GA Technologies

E-255-961 (Rev. 3)

# CALIBRATION REPORT
# RD-72 WIDE-RANGE GAS MONITOR
# HIGH AND MID-RANGE
# DETECTORS



August 1984

CHANGE RECORD

| Issue | Date | Pages Affected |
|---|---|---|
| Original | 9/81 | All |
| Rev. 1 | 11/81 | Cover, 7 |
| Rev. 2 | 1/83 | All |
| Rev. 3 | 8/84 | Cover, 11, 12, 13, 15 |

Wherever reference is made in this document to General Atomic Company or one of its divisions, it shall be understood to mean GA Technologies Inc.

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FIGURES



TABLES

# 1. INTRODUCTION

During the period August through November 1982, calibration tests were performed on the RD-72 detector.

Xenon 133 and krypton 85 radioactive gases were purchased from Isotope Products Laboratories. After the prototype detector sample chambers were filled to atmospheric pressure, the Xe-133 lecture bottle was sent to the National Bureau of Standards (NBS) for verification of calibration (see Appendix for certificates of calibration).

A number of solid uncalibrated beta and gamma sources were used to obtain counting efficiencies from individual detectors. A number of detectors obtained from production stock were evaluated using Ba-133 and Cs-137 solid gamma sources, Cl-36 and Kr-85 solid beta sources, and the calibrated Xe-133 and Kr-85 gases.

Calibrated beta, beta-gamma, and gamma sources were procured from Isotopes Products Inc. for performing energy-response tests with a number of detectors. (See Appendix for certificates of calibration.) A linearity test was performed on one detector to show response for the full 6-decade range of the detector.

## 2. DETECTOR DESCRIPTION

The RD-72 is a dual-range beta-gamma sensitive gas detector assembly, consisting of two sample chambers (approximately 0.02 cc and 30 cc active volume), coupled directly to solid-state CdTe(Cl) detectors. These detectors are connected directly to individual charge-sensitive preamplifiers and assembled inside a 6-in.-thick lead background shield.

## 3. SETUP AND PROCEDURE

A number of detectors were obtained for testing from production stock. Each detector was evaluated for response to calibrated noble gases Xe-133 and Kr-85 and a number of solid beta and gamma sources. Each detector was aligned for gross counting with a 60 keV threshold. A Canberra model 30 multichannel analyzer was used to obtain the data. (See Fig. 1 for test setup.)

Solid Ba-133 and Cs-137 gamma sources were used for the detector alignment. The initial alignment was performed using 80 keV gamma and Cs X-ray photopeaks from the Ba-133 source. The alignment was verified by observing the Ba-133 356 keV gamma and the Cs-137 662 keV gamma photopeaks.

Counting efficiencies for each detector were obtained from the prototype RD-72 sample chambers. The chambers were evacuated to less than one millimeter of mercury absolute pressure, then backfilled to atmospheric pressure with a calibrated Xe-133 or Kr-85 gas sample. The chambers and detectors were installed in the prototype RD-72 lead shield when obtaining the countrates. A fixture was used for locating the solid sources in a repeatable counting geometry.

The CdTe(Cl) crystals are approximately 2 mm x 2 mm x 5 mm in size. Because of manufacturing tolerances when cutting the crystals to size and when assembling the unit, each detector has a specific counting efficiency for beta and gamma radiations. A relationship was obtained between the gaseous sources and the solid sources. A solid Kr-85 source was selected to relate beta response to radioactive gases. A solid Ba-133 source was selected to relate gamma response to radioactive gases. Ba-133 has the same Cs X-rays as Xe-133 and an 80 keV gamma as compared to Xe-133 with an 81 keV gamma. The ratios of the solid Kr-85 beta source to the gaseous Kr-85 varied

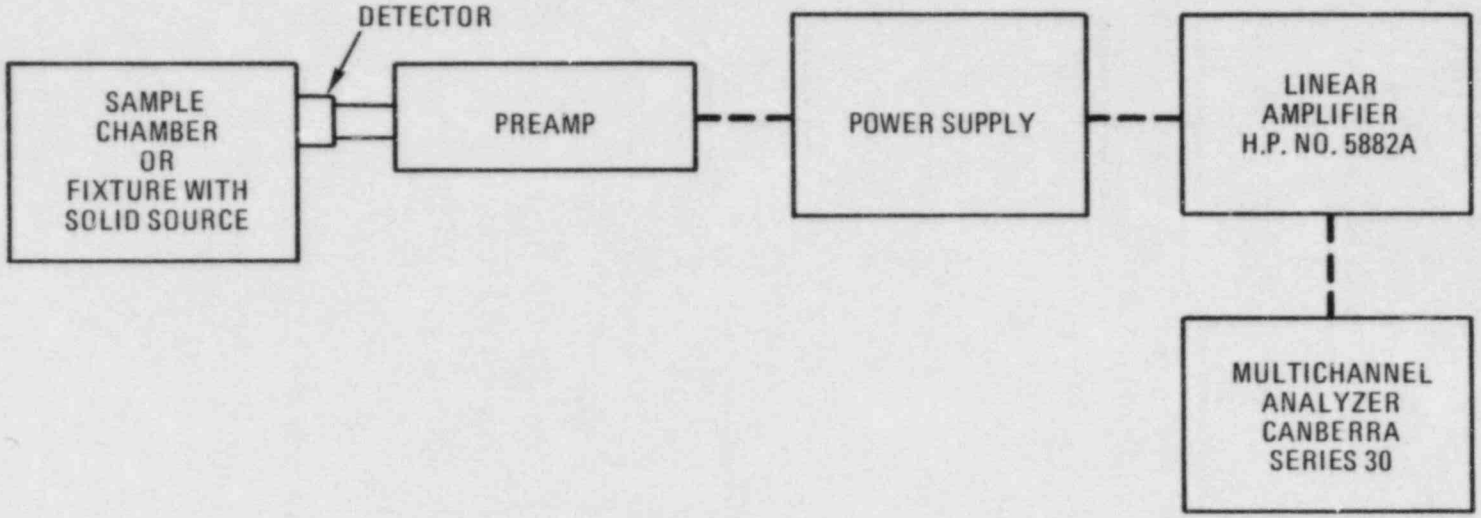


Fig. 1. Test setup for calibrating the RD-72 detector

by less than ±6% from the mean value for all the detectors tested. The ratios of the solid Ba-133 gamma source to the gaseous Xe-133 varied by ±12% from the mean value for all the detectors tested. The test results are given in Table 1.

TABLE 1
DETECTOR RESPONSE TO GASEOUS AND SOLID TEST SOURCES

Response to Xe-133 Gas

Mid-range chamber

±29% spread from a mean of $1.42 \times 10^4$ cpm (microcuries/$cm^3$)$^{-1}$

High-range chamber

±30% spread from a mean of 49.4 cpm (microcuries/$cm^3$)$^{-1}$

Ratio of responses, mid versus high chambers

±8.5% spread from a mean of 294

Response to Kr-85 Gas

Mid-range chamber

±40% spread from a mean of $1.51 \times 10^4$ cpm (microcuries/$cm^3$)$^{-1}$

High-range chamber

±36% spread from a mean of 58.9 cpm (microcuries/$cm^3$)$^{-1}$

Ratio of responses, mid versus high chambers

±5.7% spread from a mean of 252

Responses to Solid Sources

Kr-85 (source S/N KR85-109) on 9-1-82

±41% spread from a mean of 35618 cpm

Ba-133 (source S/N BA81-001) on 9-1-82

±26% spread from a mean of 14550 cpm

TABLE 1 (continued)

Responses of Solid Sources Versus Gaseous Sources

Mid-Range Chamber

Xe-133 gas versus Ba-133 solid source (BA81-001)

±12% spread from the mean

Kr-85 gas versus Kr-85 solid source (KR85-109)

±2.8% spread from the mean

High Range Chamber

Xe-133 gas versus Ba-133 solid source (BA81-001)

±12% spread from the mean

Kr-85 gas versus Kr-85 solid source (KR85-109)

±5.9% spread from the mean

## 4. DETECTOR CORRECTION FACTORS

Since there is a definite relationship between the solid Ba-133 source and Xe-133 gas and between the solid Kr-85 source and Kr-85 gas, these solid sources can be used to obtain correction factors for the individual detectors. After a detector is aligned for gross counting with a 60 keV threshold, a beta and gamma correction factor can be calculated as follows:

Beta correction factor ($C_{Fb}$)

$$C_{Fb} = \frac{\text{cpm net Kr-85 source}}{\text{mean cpm Kr-85 source} \times C_{T_{1/2}}}$$

Gamma correction factor ($C_{Fq}$)

$$C_{Fq} = \frac{\text{cpm net Ba-133 source}}{\text{mean cpm Ba-133 source} \times C_{T_{1/2}}}$$

where net cpm for the Kr-85 and Ba-133 source response is obtained from the transfer calibration procedure 0360-9010 for each detector.

Half life correction ($C_{T_{1/2}}$)

$$C_{T_{1/2}} = 0.5^{t/T_{1/2}}$$

where t = time in years since 9-1-82

$T_{1/2}$ = 10.4 years for Ba-133

= 10.73 years for Kr-85

The correction factors are now

$$C_F = \frac{(\text{cpm KR85-109})}{3.56 \times 10^4 \times 0.5^{(t/10.7)}} \text{ for beta counting}$$

$$C_F = \frac{(\text{cpm BA81-001})}{1.45 \times 10^4 \times 0.5^{(t/10.4)}} \text{ for gamma counting}$$

Half life corrected values for the Ba and Kr sources can be obtained from the graph in Fig. 2.

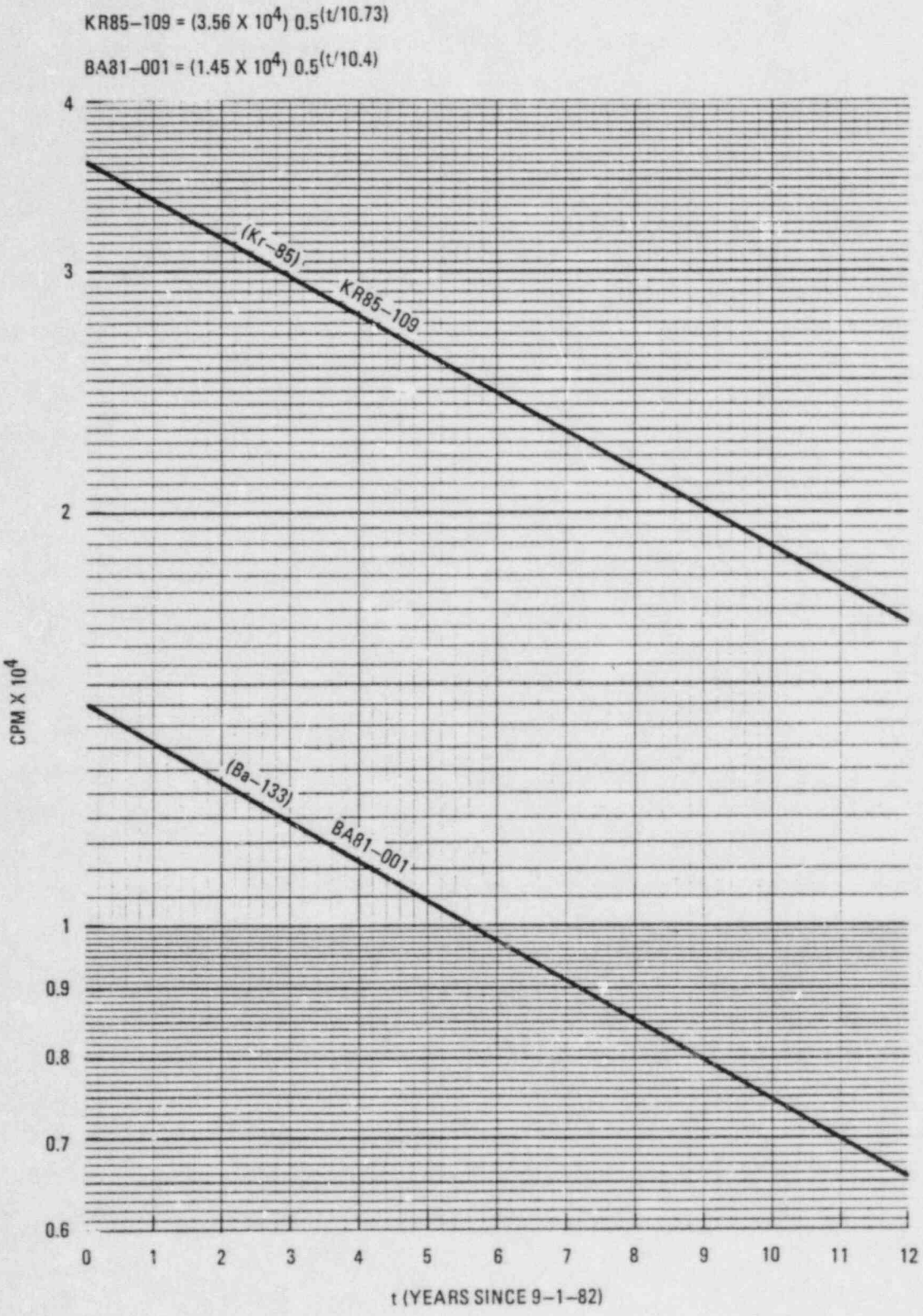


Fig. 2. Half life correction

## 5. ENERGY RESPONSE CURVE

The energy response curve can be useful when calculating a counting efficiency for an expected source term. The source term of interest has to contain the following information when calculating an expected detector response.

1. Isotopes of interest and their intensities (the sum of the individual intensities is equal to one)

2. Each beta and gamma with its energy in MeV and number produced per disintegration.

Beta and gamma responses can now be obtained from the Energy Response Curve (see Figs. 3 and 4). This response in cpm/(microcuries/$cm^3$) (assuming one gamma or beta per disintegration) must be corrected for the intensities of the isotope and the number of betas or gammas produced per disintegration. The sums of all the corrected beta responses and all the corrected gamma responses must be multiplied by the individual detector's beta or gamma correction factor. These correction factors are obtained from Section 4 of this report. The sum of the detector's gamma and beta responses is the detector's expected response in cpm/(microcuries/$cm^3$) for the source term of interest.

The reciprocal of the detector response is the detector conversion factor (microcuries/$cm^3$)/cpm. This conversion factor, when factored into the RM-80 data base, can provide a microcurie/$cm^3$ equivalent for a known source term.

The shape of the energy response curves was obtained from solid beta and gamma sources in a fixture simulating the actual detector sample chamber

geometry. The sources used are listed in Table 2. After the shapes of the curves were established, they were superimposed over the actual responses for Kr-85 and Xe-133 to produce the curves shown in Figs. 3 and 4. The beta response at 2.25 MeV is recommended as the response for higher beta end point energies. This is a conservative recommendation. The gamma response at 1.25 MeV (Co-60) was extrapolated out to 4.0 MeV based on the energy absorption attenuation coefficients for Cd and Te.

Sample calculations for a source term response are shown in Table 3.

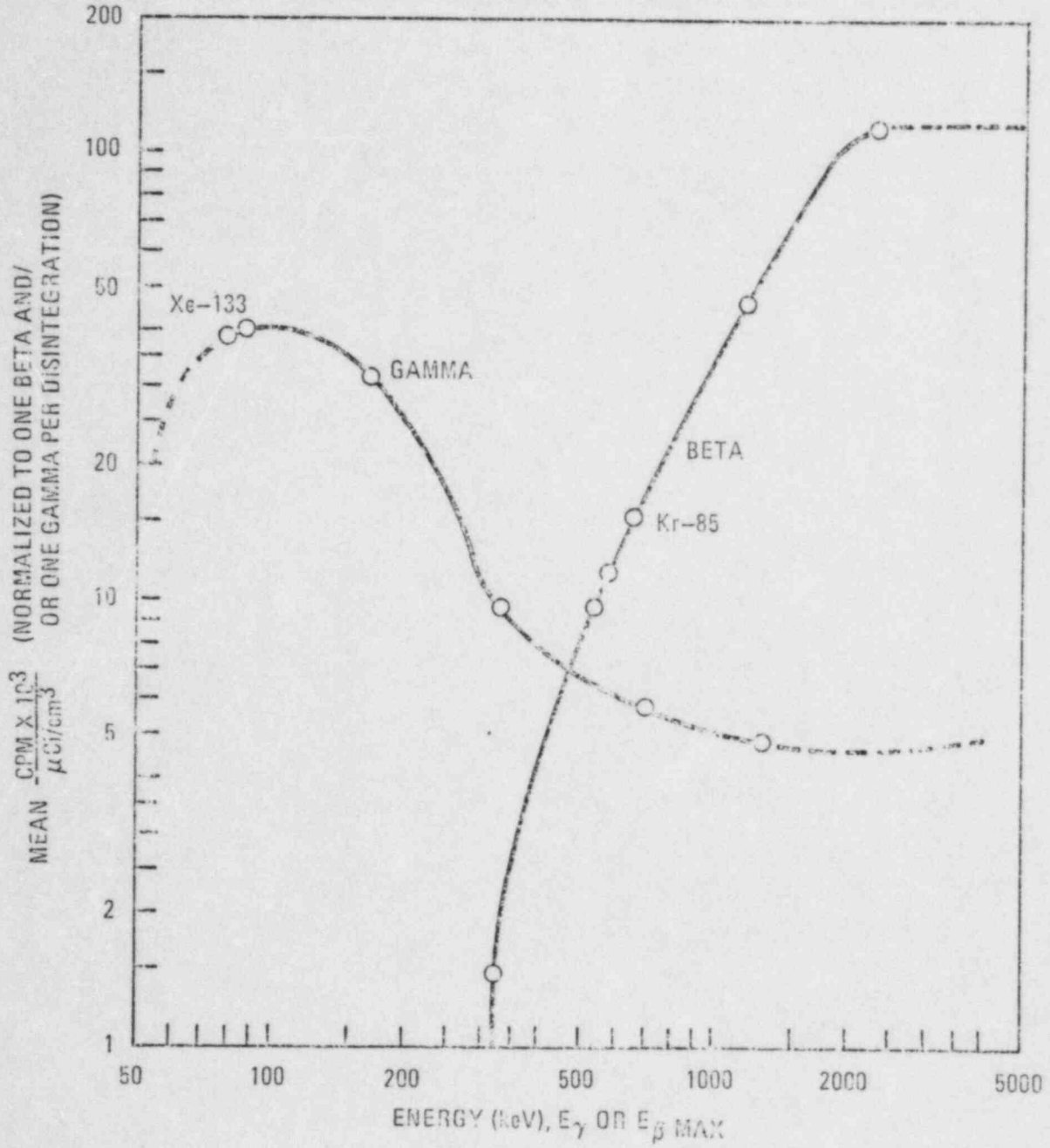


Fig. 3. Mid-range detector energy response curve

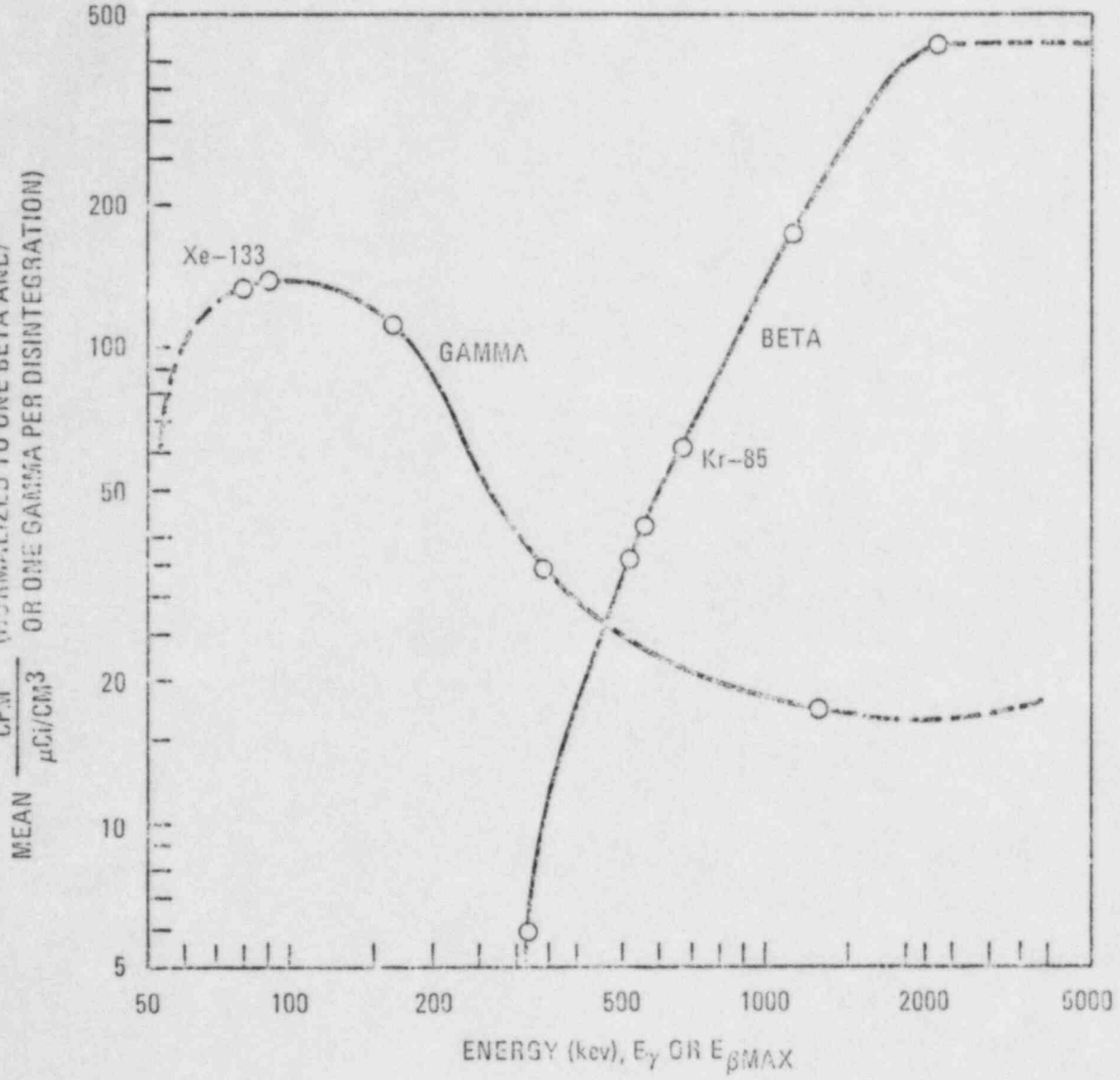


Fig. 4. High-range detector energy response curve

TABLE 2
SOLID SOURCES USED FOR ENERGY RESPONSE CURVES

| Isotope | Major Radiations | Energy (MeV) | | Intensities (%) |
|---|---|---|---|---|
| Cd-109 | gamma | 0.088 | | 5 |
| Ce-139 | gamma | 0.165 | | 80 |
| Cr-51 | gamma | 0.320 | | 9 |
| Cs-137 | gamma | 0.662 | | 85 |
| | beta | 0.514 | | 93 |
| | beta | 1.176 | | 7 |
| Co-60 | gamma | 1.173 | 1.25 av | 100 |
| | | 1.332 | | 100 |
| | beta | 0.314 | | 99+ |
| Tc-99 | beta | 0.292 | | 100 |
| Cl-36 | beta | 0.714 | | 100 |
| Sr-90/Y-90 | beta | 0.546 | | 100 |
| | beta | 2.27 | | 100 |

TABLE 3
EXAMPLE FOR CALCULATING DETECTOR RESPONSE FOR
AN EXPECTED HYPOTHETICAL SOURCE TERM FOR HIGH RANGE DETECTOR

HIGH RANGE DETECTOR $C_F$ [(a)] (DETECTOR CORRECTION FACTORS) = $\beta$ = 1.12
$\gamma$ = 0.98

| Source Term | | | Radiations Produced | | | cpm / μCi/cc from Graph | cpm / μCi/cc D x E or Actual | Expected Yield A x F x $C_F$ |
|---|---|---|---|---|---|---|---|---|
| Isotope | Activity (Ci) | Intensity | Energy MeV | β or γ | No. per Dis | | | |
| | | A | B | C | D | E | F | G |
| Xe-133 | $2.14 \times 10^8$ | 0.39 | N/A<br>Actual response obtained from calibration report | | | | 49.4 | 18.9 |
| Xe-135 | $2.04 \times 10^8$ | 0.37 | 0.25 | γ | 0.91 | 54 | 49.1 | 17.8 |
| | | | 0.61 | γ | 0.03 | 22 | 0.7 | 0.2 |
| | | | 0.92 | β | 1.00 | 103 | 103 | 42.7 |
| Kr-88 | $1.22 \times 10^8$ | 0.22 | 0.166 | γ | 0.07 | 110 | 7.7 | 1.9 |
| | | | 0.191 | γ | 0.35 | 90 | 31.5 | 7.8 |
| | | | 0.36 | γ | 0.05 | 29 | 1.5 | 0.4 |
| | | | 0.85 | γ | 0.23 | 18.5 | 4.2 | 1.0 |
| | | | 1.55 | γ | 0.14 | 17.5 | 4.0 | 1.0 |
| | | | 2.19 | γ | 0.18 | 15.5 | 2.8 | 0.7 |
| | | | 2.4 | γ | 0.35 | 15 | 5.2 | 1.3 |
| | | | 0.54 | β | 0.67 | 40 | 26.8 | 6.6 |
| | | | 0.70 | β | 0.09 | 65 | 5.9 | 1.5 |
| | | | 1.19 | β | 0.02 | 172 | 3.4 | 0.8 |
| | | | 1.88 | β | 0.02 | 375 | 7.5 | 1.8 |
| | | | 2.90 | β | 0.17 | 440 | 74.8 | 18.4 |
| Xe-133M | $5.2 \times 10^6$ | <0.01 | N/A<br>Less than 1% of Source Term | | | | | |
| Total Expected Yield for Source Term cpm $(\mu Ci/cc)^{-1}$ | | | | | | | | 109 |

(a) Notes:

| | |
|---|---|
| $C_F$ | Obtained from transfer calibration procedure (GA document 0366-9010). Used typical values of 1.12 for beta and 0.98 for gamma. |
| A | Calculated from source term |
| B,C and D | Obtained from table of isotopes |
| E | Obtained from graph in Fig. 4 of RD-72 Calibration Report |
| F | D times E or from Table 1 of RD-72 Calibration Report |
| G | A times F times $C_F$ |

# 6. LINEARITY TEST

## 6.1. OBJECTIVE

The objective is to show response of the detection system for count rate versus activity strength.

## 6.2. METHOD

A monoenergetic radioactive nuclide, 10 mCi cesium 137, was placed at a fixed distance from the detector. Lead attenuators of similar thickness, 1/4 in. (approximately one-half-value layer thickness), were inserted one at a time between the detector and the source. Countrate readings taken before and after adding each attenuator were compared and the percentages of countrate changes were calculated. The tests were repeated to cover the operating range of the detection system for the decade above background ($10^2$ to $10^3$ cpm) through the last decade of response ($10^6$ to $10^7$ cpm). See Fig. 5 for test setup and Table 4 for test data.

## 6.3. RESULTS

The actual change in countrate within the operating range of the detector from the decade above background ($10^2$ to $10^3$ cpm) through the last decade ($10^6$ to $10^7$ cpm) was found to be between 48% and 54% for one 1/4-in. thick lead attenuator. The change varied $\pm$3% from a mean of 51%. Therefore, it can be concluded that the detection system is linear within $\pm$3% when actual countrate is compared with activity strength for the operating range of one decade above background to the uppermost decade.

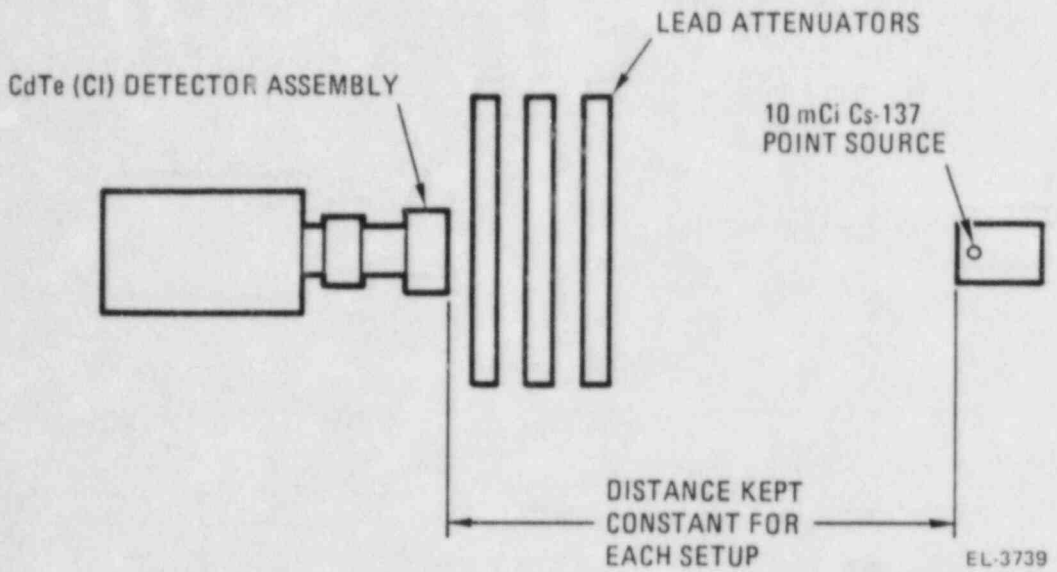


Fig. 5. Setup for linearity test

TABLE 4
LINEARITY TEST DATA[a]

| | No. of attenuators | cpm | Countrate attenuation (%) | |
|---|---|---|---|---|
| Setup 1 | 1 | 1512613 | 52 | Mean attenuation in countrate = 51% |
| | 2 | 784432 | | |
| Setup 2 | 1 | 560576 | 51 | |
| | 2 | 285194 | 50 | |
| | 3 | 143968 | 50 | |
| | 4 | 71354 | | |
| Setup 3 | 1 | 326948 | 49 | |
| | 2 | 159146 | 50 | |
| | 3 | 79874 | 49 | |
| | 4 | 38824 | 50 | |
| | 5 | 19501 | 50 | |
| | 6 | 9843 | | |
| Setup 4 | 1 | 6645 | 50 | |
| | 2 | 3337 | 52 | |
| | 3 | 1750 | 48 | |
| | 4 | 844 | 54 | |
| | 5 | 458 | 49 | |
| | 6 | 223 | | |

[a] The above data are from General Atomic Laboratory Notebook 7416, pp. 81 and 82.

## 7. ACCURACY

A. Radioactive Gases

Xe-133 $\pm$1.9%

Kr-85 $\pm$20%

$[(1.9)^2 + (20\%)^2]^{1/2}$ = $\pm$20.1%

B. Solid Sources for Energy Response Curves = $\pm$7.3%

C. Counting Error (All counts were >3000)

.. $\frac{\sqrt{3000}}{3000} \times 100$ = $\pm$1.8%

D. Spread, Solid Sources to Gaseous Sources

Beta $\leq$5.9%

Gamma 12%

$[(5.9)^2 + (12)^2]^{1/2}$ = $\pm$13.4%

Overall Accuracy

$\sqrt{A^2 + B^2 + C^2 + D^2}$ = $\pm$25.3%

## 8. BACKGROUND

The RD-72 detector assembly was scanned with a 5 mCi Co-60 point source producing a gamma flux of approximately 29 mR/hr. This gamma flux produced approximately one count-per-minute increase over the ambient background. The ambient background was 3 counts in a 10-min counting period.

The above data is recorded in General Atomic notebook No. 8185 on pages 130, 131, and 135.

# APPENDIX

# CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Ce-139 Half-Life: 137.66±0.02 d

Source No.: 10064-2

Was assayed as containing: 9.03 μCi

As of: 11-1-82

**METHOD OF CALIBRATION:**

( ✓ ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the 0.165 MeV peak (a value of c.7994 gamma rays per decay was used in the calculations), against * standard No. , in the same geometrical arrangement. *crystal-efficiency curve

( ) The source was assayed in a windowless internal proportional counter against standard No.

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. in the same geometrical arrangement.

( ) The source was prepared from a weighed aliquot of a solution whose activity in uCi/gm was determined by the method indicated above.

**ERROR CALACULATION:**

a) Systematic errors (SE)
1. Accuracy of the standard: ± 3.0%
2.

b) Randon errors (RE)
1. Precision of source count, $e_1$:
2. Precision of standard count, $e_2$:
3. Error due to background, $e_3$:

$RE = \sqrt{+e_1^2 + e_2^2 + e_3^2} = \pm 1.3\%$

c) Total Error
TE=SE + RE = ± 4.3%

IPL participates in a NBS measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NBS certification) of Standard Reference Materials.

**NOTES**

( ✓ ) The error given is calculated at the 99 % confidence level.

( ) This calibration is directly/indirectly based on NBS Standard Reference Material No.

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# CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Cd-109 Half-Life: 464 ± 1 d

Source No.: 1064-1

Was assayed as containing: 116 μCi

As of: 11-1-82

**METHOD OF CALIBRATION:**

( ✓ ) The source was assayed on a 3" x 3" NaI (TI) crystal in conjunction with a single-channel analyzer, using the 0.088 MeV peak (a value of 0.0373 gamma rays per decay was used in the calculations), against $Cd^{109}$ standard No. 1995-4, in the same geometrical arrangement.

( ) The source was assayed in a windowless internal proportional counter against standard No.

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. in the same geometrical arrangement.

( ) The source was prepared from a weighed aliquot of a solution whose activity in uCi/gm was determined by the method indicated above.

**ERROR CALACULATION:**

a) Systematic errors (SE)
1. Accuracy of the standard: ± 4.5%
2.

b) Randon errors (RE)
1. Precision of source count, $e_1$:
2. Precision of standard count, $e_2$:
3. Error due to background, $e_3$:

$RE = \sqrt{+e_1^2 + e_2^2 + e_3^2} = \pm 1.2\%$

c) Total Error
TE=SE + RE = ± 5.7%

IPL participates in a NBS measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NBS certification) of Standard Reference Materials.

**NOTES**

( ✓ ) The error given is calculated at the 99 % confidence level.

( ✓ ) This calibration is ~~directly~~/indirectly based on NBS Standard Reference Material No. 1800-1

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# CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Cr-51 Half-Life: 27.704 ± 0.004 d

Source No.: 10064-3

Was assayed as containing: 125 μCi

As of: 11-15-82, @ Noon

**METHOD OF CALIBRATION:**

( ✓ ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the 0.320 MeV peak (a value of 0.093 gamma rays per decay was used in the calculations), against * standard No. , in the same geometrical arrangement. * Energy/efficiency curve

( ) The source was assayed in a windowless internal proportional counter against standard No.

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. in the same geometrical arrangement.

( ) The source was prepared from a weighed aliquot of a solution whose activity in uCi/gm was determined by the method indicated above.

**ERROR CALACULATION:**

a) Systematic errors (SE)
1. Accuracy of the standard: ± 3.0%
2.

b) Randon errors (RE)
1. Precision of source count, $e_1$:
2. Precision of standard count, $e_2$:
3. Error due to background, $e_3$:

$RE = \sqrt{+e_1^2 + e_2^2 + e_3^2} = \pm 1.4\%$

c) Total Error
TE=SE + RE = ± 4.4%

IPL participates in a NBS measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NBS certification) of Standard Reference Materials.

**NOTES**

( ✓ ) The error given is calculated at the 99 % confidence level.

( ✓ ) This calibration is ~~directly~~/indirectly based on NBS Standard Reference Material No. 394

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FORM NBS-253
(3-69)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

# REPORT OF TEST

*for*

General Atomics
San Diego, California

| | |
|---|---|
| Radionuclide | Xenon-133 |
| Source description | Gas in a Lecture Bottle provided by General Atomics |
| Gas composition | Xenon-133 and nitrogen |
| Activity | $1.29 \times 10^9$ Bq $mol^{-1}$ ($s^{-1}mol^{-1}$)<br>$5.28 \times 10^4$ Bq $(cm^3)^{-1}$ at STP (0°C, 1 at |
| Reference time | 1200 EST August 16, 1982 |
| Random uncertainty | 0.13 percent (1) |
| Systematic uncertainty | 1.75 percent (2) |
| Total uncertainty (Random plus systematic) | 1.88 percent |
| Photon-emitting impurities (Activity ratios at reference time) | $^{131m}Xe/^{133}Xe$: 0.021 ± 0.001 (3) |
| Half life | 5.245 ± 0.006 days (4) |
| Measuring instrument | NBS pressurized "4π"γ ionization chamber A calibrated by internal gas-proportional counting |

For the Director,

Dale D. Hoppes, Group Leader
Radioactivity Group
Center for Radiation Research

Washington, D.C. 20234
August 20, 1982
P.O. #806253

*Notes on following page

## FOOTNOTES

(1) Half the 99-percent confidence interval of the mean (2.640 times the standard error computed from 89 ionization-chamber measurements).

(2) Linear sum of estimated uncertainty limits due to:

a) calibration of pressurized "4π"γ ionization chamber A, which is the linear sum of the estimated uncertainty limits due to:

| | |
|---|---|
| 1) half the 99-percent confidence interval of the weighted mean of three series of gas-counting measurements | 0.66 percent |
| 2) extrapolation of the gas-counting data | 0.22 percent |
| 3) half the 99-percent confidence interval of the mean of three series of ionization-chamber measurements | 0.01 percent |
| 4) radium-226 reference sources ratios | 0.36 percent |
| b) gram mole measurement | 0.50 percent |

(3) Limits of detection as a percentage of the gamma-ray-emission rate of the 81-keV gamma rays emitted in the decay of xenon-133 are

0.1 percent between 37 keV and 76 keV
0.01 percent between 86 keV and 1900 keV,

provided that impurity photons are separated in energy by 5 keV or more from photons emitted in the decay of xenon-133.

(4) NCRP Report No. 58, 1978, p. 387.

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# CERTIFICATION OF RADIOACTIVITY STANDARD

Radionuclide Kr-85

Nominal Activity 10 $\mu$Ci/cc

Method of Measurement

[X] 1. Calibration derived from Sigma 2 Computer Gamma Ray Spectrometer calibrated with NBS Standards.

[ ] 2. Calibration derived from Ionization Chamber Calibrated to Sigma 2 Computer Gamma Ray Spectrometer.

[ ] 3. Calibration derived from $2\pi$ internal gas proportional counter calibrated to Sigma 2 Computer Gamma Ray Spectrometer.

Accuracy Overall Limit of Error ($1\sigma$ + Systematic)

$\pm$ 20%

Remarks

Recalibration of IPL Standard S/N 65010A.

We certify that the activity(ies) was(were) as follows:

11.1 $\mu$Ci/cc on 6/25/80 at 1200.

# CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Sr. 90 Half-Life: 29.12 ± 0.24 y

Source No. 1064.8

Was assayed as containing: 10.2 μCi

As of: 12-1-82

**METHOD OF CALIBRATION:**

( ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the MeV peak (a value of gamma rays per decay was used in the calculations), against standard No. , in the same geometrical arrangement.

( ✓ ) The source was assayed in a windowless internal proportional counter against standard No. 1935-1 (Sr-90)

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. in the same geometrical arrangement.

( ✓ ) The source was prepared from a weighed aliquot of a solution whose activity in uCi/gm was determined by the method indicated above.

**ERROR CALACULATION:**

a) Systematic errors (SE)
1. Accuracy of the standard: ± 2.0%
2. Weighing error 1.6%

b) Randon errors (RE)
1. Precision of source count, $e_1$:
2. Precision of standard count, $e_2$:
3. Error due to background, $e_3$:

$RE = \sqrt{+ e_1^2 + e_2^2 + e_3^2} = \pm 1.6\%$

c) Total Error
TE=SE + RE = ± 3.2 %

IPL participates in a NBS measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NBS certification) of Standard Reference Materials.

**NOTES**

( ✓ ) The error given is calculated at the 99 % confidence level.

( ✓ ) This calibration is ~~directly~~/indirectly based on NBS Standard Reference Material No. 4919 D

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1800 No. Keystone St., Burbank, California 91504

# CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Cl-36 Half-Life: $(3.01 \pm 0.03) \times 10^5$ y

Source No. 8064-7

Was assayed as containing: 10.4 μCi

As of: 12-1-82

**METHOD OF CALIBRATION:**

( ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the MeV peak (a value of gamma rays per decay was used in the calculations), against standard No. , in the same geometrical arrangement.

( ✓ ) The source was assayed in a windowless internal proportional counter against standard No. G017 (Cl-36)

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. in the same geometrical arrangement.

( ✓ ) The source was prepared from a weighed aliquot of a solution whose activity in uCi/gm was determined by the method indicated above.

**ERROR CALACULATION:**

a) Systematic errors (SE)
1. Accuracy of the standard: ± 2.5%
2. Weighing error 0.7%

b) Randon errors (RE)
1. Precision of source count, $e_1$:
2. Precision of standard count, $e_2$:
3. Error due to background, $e_3$:

c) Total Error
TE=SE + RE = ± 5.0%

$RE = \sqrt{+e_1^2 + e_2^2 + e_3^2} = \pm 1.8\%$

IPL participates in a NBS measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NBS certification) of Standard Reference Materials.

**NOTES**

( ✓ ) The error given is calculated at the 99 % confidence level.

( ✓ ) This calibration is ~~directly~~/indirectly based on NBS Standard Reference Material No. 4943

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# CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Tc-99 Half-Life: $(2.14 \pm 0.05) \times 10^5$ y

Source No.: 1064-6

Was assayed as containing: 10.2 μCi

As of: 12-1-82

**METHOD OF CALIBRATION:**

( ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the MeV peak (a value of gamma rays per decay was used in the calculations), against standard No. , in the same geometrical arrangement.

( ✓ ) The source was assayed in a windowless internal proportional counter against standard No. 1092-1 (Tc-99)

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. in the same geometrical arrangement.

( ✓ ) The source was prepared from a weighed aliquot of a solution whose activity in uCi/gm was determined by the method indicated above.

**ERROR CALACULATION:**

a) Systematic errors (SE)
1. Accuracy of the standard: ± 3.2%
2. Weighing error 0.7%

b) Randon errors (RE)
1. Precision of source count, $e_1$:
2. Precision of standard count, $e_2$:
3. Error due to background, $e_3$:

$RE = \sqrt{+e_1^2 + e_2^2 + e_3^2} = \pm 3.4\%$

c) Total Error
TE=SE + RE = ± 7.3%

IPL participates in a NBS measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NBS certification) of Standard Reference Materials.

**NOTES**

( ✓ ) The error given is calculated at the 99 % confidence level

( ✓ ) This calibration is ~~directly~~/indirectly based on NBS Standard Reference Material No. NBS-200 8

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# CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Co-60 Half-Life: 5.271±0.001 y

Source No.: 10064-S

Was assayed as containing: 11.6 μCi

As of: 11-1-82

**METHOD OF CALIBRATION:**

( ✓ ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the 1.173 / 1.33 MeV peak (a value of 0.9989 gamma rays per decay was used in the calculations), against Co-60 standard No. 10064-2, in the same geometrical arrangement.

( ) The source was assayed in a windowless internal proportional counter against standard No.

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. in the same geometrical arrangement.

( ) The source was prepared from a weighed aliquot of a solution whose activity in uCi/gm was determined by the method indicated above.

**ERROR CALACULATION:**

a) Systematic errors (SE)
1. Accuracy of the standard: ± 2.5%
2.

b) Randon errors (RE)
1. Precision of source count, $e_1$:
2. Precision of standard count, $e_2$:
3. Error due to background, $e_3$:

c) Total Error
TE=SE + RE = ± 4.0%

$RE = \sqrt{+ e_1^2 + e_2^2 + e_3^2} = \pm 1.5\%$

IPL participates in a NBS measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NBS certification) of Standard Reference Materials.

**NOTES**

( ✓ ) The error given is calculated at the 99 % confidence level.

( ✓ ) This calibration is ~~directly~~/indirectly based on NBS Standard Reference Material No. 49SC-S

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# CERTIFICATE OF RADIOACTIVITY CALIBRATION

Isotope: Cs.137 Half-Life: 30.0±0.2y

Source No.: 1064-4

Was assayed as containing: 10.1 μCi

As of: 11-1-82

**METHOD OF CALIBRATION:**

( ✓ ) The source was assayed on a 3" x 3" NaI (Tl) crystal in conjunction with a single-channel analyzer, using the 0.662 MeV peak (a value of 0.8504 gamma rays per decay was used in the calculations), against Cs-137 standard No. 1902A, in the same geometrical arrangement.

( ) The source was assayed in a windowless internal proportional counter against standard No.

( ) The source was assayed by alpha spectrometry on a surface barrier detector in conjunction with a single-channel analyzer, against standard No. in the same geometrical arrangement.

( ) The source was prepared from a weighed aliquot of a solution whose activity in uCi/gm was determined by the method indicated above.

**ERROR CALACULATION:**

a) Systematic errors (SE)
1. Accuracy of the standard: ± 3.3%
2.

c) Total Error
TE=SE + RE = ± 4.5%

b) Randon errors (RE)
1. Precision of source count, $e_1$:
2. Precision of standard count, $e_2$:
3. Error due to background, $e_3$:

$RE = \sqrt{+e_1^2 + e_2^2 + e_3^2} = \pm 1.2\%$

IPL participates in a NBS measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NBS certification) of Standard Reference Materials.

**NOTES**

( ✓ ) The error given is calculated at the 99 % confidence level.

( ✓ ) This calibration is ~~directly~~/indirectly based on NBS Standard Reference Material No. 1081

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