AECL-5562

ATOMIC ENERGY
OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

RESULTS SUBMITTED TO BUREAU INTERNATIONAL DES POIDS ET MESURES (BIPM) FOR INTERNATIONAL COMPARISON OF ^{134}Cs ACTIVITY

Résultats soumis au Bureau international des poids et mesures (BIPM) pour la comparaison internationale de l'activité de ^{134}Cs

F.H. GIBSON, L.V. SMITH, A.R. RUTLEDGE and J.S. MERRITT

Chalk River Nuclear Laboratories   Laboratoires nucléaires de Chalk River

Chalk River, Ontario

February 1979 février

RESULTS SUBMITTED TO BUREAU INTERNATIONAL DES POIDS ET MESURES (BIPM) FOR INTERNATIONAL COMPARISON OF ^{134}Cs ACTIVITY

by

F.H. Gibson, L.V. Smith, A.R. Rutledge and J.S. Merritt

Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario

February 1979

AECL-5562

Résultats soumis au Bureau international des poids et mesures (BIPM) pour la comparaison internationale de l'activité de ^{134}Cs

par

F.H. Gibson, L.V. Smith, A.R. Rutledge et J.S. Merritt

Résumé

On décrit dans ce rapport le matériel utilisé et les résultats obtenus par le groupe d'étalonnage des radioéléments lors de sa participation à la comparaison internationale des mesures de l'activité d'une solution de césium 134, parrainée par le Bureau international des poids et mesures (BIPM). On s'est servi de la méthode des coïncidences $4\pi(PC)-\gamma$ en veillant à ce que le circuit-porte du canal γ soit strictement réglé pour que les photocrêtes soient $\simeq$ 800 keV. Les résultats sont comparés à ceux obtenus par trois autres circuits-porte de canal γ. Une évaluation des sources d'incertitude connues et présumées est incluse.

L'Energie Atomique du Canada, Limitée
Laboratoires nucléaires de Chalk River
Chalk River, Ontario

Février 1979 AECL-5562

RESULTS SUBMITTED TO BUREAU INTERNATIONAL DES POIDS ET MESURES (BIPM) FOR INTERNATIONAL COMPARISON OF ^{134}Cs ACTIVITY

F.H. Gibson, L.V. Smith, A.R. Rutledge and J.S. Merritt

ABSTRACT

This report describes the equipment used and the results obtained by the Radioisotope Standardization Group in its participation in the international comparison of activity measurements of a ^{134}Cs solution that was sponsored by Bureau International des Poids et Mesures (BIPM). The $4\pi(PC)-\gamma$ coincidence method was used with the γ-channel gate set narrowly around photopeaks of ≈ 800 keV. The results are compared with those from three other γ-channel gates. An assessment of known and suspected sources of uncertainty is included.

Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario
February 1979

AECL-5562

1. INTRODUCTION

The Bureau International des Poids et Mesures (BIPM) organized an international comparison to take place in 1978 for the measurement of the activity concentration of a ^{134}Cs solution. The working group responsible for organizing the comparison consisted of representatives from BIPM, Laboratoire de Metrologie des Rayonnements Ionisants (LMRI), U.S. National Bureau of Standards (NBS) and Atomic Energy of Canada Limited (AECL). Following procurement and purification of a stock of ^{134}Cs by AECL and purity assay of the resulting solution, sealed ampoules containing a suitable concentration of ^{134}Cs were prepared and distributed in October, 1978, by LMRI to AECL and approximately twenty-three other laboratories that volunteered to participate. All participants were requested to employ the half-life value shown in the decay scheme of Fig. 1.

The purpose of this report is to document information about the experiments at this laboratory and their results. The 4π(PC)-γ coincidence method was used with few changes from an earlier study in which a ^{134}Cs standardization was described[1].

2. ION CHAMBER MEASUREMENTS OF LMRI ^{134}Cs AMPOULES

Two sealed ampoules, numbers 27 and 30, were received from LMRI. For each it was stated that the volume of contained solution was 5 mL ± 1% and the acidity was 0.2 mol HCl per L.

The response for each ampoule was measured in the $4\pi\gamma$ ionization chamber. Although the two responses were not equal, they differed by only 0.1%. This level of agreement is good evidence that neither ampoule had leaked accidentally since the time of preparation at LMRI. Exact values for the total ^{134}Cs activity contained in each ampoule cannot be obtained from these ion-chamber data, because the wall thickness and other dimensions of the LMRI ampoules are different from those of the BIPM and Chalk River Nuclear Laboratories (CRNL) for which ion-chamber calibration data have been determined[1].

However, the attenuation of γ-rays with energy $\geq$ 600 keV is small, and therefore it seemed worthwhile to deduce the approximate activity with the available calibration data. This gave an activity for the contents of ampoule no. 27 of 112.2 μCi (415.0 kBq), or 22.43 $\mu Ci \cdot mL^{-1}$ (830.0 $kBq \cdot mL^{-1}$), at the reference time designated by BIPM (1978-October-15-00 h UT). As the density of this acid solution (0.2 mol HCl per L) should be within 0.1% of 1.000 $g \cdot mL^{-1}$ at $23^{o}C$, the activity concentration is nearly the same if stated gravimetrically.

3. *SAMPLE SIZE DETERMINATION AND SOURCE PREPARATION*

Seventeen sources were prepared from samples taken gravimetrically[2-3] from the solution contained in ampoule no. 27. The range of sample sizes was from 14 to 52 mg. A Mettler M-5 balance was used and corrections were evaluated for zero drift, linearity of the optical scale, the set of dialled weights, and buoyancy.

A duplicate set of zero readings was taken before and after each weighing of the polyethylene pycnometer[3] that contained the ^{134}Cs solution. This procedure should correct for instability of the zero. It declined gradually by 15 μg during the 1.6-hour period needed for delivery of the seventeen samples. The error in this method of correction for zero is small compared with the standard deviation of a single reading (typically 1.3 μg).

The equivalence of the optical scale and the smallest dialable weight of 10 mg, or the "sensitivity" as described by the manufacturer, was adjusted according to specifications. It was evaluated both initially and again after delivery of the seventeen samples. These tests indicated a decline of 3 μg in the optical scale reading for 10 mg over the 1.6-hour period, which causes a < 0.01% error in any single sample size that was determined.

The deviation from linearity of the optical scale is shown in Fig. 2. It was determined with a set of very small weights (1 to 20 mg) for which mass values were measured precisely (± < 1 μg) with a Mettler ME-22 balance. The graph *indicates a substantial deviation toward the high end of the scale. Therefore* only the essential region of the optical scale, from 0 to 10 mg, was used and otherwise the dialled weights ($\geq$ 10 mg) of the M-5 were employed.

The set of dialled weights of this Mettler M-5 balance was calibrated by an established procedure[2,4] with a set of calibrated class M weights. Two mass standards of 200 mg and 1 g were obtained from the Mass Measurement Section of National Research Council of Canada and were used to calibrate a set of class M weights with the high-precision Mettler ME22 balance. This calibrated set of class M weights in turn was used to determine corrections for the individual dial settings of the M-5 balance. The results are shown in Table 1.

The rapid method described by Faure and Gledhill[5] was used to determine the buoyancy correction, which was 0.103% for the atmospheric conditions that prevailed at the time the samples were taken.

TABLE I

Corrections for the built-in set of weights of the balance used for gravimetric determination of the ^{134}Cs sample sizes

Dial Setting (g)	Correction (μg)
0.01	+1
.02	-3
.03	-2
.04	-1
.05	+2
.10	+2
.20	+1
.30	+5
.40	+5
.50	+1
1.00	nil

Source mounts used were VYNS plastic film of superficial density 4 $\mu g \cdot cm^{-2}$ coated with 18%-palladium-gold alloy. The active solution was delivered to the non-metallized side of a VYNS film, the solution was dried in a box through which warm air flowed[6], and a similar metallized film was placed over the active deposit with the metallized side on top. Thus a sandwiched source was produced with metallic coating on the outer surfaces. The total superficial density of the metal was approximately 20 $\mu g \cdot cm^{-2}$.

For five of the seventeen sources prepared, the wetting agent, Catanac SN[7], was employed. Ludox SM[8] was used in the preparation of six, and no treatment was given to the remainder. In addition varying amounts of CsCl carrier were added to some of the source mounts in order to produce a few somewhat thicker sources. Thus the set of sources produced gave a range of 4π counting efficiencies.

4. 4π(PC)-γ COINCIDENCE COUNTING EQUIPMENT

The present system has evolved from that described by Campion[9] and uses a 4π flow proportional counter as the β detector and two NaI crystals as γ detectors. The outputs of all three detectors are common to two similar and separate systems of electronic circuitry, as shown in Fig. 3.

The availability of these two independent sets of electronics for $4\pi\beta$-γ coincidence counting is useful for (1) tests to determine whether the duplicate set gives the same results for the same set of counting conditions, e.g. γ-channel windows, and (2) simultaneous use of two separate sets of counting conditions. The apparatus was used for both purposes in the course of this comparison.

One of these electronic systems provides for a continuous monitor of the delay mismatch between the β and γ channels[10,11], and outputs data from which corrections for mismatch can be made, if necessary, to the individual counting results from a source.

Table II lists the particular electronic modules in use during this series of measurements for the functions outlined in Fig. 2.

The β channel uses a logarithmic charge-sensitive preamplifier[12]. Its output is fed into a double delay line amplifier with a short clipping time (0.5 μs). This amplifier feeds a single channel analyzer with an energy window sufficiently wide to accept all pulses from the proportional counter above 80 eV.

Both γ detectors are supplied by Bicron Corporation and are 76 x 76 mm integral line NaI(Tl) crystals with resolutions of 6.6 and 6.8% at 662 keV. Their charge sensitive outputs feed double delay line amplifiers with short clipping times (0.4 μs). In turn the output from each of these amplifiers feeds two independent single channel analyzers whose main function is to provide the necessary γ-energy windows and matching delays.

A requirement for any unit used in the next function of Fig. 3, that of dead-time control, is that the duration of its output pulse be independent of input rate, amplitude, or duration. The Lecroy model 125 discriminator and Lecroy model 222N gate generator were chosen to accept γ pulses from either single channel analyzer, shape them appropriately, and regulate their dead times. Pulses from the β single channel analyzer were similarly treated. The β and γ pulses from the dead-time units are passed through similar resolving-time control units and then 1) accumulated in individual scalers and 2) fed to coincidence-mixing circuits whose outputs are also scaled.

In setting up the equipment for a counting experiment, the fast-logic units used for dead-time control are preset to give approximately the output pulse duration wanted (≃ 2 μs here). The β and γ dead times of each system are determined by the source-pulser method[13,14]. In this method the source alone, and then the source together with a fixed-repetition rate pulser feeding the single channel analyzers, are counted. Such dead-time measurements are taken daily to ascertain the degree of system stability over the duration of an experiment during which counting conditions, e.g. γ-ray energy windows, are changed. The mean value of the dead-time measurements taken had a standard error of ± 5 ns and was used to compute the coincidence-counting results.

Similarly in setting up the series of ^{134}Cs measurements, the coincidence resolving time was adjusted with the resolving-time control units. It was measured by counting a source on the β systems and feeding the pulser through the γ systems. From the observed rates in β, γ, and coincidence scalers the coincidence resolving time is calculated.

The relative delay between pairs of coincident β and γ pulses is examined for each system of electronics prior to a run. The method used is based essentially on that described by Williams and Campion[10]. In setting up and testing, the same train of pulses is fed into the β and γ resolving-time control units and the start/stop delays, shown in Fig. 3, are adjusted to correspond at about mid range of the multichannel analyzer (MCA). Then the arrival time of γ pulses from a ^{134}Cs source at the coincidence-mixing circuit is adjusted, by varying the delay from the single-channel analyzers, to be equal to the mean time of arrival of pulses and to correspond to the selected mid-range point of the MCA which represents zero mismatch of the delays.

Taylor and Gibson[11] have extended the method to allow a continual record of the effectiveness with which the relative delays remain matched throughout a run during which counting data is accumulated. To accomplish this, the TAC output is fed to the MCA which outputs: a) n pulses for an event recorded in channel n, and b) a busy signal which indicates the number of events analyzed; each of a) and b) is fed to a scaler and the ratio of the contents of these scalers gives the current channel no. of the MCA that corresponds to the current relative delay. Thus any significant malfunction of the delay circuitry is evident. Another advantage of the Taylor and Gibson[11] system is that the information from these scalers can be used to deduce the actual delay mismatch that prevailed during the counting interval of an individual source, if the MCA is calibrated with respect to time.

An automatic sample changer that accommodates up to thirty-six samples was used to accumulate counting data for this comparison. A photograph and short description of the sample changer have been reported by Taylor and Baerg[15]. The sample changer is under computer control[16] and allows flexibility in the selection of various counting parameters.

TABLE II

List of Model Numbers/Suppliers of Electronic Instrumentation
Used in the CRNL $4\pi\beta$-γ Coincidence System

Module	Quantity	Model Number	Supplier
β Preamplifier	1	CRNL designed preamplifier	
γ Preamplifier	2	CI 802-9	Canberra Industries
Linear Amplifier	3	CI 1411 DDL AMP	Canberra Industries
Single Channel Analyzer	5	420 SCA	Ortec
Sum/Invert Amplifier	1	433 SIA	Ortec
Dead-Time Control	4	LRS 222N (2) & 125 (2)	LeCroy Research Systems
Resolving-Time Control	4	LRS 123, 125, & 222N (2)	LeCroy Research Systems
Coincidence Mixer	1	LRS 162 (2)	LeCroy Research Systems
Timer	1	TRI 1802 dual clock	Tomlinson Research Institutes
	1	AECL EB 5882	CRNL Electronics Br.
Scaler	8	C7030 Multiscaler	Conuclear
	1	Level Translator (4)	CRNL Standards Group
H.T. Supply	3	(2) HP6110A (0-3000V)	Hewlett Packard
		(1) 413C (0-3000V)	Fluke
Delay	2	CI 1445	Canberra Industries
Gate	1	Ortec 409	Ortec
Time to Amplitude Converter	1	Ortec 437A TAC	Ortec
Multichannel Analyzer	1	100Ch AEP 2300	Computing Devices of Canada

5. DATA ACCUMULATION AND RESULTS

All seventeen sources were counted in the 4π(PC)-γ coincidence system. During the various runs four different γ-channel gates were set as shown in figures 4-7. Three of these were narrow windows around the peaks at 1) 796 and 802 keV, 2) 605 keV and 3) 1365 keV; the fourth was a wider window from 730 to 1520 keV. From a previous study[1] the first of these was judged to offer the capability of the highest accuracy. Therefore, during the initial run the narrow gate around ≈ 800 keV was used to collect data simultaneously from both systems of electronics for the seventeen sources, each counted three times (n=51). The computed coincidence results showed that the average of the 51 values for the difference between electronic systems, and its standard deviation were (0.011 ± 0.008)%, where the ranges of source activity and 4π-counting efficiency were 0.35 to 1.2 µCi (13 to 43 kBq) and 0.93 to 0.71 respectively. In general the largest differences observed corresponded to about mid-range of both source activity and efficiency, and the smallest differences to the lowest activity and highest efficiency tested. In such a test, where the same sample of decay statistics from a source is involved, the statistical counting uncertainty in comparing the results from the two systems should cancel. Typically this uncertainty was ± 0.05%.

This comparison of the two systems indicates that the reproducibility of the experimental setup is good, but it does not satisfactorily test for several sources of systematic uncertainty or bias, such as errors in the dead-time values, which are discussed in the next section.

In other runs (nos. 2 to 5 of Table III) data were accumulated with the same γ-channel gate (around 800 keV) in one system and another γ-channel gate in the second system. Subsequently in runs 6 and 7 the efficiency of a source was varied by the technique of adding foils[7], which showed that the efficiency-dependent parameters were similar to those obtained in an earlier study[1].

The coincidence formulae used follow Bryant[17] with modifications to accommodate small differences between channels in the measured dead times (θ's) and resolving times (τ's) and to include the Gandy[18] delay offset term (δ); primed quantities are the observed rates, rate-dependent corrections to the backgrounds are neglected, θ_c is the lesser of θ_β or θ_γ, and δ is positive when the γ pulse arrives first:

$$N_o = \frac{N_\beta N_\gamma[2-N_\beta'\theta_\beta-N_\gamma'\theta_\gamma+2N_c'\theta_c-2(N_\beta'\tau_{R\gamma}+N_\gamma\tau_{R\beta})+2\delta(N_\beta'-N_\gamma')]}{[N_c'-N_\beta'N_\gamma'(\tau_{R\beta}+\tau_{R\gamma})](2-N_\beta'\theta_\beta-N_\gamma'\theta_\gamma)}$$

A least-squares fitting program based upon one developed by J.H. Schmidt[19)] for use at the CRNL computation centre was used to compute for each run the activity that would correspond to 100% 4π-counting efficiency. In addition, data from several runs for the narrow ≈ 800 keV γ-channel gate were combined (n=176) and fitted together.

The results are summarized in Table III. All activity values have been corrected for decay to the reference time (RT) requested by BIPM, 1978-October-15-00 h UT. The statistical standard errors are shown. As a matter of curiosity, the results obtained from second order fits to the data are included and are shown in brackets. The weighted mean of the results from the group of runs for γ-channel gate no. 1, 830.11 ± 0.17, is adopted as our best value for the activity concentration of the ^{134}Cs solution. It is selected over the value listed above it, i.e. the least-squares fit of the same data combined, because the γ-channel count rate data show slight inconsistencies from one run to another. This indicates that, despite our intention to reproduce the γ-channel window settings from one run to the next, small differences prevailed among runs with the same γ-channel gate. These differences seem to give slightly different efficiency-dependent parameters, and therefore we prefer to treat each run as a separate population of data.

As a matter of interest Table IV shows our best value, 830.11 ± 0.17 $s^{-1}\cdot mg^{-1}$, together with the average values of the results from the other three γ-channel gates. Also shown is the weighted mean of these four values computed with weighting factors obtained from the statistical uncertainties. The last line of Table IV shows the weighted mean obtained if, instead of only statistical uncertainties, the systematic uncertainties also are used to obtain weighting factors.

Table III

Summary of ^{134}Cs Coincidence Results

Run No.	System No.	γ-Gate No.	Activity at RT ($s^{-1} \cdot mg^{-1}$)	
1	1	1	829.87 ± 0.16	(830.01)
1	2	1	829.75 ± 0.16	(829.81)
2	1	1	Equipment malfunction	
2	2	2	830.79 ± 0.27	(830.04)
3	1	1	Equipment malfunction	
3	2	4	830.58 ± 0.31	(828.59)
4	1	1	830.15 ± 0.19	(830.13)
4	2	3	832.98 ± 0.64	(829.29)
5	1	1	830.35 ± 0.21	(829.76)
5	2	3	832.47 ± 0.78	(828.37)
6	1	1	830.29 ± 0.28	(829.93)
6	2	2	829.91 ± 0.32	(826.53)
7	1	4	831.60 ± 0.19	(830.42)
7	2	3	832.86 ± 0.66	(828.03)
1,4,5&6		1	830.29 ± 0.13	(830.13)
Mean of 1,4,5&6		1	830.11 ± 0.17* 0.10†	(829.90)

* External error in the mean of four runs

† Internal error in the mean of four runs

Table IV

Average Values of Results for First and Second Orders of Fitted Polynomial

γ-channel gate	First Order ($s^{-1}\cdot mg^{-1}$)	Second Order ($s^{-1}\cdot mg^{-1}$)
1	830.11 ± 0.17	829.90 ± 0.17
2	830.42 ± 0.44	828.58 ± 1.73
3	832.805 ± 0.40	828.60 ± 0.40
4	831.32 ± 0.46	829.92 ± 0.82
Weighted mean of above	830.59 ± 0.53*	829.70 ± 0.28†
	± 0.14†	± 0.16*
Mean (weighted from Table V)	830.54 ± 1.24†	829.44 ± 1.24†

* External error in the mean

† Internal error in the mean

6. ASSESSMENT OF SOURCES OF UNCERTAINTY

BIPM requested that participants in this comparison give information about estimates of the systematic uncertainty *in the final result* that arises from weighing, dead time, resolving time, delay mismatch, pile-up, background, extrapolation of the efficiency function to 100% 4π-counting efficiency, and any others. Limits of uncertainty from most of these causes can be given readily, but more realistic or likely estimates[20)] are more relevant here for the comparison of results from international participants. Accordingly Table V lists such estimates.

Table V

Sources of Systematic Uncertainty or Instrumental Bias

	Estimated % Uncertainty	Limit of % Uncertainty
Weighing	0.003	<0.01
Dead time	0.002	<0.005
Resolving time	0.004	<0.01
Delay mismatch	0.018	<0.03
Pile-up	(0.02)	<0.1
Background	0.003 to 0.05	<0.01 to <0.2
Extrapolation to intercept of efficiency function	0.07 to 0.5	<0.1 to <0.5
Decay	0.003	<0.006

The uncertainty in the mass of a sample of solution, σ_m, is taken as the sum of the systematic uncertainties and the combination in quadrature of the statistical errors involved, and for these measurements is

$$\sigma_M = \sigma_B + \sigma_{OS} + \sigma(ns^2)^{1/2}$$

where σ_B is the uncertainty in buoyancy correction of 0.001%

σ_{OS} is the uncertainty from calibration of the optical scale and/or its stability during the sampling period s is the standard deviation for an M-5 balance

and n is the number of such standard deviations involved.

The uncertainty in the calibration of the dialled weights is treated statistically because most of this uncertainty arises from the lack of reproducibility of the M-5 balance (i.e. not from the ME22 or the larger reference certified masses), and because four of the M-5's dialled weights are involved in each delivery of a sample by difference weighing. If this uncertainty in calibration were treated as systematic, we would be tending toward the expression of a limit of uncertainty. For essentially the same reason, the zero correction is treated statistically. Thus seventeen standard deviations are involved in delivery of a single sample to a source mount (one common zero reading between the two pycnometer readings), and eighteen for the total mass of solution delivered to the seventeen sources. σ_{0S} for a single source size is taken from Fig. 2 as 0.3 µg, and for the total mass of seventeen sources as the discrepancy of 3 µg in the optical scale during the 1.6-hour sampling period. This gives ± 6 µg (≈0.02%) for the estimated uncertainty in weighing for an individual sample, and ± 10 µg (0.002%) for the total mass delivered to the seventeen sources. To the latter, 0.001% is added for the change in solution concentration from evaporation during the sampling period (see Table V). This sum of 0.003% is the uncertainty in the final result from weighing.

The uncertainties from the parameters of dead time, resolving time, and delay mismatch were estimated by recalculating the results for a run with the parameter changed by two standard errors. The difference between this recalculation and the original is our estimate of systematic uncertainty from the tested parameter. A similar approach was used to estimate the uncertainty from background, and largely consists of the contribution from γ-channel background. Table V shows the estimate for the preferred γ-channel gate, no. 1; it is much larger (≈0.05%) for γ-channel gate no. 3.

We have not been able to estimate satisfactorily the uncertainty from pile-up. From observations of the consistency of γ-channel counting rate with source activity for the range tested (factor of 4), a limit of <0.1% is set. If the suggestion of Smith et al.[21] is followed, the estimate is 0.02%.

The uncertainty in the intercept obtained from extrapolation of the efficiency function is estimated to be the difference between the highest and lowest values of the runs with γ-channel gate no. 1 (0.07%), because the ratio for slope/intercept of this function is very small (0.01). However, for other γ-channel gates the ratio is large (0.12 to 0.36) and for these cases the difference between the fitted values from first and second order polynomials is taken as the estimated uncertainty; this is largest for γ-channel gate no. 3 (0.5%).

The uncertainty in the final result from uncertainty in decay correction was estimated from the uncertainty in the half-life value (753.1 ± 1.8 days) recommended by BIPM for this comparison. In good agreement with their half-life value is the value we are in the process of determining with the 4πγ ionization chamber for our recent ^{134}Cs standard[1]. Our preliminary half-life value is 754.4 days with a standard deviation of ±0.7 day.

7. *ACKNOWLEDGEMENTS*

The authors are grateful to E. Green and R. Gendron of National Research Council of Canada for mass calibration of two weights, and to R.L. Graham, J.G.V. Taylor and J.S. Geiger for their helpful comments and interest in this work.

REFERENCES

1) J.S. Merritt and F.H. Gibson, Atomic Energy of Canada Limited Report No. AECL-5834 (1977).

2) J.S. Merritt, Nucl. Instr. & Methods 112, 235 (1973).

3) J.S. Merritt and J.G.V. Taylor, Atomic Energy of Canada Limited Report No. AECL-2679 (1967).

4) H.A. Bowman, R.M. Schoonover and M.W. Jones, J. Res. Nat. Bur. Std. 71C, 179 (1967).

5) P.K. Faure and J.A. Gledhill, Anal. Chem. 30, 1304 (1958).

6) G.C. Bowes and A.P. Baerg, National Research Council of Canada Report No. NRC-11513 (1970).

7) A.P. Baerg, S. Meghir and G.C. Bowes, Intern. J. Appl. Rad. & Isotopes 15, 279 (1964).

8) J.S. Merritt, J.G.V. Taylor and P.J. Campion, Can. J. Chem. 37, 1109 (1959).

9) P.J. Campion, Int. J. Appl. Rad. & Isotopes 4, 232 (1959).

10) A. Williams and P.J. Campion, Int. J. Appl. Rad. & Isotopes 16, 555 (1965).

11) J.G.V. Taylor and F.H. Gibson, private communication (1973).

12) G. Frketich and J.G.V. Taylor, Atomic Energy of Canada Limited Report No. AECL-3667 (1970).

13) J.G.V. Taylor, private communication (1976).

14) J.W. Müller, BIPM Report No. 76/5 (1976).

15) J.G.V. Taylor and A.P. Baerg, p.69, NBS Special Publication 331 (1970).

References cont.

16) R.N. Paul, Atomic Energy of Canada Limited Report No. EB-8051-SP-1 (1973).

17) J. Bryant, Int. J. Appl. Rad. & Isotopes 14, 143 (1963).

18) A. Gandy, Int. J. Appl. Rad. & Isotopes 11, 75 (1961).

19) J.H. Schmidt, in report by L.E. Evans, Atomic Energy of Canada Limited Report, CRNL-486, (1976).

20) S. Wagner, PTB-Mitteilungen 79, 343 (1969), available in English as Report PTB-FMRB 31/69 from Physikalisch-Technische Bundesanstalt, Braunschweig, Federal Republic of Germany.

21) D. Smith, A. Williams and M.J. Woods, *Report on the intercomparison of high count rate* ^{60}Co *sources*, organized by NPL on behalf of BIPM (1977), available from National Physical Laboratory, Teddington, U.K.

FIGURE CAPTIONS

Figure 1 ^{134}Cs decay scheme proposed by BIPM for the comparison. Intensities suggested by BIPM for the 605-, 796-, 802- and 1365-keV γ-rays are 0.976, 0.854, 0.0873 and 0.0304 respectively, but these data are not required for the 4π(PC)-γ method.

Figure 2 Deviation from linearity of the optical scale of the Mettler M-5 balance.

Figure 3 Block diagram of detectors and electronic equipment. A detailed list of components is given in Table II.

Figure 4 ^{134}Cs γ-ray spectrum showing position of γ-channel gate no. 1. The gate is set to accept counts from the photopeaks at 796 and 802 keV.

Figure 5 ^{134}Cs γ-ray spectrum showing position of γ-channel gate no. 2. The gate is set to accept counts from the 650 keV photopeak.

Figure 6 ^{134}Cs γ-ray spectrum showing position of γ-channel gate no. 3. The gate is set to accept counts from the 1365 keV photopeak.

Figure 7 ^{134}Cs γ-ray spectrum showing position of γ-channel gate no. 4. This wide gate is set to accept counts from 730 to 1520 keV.

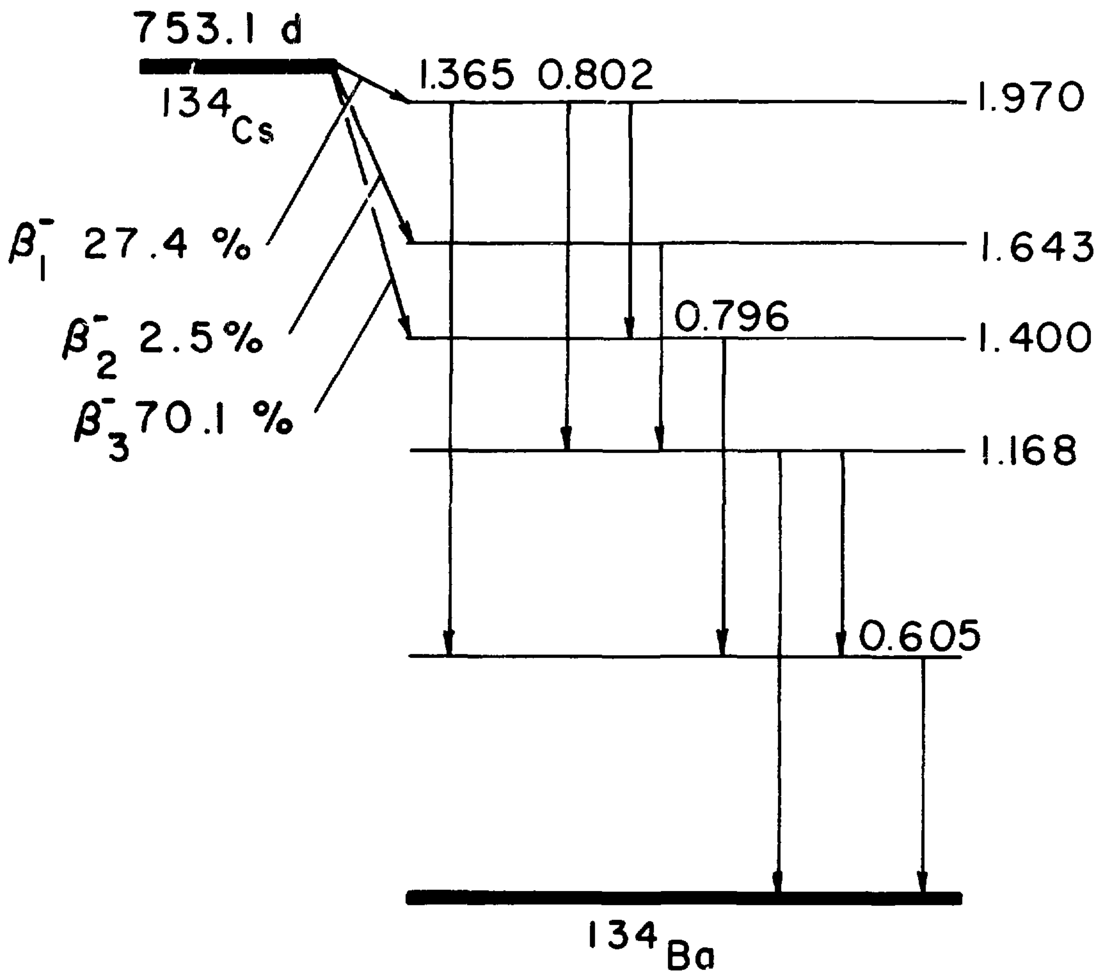

Figure 1 ^{134}Cs decay scheme proposed by BIPM fcr the comparison. Intensities suggested by BIPM for the 605-, 796-, 802-, and 1365-keV γ-rays are 0.976, 0.854, 0.0873 and 0.0304 respectively, but these data are not required for the 4π(PC)-γ method.

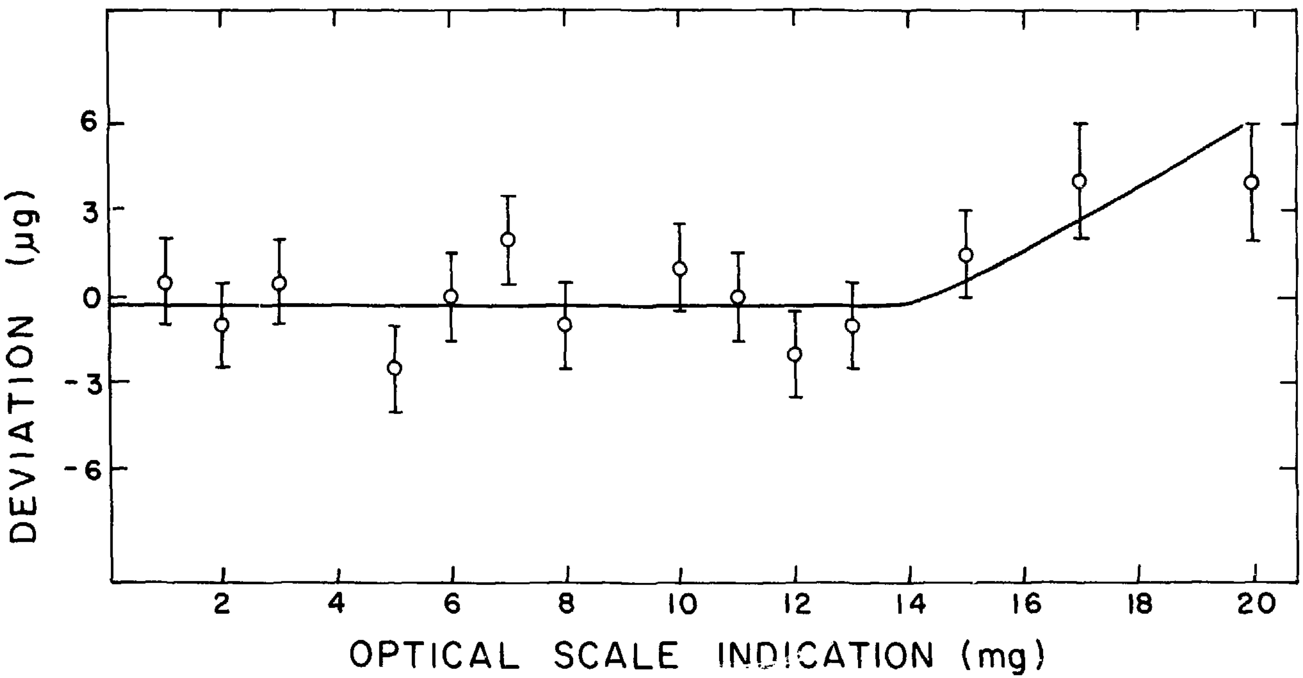

Figure 2 Deviation from linearity of the optical scale of the Mettler M-5 balance.

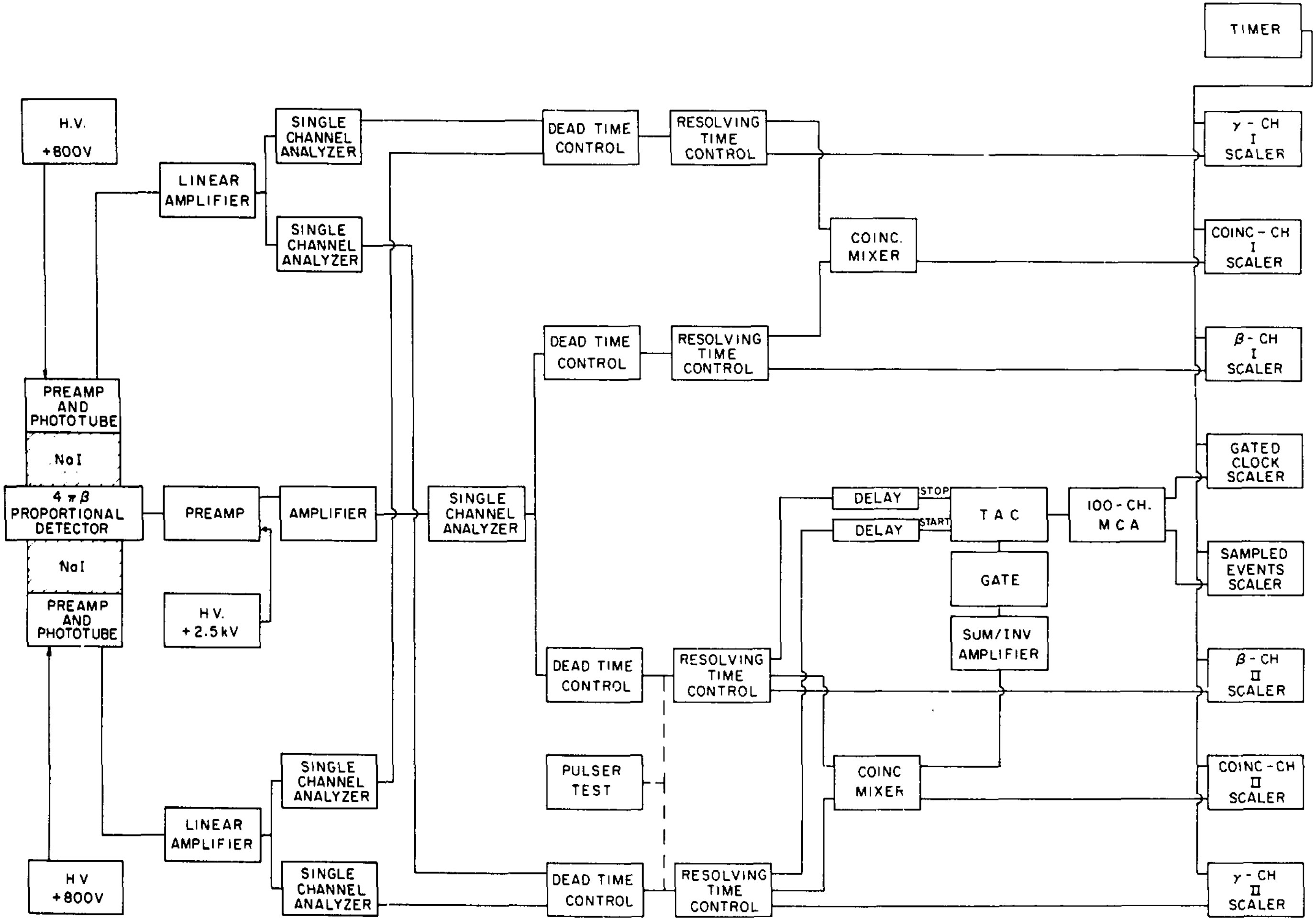

Figure 3 Block diagrams of detectors and electronic equipment. A detailed list of components is given in Table II.

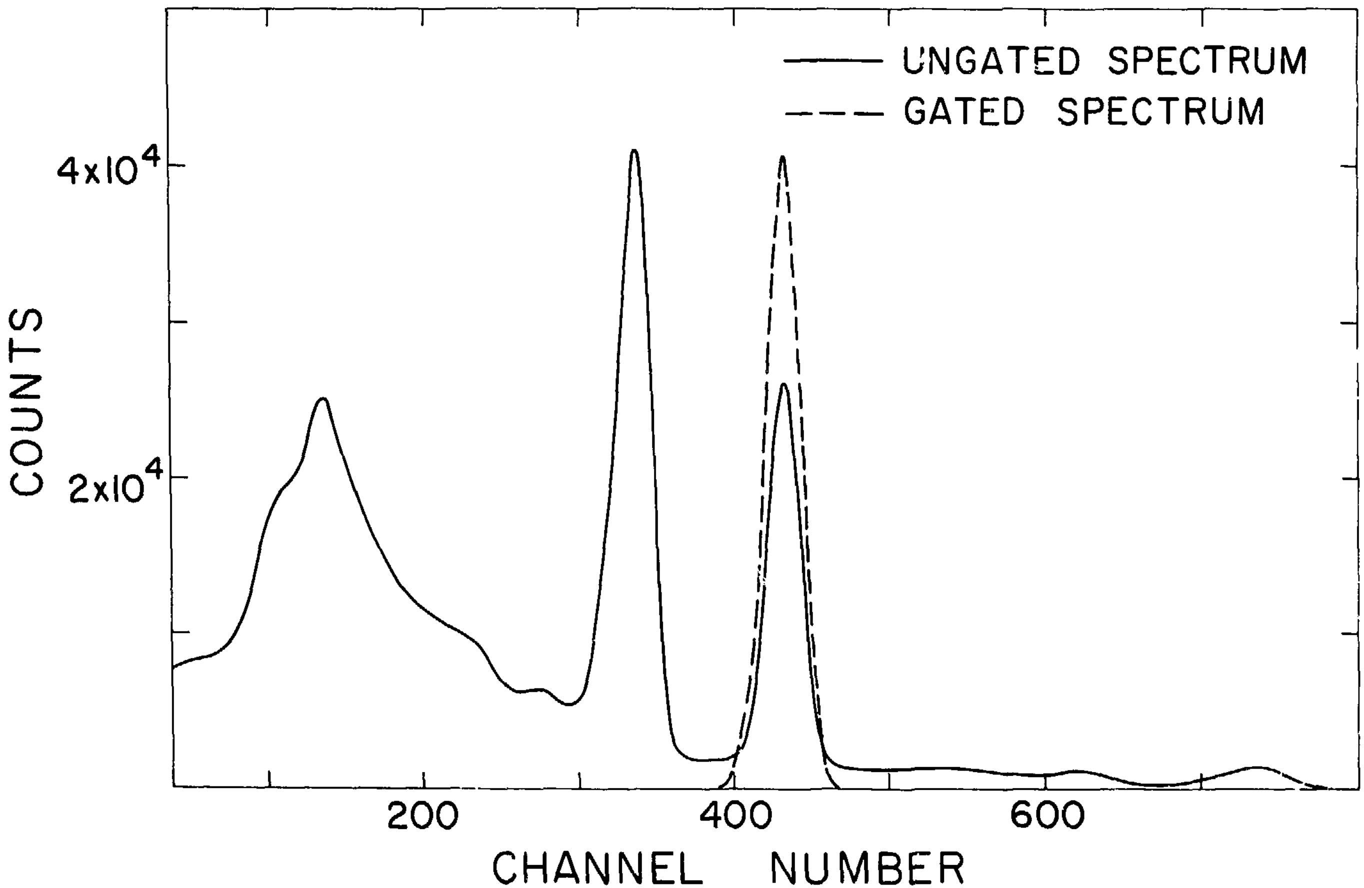

Figure 4 ^{134}Cs γ-ray spectrum showing position of γ-channel gate no. 1. The gate is set to accept counts from the photopeaks at 796 and 802 keV.

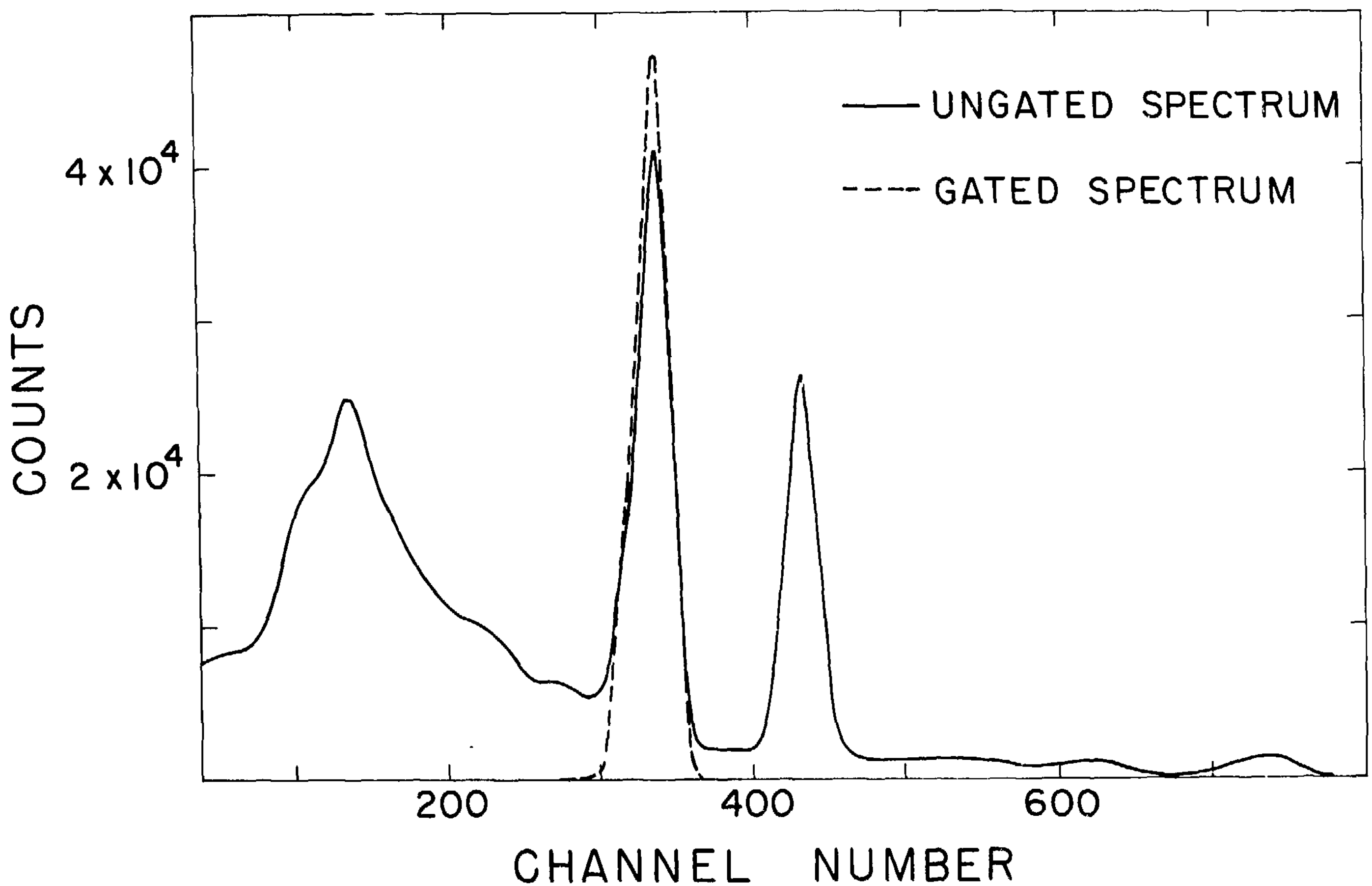

Figure 5 ^{134}Cs γ-ray spectrum showing position of γ-channel gate no. 2. The gate is set to accept counts from the 650 keV photopeak.

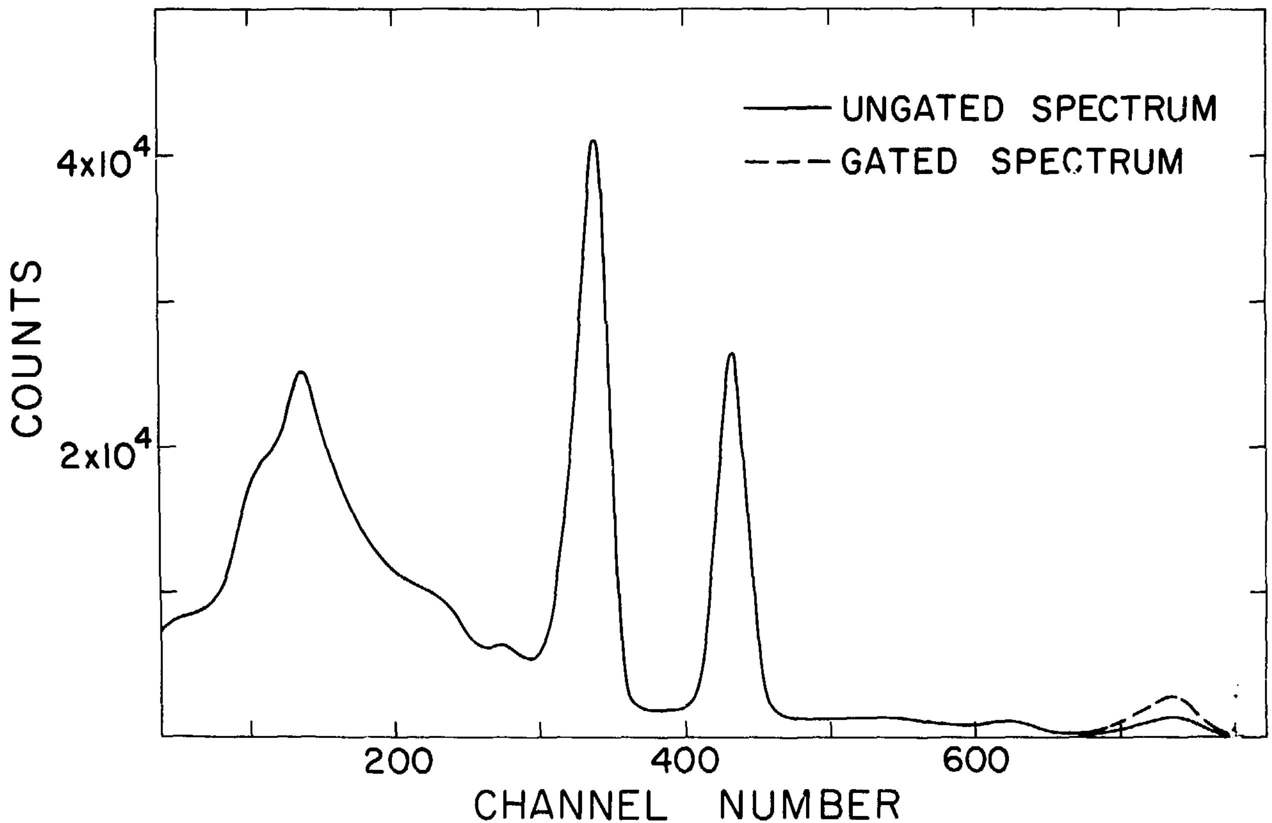

Figure 6 ^{134}Cs γ-ray spectrum showing position of γ-channel gate no. 3. The gate is set to accept counts from the 1365 keV photopeak.

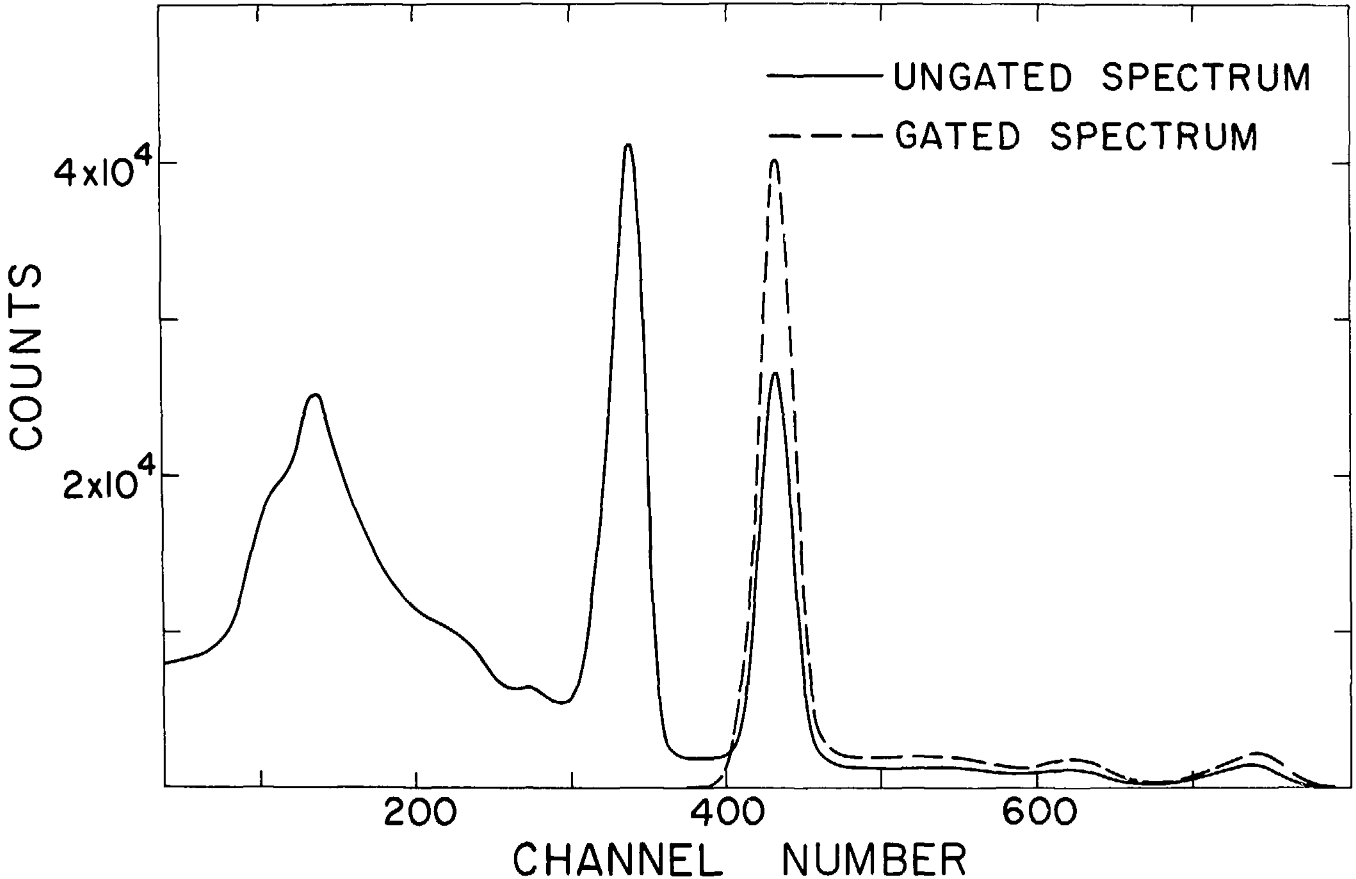

Figure 7 ^{134}Cs γ-ray spectrum showing position of γ-channel gate no. 4. This wide gate is set to accept counts from 730 to 1520 keV.

ISSN 0067 - 0367

To identify individual documents in the series we have assigned an AECL- number to each.

Please refer to the AECL- number when requesting additional copies of this document

from

Scientific Document Distribution Office
Atomic Energy oı Canada Limited
Chalk River, Ontario, Canada
KOJ 1JO

Price $3.00 per copy

ISSN 0067 - 0367

Pour identifier les rapports individuels faisant partie de cette série nous avons assigné un numéro AECL- à chacun.

Veuillez faire mention du numéro AECL- si vous demandez d'autres exemplaires de ce rapport

au

Service de Distribution des Documents Officiels
L'Energie Atomique du Canada Limitée
Chalk River, Ontario, Canada
KOJ 1JO

Prix $3.00 par exemplaire