NIST Measurement Services:

Alpha-Particle Calibrations (2004)

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National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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NIST MEASUREMENT SERVICES:
Alpha-Particle Calibrations (2004)

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ABSTRACT

This document describes the alpha-particle calibration services offered by the Radioactivity Group of the National Institute of Standards and Technology (NIST) (Scheduled Calibrations; 43030C, 43040C, and 43050C). The fundamental measurement quantities are defined, the measurement approach is described (or reviewed), and the operating procedures are described from the point of view of the calibration technician or metrologist. The measurement uncertainties, and how they are estimated, are described. Methods for maintaining and assessing quality control, e.g., international comparisons, MQA programs, etc. are also briefly reviewed. This edition updates and supersedes NIST Special Publication 250-5, July 1987.

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1. Introduction

Alpha particles emitted from radioactive sources are measured at the National Institute for Standards and Technology (NIST) in three systems, the 2π steradian, α-proportional counting system (denoted small $2\pi\alpha$ PC), the large area 2π steradian, α-proportional counting system (denoted the large $2\pi\alpha$ PC), and the 0.8π steradian α-CsI(Tl) scintillation system (denoted $0.8\pi\alpha$ SC). The full energy of the alpha particles is absorbed in the counting gas in the first two systems and in the scintillator in the second system. A ("frequency") spectrum of alpha-particle counts in a counting period versus alpha-particle energy deposited in either the gas or scintillator is collected and displayed in a multichannel analyzer within a computer. Overall counting rates are determined from sums of all or parts of these spectra as discussed below.

2. Description of Service [1]*: 43030C, 43040C, and 43050C

Alpha-particle sources are submitted by outside laboratories to NIST for calibration of either their $2\pi\alpha$ steradian emission rate or of their total activity. Emission rate is measured in alpha-particles per second detected in 2π geometry - in this case by one or both of the 2π proportional counters. Because the resulting pulse-height distribution is continuous down to zero energy and alpha particles cannot always be separated from pulses produced by recoiling daughters and instrument noise in the proportional counter the spectrum must be extrapolated from above 100 keV down to zero energy. (This is discussed further in the General Operational Procedures section.) In the case of measurements with the $0.8\pi\alpha$ SC and sometimes the proportional counters as we shall see, activity, N_o, is measured in becquerels (Bq), the SI unit which is also dimensionally "per second," and represents the total number of disintegrations per second produced by the alpha-particle emitting source. When the $2\pi\alpha$ PC's are used for activity measurement, conversion factors that when multiplied into the emission rate for a given source, convert the result to activity for that source.

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*Numbers in brackets indicate literature references at the end of this document.

Calibrations are checked by simultaneously calibrating a previously-calibrated standard source.

Typical calibration reports for $2\pi\alpha$-emission rate measurement and $0.8\pi\alpha$-particle emission rate are given in Appendices Ei, Eii, and Eiii.

Sources submitted by the customer to NIST for calibration must satisfy certain requirements. Packaging for all sources must be in compliance with Department of Transportation (DOT) and Nuclear Regulatory Commission (NRC) regulations. Copies of regulations may be obtained from Operations Division, Office of Hazardous Materials, Department of Transportation, Washington, D.C. 20590. Postal regulations prohibit mailing radioactive materials, which require a caution label under DOT regulations. Alpha-particle solid sources must be supplied in special source holders such that the active area is not touched by any material. For sources measured in the small $2\pi\alpha$ PC counter (Calibrations 43030C and 43050C) the diameter of the source must be less than 10 cm and that of the active surface less than 9 cm. For the large $2\pi\alpha$ PC (Calibrations 43030 and 43050C) the maximum dimensions on a rectangular source must be 18cm by 30cm. For the 0.8π α SC counter (Calibration 43040C), the maximum diameter is only 1.6 cm.

Further specifications for these calibration services are given in the following table. (Table 1)

Table 1. Specifications for calibrations using the proportional counters and the 0.8π defined solid angle counter.

	Calibrations 42030C and 43050C	Calibration 43040C
Counting system	NIST proportional counters	NIST 0.8 π defined-solid-angle counter
Sources calibrated for	Alpha-particle emission rate into 2π steradians	Total activity
Nominal uncertainty 2σ	1.5 percent	1.5 percent
Activity range	$(0.4 - 10^4)\ s^{-1}$	$(40 - 10^4)\ s^{-1}$
Maximum diameter Maximum size	Small area: 10 cm Large area: 18 cm by 30cm	1.6 cm

3. Design Philosophy and Theory *

The proportional counters [2] are used because they record alpha particles with little interference from emitted beta particles or gamma rays. In proportional counters, all alpha particles leaving the source into the forward hemisphere ionize atoms in the counting gas, with the number of ions produced proportional to the α-particle energy deposited. The electrons released in the ionization are accelerated in an electric field toward a collecting electrode, multiplying their number by impact ionization. The resulting electrical pulse is electronically amplified, and sorted as to pulse height. The fact that the source is "internal" (inside the counter) allows all emitted particles to be recorded without absorption by possible counter casings. (For further discussion of proportional counters see NCRP 58 [3].)

The advantage of these detection systems is that sources up to relatively large areas can be measured; however, because of the high detection efficiencies and count rate limitations in the electronics, the measurements are limited to sources with activities of less than 20,000 Bq. At the lower end, count rates should be greater than 10 times background, which is on the order of 0.06 s^{-1}.

3.1. The small $2\pi\alpha$ Proportional Counter (small $2\pi\alpha$ PC)

The calibration of alpha-particle sources started at the National Institute for Standards and Technology in the early 1950's [4]. The alpha-particle detector used consisted of a 12-cm-diameter hemispherical gas-flow proportional counter as shown in Figs. 1, 2, and 3.

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* Excerpted in part from Lucas [2]

12 CENTIMETER DIAMETER PROPORTIONAL COUNTER CHAMBER
(small $2\pi\alpha$ PC)

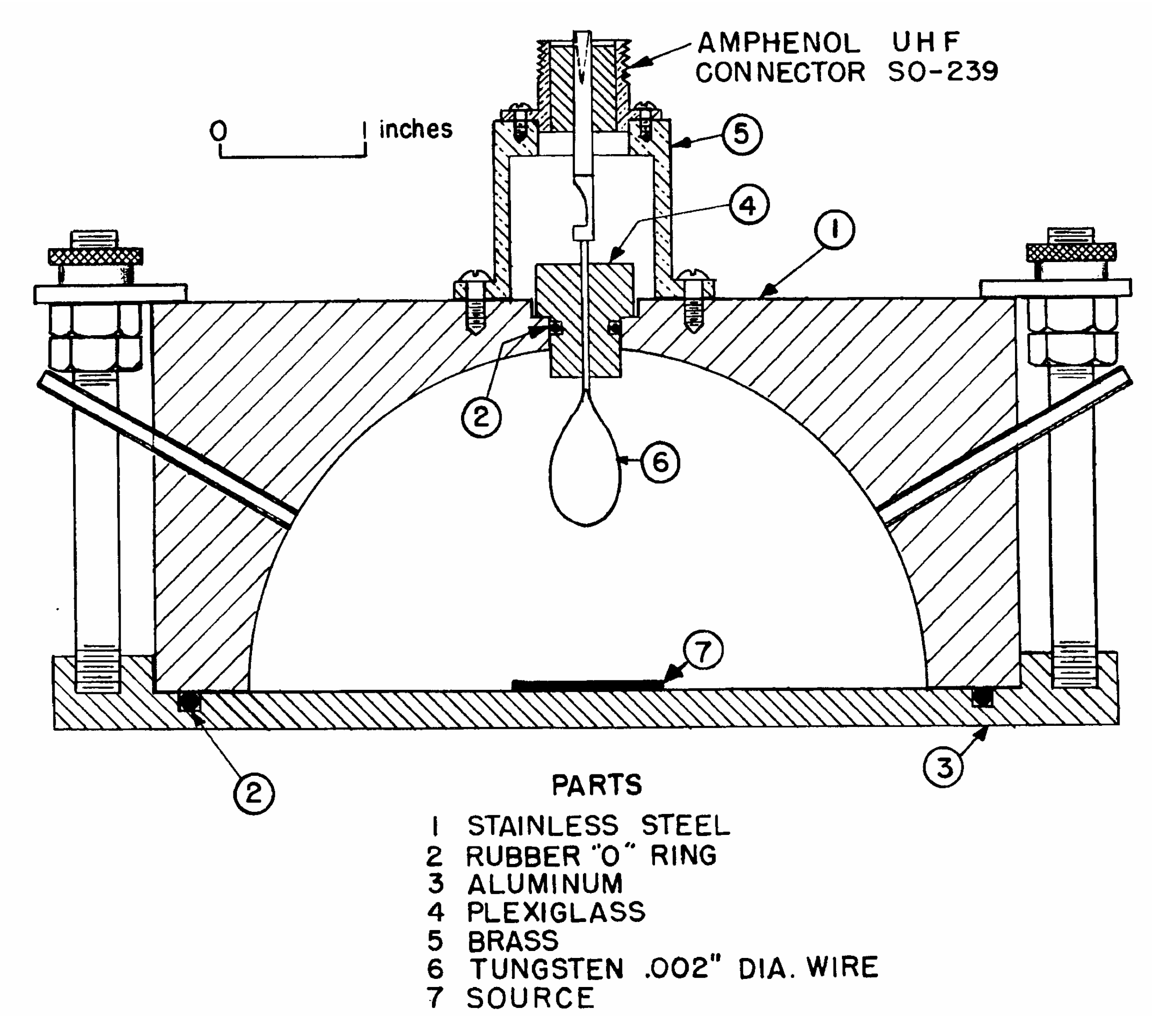

Fig. 1. Schematic diagram of the small area $2\pi\alpha$ PC

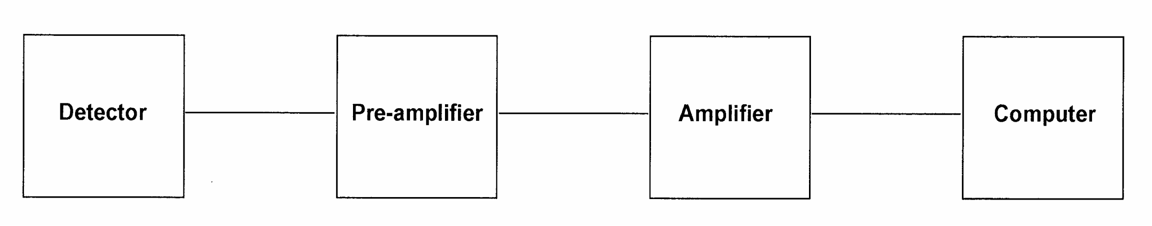

Fig. 2. Hook-up of electronic components of all three counters

This counter has been in use constantly since that time and is still much used today. Description of the characteristics and usage of such detectors follows.

Fig.3. Photograph of the small 2π α PC

Extrapolation to Zero Pulse Height - Regardless of the type of detection system used, an accurate determination of the total alpha-particle count rate requires that the alpha-particle pulse-height spectrum be recorded and extrapolated to zero pulse height, as shown in Fig. 4. The high-count rate at low channel numbers is primarily due to system noise. At NIST we generally fit to a second-order polynomial, although a simple first-order polynomial (straight-line extrapolation) is often adequate. When the pulse-height spectrum is extrapolated to zero pulse-height in this way, the total count rate remains almost constant despite a large change in the system gain, whereas the count rate above a fixed discrimination level varies significantly with the same change in the system gain. The effect of using an extrapolation-to-zero pulse height is demonstrated in Fig. 4 in terms of a plot of relative count rate versus counter voltage and in Fig. 5 in terms of a plot of relative count rate versus point-source position.

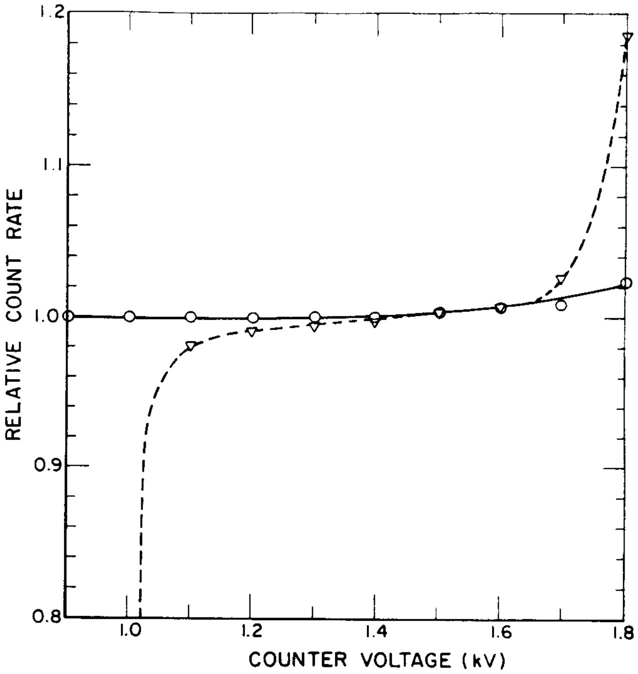

Fig.4. Relative counting rate versus counter voltage for the small $2\pi\alpha$ PC (see Fig. 1). An ^{241}Am point source was located in the center of the chamber. The counting gas was P-10 at atmospheric pressure. The solid line is the count rate data using an extrapolation to zero pulse height. The dashed line represents data from count rates above a fixed discrimination level.

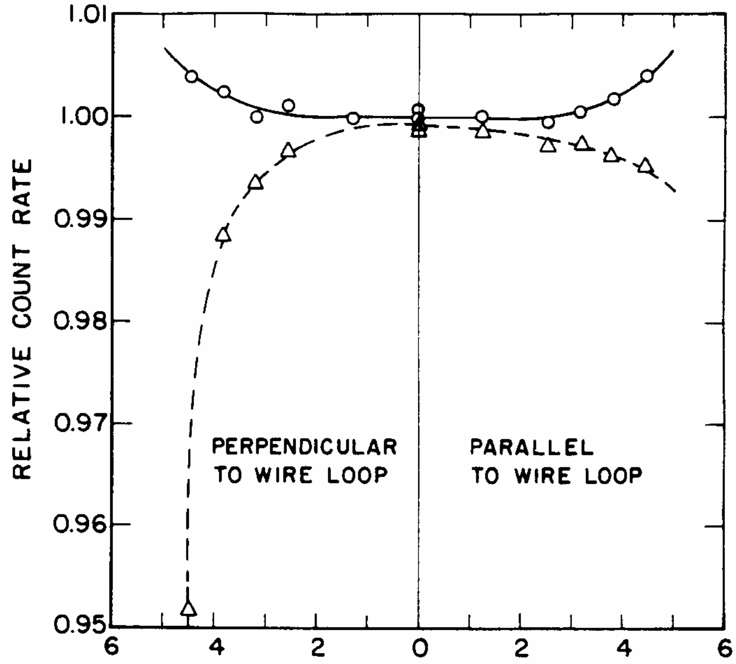

Fig.5. Relative count rate versus position for an ^{241}Am point source in the small $2\pi\alpha$ PC (see Fig. 1). The counter voltage was 1400V. The counting gas was P-10 at atmospheric pressure. The solid line is the count rate extrapolated to zero pulse height. The dashed line is the count rate above a fixed discrimination level.

Maximum Source Size - For uniformly high detection efficiency (1.000 ± 0.005) from the surface of an extended source, the source diameter should not be larger than about one half of the counter diameter. The maximum permissible source size using this criterion depends upon the electric field distribution within the counter (especially the shape and position of the anode wire loop) and upon the composition of the counting gas (for example, it is larger for P-10 than for methane [5]) and can be determined for any given counter by plotting the count rate versus the position of a point source. Fig. 5 shows such data for the small $2\pi\alpha$ PC at NIST under normal operating conditions (1 atm. of P-10 gas, 1400 V). Note the difference when the pulse-height spectrum is extrapolated to zero pulse height.

Counting Gas - In a proportional counter the counting gas serves two purposes:

1. It provides a medium in which an alpha particle can dissipate its kinetic energy to form free electrons and ionized atoms or molecules.

2. It provides a medium in which the free electrons so formed can be accelerated in the presence of an electric field to produce additional ionization (that is, electron multiplication and hence amplification or "gas gain").

Methane and P-10 (90 percent argon, 10 percent methane) are the gases most often used for gas-flow proportional counters. The gas of choice in any given system or for any given application depends upon a number of factors, including cost, availability, purity, and background count rate. There are also other considerations. A much higher electric field (that is, a much higher anode voltage) is required in methane than in P-10 for the same average electron multiplication, and the electron multiplication in methane is less affected by the presence of small concentrations of electronegative gas impurities, such as O_2 and H_20 [5]. However, if the pulse-height spectrum is extrapolated to zero pulse height, the effect of the change in system gain due to the presence of impurities in the counting gas will be minimal, even with P-10.

Scattering - For reasons of stability and convenience, an alpha-particle source is commonly mounted on a flat metal backing. When such a source is measured in a detector having 2π geometry, the 2π counting rate, $C_{2\pi}$, is generally not one half of the activity, N_o, because some of the alpha particles initially emitted downward are backscattered into the sensitive volume of the detector, while some of the alpha particles initially emitted upward are scattered or absorbed in the source or both. As a result, the measured $C_{2\pi}$,/N_o ratio can vary significantly from 0.50. This is shown in Appendices A, B, C, and D, which are from the latest and most comprehensive [6] of a number of papers dealing with this subject. Note that, even for a weightless source, the correction can be very significant.

3.2 The NIST large area 2π large area α (large 2πα PC) proportional counter. Figs. 6 and 7 show this counter.

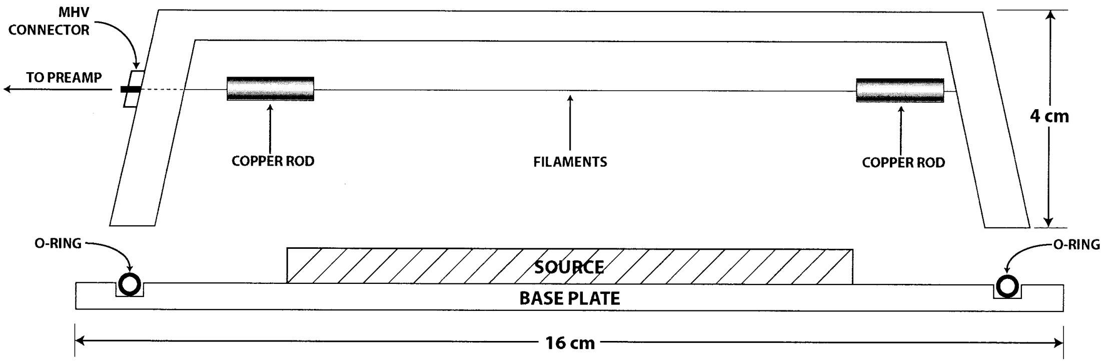

Fig.6. Schematic diagram of the NIST large 2πα PC (not to scale)

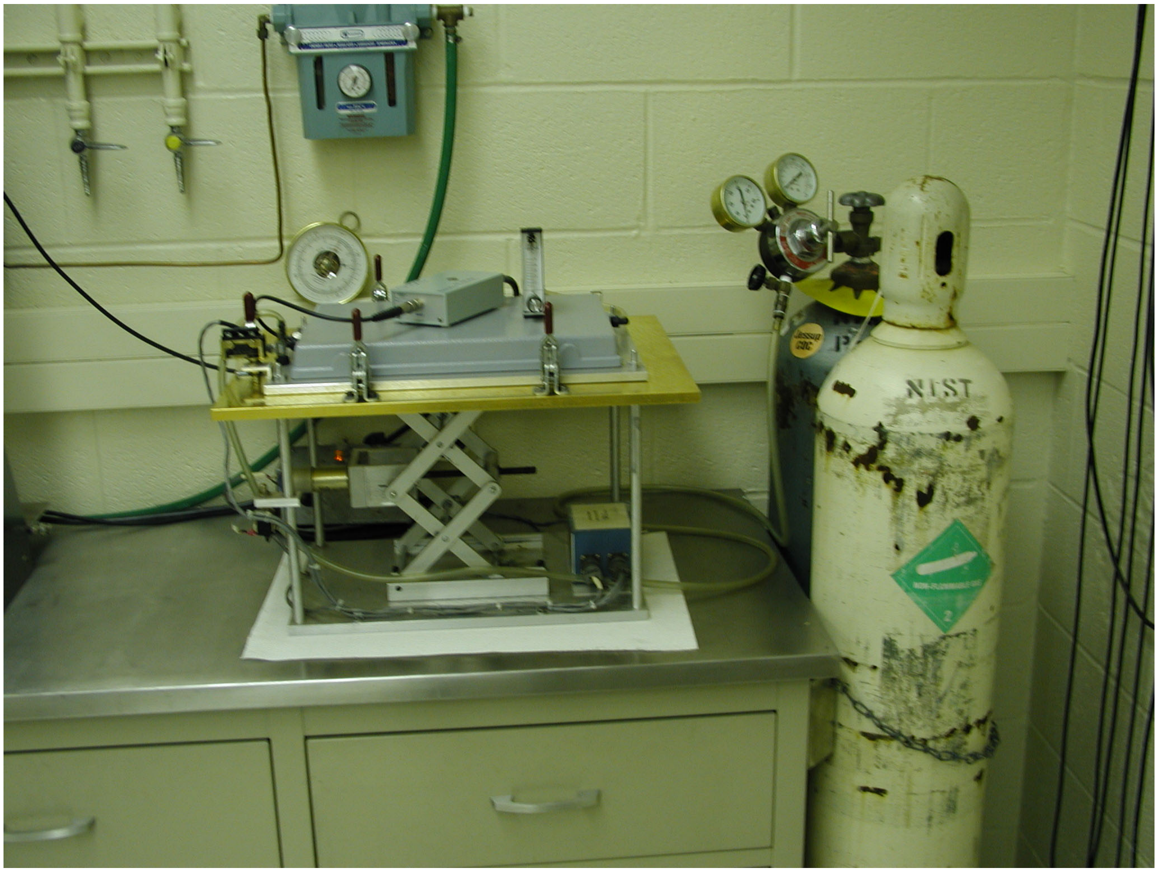

Fig.7. Photograph of the large area counter.

The functioning of the large $2\pi\alpha$ PC is virtually identical with that of the small $2\pi\alpha$ PC. All above descriptions apply.

3.3 $0.8\pi\alpha$ Scintillation Counter

The $0.8\pi\alpha$ SC, the so-called Robinson counter [7], after the designer of the instrument, is a CsI(Tl) scintillation counter, with defined solid angle, and a three dimensional central baffle (Figs. 8 and 9). Alpha particles striking the scintillator produce light flashes proportional to the energy imparted. These flashes are transformed to electrical pulses and amplified for pulse-height analysis. The baffle is designed such that the detection efficiency is insensitive to positional changes in the source with respect to the detector. As shown in [7], a 10 mm vertical or horizontal displacement of the source results in a count rate change on the order of 0.1 percent. This detector should not be used with sources with diameters greater than 1.6 cm. However, since the efficiency is approximately 40 percent of that of the 2π counters, maximum source activities can be correspondingly greater. Unfortunately, the background is significantly higher than that in the 2π counters and, therefore, the minimum activity sources are significantly higher - on the order of 40 Bq. A pulse height spectrum is shown in Fig. 10.

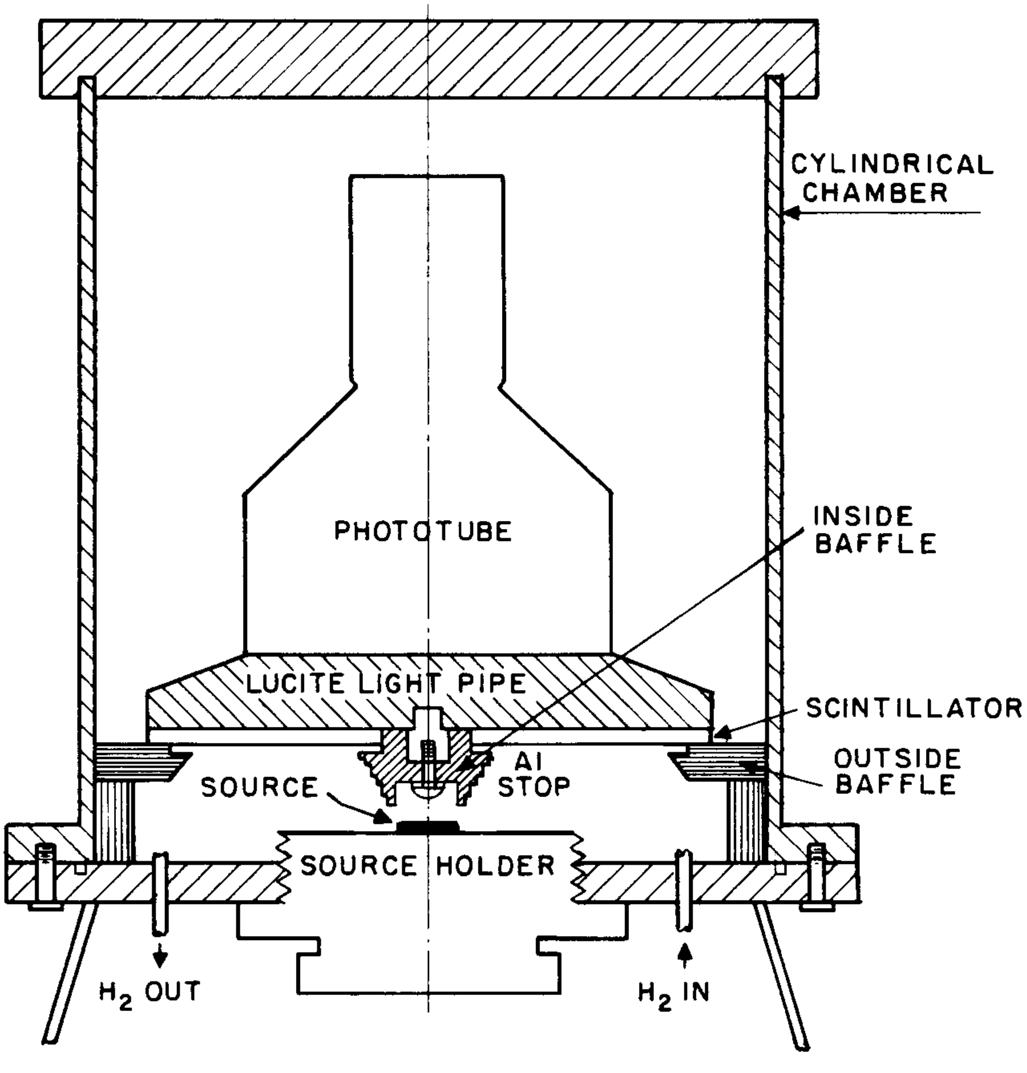

Fig. 8. Schematic of 0.8πα SC.

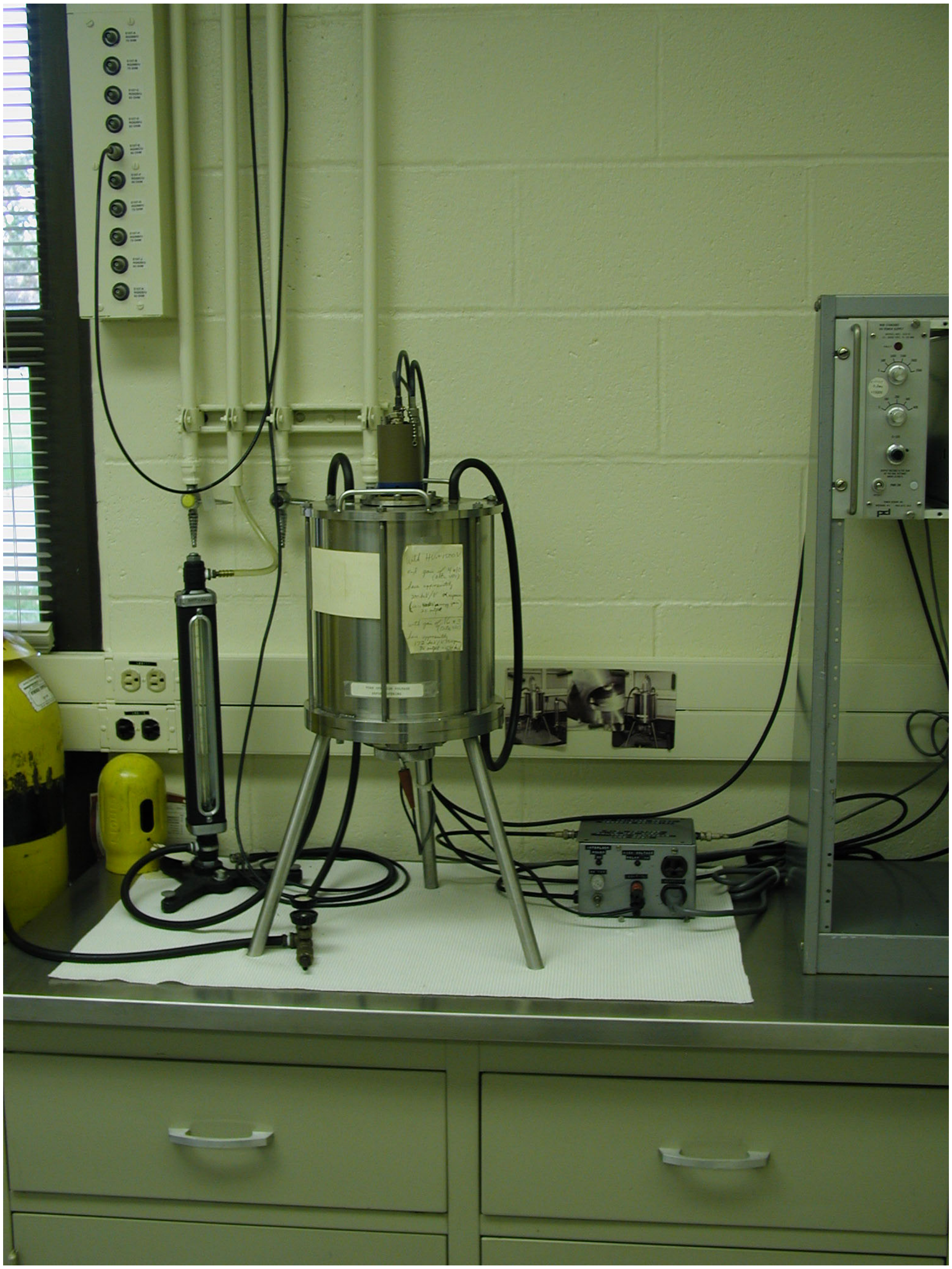

Fig. 9. Photograph of the 0.8πα SC.

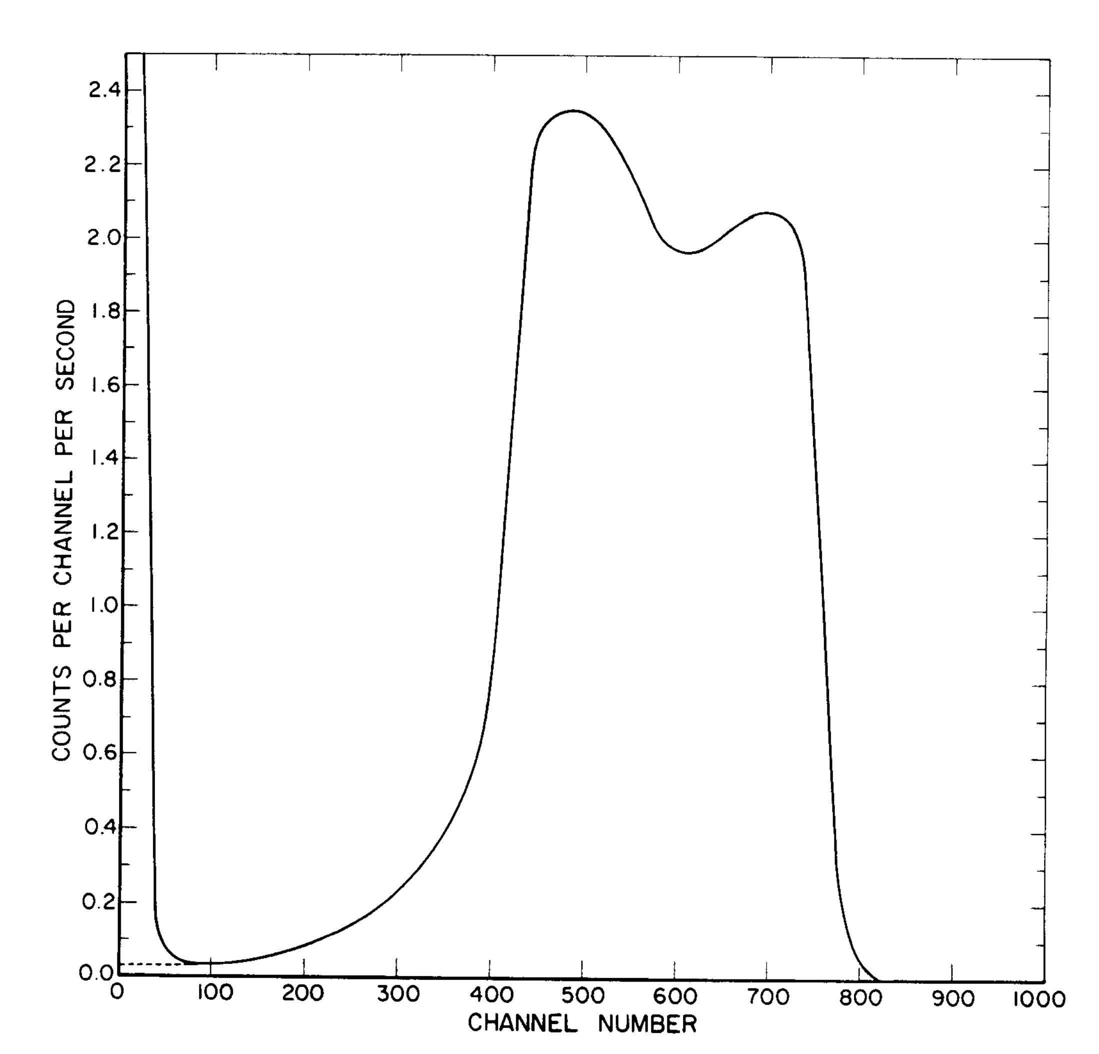

Fig. 10. The pulse-height spectrum from a sample of ^{239}Pu in the $0.8\pi\alpha$ SC showing the extrapolation to zero pulse.

In about 1960 an experimental investigation of the energy and angular distributions of the emitted and scattered alpha particles, was carried out at NIST by Walker [8]. Her results for all emitted alpha particles at various angles are shown in Fig. 11 Backscattered alpha particles are all emitted within about 20^0 of the plane of the source (70° to 90° in Fig. 11). Therefore if the solid angle subtended by the detector is such as to exclude all alpha particles emitted within 20° or more of the plane of the source, then the scattering correction, and the uncertainty associated with it, is eliminated. The slight slope in the central portion of the curve was apparently due to the center of rotation of the detector not being coincident with the source. Figure 11 also shows the angles subtended by several of the defined-geometry counters for the standardization of alpha-particle sources.

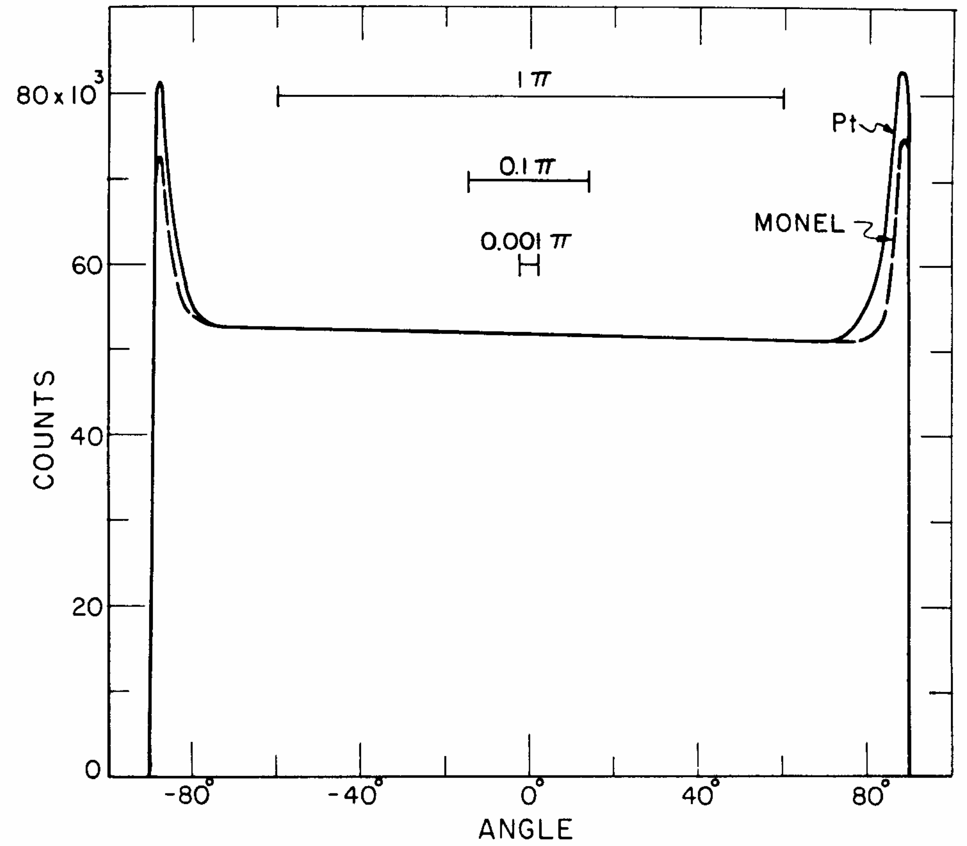

Fig. 11. Count rate versus angle of emission for alpha particles emitted by ^{210}Po that had been deposited on the surfaces of platinum and monel disks. (0 is perpendicular to the surface of the disk.) See Ref. 8 for complete details. Also shown are the angles subtended by the detectors in several defined-geometry counters.

Several defined-geometry counters have been described in the literature [7,9,10,11]. One problem that arises in the use of such counters, especially those with large solid angles, is that the geometry is very dependent upon the position of the source in the counter. The design described by Robinson (9) almost eliminates such position dependence over a wide range of horizontal and vertical displacements of the source.

To obtain the highest accuracy from a defined-geometry counter, it is desirable to minimize the energy loss and the scattering in the region between the alpha-particle source and the collimator(s) and detector. As a result most

[9,10], but not all [7,11], counters of this type are operated with the chamber under vacuum and with a solid scintillator as the alpha-particle detector. A question that always arises is, "What is the intrinsic detection efficiency of the solid scintillator?" Our results at NIST indicate that the alpha-particle-detection efficiencies of our commercially prepared inorganic scintillation crystals [cesium iodide (thallium) and calcium fluoride (europlum)] and organic scintillation plastics are at least 0.999. The alpha-particle-detection efficiencies of zinc sulfide (silver) layers are considerably more variable because this material is available only in the form of microcrystalline powder that must be deposited as a thin layer (often with a binder) to form a suitable detector. Nonetheless, for carefully prepared deposits, efficiencies of 0.999 appear to be reproducibly attainable [9]. There are, however, important differences between the various solid scintillators, especially in relative light output for alpha particles compared with beta particles and gamma rays. Table 2 lists a number of commonly used scintillators, their relative light outputs, and their α/β response ratios.

Table 2. Approximate relative scintillation efficiencies of various commercially available materials at room temperature. The relative light output of sodium iodide (thallium) per unit energy deposited by beta particles is taken as 1.00.

Solid scintillator	α	β	α/β
ZnS(Ag)	2.0	1	2.0
CsI(Tl)	0.4	0.5	0.8
NaI(Tl)	0.5	1.00	0.5
CsBr(Tl)	0.05	0.15	0.3
KBr(Tl)	0.01	0.04	0.25
CaF_2(Eu)	0.1	0.4	0.25
NaCl(Ag)	0.01	0.04	0.2
Organic	0.02	0.25	0.08
Ionization detectors			1

If one is counting a source that emits only alpha particles, the a/β response ratio is not of significance. Mechanical and chemical properties would be the basis on which to select a scintillator. But if the source also emits beta particles or gamma rays or both, or if these radiations constitute an important part of the background, then the a/β response ratio may be the most important parameter in the choice of a scintillator. For example, suppose that one is counting 5.5-MeV alpha particles in the presence of 500-keV conversion electrons and that both types of particles deposit their full energies in the scintillator.* If the scintillator is zinc sulfide (silver), the light output due to the alpha particles will be more than 20 times that due to the conversion electrons. Hence the conversion electrons may be readily discriminated against on the basis of pulse height. If the scintillator is an organic plastic, the light outputs due to the two types of particles will be the same. In this case it will not be possible to discriminate against the conversion electrons on the basis of pulse height.

4. Description of Systems

4.1. Small and large 2πα PC's: The 2πα proportional counter systems are pictured in Figures 1, 2, 3, 6, and 7. The source is centered inside each counter and sits on the aluminum base plate. Alpha particles emitted into the sensitive volume ionize counting gas (P-10) atoms, which are attracted and cascade to the positively charged anode loop where they are collected. The pulse of charge is presented to a charge sensitive preamplifier after which the pulse is amplified to overload. The resulting spectrum is collected in a multi-channel analyzer within a computer system.

By amplifying to overload, the condition is nearly satisfied that all alpha particles, regardless of energy, will be detected in the data collection system. Consequently under these conditions, extrapolation to zero pulse height is more easily accomplished because the low-energy region can be examined in detail.

4.2. 0.8πα SC: The 0.8πα CsI(Tl) scintillation "Robinson" counter is shown in Figs. 8 and 9. The source is mounted on the "source mount" and the enclosed volume between it and the scintillator is flushed with hydrogen gas to permit the alpha particles to move with minimum loss of energy. The outside baffle and the Al stop are accurately machined with tolerances on the order of 0.005 cm so that the detection geometry is known to approximately 0.1 percent. Light pulses are collected in the light pipe and passed into the phototube. The resulting pulses are amplified to overload as with the 2π systems and the spectrum is collected in a computer.

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* In actual practice, one generally tries to minimize the energy deposition of the beta particles and gamma rays by using a solid scintillator that is just thick enough to stop the alpha particles.

Without the inside baffle, the source geometrical factor would be sensitive to vertical positioning of the source. As explained by Robinson [9], the three dimensional central baffle is so designed that changes in the geometrical factor defined by the outside baffle due to changes in source position, are offset by equal and opposite changes in the screening of the alpha-particle beam by the central baffle. Hutchinson et al. [7] have shown that for a vertical displacement of 0.4 cm or a horizontal displacement of 1 cm of the source from the central position, the change in the count rate varies by less than 0.3 percent.

A big advantage of this counter relates to the fact that multiply-scattered alpha particles, essentially all of which are emitted at grazing angles to the source, are not detected. The difficult problem of estimating the back-scattering contribution is thus avoided.

The total efficiency $\varepsilon_{0.8\pi}$, for this geometry, approximately 0.8π steradians, of the counter was deduced from measurements on thin sources with the small 2π and 0.8π counters for different values of atomic number, Z, of the backing material [12].

The 2π count rate, $N_{2\pi}$ divided by the 0.8π count rate, $N_{0.8\pi}$ was plotted as a function of Z, and extrapolated to Z = 0 where, theoretically, $\varepsilon_{0.8\pi} = N_{0.8\pi}/2N_{2\pi} = N_{0.8\pi}/N_0$. A schematic diagram of the spectrum and extrapolation to zero pulse height for the 0.8π counter is shown in Fig. 10. The multi-channel analyzer is set to integrate counts above a level just above noise. The number of true counts in the noise region are estimated by means of the extrapolations.

5. General Operational Procedures

5.1. Small and large $2\pi\alpha$ PC's: After the source has been introduced into the counter and the sensitive volume flushed until the pulses observed on the pulse-height analyzer have reached their maximum height, the counting procedure is initiated. Typically, the counting proceeds in the order: background, standard reference source, submitted source, background. The counting times are adjusted so that 10^6 counts from the source are collected (corresponding, of course, to 0.1 percent statistical uncertainty). These total counts are collected usually over five repetitions, or approximately 2×10^5 counts per measurement.

The functioning of the instrument is checked by comparing the measurement results for the standard, corrected for decay, and the background with previous results.

Five collection windows are set covering the lower end of the spectrum for the purpose of obtaining an extrapolation in the case where the total number of counts into 2π are required. The extrapolation is based on the assumption that the "true" tail of the spectrum (e.g. as in Fig. 10) can be represented as a flat horizontal line with a height corresponding to the spectrum minimum.

So-called type B errors are estimated at the $l\sigma$ level and are added to type A errors in quadrature. The overall uncertainty quoted in the certificates is two times the calculated combined uncertainty [13] as shown in Appendices E_i, E_{ii}, and E_{iii}.

5.2. <u>$0.8\pi\alpha$ SC:</u> Generally the same procedure for data collection and reduction is employed with the $0.8\pi\alpha$ SC as with the 2π counters. Only activity measurements are made with the $0.8\pi\alpha$ SC, therefore all measurements involve extrapolated values to which a calibration factor of $1/\varepsilon_{0.8\pi} = 5.0638$ is applied (see reference 6). A sample certificate is shown in Appendix E_{iii}. The one significant operational difference from the 2π counter is that the correct source height must be determined by varying the vertical position of the source through screwing the mount in or out as required. The count rates will go through a maximum with changing vertical adjustment representing the correct vertical setting.
Source positioning is achieved in the horizontal and vertical directions as follows:

> Horizontal - The available spacers fit most source diameters that we encounter. For those sources of a different diameter, a new spacer can be made, or the source may be centered on the block and secured with a minimum of double-stick tape. The tape method is not recommended for thin source mounts such as thin platinum.
>
> Vertical - The optimum vertical position for counting a source will vary with the thickness of the source mount, and the type of deposit (electroplated, vacuum evaporation, or dried deposit). This position is determined by counting the source (or one of a batch of similar sources) at the "0" turns or stop position, which is the point at which the block is against the bottom of the counter. Then, count at each 1/4 or 1/2 turn down, to the point where the count obviously decreases. These measurements can be plotted as count-rate-vs-breechblock position, and the operating point selected. The position which is thus determined can then be used for sources of the same configuration.

6. Step-by-Procedures

6.1 Preliminary

- Customer contact - give specifications for physical dimensions and activity limits, emphasize that source container must protect active area from contact with anything within the container, and send calibration booklet to the customer.

- Inspection for damage - if damage has occurred, the customer will be notified before proceeding with the calibration.

- Test check measurements - perform measurements of background and a calibrated test source to make sure the system is operating correctly.

- NIST paperwork and acceptance procedure- submit completed NIST 364 for approval before arrival of materials, notify the Chief of Health Physics of the arrival and departure of all plutonium and uranium, complete other necessary forms (NIST 64,77,796A).

Test folders - request test folder from OPMS on receipt of material to be calibrated. Note dates of material received and returned.

6.2 Counting Procedure

The measurements are taken in the following order: background, standard reference source, submitted source, background. The counting times are adjusted so that 10^6 counts from the source are collected. The functioning of the instrument is checked by comparing the measurement results for the standard, corrected for decay and background, with previous results. The data is reduced as described in the following sections and certificates are prepared and submitted to the customer.

Procedures for calibrations using three instruments are described: (1) small $2\pi\alpha$ PC used for thin alpha-particle sources up to a diameter of 10 cm, (2) large $2\pi\alpha$ PC for large area sources up to a rectangular shape of 10 cm by 15 cm, and (3) the $0.8\pi\alpha$ SC used for the determination of source activity for thin sources up to a diameter of 2.5 cm.

6.3 Set-up Procedure for All Counters

- Introduce source into the counter.
- Turn on the High Voltage and other electronics.
- Turn on the air pressure valve Flush P-10 gas through the system until the pulses recorded on an oscilloscope reach a maximum value.

6.4 2π Alpha- Particle Step-by-Step Procedure

To Start

- Turn on the electronics.
- Turn on the air pressure valve.
- Raise top of counter by pulling handle up slowly.
- Place source in the center of the counter, handling the source with gloves to prevent possible contamination.
- Lower top of counter by pulling handle down slowly.
- Turn on P-10 gas flow-pressure at 7 psi.
- Open black knob on regulator and flush rapidly for 10 minutes until pulses on the oscilloscope have reached a maximum.
- Turn on high voltage (1450 volts) at the start of the flushing.
- Reduce flow to approximately 60 cc per minute.
- Use the following settings for the Tenelec TC 247 Dual Amplifier –coarse gain of 200 and fine gain of 10.0.

Data Collection

- Feed the pulses from the amplifier into the computer which uses a MAESTRO program services.
- Initiate job control.
- Use file named: prop1.job.
- Edit file to establish set-up parameters including:
  - number of sets of measurements(spectra)
  - elapsed live times
  - sample description
  -file name
  -counter description.
- Collect spectral data (hit OPEN).
- Hand record history of measurements.

Data Reduction

When the data collection is complete, bring up file called SPECTINC, which sets 6 regions to be used in an extrapolation procedure which gives the integrated total count-rate.
Typically the regions would be channel integrals from 0-20, 21-40,41-60,61-80,81-100,101-1000.
Then, on EDIT file, type number of files to be reduced.
Run program called NLEVCON.EXE, which executes the data reduction into counts per second for each integral region specified above.
As a check on the results arrived at above, run the data called NLEVEL.EXE which performs the extrapolation automatically.

To Change Source

- Cut off High Voltage.
- Turn off gas flow at black knob.
- Raise top of counter by pulling handle up slowly.
- Remove source carefully.
- Place next source in center of counter.
- Lower counter top slowly.
- Turn on gas with black knob.
- Continue as above.

To Shut Down

- Turn off electronics.
- Turn of gas (close black knob, main valve, and release the diaphragm control)
- Turn off air-pressure valve.
- Take smears of counter and immediate area.

6.5 Large Area 2πα Proportional Counter

To Start

Turn on the electronics
- Turn on the air pressure valve to 40 psi.
- Release 6 stops on the base-plate movement-switch in down position.
- Lower base-plate handle down slowly.
- Place source in the center of the counter, handling the source with gloves to prevent possible contamination.
- Raise baseplate by switching on in up position.
- Turn on P-10 gas flow.
- Open black knob on regulator and flush rapidly at 3.0 cubic feet per hour for 10 minutes.

- Turn on high voltage (1150 volts) at the start of the flushing.
- Reduce flow to approximately 1.5 cubic feet per hour.
- Use the following settings for theTenelec TC 247 Dual Amplifier –coarse gain of 200 and fine gain of 10.0.

Data Collection

- Feed the pulses by datalink from the amplifier into the computer which uses a MAESTRO program services.
- Initiate job control.
- Use file named: prop1.job.
- Edit file to establish set-up parameters including:
  - number of sets of measurements(spectra)
  - elapsed live times
  - sample description
  -file name
  -counter description.
- Collect spectral data (hit OPEN).
- Hand record history of measurements.

Data Reduction

When the data collection is complete, bring up file called SPECTINC, which sets 6 regions to be used in an extrapolation procedure, which gives the integrated total count-rate.
Typically the regions would be channel integrals from 0-20, 21-40,41-60,61-80,81-100,101-1000.
Then, on EDIT file, type number of files to be reduced.
Run program called NLEVCON.EXE, which executes the data reduction into counts per second for each integral region specified above.
As a check on the results arrived at above, run the data called NLEVEL.EXE which performs the extrapolation automatically.

To Change Source

- Cut off High Voltage.
- Turn off gas flow at black knob.
- Lower base-plate.
- Remove source carefully.
- Place next source in center of counter.
- Raise base-plate slowly.
- Turn on gas with black knob.
- Continue as above.

To Shut Down

- Turn off electronics (High Voltage and NIM BIN).
- Turn of gas (close black knob, main valve, and release the diaphragm control)
- Turn off air-pressure valve.
- Take smears of counter and immediate area.

6.6 0.8π Defined Solid-Angle-Alpha-Particle Counter

To Start

- Turn on electronics (NIM BIN) and high voltage interlock box.
- High voltage power supply must be in the off position.
- Remove electrical connection from interlock to breechblock.
- Carefully unscrew breechblock which is also the source mount.
- Be ready to support the weight of the breechblock (approximately 2000 grams when it comes free).
- Place source in center of breechblock (spacers for sources of various diameters in drawer under counter).
- Replace block and turn to stop position carefully. (Care should be taken not to advance source to the point of contact with the central baffle).
- Replace electrical connection from the interlock.
- Turn on gas (hydrogen) at main valve and adjust diaphragm control to about 10 psi. (The gas is exhausted directly to the outside.)
- Open black knob between regulator and flow meter and flush for about 10 minutes, at 3 L min^{-1} as indicated on the flow meter.
- Turn on high voltage, (+) 1500, at start of flushing.
- Reduce flow rate to about 0.5 L min^{-1}; observe flow rate on flow meter.
- Connect amplifier output to analyzer at attenuator input; coarse gain + 4, fine gain = 3.20.
- Counting may begin.

Data Collection

- Feed the pulses by datalink from the amplifier into the computer which uses a MAESTRO program services.
- Initiate job contro.l
- Use file named: prop1.job.

Edit file to establish set-up parameters including:

  - number of sets of measurements(spectra)
  - elapsed live times
  - sample description
  -file name
  -counter description.

- Collect spectral data (hit OPEN).
- Hand record history of measurements.

Data Reduction

When the data collection is complete, bring up file called SPECTINC, which sets 6 regions to be used in an extrapolation procedure, which gives the integrated total count-rate.
Typically the regions would be channel integrals from 0-20, 21-40,41-60,61-80,81-100,101-1000.
Then, on EDIT file, type number of files to be reduced.
Run program called NLEVCON.EXE, which executes the data reduction into counts per second for each integral region specified above.
As a check on the results arrived at above, run the data called NLEVEL.EXE which performs the extrapolation automatically.

<u>To Change Source</u>

- Turn off high voltage.
- Turn off gas flow by closing black knob.
- Remove interlock lead.
- Remove source carefully.
- Take smears of block and counter area and count at Health Physics.
- Replace block and turn to stop position.
- Turn off interlock control.

<u>To Shut Down</u>

- Turn off electronics (high voltage and NIM bin).
- Turn off gas (close black knob, main valve, and release diaphragm).
- Remove interlock lead.
- Remove source carefully.
- Take smears of block and counter area and count at Health Physicslace block and turn to stop position.
- Replace block and turn to stop position.
- Turn off interlock control.

7. Determination of Uncertainties

The corrections and uncertainty components considered are given in Table 3.

Table 3. Listing of count rate correction factors and typical 1σ uncertainties for 2π and 0.8π measurements.

Correction	2π Counters Typical Correction Factor	 Typical Uncertainty (%) 1σ	0.8π Counter Typical Correction Factor	 Typical Uncertainty (%) 1σ
Counter geometry	2.000	0.05	40.000	0.05
Extension and non-uniformity of source	1.000	0.05	1.005	0.05
Self-absorption and scattering from Source and support	1.100	0.5	1.000	0.05
Scattering off counter wall			1.000	0.02
Transmission through collimator edge			1.000	0.02
Scattering in/on detector	1.000	0.01	1.000	0.01
Transmission through detector (no count)	1.000	0.01	1.000	0.01
Background	0.999	0.01	0.990	0.01
Deadtime	1.010	0.01	1.010	0.01
Extrapolation to zero pulse height	1.050	0.5	1.010	0.5
Counting Statistics		0.1	1.000	0.1

Although this table lists typical uncertainties, one could, by using these numbers, derive typical total uncertainties for the various measurements by combining the relevant uncertainty components in quadrature and multiplying by an arbitrary factor of 2. The measurements and these "typical" uncertainties in percent are follows:

In Table 3 typical corrections and uncertainties associated with the determination of alpha-particle activity are given. A source with a thickness equal to one fourth of the alpha-particle range., and an activity of $2000 s^{-1}$ is assumed. These uncertainties will vary in individual cases depending on such factors as source size, source uniformity, alpha-particle energy, impurities, interfering radiations and count rate to background ratio. Appendices E give examples of uncertainty computation in three specific cases. Uncertainties for other sample measurements will, in general, be different from these two examples but are nearly always within 0.5 percent in the quoted overall uncertainty. A number of the entries in Table 3 have been considered and evaluated but are normally negligible and are not included in the examples given in Appendices E.

The uncertainty estimates are given at roughly the $I\sigma$ level. For the most part the table is self-explanatory. Symbols used in this section are identified in Table 3.where the symbols are defined in Table 3. Now follow some notes on the sources of error:

7.1. <u>Counter Geometry:</u> The uncertainty in the detector solid angle $\Omega(0.8\pi)$ is estimated from possible differences between the calculated values, previously described, based on alternate extrapolations to Z = 0.

7.2. <u>Extension and Non-Uniformity of Source:</u> If the source is large enough, it will impinge on the region of point-source position for which the response of the detector is significantly (>0.1 percent) different from that at the center. These effects have been previously described in the Design Philosophy and Theory Section.

7.3. <u>Self-Absorption and Scattering from Source and Support:</u> This effect is very much larger for 2π sources because, as previously pointed out, back and forward scattered particles involve those alphas which are coming off the source at grazing angles. For even moderately thick sources, this correction could be quite significant for 2π sources yet be completely insignificant in 0.8π geometry because the 0.8π counter measures those forward directed, relatively scatter-free, particles. As discussed on page 11 under <u>Scattering,</u> the activity of an alpha-particle-emitting source can be obtained from the 2π extrapolated 2π counting rate using a theoretical $2\pi/N_o$ counting rate [8].

7.4. Scattering off Counter Wall: This effect does not exist in the 2πα PC's counter because alpha particles do not reach the wall. The dimensions of the 0.8π counter are such that very rare large-angle scattering would be required to produce such events.

7.5. Transmission through Collimator Edge: This applies only to the 0.8πα SC and is negligible based on the range of alpha particles in the collimator material.

7.6. Scattering in/on Detector: This is a conceivable, but entirely negligible effect for these counters.

7.7. Background: This is not observed as being variable with time and could supposedly be driven down through collection of massive statistics. Generally, enough counts are accumulated to reduce the background uncertainty contribution to less than 0.1 percent.

7.8. Dead-time: The expression for dead-time correction is given in the measurement equations for uncompensated systems. However, the multichannel analyzer, which is the dominant source of dead-time losses, has a highly precise dead-time compensator so that for a one percent dead time correction, for example, the uncertainty due to this effect is entirely negligible.

7.9. Extrapolation to Zero Pulse Height: The shapes of the spectra in the low energy region have significant curvature. Consequently, an extrapolation based on the minimum value has significant uncertainty.

7.10 Counting Statistics: The standard deviation of the mean of repeated counts is taken as the basic measure of statistical uncertainty.

The overall uncertainty is estimated by summing in quadrature, the standard errors of all calculated or estimated uncertainties and multiplying by a factor of three which then gives approximately a 99 percent confidence level.

8. Quality Control and Records

The day-to-day control of the instruments uses a known standard, which is measured at the time of a calibration.

Cross-checks between the counters and other specialized counters such as the 0.1π counter [4] are also performed. For example, a given calibration will be performed and a quick cross-check of this source on another counter will be made. Such checks provide a feeling for the quality of a source, a check on the functioning of the calibration counting system, and cross calibration in the (unlikely) event that questions are raised at a later date.

Records maintained are a customer log sheet including customer name, date received, kind of source, source number and identification including Radioactive Source (RS) number and test number, date calibrated, date returned to customer. In addition an alpha calibration record book includes hard copy of the data, data reduction procedures, calibration results, and copy of the certificate. Computer records include information contained in the customer log sheet and the alpha calibration record book.

The only large international intercomparison of alpha-particle-emitting sources was performed under the sponsorship of the B1PM in 1963 on a solution of ^{241}Am. The agreement of NIST (then NBS) with the international average was in the 0.1 percent range. It was concluded at that time that the calibration of alpha-particle emitters was well understood and no further international comparisons have been made on alpha-particle emitters.

9. REFERENCES

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10. APPENDICES

Appendix—A

Table 27. Counting yield Y(0) of alpha-particle sources at the surface of a backing of atomic number Z, as a function of the source energy E.

E (MeV)	Z = 4	5	6	11	12	13
9.0	0.5031	0.5035	0.5037	0.5055	0.5057	0.5061
8.8	0.5031	0.5035	0.5037	0.5055	0.5057	0.5061
8.6	0.5031	0.5035	0.5037	0.5056	0.5058	0.5061
8.4	0.5031	0.5035	0.5037	0.5056	0.5058	0.5062
8.2	0.5032	0.5035	0.5038	0.5056	0.5058	0.5062
8.0	0.5032	0.5035	0.5038	0.5056	0.5058	0.5062
7.8	0.5032	0.5036	0.5038	0.5057	0.5059	0.5062
7.6	0.5032	0.5036	0.5038	0.5057	0.5059	0.5063
7.4	0.5032	0.5036	0.5038	0.5057	0.5059	0.5063
7.2	0.5032	0.5036	0.5038	0.5057	0.5059	0.5063
7.0	0.5032	0.5036	0.5039	0.5058	0.5060	0.5064
6.8	0.5033	0.5036	0.5039	0.5058	0.5060	0.5064
6.6	0.5033	0.5037	0.5039	0.5058	0.5060	0.5064
6.4	0.5033	0.5037	0.5039	0.5059	0.5061	0.5065
6.2	0.5033	0.5037	0.5039	0.5059	0.5061	0.5065
6.0	0.5033	0.5037	0.5040	0.5059	0.5061	0.5066
5.8	0.5033	0.5037	0.5040	0.5060	0.5062	0.5066
5.6	0.5034	0.5038	0.5040	0.5060	0.5062	0.5066
5.4	0.5034	0.5038	0.5041	0.5061	0.5063	0.5067
5.2	0.5034	0.5038	0.5041	0.5061	0.5063	0.5067
5.0	0.5034	0.5039	0.5041	0.5062	0.5064	0.5068
4.8	0.5035	0.5039	0.5041	0.5062	0.5064	0.5069
4.6	0.5035	0.5039	0.5042	0.5063	0.5065	0.5069
4.4	0.5035	0.5040	0.5042	0.5063	0.5065	0.5070
4.2	0.5036	0.5040	0.5043	0.5064	0.5066	0.5071
4.0	0.5036	0.5040	0.5043	0.5065	0.5067	0.5071
3.8	0.5037	0.5041	0.5044	0.5065	0.5068	0.5072
3.6	0.5037	0.5041	0.5044	0.5066	0.5069	0.5073
3.4	0.5038	0.5042	0.5045	0.5067	0.5070	0.5074
3.2	0.5038	0.5043	0.5046	0.5068	0.5071	0.5075
3.0	0.5039	0.5043	0.5046	0.5069	0.5072	0.5077

Table 27, continued

E (MeV)	Z = 14	19	20	21	22	23
9.0	0.5062	0.5076	0.5078	0.5083	0.5087	0.5090
8.8	0.5063	0.5077	0.5078	0.5084	0.5087	0.5090
8.6	0.5063	0.5077	0.5078	0.5084	0.5087	0.5091
8.4	0.5063	0.5077	0.5079	0.5084	0.5088	0.5091
8.2	0.5063	0.5078	0.5079	0.5085	0.5088	0.5091
8.0	0.5064	0.5078	0.5079	0.5085	0.5088	0.5092
7.8	0.5064	0.5078	0.5080	0.5085	0.5089	0.5092
7.6	0.5064	0.5079	0.5080	0.5086	0.5089	0.5093
7.4	0.5065	0.5079	0.5080	0.5086	0.5090	0.5093
7.2	0.5065	0.5080	0.5081	0.5087	0.5090	0.5094
7.0	0.5065	0.5080	0.5081	0.5087	0.5091	0.5094
6.8	0.5066	0.5080	0.5082	0.5088	0.5091	0.5095
6.6	0.5066	0.5081	0.5082	0.5088	0.5092	0.5095
6.4	0.5066	0.5081	0.5083	0.5089	0.5092	0.5096
6.2	0.5067	0.5082	0.5083	0.5089	0.5093	0.5096
6.0	0.5067	0.5082	0.5084	0.5090	0.5093	0.5097
5.8	0.5068	0.5083	0.5084	0.5090	0.5094	0.5098
5.6	0.5068	0.5084	0.5085	0.5091	0.5095	0.5098
5.4	0.5069	0.5084	0.5085	0.5092	0.5095	0.5099
5.2	0.5069	0.5085	0.5086	0.5093	0.5096	0.5100
5.0	0.5070	0.5086	0.5087	0.5093	0.5097	0.5101
4.8	0.5070	0.5086	0.5088	0.5094	0.5098	0.5102
4.6	0.5071	0.5087	0.5088	0.5095	0.5099	0.5103
4.4	0.5072	0.5088	0.5089	0.5096	0.5100	0.5104
4.2	0.5072	0.5089	0.5090	0.5097	0.5101	0.5105
4.0	0.5073	0.5090	0.5091	0.5098	0.5102	0.5106
3.8	0.5074	0.5091	0.5092	0.5099	0.5103	0.5107
3.6	0.5075	0.5092	0.5094	0.5101	0.5105	0.5109
3.4	0.5076	0.5094	0.5095	0.5102	0.5106	0.5110
3.2	0.5077	0.5095	0.5097	0.5104	0.5108	0.5112
3.0	0.5079	0.5097	0.5098	0.5105	0.5110	0.5114

Table 27, continued

E (MeV)	Z = 24	25	26	27	28	29
9.0	0.5091	0.5094	0.5095	0.5098	0.5098	0.5103
8.8	0.5091	0.5094	0.5095	0.5099	0.5098	0.5103
8.6	0.5092	0.5095	0.5096	0.5099	0.5099	0.5104
8.4	0.5092	0.5095	0.5096	0.5099	0.5099	0.5104
8.2	0.5093	0.5096	0.5097	0.5100	0.5100	0.5105
8.0	0.5093	0.5096	0.5097	0.5100	0.5100	0.5105
7.8	0.5093	0.5097	0.5098	0.5101	0.5101	0.5106
7.6	0.5094	0.5097	0.5098	0.5101	0.5101	0.5106
7.4	0.5094	0.5098	0.5099	0.5102	0.5102	0.5107
7.2	0.5095	0.5098	0.5099	0.5102	0.5102	0.5107
7.0	0.5095	0.5099	0.5100	0.5103	0.5103	0.5108
6.8	0.5096	0.5099	0.5100	0.5104	0.5103	0.5108
6.6	0.5096	0.5100	0.5101	0.5104	0.5104	0.5109
6.4	0.5097	0.5100	0.5101	0.5105	0.5105	0.5110
6.2	0.5098	0.5101	0.5102	0.5105	0.5105	0.5110
6.0	0.5098	0.5102	0.5103	0.5106	0.5106	0.5111
5.8	0.5099	0.5102	0.5103	0.5107	0.5107	0.5112
5.6	0.5100	0.5103	0.5104	0.5108	0.5107	0.5113
5.4	0.5100	0.5104	0.5105	0.5109	0.5108	0.5114
5.2	0.5101	0.5105	0.5106	0.5109	0.5109	0.5115
5.0	0.5102	0.5106	0.5107	0.5110	0.5110	0.5116
4.8	0.5103	0.5107	0.5108	0.5111	0.5111	0.5117
4.6	0.5104	0.5108	0.5109	0.5112	0.5112	0.5118
4.4	0.5105	0.5109	0.5110	0.5114	0.5113	0.5119
4.2	0.5106	0.5110	0.5111	0.5115	0.5114	0.5120
4.0	0.5107	0.5111	0.5112	0.5116	0.5116	0.5122
3.8	0.5109	0.5113	0.5114	0.5118	0.5117	0.5123
3.6	0.5110	0.5114	0.5115	0.5119	0.5119	0.5125
3.4	0.5112	0.5116	0.5117	0.5121	0.5121	0.5127
3.2	0.5114	0.5117	0.5119	0.5123	0.5122	0.5129
3.0	0.5115	0.5119	0.5121	0.5125	0.5124	0.5131

Table 27, continued

E (MeV)	Z = 30	31	32	33	34	42
9.0	0.5105	0.5109	0.5112	0.5114	0.5118	0.5132
8.8	0.5105	0.5109	0.5112	0.5114	0.5118	0.5133
8.6	0.5106	0.5110	0.5113	0.5115	0.5119	0.5134
8.4	0.5106	0.5110	0.5113	0.5115	0.5119	0.5134
8.2	0.5106	0.5111	0.5114	0.5116	0.5120	0.5135
8.0	0.5107	0.5111	0.5114	0.5116	0.5120	0.5135
7.8	0.5107	0.5112	0.5115	0.5117	0.5121	0.5136
7.6	0.5108	0.5112	0.5115	0.5117	0.5121	0.5137
7.4	0.5109	0.5113	0.5116	0.5118	0.5122	0.5137
7.2	0.5109	0.5114	0.5116	0.5119	0.5123	0.5138
7.0	0.5110	0.5114	0.5117	0.5119	0.5123	0.5139
6.8	0.5110	0.5115	0.5118	0.5120	0.5124	0.5140
6.6	0.5111	0.5116	0.5118	0.5121	0.5125	0.5141
6.4	0.5112	0.5116	0.5119	0.5122	0.5126	0.5142
6.2	0.5112	0.5117	0.5120	0.5122	0.5126	0.5142
6.0	0.5113	0.5118	0.5121	0.5123	0.5127	0.5143
5.8	0.5114	0.5119	0.5122	0.5124	0.5128	0.5144
5.6	0.5115	0.5119	0.5123	0.5125	0.5129	0.5146
5.4	0.5116	0.5120	0.5123	0.5126	0.5130	0.5147
5.2	0.5117	0.5121	0.5124	0.5127	0.5131	0.5148
5.0	0.5118	0.5122	0.5126	0.5128	0.5132	0.5149
4.8	0.5119	0.5124	0.5127	0.5129	0.5133	0.5151
4.6	0.5120	0.5125	0.5128	0.5130	0.5135	0.5152
4.4	0.5121	0.5126	0.5129	0.5132	0.5136	0.5154
4.2	0.5122	0.5127	0.5131	0.5133	0.5138	0.5155
4.0	0.5124	0.5129	0.5132	0.5135	0.5139	0.5157
3.8	0.5125	0.5130	0.5134	0.5136	0.5141	0.5159
3.6	0.5127	0.5132	0.5136	0.5138	0.5143	0.5161
3.4	0.5129	0.5134	0.5138	0.5140	0.5145	0.5164
3.2	0.5131	0.5136	0.5140	0.5143	0.5147	0.5166
3.0	0.5133	0.5139	0.5142	0.5145	0.5150	0.5169

Table 27, continued

E (MeV)	Z = 46	47	48	49	50	64
9.0	0.5141	0.5142	0.5146	0.5148	0.5151	0.5179
8.8	0.5142	0.5143	0.5147	0.5148	0.5151	0.5180
8.6	0.5142	0.5143	0.5147	0.5149	0.5152	0.5181
8.4	0.5143	0.5144	0.5148	0.5150	0.5153	0.5182
8.2	0.5144	0.5145	0.5148	0.5150	0.5154	0.5182
8.0	0.5144	0.5145	0.5149	0.5151	0.5154	0.5183
7.8	0.5145	0.5146	0.5150	0.5152	0.5155	0.5184
7.6	0.5146	0.5147	0.5151	0.5153	0.5156	0.5185
7.4	0.5146	0.5148	0.5152	0.5154	0.5157	0.5186
7.2	0.5147	0.5149	0.5152	0.5154	0.5158	0.5187
7.0	0.5148	0.5149	0.5153	0.5155	0.5158	0.5188
6.8	0.5149	0.5150	0.5154	0.5156	0.5159	0.5190
6.6	0.5150	0.5151	0.5155	0.5157	0.5160	0.5191
6.4	0.5151	0.5152	0.5156	0.5158	0.5161	0.5192
6.2	0.5152	0.5153	0.5157	0.5159	0.5162	0.5193
6.0	0.5153	0.5154	0.5158	0.5160	0.5164	0.5195
5.8	0.5154	0.5155	0.5159	0.5161	0.5165	0.5196
5.6	0.5155	0.5157	0.5161	0.5163	0.5166	0.5198
5.4	0.5156	0.5158	0.5162	0.5164	0.5167	0.5199
5.2	0.5158	0.5159	0.5163	0.5165	0.5169	0.5201
5.0	0.5159	0.5160	0.5165	0.5167	0.5170	0.5203
4.8	0.5161	0.5162	0.5166	0.5168	0.5172	0.5205
4.6	0.5162	0.5164	0.5168	0.5170	0.5174	0.5207
4.4	0.5164	0.5165	0.5170	0.5172	0.5175	0.5209
4.2	0.5166	0.5167	0.5171	0.5174	0.5177	0.5211
4.0	0.5168	0.5169	0.5173	0.5176	0.5179	0.5214
3.8	0.5170	0.5171	0.5176	0.5178	0.5182	0.5216
3.6	0.5172	0.5174	0.5178	0.5180	0.5184	0.5219
3.4	0.5175	0.5176	0.5181	0.5183	0.5187	0.5223
3.2	0.5177	0.5179	0.5183	0.5186	0.5190	0.5226
3.0	0.5180	0.5182	0.5187	0.5189	0.5193	0.5230

Table 27, continued

E (MeV)	Z = 73	74	78	79	82	92
9.0	0.5195	0.5197	0.5205	0.5206	0.5212	0.5231
8.8	0.5196	0.5198	0.5205	0.5207	0.5213	0.5232
8.6	0.5197	0.5199	0.5206	0.5208	0.5214	0.5233
8.4	0.5198	0.5200	0.5207	0.5209	0.5215	0.5234
8.2	0.5199	0.5201	0.5208	0.5210	0.5216	0.5235
8.0	0.5200	0.5202	0.5209	0.5211	0.5217	0.5237
7.8	0.5201	0.5203	0.5210	0.5212	0.5218	0.5238
7.6	0.5202	0.5204	0.5212	0.5213	0.5219	0.5239
7.4	0.5203	0.5205	0.5213	0.5214	0.5221	0.5240
7.2	0.5204	0.5206	0.5214	0.5215	0.5222	0.5242
7.0	0.5205	0.5207	0.5215	0.5216	0.5223	0.5243
6.8	0.5207	0.5209	0.5216	0.5218	0.5225	0.5245
6.6	0.5208	0.5210	0.5218	0.5219	0.5226	0.5246
6.4	0.5209	0.5211	0.5219	0.5221	0.5228	0.5248
6.2	0.5211	0.5213	0.5221	0.5222	0.5229	0.5250
6.0	0.5212	0.5214	0.5222	0.5224	0.5231	0.5252
5.8	0.5214	0.5216	0.5224	0.5225	0.5233	0.5253
5.6	0.5216	0.5218	0.5226	0.5227	0.5234	0.5255
5.4	0.5217	0.5219	0.5228	0.5229	0.5236	0.5258
5.2	0.5219	0.5221	0.5230	0.5231	0.5238	0.5260
5.0	0.5221	0.5223	0.5232	0.5233	0.5241	0.5262
4.8	0.5223	0.5225	0.5234	0.5235	0.5243	0.5265
4.6	0.5225	0.5228	0.5236	0.5238	0.5245	0.5267
4.4	0.5228	0.5230	0.5239	0.5240	0.5248	0.5270
4.2	0.5230	0.5233	0.5241	0.5243	0.5251	0.5273
4.0	0.5233	0.5236	0.5244	0.5246	0.5254	0.5277
3.8	0.5236	0.5239	0.5247	0.5249	0.5257	0.5280
3.6	0.5239	0.5242	0.5251	0.5252	0.5260	0.5284
3.4	0.5243	0.5245	0.5255	0.5256	0.5264	0.5288
3.2	0.5247	0.5249	0.5259	0.5260	0.5269	0.5293
3.0	0.5251	0.5254	0.5263	0.5265	0.5273	0.5298

Appendix—B

Table 29. Relation between the counting yield of a plane alpha-particle source at the surface of a backing, Y(0), and the yield of a uniform layer source extending to a depth x_o below the surface, $Y_{av}(x_o)$. The tabulated quantity is the percentage reduction 100 $[1-Y_{av}(x_o)/Y(0)]$, as a function of x, the particle energy E, and the atomic number Z of the backing.

E = 9.2 MeV

x_o (10^{-6} g/cm^2)	Z = 4	13	26	47	78	92
0.0	0.00	0.00	0.00	0.00	0.00	0.00
1.0	0.06	0.08	0.08	0.08	0.06	0.07
2.0	0.10	0.12	0.12	0.12	0.09	0.10
3.0	0.13	0.15	0.15	0.15	0.12	0.13
4.0	0.15	0.18	0.18	0.18	0.14	0.15
5.0	0.18	0.20	0.20	0.20	0.17	0.17
6.0	0.20	0.23	0.23	0.23	0.19	0.19
8.0	0.24	0.27	0.27	0.27	0.22	0.22
10.0	0.28	0.31	0.31	0.30	0.26	0.25
12.0	0.31	0.35	0.35	0.34	0.29	0.28
15.0	0.36	0.40	0.40	0.39	0.33	0.32
20.0	0.43	0.48	0.48	0.46	0.40	0.37
25.0	0.50	0.54	0.55	0.52	0.45	0.42
30.0	0.56	0.61	0.61	0.58	0.51	0.47
40.0	0.68	0.72	0.73	0.68	0.61	0.55
50.0	0.78	0.83	0.84	0.78	0.70	0.63

Table 29, continued.

E = 6.4 MeV

x_o (10^{-6} g/cm^2)	Z = 4	13	26	47	78	92
0.0	0.00	0.00	0.00	0.00	0.00	0.00
1.0	0.09	0.10	0.10	0.09	0.08	0.09
2.0	0.14	0.16	0.16	0.14	0.13	0.14
3.0	0.18	0.21	0.20	0.18	0.17	0.18
4.0	0.22	0.25	0.24	0.22	0.20	0.21
5.0	0.26	0.29	0.28	0.25	0.23	0.24
6.0	0.29	0.32	0.31	0.28	0.26	0.27
8.0	0.35	0.38	0.37	0.34	0.31	0.32
10.0	0.41	0.44	0.43	0.39	0.35	0.37
12.0	0.46	0.50	0.48	0.44	0.40	0.41
15.0	0.54	0.57	0.55	0.50	0.46	0.47
20.0	0.65	0.68	0.66	0.60	0.55	0.56
25.0	0.75	0.78	0.76	0.69	0.63	0.64
30.0	0.85	0.88	0.85	0.77	0.71	0.71
40.0	1.03	1.05	1.01	0.93	0.84	0.85
50.0	1.19	1.20	1.16	1.06	0.97	0.97

E = 5.3 MeV

x_o (10^{-6} g/cm^2)	Z = 4	13	26	47	78	92
0.0	0.00	0.00	0.00	0.00	0.00	0.00
1.0	0.11	0.12	0.12	0.12	0.10	0.10
2.0	0.17	0.19	0.19	0.18	0.16	0.16
3.0	0.22	0.25	0.24	0.23	0.20	0.20
4.0	0.27	0.30	0.29	0.27	0.24	0.24
5.0	0.31	0.34	0.33	0.31	0.27	0.28
6.0	0.35	0.38	0.37	0.35	0.31	0.31
8.0	0.43	0.46	0.44	0.41	0.36	0.37
10.0	0.50	0.53	0.51	0.47	0.42	0.42
12.0	0.56	0.59	0.57	0.53	0.46	0.47
15.0	0.66	0.68	0.65	0.61	0.53	0.54
20.0	0.80	0.82	0.78	0.72	0.63	0.65
25.0	0.93	0.94	0.90	0.83	0.72	0.75
30.0	1.05	1.06	1.00	0.92	0.81	0.84
40.0	1.27	1.27	1.20	1.10	0.96	1.00
50.0	1.48	1.46	1.37	1.26	1.10	1.14

Table 29, continued.

E = 4 MeV

x_o (10^{-6} g/cm^2)	Z = 4	13	26	47	78	92
0.0	0.00	0.00	0.00	0.00	0.00	0.00
1.0	0.12	0.16	0.15	0.14	0.13	0.11
2.0	0.20	0.25	0.23	0.21	0.19	0.17
3.0	0.27	0.32	0.30	0.27	0.25	0.22
4.0	0.33	0.39	0.36	0.33	0.30	0.27
5.0	0.39	0.44	0.41	0.37	0.34	0.31
6.0	0.44	0.50	0.46	0.42	0.38	0.35
8.0	0.55	0.60	0.55	0.50	0.45	0.42
10.0	0.64	0.70	0.64	0.57	0.52	0.49
12.0	0.73	0.78	0.72	0.64	0.58	0.55
15.0	0.86	0.90	0.82	0.73	0.66	0.63
20.0	1.05	1.09	0.99	0.87	0.79	0.76
25.0	1.24	1.25	1.13	1.00	0.91	0.87
30.0	1.41	1.41	1.27	1.12	1.02	0.98
40.0	1.73	1.69	1.52	1.33	1.21	1.18
50.0	2.03	1.95	1.75	1.52	1.39	1.36

E = 3 MeV

x_o (10^{-6} g/cm^2)	Z = 4	13	26	47	78	92
0.0	0.00	0.00	0.00	0.00	0.00	0.00
1.0	0.16	0.17	0.17	0.12	0.14	0.15
2.0	0.27	0.28	0.27	0.20	0.22	0.23
3.0	0.36	0.37	0.35	0.27	0.29	0.29
4.0	0.44	0.45	0.43	0.33	0.34	0.35
5.0	0.52	0.53	0.50	0.39	0.39	0.40
6.0	0.60	0.60	0.56	0.44	0.44	0.45
8.0	0.74	0.73	0.68	0.54	0.52	0.54
10.0	0.87	0.85	0.79	0.64	0.60	0.62
12.0	0.99	0.97	0.89	0.73	0.67	0.69
15.0	1.17	1.14	1.03	0.86	0.77	0.79
20.0	1.45	1.39	1.25	1.06	0.92	0.95
25.0	1.70	1.62	1.45	1.24	1.06	1.09
30.0	1.94	1.84	1.64	1.42	1.18	1.22
40.0	2.40	2.25	1.98	1.75	1.41	1.46
50.0	2.82	2.62	2.29	2.06	1.62	1.67

Appendix—C

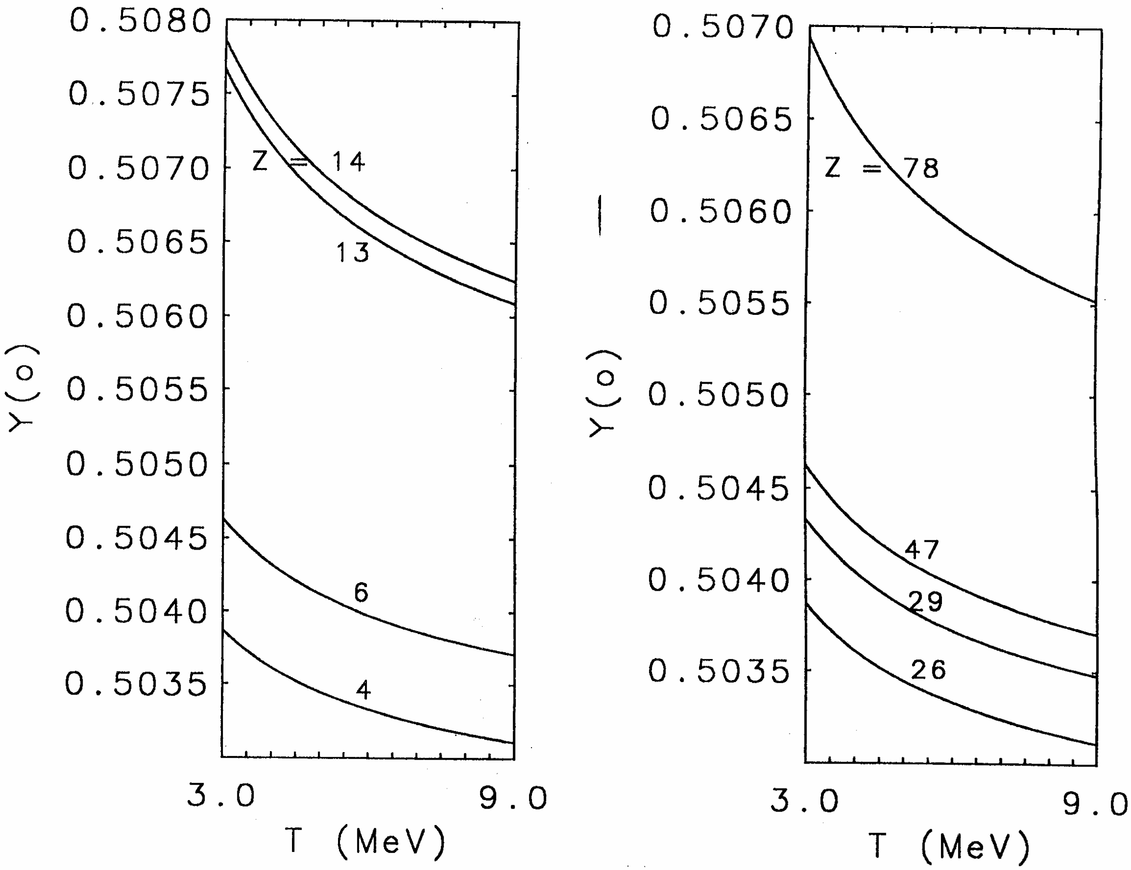

Fig. 12. Counting yields, Y(o), as a function of alpha-particle energy, for a plane source at the surface (depth x=o) of a backing of atomic number Z.

Appendix—D

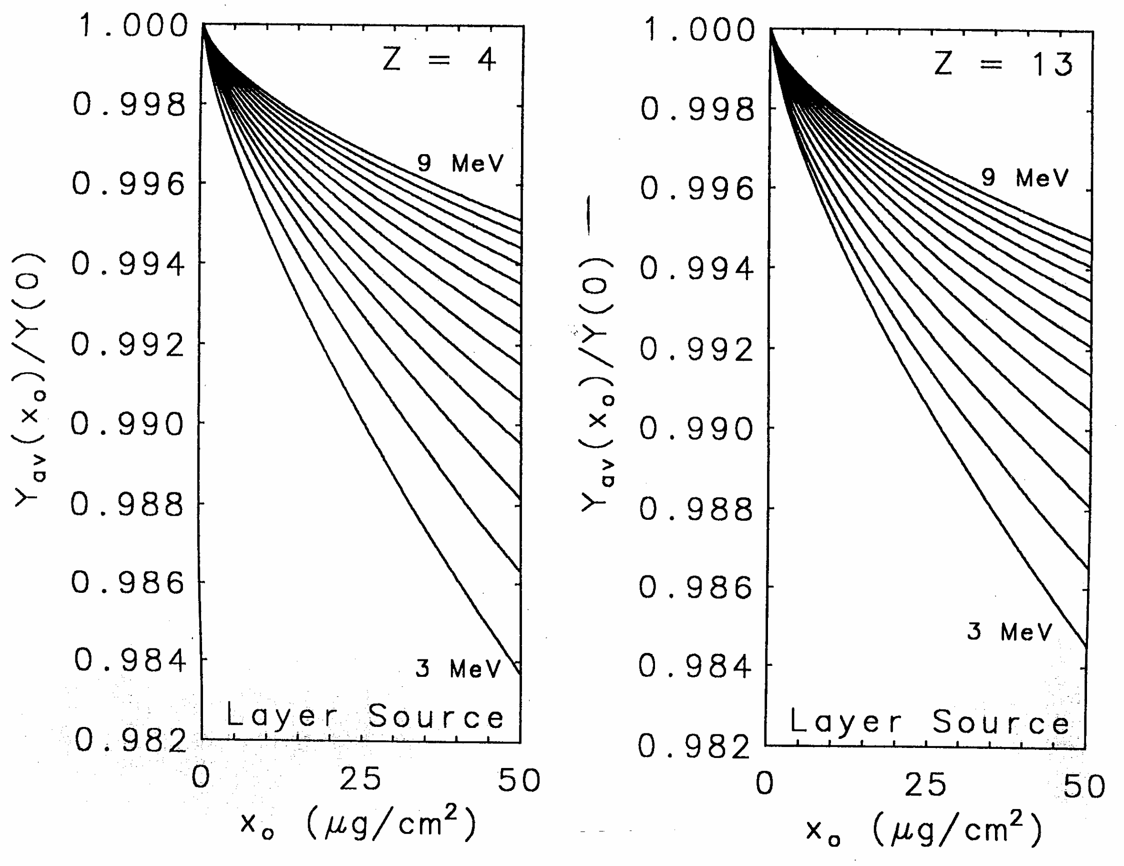

Fig. 13. Redaction ratio Y_{av} (x_0)/Y(o) for uniform layer sources extending to depth x0 below the surface of the backing

a. for backings with Z=4 and 13
b. for backings with Z=26 and 78.

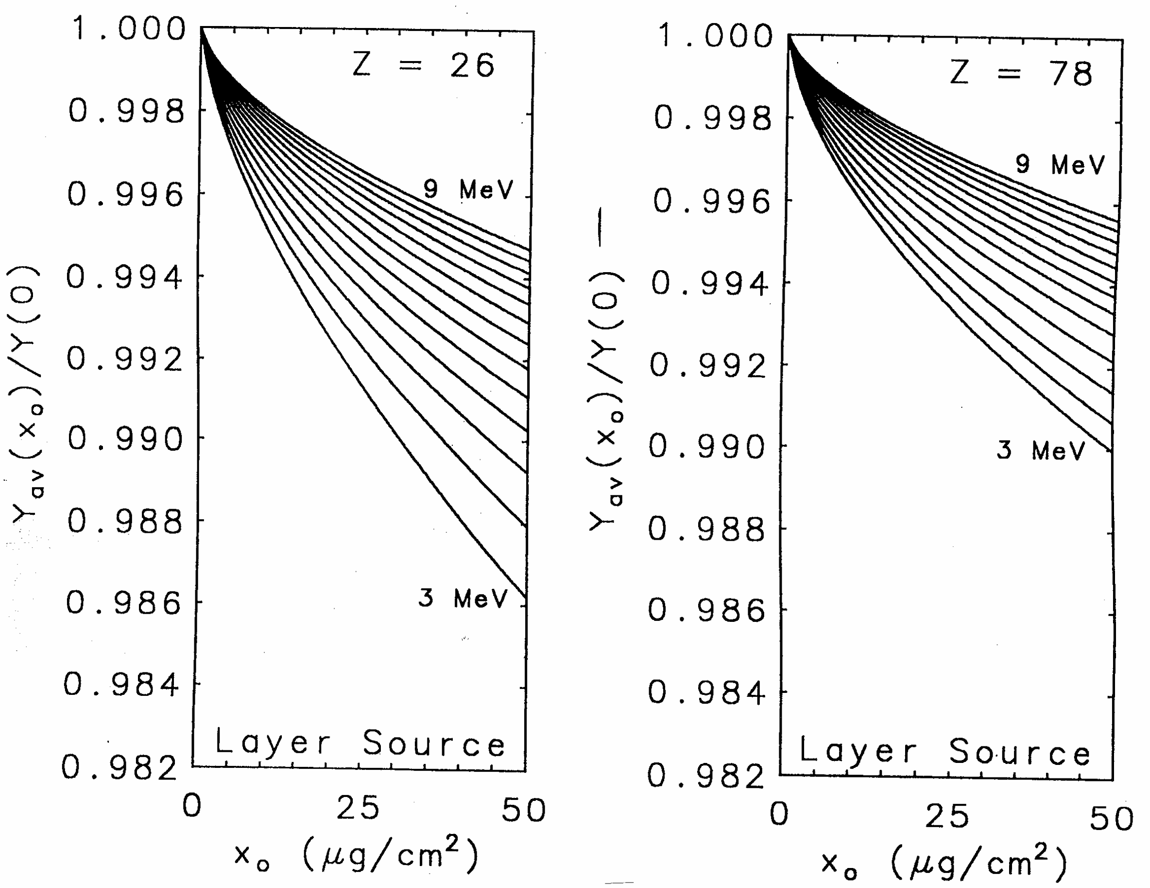
1.000
0.998
0.996
0.994
0.992
0.990
0.988
0.986
0.984
0.982
$Y_{av}(x_o)/Y(0)$
Z = 26
9 MeV
3 MeV
Layer Source
0
25
50
x_o (μg/cm^2)
1.000
0.998
0.996
0.994
0.992
0.990
0.988
0.986
0.984
0.982
$Y_{av}(x_o)/Y(0)$
Z = 78
9 MeV
3 MeV
Layer Source
0
25
50
x_o (μg/cm^2)

Fig. 13b

APPENDIX--Ei

U.S. DEPARTMENT OF COMMERCE
National Institute of Standards & Technology
Gaithersburg, MD 20899

REPORT OF CALIBRATION

for

Bionetics, AFPSL
Heath, Ohio

Radionuclide	Plutonium-239
Source identification	7404
2π alpha-particle counting rate	$2.383 \times 10^{3}\ s^{-1}$ (1)*
Reference time	July 29, 2003
Overall uncertainty	1.4 percent (2)
Measurement method	NIST $2\pi\beta/\alpha$ proportional counter

For the Director,
National Institute of Standards and Technology by

Michael P. Unterweger, Acting Group Leader Radioactivity Group Physics Laboratory	Lisa R. Karam, Acting Chief Ionizing Radiation Division Physics Laboratory

Gaithersburg, MD 20899
August 2003
NIST Test No. 268916-03

*Notes on back

NOTES

(1) The total number of alpha particles counted per second emitted into
a 2π-steradian geometry (including those scattered).

(2) The overall uncertainty is two times the value found from combining quadratically the standard deviations of the mean, or approximations thereof, of the following:

a) one standard deviation of the mean of five measurements 0.12 percent

b) pulse-height extrapolation 0.70 percent

Percent difference in the certified value between the estimate based on horizontal extrapolation from the minimum point on the spectrum to that from the same spectral point to zero count rate at zero energy.

c) system live time 0.1 percent

Using the two-source method, the live time was verified to within 0.1 percent.

For further information, contact Michael P. Unterweger at (301) 975-5536, or Pamela A. Hodge at (301) 975-5544.

Source identification 7404
NIST Test No. 268916-03

APPENDIX--Eii

U.S. DEPARTMENT OF COMMERCE
National Institute of Standards & Technology
Gaithersburg, MD 20899

REPORT OF CALIBRATION

for

Bionetics Corporation
Heath, Ohio

Radionuclide	Plutonium-238
Source identification	BV691
2π alpha-particle counting rate	2.260 x 10^{3} s^{-1} (1)*
Reference time	June 9, 2003
Overall uncertainty	1.4 percent (2)
Measurement method	NIST large-area $2\pi\alpha/\beta$ proportional counter

For the Director,
National Institute of Standards and Technology

by

Michael P. Unterweger, Acting Group Leader
Radioactivity Group
Physics Laboratory

Lisa R. Karam, Acting Chief
Ionizing Radiation Division
Physics Laboratory

Gaithersburg, MD 20899
June 2003
NIST Test No. 268749-03

*Notes on back

NOTES

(1) The total number of alpha particles counted per second emitted into a 2π-steradian geometry (including those scattered).

(2) The overall uncertainty is two times the value found from combining quadratically the standard deviations of the mean, or approximations thereof, of the following:

a)	one standard deviation of the mean of five measurements	0.03 percent
b)	pulse-height extrapolation Percent difference in the certified value between the estimate based on horizontal extrapolation from the minimum point on the spectrum to that from the same spectral point to zero count rate at zero energy.	0.70 percent
c)	system live time Using the two-source method, the live time was verified to within 0.1 percent.	0.1 percent

For further information, contact Dr. M.P. Unterweger at (301) 975-5536, or Pamela A. Hodge at (301) 975-5544.

Source BV691
NIST test No. 268749-03

APPENDIX--Eiii

U.S. DEPARTMENT OF COMMERCE
National Institute of Standards & Technology
Gaithersburg, MD 20899

REPORT OF TEST

for

Sandia National Laboratories
Albuquerque, New Mexico

Radionuclide	Americium-241
Source identification	4904SG-34
Activity	3.031 x 10^3 Bq
Reference time	November 10, 1998
Overall uncertainty	1.4 percent (1)*
Measuring instrument	NIST "0.8π"α counter (2)

For the Director,

Gaithersburg, MD 20899
November 1998

Lisa R. Karam, Group Leader
Radioactivity Group
Physics Laboratory

*Notes on back

NOTES

(1) The overall uncertainty is two times the value found from combining quadratically the standard deviations of the mean, or approximations thereof, for the following:

a) one standard deviation of the mean of five measurements 0.07 percent

b) pulse-height extrapolation to zero energy 0.70 percent

Percent difference in the certified value between the estimate based on horizontal extrapolation from the minimum point on the spectrum to that from the same spectral point to zero count rate at zero energy.

c) system live time 0.1 percent

Determined with a gated oscillator (∀ 0.1 percent) plus 1 percent multiplied by the live time divided by the dead time.

(2) Defined-solid-angle counter with scintillation detector.

For further information, please contact M.P. Unterweger at (301) 975-5536 or Pamela A. Hodge at (301) 975-5544.

Source identification 4904SG-34