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International comparison of activity measurements of a solution of ^{133}Ba (March 1984)

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Abstract

Samples of a solution prepared, checked and bottled by the National Bureau of Standards have been sent to 19 participating laboratories for an international comparison of activity measurements organized by the Bureau International des Poids et Mesures. Two preceding trial comparisons among six laboratories, using two different solutions, had been unsuccessful, presumably because of insufficient contents of carrier substance. The adsorption on the ampoule walls was checked and found to be far too small to explain the discrepancies observed.

Most participants applied coincidence counting (or similar methods), with proportional counters or liquid-scintillation detectors in the β channel. Two laboratories used large well-type scintillation counters. Details of source preparation and equipment are given, and some information on pulse shapes, time distributions between γ and β pulses and efficiency functions are presented graphically.

Due to the presence of low-energy conversion electrons in the decay of ^{133}Ba, the extrapolation of efficiency functions obtained by coincidence counting may depend considerably on the γ-channel setting, and most participants therefore used a threshold of at least 200 keV.

A detailed list of uncertainty components is given, and the final results of the comparison are represented in tabular and graphical form. The total range is 1.7 %, and the standard deviation of the mean value amounts to 0.36 %. The results from the International Reference System are shown in the same graph.

1. Introduction

When Section II (Mesure des radionucléides) of the Comité consultatif pour les étalons de mesure des rayonnements ionisants had to choose, in 1979, a radionuclide for the next international comparison, ^{133}Ba was proposed, among several others. One of the reasons advanced was that the results obtained for this nuclide with the International Reference System could be interpreted as being split into two groups about 1 % apart from each other. Further, ^{133}Ba is an often-used multi-γ-ray energy standard [1].

Following usual practice, a preliminary comparison was organized by BIPM, with AECL, BCMN, BIPM, LMRI, OMH and PTB* as participants. The solution was prepared, bottled and distributed by LMRI in December 1980. The results [2] were obtained mostly by using coincidence techniques, with gas counters in the β channels and by efficiency extrapolation. Their unexpectedly large scatter could only partially be explained by wall adsorption.

Under these circumstances, Section II decided to organize a second trial comparison with the same participants. This time, the solution was supplied by PTB and the carrier content was increased by 50 %, namely to 23 µg of $BaCl_2$ per gramme of solution 9 (distributed in October 1981). It had become clear that wall adsorption should be given special attention. In addition, a new and more detailed reporting form was distributed. The results of this second precomparison [3] were still rather disparate and gave no clear answer as to the exact reason for the large scatter. Nevertheless, one had the impression that the difficulties might disappear if a solution containing much more carrier substance were used. Therefore, a third precomparison, carried out in November/December 1983, could be restricted to ionization-chamber measurements on a solution that would then also serve for a subsequent full-scale comparison, provided the preliminary results were satisfactory, as was indeed the case. The results from the three preliminary comparisons are represented graphically on fig. 1. The link between the activity concentrations of the three different solutions was obtained through the International Reference System for activity measurements of γ-ray-emitting nuclides (SIR) [4].

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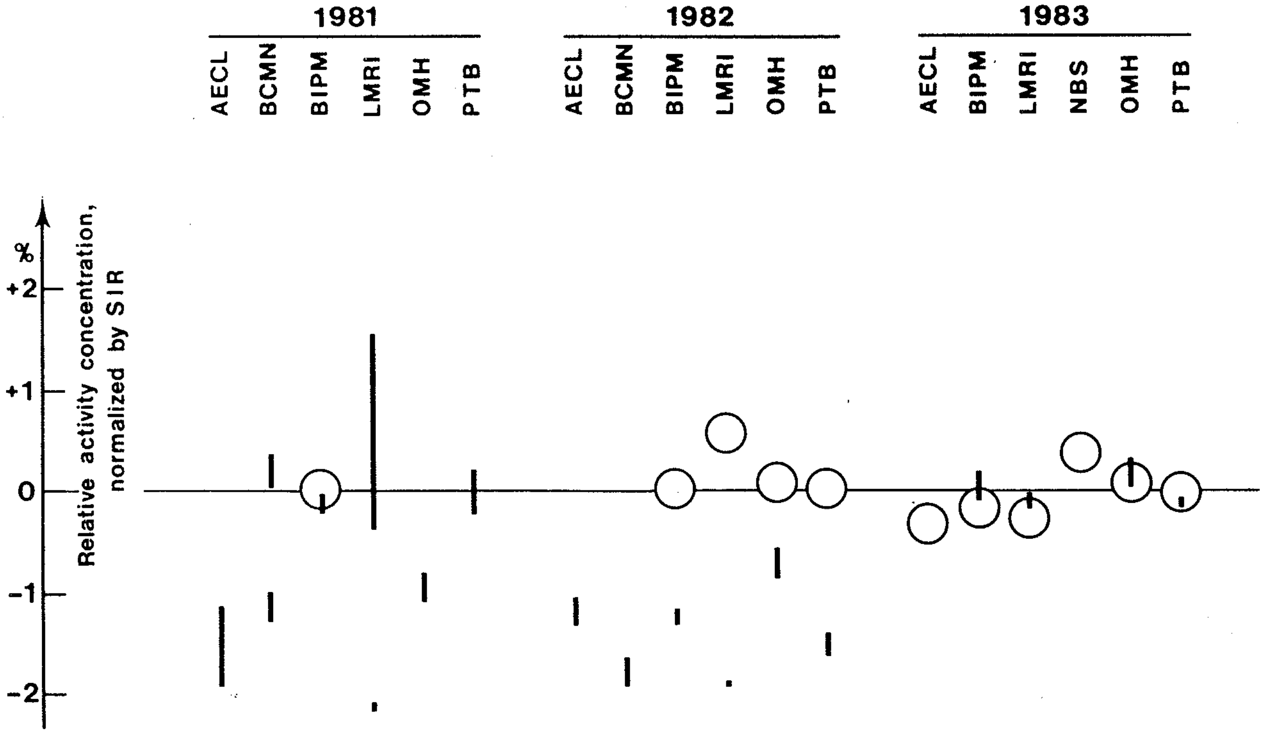
* The names of the participating laboratories can be found in table 1.



| absolute measurements, with uncertainty; ○ ionization-chamber measurement, uncertainty ≈ diameter

Fig. 1 - Relative position of the measurements of three preliminary comparisons. The solution of 1983 was identical with that used for the subsequent full-scale comparison.

2. Description of the solution used in the full-scale comparison

The primary material was supplied and checked for stability by NBS, using 4πγ ionization-chamber measurements. After a dilution, the master solution was prepared and made ready for distribution. The filled and sealed ampoules were sterilized and measured in the ionization chamber. All the solution masses had been measured accurately when filling the ampoules. The distribution for the third trial comparison took place at the beginning of November 1983. The remaining ampoules (except the ones for participants in North or South America) were sent to PTB, from where they were distributed early in March 1984, after the third trial comparison had been found to be satisfactory. The participants in that comparison did not receive any further ampoule.

Each ampoule contained about 3.6 g of an aqueous solution of 1 mol HCL per dm^3 with 60 μg of $BaCl_2$ per gramme of solution. The activity concentration was about 1 100 $kBq \cdot g^{-1}$; the density was 1.016 $g \cdot cm^{-3}$ at 20 °C.

The solution was checked for γ-ray-emitting impurities. The only radionuclide identified was ^{134}Cs at an activity ratio relative to ^{133}Ba of less than 10^{-5} (NBS) and (1.1 ± 0.5) 10^{-5} (PTB).

3. Decay scheme of ^{133}Ba

A complex decay scheme does not necessarily render coincidence measurements more difficult, as was exemplified by ^{134}Cs [5]. However, with an electron-capture decay, the situation is likely to be more involved. Therefore, it was felt that the decay scheme, as shown on fig. 2, should be completed by the data presented in table 2.

Recent half-life measurements yielded values between about 3 785 and 3 923 d, and for this comparison a value of (3 846 ± 15) d was suggested. As all the activity measurements took place within an interval of 150 d, this choice could not introduce any significant error.

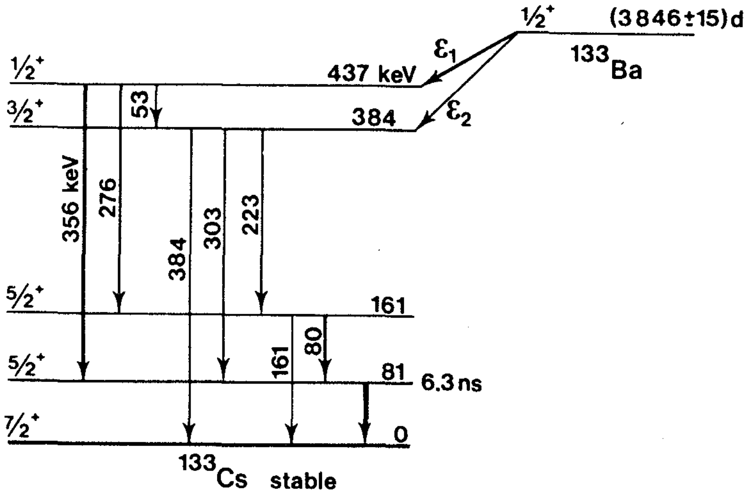


Fig. 2 - Decay scheme of ^{133}Ba. Data (except half life) taken from [20].

4. Ionization-chamber measurements and adsorption tests

The results of the second trial comparison could be due to adsorption of activity on the ampoule walls or, less convincingly, to an increase of the mass of solution. Therefore, the participants were asked to carry out the following checks:

- Measurement of the activity concentration by using a calibrated $4\pi\gamma$ ionization chamber and the solution mass as indicated by NBS,
- Quantitative transfer of the whole solution to an ampoule of the type normally used by the participant and remeasurement of the activity concentration,
- Rinsing the "empty" ampoule twice with 4 cm^3 of distilled water and remeasurement,
- Additional rinsings and remeasurement.

The results of these tests are summarized in table 3. It can be seen that the mass of solution extracted from the original ampoule was very nearly equal to that filled in by NBS. We mention by the way that it is not easy to empty an ampoule to less than 10 mg. With one exception, the activity concentration after transfer of the solution was different by no more than 0.25 %, and often by much less. As far as wall adsorption is concerned, two participants found that the walls retained up to 0.14 % of the total activity, but for the others this fraction was mostly ten to a hundred times less. IRK reported that the ampoule head, after withdrawing the solution, still contained 0.03 % of the total activity.

5. Measurements involving proportional counters

Source preparation - The efficiency of gas-flow proportional counting of electron-capture nuclides is often quite low. Therefore, it is important to prepare very thin sources, especially for ^{133}Ba where efficiency variation, e.g. by superposed absorber foils, may affect the very-low-energy events differently from the rest. Table 4 summarizes the various procedures for preparing sources and source backings applied by the participants. As the efficiency parameter, N_c/N_γ, depends also on details of the electronic system and on the γ-channel setting, it does not completely characterize the counting efficiency in the β channel. Nevertheless, it is often quite useful. Thus it will be noticed that there is a large range of the highest efficiencies achieved by the participants (see the last column of table 4). AAEC and PTB used the technique of depositing the solution drops on pads of ion-exchange resin, which gives a very uniform activity distribution and, thus, higher efficiency values. Treatment with NH_3 (by IMM) seems also to have had a favourable effect. As to the various applications of seeding or wetting agents and of drying methods, no clear preference can be deduced.

Equipment for 4π(PC)-γ coincidence counting - A condensed description of the detectors used by most of the participating laboratories can be found in an earlier report [6]. Therefore, table 5 describes only the detectors of the four laboratories that did not participate in the ^{137}Cs comparison.

6. Measurements using liquid-scintillation counting

Only two participants applied this technique; both combined it with coincidence counting. The equipment used is summarized in table 6.

NAC reported further that 24 days after preparing a source and subsequent decanting, 1.3 % of its activity was found left in the vial.

NPL added a small amount of saturated $Pb(NO_3)_2$ solution with some carrier to the "cocktail". This high-Z additive increased considerably the detection efficiency of electron-capture events (X rays). As there is no equivalent to the Cox-Isham formula known for the computer-discrimination method, a modified Campion formula was used.

7. $4\pi\gamma$ counting with a large NaI well-type crystal

As the report by LMRI points out, the decay scheme of ^{133}Ba (see fig. 2) favours highly accurate activity measurements by this method (used by IRK and LMRI). Because of the numerous cascades of up to five photons emitted (X or γ, conversion electrons of sufficient energy) very reliable efficiency values can be calculated which depend little on the exact decay data. In addition, the nine γ rays are in a convenient range for efficient detection. Descriptions of equipments have been published in [5, 7, 8, 9, 10, 11, 12] and will not be repeated here.

IRK prepared 24 sources from three dilutions made with substances checked for absence of any significant activity. The respective dilution factors were about 170, 100 and 60. All pycnometers used were rinsed with carrier solution, then dried, and rinsed with a part of the active diluted solution before dispensing the source droplets. The dilution masses were from 10 mg to 52 mg and the source diameters from 3 mm to 6 mm. The drop masses were measured by the pycnometer method and also by the evaporation method, the latter giving masses smaller by about 0.1 %, on the average. Special attention was devoted to avoiding splashing. Count rates were from 170 to 850 s^{-1} and the background rate about 50 s^{-1}. The data were taken with a lower-level discriminator and a dead time of (11.4 ± 0.3) μs. The detector had an efficiency, calculated for ^{133}Ba, of (98.49 ± 0.25) %; the well was lined with Al and TiO_2 (see [8]). An energy-discrimination level of 22.1 keV was imposed.

Test measurements were taken with different amplifications and dead times, and also with a live-timed multichannel analyser. There was agreement within 0.1 %.

LMRI measured 9 sources prepared without diluting the original solution. The well of the detector was lined with beryllium and the efficiency for ^{133}Ba has been calculated as (99.12 ± 0.05) %. With a discrimination threshold set at 5 keV, the observed count rates ranged from 20 000 s^{-1} to 73 000 s^{-1}. The measurements included automatic correction for an extendable dead time of 5 μs. The low uncertainty of the results obtained is due to the high detector efficiency, to the low threshold energy, and to the high count rates.

The uncertainty components have been assessed rather differently by the two laboratories:

	IRK	LMRI
counting statistics	0.1 %*	0.017 %
weighing	0.05	0.020
dilution	0.01	
dead-time correction	≤ 0.1	0.010
timing		0.003
background correction	included in counting statistics	0.001
decay correction	0.008	0.006
extrapolation	-	0.010
detection efficiency	0.25	0.051
impurities	0.001	-
adsorption	negligible	-
combined uncertainty	0.292	0.060

* including random uncertainty of weighings

8. Coincidence counting

Some particulars concerning 4π(PC)-γ or 4π(PPC)-γ and 4π(LS)-γ coincidence counting are presented in table 7 together with the values of dead times and resolving times. The participants have also been asked to supply information regarding pulse shapes at amplifier outputs and time distributions of γ pulses relative to correlated β pulses. A selection of these recordings is reproduced on figs. 3 and 4. As far as the formulae used for activity calculations are concerned, it appears that the original Campion formula is gradually replaced by some more accurate expressions.

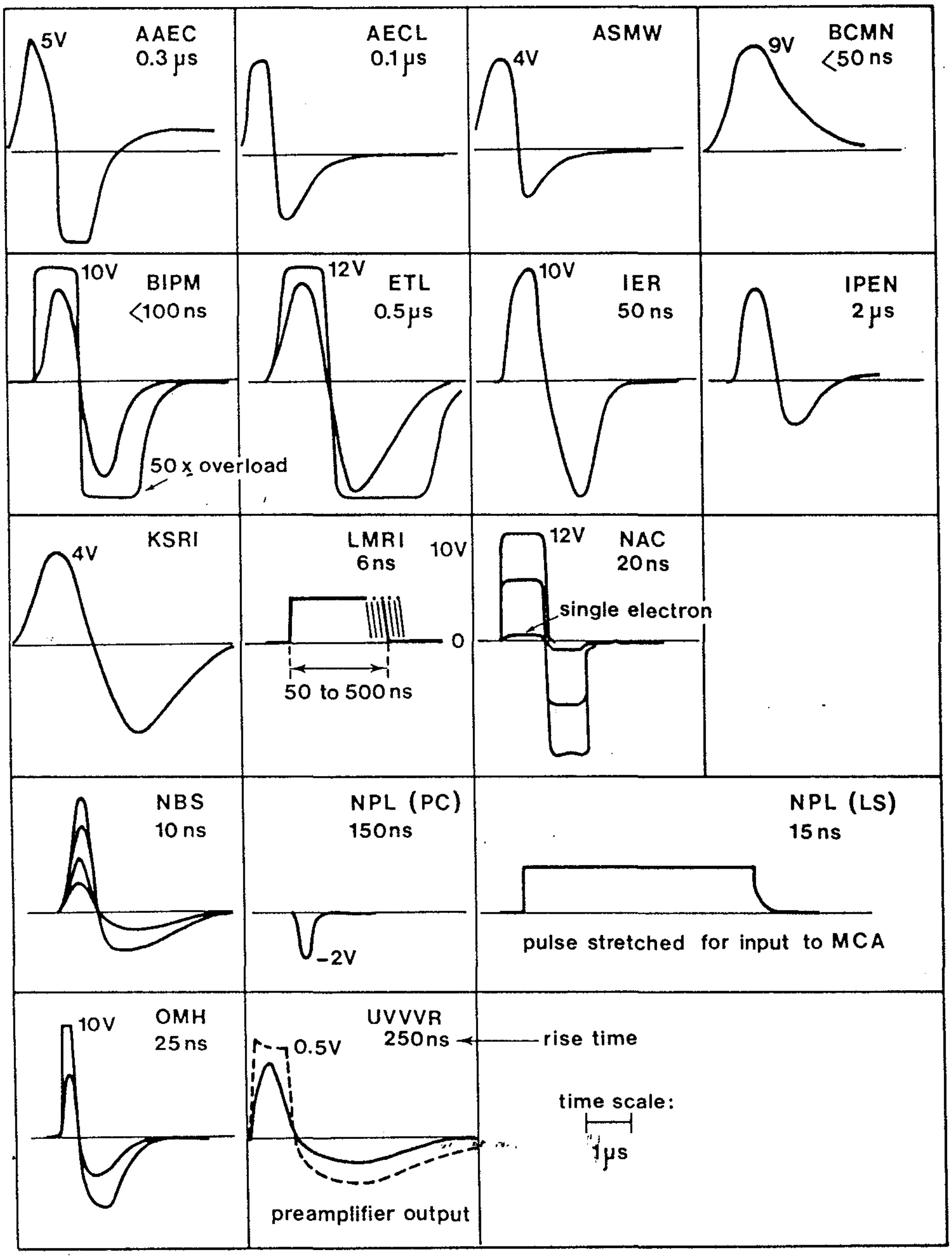


Fig. 3 - Pulse shapes at main-amplifier outputs

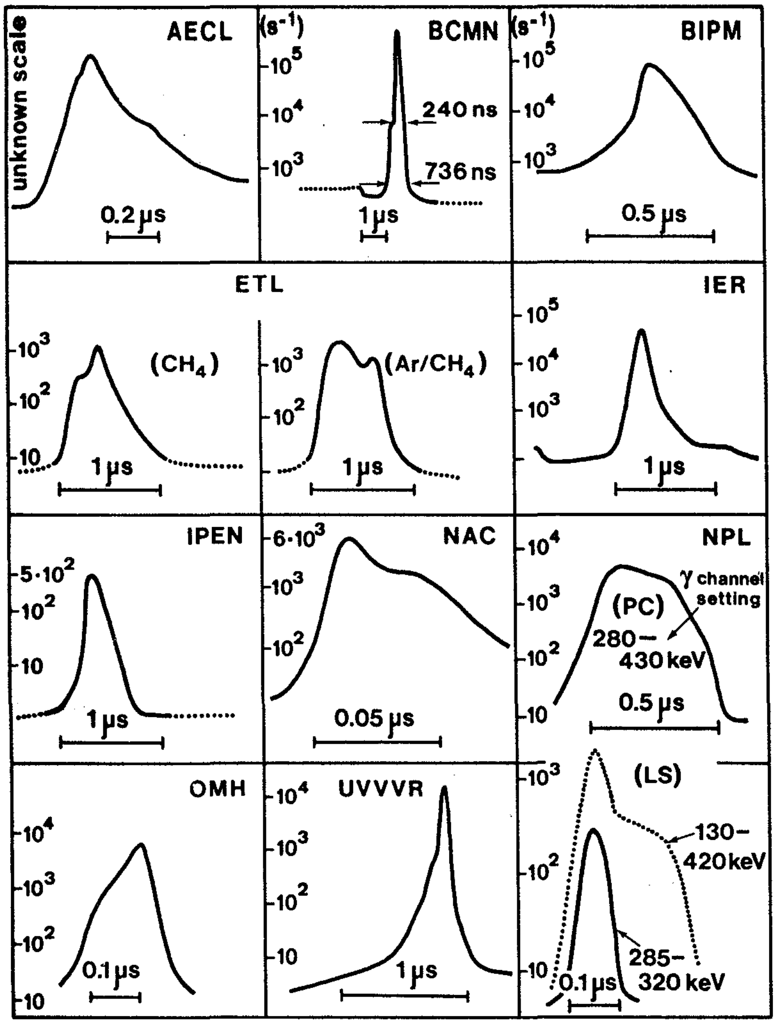


Fig. 4 – Time distributions of β pulses triggered by partners in the γ channel (ordinates: in s^{-1}, logarithmic scale)

Table 8 contains the most important counting data for the extrapolations of coincidence and anti-coincidence measurements. Those from NPL had to be presented in a different format at the end of the table. We further add the following comments by Smith on his 4π(LS)-γ measurements. He states that the discrepancy between the results of the four multiparametric extrapolations "is not really understood", but it is suspected that "it is due to the multiparametric fits being sometimes unable to adequately sample different contributions from two β branches. I.e. it is necessary that the ratio of γ counts in one channel arising from the two different β branches should be substantially different from the similar ratio of γ counts in the other channel(s)". It is further believed that the single-channel extrapolation (120 to 200 keV) will not give the correct activity, because the 160 keV γ radiation results almost entirely from <u>one</u> β branch, so the difference in P_K and P_L ratios between the two β branches is ignored.

9. Efficiency functions

For a radionuclide with a complex γ-ray spectrum it is sometimes possible to choose two or more different gates in the γ channel in order to obtain different efficiency functions which are expected to converge to a common intercept with the y axis, as the efficiency parameter N_c/N_γ approaches unity. This was indeed achieved in the case of ^{134}Cs [5]. Fig. 5 shows a typical γ-ray spectrum of ^{133}Ba as observed with the γ detector of the BIPM coincidence set.

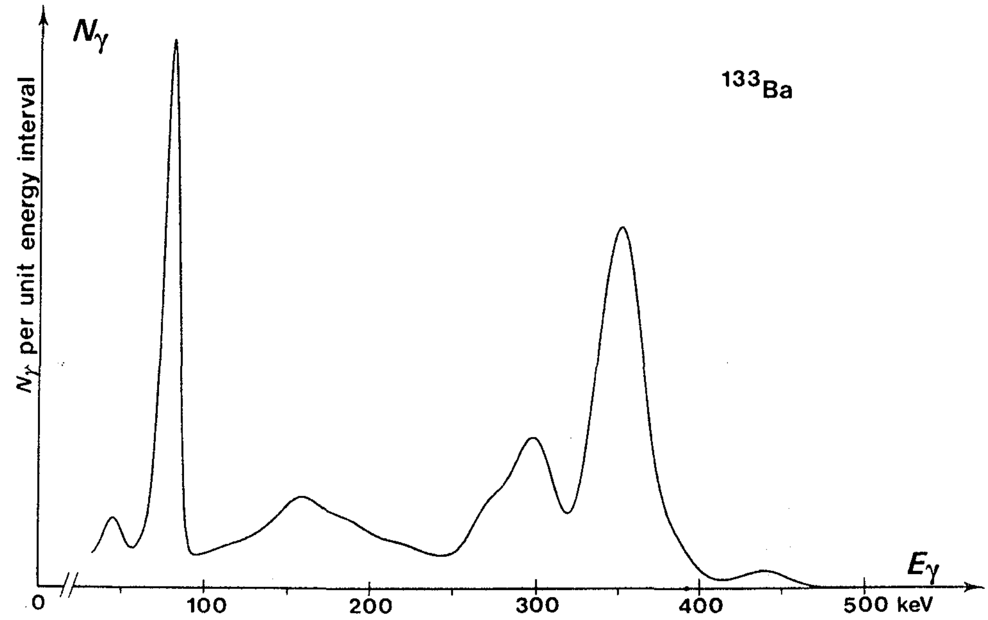


Fig. 5 - Typical γ-ray spectrum observed with the Na(I) detector of the 4π(PC)-γ set of BIPM

However, as pointed out by Nylandstedt-Larsen and Celen [13], the detection efficiency for low-energy electrons may vary in some peculiar manner when N_c/N_γ changes. This problem has recently been treated on a more general basis by Funck and Nylandstedt-Larsen [14]. A way to circumvent this difficulty may be to set a discrimination threshold in the γ channel at about 250 keV, thus avoiding coincidences with low-energy conversion electrons.

As can be seen in table 8, most participants have chosen a γ-ray threshold near to this value. Three have also used a lower threshold and obtained slightly higher activity values (IER, NAC and OMH). Tentative measurements carried out at BIPM with a γ-channel threshold at 100 keV instead of 250 keV led to results higher by about 0.4 %.

Neither the range of efficiency-parameter values nor their highest value reached had any detectable systematic effect on the resulting activity. This seems to indicate that the efficiency functions did not change their shape with the range of the observations. Most participants used first-order polynomials to be fitted to the observed data. The reduced χ^2 values often deviated considerably from unity. On the other hand, the very low values reported by some participants might be due to a different interpretation of this quantity. The participating laboratories had been asked to supply graphs of their efficiency functions and of the residuals of the observed data. A selection of these graphs is presented on fig. 6.

Fig. 6 – A selection of residuals corresponding to reported efficiency extrapolations. The bars of the data points correspond in general to uncertainties estimated from the efficiencies ε_β, ε_γ and from the standard deviation of the mean number of counts.

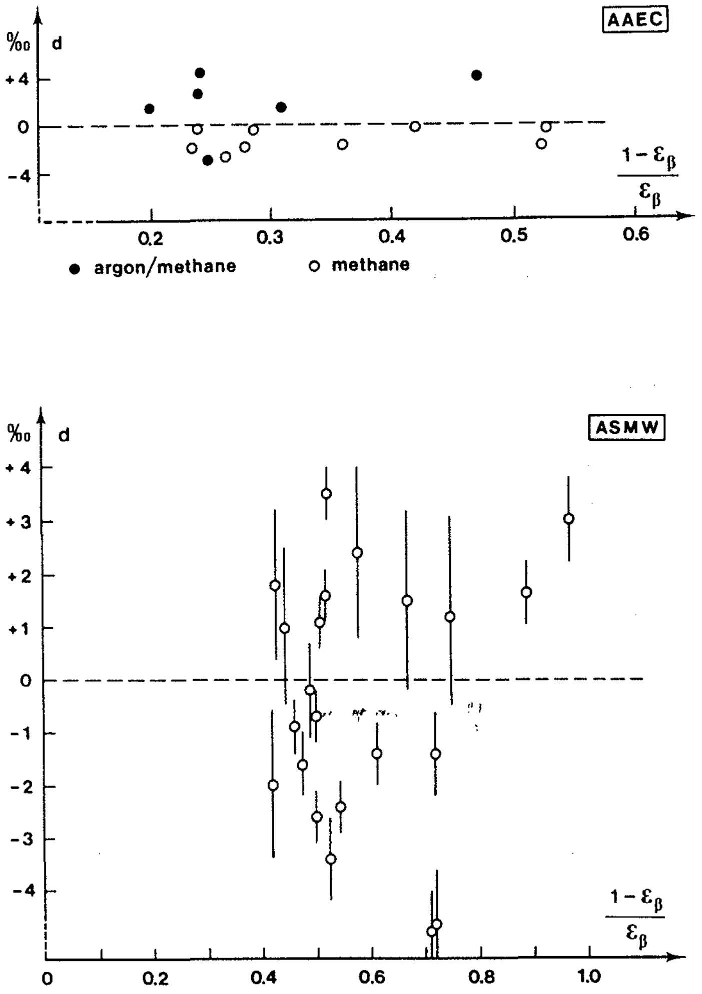


Fig. 6 (cont'd)

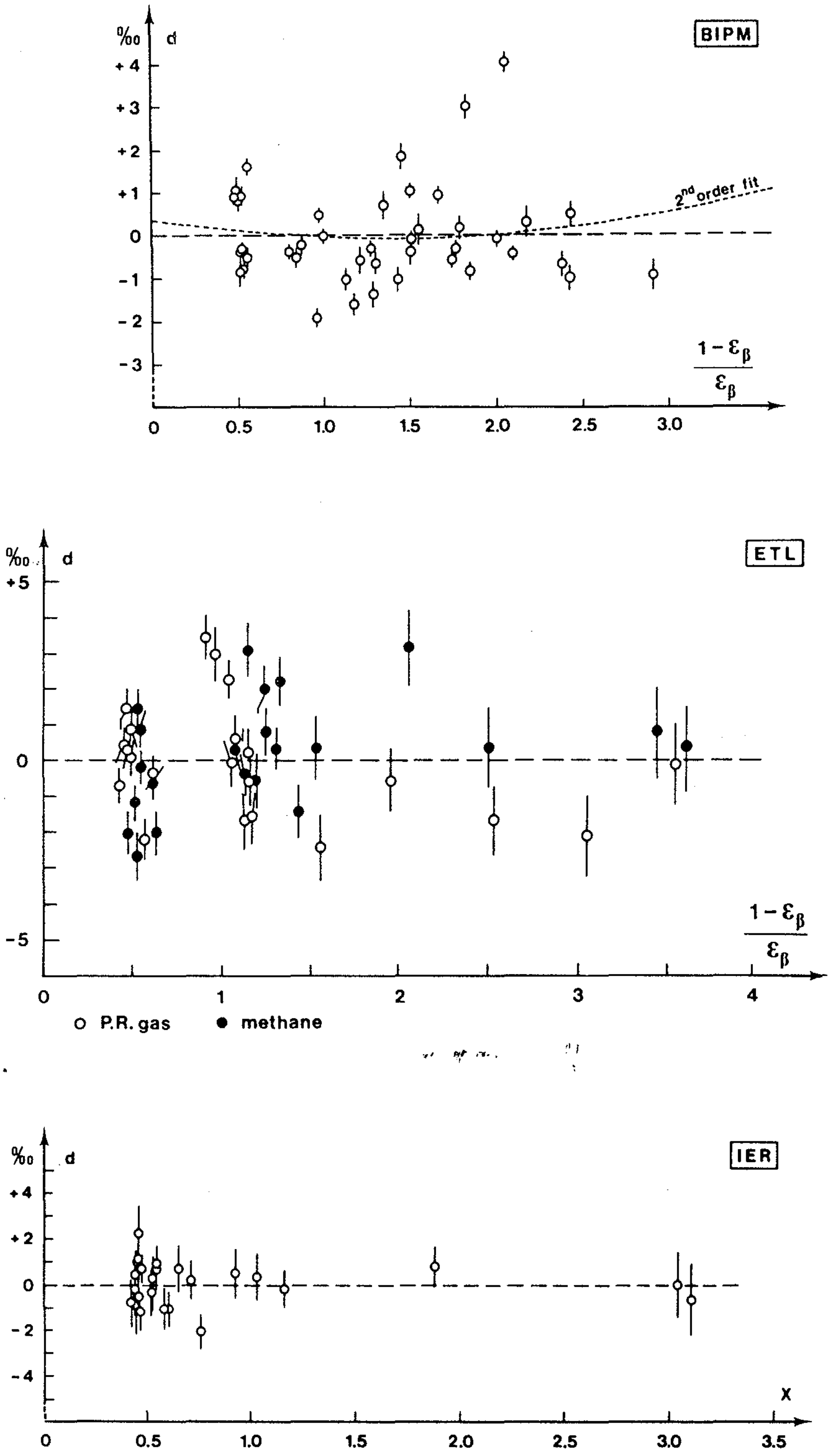
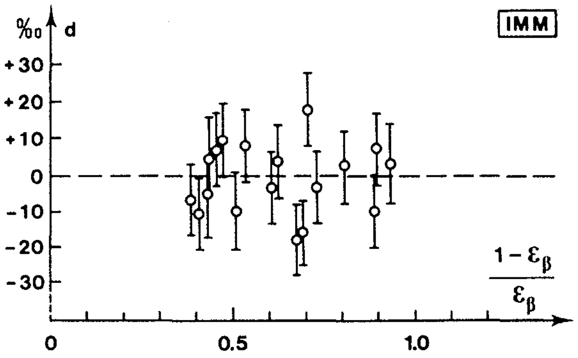
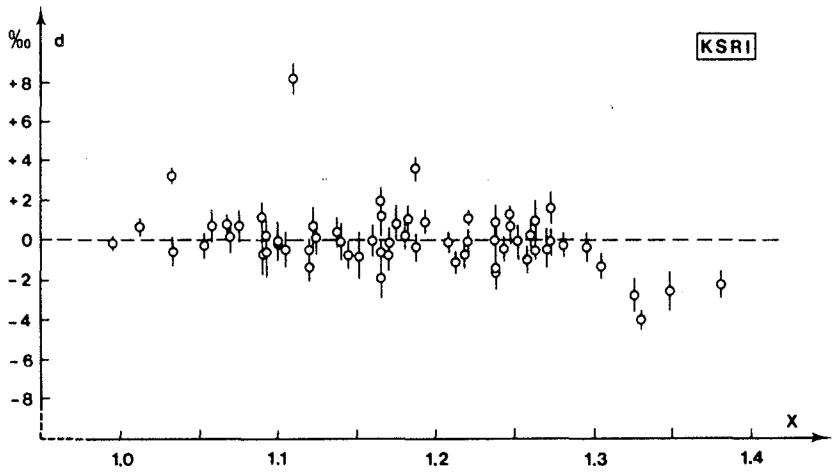

BIPM
‰ d
+4
+3
+2
+1
0
-1
-2
-3
2nd order fit
$\frac{1-\varepsilon_\beta}{\varepsilon_\beta}$
0
0.5
1.0
1.5
2.0
2.5
3.0
ETL
‰ d
+5
0
-5
$\frac{1-\varepsilon_\beta}{\varepsilon_\beta}$
0
1
2
3
4
○ P.R. gas
● methane
IER
‰ d
+4
+2
0
-2
-4
x
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

Fig. 6 (cont'd)


IMM
‰ d
+30
+20
+10
0
-10
-20
-30
$\frac{1-\varepsilon_\beta}{\varepsilon_\beta}$
0
0.5
1.0


KSRI
‰ d
+8
+6
+4
+2
0
-2
-4
-6
-8
X
1.0
1.1
1.2
1.3
1.4

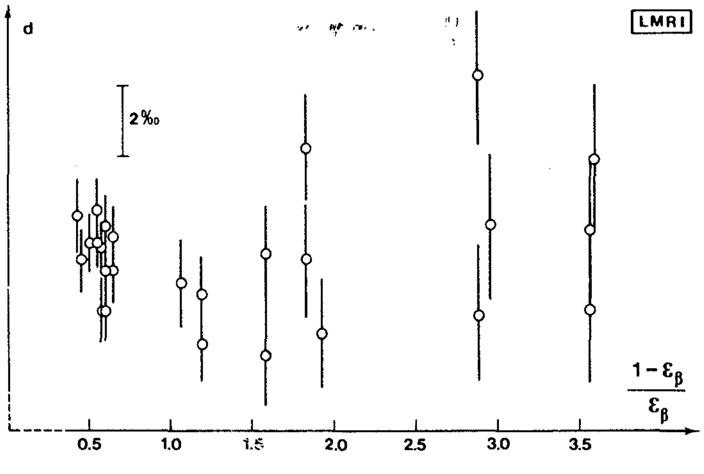
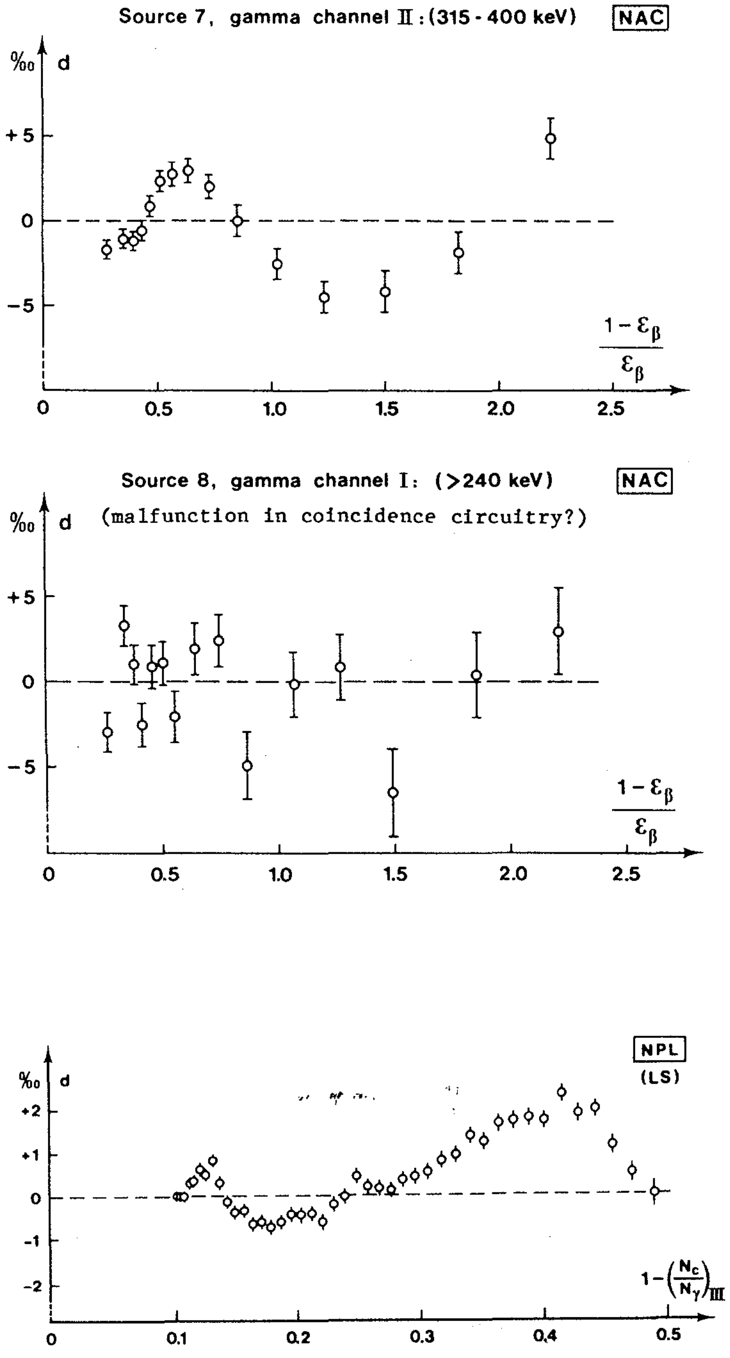

LMRI
d
2‰
$\frac{1-\varepsilon_\beta}{\varepsilon_\beta}$
0.5
1.0
1.5
2.0
2.5
3.0
3.5

Fig. 6 (cont'd)



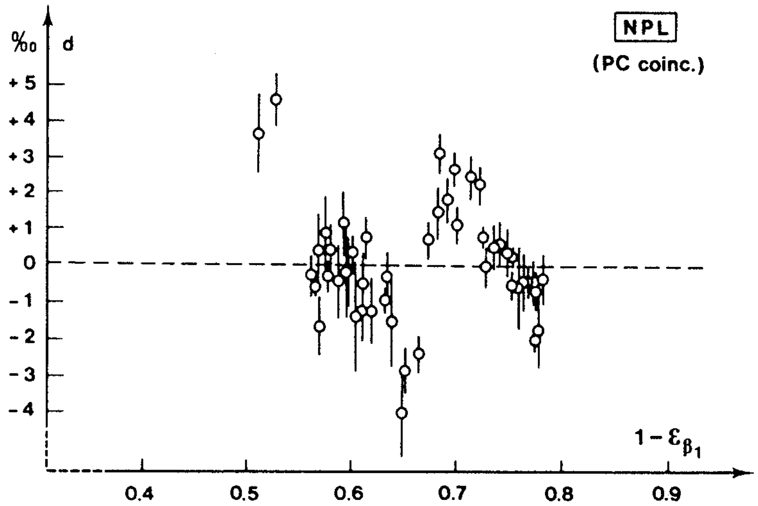
Source 7, gamma channel II: (315 - 400 keV) **NAC**

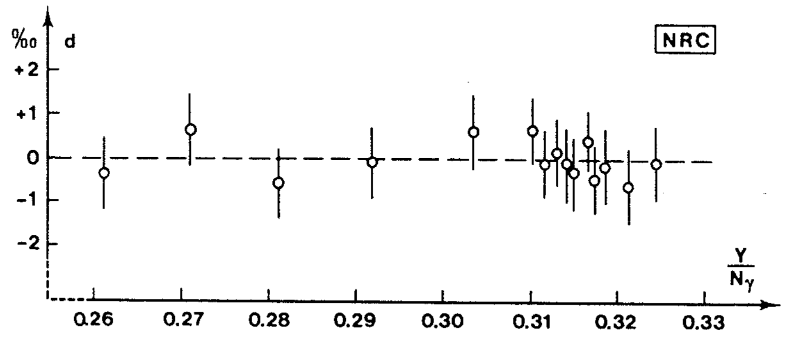
Source 8, gamma channel I: (>240 keV) **NAC**

(malfunction in coincidence circuitry?)

NPL (LS)

Fig. 6 (cont'd)


NPL
(PC coinc.)
‰ d
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
$1-\varepsilon_{\beta_1}$
0.4
0.5
0.6
0.7
0.8
0.9


NRC
‰ d
+2
+1
0
-1
-2
$\frac{Y}{N_\gamma}$
0.26
0.27
0.28
0.29
0.30
0.31
0.32
0.33

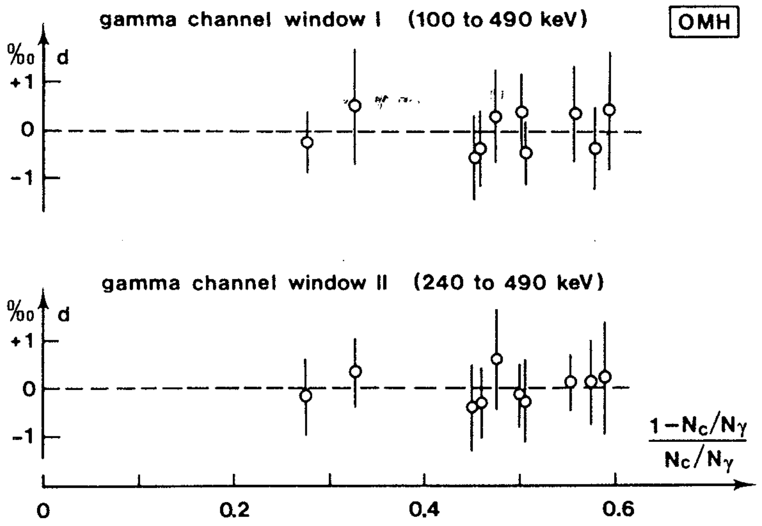
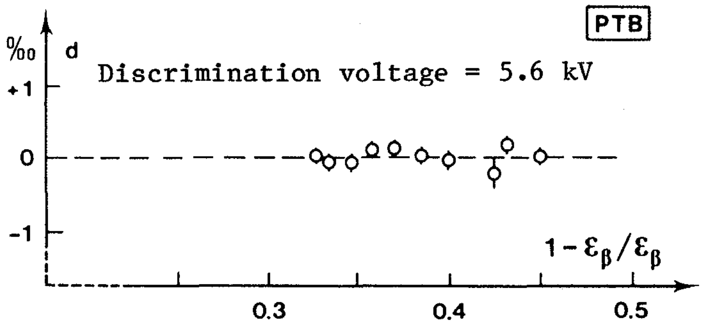
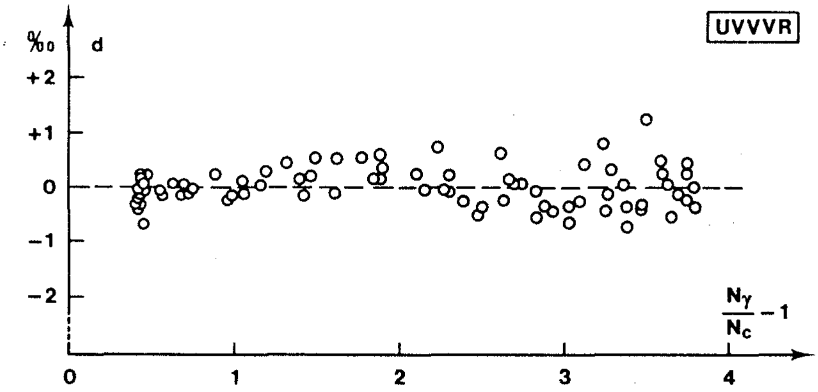

OMH
gamma channel window I (100 to 490 keV)
‰ d
+1
0
-1
gamma channel window II (240 to 490 keV)
‰ d
+1
0
-1
$\frac{1-N_c/N_\gamma}{N_c/N_\gamma}$
0
0.2
0.4
0.6

Fig. 6 (cont'd)


PTB
‰
d
Discrimination voltage = 5.6 kV
+1
0
-1
1 - ε_β/ε_β
0.3
0.4
0.5


UVVVR
‰
d
+2
+1
0
-1
-2
Nγ/Nc - 1
0
1
2
3
4

10. Uncertainties

Following the Recommendation of the Comité International des Poids et Mesures (CIPM) [15] concerning the statement of uncertainties, the participants were asked to assess values for the uncertainty components according to the published guidelines [16, 17] and to indicate how these values were obtained. The numerical values are presented in table 9. It must be admitted that such an analysis is incomplete without the statement of interdependences between the different uncertainty components. However, although the existence of such links is quite obvious, as for instance between "counting statistics" and "fitting procedure", it would most often be very difficult, if not impossible, to obtain reliable values for the corresponding covariances. For this reason they had not been asked for.

Each participant used his own way of determining the values of the uncertainty components. Many of these procedures have been explained briefly in a preceding report [5] and will not be repeated here. There are, however, several remarks that are specific to the present comparison. They were made in connection with other uncertainty components than those listed and are of sufficient interest to be reproduced at the bottom of table 9.

11. Final results

Nineteen laboratories have reported 22 different results (see table 10). The six different methods applied are distributed as follows.

4π(PC)-γ	coincidence	13 laboratories
4π(PPC)-γ	coincidence	5 laboratories
4π(PPC)-γ	anti-coincidence	1 laboratory
4π(LS)-γ	coincidence	2 laboratories
4π(PC)-γ	selective sampling	1 laboratory
4π(NaI)γ	well-type crystal	2 laboratories.

The abbreviations in parentheses have the following signification:

PC = proportional counter
PPC = pressurized proportional counter
LS = liquid-scintillation counter
NaI = large NaI(Tl) well-type crystal.

Table 10 further presents absolute and relative values of the combined uncertainties (associated to one standard deviation) and the relative deviations from the mean activity concentration. This mean value is the arithmetical mean of 19 results, where for LMRI and NPL the respective averages were taken. The use of equal weights seems appropriate, in the present case, and also in the light of a recent paper by Müller [18].

The mean activity per unit mass of the solution used in the present comparison is thus

activity concentration = (1 160.8 ± 4.2) Bq$\cdot$mg^{-1}
at the reference date 1984-03-15, 00 h UT.

The uncertainty is one estimated (external) standard deviation (of an individual measurement).

It may be seen that the 19 results have a range of 1.7 % and a standard deviation of 0.36 %, which both lay between the corresponding figures obtained in the two preceding comparisons.

The SIR [4] offers the possibility to compare results obtained at different places and times, including those from the three recent trial comparisons reported before. On fig. 7 these results are plotted with their respective uncertainties and deviations from the (arithmetical) mean of the 15 SIR results. It will be noted that there are some minor deviations from earlier graphs [19] which are due to additional or corrected results.

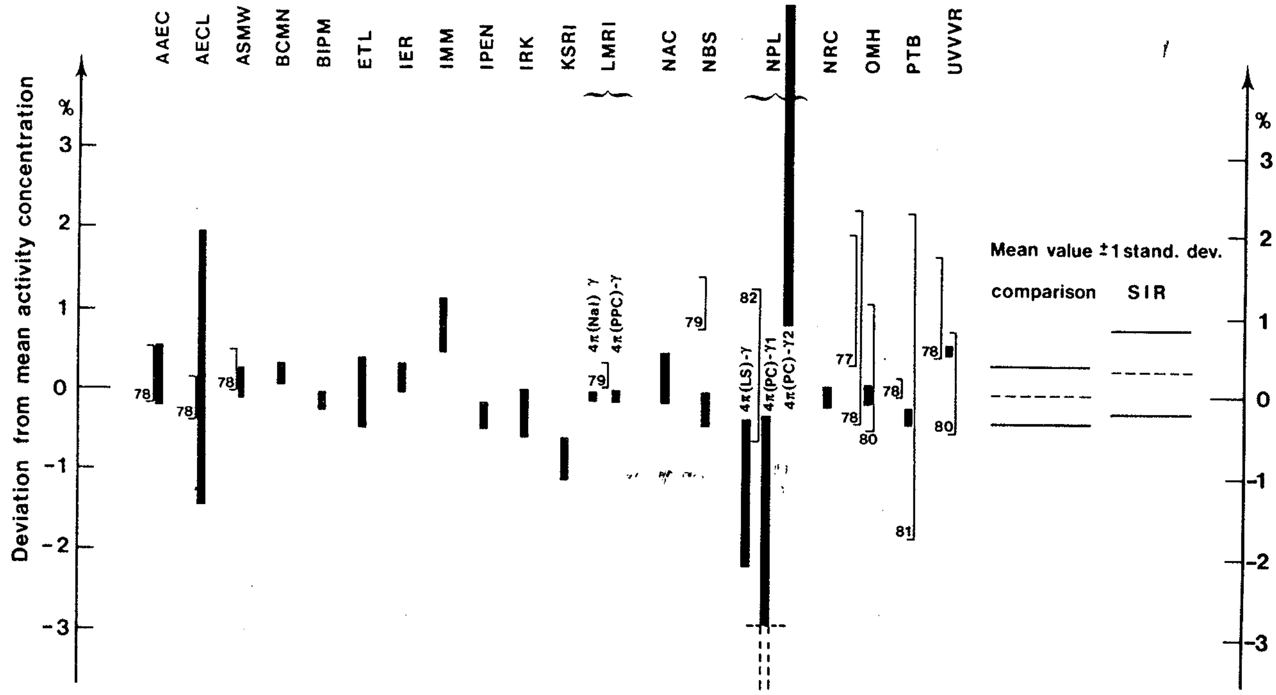


Fig. 7 - Graphical representation of the results and their combined relative uncertainties (one standard deviation). If a participant has also contributed to the SIR, these values are plotted as well, with indication of the year.

12. Conclusion

It has been shown once more how important it is that international comparisons of activity measurements be preceded by trial comparisons, in order to avoid misadventures. In the present case, the initial difficulty seemed to be of a chemical nature and could eventually be eliminated by adding considerably more carrier substance to the solution distributed than is usual in similar cases. Although there is no direct proof, this behaviour might be specific for the element barium and could partly be responsible for the rather large scatter of the results obtained with the SIR.

The range and standard deviation of the results from this comparison have been found to be somewhat larger than corresponding values for nuclides with a complex β-γ decay. Also, there is little doubt that, due to the considerable contribution of low-energy events to the counts in the β channel, coincidence measurements of electron-capturing nuclides are liable to higher uncertainties than those of nuclides emitting β particles alone. Systematic deviations in coincidence counting are likely to occur when low-energy conversion electrons of different energy traverse absorbing material of varying thickness. This effect has been pointed out earlier [13, 14] but is difficult to evaluate with sufficient precision. Therefore, most participants preferred to minimize it by excluding such low-energy events from the coincidence counts setting a high enough threshold energy in the γ channel.

Multiparametric efficiency extrapolation has been used by three participants. While AAEC and NRC did not report any special difficulties, the widely differing and mutually incompatible results obtained by NPL might indicate the existence of a real, yet unsolved, problem in coincidence counting which is to be attributed to the low-energy electrons and seems to pertain to 4π(LS)-γ as well as to 4π(PC)-γ counting.

The rather large spread of source quality, as expressed by the highest efficiency values reached (see table 4), shows that this possibility of improving the measurements has not always been exploited sufficiently. On the other hand, the good agreement of most of the results obtained by several widely differing methods and techniques strengthens our confidence in their validity.

It has been mentioned in the Introduction that the SIR results available in 1979 could be interpreted as forming two groups about 1 % apart. There were indeed four "high" results (from NBS, OMH and UVVVR, see fig. 7) and five "low" ones. However, all the results of later measurements were also "low", and these included values obtained by OMH and UVVVR. In addition, all the low results agree well with the mean value derived from this comparison. Therefore, the previous interpretation cannot be maintained.

Table 1 - List of the participating laboratories

		Names of the persons who carried out the measurements
AAEC	Australian Atomic Energy Commission, Lucas Heights, Australia	H.A. Wyllie, K. Mears
AECL	Atomic Energy of Canada Limited, Chalk River, Canada	R.H. Martin
ASMW	Amt für Standardisierung, Messwesen und Warenprüfung, Berlin, DRG	K. Groche
BCMN	Central Bureau for Nuclear Measurements, Euratom, Geel, Belgium	D. Reher, E. Celen
BIPM	Bureau International des Poids et Mesures, Sèvres, France	P. Bréonce, C. Colas, C. Veyradier
ETL	Electrotechnical Laboratory, Ibaraki, Japan	Y. Hino, Y. Kawada
IER	Institut d'électrochimie et radiochimie de l'EPFL, Lausanne, Switzerland	J.-J. Gostely
IMM	Institut de Métrologie D.I. Mendéléev, Leningrad, USSR	A. Konstantinov, T. Sazonova
IPEN	Instituto de Pesquisas Energêticas e Nucleares, São Paulo, Brazil	M.S. Dias, M.F. Koskinas, E. Pocobi
IRK	Institut für Radiumforschung und Kernphysik, Vienna, Austria	G. Winkler, F. Hernegger
KSRI	Korea Standards Research Institute, Taedǒk Science Town, Republic of Korea	T.S. Park, P.J. Oh, S.T. Hwang
LMRI	Laboratoire de Métrologie des Rayonnements Ionisants, Saclay, France	J. Bouchard, B. Chauvenet, P. Blanchis, M. Foulley, R. Vatin
NAC	National Accelerator Centre, Faure, South Africa	B.R. Meyer
NBS	National Bureau of Standards, Gaithersburg, USA	D. Golas, A.T. Hirshfeld
NPL	National Physical Laboratory, Teddington, UK	D. Smith, C.E. Grant, A. Munster, S. Lucas, M.J. Woods,
NRC	National Research Council of Canada, Ottawa, Canada	D.C. Santry
OMH	Országos Mérésügyi Hivatal, Budapest, Hungary	Á. Szörényi, A. Zsinka, M. Csikós
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig, FRG	E. Funck, K.F. Walz
UVVVR	Institute for research, production and application of radioisotopes, Prague, ČSSR	J. Plch

Table 2 – Selected data concerning the ^{133}Ba decay

(rounded values from [20])

1. Transitions by electron capture

	Energy (keV)	Transition probability (%)	P_K	P_L	P_{MN}
ε_1	83.4	85.9	0.69	0.25	0.06
ε_2	136.6	14.1	0.78	0.18	0.05

2. Emission probabilities

Electrons

Auger	Energy (keV)	Emission probability (%)
e_{A1}	2.6 to 5.7	135
e_{AK}	24 to 36	14
Internal conversion		
ec_{1K}	17	10.7
ec_{2K}	44	4.0
ec_{3K}	45	46.4
ec_{3L}	76	7.3
$ec_{3MN...}$	80	2.2
ec_{8K}	320	1.3
all others		(each) < 1

Photons

	Energy (keV)	Emission probability (%)
X_L	3.8 to 5.7	15
X_K	31 to 36	122
γ_1	53.2	2.2
γ_2	79.6	2.6
γ_3	81.0	34.1
γ_4	160.6	0.64
γ_5	223.2	0.45
γ_6	276.4	7.2
γ_7	302.9	18.3
γ_8	356.0	62.0
γ_9	383.9	8.9

Table 3 – Ionization chamber measurements

	Δ mass*	Activity concentration found		Activity remaining after 2 rinsings	Number of additional rinsings	Final residual activity
		before	after			
		transfer				
	(mg)	(kBq·g^{-1})		(Bq)		(Bq)
AAEC	–	1 133.6	1 134.3	472 ± 50	2	502 ± 50
AECL	– 1,98	1 158.1	1 158.0	5 869 (2 900)**	2 + 1 (2)	3 528 (2 900)
ASMW	–	1 208	1 162 ± 14	< 5 000	–	< 5 000
BCMN	–	–	–	– (2 300)	– (2)	– (1 000)
BIPM	– 6.83	1 163.9 ±1.3	1 163.8	49 ± 66 $\left(\begin{smallmatrix}706\\676\end{smallmatrix} \pm 30\right)$	– (5)	– $\left(\begin{smallmatrix}656\\357\end{smallmatrix}\right)$
ETL	–	–	–	1 300	10	≈ 0
IER	–	–	–	< 270	–	< 270
IMM	–	–	–	–	–	–
IPEN	–	–	–	2 670	3	1 750
IRK	–	–	–	45	2	28
KSRI	–	–	–	–	–	–
LMRI	+ 0.10	1 157	1 158	630 (1 200)	1 (3)	400 (520)
NAC	–	–	–	240	3	140
NBS	–	1 166.5	–	no detectable change		
NPL	–	1 160.7 (based on 1982 meas.)	1 163.6	–	–	–
NRC	–	–	–	137	–	137
OMH	– 7.92	1 162.2	1 163.8	33 ± 5 (38)	3 (1)	15 ± 3 (39)
PTB	+ 0.12	1 162.7	1 160.4	41 (34)	2 (2)	16 (11)
UVVVR	–	–	–	22.1 ± 5	2	10.0

* Δ mass is the difference between the solution mass measured by the participant and the nominal mass.

** In parentheses are the results obtained by the six laboratories participating in the second trial comparison.

Table 4 - Source preparation for 4π(PC)-γ or 4π(PPC)-γ counting

Laboratory	How many dilutions? (0 = no dil.)	Source backing			1. Wetting agent 2. Special treatment 3. Drying	1. Range of source mass (mg) 2. Highest value of N_c/N_γ (%)
		1. Nature 2. Metal coating	3. How many layers of metal? above, below 4. Number of films per source	5. Was solution dispensed onto metal layer? 6. Total mass per cm^2 (μg·cm^{-2})		
AAEC	3	1. VYNS or Mylar 2. Au-Pd	3. a) 1 b) 0 or 1 4. 1 or 2 or 4	5. yes and no 6. 35 or 85 or 125 or 1 050	1. el.-sprayed ion-exch. resin or Catanac 2. -, 3. oven at 50 °C	1. 12 to 31 2. 83.3
AECL	1	1. VYNS 2. Au-Pd	3. a) 0 b) 1 or 2 4. 1 or 2	5. no 6. ⩾ 15	1. Catanac SN, Ludox 3. Covered box 45 °C with dry air purge	1. 15 to 60 (undiluted) 19 to 58 (diluted) 2. 70
ASMW	0	1. VYNS 2. Au-Pd	3. a) 1 b) 0 4. 1	5. yes 6. 25	1. Insulin 100 μg·cm^{-3} in 0.01 n CH_3COOH 2. -, 3. in air	1. 15 to 19 2. 70
BCMN	0	1. VYNS 2. Au/Al	3. a) 1 b) 1 4. 9	5. yes 6. 1 000	1. Ludox 2. -, 3. air stream	1. 11 to 19 2. 65
BIPM	0	1. VYNS 2. Au	3. a) 1 b) 1 4. 2	5. no 6. 100	1. Ludox SM 10^{-4} 2. -, 3. ambient air, under cover	1. 8 to 37 2. 67.4
ETL	0	1. VYNS 2. Au	3. a) 1 b) 1 4. 1	5. yes 6. 45	1. Ludox SM 30 2. -, 3. in a dessicator with silicagel	1. 9 to 16 2. 68
IER	0	1. VYNS 2. Au	3. a) 1 b) 1 4. 1	5. yes 6. 50	1. Ludox SM 10^{-4}, 1 drop 2. -, 3. dry air, at room temperature	1. 12 to 44 2. 70.2
IMM	0	1. x-ray film 2. Au	3. a) 1 b) 1 4. 1	5. yes 6. 30	1. Insulin + Catanac 2. NH_3 atmosphere 3. Infrared lamp	1. 5 to 15 2. 72

Table 4 (cont'd)

Laboratory	How many dilutions? (0 = no dil.)	Source backing			1. Wetting agent 2. Special treatment 3. Drying	1. Range of source mass (mg) 2. Highest value of N_c/N_γ (%)
		1. Nature 2. Metal coating	3. How many layers of metal? above, below 4. Number of films per source	5. Was solution dispensed onto metal layer? 6. Total mass per cm^2 ($\mu g \cdot cm^{-2}$)		
IPEN	4	1. Collodion 2. Au	3. a) 0 b) 1 4. 1	5. yes 6. 30	1. Cyastat SN 2. –, 3. warm N_2 jet	1. 27 to 38 2. 79
KSRI	0	1. Collodion 2. Au	3. a) 0 b) 1 4. 2	5. yes 6. 30	1. Ludox SM 15 10^{-4} 2. –, 3. air	1. 15 to 19 2. 70
LMRI	0	1. Cellulose 2. Au	3. a) 1 b) 1 4. 1	5. yes 6. 30	1. Insulin 2. –, 3. free air	1. 18 to 52 2. 69.1
NBS	1	1. Collodion 2. Au	3. a) 0 b) 1 4. 2	5. yes 6. 30	1. Ludox 2. –, 3. air drying	1. 12 to 46 2. 80
NPL	1	1. VYNS 2. Au	3. a) 1 b) 1 4. 1	5. yes 6. 30	1. Catanac 50 µg/g 2. –, 3. evaporation	1. 55 to 62 2. 48 to 85, according to γ gate
NRC	1	1. VYNS 2. Au-Pd	3. a) 1 b) 1 4. 1	5. yes 6. 40	1. Catanac SN 2. –, 3. air stream, 40 °C	1. 11 to 24 2. 74
OMH	0	1. VYNS 2. Au-Pd	3. a) 1 b) 1 4. 1	5. yes 6. 30	1. Ludox + Teepol 2. Infrared lamp	1. 10 to 36 2. 79
PTB	0	1. VYNS 2. Au-Pd	3. a) 1 b) 1 4. 1	5. yes 6. 50	1. pads of ion-exch. resin 2. air	1. 10 to 14 2. 74
UVVVR	2	1. VYNS 2. Au	3. a) 1 b) 1 4. 3	5. yes 6. 40 to 50	1. Ludox + Aquadak 2. –, 3. air	1. 12 to 60 2. 70

Table 5 - Detectors used by those laboratories which did not participate in the ^{137}Cs comparison [6]

Laboratory	Wall material	Height of each half (mm)	Anode of the 4π proportional counter 1. Nature 2. Wire diam. (μm) 3. " length (mm) 4. Distance from the source (mm) 5. Voltage applied (kV)	Gas 1. Nature 2. Pressure (MPa) 3. Discrimination level (keV)	Gamma-ray detector 1. Number of NaI crystals 2. Diameter / height (mm) 3. Year of purchase 4. Resolution at 662 keV (%)
ASMW	Al	21	1. Mo + Au 2. 40 3. 55 4. 10 5. 4.3	1. C_3H_8 2. 0.1 3. 2	1. One ordinary 2. 102 / 76 3. 1967 4. 8.3
IMM	Al	20	1. W 2. 30 3. 90 4. 15 5. 2.3	1. Ar/CH_4 2. 0.1 3. 0.1	1. One ordinary 2. 40 / 25 3. 1982 4. 6.5
IPEN	Brass	22.5	1. Stainless steel 302 SS 2. 50 3. 120 4. 13 5. 2.05	1. Ar/CH_4 2. 0.1 3. 0.91	1. Two ordinary ones 2. 76 / 76 3. - 4. 8.1/9.2
KSRI	Al 6061	28.3	1. Stainless steel 2. 51 3. 53 4. 14 5. 6.25	1. Ar/CH_4 2. 1.31 3. 5 to 12	1. Two ordinary ones 2. 76 / 76 3. 1980 4. 6.4

Table 6 – Source preparation and equipment for liquid-scintillation counting

Laboratory	Volume and composition of the scintillator "cocktail"	1. Material + volume of counting vial 2. Nb. of sources used 3. Mass range of added acting solvent	LS detector system 1. Phototubes (nb. and type) 2. Spurious pulses	γ-ray detector 1. NaI crystals, dimensions, year of purchase 2. Phototube 3. Resolution at 662 keV	Remarks
NAC	12 cm^3, Instagel (Packard), with 280 mg/dm^3 $BaCl_2$ + 12 mg/dm^3 3M HCl	1. Glass, 20 cm^3 2. 10 3. 24 to 42 mg	1. Two RCA 8850 in coincidence 2. 0.40 %, measured and corrected for	1. One ordinary 76 x 76 mm (1970) 2. 9531 KA (integral assembly) 3. 9.5 %	Adsorption test, 24 d after preparation showed 1.3 % of activity left behind in vial, after only decanting the solution.
NPL	7 cm^3, 6.3 cm^3 Unisolve 294 (Koch Light Ltd) + 0.7 cm^3 saturated $Pb(NO_3)_2$ solution + 30 mg carrier ($BaCl_2$ in 0.1 molar HCl)	1. Glass, 10 cm^3 2. 12 3. 10 to 23 mg	1. One RCA 31000 D (development tube of RCA 8850) 2. 0.05 %, checked by correlation counting	1. One, well type 100 x 100 mm (≈ 1960) well diam. 25, 40 mm deep 2. Type? 3. 9.8 %	$Pb(NO_3)_2$ is used as a high-Z additive, which increases the efficiency of detection of ec events (x rays) considerably. - Modified Campion formula (since no analogue to the Cox-Isham formula is known for computer-discrimination method).

Table 7 – Coincidence and anti-coincidence counting; details of electronic circuits

Laboratory	Methods used	Dead times τ_β (µs)	τ_γ (µs)	Coinc. resolv. time 1) (µs)	Gandy effect Delay mismatch 1) (µs)	Effect on final result (%)	Discrimination mode cf = constant fraction le = leading edge zc = zero cross over	Coincidence formula used
AAEC	4π(PC)–γ M	9.13 (8)	18.6 (1)	1.090 (6)	0.00 (1)	0	le	C
AECL	4π(PC)–γ	1.92 (3)	2.02 (3)	0.734 (3)	⩽ 0.09 (1)	0	zc	B + corr.
ASMW	4π(PC)–γ	3.908 (18)	3.922 (18)	0.979 (5)	0.10 (5)	0 2)	le	S
BCMN	4π(PC)–γ	5.97 (2)	6.53 (2)	1.35 (8)	0.00 (8)	0	cf	CI–S
BIPM	4π(PC)–γ SESAM 3)	6.000 (2) 6.000 (2) 4)	6.000 (2) 6.000 (2)	1.06 (1) –	0.00 (1) –	0 –	zc zc	CI–S –
ETL	4π(PC)–γ	4.35 (5)	2.11 (5)	0.836 (3)	0.00 (5)	0	le	C
IER	4π(PC)–γ	3.201 (1)	3.196 (1)	1.075 (2)	0.000 (1)	0	zc	CI–S
IMM	4π(PC)–γ	2.5 (3)	2.5 (3)	1.01 (2)	0.50 (5)	0.01	le	C
IPEN	4π(PC)–γ	3.24 (1)	3.19 (1)	0.926 (6)	–	–	zc	B
KSRI	4π(PPC)–γ	3.15 (2)	3.15 (2)	1.01 (2)	–	–	le	5) [23]
LMRI	4π(NaI)γ 4π(PC)–γ	–	–	see [21]	0.050 (5)	0.005	zc	see [21]
NAC	4π(LS)–γ	1.119 (30) 1.405 (50)	0.981 (17)	0.499 (1) 0.512 (1)	–	–	cf	6)
NBS	4π(PPC)–γ AC	4.3	10.0 (2)	–	–	–	zc	–
NPL	4π(LS)–γ M	18.8 (2)	2.3 to 6.0 (20) including out-of-channel events	0.30 (2)	0.000 (5)	0	le	C modified
	4π(PC)–γ M	1.745 (10)	2.338 (500) 2.340 (500) 1.894 (500)	0.594 (5) 0.545 (5) 0.544 (5)	0.00 (1)	0	le	CI–S

Table 7 - (cont'd)

Laboratory	Methods used	Dead time s τ_β (μs)	 τ_γ (μs)	Coinc. resolv. time 1) (μs)	Gandy effect Delay mismatch 1) (μs)	 Effect on final result (%)	Discrimination mode cf = constant fraction le = leading edge zc = zero cross over	Coincidence formula used
NRC	4π(PPC)-γ 4π(PPC)-γ AC M	1.96 (1) 5.06 (5)	1.96 (1) 5.06 (2)	0.958 (5) -	-	-	zc	B Ba
OMH	4π(PPC)-γ	3.053 (5)	3.007 (5) 3.018 (5)	1.030 (10) 1.027 (10)	0.000 (15)	0	cf	CI-S
PTB	4π(PPC)-γ	5.000 (15)	5.000 (15)	1.000 (3)	0.00 (2) automatic delay matching	0	le	CI-S
UVVVR	4π(PC)-γ	8.960 (10)	8.960 (10) 9.000 (15)	0.990 (10) 0.990 (12)	0.000 (19)	-	le	CI + corr.

1) in parentheses: uncertainty in units of the last digit,

2) delays between -0.4 μs to +0.7 μs did not have any measurable effect,

3) selective sampling [22],

4) taking into account the "first" dead time of (1.13 ± 0.01) μs

5) $$\frac{N_c}{N_\gamma} = \frac{N'_c/N'_\gamma\ (b'_c/b'_\gamma)(b''_\gamma/N''_\gamma)(1 - N''_\gamma\tau)/(1 - b''_\gamma\tau)}{1 - (b''_\gamma/N''_\gamma)(1 - N''_\gamma\tau)/(1 - b''_\gamma\tau)} \approx \frac{N'_c/N'_\gamma - b''_\gamma/N''_\gamma}{1 - b''_\gamma/N''_\gamma} \quad \text{(KSRI)},$$

6) $$\frac{N_\beta N_\gamma}{N_c} = \frac{BG}{C}\left[1 + C\tau_d + 2\tau_r\left(\frac{BG}{C} - \frac{B + G}{2}\right)\right] \quad \text{(NAC)},$$

where B, G and C are count rates corrected for background; B was also corrected for spurious pulses.

PC: proportional counter, PPC: pressurized proportional counter, LS: liquid-scintillation counter, AC: anti-coincidence, M: multi-parametric extrapolation [27].

Coincidence formulae used: B Bryant [24], Ba Baerg [23], C Campion [25], CI Cox-Isham [26], S Smith [27].

Table 8 – Coincidence and anti-coincidence counting data

Laboratory	γ-channel setting (keV)	Typical count rates (s^{-1}) a) source b) background β	γ	c	Number of sources measured	data points	degrees of freedom	Range of efficiency parameter, N_c/N_γ (%)	Order of fitted polynomial	Reduced χ^2	Intercept ($Bq \cdot mg^{-1}$, 1σ, 1984-03-15)	Mean time per data point (s)
AAEC	> 200	a) 6 500 b) 1.1	550 26	400 0.05	9	15	13	83.3 to 65.5	1	1.1	1 162.7 ± 4.4	1 000
AECL	250 to 490	29 000 0.55	9 000 8.3	5 500 0.05	14	42	41	70 to 43	1	15.1	1 162.2 ± 1.1	500
	250 to 490	28 000 0.57	8 600 7.3	5 200 0.05	12	46	45	70 to 42	1	23.6	1 159.9 ± 1.4	500
	250 to 490	7 100 0.67	1 300 7.0	900 0.04	1	15	14	69 to 51	1	1.0	1 168.6 ± 1.3	500
ASMW	240 to 470	12 700 3	2 560 6	1 360 0.05	7	45	26	70 to 50	1	4.9	1 163.5 ± 2.0	600
BCMN	> 250	13 000 0.15	2 400 4.5	1 500 0.1	11	14 – 18 per source	12 – 16	65 to 40	1	1.6	1 163 ± 1.4	1 000
BIPM	250	15 000 2.0	2 900 9.2	1 800 1.0	4	37	35	67.4 to 25.5	1	25	1 158.7 ± 0.5	6 000
					4	37	35	selective sampling	1	5.2	1 159.5 ± 0.6	6 000
							34	" "	2	5.2	1 158.0 ± 1.7	6 000
ETL	230 to 470	9 500 2.03	1 850 6.18	1 250 0.07	22	44	42	68 to 17	1	3.65	1 160.8 ± 0.4	1 000
									2	3.70	1 160.4 ± 0.7	1 000
IER	> 240	20 837 1.61	2 556 17.66	1 613 0.29	12	28	25	70.2 to 24.4	2	1.0	1 162.5 ± 0.1	300
	> 114	21 968 1.61	3 734 28.19	2 480 0.25	12	27	24	70.2 to 24.4	2	1.37	1 162.8 ± 1.0	240
IMM	200 to 410	8 700 5	330 9	230 0	5	18	17	72 to 29	1	1.1	1 170 ± 2	4 000
IPEN	220 to 420	1 600 1.0	250 7.2	190 0.02	3	43	40	79 to 46	2	4.97	1 159.9 ± 1.5	4 200

Table 8 – (cont'd)

Laboratory	γ-channel setting	Typical count rates (s^{-1}) a) Source	b) Background		Number of			Range of efficiency parameter, N_c/N_γ	Order of fitted polynomial	Reduced χ^2	Intercept (Bq mg^{-1}, 1σ, 1984-03-15)	Mean time per data point
	(keV)	β	γ	c	sources measured	data points	degrees of freedom	(%)				(s)
KSRI	325 to 415	12 750 0.7	1 850 3.2	1 300 0.01	7	66	8 to 9	70 to 65	1	1.38	1 141 to 1 159	600
IMRI	270 to 500	20 000 1.9	540 8.8	380 0.01	10	33	31	69.1 to 21.8	1	1.4	1 156.4 ± 0.4	1 500
NAC	> 240	27 722 7.8	3 407 9.2	2 676 0.2	10	15	13	79 to 32	1	0.25	1 162.5 ± 1.8	800
	315 to 400	27 061 3.7	2 008 1.1	1 543 0.02	10	15	12	77 to 29	2	0.31	1 159.5 ± 4.9	800
NBS	260 to 395	1 500 1.6 to 3.6	270 3.3	AC 60–90 3.2	4	8 to 17 per source	7 to 16	80 to 31	1	0.0066	1 158.1 ± 2.4	4 000
	260 to 480	1 500 1.6 to 3.6	300 4.3	AC 70–240 4.2	2	11 to 16 per source	10 to 15	78 to 24	1	0.0057	1 158.9 ± 0.3	4 000
NPL	see Appendix to this table											
NRC	250 to 490	7 300 0.45	730 1.1	AC 184 1.1	10	15 per source	12	74 to 67	1	0.51	1 159.1 ± 1.1	1 000
	250 to 490	7 300 0.45	1 400 4.01	C 1 038 0.013	2	15	13	74 to 67	1	0.67	1 160.9 ± 2.2	1 000
OMH	100 to 490	17 800 1.45	3 700 12.7	2 600 0.18	14	14	9	79 to 63	1	0.27	1 161.6 ± 0.3	1 000 to 1 500
	240 to 490	17 800 1.45	2 500 7.16	1 700 0.08	14	14	9	79 to 63	1	0.15	1 159.5 ± 0.3	
PTB	>250	11 800 0.7	1 560 4.0	1 130 0.1	12	> 100	>100	74 to 67	1	0.94	1 157.7 ± 1.2	1 000
UVVVR	>251	6 140 11	1 813 12.9	1 224 0.68	30	120	88	70 to 20	1	0.014	1 171.9 ± 0.9	700
	251 to 518	6 140 11	1 802 5.1	1 221 0.16	30	120	88	70 to 20	1	0.015	1 172.0 ± 0.9	700

Appendix to table 8 - Multiparametric coincidence measurements by NPL [28]

1. 4π(LS)-γ measurements on 12 sources: 45 data points measured during 1 000 s each, 43 degrees of freedom with each γ gate

γ-channel setting gate	(keV)	Typical count rates (s^{-1}) source/background β	γ	c	Range of efficiency parameter, N_c/N_γ (%)	Combination of gates	Order of fitted polynomials	Reduced χ^2	Intercept ($Bq \cdot mg^{-1}$; 1σ, 1984-03-15)
A	55 to 100	2 500	210	134	64 to 24	A alone			poor fit
		7.0	0.73	0.02		B "	1	0.8	1 163.3 ± 2.2
B	120 to 200	2 500	99	84	85 to 49	C "			poor fit
		7.0	0.69	0.02		D "			" "
C	285 to 320	2 500	66	59	90 to 50	E "			" "
		7.0	0.15	0.006		F "			" "
D	350 to 400	2 500	145	110	77 to 25				
		7.0	0.24	0.004		A + E	1 + 1	0.7 to 1.3	1 162.8 ± 1.1
E	130 to 420	2 500	775	660	85 to 40	C + D	1 + 1	1.1 " 1.9	1 134.4 ± 2.0
		7.0	2.60	0.007		A + C	1 + 1	0.8 " 1.5	1 149.0 ± 2.8
F	250 to 420	2 500	620	510	82 to 35	A + C + D	1 + 1 + 1	0.9 " 2.0	1 139.7 ± 2.7
		7.0	1.24	0.04					

2. 4π(PC)-γ measurements: 2 extrapolations using 3 sources from original set and 2 electrodeposited sources, respectively, in order to calculate efficiency functions of the form $y = a_o + a_G[1 - (N_c/N_\gamma)_G] + a_H[1 - (N_c/N_\gamma)_H]$

γ-channel setting Gate	(keV)	Typical count rates (s^{-1}) β	γ	c
G	55 to 105	5 000	700	350
		3	15	0.02
H	280 to 430	5 000	3 000	2 000
		3	7	0.2

Sources number	Sources preparation	Numbers of data points	Numbers of deg. of freedom	γ gates	Efficiency parameter N_c/N_γ range (%)	Efficiency parameter N_c/N_γ method for variation	Reduced χ^2	Intercept ($Bq \cdot mg^{-1}$; 1σ, 1984-03-15)
3	original set	52	47	G H	48 to 21 75 to 38	VYNS + Al foils	7.8	1 133.3 ± 0.4
2	by electro-deposition	56	53	G H	67 to 17 85 to 30	sublimation of NH_4Cl and add. of VYNS + Al foils	16.4	1 193.8 ± 1.0

Table 9 - Uncertainty components of the final results (in %)

Component due to	AAEC	AECL	ASMW	BCMN	BIPM	ETL	IER	IMM	IPEN	KSRI	IMRI	NAC	NBS	NPL		NRC	OMH	PTB	UVVVR
														LS	PC				
counting statistics	0.2	0.06	0.07	(0.2)	0.033	0.2	0.10	0.1	0.05	0.22	–	0.068	0.07	0.06	0.06	0.041	0.019	0.02	0.041
weighing	0.1	0.03	0.11	0.09	0.050	0.1	0.06	0.1	0.05	0.03	0.02	0.033	0.1	0.06	0.028	0.050	0.005	0.02	0.028
dead time	0.2	0.02	0.01	0.05	0.001	0.05	0.05	0.01	0.0001	0.02	0.001	0.040	0.02	0.05	0.04	–	0.005	0.014	0.0040
resolving time	0.05	0.01	0.01	0.05	0.030	0.02	0.001	0.01	0.002	0.02	–	0.005	–	0.01	0.03	–	0.010	0.009	0.0060
delay mismatch	0.04	0.02	–	0.06	0.020	0.05	–	0.01	–	–	0.005	–	–	0.002	0.03	–	0.020	0.02	0.0083
pile-up	–	0.10	–	–	0.001	0.02	–	0.01	–	–	–	–	–	0.02	–	–	–	–	–
background	0.2	0.01	0.045	0.01	0.002	0.02	0.02	0.2	0.04	0.01	–	0.004	0.1	0.10	0.03	0.009	0.005	–	0.0073
timing	0.01	0.01	0.002	–	0.001	0.02	0.002	0.001	–	0.0005	0.003	–	0.004	0.003	–	0.010	0.005	–	0.007
fitting procedure	0.1	1.66	0.13	0.05	0.042	0.2	0.12	0.2	0.13	0.13	0.039	0.092	0.13	0.9	2.1	0.036	0.120	–	0.038
adsorption	0.01	0.04	–	≤ 0.02	0.002	0.05	0.001	–	0.04	–	–	–	0.05	0.05	0.08	0.010	0.001	0.001	–
impurities	0.001	0.01	–	–	–	0.1	–	–	–	0.001	–	0.001	0.001	0.001	0.003	–	0.003	–	–
others*	–	0.01	–	–	0.080	0.3	–	–	–	0.0015	0.05	0.296	0.01	0.037	–	0.080	0.003	–	0.015
Combined uncertainty	0.38	1.67	0.19	0.14	0.114	0.45	0.18	0.32	0.16	0.26	0.067	0.32	0.21	0.91	2.1	0.110	0.124	0.038	0.066

* the specifications for "others" are given hereafter:

Laboratory	uncertainty (%)	due to
AECL	0.01	uncertainty of half life
BIPM	0.08	low-energy electrons
ETL	0.3	inadequate γ-window setting
KSRI	0.001 5	decay correction
LMRI	0.051	detection efficiency
	0.010	extrapolation to zero threshold
	0.006	decay
NAC	0.100	spurious pulses
	0.279	2/3 of difference between results obtained with different γ-channel settings
NBS	0.01	uncertainty of half life
NPL (LS)	0.03	dilution
	0.02	adsorption on counting vessel
	0.01	coincidence formula
NRC	0.08	evaporation and dilution of original solution
OMH	0.003	uncertainty of half life
UVVVR	0.015	correction for improper function of timing

Table 10 - Final results with combined uncertainties

Laboratory	Activity concentration ($Bq \cdot mg^{-1}$, on ref. date: 1984-03-15, 00 h UT)	How was it obtained from the results in table 8 ?	Combined uncertainty (one stand.deviation) ($Bq \cdot mg^{-1}$)	(%)	Deviation from mean (%)
AAEC	1 162.7		4.4	0.38	+ 0.17
AECL	1 163.7	Weighted mean	19.4	1.7	+ 0.25
ASMW	1 161.7		2.2	0.19	+ 0.08
BCMN	1 163.1		1.6	0.14	+ 0.20
BIPM	1 159.0	Weighted mean of first order fits	1.3	0.11	- 0.15
ETL	1 160.6		5.2	0.45	- 0.01
IER	1 162.7	Arithmetical mean	2.1	0.18	+ 0.17
IMM	1 170		4	0.34	+ 0.83
IPEN	1 157.3	Weighted mean of 55 sources from 4 dilutions, corrected according to efficiency functions	1.9	0.16	- 0.30
IRK	1 157.5		3.5	0.30	- 0.28
KSRI	1 151.0	Weighted mean	3.0	0.26	- 0.84
LMRI	4π(NaI)γ 1 160.1		0.7	0.06	- 0.06
	4π(PPC)-γ 1 160.1		0.8	0.07	- 0.06
NAC	1 162.8	Average of 10 first order fits	3.7	0.32	+ 0.18
NBS	1 158.4	Unweighted mean of 6 intercepts	2.5	0.21	- 0.20
NPL	4π(LS)-γ 1 146.3	Arithmetical mean of the 4 multiparametric extrapolations	10.4	0.91	- 1.24
	4π(PC)-γ1 1 133	Efficiency functions were used to correct the measurements on eight sources	24	2.1	- 2.39
	4π(PC)-γ2 1 194		24	2.0	+ 2.86
NRC	1 159.9	Weighted mean of all anti-coincidence measurements	1.3	0.11	- 0.07
OMH	1 160.6	Weighted mean	1.4	0.12	- 0.01
PTB	1 157.7		1.2	0.10	- 0.26
UVVVR	1 167.4	Arithmetical mean of 8 sets of measurements on 15 sources from each dilution, corrected according to efficiency functions	0.8	0.07	+ 0.57

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