American National Standard Calibration and Usage of Alpha/Beta Proportional Counters

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American National Standard Calibration and Usage of Alpha/Beta Proportional Counters

Sponsor

National Committee on Radiation Instrumentation, N42

accredited by the

American National Standards Institute

Secretariat

The Institute of Electrical and Electronics Engineers, Inc.

Approved 6 January 1997

American National Standards Institute

Abstract: This standard establishes methods for the calibration and use of gas proportional counters with and without active guard detectors. This standard also establishes methods for measuring the alpha and beta counting plateau, crosstalk factors, background, alpha and beta efficiency from prepared standards, correction factors for samples whose self-attenuation or mass differs from that of the standard, and calculation of the sample activities together with their random and total uncertainties. Correction for pulse pileup due to high count rate is also discussed. Although many principles articulated in this standard apply to the counting of radionuclides emitting a maximum beta energy below 100 keV as well, the counting of these low-energy beta emitters requires a higher degree of attention to detail in sample preparation, instrument calibration, and measurement correction factors than addressed in this standard. Therefore, this standard is intended for measuring radionuclides with maximum beta energies above 100 keV.
Keywords: alpha/beta proportional counters, calibration

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Introduction

(This introduction is not part of ANSI N42.25-1997, American National Standard Calibration and Usage of Alpha/Beta Proportional Counters.)

This standard is the responsibility of the Accredited Standards Committee on Radiation Instrumentation, N42. Committee N42 delegated development of this standard to Subcommittee N42.RM. Drafts were reviewed by Committee N42, Subcommittee N42.RM, and other interested parties, and the comments received were utilized in producing the standard as finally approved. The standard was approved by N42 letter ballot of 18 March 1996.

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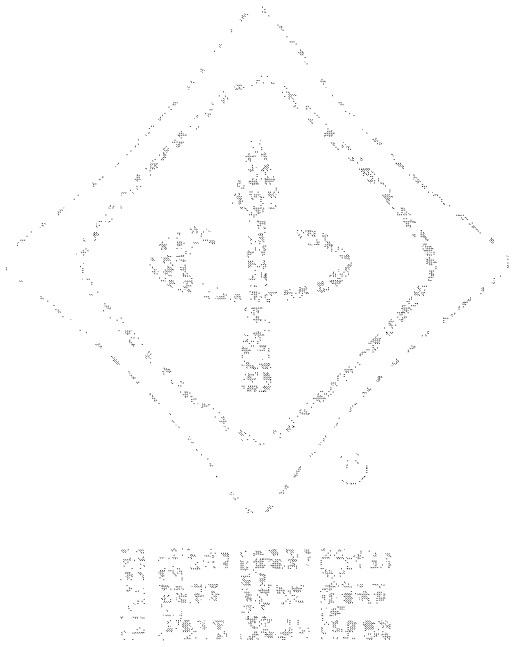
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American National Standard Calibration and Usage of Alpha/Beta Proportional Counters

1. Overview

This standard provides a basis for the routine calibration and use of gas proportional counters with or without active guard detectors. Gas proportional counters are used for the measurement of alpha and beta emission rates, and for the measurement of radionuclide activities when interferences from other radionuclides are not present. This standard is intended for use by persons who have an understanding of the principles of gas proportional counting and are responsible for the development of correct procedures for the calibration and use of these radiation measurement counters. References [B6], [B7], and [B11][1] provide information on the principles of operation of alpha/beta proportional counters.

A typical alpha/beta gas proportional counter consists of one or more gas proportional counters, active guard detectors, associated counting gas, signal processing electronics, and a scaler, or a multi-channel analyzer to record the detected counts. Computers are commonly interfaced to these systems to provide computer control as well as to permit automatic correction for efficiency, self attenuation, and other sample specific factors, and for storage of quality assurance/quality control information. Automatic propagation of uncertainties is also provided by many commercially supplied computer-controlled instruments.

1.1 Scope

This standard establishes methods for the calibration and use of gas proportional counters with and without active guard detectors. This standard also establishes methods for measuring the alpha and beta counting plateau, crosstalk factors, background, alpha and beta efficiency from prepared standards, correction factors for samples whose self-attenuation or mass differs from that of the standard, and calculation of the sample activities together with their random and total uncertainties. Correction for pulse pileup due to high count rate is also discussed. Although many principles articulated in this standard apply to the counting of radionuclides emitting a maximum beta energy below 100 keV as well, the counting of these low-energy beta emitters requires a higher degree of attention to detail in sample preparation, instrument calibration, and measurement correction factors than addressed in this standard. Therefore, this standard is intended for measuring radionuclides with maximum beta energies above 100 keV.

[1]The numbers in brackets correspond to those of the bibliography in Annex C.

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1.2 Special word usage

The word *shall* denotes a requirement, the word *should* denotes a recommendation, and the word *may* denotes permission. To conform to this standard, gas proportional counting shall be performed in accordance with the requirements of this standard, but not necessarily with its recommendations. However, justification should be documented for deviations from a recommendation.

2. References

ANSI N42.14-1991, American National Standard Calibration and Use of Germanium Spectrometers for the Measurement of Gamma-Ray Emission Rates of Radionuclides.[2]

ANSI N42.22-1995, American National Standard Traceability of Radioactive Sources to the National Institute of Standards and Technology (NIST) and Associated Instrument Quality Control.

ANSI N42.23-1996, American National Standard Measurement and Associated Instrumentation Quality Assurance for Radioassay Laboratories.

3. Definitions

3.1 Glossary

3.1.1 active guard detector: A detector constructed from similar materials with similar geometry to the main sample counting detector. This detector is mounted in proximity to the sample counting detector in order to intercept and react to the same background cosmic and terrestrial radiation field as the sample detector. Normally this detector is used in an anti-coincidence mode to cancel out the effect of this background radiation field on the sample detector in order to produce a real-time adjusted net count rate for the sample detector.

3.1.2 activity: The expected number of spontaneous nuclear decays (transformations) in unit time from a specified energy state (excluding prompt decays from a lower nuclear level) for a given amount of a radionuclide. Its standard unit (SI) is the becquerel (Bq), where one Bq equals one decay per second. Activity is often also expressed in curies, where 3.7×10^{10} Bq equals one Ci exactly or in disintegrations per minute (dpm), where 1 dpm equals 1/60 Bq exactly.

3.1.3 alpha emission rate: The rate at which alpha particles of all energies are emitted from one or all alpha-emitting radionuclides present in a source or sample.

3.1.4 alpha surface emission rate: The rate at which alpha particles of all energies emanate from the surface of a source or sample that contains one or more alpha-emitting radionuclides.

3.1.5 attenuation: The net loss of radiation field from the sample resulting from scattering or absorption in the sample or in material between the sample and the active volume of the counting chamber.

3.1.6 background count rate: Events per unit time from radioactive decay not caused by a calibration source or sample but rather from that occurring in the surrounding environment or from cosmic-ray interactions in or adjacent to the detector that have escaped detection by the guard detector, when present.

[2]These ANSI N42 publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

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Contributions to the background count rate can include naturally occurring radioactive decay in the structural materials comprising the counter, shielding, and cosmic-ray-induced ionizing radiation.

3.1.7 beta emission rate: The rate at which beta particles of all energies are emitted from one or all beta-emitting radionuclides present in a source or a sample.

3.1.8 beta surface emission rate: The rate at which beta particles of all energies emanate from the surface of a source or sample that contains one or more beta-emitting radionuclides.

3.1.9 blank count rate: Events per unit time from radioactive decay or cosmic-ray interactions in materials that make up the proportional counter, surrounding materials (background count rate), and the sample blank (consisting of the planchet and sample matrix). A sample blank may contain naturally occurring radionuclides and their daughter products.

3.1.10 check source: A radioactive source, not necessarily calibrated, which is used to confirm satisfactory operation of an instrument.

3.1.11 combined uncertainty: The uncertainty resulting from combining category A and category B uncertainties, as defined by the Bureau International des Poids et Measures (BIPM) (see [B5]), using standard statistical methods. Category A uncertainties are evaluated by applying statistical methods to a series of repeated measurements and are characterized by the estimated standard deviation, s_A; category B uncertainties are assigned to quantities whose variation is not explicitly observed. Category B uncertainties are determined by estimating from other information an approximation to a corresponding "standard deviation," s_B, whose existence is assumed. They are combined as if they are all standard deviations.

3.1.12 count rate: The rate at which detector pulses are being registered in a selected voltage interval. The unit is reciprocal seconds (i.e., s^{-1}) or reciprocal minutes (i.e., min^{-1}).

3.1.13 crosstalk: The fraction of all recorded pulses from alpha particles that are recorded in the beta channel due to degradation in their pulse height or the fraction of all recorded pulses from beta particles that are recorded in the alpha channel due to pulse pileup or other phenomenon. The beta crosstalk into the alpha channel should be negligible if the operation point (see definition) has been selected correctly. This term is equivalent to the term *spillup/spilldown*. Crosstalk is commonly used to indicate that the method of discrimination is pulse-height discrimination. *See also:* **spillup/spilldown.**

3.1.14 dead band: A region between the highest beta pulse and the lowest alpha pulse for a given radionuclide or mix of radionuclides that contains no pulses when using energy or rise time discrimination. Due to physical processes or electronic limitations this region may contain pulses not anticipated to be present.

3.1.15 interference or cross chamber interference: The fraction of all recorded pulses in either the alpha channel or the beta channel of a multiple chamber counting system that are due to the presence of a sample in an adjacent counting chamber.

3.1.16 measurements assurance program (MAP): A program that allows manufacturers to verify the accuracy of their measurements through exchange of samples with the National Institute of Standards and Technology (NIST). This involves the analysis of blind test samples sent to the suppliers by NIST, and NIST measurement of sources certified and provided by the supplier.

3.1.17 NIST: National Institute of Standards and Technology (formerly National Bureau of Standards, NBS).

3.1.18 NSLR: A country's National Standardizing Laboratory for radioactivity measurements.

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3.1.19 operation point: The locations in channels or voltage settings of the lower-level and upper-level discriminators for each counting channel and when appropriate the setting of a dead band region to separate the alpha and beta counting regions by pulse height or by rise time discrimination.

3.1.20 P-10 counting gas: A gas mixture commonly used in alpha/beta counters consisting of approximately 10% methane and 90% argon.

3.1.21 pulse pileup: Occurrence of two or more successive pulses closely associated in time but from separate decays such that they contribute to each other's height and shape. Usually the system processes the multiple inputs as a composite single pulse. Pulse pileup is a function of the amplifier pulse width and of the square of the count rate. *Syn:* random summing.

3.1.22 radioactive sample: A sample containing one or more radionuclides whose activity, activity concentration, emission rate or surface emission rate of ionizing radiation is to be measured.

3.1.23 radioactive source: A sample containing one or more known radionuclides whose activity, activity concentration, or emission rate of ionizing radiation may be but is not necessarily known.

3.1.24 spillup/spilldown: The fraction of all recorded pulses from alpha particles that are recorded in the beta channel due to their long rise time or the fraction of all recorded pulses from the beta particles in the alpha channel that are recorded due to their short rise time. This term is equivalent to the term crosstalk. Spillup/spilldown is commonly used to indicate that the method of discrimination is rise time (pulse shape) discrimination. *See also:* **crosstalk.**

3.1.25 total alpha emission rate: The rate at which alpha particles of all energies are emitted from alpha-emitting radionuclides present in a source or sample.

3.1.26 total beta emission rate: The rate at which beta particles of all energies are emitted from beta-emitting radionuclides present in a source or sample.

3.1.27 traceability: The ability to relate the measurement accuracy of radionuclide sources to national physical standards. Traceability is achieved by demonstrating the capability to produce accurate standardized sources by participation in a Measurements Assurance Program (MAP) with linkage to the National Institute of Standards and Technology (NIST) and production of certified materials in accordance with a quality assurance program that meets the guidance provided in this standard. Traceability of sources requires demonstrated measurement traceability as described in 8.3 of [B7] and in Clause 6 of ANSI N42.22-1995[3] and applies only to products produced in accordance with the procedures described in ANSI N42.22-1995.

3.1.28 ultra-high purity counting gas: In the case of P-10 counting gas, 99.999% pure argon, and 99.97% pure methane.

3.1.29 uncertainty: The likely inaccuracy of a reported value, expressed in terms of estimated standard deviations. *See also:* **combined uncertainty.**

3.1.30 window width: The difference, expressed in volts or energy (keV or MeV), between the lower-level and upper-level pulse-height discriminator settings.

3.1.31 working standard: Various prepared samples containing a known activity concentration of a radionuclide and traceable to a known National Institute of Standards and Technology (NIST) physical standard.

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[3]Information on references can be found in Clause 2.

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3.2 Symbols

$T_{\alpha+\beta}$	is the number of counts in the detector voltage adjustment (DVA) method alpha/beta mode
T_{α}	is the number of counts in the DVA alpha-only mode
T_{β}	is the number of counts in the DVA beta-only mode
R_{α}	is the net alpha count rate [in counts per minute (c/min)]
N_{α}	are the total counts in the alpha channel (in counts)
t_0	is the sample count time (in minutes)
$R(B)_{\alpha}$	is the alpha background count rate (in c/min)
$X_{\beta\rightarrow\alpha}$	is the beta-to-alpha crosstalk factor in percent in the pulse height discrimination (PHD) method, or the beta-to-alpha spillup factor in percent in the rise time discrimination (RTD) method
R_{β}	is the net beta count rate (in c/min)
N_{β}	are the total counts in the beta channel (in counts)
$R(B)_{\beta}$	is the beta background count rate (in c/min)
$X_{\alpha\rightarrow\beta}$	is the alpha-to-beta crosstalk factor in percent in the PHD method, or the alpha-to-beta spill-down factor in percent in the RTD method
t_B	is the background count time (in minutes)
C_{α}	is the concentration for alphas (in pCi/volume)
V	is the sample volume
ε_{α}	is the alpha efficiency (in percent)
C_{β}	is the concentration for betas (in pCi/volume)
ε_{β}	is the beta efficiency (in percent)
$\sigma_{R\alpha}$	is the net alpha count rate uncertainty
$\sigma_{R\beta}$	is the net beta count rate uncertainty
W_{α}	is the correction factor required for the alpha efficiency loss
W_{β}	is the correction factor required for the beta efficiency loss

3.3 Apparatus

A typical gas proportional counter system consists of a counting cave with or without lead or other shielding to block external radiation, one or more guard detectors, one or more proportional counter detectors, a power supply, amplifier electronics and a gas-flow system. There are also systems without guard detectors as well as systems without a gas flow. Either an integral computer to provide automatic data processing capabilities, or as a minimum an output on the proportional counter system for connection to an external computer is available with essentially all commercial systems.

4. Calibration

4.1 General

Calibration of the system involves measurements with standards for all possible radionuclides that may be present in unknown samples. Different types of measurements are also required for windowed and windowless detectors. Two types of sources are used to calibrate a system as follows:

— Efficiency calibration sources
— Check sources

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Efficiency calibration sources are themselves calibrated, traceable, have a high activity (typically about 30 000 dpm), and should also reproduce the expected geometry of the unknown samples, i.e., point source standards for point source samples and distributed standards for distributed samples, etc. The process of efficiency calibration should be repeated whenever one or more of the following occurs:

— A hardware component has been replaced or repaired.
— Changes have been made to the system (e.g., the gas-flow rate has been adjusted, the sample preparation procedure has been changed, etc.).
— The quality or manufacturer of the counting gas has been changed.

In addition, a check source should be used to verify that instrument performance has not changed every time a new bottle of counting gas replaces an expended one, even if the new gas is of the same type and purity and from the same manufacturer as the old one.

Quality control check sources are used to verify system performance on a daily basis. These sources have activities of at least 10 000 dpm and exhibit very little self-absorption. Typically, they are electroplated or anodized.

4.2 Detector plateau measurement

In order to determine the proper operating voltage of the instrument, it needs to be characterized for its count rate vs. voltage performance (the plateau curve). The plateau curve shall be measured when starting to use the instrument for the first time. The plateau curve shall be remeasured every time there is a change of gas cylinder unless tests indicate that there have been no changes in the instrument count rate response or charge collection timing due to the gas multiplication of the new gas for the range of maximum beta energies to be encountered. If the plateau curve is remeasured, the efficiency factor, discriminator setting, and background rate shall be checked, and, if found changed, reestablished.

The length of the plateau (in units of detector voltage, typically about 150 V) is dependent on the instrument and the counting geometry. Therefore, the plateau curve should be established with sources that simulate the samples to be analyzed. If the manufacturer's recommendations for operational voltages do not include a description of the length of the plateau, it shall be established as part of the calibration procedure.

There are three basic methods of alpha/beta discrimination, which fall into the following categories:

a) **Detector Voltage Adjustment (DVA).** In this method, the sample is first counted with the detector biased in the alpha-only mode of detection (to derive an alpha count), and then in the alpha/beta mode. For this method, both alpha and beta plateaus shall be determined.

b) **Pulse Height Discrimination (PHD).** In this method, the sample is typically counted with the detector biased in the alpha/beta mode, and the alphas are differentiated from the betas by virtue of their larger signal amplitude. In the alpha/beta mode, only the beta plateau needs to be determined. This type of an instrument can also be used in an alpha-only mode. For such operation, a separate alpha plateau shall be determined.

c) **Rise Time Discrimination (RTD).** In this method, the sample is typically counted with the detector biased in the alpha/beta mode, and the alphas are separated from the betas by virtue of the fact that the signal rise time of the alpha pulses is shorter (due to higher ionization density) than for the beta pulses. In the alpha/beta mode, only the beta plateau needs to be determined. This type of an instrument can also be used in an alpha-only mode. For such operation, a separate alpha plateau shall be determined.

NOTE—This method of differentiating between the alphas and the betas may also be called *pulse shape discrimination.*

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When using the PHD or the RTD method, the count rate vs. voltage curves (i.e., the plateaus) shall be determined with the chosen channel set fully open, so as not to exclude any energy shifted alphas or betas. The beta plateau shall be determined with a separate beta-only source and the alpha plateau with a separate alpha-only source. Mixed alpha and beta sources shall not be used.

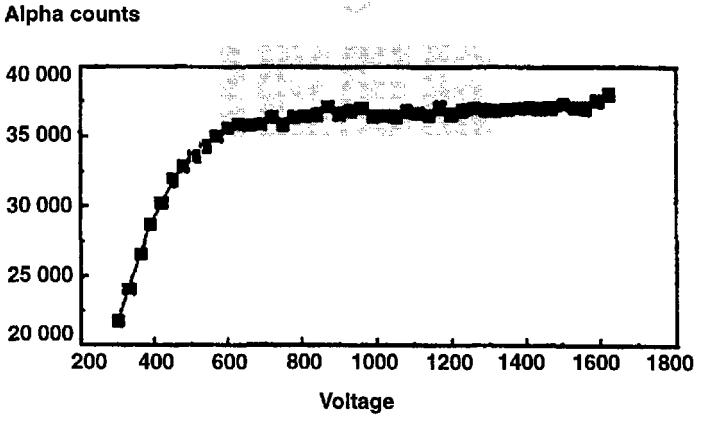
A plateau curve is generated by a series of source counts while increasing (stepping) the high voltage applied to the detector after each count. This procedure should be performed with small voltage increments (e.g., 10 V but no more than 50 V per step) from about 300 V to about 1500 V in most systems.

After a source is counted, a graph should be prepared which plots high voltage vs. the total number of counts accumulated at each high-voltage setting. Using P-10 counting gas, the curve generated by an alpha source will begin to increase from zero counts at about 400 V and level off at about 700 V.

NOTE—The plateau voltages as well as the other information given here are typical of ultra-high-purity grade P-10 gas and an anode wire diameter of 0.050 mm. Other characteristics may be found if a different gas or a different anode wire thickness is used.

The curve generated by a beta-emitting source will begin to increase from zero counts at about 1000 V and level off at about 1400 V. The bias voltages for the two modes should be selected within the plateau regions on the curves. The optimum operational voltages for alpha-only and simultaneous alpha/beta operation correspond to the points of minimum slope on the respective curves and 30–150 V above the knee of the plateau curve. For a point source in close proximity to the detector, the alpha plateau should not have a slope greater than 5% over a range of 100 V. If the slope increase is greater than 5%, the cause should be identified. For example, the counting gas or the anode wire may be the cause and need replacing. Likewise, if under the same kind of conditions, the beta plateau has a slope greater than 5% over a range of 100 V, the cause should be identified and proper action should be taken. Figures 1 and 2 show typical alpha and beta plateau curves taken with ^{210}Po (alpha) and ^{90}Sr-^{90}Y (beta) sources, respectively, using P-10 counting gas in a pancake-shaped counter.

NOTE—For distributed sources, the plateau slope may be larger than 5% over 100 V. The test is for point sources only.

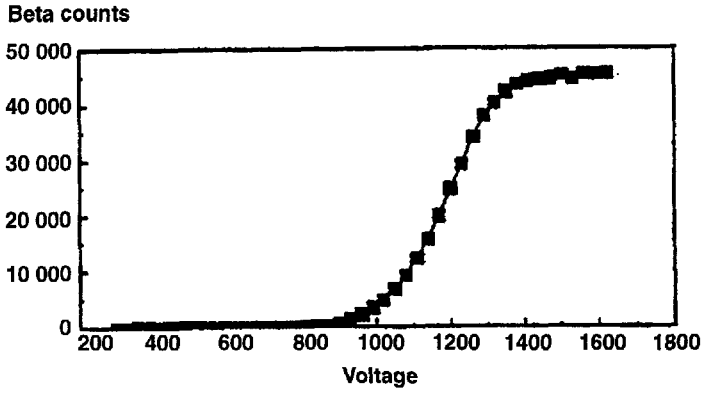


NOTE—One minute counts for each voltage.

Figure 1—An alpha plateau measured with a Po-210 source

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NOTE—One minute counts for each voltage.

Figure 2—A beta plateau measured with an Sr-90 source

4.3 Discriminator settings

In the DVA mode, the differentiation between alphas and betas is achieved through the selection of the operating voltage. The discriminators should be set to a wide open position.

A more typical proportional counting system uses either PHD or RTD electronics to differentiate between pulses arising from alpha and beta events. Adjustment of these settings is of importance to the accuracy of the final result, particularly in the case of mixed radionuclides, and/or in cases where there is variable sample self-absorption.

Crosstalk (in the case of PHD) and spillup/spilldown (in the case of RTD) is an effect whereby an alpha event is recorded by the system as a beta event and vice versa. This effect can be caused by the detector design, counting gas, electronic settings, and to some extent by the physical condition of the sample. Crosstalk and spillup/spilldown are usually stated as a percentage of the total events from the channel from which they came. That means the alpha crosstalk, in percentage, is the amount of alpha-induced count rate showing up in the beta channel expressed as a percentage of the alpha-induced count rate occurring simultaneously in the alpha channel, and vice versa for the beta crosstalk.

If the chemical and physical form of the radionuclides (as well as the radionuclides themselves) to be counted are known to produce a dead band, the use of a dead band between the alpha and beta channels is permissible. If the sample composition and physical and chemical form cannot be fully emulated during calibration, a dead band shall not be used. The reason for this is that due to self-absorption and/or an unknown mixture of nuclides, there may be alpha and/or beta counts that fall into the energy or rise time dead band and therefore would not be counted. On the other hand, when these parameters are known, and when the calibration source can be made to duplicate the counted sample, the use of a dead band can be used.

CAUTION—The use of a dead band may lead to significant underestimation of the actual source activities if the sample does not conform to the assumptions made in setting up the dead band.

Since crosstalk and spillup/spilldown can affect the accuracy of a measurement, minimization of the effect is important. However, it is more important to know the crosstalk and spillup/spilldown factors precisely than

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to choose operational settings that make it the minimum. A large error in this correction factor, even if it is relatively small, can lead to a deterioration of the overall accuracy of the measurement.

Crosstalk or spillup/spilldown adjustments can be made using check sources of the same radionuclide and physical construction as used with each sample type since only an accurate energy representation for each source type is important. The detector bias should be set at the optimum plateau voltage for simultaneous alpha/beta operation. The first step in setting the crosstalk is to place the beta source inside the detector sample chamber. The alpha channel lower-level discriminator should be set well above the expected pulse height of any beta event, but below the lowest expected alpha energy. The beta upper-level discriminator should be set at the same level as the alpha lower-level discriminator. The beta lower-level discriminator should be set just above the noise level of the electronics to prevent triggering the beta counter on noise. The alpha channel upper-level discriminator should be set above the highest expected alpha energy, or as high as the instrument permits. The beta upper-level and alpha lower-level discriminators should be decreased together until the crosstalk percentage of the beta events into the alpha channel is at the desired level. The beta source should be removed from the chamber and an alpha-only source should be inserted. The beta upper-level discriminator should be adjusted until the desired level of alpha into beta crosstalk is achieved.

In the case of RTD electronics, the first step shall be to ensure that the detector bias is set to the optimum plateau voltage for simultaneous alpha/beta counting as previously described. The beta-only check source shall be placed in the sample chamber, and the alpha RTD adjustment shall be set to the longest rise time permitted by the instrument. The beta RTD window adjustment shall then be fully adjusted toward the shortest rise time permitted by the instrument (i.e., fully opened). This will have the effect of including all the possible beta counts in the beta channel and some beta-induced counts showing up in the alpha channel. Utilizing the value of the beta counts in the beta channel as 100%, the alpha RTD control shall then be carefully adjusted toward the shorter rise time direction until the beta-induced count rate appearing in the alpha channel has been reduced to the desired level (e.g., 3–5% of the beta channel counts). Note this RTD control setting as the "alpha RTD setting."

The beta-only check source shall be removed and replaced with an alpha-only check source. In a similar fashion to the alpha channel adjustment, the beta RTD adjustment shall be set to the shortest rise time permitted by the instrument. The alpha RTD window adjustment shall then be fully adjusted toward the longest rise time permitted by the instrument (i.e. fully opened). This will have the effect of including all the possible alpha counts in the alpha channel and some alpha-induced counts showing up in the beta channel. Utilizing the value of the alpha counts in the alpha channel as 100%, the beta RTD control shall then be carefully adjusted toward the longer rise time direction until the alpha-induced count rate appearing in the beta channel has been reduced to the desired level (e.g., 3–5% of the alpha channel counts). Note this control setting as the "beta RTD setting."

Finally, set and lock the alpha RTD control to the "alpha RTD setting" found in the first setup step, and ensure that the beta RTD control is set and locked at the "beta RTD setting" found in the second setup step. No further setting is necessary.

4.4 Background

There are two types of background measurements that shall be made on a regular basis. The first type shall be made at least quarterly. This measurement should be for a long period of time (several hours) or several shorter counts for a total of several hours, so that good counting statistics can be obtained. It shall also be made at the same time of the day as the sample measurements to avoid biases caused by the diurnal variation in the background. See Figure 3 for an example of the extent of the diurnal variation. The background data

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obtained from this measurement shall be used if background subtraction is required. This type of background measurement is not required if background subtraction is not used.

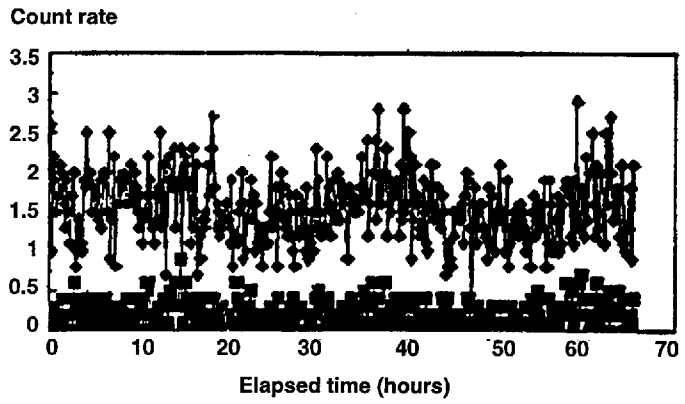


Figure 3—Alpha (n) and beta (t) background count rates over a long period of time

The other type of background count shall be performed daily. It is necessary to acquire this data for a period of time comparable to the count time of the samples. This data should be used as a quality control check to verify that the system has not become contaminated and is performing within acceptable limits. This data should be archived as part of the quality control check. Background counts shall be taken for both alpha-only and simultaneous alpha/beta modes if both are used.

It is recommended that more than one sample carrier be used to acquire the lengthy background data. This will ensure that the background corrected measurements will represent a random sampling of many possible carriers. Also, the same carriers that are used to make the background measurements shall be used to acquire data on samples of unknown activity. It is worth noting that the background data from many carriers may not necessarily follow a normal distribution. A minimum purge time in between carrier changes shall be specified by the manufacturer or determined by the operator for gas-flow systems that operate in a windowless mode to fully flush the system. Sufficient time is needed for the system to stabilize.

CAUTION—The presence of high level (≥ 1mCi) radioactive sources in the vicinity of the proportional counter should be prohibited during the counting of samples to avoid undocumented changes in the background count rates.

4.5 Efficiency

The efficiency for each radionuclide that may be found in samples shall be measured. The calibration sources that are used for each efficiency calibration measurement should consist of a pure radionuclide only. There should be a set of calibration sources for each sample geometry. For alpha-only operation of the counter, an alpha-only efficiency is sufficient. For alpha/beta operation of the counter, the alpha and beta efficiencies shall be determined simultaneously using the counter in an alpha/beta mode. At least 100 000 gross counts should be accumulated for efficiency data in all cases. Data from efficiencies that do not reflect the correct sample geometry or radionuclide should not be used unless a correlation function correcting for the differences is established, verified, and applied.

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5. Sources

5.1 Efficiency calibration sources

Efficiency sources should be available for each type of alpha and beta emitter expected to be present in samples. The sources shall be of either Type 1 or Type 2. The activity of a Type 1 calibration source shall have a traceability to NIST (or to the NSLR in the country in which the source is used). Type 2 calibration sources shall be prepared from radioactive solutions traceable to NIST or purchased from a supplier who has an active Measurements Assurance Program (MAP) with NIST.

CAUTION—An efficiency source shall not consist of multiple radionuclides, and it should duplicate the expected sample geometry and matrix.

The efficiency source activity should be large enough that calibration data on that source can be acquired in a reasonable amount of time, yet without creating more than a few percent dead time in the instrument.

The use of efficiency attenuation data for a sample type shall be used whenever appropriate. A set of efficiency sources for calibration of attenuation corrections should hold the activity of the particular radionuclide constant while the source mass per unit area is varied. An attenuation chart of the efficiency as a function of source mass should be made. Samples with mass per unit area (g/cm^2) may then be corrected for efficiency according to the chart. An attenuation chart should be made for each radionuclide, sample geometry, and sample matrix that will be measured.

CAUTION—Backscatter of betas can result in an apparent increase in the measured efficiency of many sources, and, likewise improve the measurement sensitivity for some samples. Care shall be taken in the correction of sample data when backscatter is prevalent. Efficiency corrections may not be properly applied if data based on a massless calibration source is used to correct data from a sample with backscatter, or attenuating mass. In addition, data taken with a windowed detector shall not be used to correct for the activity of a sample measured with a windowless detector, and vice versa.

WARNING

Caution shall be used in purchasing efficiency calibration sources. It is not uncommon to find planchet sources useful for low-level alpha/beta counting with a certified NIST (or other NSLR) activity calibration that are not suitable for use as a surface emission rate calibration standard. The reason for this is that the standard is calibrated by liquid scintillation or a gamma measurement. As such, the activity calibration is correct in terms of becquerels for the source content, but not correct as the 2π alpha or beta-particle emission rate from the surface of a prepared source. When the 2π emission rate from a sample is required, the efficiency shall be accurately measured with a beta surface emission standard.

5.2 Check sources

Two types of check sources can be used to verify the performance of a gas proportional detector instrument. The first type of check source is used to determine the detector plateau characteristics and set the alpha/beta discriminators (via either PHD or RTD). Only massless point sources should be used for these measurements. If both alpha and beta measurements are to be made with the instrument, two separate sources, one for the alpha performance, and one for the beta performance, shall be used for these check measurements.

The activity of these types of check sources should be chosen so that a statistically meaningful number of events above the background can be collected in a convenient period of time. The accuracy of the reported

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activity is not an important consideration since the sources are not used for measuring the efficiency correction factors, although the use of sources with accurately known activities is permitted. The source activities should not be so great that the dead time of the electronics results in a large percentage (> 5%) of lost events. An activity from 10 000 to 50 000 decays per minute should be sufficient to yield good results and yet not create too much dead time in the electronics. If the operator's manual does not contain information on the degree to which the dead time is affected by the count rate, it should be measured empirically from a decaying source with a short, precisely known half-life (e.g., ^{56}Mn) or with a set of sources (e.g., ^{60}Co) whose relative ratios of activity are precisely known and whose activities change from low to over 100 000 counts per second (see ANSI N42.14-1991 and [B4]). Such a set of sources can be obtained commercially.

The size of the active area of a check source should be as small as possible. A circular active area of a few millimeters in diameter deposited on a planchet is sufficient. Only a source consisting of a pure radionuclide should be used to measure plateaus and set discriminator levels. If in-growth of daughter products or radon daughter deposits contaminate the source, then it should not be used.

Another type of check source is used to establish the statistical variance of the instrument via a daily check of efficiency. It is not necessary for these sources to have any particular activity, accuracy, or geometry, although the use of accurately characterized sources is permitted. However, these quality assurance/quality control measurements shall always be made employing the same sources, the same counting geometry, and the same measurement time. If daughter products are present in a source, then all constituents shall be at equilibrium for all measurements.

6. Performance tests

All of the following tests shall be performed. The specific performance requirements and recommendations are included within the description of each test.

6.1 Sources

The system repeatability should be tested by measuring an efficiency calibration source multiple times, removing it from the counting position between each measurement to average statistical variations. The result from each measurement should be within the range of statistical variation for the selected source strength and count time. If working standards are prepared for the measurement of system repeatability, at least three standards should be prepared and counted.

The system efficiency should be tested by measuring standards of different source strengths that cover the range of activities expected from actual measurements.

A calibrated system should be tested daily or prior to each usage using sources of known activity. Both alpha-emitting and beta-emitting sources should be counted individually. The measured activity of each known source shall lie within two estimated standard deviations (i.e., the 95% confidence level) of the known activity for proper system performance. If agreement within this range is not obtained, recount the source. If after the second count agreement is not obtained, identify the cause of the disagreement (e.g., change in background count rates, damaged or old source, counting parameters no longer in calibration, bad counting gas, failing anode wire, failure in the guard detector, or pulse processing circuitry, etc.).

6.2 Verification of counter background

With all parameters set including the counter bias and discriminators and no source or empty planchet present in the counting chamber, acquire a background count for a period of >10 000 s. The number of

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recorded counts in the beta and alpha channels should lie within three standard deviations of the mean of previously acquired background counts for an empty counting chamber. If the proportional counter is equipped with an effective guard detector, variations in the cosmic-ray component of the beta background should not be detectable. If the proportional counter is not equipped with a guard detector, the cosmic-ray component of the background could cause measurable changes in the beta background count rate. Background counts should be counted at the same time of the day as the sample counts.

WARNING

High activity and high energy γ-ray sources that are present in the vicinity of the proportional counter can raise the backgrounds in the chamber appreciably and, if a background count under these high background conditions is not acquired, it can cause serious errors in the measured count rates.

6.3 Verification of alpha, beta, and guard plateau bias points

The high-voltage bias setting for the alpha and beta plateaus should be set high enough above the knee of the plateau to minimize count rate effects due to variances in the high-voltage bias or due to the minor variations in the diameter of the sample or its distance from the detector window. However, the bias should not be set so high above the knee as to unnecessarily increase the pulse width of the collected pulses. Typically, the bias should be set between 30 V and 150 V above the knee of the plateau curve. The bias setting should be recorded and compared with previous plateau measurements.

CAUTION—Changes in the high-voltage position of the knee of the plateau curve for a given radionuclide source and fixed counting conditions may be indicative of changes in the quality of the anode wire, purity of the counting gas, leakage current, or other malfunction, or degradation in the counting system. A minor change may be observed in the alpha or in the beta plateau curves by changing the source radionuclide used to measure the respective plateau curves.

CAUTION—Even if plateau curves are provided by the manufacturer of the instrument, they shall be reestablished to verify their correctness.

6.4 Verification of crosstalk (spillup/spilldown)

To verify that the alpha and beta pulse-height discriminators have been set correctly so as to allow correction for the number of alpha counts in the beta channel and the number of beta counts in the alpha channel, when the alpha plus beta plateau is used, standardized sources of ^{241}Am (or ^{210}Po) and ^{90}Sr-^{90}Y each of known activity are counted separately at their appropriate settings until >50 000 counts have been accumulated. The percent crosstalk (spillup/spilldown) into the opposite channel should agree with previous measurements to within 10% for the alpha crosstalk (spilldown) into the beta channel and to within 3% for the beta crosstalk (spillup) into the alpha channel. If agreement is not achieved, the operation point for crosstalk (spillup/spilldown) shall be redetermined.

6.5 Effectiveness of guard detector

To measure the effectiveness of the guard, the number of beta and alpha counts should be measured from two check sources for a 1000 s count time or from a mixed check source with an activity of ~10 nCi with no external sources present outside of the counter. Record the beta and the alpha counts. Place a high-energy γ-ray source (e.g., ^{60}Co) with an activity of ~1 μCi above or below the guard of the proportional counter so that only rays passing through the guard detector can intersect the active counter. Acquire data for a 1 000 s count time and record the beta and alpha counts. The latter counts should agree with the former within <3%.

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6.6 Verification of alpha and beta efficiency

To confirm the calibration settings and measured detector efficiency for a particular radionuclide, sample matrix, and measurement geometry, a sample of a radionuclide of known activity is counted under the same conditions until >50 000 counts have been accumulated. The emission rate is measured in the normal manner with all correction factors applied. The measured emission rate shall agree with the known value to within two standard deviations of the propagated uncertainty where the propagated uncertainty of the measured value includes uncertainties of type A and B (see Clauses 3 and 7, and [B10]).

6.7 Estimated uncertainty for gross alpha/beta screening

Gas proportional counters as integral counters are designed for the measurement of the emission rates of a single radionuclide, two radionuclides in which one decays by alpha emission and the other decays by beta emission, or of alpha/beta-emitting radionuclides in equilibrium with their daughter activities. The ability of a gas proportional counter to screen samples of unknown radionuclide composition is limited. In the case of beta-emitting radionuclides, the beta efficiency of the counter varies as a function of energy. A conservative approach to the use of alpha/beta proportional counters for measuring gross activity is to calibrate the efficiency with the radionuclide having the lowest maximum beta energy (e.g., Co-60) anticipated to be present in the samples. Only samples with approximately the same self-attenuation shall be considered for gross screening (e.g., air particulate filters with significantly different mass loading are unacceptable) unless the attenuating mass can be measured and the attenuation correction applied.

WARNING

Electron capture radionuclides free of positron emission should be restricted to counting single radionuclides because the efficiency of a proportional counter is a rapidly changing and nonlinear function of the x-ray energy due to the rapidly changing photoelectric mass absorption coefficient of the counting gas as a function of energy at low energies.

In the case of alpha-emitting radionuclides, the attenuation factor is extremely sensitive to the thickness and composition of the matrix composing the sample. Therefore, the emission rates even with no added attenuating mass may result in measurements with large errors.

To the extent that the anticipated radionuclides present in the samples have similar maximum beta energies and similar relative radionuclide composition, and the mass per unit area of the samples is nearly the same and of the same matrix composition, it may be possible to use the gas proportional counter as a screening device to measure the alpha and beta surface emission rates.

The measured emission rates and associated uncertainties may be determined from an efficiency derived from an estimated weighted average of the efficiencies and associated uncertainties from the expected relative radionuclide composition.

A set of at least five quality control samples whose emission rates are known and that contain mixtures in approximate proportion to the anticipated radionuclides in the samples should be counted, analyzed, and compared with the known emission rates. The relative radionuclide composition and emission rates of the individual quality control samples should each vary approximately ±25% about their average. The assigned uncertainty, which may exceed 50%, shall not be less than the standard deviation of such measurements.

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7. Determination of uncertainties and their propagation

All uncertainties, including those not derived from a complete statistical analysis, should be stated as approximations to standard deviations (of the mean if the mean is used). This convention follows that proposed by the Bureau International des Poids et Mesures (BIPM). It allows all of the uncertainty components to be propagated by statistical rules and results in a combined uncertainty (Categories A and B as defined in 3.1.11; also see [B10] and [B5]). Table 1 lists the equations for propagating uncertainties for several common algebraic expressions. See Chapter 2 of [B9] or [B11] for a more detailed discussion of uncertainties and their propagation. The principal components of the combined uncertainty in a measured alpha or beta emission rate (from the source or sample) are those in the sample count rate, blank count rate, efficiency, operational parameters including plateau bias, discriminator settings, crosstalk and spillup/spilldown corrections, pileup, attenuation in the sample, and decay corrections for the respective counting channels. When the activity of a particular radionuclide is being measured, and there is more than one decay mode, correction for the percent branching and the associated uncertainty shall be propagated with the other components as described above. The tests of performance in this standard should provide a good initial estimate of the uncertainty components for a given experimental setup. These estimates should be refined for these uncertainty components as experience is gained. Initial estimates of these components are given in Table 2.

Table 1—Uncertainties

Function*	Manipulation	Uncertainty†
$y = a_1x_1 - a_2x_2$	Addition/subtraction	$s_y = \sqrt{a_1^2 x_1^2 + a_2^2 x_2^2}$
$y = a_1x_1 + a_2x_2$	Addition/subtraction	$s_y = \sqrt{a_1^2 x_1^2 + a_2^2 x_2^2}$
$y = a_1x_1x_2$	Multiplication/division	$\frac{s_y}{y} = \sqrt{\left(\frac{s_{x_1}}{x_1}\right)^2 + \left(\frac{s_{x_2}}{x_2}\right)^2}$
$y = a_1\left(\frac{x_1}{x_2}\right)$	Multiplication/division	$\frac{s_y}{y} = \sqrt{\left(\frac{s_{x_1}}{x_1}\right)^2 + \left(\frac{s_{x_2}}{x_2}\right)^2}$
$y = x^m$	Power of x	$\frac{s_y}{y} = \frac{ms_x}{x}$
$y = e^{-ax}$	Power of e	$\frac{s_y}{y} = as_x$
$y = f(x_1, x_2)$	Function of two variables	$s_y = \sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 s_{x_1}^2 + \left(\frac{\partial f}{\partial x_2}\right) s_{x_2}^2}$

* a, a_1, a_2, and m are constants. x, x_1, and x_2 are independent variables. y is the dependent variable.

† s_y is the estimated standard deviation in variable y.

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Table 2—Uncertainty contribution

Uncertainty contribution	Typical magnitude[a]
Activity of standard source	0.1–2
Source aliquots	0.1–3
Uncorrected alpha/beta emission rate	0.1–25
Blank or background count rate	0–20
Variations in sample attenuation	0–100
Source—detector geometry	0.1–5
Crosstalk or spillup/spilldown	0–5
Pulse pileup (high count rate)	0–10
Decay of radionuclide	0–5
Alpha or beta branching probability	0–5
Alpha, beta efficiency	0–5

[a] Uncertainties are one estimated standard deviation expressed as a percentage.

Whenever a set of values with equally sized uncertainties is to be averaged, a simple mean is computed along with its standard deviation as follows:

$$\mu_x = \sum_{i=1}^{n} \frac{x_i}{n} \quad ; \quad s_x^2 = \frac{1}{(n-1)} = \sum_{i=1}^{n} (x_i - \mu_x)^2 \tag{1}$$

where

x_i are the values to be averaged;
n is the number to be averaged;
μ_x is the average value;
s_x^2 is the sample variance (the standard deviation of the sample is the square root of the variance).

Whenever a set of data with associated uncertainties is to be averaged, a weighted average should be taken as follows:

$$\mu_x = \frac{\sum_{i=1}^{n} \frac{x_i}{s_i^2}}{\sum_{i=1}^{n} \frac{1}{s_i^2}} \tag{2}$$

The uncertainty in the weighted average is dependent upon whether the data are internally consistent as determined by the chi-square (χ^2) test. If $[\chi^2/(n-1)] >> 1$, where n–1 is the number of degrees of freedom, the

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data are inconsistent or the uncertainties in the individual measurements are underestimated. The internal variance of the weighted mean is calculated as

$$s^2(\mu_x, 1) = \frac{1}{\sum_{i=1}^{n} \frac{1}{s_i^2}} \tag{3}$$

and the external variance, the larger of the two values, $s^2(\mu_x,1)$ and $s^2(\mu_x,2)$, is chosen for the uncertainty in the weighted average, and is calculated as

$$s^2(\mu_x, 2) = \frac{\sum_{i=1}^{n} \frac{1}{s_i^2}(x_i - \mu_x)^2}{(n-1)\sum_{i=1}^{n} \frac{1}{s_i^2}} \tag{4}$$

Whenever it is necessary to multiply the combined uncertainty by a factor to obtain a more conservative overall uncertainty, the multiplying factor shall be stated (e.g., 2, reporting uncertainties at about a 95% confidence level).

Whenever a set of counts have been taken for a constant number of counts (i.e., the counting times vary), these counts shall be averaged using the harmonic mean (see [B1]).

Whenever environmental and other very low-level activity samples are analyzed, the alpha/beta emission rates or activity should be reported with two uncertainties. The uncertainty in the respective net count rate and the combined uncertainty should be reported. The uncertainty in the net count rate will indicate whether or not the count rate is truly a positive count rate (i.e., different from pure background) while the combined uncertainty will indicate the accuracy with which the reported value is known.

For accurate estimates of combined uncertainty, it may be necessary to consider correlations between the component uncertainties. See [B9] for further information on the propagation of correlated uncertainties.

8. Quality control and assurance

Assuring the quality of data produced by radioanalytical instrumentation and laboratories is important, not only because technical professionals have this obligation to the users of their measured data, but also because government regulations and the public demand it. Quality assurance goes beyond the technical adequacy of methods used to make measurements or conduct analyses, and also involves control of the measurement processes through calibration and statistical control. It also concerns overall control of operations through various administrative practices. The combination of technical and administrative practices constitutes a quality assurance program.

In order for a laboratory to comply with this standard, a written quality assurance program shall be implemented. The elements of the program shall be determined by the level of quality required by the laboratory and customer, and applicable regulations. ANSI N42.23-1996 shall be implemented for measurements performed by a radioanalytical laboratory.

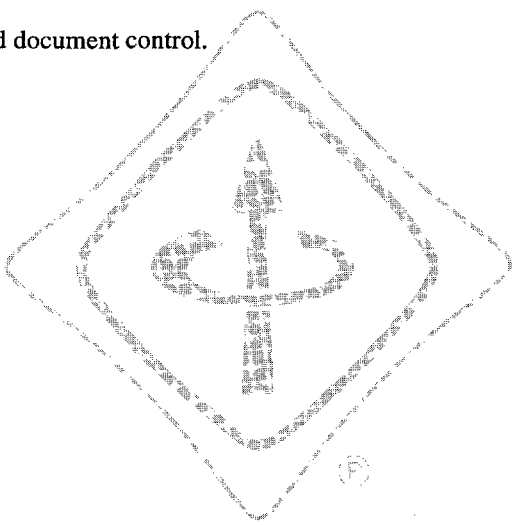
Measurements performed specifically for screening purposes, radioactive contamination control, or to limit personnel exposure to ionizing radiation, that do not become part of an officially reported record shall be used to implement a written quality assurance program containing those elements that ensure

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the quality of the measurements being made for the purpose intended. These elements are outlined in 4.2.4 of ANSI N42.23-1996 and include at a minimum the following:

a) Calibration and operation,
b) Analytical methods and methods validation,
c) Data verification,
d) Inter- and intra-laboratory quality control programs,
e) Software quality assurance,
f) Preventive maintenance,
g) Training and qualification of personnel,
h) Corrective actions,
i) Procurement of quality related items,
j) Sample receipt and control,
k) Radioactive material handling and waste disposal,
l) Quality assessment procedures,
m) Chain-of-custody during assay,
n) Sampling,
o) Disposal of samples,
p) Records retention and document control.



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Annex A

(informative)

Preparation of working standards from standard solutions

Working standards for the calibration of proportional counters can be prepared from radionuclide solutions by careful deposition of measured amounts of standard solution. The choice of matrix onto which the solution is deposited, the backing material, and any absorptive layers between the activity and the detector can influence the surface emission rate of the source.

Solutions of radioactive nuclides are readily available from commercial suppliers. Most suppliers can provide solutions whose activity and/or activity per unit volume or mass is traceable to the National Institute of Standards and Technology (NIST). See ANSI N42.22-1995 for details.

Working standards should resemble the samples for which the detector is being calibrated. For example, filter paper smear samples are usually prepared with active filter paper standards. If a solid residue is usually part of the sample to be assayed, it should also be part of the working standard.

The radionuclide solution should be transferred in a manner consistent with the concentration data provided by the supplier. If the concentration is provided in terms of activity per unit mass, gravimetric means are recommended to prepare the working standard. If the concentration is provided in terms of activity per unit volume, volumetric means are recommended to prepare the working standard. If the density of the solution is provided, either volumetric or gravimetric means may be used but gravimetric is more accurate although more tedious.

Care shall be taken with standard solutions that contain volatile elements or compounds. Solutions shall be thoroughly mixed before use. Solutions containing volatile materials should be precipitated onto or chemically bound to a backing surface. Certain elements tend to volatilize (e.g. iodine, mercury, and selenium) whenever the standard solution is taken to dryness.

If the solutions for preparing working standards are to be used daily, they shall be kept sealed to prevent evaporation when not in use. For extended storage, flame sealing in glass ampules is the method of choice. Consideration shall be given to covering or encapsulating the working standards of samples to prevent contamination. Thin films of mylar, polyester, acrylic, and light metal materials have successfully been used for this purpose.

CAUTION—If working standards will be used to calibrate windowless gas proportional detectors, care shall be taken to maintain a conductivity path through the backing and window materials of the source. Non-conductive backing materials should not be used because they disrupt the electric field of the counter.

A.1 Simple volumetric preparation of planchet style sources

This method employs a calibrated volumetric micropipette and planchet(s) of the same size and materials as the samples to be assayed. Withdraw a desired amount of solution into the tubing and dispense onto the planchet in a distributed fashion. For additional information see, Chapter 5 of [B7].

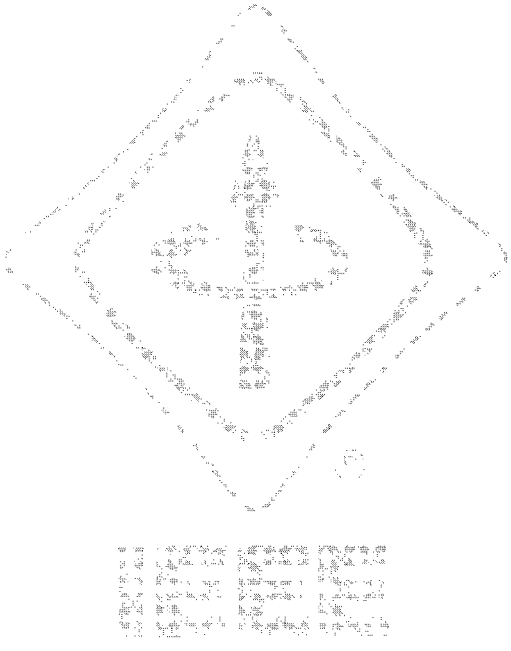
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A.2 Simple gravimetric preparation of planchet style sources

This method employs a micropipette or syringe, polyethylene capillary tubing, high precision balance, and planchet(s). Connect the capillary tubing to a pipette or a syringe. Withdraw the desired amount of solution into the tubing. Make sure the syringe or pipette has "extra" air or volume to expel the solution from the tubing, and that air has also been drawn into the tubing after the solution. This reduces the risk of contamination during transfer. Weigh the tubing and syringe. Dispense the solution onto the planchet in a distributed pattern. Weigh the tubing and syringe. The difference between the two masses is the dispensed mass. For additional information, see Chapter 5 of [B7].

The addition of a wetting or seeding agent such as a dilute solution of Ludox™[4] has been shown to improve the mass distribution of the evaporated solution. A light acrylic spray can be used to seal the source with minimal absorption effects.



[4]Ludox, a silica gel, is a trademark of the DuPont Chemical Co.

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Annex B

(informative)

Guidance on measurement of samples

B.1 General precautions

If the system consists of a gas-flow proportional counter, the gas flow should be on for 24 h before making actual measurements including establishing the plateaus. A double gas regulator should be used to control the gas flow and potential pressure to which the proportional counter may be exposed due to regulator failure. Adjust the gas flow to conform with the manufacturer's recommendation.

If the high voltage has been off, it should be applied to the counter(s) at least 15 min before making actual measurements.

The gas of the proportional counter should meet the manufacturer's purity specifications for valid results, or be of at least laboratory grade. Ultra-high purity counting gas is recommended.

B.2 Net count rates

B.2.1 Detector voltage adjustment (DVA) method

In the DVA method, the sample is first counted with the detector biased in the alpha-only mode of detection (to derive an alpha count rate), and then counted in the alpha/beta mode. The count time is the same for both counts. The alpha count rate is calculated as

$$R_\alpha = \frac{T_\alpha}{t} \tag{B.1}$$

where

T_α is the number of counts in count time t.

The beta count rate is calculated as

$$R_\beta = R_{\alpha+\beta} - R_\alpha \tag{B.2}$$

where

$R_{\alpha+\beta}$ is the count rate in the alpha/beta mode;
R_α is the count rate in the alpha-only mode;
R_β is the count rate in the beta-only mode.

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The uncertainty of the beta count rate is calculated as

$$\sigma_{R_\beta} = \frac{\sqrt{T_{\alpha+\beta} + T_\alpha}}{t} \tag{B.3}$$

where

$T_{\alpha+\beta}$ is the number of counts in time t in the alpha/beta mode;
T_α is the number of counts in time t in the alpha-only mode;
t is the common count time for both measurements.

If the background in the alpha-only and alpha/beta modes is significant enough to be considered, it can be included to modify the alpha count rate as follows:

$$R'_\alpha = \frac{T_\alpha}{t} - \frac{T_{b(\alpha)}}{t_b} \tag{B.4}$$

where

$T_{b(\alpha)}$ is the number of background counts in time t_b in the alpha-only mode;
t_b is the count time for the background measurement.

The modified beta count rate is calculated as

$$R'_\beta = \left(\frac{T_{\alpha+\beta}}{t} - \frac{T_{b(\alpha+\beta)}}{t_b}\right) - \left(\frac{T_\alpha}{t} - \frac{T_{b(\alpha)}}{t_b}\right) \tag{B.5}$$

where

$T_{b(\alpha+\beta)}$ is the number of background counts in time t_b in the alpha/beta mode.

NOTE—The above equations assume that the background count time is the same in both the alpha/beta and alpha-only modes.

The uncertainty of the beta count rate when a background is subtracted is

$$\sigma_{R'_\beta} = \sqrt{\frac{T_{\alpha+\beta}}{t^2} + \frac{T_{b(\alpha+\beta)}}{t_b{}^2} + \frac{T_\alpha}{t^2} + \frac{T_{b(\alpha)}}{t_b{}^2}} \tag{B.6}$$

B.2.2 Pulse height discrimination (PHD) and rise time discrimination (RTD) methods

In the PHD method, and in the RTD method, the sample is counted with the detector biased in the alpha/beta mode, and the alphas are separated from the betas by the PHD channels or the RTD channels, respectively. In both methods, the net alpha count rate is determined as

$$R_\alpha = \frac{N_\alpha}{t_0} - R(B)_\alpha - \frac{R_\beta \times X_{\beta\to\alpha}}{100} \tag{B.7}$$

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where

R_α is the net alpha count rate (in c/min);
N_α are the total counts in the alpha channel (in counts);
t_0 is the sample count time (in minutes);
$R(B)_\alpha$ is the alpha background count rate (in c/min);
$X_{\beta\to\alpha}$ is the beta-to-alpha crosstalk factor in percent in the PHD method, or the beta-to-alpha spillup factor in percent in the RTD method;
R_β is the net beta count rate (in c/min), which is determined as

$$R_\beta = \frac{N_\beta}{t_0} - R(B)_\beta - \frac{R_\alpha \times X_{\alpha\to\beta}}{100} \tag{B.8}$$

where

N_β are the total counts in the beta channel (in counts);
$R(B)_\beta$ is the beta background count rate (in c/min);
$X_{\alpha\to\beta}$ is the alpha-to-beta crosstalk factor in percent in the PHD method, or the alpha-to-beta spilldown factor in percent in the RTD method.

The uncertainty for the net alpha count rate is

$$\sigma_{R_\alpha} = \sqrt{\frac{R_\alpha}{t_0} + \frac{R(B)_\alpha}{t_0} + \frac{R(B)_\alpha}{t_B} + \frac{R_\beta \times X_{\beta\to\alpha}}{t_0 \times 100} + \left(\frac{X_{\beta\to\alpha} \times \sigma_{R_\beta}}{100}\right)^2} \tag{B.9}$$

where

t_B is the background count time (in minutes), and assuming a negligible $X_{\alpha\to\beta}$ uncertainty.

The uncertainty for the net beta count rate is

$$\sigma_{R_\beta} = \sqrt{\frac{R_\beta}{t_0} + \frac{R(B)_\beta}{t_0} + \frac{R(B)_\beta}{t_B} + \frac{R_\alpha \times X_{\alpha\to\beta}}{t_0 \times 100} + \left(\frac{X_{\alpha\to\beta} \times \sigma_{R_\alpha}}{100}\right)^2} \tag{B.10}$$

assuming a negligible $X_{\beta\to\alpha}$ uncertainty.

B.3 Concentrations

The concentration for an alpha-emitting nuclide is calculated as

$$C_\alpha = \frac{R_\alpha}{60 \times V \times \varepsilon_\alpha} \tag{B.11}$$

where

C_α is the concentration for alphas (in Bq/volume);
R_α is the net alpha count rate defined in equation (B.12);
V is the sample volume;
ε_α is the alpha efficiency.

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The concentration for a beta-emitting nuclide is

$$C_\beta = \frac{R_\beta}{60 \times V \times \varepsilon_\beta} \quad \text{(B.12)}$$

where

C_β is the concentration for betas (in Bq/volume);
R_β is the net beta count rate defined in equation (18);
V is the sample volume;
ε_β is the beta efficiency.

The uncertainty estimate for the alpha concentration is calculated as

$$\sigma_{C_\alpha} = \frac{\sigma_{R_\alpha}}{60 \times V \times \varepsilon_\alpha} \quad \text{(B.13)}$$

where

σ_{R_α} is the net alpha count rate uncertainty defined in equation (20) and assuming no efficiency error.

The uncertainty estimate for the beta concentration is calculated as

$$\sigma_{C_\beta} = \frac{\sigma_{R_\beta}}{60 \times V \times \varepsilon_\beta} \quad \text{(B.14)}$$

where

$\sigma_{R\beta}$ is the net beta count rate uncertainty defined in equation (22), and assuming no efficiency error.

B.4 Weight correction

If the sample thickness (e.g., measured in mg/cm^2) is different from that of the calibration source, the results should be corrected for self-attenuation. The correction to the concentration calculation results in the following equation for alphas:

$$C_\alpha' = \frac{R_\alpha}{60 \times V \times \varepsilon_\alpha \times W_\alpha} \quad \text{(B.15)}$$

where

W_α is the correction factor required for the alpha efficiency loss due to the sample weight compared to the standard with which the efficiency was measured.

An equivalent equation should also be applied for betas as appropriate, i.e.,

$$C_\beta' = \frac{R_\beta}{60 \times V \times \varepsilon_\beta \times W_\alpha} \quad \text{(B.16)}$$

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where

W_β is the correction factor required for the beta efficiency loss due to the sample weight compared to the standard with which the efficiency was measured.

B.5 Health physics smear samples

Gas proportional counters are frequently used to determine if a surface, tool, or piece of apparatus is surface contaminated with removable radioactivity. Most often these determinations are made by counting a smear sample taken of 100 cm^2 of surface with a specified type of paper filter attached to a flat backing (e.g., a cork or rubber stopper). Porous material such as glass fiber filters or cotton swabs should not be used to smear uncovered surfaces for removable contamination. A net disintegration rate per square centimeter above that designated by regulation indicates that the smeared item has removable radioactive surface contamination.

Because the gathering of smear samples is subjective, measurement of the contamination level with a smear sample is inexact in practice. This is in part due to the lack of information regarding the binding forces of the radionuclides, and the chemical nature of the radionuclides themselves. For this reason, smear samples should only be used in combination with other direct methods to ascertain if an item or surface is free of contamination. Process knowledge should be used to determine which radionuclides are potentially contaminating the article or surface in question. This information should be used to determine how the smears should be counted and what efficiencies should be used.

Even with a number of undefined sample variables, the techniques for gathering and measuring smear samples can be conducted so as to reduce the uncertainty in the resulting measurement. The alpha efficiency for a given sample, free of attenuating material and for a given instrument and counting geometry is relatively constant as a function of energy (~30% to 45%), but attenuating material has a large effect on the count rate of alpha contaminated smears. Proper efficiency correction is key to the measurement of smear samples. The following recommendations are offered to improve the repeatability and accuracy of gathering and counting smears:

a) Use only the type of smear specified by regulation (e.g., Whatman 50 paper is often specified).

b) Do not take smears of items or surfaces covered with a significant amount of dust. The added material will attenuate the radiation to be measured and result in a false measurement. Smears should be taken of only physically clean surfaces.

c) Smear the size of surface area specified by regulation. If only smaller surfaces can be smeared due to the size of the item, correctly calculate the disintegration rate per unit area using the smaller area covered.

d) Whenever permitted by regulation, smear for alpha contamination with membrane type filters that are not porous, and smear only clean surfaces or items to avoid attenuations of the alphas emitted from the contaminant radionuclide atoms.

e) Smears should be counted in the same geometry and under the same counting conditions as used to measure the efficiencies for smear samples. A counting time should be selected to achieve the sensitivity required by regulations for release of a potentially contaminated item.

f) When the radionuclide responsible for contamination is known, use the efficiency measured for that radionuclide and smear type.

g) When several radionuclides contribute to potential contamination, use the efficiency measured for the radionuclide with the lowest beta energy.

These guidelines will reduce the possibility of releasing material as uncontaminated when, in fact, it is contaminated with removable contamination.

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Annex C

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Bibliography

[B1] Colle, R., "Use of the Harmonic Mean: On Averaging Count14 Rate Data for Variable-Time, Fixed-Count Intervals," *Radioactivity & Radiochemistry*, vol. 7, no. 1, 1996.

[B2] Curran, S. C., "Proportional Counter Spectrometry," in *Beta and Gamma-Ray Spectroscopy*, K. Siegbahn, Ed., North Holland Publishing Co., Amsterdam, vol. XLV, ch. VI, 1955.

[B3] Ehmann, W. D., and Vance, D. E., *Radiochemistry and Nuclear Methods of Analysis*, John Wiley & Sons, New York, pp. 207–220, 1991.

[B4] Gehrke, R. J., and Johnson, L. O., "A 4π β-γ Coincidence System with Minimally Broadened Pulses for High Count Rates," *Nuclear Instrumentation & Methods*, 204 (1982) 191.

[B5] Giacomo, P., "News from the BIPM," *Metrologia*, 17 (1981) 69.

[B6] Knoll, G. F., *Radiation Detection and Measurement*, 2d ed., John Wiley & Sons, New York, 1989.

[B7] NCRP Report No. 58, *A Handbook of Radioactivity Measurements Procedures*.

[B8] Rossi, and Staub, H. H., *Ionization Chambers and Counters*, McGraw-Hill, New York, 1949.

[B9] Smith, D. L., "Probability, Statistics, and Data Uncertainties in Nuclear Science and Technology," *OECD Nuclear Energy Agency Nuclear Data Committee Series, Neutron Physics and Nuclear Data in Science and Technology*, vol. 4, American Nuclear Society, 1991.

[B10] Taylor, B. N., and Kuyatt, C. E., "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Result," *NIST Technical Note 1297*, United States Department of Commerce and Technology Administration, National Institute of Standards and Technology, Gaithersburg, MD 20899, Jan. 1993.

[B11] Tsoulfanidis, N., *Measurement and Detection of Radiation*, McGraw-Hill Book Company, New York, 1983.

[B12] Wilkinson, D. H., *Ionization Chambers and Counters*, Cambridge University Press, Cambridge, 1950.

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