C and 40% relative humidity.

7.7.2 Test method

The relative humidity shall be stabilized at 40% for a minimum of 2 h and readings obtained. The humidity level shall then be increased at a rate not exceeding 10% relative humidity per hour until attaining 93% ± 3%. The humidity shall be maintained at this value for at least 96 h. The indication of the assembly shall be measured during the last 30 min of this period and compared with the readings obtained at 40%. The humidity shall be reduced to 40% while maintaining the temperature at 30 °C ± 2 °C and readings obtained after allowing the monitor to stabilize at that value for a minimum of 2 h.

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7.8 Atmospheric pressure

The influence of atmospheric pressure is, in general, only significant for an unsealed detector utilizing a gas as the detecting medium. In this case, the atmospheric pressure at which all tests are carried out shall be stated, and the effects of variations in atmospheric pressure should be indicated. Representative tests at other atmospheric pressures should be performed, if required by the user.

The manufacturer shall provide information regarding atmospheric pressure effects on the monitor's response, when necessary.

7.9 Radio frequency fields

7.9.1 Requirement

A monitor's susceptibility to radio frequency fields shall be known. It should not be susceptible to radio frequency fields from 80 MHz to 1000 MHz at 10 V/m. In order to determine the level and extent of susceptibility, if any, the monitor shall be exposed to a radio frequency scan from 80 MHz to 1000 MHz at 20 V/m. Each monitor's response, when exposed to the radio frequency fields of interest, shall remain within ± 15% (± 1 LSD) of the reference value obtained without the field present. No alarms or other operational abnormalities shall be caused by radio frequency fields.

7.9.2 Test method

Expose the monitor to a gamma source of sufficient intensity to produce an equivalent tritium response that is approximately midscale on the range being tested. Record this response as the reference response. If the monitor has an adjustable alarm set point, set the alarm to 15% over the reference response.

While still exposed to the radiation source, expose the monitor to a frequency scan from 80 MHz to 1000 MHz, 80% amplitude modulated with a 1 kHz sine wave, at 20 V/m. The scan rate should be based on IEC 61000-4-3-2002 [B4].

Observe the monitor's response during the scan and record any frequencies where the response is greater than ± 15% (± 1 LSD) of the reference value.

Document any alarm activations or other abnormalities observed during the scan.

7.10 Conducted immunity

7.10.1 Requirement

The test applies to monitors used in the presence of radio frequency transmitters in the frequency range of 150 kHz to 80 MHz. Monitors that do not have at least one conducting cable (e.g., mains supply, signal line, or earth connection) are excluded. A monitor's susceptibility to conducted radio frequency fields shall be known. The monitor should not be susceptible to conducted radio frequency fields from 150 kHz to 80 MHz at an intensity of 140 dB (μV).

7.10.2 Test method

In order to determine the level and extent of susceptibility, if any, the monitor shall be exposed to an automated sweep at a rate not greater than 1.5×10^{-3} decades per second, or 1% of the fundamental over a frequency range of 150 kHz to 80 MHz at an intensity of 140 dB (μV) with the signal 80% amplitude modulated with a 1 kHz sine wave. The monitor's response shall remain within ± 15% (± 1 LSD) of the ref-

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erence value obtained without the field present. No alarms or other operational abnormalities shall be caused by radio frequency fields.

7.11 Magnetic fields

7.11.1 Requirement

The monitor shall remain operational when exposed to a 10 Gauss dc magnetic field in two orthogonal orientations. The monitor's response shall remain within ± 15% (± 1 LSD) of the reference value obtained without the field present, and no alarms shall be activated.

7.11.2 Test method

Expose the monitor to a gamma source of sufficient intensity to produce an equivalent tritium response that is approximately midscale on the range being tested. Record this response as the reference response. If the monitor has an adjustable alarm set point, set the alarm to 15% over the reference response.

While still exposed to the radiation source, expose the monitor to a 10 Gauss dc magnetic field and observe the monitor's response.

Change the monitor's orientation in relation to the magnetic field by 90° and repeat the process.

8. Air circuit operation

8.1 Control and adjustment range of the flow rate

The flow-rate test is to determine the nominal sampling flow rate under standard test conditions and includes any pressure loss arising exclusively within the air circuit.

8.1.1 Requirements

The nominal flow rate and the range of adjustment shall be stated by the manufacturer. The flow rate obtained after 24 h of operation shall not differ by more than ± 10% from the nominal flow rate obtained after the required warm-up time.

8.1.2 Test method

For this test, a highly accurate calibrated flow-rate meter (or calibrated volumetric device) is incorporated in the air circuit at a point specified by the manufacturer.

Take a series of at least ten independent readings at start-up, after the assembly has been operating for 1 h, and after 24 h. The flow rate obtained shall be within ± 10% of the rate obtained 1 h after start-up.

9. Identification certificate

An identification certificate shall accompany each unit and give at least the following information:

— Name of manufacturer or trademark
— Type of unit and serial number
— Effective range of measurement

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- Graduation of scale
- Form of tritium measured (degree of selectivity)
- Response to other forms of tritium (if selective)
- Response to other radioactive gases
- Nature and dimensions of the aerosol trapping device
- Nominal airflow

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Annex A

(normative)

Pass/Fail criteria

The random uncertainty associated with the mean $\bar{x}$ of a series of measurements is expressed by the 95% confidence interval, I, about $\bar{x}$. A Pass/Fail decision for a test is based on the relation of the mean and its 95% confidence interval to the test acceptance limits. The mean and 95% confidence interval must lie completely between the upper acceptance limit L_U and the lower acceptance limit L_L in order that the test is *Passed*:

$$L_L \leq \bar{x} \pm I \leq L_U \tag{A.1}$$

The test is *Failed* if the mean and 95% confidence interval lie completely outside the acceptance limits, i.e., either

$$\bar{x} + I < L_L \tag{A.2}$$

or

$$\bar{x} - I > L_U \tag{A.3}$$

An unequivocal Pass/Fail decision cannot be made if the mean and 95% confidence interval do not lie completely within or outside of the test acceptance limits. It is not sufficient that the mean alone lies within the acceptance limits for the test to be considered Passed; both the mean and all of its associated 95% confidence interval must lie within acceptance limits in order to Pass.

The 95% confidence interval is determined from the standard deviation of measured values about their mean and from the acceptable probability that the interval excludes likely measurement results. It may be estimated using quantile values of the Student's t distribution, which is appropriate for small numbers of measurements. The expression for the 95% confidence interval, which is used in this standard, is given by

$$I = \frac{t_{0.05,\,v}\, S}{\sqrt{n}} \tag{A.4}$$

where

$t_{0.05,\,v}\, S$ is the 0.95 quantile of the Student's t distribution with $v = n - 1$ degrees of freedom;
S is the unbiased standard deviation of the measured values;
n is number of measurements.

Values of $t_{0.05,\,v}$ corresponding to selected values of n are given in Table A.1.

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Table A.1—Values of the 0.95 quantile of Student's *t* distribution with $v = n - 1$ degrees of freedom

n	$t_{0.05,\, v}$
2	12.71
3	4.30
4	3.18
5	2.78
6	2.57
7	2.45
8	2.37
9	2.31
10	2.26
15	2.15
20	2.09
25	2.06
30	2.05
40	2.02
60	2.00
120	1.98
∞	1.96

The following criterion must, for example, be met if the mean measured value can be said to lie within 10% of the conventionally true value at the 95% confidence level:

$$0.9\,C \leq \bar{x} \pm l \leq 1.1\,C \tag{A.5}$$

where

$\bar{x}$ is the mean of the measured values;
C is the conventionally true value.

The conventionally true value is typically considered to be without error for purposes of determining whether the performance requirement is met.

The confidence interval becomes smaller as n increases, so that reducing the overall uncertainty by increasing the number of measurements provides a means for obtaining an unambiguous Pass/Fail decision when the mean lies close to one of the acceptance limits.

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Annex B

(informative)

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[B1] ANSI N13.27-1981 (Reaff 1992), Performance Requirements for Pocket-Sized Alarm Dosimeters and Alarm Ratemeters.[2]

[B2] ANSI N42.17B-1989, Performance Specifications for Health Physics Instrumentation—Occupational Airborne Radioactivity Monitoring Instrumentation.

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[B4] IEC 61000-4-3-2002, Electromagnetic Compatibility (EMC)—Part 4: Testing and Measurement Techniques—Section 3: Radiated, Radio Frequency, Electromagnetic Field Immunity Test.[3]

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[B6] IEC 61000-4-6-2001, Electromagnetic Compatibility (EMC)—Part 4: Testing and Measurement Techniques—Section 6: Immunity to Conducted Disturbances, Induced by Radio Frequency Fields.

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[B8] IEC 60761-1-2002, Equipment for Continuously Monitoring Radioactivity in Gaseous Effluents—Part 1: General Requirements.

[B9] IEC 60761-5-2002, Equipment for Continuously Monitoring Radioactivity in Gaseous Effluents—Part 5: Specific Requirements for Tritium Monitors.

[B10] IEEE Std C62.41™-1991, IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits.[4]

[B11] NCRP 87-1987, Use of Bioassay Procedures for Assessment of Internal Radionuclide Deposition.[5]

[2]ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[3]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[5]NCRP publications are available from the National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Suite 800, Bethesda, MD 20814, USA.

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