

Trial comparison of activity measurements
of a solution of ^{125}I

Final report

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Abstract

Activity measurements of a ^{125}I solution, supplied by OMH, have been carried out as a trial intercomparison by seven laboratories. Four different methods were used. Details on source preparation, detectors and counting data are reported. The measured activity-concentration values (based on seven results) show a spread of 1.6 % and a standard deviation of the mean of 0.18 %. The weighted mean value is $(2\ 052 \pm 4)$ kBq g $^{-1}$.

1. Introduction

Because of its practical importance in medicine and - as a result of its low gamma-ray energy - of the difficulties encountered for its measurement in the SIR system by an ionization chamber, the Working Group for advising on future comparisons selected ^{125}I as a suitable nuclide for one of its trial intercomparisons, as they are periodically organized by BIPM on behalf of the Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants (CCEMRI).

Confirming its offer made at the 1985 meeting of Section II of CCEMRI, OMH kindly supplied, prepared and forwarded the amount of ^{125}I necessary for the comparison.

The ampoules were dispatched from OMH on February 19, 1987. Each participant (Table 1) received a flame-sealed NBS-type ampoule containing about 3.6 g of the undiluted solution.

Table 1 - List of participants

AECL	Atomic Energy of Canada Limited, Chalk River, Canada
BIPM	Bureau International des Poids et Mesures, Sèvres, France
CBNM	Central Bureau for Nuclear Measurements, Euratom, Geel, Belgium
IER	Institut d'Electrochimie et Radiochimie, EPFL, Lausanne, Suisse
LMRI	Laboratoire de Métrologie des Rayonnements Ionisants, Saclay, France
OMH	Országos Mérésügyi Hivatal, Budapest, Hungary
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig, Federal Republic of Germany

The ^{125}I activity concentration was about 2.1 MBq g $^{-1}$ in an aqueous solution of NaOH (5×10^{-4} mol/l), with 50 μg I as KI and 50 μg Na $_2\text{S}_2\text{O}_3$ per gram of solution.

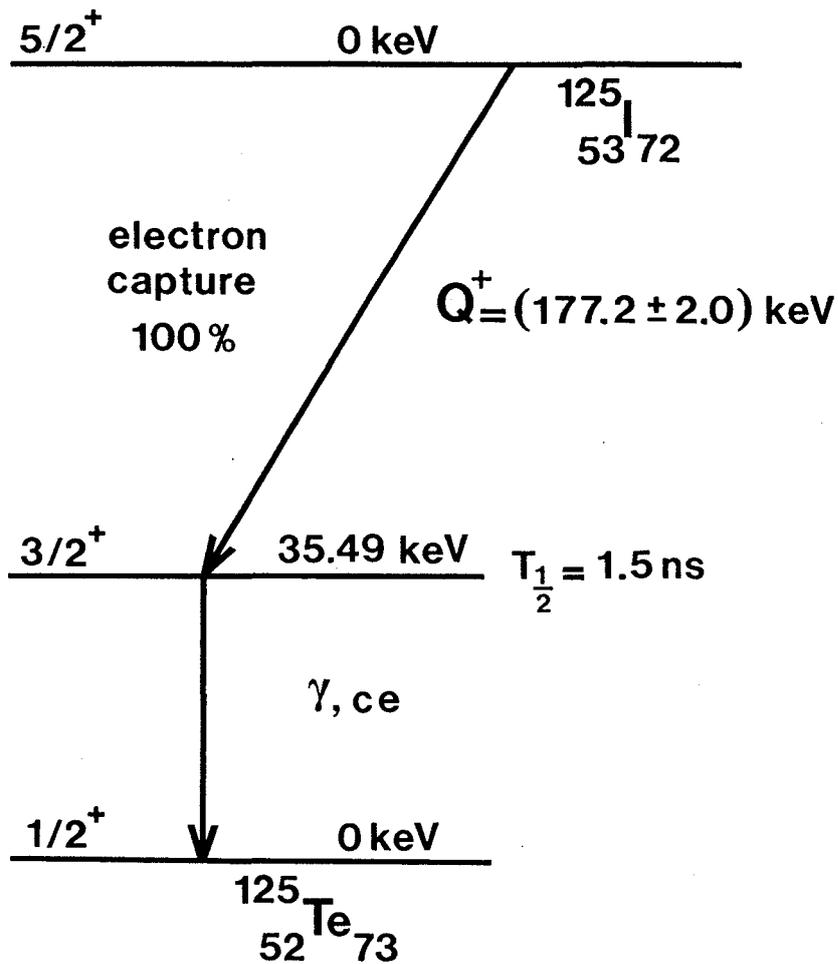


Fig. 1 - Decay scheme of ^{125}I taken from [3].
For the half life see text below.

Purity checks, performed by OMH, revealed $(0.0020 \pm 0.0004) \%$ of ^{126}I as impurity. The detection limits over the 100 to 2500 keV energy range varied between 0.01 and 0.00005%. For the half life the value $(59.89 \pm 0.15) \text{ d}$ [1] was proposed. PTB used its own value of $(59.39 \pm 0.02) \text{ d}$ [2]; OMH measured a half life of $(59.38 \pm 0.05) \text{ d}$ and CBNM used a value of $(59.9 \pm 0.11) \text{ d}$ [3]. Figure 1 shows the decay scheme of ^{125}I .

A reporting form had been set up and was distributed by BIPM on January 20, 1987. The deadline for submitting the results to BIPM was May 1st, 1987. Actually, six results reached BIPM between May 6 and 22, 1987 and were discussed in the draft report; one result arrived too late to be included.

2. Mass of solution contained in the ampoules, activity concentration from ionization-chamber measurements and adsorption tests

Some participants measured the activity concentration of the ^{125}I solution by means of a calibrated ionization chamber. The mass of the solution in the vials was also determined and adsorption tests were carried out. All information concerning this subject is assembled in Table 2.

3. Source preparation

The technical data referring to source preparation are collected in Table 3.

All laboratories used a diluted solution, except PTB (and IER for some series of measurements). AECL prepared sources by gravimetric dispensing of active solution into a AgNO_3 solution on the adhesive side of a 6.3 mg cm^{-2} mylar tape. Some sources were also sandwiched between strips of the same mylar tape in tests made to investigate electron-range effects. Finally CBNM, IER and PTB used AgNO_3 for the preparation of their sources.

4. Activity measurements

In order to measure the activity concentration of the ^{125}I solution, four different methods have been applied. The first one makes use of a single NaI(Tl) crystal - a well type in the case of CBNM, LMRI and OMH - which detects single or coincident events, as described in reference [4]. Four laboratories used this technique (AECL, BIPM, LMRI and OMH). The second method, developed by Taylor [5], has been applied by two laboratories (AECL and IER). This method makes use of two NaI(Tl) detectors and measures X-(X+ γ) coincidences. Some typical spectra are reproduced in Fig. 2. For the third method, AECL applied 4π -X coincidence efficiency extrapolation, using a gas-flow proportional counter at normal pressure and two NaI crystals. The results are shown in Fig. 3. This method was also chosen for determining the ^{109}Cd activity concentration [6]. PTB developed a new photon-photon coincidence-counting and efficiency-extrapolation method [7]. Two thin NaI(Tl) detectors were used.

Details on the counting equipment are given in Table 4. The counting data are listed in Table 5. Table 6 summarizes the formulae used by the participating laboratories.

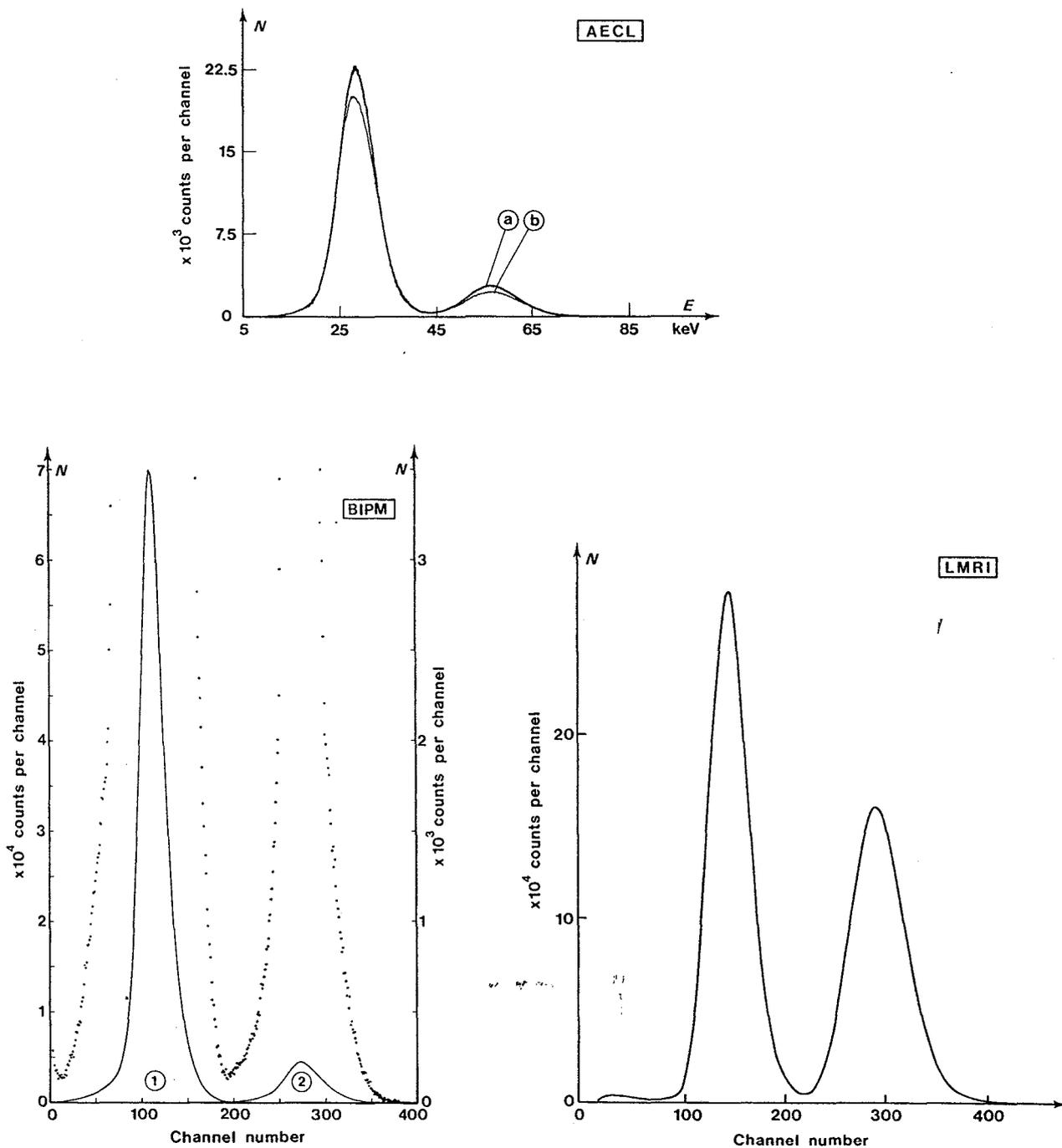


Fig. 2.1 - Some typical spectra of ^{125}I obtained by means of the sum-peak method [4]. In the case of AECL, (a) refers to the sum-peak method and (b) to the other two methods. For BIPM, (1) and (2) indicate the singles peak A_1 and the sum peak A_2 , respectively, as defined in ref. [4].

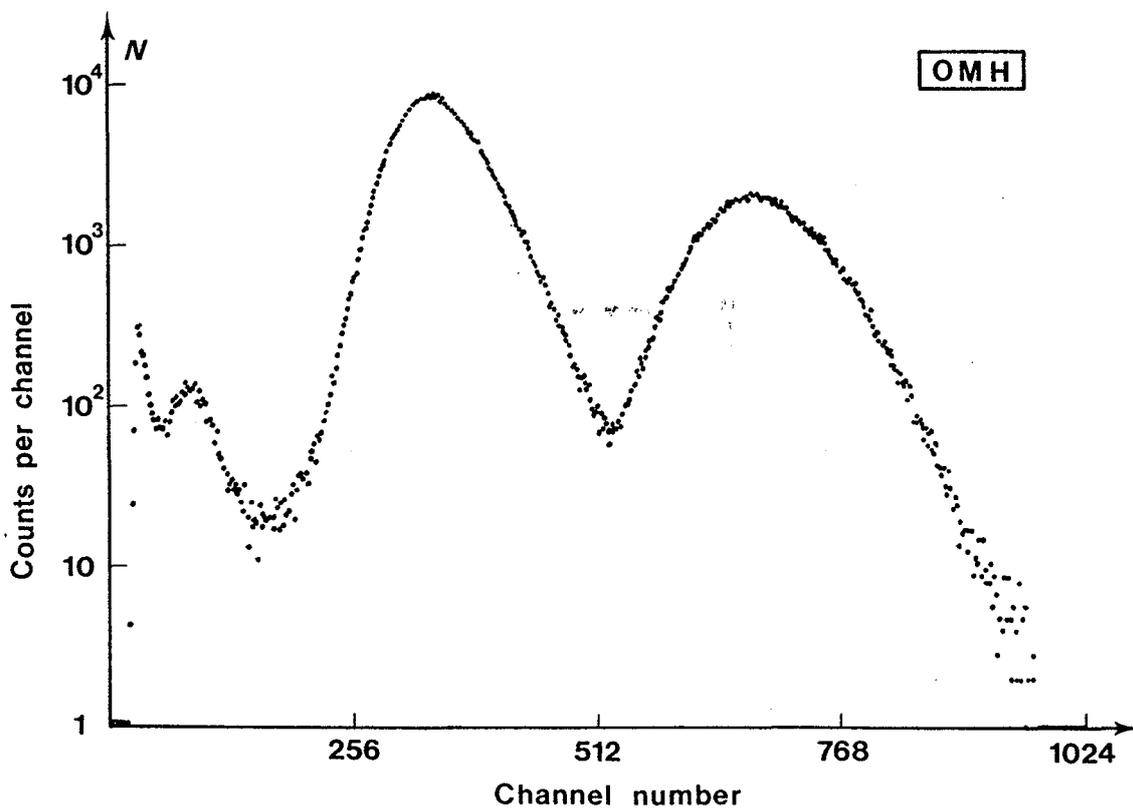
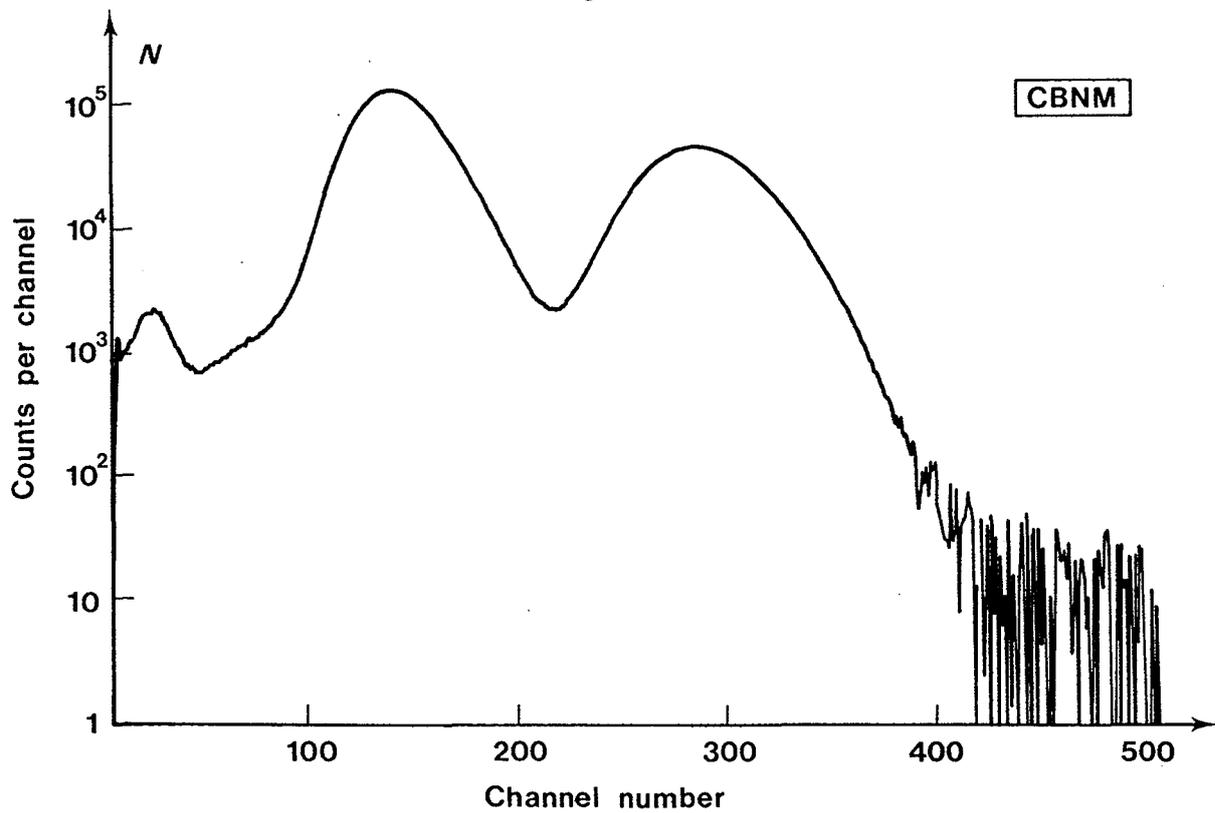


Fig. 2.2 - Some typical spectra of ^{125}I obtained by means of the sum-peak method [4], in a logarithmic scale.

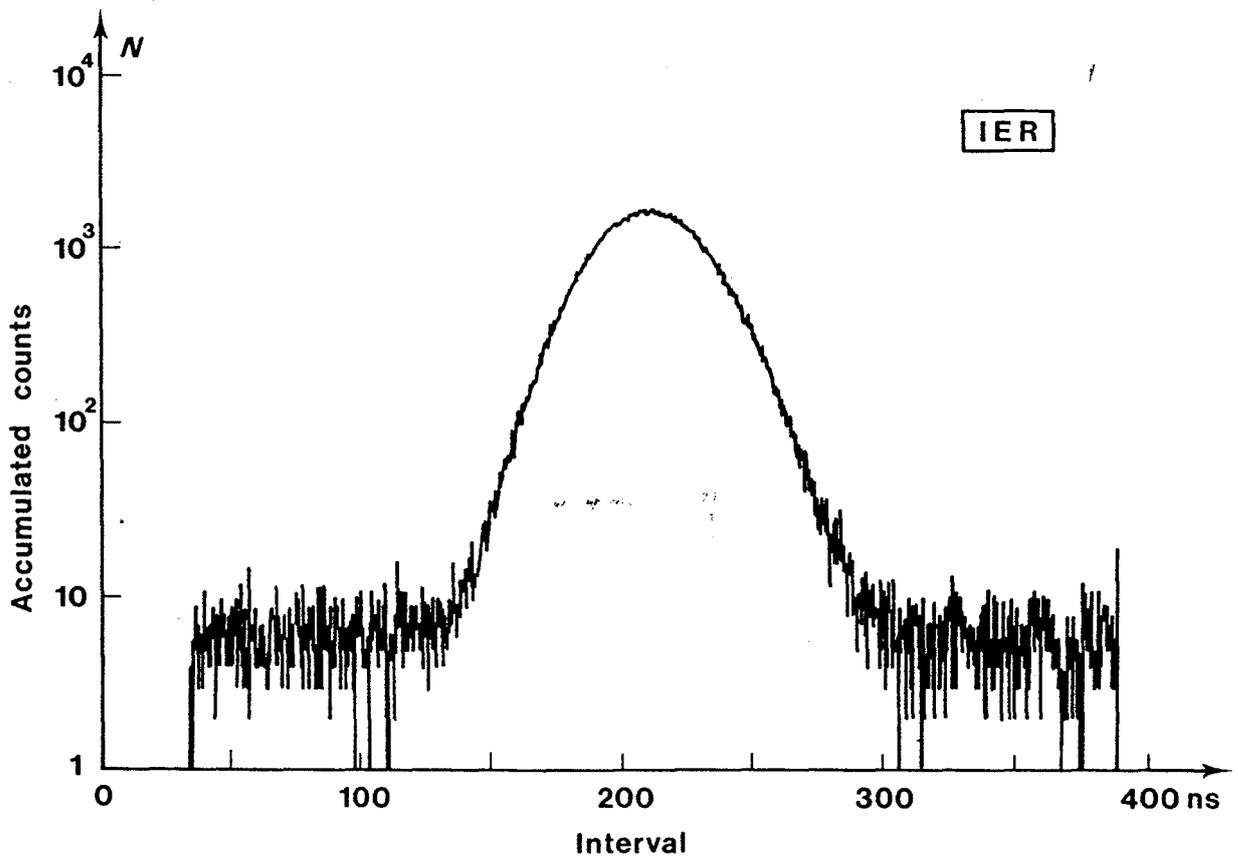
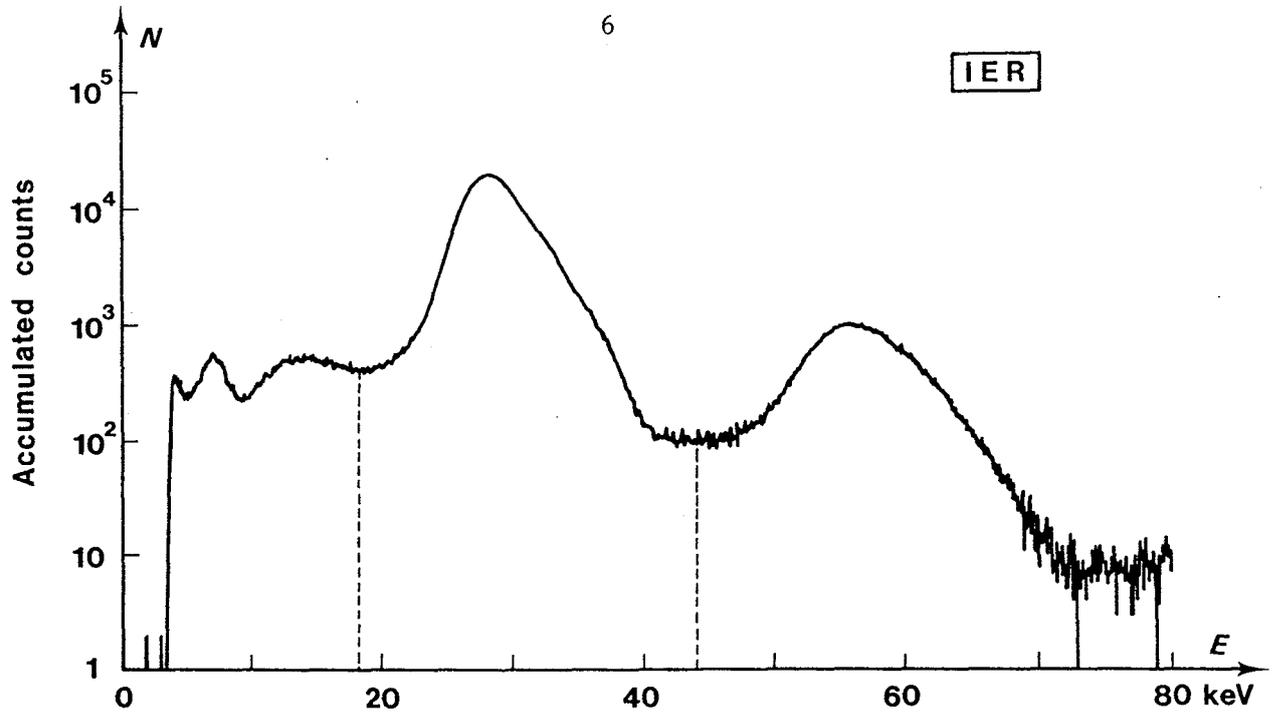


Fig. 2.3 - Typical spectra of ^{125}I obtained by IER with the second method [5]. The upper drawing refers to the X- and γ -ray spectrum of ^{125}I . The lower one shows the interval distribution between the pulses of the two NaI detectors of the coincidence system.

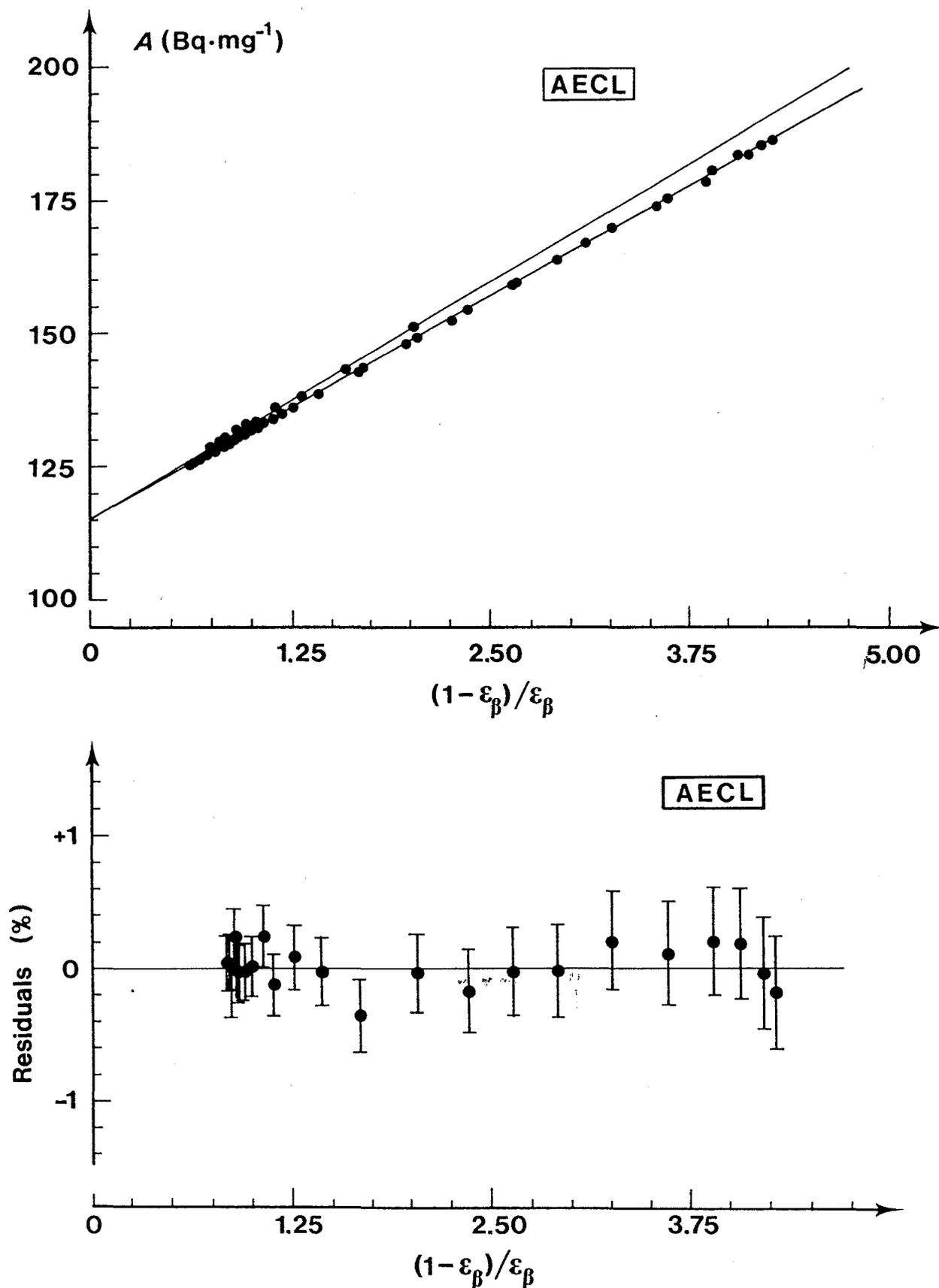


Fig. 3 - Results obtained by means of the $4\pi e$ -X coincidence efficiency extrapolation method. The upper drawing presents linear least-squares fits of the activity concentration of the diluted solution versus $(1 - \epsilon_\beta) / \epsilon_\beta$. The lower one shows a plot of the residuals for one of these extrapolations.

5. Corrections

AECL applied the same corrections for methods 1 and 2, i.e. the individual results were corrected for background, dead time and decay. In the case of method 3, corrections were made to the electron rates obtained by means of a proportional counter (the electron efficiency of which was changed by varying the high voltage) for background, measured at every second voltage increment over the complete voltage range. Corrections for dead time, decay and accidental coincidences were also applied.

BIPM (method 1) corrected data for background, decay and dead time. An extrapolation to zero count rate was applied in order to eliminate the effect of accidental summing in line A_2 defined in ref. [4].

CBNM (method 1) corrected data for background and decay. The dead-time corrections were directly included by means of the multichannel analyser. The total count rate contained in lines A_1 and A_2 was obtained by summing the events between 0 and 86 keV. The contribution in line A_2 was computed as the sum of a tail and the counts between 43 and 86 keV. The tail was evaluated by means of the following three methods:

- applying logarithmic fit to the high-energy side of the "singles peak" (i.e. peak formed by single events) and to the low-energy side of the sum peak,
- fitting with four gaussians,
- the Heath method [8].

IER (method 2) applied the Cox-Isham formula [9] for correcting the count rates.

LMRI (method 1) took into account a correction of 0.7 % for the tail of the sum peak.

The corrections used by OMH (method 1) are of the same type as those applied by BIPM.

PTB corrected the measured single count rates for background and dead time, and the coincidence rate by means of the Cox-Isham formula [9].

6. Uncertainties

The combined uncertainties and their components are presented in Table 7. It will be noted that the method described by Eldridge and Crowther [4] is apparently the least precise way for determining the activity concentration of ^{125}I . For this method, the main contributions to the uncertainty stem from the product $P_1 P_2 / (P_1 + P_2)^2$, the extraction of the individual contributions A_1 and A_2 from the measured spectrum of ^{125}I and the gate settings.

For the method described in [5], the main uncertainty contributions are those due to counting statistics, pile up (for AECL) and source preparation (for IER).

For methods 3 and 4, uncertainties due to counting statistics and the fitting of an extrapolation curve are the main contributions. An important source of discrepancy for the results, which (for the time being) cannot be avoided, comes from the use of four different half lives by the participating laboratories for calculating the activity concentration at the reference date. Since the interval between the average time of measurement and the reference date was often of the order of the half life, this correction may have degraded the quality of the measurements.

7. Final results

The results are presented in Table 8 and Figure 4.

AECL used three different methods, but gave as its result a weighted mean of $(2\ 050.4 \pm 4.3)$ kBq g^{-1} . For the sake of simplicity we consider all the seven submitted results as being independent of each other and assume that their respective uncertainties have been reliably assessed. We then obtain for the weighted mean of all the results

$$(2\ 052.0 \pm 3.6) \text{ kBq g}^{-1} ,$$

and for their unweighted mean

$$(2\ 056.0 \pm 4.2) \text{ kBq g}^{-1} ,$$

always at the reference date of 1987-03-01, 0 h UT.

The results of this trial comparison cover a total range of 32.1 kBq g^{-1} (1.56 %). The deviations of the lowest and the highest value from the weighted mean are - 0.63 % and 0.93%, respectively.

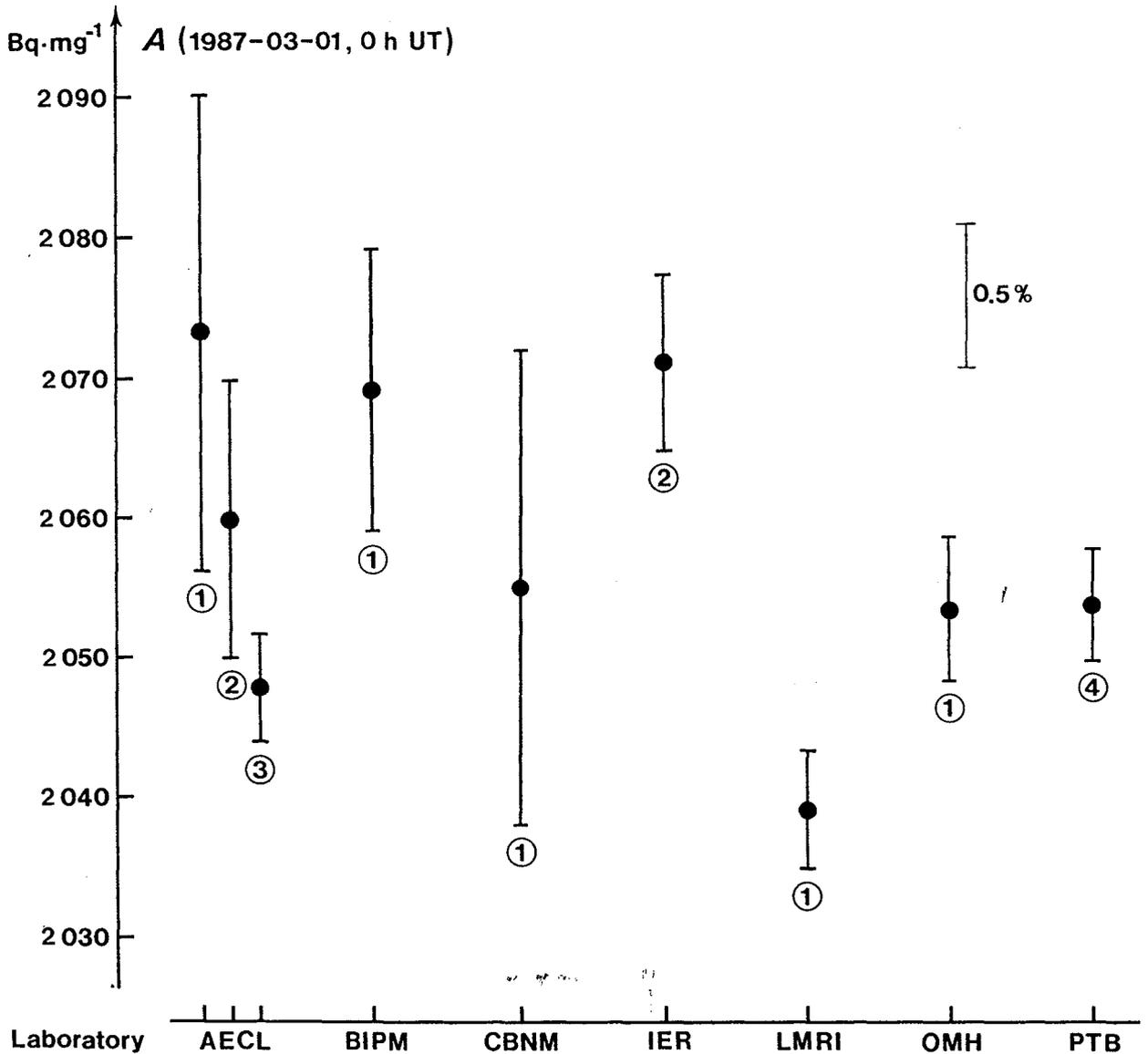


Fig. 4 - Final results of the ^{125}I trial comparison. The numbers refer to the four methods applied:

- 1) Sum-peak method [4],
- 2) X-(X+ γ) coincidences [5],
- 3) $4\pi\epsilon$ -X coincidence efficiency extrapolation [6],
- 4) Photon-photon coincidence counting and efficiency-extrapolation method [7].

Table 2 - Mass measurements, ionization-chamber measurements and adsorption tests

	AECL	BIM	CBM	IER	IMRI	OMH	PTB
Ampoule number	8 222	8 224	8 223	8 225	8 226	8 228	8 227
Mass of solution (g)							
- indicated by OMH	3.601 6	3.604 0	3.605 7	3.600 2	3.602 5	3.603 2	3.605 7 (5)
- determined by laboratory	3.601 3 (1)			3.589 7		3.596 1	3.606 1
Activity concentration (kBq g ⁻¹) at ref. date (1987-03-01, 0 h UT)					2 035 ± 8 a (1987-04-13)	2 060 a (1987-02-09)	2 039 ± 14 a,c (1987-03-04 to 03-16)
(date of the measurement)				2 064 ± 10 b (1987-03-25)	2 035 ± 8 b (1987-04-15)	2 058 b (1987-03-10)	2 048 ± 6 b,c (1987-03-25 to 05-06)
Activity remaining in the "empty" ampoule after 2 rinsings with distilled water (Bq)	134 ± 10 (2)			48 ± 0.5 (3)		840 ± 50 (4)	
Date of the test	1987-03-30			1987-04-29			
Additional rinsings						2 with diluent	
Final residual activity						60 ± 20 (4)	
Date of the test						1987-03-11	

a before opening the ampoule, b after transfer of the contents of the ampoule,
c using geometric correction factors for 3.6 ml and 2 ml of solution (without calibration constants).

- (1) The mass of the solution was found by weighing the empty dry ampoule and subtracting from that of the unopened but file-marked ampoule. The mass of solution actually transferred usefully to the pycnometer was 3.579 8 g.
- (2) Measurements performed by means of a Ge(Li) spectrometer.
- (3) Rinsing was done just after the transfer on 1987-03-24. The adsorption tests were performed with a 2" x 2" well-type NaI detector.
- (4) Measurements performed by means of a HP-Ge detector with a Be window.
- (5) Weighing procedure like (1).

Table 3 - Source preparation

	AECL	BIEM	CBNM	IER	IMRI	OMH	PTB
<u>Dilution</u>							
Diluent	16 µg/ml NaI + 19 µg/ml Na ₂ SO ₃ pH 8 with LiOH	50 µg/g KI + 50 µg/g Na ₂ S ₂ O ₃ in 5·10 ⁻⁴ mol/l NaOH	30 µg/g NaI + 16 µg/g Na ₂ SO ₃ in 2·10 ⁻⁴ mol/l NaOH	0.02 g/l Na ₂ SO ₃ + 0.02 g/l LiOH + 0.05 g/l KI in H ₂ O	66 µg/g KI + 74 µg/g (Na ₂ SO ₃ + 5 H ₂ O) in 5·10 ⁻⁴ mol/l NaOH	50 µg/g KI + 50 µg/g KIO ₃ + 50 µg/g Na ₂ S ₂ O ₃ in 10 ⁻³ mol/l NaOH	-
Number of dilutions	1	1	1	2	1	1	
Dilution factors	17.766	7.340 72	7.784 7	1.000, 9.642 6, 8.444 9	42.345 2 ± 0.001 2	20.013 ± 0.002	
<u>Source preparation</u>	(1)		(4)			(10)	
Source backing: substrate	VYNS	VYNS	VYNS	mylar	mylar		VYNS
Metal coating	Au-Pd	Au	Au	aluminium			-
Number of films	1 or 2	1	1	1	2		2
Metal layers above	0	0	1	1			
below	1 or 2	1	1	1			
Total mass per unit surface (µg cm ⁻²)	20 to 30	35	35	1 000	40		50
Wetting or seeding agent	-	Ludox 10 ⁻⁴	-	Ludox 10 ⁻⁴ (6)			
Drying	flow of dry air at ambient temp.	air	flow of air at ambient temp.	ambient atm.	air		air
Special treatment	(2)	-	(5)	(7)	(8)		precipitated with AgNO ₃ (8)
Range of source mass (mg)	1.08 to 3.36 (3)	18.06 to 74.92	9.20 to 16.55	10.5 to 61.7	10 to 45 (9)	12 to 90	20 to 24

Table 3 (cont'd)

- (1) For $4\pi\epsilon$ -X coincidence efficiency extrapolation. Sources for methods 1 and 2 were prepared by gravimetric dispensing of active solution into AgNO_3 solution on the adhesive side of 6.3 mg cm^{-2} mylar tape. After drying slowly with flowing air at ambient temperature, the deposit was covered with a layer of the same mylar tape. The range of source mass was 0.93 to 2.13 mg of the original solution. Some sources were further sandwiched by the same mylar tape in tests to investigate electron-range effects.
- (2) Drops were dispensed into $\approx 20 \text{ }\mu\text{l}$ of a $470 \text{ }\mu\text{g/ml}$ AgNO_3 solution.
- (3) Of the original solution.
- (4) The source mounts were attached to a paper liner and placed at the bottom of the well-type detector.
- (5) Iodine was precipitated on the source mount by adding a double excess of AgNO_3 and keeping the droplet in a humid atmosphere for half an hour before drying.
- (6) For the original solution.
- (7) The active solution was deposited on a drop of solution of AgNO_3 ($\approx 10 \text{ mg}$ of solution).
- (8) A drop of AgNO_3 ($160 \text{ }\mu\text{g/g}$ of solution) was deposited on the active solution.
- (9) Two types of sources were used for the measurements: polyethylene tubes containing a drop of solution and a sandwich of mylar foils with "dried drops".
- (10) Sources used were Brown medical glass ampoules (body diameter = 15 mm, height of liquid = 8 mm). The ampoules were filled to 1 g.

Table 4 - Equipment for counting

	AECL	BIM	CBM	IER	IMRI	OMH	PTB
<u>4π proportional counter</u>							
Wall material	stainless steel						
Height of each half (mm)	21						
Anode							
- Nature	stainless steel						
- Wire diameter (mm)	0.013						
- Wire length (mm)	36						
- Distance from source (mm)	10						
- Voltage applied (kV)	1.8 to 2.3						
Gas							
- Nature	CH ₄						
- Pressure (MPa)	0.1						
- Discrimination level (keV)	≈ 10						
<u>Scintillation detector</u>							
Number of crystals: ordinary	(1)	1		2			2
well type			1		1	1	
Diameter (mm)	51	76	152.4	76	125	28	75
Height (mm)	1	76	152.4	76	100	35	6
Well diameter (mm)			50		14.5	16	
" depth (mm)			100		50	29	
Resolution (FWHM*) (%)	< 35	19.4	29	6.1, 7.6	7	19.2	≈ 30
at ... (keV)	28	28	27.47	662	662	59.5	≈ 30
Solid angle (sr/4 π)	method 1: 0.425		0.983		0.994	0.975	< 0.5
	" 2: 0.425 (2)						
	" 3: 0.325 (3)						
Distance from photon counter	methods 1 & 2: 4	14	< 1 (4)	15			3 to 220
to source (mm)	" 3: 23						

* full width at half maximum

(1) method 1: 1 NaI; method 2: 2 NaI

(2) for each detector

(3) sum of 2 detectors

(4) at bottom of well

Table 5 - Counting data for the different methods

		Counting channel window limits (keV)	Typical count rates (s ⁻¹)	Background rates (s ⁻¹)	Number of sources measured	Typical time for one measurement (s)	Dead times (μs)	Coincidence resolving time (μs)
AECL								
Method 1	A ₁ A ₂	10 to 43, window 1 43 to 77, window 2	1 430	0.57	4	1 000	2.00 ± 0.02 (1) 2.00 ± 0.02 (1)	
Method 2		10 to 43 and 10 to 77 10 to 43 and 10 to 77	3 400	0.30	4	1 000	2.03 ± 0.03 (1) 2.04 ± 0.03 (1)	
Method 3		10	1 500	4.5	5	500	2.03 ± 0.02 (1)	0.695 ± 0.001 (1)
BIM								
Method 1			1 500 to 5 800	1.1	31	1 800	live timing	
CBNM		0 to 86	1 200	16.6	3	15 000	(2)	
IER								
Method 2		18 to 44 and 18 to 73			4 dil. fact. 1.0 3 " " 9.642 6 3 " " 8.444 9		3.201 ± 0.001 (3) 3.196 ± 0.001 (3)	1.075 ± 0.002 (3)
LMRI								
Method 1	A ₁ A ₂	15 to 42.7 42.7 to 81 4.7 (4)	250 to 1 000	30	12	7 200	3.8	

Table 5 (cont'd)

	Counting channel window limits (keV)	Typical count rates (s ⁻¹)	Background rates (s ⁻¹)	Number of sources measured	Typical time for one measurement (s)	Dead times (μs)	Coincidence resolving time (μs)
OMH							
Method 1	A ₁	13 to 43	3 500	14	500	6.036 ± 0.005 (5)	
	A ₂	43 to 78				6.025 ± 0.005	
PTB							
Method 4	17 to 100	≤ 20 000 (6)	2	6	≤ 1 000 (7)	5.00 ± 0.05 (8) 5.00 ± 0.05 (8)	1.00 ± 0.02 (8)

A₁ Peak of individual events [4].

A₂ Sum-coincidence peak [4].

(1) The source-pulser method, as described in NCRP 58 [10], was used for their determinations.

(2) Live-time correction of the multichannel analyser.

(3) The dead times were generated numerically and determined by means of the two-oscillator method.

(4) Discrimination threshold.

(5) For obtaining the area under the singles peak (A₁) and the sum coincidence peak (A₂), two timing SCA units were used (Canberra model 2037A with OMH dead-time generator).

(6) Maximum value at low distance.

(7) About 400 data points per extrapolation.

(8) Dead times and resolving time were determined by means of the two-oscillator method.

Table 6 - Formulae used for calculating the results

Method 1 [4] (AECL, BIPM, CBNM, LMRI, OMH)

$$N_o = \frac{P_1 P_2}{(P_1 + P_2)^2} \frac{(A_1 + 2 A_2)^2}{A_2},$$

where A_1 and A_2 are the contents of the singles peak and the sum coincidence peak.

AECL, BIPM and OMH used the following expressions for P_1 and P_2 :

$$P_1 = P_K \omega_K, \quad P_2 = \frac{1 + \alpha_K \omega_K}{1 + \alpha_T}.$$

CBNM and LMRI applied the relations

$$P_1 = P_K \omega_K = 0.699 0 \quad \text{and} \quad P_2 = \frac{\alpha_K \omega_K}{1 + \alpha_T} + \left(\frac{\epsilon_Y}{\epsilon_{KX}} \right) \frac{1}{1 + \alpha_T} = 0.774 9 .$$

AECL, CBNM, LMRI and OMH took their values from [3].

BIPM used a somewhat different value for ω_K and α_T , namely

$$\omega_K = 0.882 \pm 0.028 \quad [11] \quad \text{and} \quad \alpha_T = 14.02 \pm 0.01 \quad [12].$$

For this laboratory P_1 and P_2 had the values

$$P_1 = 0.703 8 \pm 0.022 3 \quad \text{and} \quad P_2 = 0.770 4 \pm 0.010 2 .$$

Method 2 [5] (AECL, IER)

$$N_o = \frac{4K}{(1 + K)^2} \left[N_1 + \frac{N_c(1 - N_c/N_2)}{(1 - N_c/N_1)} \right] \left[N_2 + \frac{N_c(1 - N_c/N_1)}{(1 - N_c/N_2)} \right] \frac{1}{2N_c},$$

$$\text{where } K = \frac{1 + \alpha_K \omega_K}{P_K \omega_K (1 + \alpha_T)} \quad \text{and} \quad \frac{4K}{(1 + K)^2} = 0.999 6 ,$$

if the formula used for the gate includes the singles peak only. However,

$$N_o = \frac{4K}{(1 + K)^2} \left[N_1 + \frac{N_c(1 - N_c/2N_2)}{2(1 - N_c/2N_1)} \right] \left[N_2 + \frac{N_c(1 - N_c/2N_1)}{2(1 - N_c/2N_2)} \right] \frac{1}{2N_c},$$

if the formula used for the gate includes both the singles and the sum peaks.

.../...

Table 6 (cont'd)

Method 3 (AECL) - $4\pi e$ -X coincidence efficiency extrapolation [6]

$$N_o = \frac{N_{\beta}^* N_{\gamma}^*}{N_c^*},$$

where

$$N_{\beta}^* = \frac{N'_{\beta}}{1 - \tau_{\beta} N'_{\beta}} - B'_{\beta},$$

$$N_{\gamma}^* = \frac{N'_{\gamma}}{1 - \tau_{\gamma} N'_{\gamma}} - B'_{\gamma} \quad \text{and}$$

$$N_c^* = \frac{[N_c - (\theta_{\beta} + \theta_{\gamma}) N'_{\beta} N'_{\gamma}] (2 - \tau_{\beta} N'_{\beta} - \tau_{\gamma} N'_{\gamma})}{[2 - \tau_{\beta} N'_{\beta} - \tau_{\gamma} N'_{\gamma} + 2\tau N'_c - 2(\theta_{\gamma} N'_{\beta} + \theta_{\beta} N'_{\gamma}) + 2\delta(N'_{\beta} - N'_{\gamma})] (1 - \tau_{\beta} N'_{\beta}) (1 - \tau_{\gamma} N'_{\gamma})} - B'_c,$$

where the primes (') designate observed rates, θ refers to the coincidence resolving time, τ is the dead time, δ is the delay mismatch between the two channels and B refers to the background rates.

Method 4 (PTB) - Photon-photon coincidence counting and efficiency extrapolation method [7]

$$\frac{N_1 N_2}{2 N_c} = N_o \frac{(1 + K)^2}{4 K} \left\{ 1 - \frac{K}{1 + K} (\epsilon_1 + \epsilon_2) + \frac{K^2}{(1 + K)^2} \epsilon_1 \epsilon_2 \right\},$$

where

$$K = \frac{\alpha_K P_{\gamma} \omega_K + P_{\gamma}}{P_K \omega_K} = 1.112 \quad \text{and} \quad \epsilon_1 = \frac{(1 + K)}{2K} \frac{N_c}{N_2} \left(1 - \frac{1}{2} \frac{N_c}{N_1} \right) / \left(1 - \frac{1}{4} \frac{N_c^2}{N_1 N_2} \right).$$

ϵ_2 is obtained by permutation of the indices in the expression for ϵ_1 . A linear extrapolation function for $\epsilon_i \rightarrow 0$ ($i = 1, 2$) is applied for large distances.

The physical constants used are

$$P_K = 0.797 \pm 0.001, \quad \omega_K = 0.877 \pm 0.020, \quad P_{\gamma} = 0.0667 \pm 0.0013,$$

$$\alpha_K = 11.9 \pm 0.2, \quad \alpha_{\gamma} = 14.0 \pm 0.3.$$

All these values are taken from the literature, for instance from [3].

Remark - In the calculation of the ratio $4K/(1+K)^2$ by the methods 2 and 4, the differences of the values of these constants, when taken from various references, do not contribute significantly to the uncertainty of the ratio (and thus also of N_o).

Table 7 - Uncertainty components of the final result (in %)

Components due to	A E C L			BIEM	CBNM	IER	IMRI	OMH	PTB
	method 1	method 2	method 3	method 1		method 2	method 1	method 1	method 4
Counting statistics	0.07	0.16	0.17	0.09	0.15	0.23	0.05	0.02	0.01
Weighing	0.02	0.02	0.02	0.07	0.12 (5)	0.06	0.05	0.015 (10)	0.02
Dead time	< 0.01	< 0.01	0.02		0.01	0.01	0.02	0.005	0.02
Background	(1)	(1)	< 0.03	(1)	0.10	0.002	0.05	0.01	0.02
Pile up	0.17	0.43	-		0.01		0.01		0.01
Timing	< 0.05	< 0.05	< 0.05		-	0.01	0.01	0.005	0.01
Adsorption	< 0.01	< 0.01	< 0.01		0.05 (6)			< 0.001	0.05 (12)
Impurities	< 0.01	< 0.01	< 0.01		< 0.001			0.002	0.01
Gates	0.70 (2)								
Decay constant or half-life correction	0.12	0.12	0.12	< 0.02	0.22		0.16	0.02	0.03
Decay scheme correction $P_1 P_2 / (P_1 + P_2)^2$ $4K / (K+1)^2$				0.16			0.04	0.08	≈ 0.02 (13)
Other corrections	0.45 (3)	0.03 (4)			0.06 (7)				- (12)
Source preparation						0.2			
Dilution							< 0.01		
Time basis							0.01		
Peak separation				0.45	0.10 (8)		0.04	0.10	
Extrapolation					0.76 (9)		0.01	0.10 (11)	0.2 (14)
Axial and radial effie. variation of source					0.10				
Combined uncertainty	0.86	0.48	0.22	0.49	0.84	0.31	0.19	0.17	0.2

- (1) Included in counting statistics.
- (2) Uncertainty of 1 keV in X-gate settings.
- (3) Effect of 1σ in P_1 and P_2 in formula for N_0 .
- (4) Effect of 1σ in α_K , α_T , P_K and ω_K [3].
- (5) Average of standard deviation.
- (6) Adsorption and evaporation.
- (7) Correction due to decay data and the $\epsilon_\gamma / \epsilon_{KX}$ ratio.
- (8) Choice of valley midpoint.
- (9) Tail of A_2 .
- (10) Weighing and dilution.
- (11) Extrapolation to zero count rate.
- (12) Adsorption and chemical effects, including source preparation, known by experience.
- (13) See remark p. 18.
- (14) Fitting of extrapolation curve.

Table 8 - Final results

	A E C L			BIPM	CBNM	IER	IMRI	OMH	PTB
	method 1	method 2	method 3	method 1		method 2	method 1	method 1	method 4
Half life used by the laboratory (d)	59.90 ± 0.11	59.90 ± 0.11	59.90 ± 0.11	59.89 ± 0.15	59.90 ± 0.11	59.89 ± 0.15	59.89 ± 0.15	59.38 ± 0.05 (2)	59.39 ± 0.02
Activity concentration obtained at the date of meas. (kBq g ⁻¹)								1 697.3 ± 2.8	
Date of measurement				87-03-02 to 87-03-06	87-05-11 to 87-06-01	87-04-24 to 87-04-30	87-04-23 to 87-04-30	87-03-17 11 h 00 UT	87-03-27 to 87-05-07
Activity concentration at the reference date (1987-03-01, 0 h UT) (kBq g ⁻¹)	2 073.3 (1)	2 059.8 (1)	2 047.9 (1)	2 069.3	2 055	2 071.1	2 039	2 053.5	2 054
Combined uncertainty (kBq g ⁻¹)	17.8	9.9	3.9	10.2	17	6.4	4	3.4	4

(1) The weighted mean of these three values is $A = (2\ 050.4 \pm 4.3) \text{ kBq g}^{-1}$.

(2) Result of a measurement done at OMH.

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