# Report on a trial comparison of activity measurements of a solution of $^{109}Cd$

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## Abstract

Activity measurements of a $^{109}Cd$ solution have been carried out in view of a forthcoming large-scale international comparison. Details on the widely differing methods and detectors used by the six participants are reported. The measured activity-concentration values have a spread of 1.7 % and a standard deviation of the mean of 0.53 %. Some results of the γ-ray-emission rate have also been produced.

## 1. Introduction

This trial comparison was carried through by the Working Group for advising on future comparisons on behalf of Section II (Mesure des Radionucléides) of the Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants (CCEMRI).

As decided during the 1983 meeting of CCEMRI Section II, OMH diluted and bottled the $^{109}Cd$ solution supplied by the National Accelerator Centre (NAC, South Africa) for the trial comparison.

The ampoules were dispatched from the OMH on 26 November 1984. Each participant (Table 1) received one flame-sealed NBS-type ampoule containing about 2 g of solution. The exact mass was indicated. In addition, BIPM received one ampoule containing 3.6 g of the undiluted solution, for the International Reference System (SIR).

Table 1 - List of participants

| | | |
|---|---|---|
| AECL | Atomic Energy of Canada Limited, Chalk River, | Canada |
| BCMN | Bureau Central de Mesures Nucléaires, Euratom, Geel, | Belgium |
| LMRI | Laboratoire de Métrologie des Rayonnements Ionisants, Saclay, | France |
| NPL | National Physical Laboratory, Teddington, | United Kingdom |
| OMH | Országos Mérésügyi Hivatal, Budapest, | Hungary |
| PTB | Physikalisch-Technische Bundesanstalt, Braunschweig | Federal Republic of Germany |

The $^{109}Cd$ activity concentration was about 1.2 MBq $g^{-1}$ in an aqueous solution of HCl (0.1 mol per $dm^3$) with 20 μg of $CdCl_2$ per gram of solution.

Purity checks by OMH disclosed no gamma-ray-emitting impurities at the level of about $10^{-6}$ of the $^{109}Cd$ activity. For the half life it was proposed to use the value (462.6 ± 0.4) d [1].

A reporting form had been set up and was distributed with the ampoules. The dead line for submitting the results to OMH was 28 February 1985. The results arrived at OMH between 4 March and 3 May 1985.

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

The participants were asked to measure the activity concentration by a calibrated ionization chamber and the mass of solution contained in the ampoules as well as to carry out adsorption tests. The results of these measurements can be seen in Table 2.

## 3. Source preparation

A summary of technical details reported in the forms is presented in Table 3.

Dilutions were made by AECL, BCMN, LMRI and NPL.

AECL: Dilution was needed for both the $^{109}Cd$ and the $^{109}Pd$ solution because of the large difference between the rate of detectable radiations and the differences in detection efficiency for the PC and the Ge(Li) counting.

NPL: It was necessary to dilute the solution in order to reduce the correction for x-x summing.

## 4. Activity and gamma-ray emission-rate measurements

A summary of technical details reported in the forms is presented in Tables 4, 5, 6 and 7.

BCMN, LMRI, NPL, OMH and PTB applied 4π proportional detectors for counting the conversion electrons. BCMN, NPL and OMH calculated the activity from the count rate of conversion electrons. Typical spectra are presented on Figure 1. In addition to the measurements of conversion electrons, LMRI and PTB measured also the γ-ray emission rate. AECL used the following method: a solution of $^{109}Pd(+^{109}Ag^m)$ prepared from irradiated palladium was standardized by 4π(PC) counting. Sources

prepared from the $^{109}Cd$ solution distributed by OMH were compared as to the 88 keV γ-ray-emission rate with sources from the standardized $^{109}Pd$ solution. Both $^{109}Pd$ and $^{109}Cd$ decay via the 88 keV level of $^{109}Ag^{m}$ by γ-ray emission. This comparison was made with both a Ge(Li) detector and a pair of NaI crystals. Despite the poor statistics of the NaI γ counting, the agreement with the Ge(Li) counting was satisfactory.

In addition to the 4π(PPC) measurement BCMN used also two other methods:

- 4πLS counting of the rate of conversion electrons,
- 4πCsI(Tl) scintillation counting of the rate of conversion electrons and γ photons.

## 5. Uncertainties

The combined uncertainties and their components are summarized in Table 8.

## 6. Final results

The results are presented in Table 8 and Figure 2.

BCMN used three different methods for the activity measurement, but the results were not combined into a single result. The three BCMN results have therefore been taken as three independent values, in the calculation of the mean.

The weighted mean of 8 results is (1 187.6 ± 2.4) kBq $g^{-1}$,
and the unweighted mean (1 187.9 ± 6.3) kBq $g^{-1}$,
at the reference date (1984-12-15, 00 h UT).

The results of this trial comparison show a total spread of 20 kBq $g^{-1}$ (1.7 %).

The deviation of the lowest value from the mean is −1.2 %,
that of the highest value is +0.5 %.

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

| | AECL 1) | BCMN | IMRI | NPL | OMH | PTB |
|---|---|---|---|---|---|---|
| Ampoule number | 6991 | 6992 | 6993 | 6994 | 6990, 6998 | 6995 |
| Mass of solution (g) | | | | | | |
| - indicated by OMH | 2.0049 | 2.0018 | 2.0023 | 2.0023 | 2.0009, 2.0024 | 2.0030 |
| - determined by laboratory | 1.997 ± 0.020 | - | - | 1.999 51 | 1.9969, 1.9984 | 2.0029 ± 0.0002 |
| Activity concentration ($kBq\ g^{-1}$) | 1 196 ± 14 2) o | - | 1 260 3) o | 1 186 (1976 cal.) o | the chamber was not calibrated | activity too low for IC measurements |
| at reference date | 1 201 ± 23 t | | 1 179 t | 1 210 (1979 cal.) o | | |
| Activity remaining in the "empty" ampoule after 2 rinsings with distilled water (Bq) | 14 ± 13 | - | - | 400 4) | 200 ± 20 | 5 |

1) The uncertainty of measurements made with a calibrated ionization chamber includes an allowance for the calibration (≈ 1 %) of the ionization chamber. The large uncertainty in the total mass of solution reflects the fact that the amount of solution remaining in the pycnometer was only estimated.

2) o - original ampoule
t - transfer to another ampoule

3) Geometry conditions different from those used for calibration.

4) Three rinsings with carrier solution.

Table 3 – Source preparation

| | AECL | BCMN | IMRI | NPL | OMH | PTB |
|---|---|---|---|---|---|---|
| **Dilution** | | | | | | |
| Diluent: µg of $CdCl_2$ per g of solution | 18 | 20 | 10 | 20 3 | – | – |
| mol of HCl per $dm^3$ of solution | 0.1 | 0.1 | 1 | 0.1 0.1 | – | – |
| Number of dilutions | 2 | 2 | 1 | 2 | – | – |
| Dilution factors | 10.100 47.618 | 9.7 102 | 73.388 5 ± 0.002 5 | 72.584 57.018 | – | – |
| **Source preparation for proportional counting** | | | | | | |
| Source backing: substrate | VYNS | VYNS | Cellulose | VYNS | VYNS | VYNS |
| Metal coating | Au + Pd | Au | Au | Au | Au + Pd | Au + Pd |
| Number of films | 1 or 2 | 1 | 1 | 1 | 1 | 1 |
| Metal layers: above | 0 | 1 | 1 | 1 | 1 | 1 |
| below | 1 or 2 | 1 | 1 | 1 | 1 | 1 |
| Total mass (µg $cm^{-2}$) | 15 | 26 | 20 | 50 | 30 ± 5 | 55 |
| Drops dispensed onto metal | No | Yes | Yes | Yes | Yes | Yes |
| Wetting or seeding agent | Catanac SN | Catanac 1) | – | Catanac 2) | Ludox + Teepol | Ludox SM 3) |
| Drying | Dry air 50–60°C | Air stream | Air | Air | IR lamp | Air |
| Special treatment | – | – | 4), 9) | – | – | 5) |
| Range of source mass (mg) | 6) | 10 to 15 | 19 to 26 | 30 to 80 | 8 to 12 | 9 to 11 |
| **Source preparation for γ and/or x-ray count.** | | | | | | |
| Substrate | Polyester tape sandwich | VYNS Polyimide | Mylar (sandwich) | – | – | Polyethylene |
| Ring diameter (outer/inner) (mm) | 38/25 | 64 | 10 | | | 20 |
| " thickness (mm) | 0.5 | 20 to 50 µg$cm^{-2}$ | 0.04 | | | 0.015 |
| Diameter of active area (mm) | 8 6.3 mg $cm^{-2}$ 10) | 4 8) | 5 | | | 4 to 5 11) |

Remarks

1) 7 mg per g of solution[7]. 2) 50 µg per g of solution. 3) $10^{-4}$ on 4 sources. 4) Electro-deposition of resin (2 sources). 5) Electro-deposition (4 sources), electro-sprayed resin (8 sources). 6) $^{109}Pd$: 0.42 to 18.14 mg, $^{109}Cd$: 0.31 to 3.39 mg (drop masses/dilution factor). 7) A spot of about 10 mm diameter was wetted with a droplet of Catanac and removed immediately thereafter. This left a very thin film sufficient to spread the activity droplet. 8) No metal coating; wetting agent: Catanac (7 mg per g); drying in air stream; mass range: 10 to 15 mg. 9) $AlCl_3$ and drying in $NH_3$ atmosphere (1 source). 10) Tape thickness. 11) Precipitated in $H_2S$ atmosphere.

Source preparation for liquid-scintillation counting (BCMN): about 15 mg of solution in 12 $cm^3$ of scintillator Aqualuma Plus (Lumac) pre-loaded with 0.5 µg of $CdCl_2$ per g of solution.

Table 4 – Equipments for counting

| | AECL | BCMN | IMRI | NPL | OMH | PTB |
|---|---|---|---|---|---|---|
| 4π proportional counter | | | | | | |
| Wall material | stainless steel | Al | Plexi + Au | steel | Al | Al |
| Height of each half (mm) | 21 | 40 | 22 | 120 | 20 | 20 |
| Anode | | | | | | |
| – Nature | stainless steel | stainless steel | stainless steel | gold-coated W | stainless steel | gold-coated Mo |
| – Wire diameter (mm) | 0.013 | 0.021 | 0.02 | 0.05 | 0.021 | 0.1 |
| – Wire length (mm) | 36 | 150 | 160 | 250 | 40 | 40 |
| – Distance from source (mm) | 10 | 20 | 20 | 70 | 10 | 10 |
| – Voltage applied (kV) | 2.4 | 2.0 to 2.6 | 3.5 | 4.6 | 3.65 | 7.3 |
| Gas | | | | | | |
| – Nature | $CH_4$ | $Ar + CH_4$ | $Ar + CH_4$ | $Ar + CH_4$ | $Ar + CH_4$ | $Ar + CH_4$ |
| – Pressure (MPa) | 0.1 | 0.3 to 0.5 | 1.0 | 0.5 | 1.1 | 1.1 |
| Discrimination level (keV) | ≈ 0.1 | 3.5 | ≈ 40 | 31.0 | 37.0 | 30.0 |
| Scintillation detector | | LS CsI | NaI | – | – | – |
| Number of crystals: ordinary | 2 NaI | – 2 (sandwich) | 1 | | | |
| well type | None | – None | Yes | | | |
| Diameter (mm) | 76 | 32 52.4 | 125 | | | |
| Height (mm) | 76 | 15 25.4 | 100 | | | |
| Well diameter (mm) | – | – – | 14.50 | | | |
| depth (mm) | – | – – | 48.42 | | | |
| Year of purchase | 1976/77 | – 1975 | 1970 | | | |
| Phototube(s) | 75 B01 (SRC) | RCA 8850, EMI 9658R | ? | – | – | – |
| Resolution at 662 keV (FWHM*) (%) | 7.2 | – 20 (at 60 keV) | ? | – | – | – |
| Solid angle (sr/4π) | 0.7 | 1 1 | 0.993 | – | – | – |

* full width at half maximum

Table 4 (cont'd)

| | AECL | BCMN | IMRI | NPL | OMH | PTB |
|---|---|---|---|---|---|---|
| Semiconductor detector | | | | | | |
| Nature | Ge(Li) | – | 1) Ge(Li)<br>2) high-purity Ge | – | – | high-purity Ge* |
| Type (geometry) | coaxial | | 1) coaxial<br>2) planar | – | – | planar |
| Volume or relative efficiency | nominal 10 % | | 1) 100 $cm^3$<br>2) 2 $cm^3$ | – | – | length 25 mm<br>diameter 22 mm |
| Energy resolution<br>FWHM (keV)/ref. energy (keV) | 1.4/88 | | 1) 1.2/122<br>2) 0.54/122 | – | – | 0.38/5.9<br>0.570/122 |
| Material and thickness of window (mm) | Al, 0.5 | | 1) Al, 0.5<br>2) Be, 0.06 | – | – | Be, 0.2 |
| Dead times (μs) | | | | | | |
| – for PC channel | 2.018 ± 0.015** | 10.0 ± 0.1 | cumulative | 15.0 ± 0.2 | 3.026 ± 0.005 | 5.000 ± 0.002 |
| – for γ– and/or X-ray channel | 2.015 ± 0.014 (NaI) | 10.50 ± 0.05*** (CsI) | – | – | – | – |

* Other detectors: Ge(Li), true coaxial, 5 % efficiency,
Ge(Li), one end open, 11 % efficiency.

** Another channel of electronics was set up by AECL to gate off the γ rays in coincidence with $^{109}$Pd β rays in order to inhibit the counting of bremsstrahlung by the γ-ray channel. The dead time of this channel was the same as that for the PC channel.

*** The measurements by 4πLS counting were carried out with MCA live time.

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 | Number of data points, time per point (s) | Time of the measurements |
|---|---|---|---|---|---|---|
| **AECL** | | | | | | |
| PC channel | – | 830 to 32 000 | 0.4 to 1.4 | 6 $^{109}$Pd | 19 600 | |
| NaI channel | 70 to 108 | 4 to 530 | 1 to 3 | 6 $^{109}$Cd | 19 600 | 85-01-15 to |
| NaI (anti-coincidence) | 70 to 108 | 4 to 350 | 1 to 3 | 6 $^{109}$Pd | 19 600 | 85-02-08 |
| Ge(Li) for $^{109}$Pd | 85 to 91 | 0.2 to 580 | 0.02 to 0.04 | 6 tape sources | | |
| " for $^{109}$Cd | | 6.6 to 14 | | 6 " " | 9 6 000 | |
| **BCMN** | | | | | | |
| LS channel, original sol. | – | 12 000 | 1.2 | 2 | 2 2 000 | 85-03-25 to |
| " dilution | – | 1 200 | 1.2 | 3 | 6 20 000 | 85-03-30 |
| CsI channel | – | 120 to 1 500 | 37 | 4 | 13 | 85-04-01 to 04-20 |
| PPC channel | 3.5 integral | 140 to 1 300 | 3.4 | 3 | 15 3 000 to 10 000 | 85-03-28 to 04-17 |
| **LMRI** | | | | | | |
| PPC channel | 40 integral | 300 | 0.8 | 5 | 5 5 000 | |
| 4πγ channel | 50 to 120 | 6 to 26 | 2.014 | 7 | 7 60 000 | 85-02 |
| **NPL** | | | | | | |
| PPC channel | 31.0 integral | 400 | 12 | 7 | 3 per source 4 000 | 85-03-05 to 03-15 |
| **OMH** | | | | | | |
| PPC channel | 37.0 integral | 9 600 | 0.2 | 28 | 26 (2 to 3)x200 | 84-12-10 to 12-21 |
| **PTB** | | | | | | |
| PPC channel | 30.0 integral | 9 000 | 0.6 | 10 | 10 1 000 | 85-02-06 |
| Ge channel | 88 | 50 (integral) | – | 4 | 20 000 | 85-01-28 |

Table 6 - Formulae used for calculating the results

AECL

$$N_o(^{109}Pd) = \frac{N(^{109}Pd + ^{109}Ag^m)}{EF},$$

where N is corrected for dead time, background, impurities ($^{65}Zn$, $^{111}Ag$) and decay,
EF = $4\pi$(PC) efficiency for counting $^{109}Pd + ^{109}Ag^m$ = (1.9444 ± 0.0095),
$T_{\frac{1}{2}}(^{109}Pd)$ = (13.402 ± 0.006) h.

$$N_o(^{109}Cd) = \frac{N_o(^{109}Pd) \cdot 88 \text{ keV rate (Cd sources)}}{88 \text{ keV rate (Pd sources)}},$$

where the count rates are corrected for losses and decay.

BCMN

$$N_o = N_{ce}\, C_{ce}\, C_{sp}\, (4\pi LS),$$

$$N_o = N_{ce+\gamma}\, C_{sp}\, (4\pi CsI),$$

$$N_o = N_{ce}\, C_{ce}\, C_{sp}\, (4\pi PPC),$$

where $N_{ce+\gamma}$ and $N_{ce}$ are corrected for background and decay (live-time measurements were applied in all cases).

LMRI

$$N_o = N_{ce} + N_\gamma,$$

where $N_{ce}$ is corrected for background and decay (cumulative dead times were applied), and extrapolated exponentially to 0 keV,

$N_\gamma$ = result of $4\pi\gamma$ counting.

NPL

$$N_o = N_{ce}\, C_{ce}\, C_{sp}\, C_{sum}\, C_s,$$

where $N_{ce}$ is corrected for dead time, background and decay.

OMH

$$N_o = N_{ce}\, C_{ce}\, C_{sp}\, C_g\, C_s.$$

where $N_{ce}$ is corrected for dead time, background and decay.

PTB

$$N_o = N_{ce} + N_\gamma,$$

where $N_{ce}$ is corrected for dead time, background and decay and
$N_\gamma$ = result of measurement of $\gamma$ rate.

Table 7 - Corrections applied for calculating the results

(in parentheses uncertainty in units of the last digit)

| | AECL | BCMN | LMRI | NPL | OMH | PTB |
|---|---|---|---|---|---|---|
| Corrections applied | | | | | | - |
| $C_{ce} = (1 + \alpha_t)/(\alpha_t + \varepsilon_\gamma)$ | | 1.0381(5) (LS,PPC) [2] | | 1.0376 (8) | 1.0379 (7) | |
| ($\alpha_t = 26.4 \pm 0.5$) [1] | | $\varepsilon_\gamma = 0.0025$ (25) | | $\varepsilon_\gamma = 0.008$ (2) at 0.5 MPa | $\varepsilon_\gamma = 0.00$ % (5) | |
| for spectrum extrapolation, $C_{sp}$ below threshold electrons above threshold x rays | | 1.012 (2) (LS)<br>1.007 (2) (CsI)<br>1.001 (1) (PPC) | 0.1 to 0.3 % | 0.20 % (20) | 1.002 (2) | |
| for source self-absorption ($C_s$) | | | | 0.15 % (15) | 1.0003 (3) | |
| for geometry loss ($C_g$) | | | | | 1.0016 (5) | |
| for x-ray summing, above threshold ($C_{sum}$) | | | | - 0.01 % (1) | | |
| for Ge(Li) losses (dead time, pile up) | 1.0185 (21) (max.) | | | | | |
| for $4\pi\gamma$ counting, linear extrapolation to zero mass<br>- for the spectrum between 38 and 50 keV (pile-up suppression) [3] | | | 0.95 % (10) | | | |
| - and for the spectrum between 0 and 38 keV [3] | | | 1.2 % (4) | | | |

Table 8 – Uncertainty components of the final result (in %)

| Components due to | AECL | BCMN | | | LMRI | | NPL | CMH | PTB |
|---|---|---|---|---|---|---|---|---|---|
| | | LS | CsI | PPC | PPC | $4\pi\gamma$ | | | |
| Counting statistics | 0.19 | 0.1 | 0.1 | 0.1 | 0.08 | 0.08 | 0.06 | 0.06 | 0.05 |
| Weighing | 0.02 | 0.1 | 0.1 | 0.1 | 0.017 | 0.01 | 0.05 | 0.01 | 0.02 |
| Dead time | 0.01 (NaI/PC) | 0.1 | 0.1 | 0.1 | – | – | 0.02 | 0.005 | 0.02 |
| Resolving time | – | – | – | – | – | – | – | – | – |
| Delay mismatch | – | – | – | – | – | – | – | – | – |
| Pile up | 0.01 (NaI) | 0.02 | 0.1 | 0.1 | – | – | 0.05 | – | – |
| Background | included in counting statistics | 0.02 | 0.2 | 0.2 | 0.004 | 0.05 | 0.1 | 0.01 | – |
| Timing | 0.05 | – | – | – | 0.003 | 0.01 | 0.005 | 0.005 | – |
| Adsorption | 0.01 | 0.05 | – | – | – | – | 0.02 | 0.01 | – |
| Impurities | 0.14 (in the $^{109}$Pd sol.) | – | – | – | – | – | 0.05 | $2 \cdot 10^{-4}$ | – |
| Efficiency for PC counting of $^{109}$Pd + $^{109}$Ag$^{m}$ | 0.49 | – | – | – | – | – | – | – | – |
| Source self-absorption | – | – | – | – | – | – | 0.15 | 0.03 | – |
| Uncertainty in $C_{ce}$ | – | 0.05 | – | 0.1 | – | – | 0.08 | 0.07 | – |
| Correction for below-threshold electrons and above-threshold x rays | – | 0.2 | 0.2 | 0.3 | 0.23 | – | 0.2 | 0.2 | 0.15 |
| Foil absorption | – | – | 0.1 | – | – | – | – | – | – |
| Threshold setting | – | – | – | – | – | – | 0.05 | 0.1 | – |
| Correction for geometry loss | – | – | – | – | – | – | – | 0.05 | – |
| Measurement of $\gamma$ rate by Ge(Li) | – | – | – | – | – | – | – | – | 0.06 |
| Half life | – | – | – | – | 0.01 | 0.01 | – | 0.001 | – |
| Dilution | – | 0.1 | – | 0.1 | 0.003 | 0.003 | – | – | – |
| Extrapolation for $4\pi\gamma$ counting (0 to 50 keV) | – | – | – | – | – | 0.41 | – | – | – |
| Efficiency for $4\pi\gamma$ counting | – | – | – | – | – | 0.02 | – | – | – |
| Combined uncertainty | 0.55 | 0.29 | 0.4 | 0.4 | 0.25 | 0.42 | 0.31 | 0.25 | 0.17 |

Table 8 (cont'd)

| | AECL | BCMN | | | IMRI | NPL | OMH | PTB |
|---|---|---|---|---|---|---|---|---|
| FINAL RESULT | | LS | CsI | PPC | | | | |
| Radioactivity concentration ($kBq\ g^{-1}$) at the reference date (1984-12-15, 00 h UT) | 1 184.5 | 1 194 | 1 193 | 1 189.2 | 1 174 | 1 190.0 | 1 189.0 | 1 189.7 |
| Combined uncertainty ($kBq\ g^{-1}$) | 6.5 | 3.5 | 5 | 4.8 | 3 | 3.7 | 3.0 | 2.2 |
| $\gamma$-ray emission rate at the reference date ($s^{-1}\ g^{-1}$) | | | | | $43.73 \cdot 10^3$ ($4\pi\gamma$)<br>$43.6 \cdot 10^3$*<br>$43.4 \cdot 10^3$* | | | $43.73 \cdot 10^3$ |
| Combined uncertainty ($s^{-1}\ g^{-1}$) | | | | | $0.18 \cdot 10^3$ ($4\pi\gamma$)<br>$0.3 \cdot 10^3$*<br>$0.4 \cdot 10^3$* | | | $0.85 \cdot 10^3$ |

* Results by $\gamma$-ray spectrometry (Ge(Li) and Ge Hp).

Weighted mean of 8 results: (1 187.6 ± 2.4) $kBq\ g^{-1}$, at the reference date (1984-12-15, 00 h UT)

Unweighted mean " : (1 187.9 ± 6.3) $kBq\ g^{-1}$, " " " "

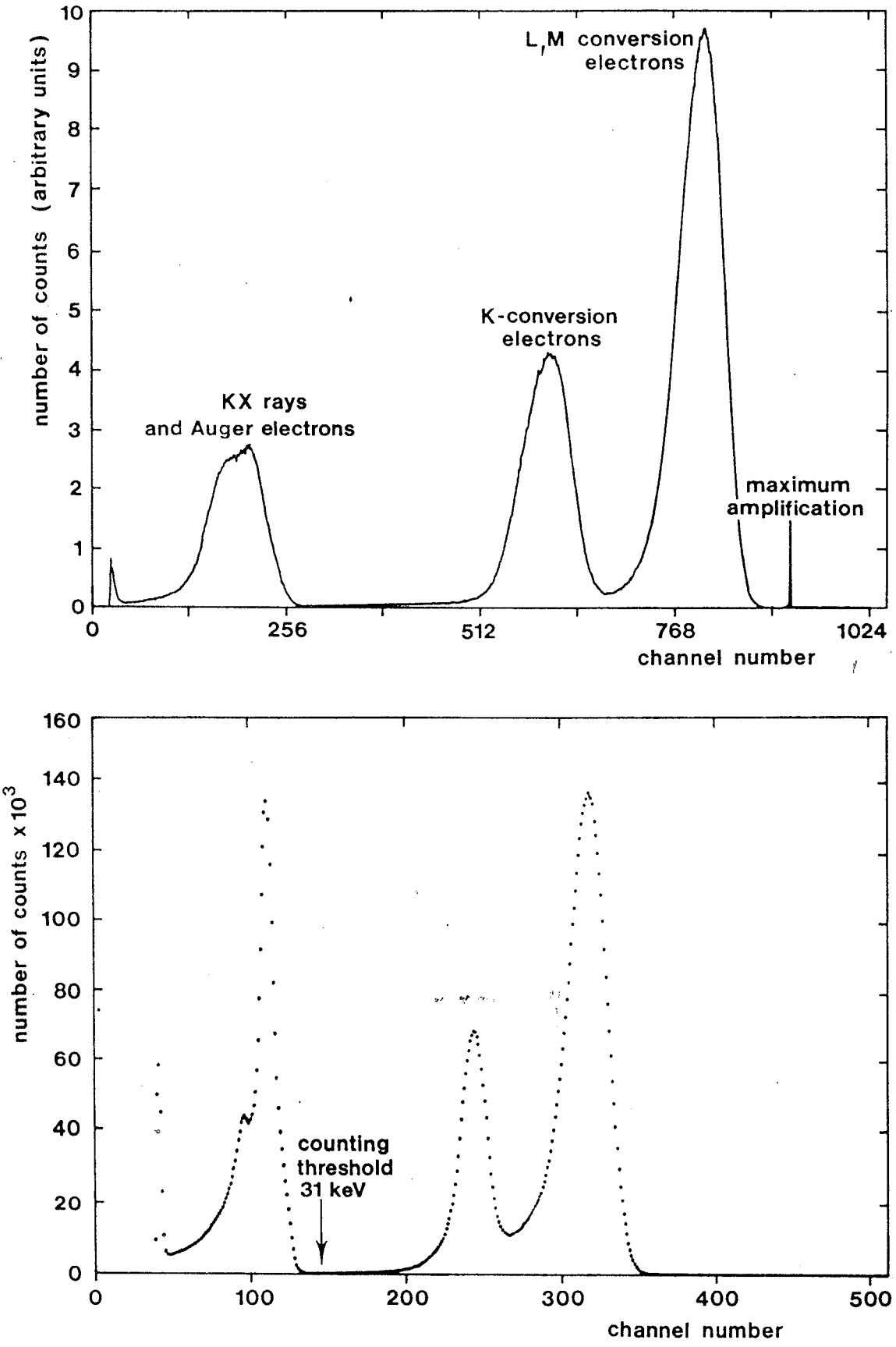


Figure 1 - Typical spectra observed with pressurized $4\pi$ proportional counters using a 9 to 1 mixture of Ar-$CH_4$ at a pressure of 0.3 MPa (BCMN, top) and of 0.5 MPa (NPL, bottom).

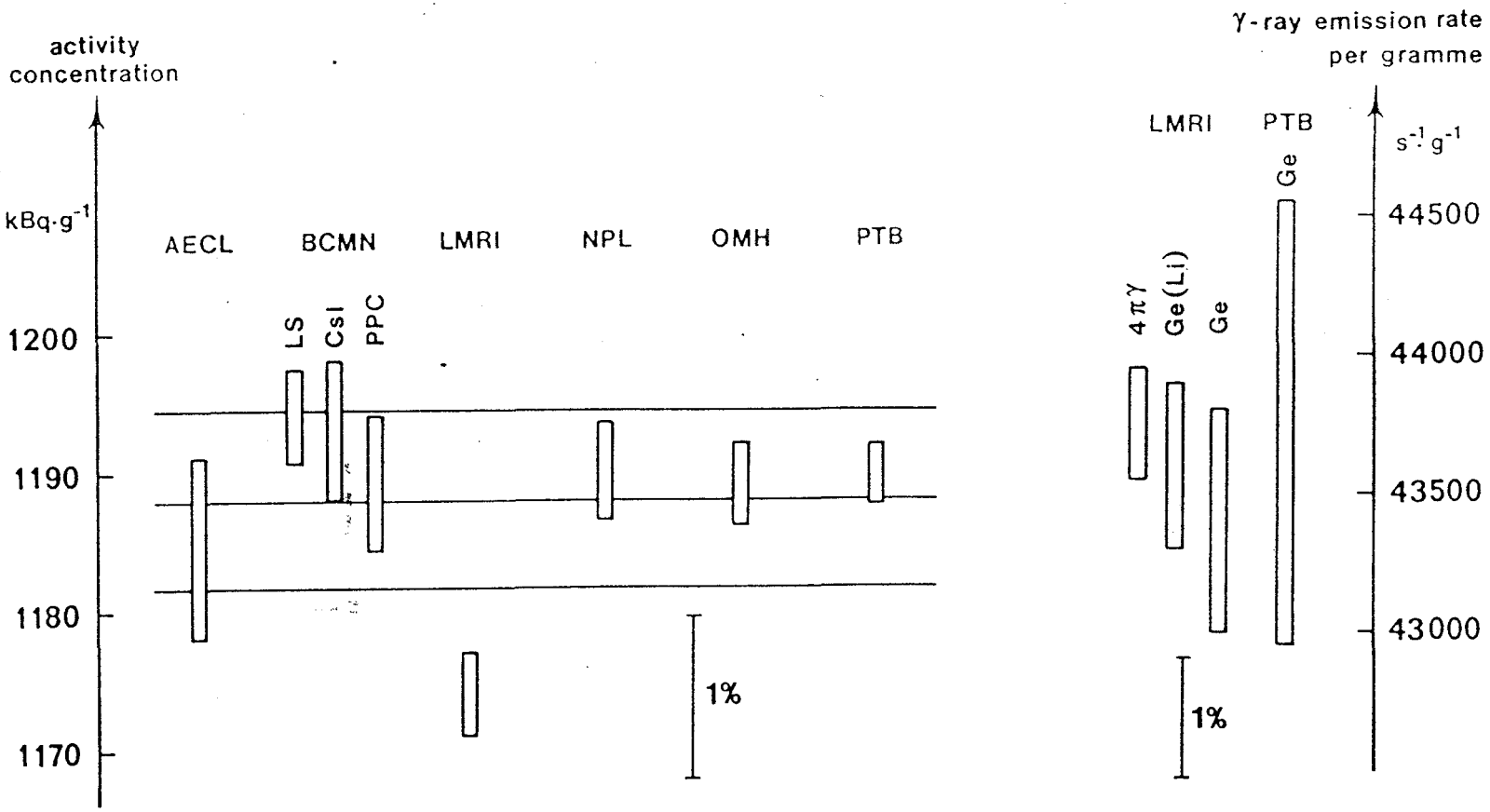


Figure 2 - Graphical representation of the results

References

[1] Table de Radionucléides, CEA-BNM, LMRI, 1982.

[2] $P_\gamma = 1/(1 + \alpha_t) = 0.0368$ (5), in R. Vaninbroukx, "Emission probabilities of selected gamma rays for radionuclides used as detector calibration standards", paper P52, IAEA Advisory Group Meeting, Nuclear Standard Reference Data, Geel, November 1984.

[3] J.M.R. Hutchinson and S.B. Garfinkel, "Standardization of cadmium-109 sources for γ-ray emission rate", Int. J. Appl. Radiat. Isot. 22, (1971) p. 405-414.

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