



**ACTIVITY MEASUREMENTS AND GAMMA
EMISSION INTENSITIES DETERMINATION IN THE
DECAY OF ^{65}Zn**

par

M-M. Bé.

And all the participants to the Euromet action 721 :
M.-N. Amiot, C. Bobin, M.-C. Lépy, J. Plagnard, J.M. Lee,
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A. Stroak.

CEA SACLAY

DIRECTION DE LA RECHERCHE TECHNOLOGIQUE

DÉPARTEMENT DES TECHNOLOGIES DU CAPTEUR
ET DU SIGNAL

LABORATOIRE NATIONAL HENRI BECQUEREL



DIRECTION DES SYSTEMES
D'INFORMATION

**RAPPORT
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Activity measurements and gamma emission intensities determination in the decay of ^{65}Zn

Abstract

Over the last twenty years, a number of laboratories have participated to the *Système International de Référence* (SIR – BIPM) and it appeared that the mass activity of ^{65}Zn determined by the gamma-ray spectrometry was less by about 2 % than the one determined by using $4\pi\beta\text{--}\gamma$ coincidence counting.

An international exercise EUROMET, action 721, was organized with the objective of improving the knowledge of decay data in the ^{65}Zn disintegration. Nine laboratories participated, sending results for the activity measurement and the 1115-keV gamma emission intensity. For the activity measurement, the participants used the $4\pi\beta\text{--}\gamma$ coincidence method mainly, resulting values and uncertainty budgets are described.

From the new gamma emission intensities measured in this exercise and, taking into account previous published values, the intensity of the 1115-keV gamma emission has been determined being equal to: 50.22 (11) %. This new value must lead to derivate activity values higher than those previously obtained, reducing the difference, with other techniques of measurement, to 1%. Moreover, the uncertainty on the emission intensity value has been divided by a factor of two.

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Mesure de l'activité et des intensités des émissions gamma lors de la décroissance du ^{65}Zn

Résumé

Durant ces vingt dernières années, un certain nombre de laboratoires ont participé au *Système International de Référence* (SIR – BIPM) et il est apparu que l'activité massique du ^{65}Zn déterminée par la méthode de spectrométrie gamma était inférieure d'environ 2 % à celle déterminée en utilisant la méthode de comptage en coïncidence $4\pi\beta\text{--}\gamma$.

Un exercice international EUROMET, action 721, a été organisé avec l'objectif d'améliorer la connaissance des données de décroissance du ^{65}Zn . Neuf laboratoires y ont participé, envoyant des résultats pour la mesure d'activité et pour la mesure de l'intensité de la raie gamma de 1115 keV. Pour la mesure d'activité, les participants ont, majoritairement, mis en œuvre la méthode de comptage en coïncidence $4\pi\beta\text{--}\gamma$. Les résultats obtenus et les diverses composantes des incertitudes associées sont décrits ici.

A partir des nouvelles valeurs des intensités gamma mesurées lors de cet exercice, et en tenant compte des valeurs précédemment publiées, l'intensité de la raie gamma de 1115 keV a été déterminée égale à : 50,22 (11) %. Cette nouvelle valeur devrait amener à déduire des valeurs d'activité supérieures à celles obtenues jusqu'à présent et, donc réduire l'écart avec les autres méthodes de 1 % environ. De plus, l'incertitude sur la valeur de l'intensité d'émission a été divisée par deux.

CEA Saclay
Direction de la Recherche Technologique
Département des Technologies du Capteur et du Signal
Laboratoire National Henri Becquerel

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Activity measurements and gamma emission intensities determination in the decay of ^{65}Zn

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Activity measurements and gamma emission intensities determination in the decay of ^{65}Zn

PART A – Euromet 721 Results

I- Introduction

Over the last twenty years, a number of laboratories have participated to the SIR (BIPM) and it appeared that the mass activity of ^{65}Zn determined by the gamma-ray spectrometry was less by about 2 % than the one determined by using $4\pi\beta\text{-}\gamma$ coincidence counting.

The activity determination using the gamma-ray spectrometry technique is directly correlated to the intensity of the 1115-keV gamma emission and to its associated uncertainty.

As the gamma-ray spectrometry is one of the easiest measurement techniques to make use of and thus, one of the most commonly used ; it is of practical interest to reduce the difference on the activity values obtained by mean of the different measurement methods.

In 2002, Zn-65 was the object of a CCRI(II) BIPM Key Comparison, the final report has not yet been published, but preliminary results show the same deviation between the measured activity values. This is why the participants in this comparison had suggested that a new exercise takes place with a solution of zinc suitable for the measurement of gamma emission intensities.

The aim of this project EUROMET 721 is then to improve the accuracy of the Zn-65 decay data.

In this exercise, the participants were requested to measure the X- and γ - emission intensities and the activity of the solution sent by the Laboratoire National Henri Becquerel (LNHB).

II- Decay scheme of zinc 65

Zn-65 disintegrates by electron capture (50,6 %) to the 1115 keV excited level and by electron capture and beta plus emission to the ground state level of Cu-65.

The decay measurements which were carried out from 1959 to nowadays concern the 1115-keV gamma-ray mainly, and its recommended emission intensity value of 0,5060 is affected by an uncertainty of 0,4%. The 344- and 770-keV low intensity gamma rays were measured only once. For the 511-keV gamma ray, four measurements lead to a beta plus branching ratio ranging between 0,0170 (10) and 0,0142 (2). New determinations could improve this value and then the accuracy on the electron capture transition probabilities.

There is only one X-rays measurement available, for the $K\alpha$ and $K\beta$ rays. So, an intensive exercise giving several other results could improve the accuracy on these values. Finally, from the comparison between the theoretical values calculated from the decay scheme and the measured values, the consistency of this decay scheme could be checked.

The technical sheet provided by the supplier mentioned the following chemical composition of the solutions: 10 µg/g of ZnCl₂ in HCl 0,1 M, which seemed unrealistic. An analysis of these solutions, by mean of an ionic chromatography apparatus, pointed out that the real amount in ZnCl₂ was 3,24 (5) mg/g.

Before the sample preparation, purity tests of the initial solution were carried out using gamma ray spectrometry (GeHP, ~ 100 cm³). An impurity (Co-60) was found, the activity ratio A(Co-60) / A(Zn-65) equal to 4 10⁻⁵. When reported, this very low level of impurity was confirmed by the participants and was then considered negligible.

All manipulations of the active solutions were carried out in a lead protected glove, and the two solutions have been finally mixed in order to obtain an homogeneous solution.

In order to obtain a final activity equal to about 850 kBq/g, this solution has been diluted. In a flask, about 30 g of HCl 0,1M then 9,2932 g of the Zn-65 radioactive solution and, then HCl 0,1M was added, giving a 74,5626 g total mass solution.

This means that we had a dilution factor equal to 8,0233 and a final activity equal to 858,7 kBq/g (15/01/04, 0 h U.T.C.).

Each ampoule was weighted empty, and 5 mL of the solution were added. Then, the ampoule was weighted again to deduce the exact mass of solution. Fifteen ampoules were prepared, and sealed by flame.

The ampoule homogeneity was checked using an ionisation chamber. The homogeneity factor was found being of the order of 0,1 %.

Each participating laboratory received one ampoule of Zn-65 before the end of January 2004. The adopted reference date was January 15, 2004, 0 h UTC.

*(M.G. Iroulart, T. Branger. Technical Note LNHB/MGI/cl/04-21 (2004)
Composition chimique d'une solution de Zn-65 pour l'exercice Euromet 721)*

IV- List of participating laboratories

EUROMET 721 : Zn-65			
Laboratory	Address	People who carried out the measurements	
NMIJ	National Institute of Metrology of Japan Tsukuba Central 2, Umezono 1-1-1 Tsukuba 305-8568, Japan	Y. Hino, Y. Sato	hino@etl.go.jp
PTB	Physikalish Technische Bundesanstalt Bundesallee 100 38 116 Braunschweig, Germany	K. Kossert (LSC) R. Klein (4πβ-γ CC) M.K.H. Schneider (γ- spectrometry) H. Schrader (IC)	Karsten.Kossert@ptb.de
CMI	Czech Metrological Institute Radiova 1, CZ 10200 Praha 10, Czech Republic	P. Dryak, J. Sochorová, P. Kovar, P. Auerbach, M. Havelka	pdryak@cmi.cz
IRMM	Institute for Reference Material and Measurements Retiesweg, 2440 Geel, Belgium	T. Altzitzoglou	Timotheos.altzitzoglou@cec.eu.int
IRD-LNMRI	Laboratorio Nacional de Metrologia das Radiações Ionizantes Av. Salvador Allende s/n° Recreio Rio de Janeiro, Brazil	A. Iwahara, M.A.L. da Silva, J.U. Delgado, C.J. da Silva	delgado@ird.gov.br

NPL	National Physical Laboratory Queens Road Teddington, Middlesex, TW11 OLW, U.K.	L. Johansson, S. Collins, A. Stroak	lena.johansson@npl.co.uk
KRISS	Korea Research Institute of Standards and Science P.O. Box 102 Yusong, Taejon, 305-600, South Korea	Jong-Man Lee, Kyung Beom Lee, T.S. Park	jmlee@kriss.re.kr , tspark@kriss.re.kr
IFIN-HH	"Horia Hulubei" National Institute of Physics and Nuclear Engineering P.O. Box MG-6 Bucharest, Romania	A. Luca (γ -ray spectrometry), M. Sahagia and A.C. Razdolescu, ($4\pi\beta$ - γ CC and sources preparation), E.L. Grigorescu (IC)	aluca@ifin.nipne.ro msahagia@ifin.nipne.ro razdo@yahoo.com elgrigorescu@yahoo.com
LNHB	Laboratoire National Henri Becquerel CEA 91191 Gif-sur-Yvette Cedex, France	C. Bobin ($4\pi\beta$ - γ CC) J. Plagnard (γ - spectrometry) M.C. Lépy (γ - spectrometry) M.N. Amiot (IC) + sources preparation	christophe.bobin@cea.fr johann.plagnard@cea.fr marie-christine.lepy@cea.fr marie-noelle.amiot@cea.fr

V- Analysis methods

The participants were requested to follow the rules expressed in "Guide to expression of uncertainty in measurements". The uncertainty components were considered as approximations of the corresponding standard deviations and added quadratically.

When the same measurement technique has been applied by several authors, a weighted average, a_w , is calculated using the combined uncertainties of the individual values as weights.

For n independent values a_i , each with a combined standard uncertainty u_{ci} ; a weight p_i proportional to the inverse of the square of the individual u_{ci} can be assigned to each value.

$$a_w = \frac{\sum_{i=1}^n p_i a_i}{\sum_{i=1}^n p_i}$$

where the weights are $p_i = 1/u_{ci}^2$.

An internal and an external uncertainty can be assigned to the mean value :

$$s_{\text{int}}(a_w) = \left[\sum_i (1/u_{ci}^2) \right]^{-1/2}$$

The internal variance $s_{\text{int}}^2(a_w)$ is the expected uncertainty of the mean, based on the individual *a priori* variances u_{ci}^2 (by uncertainty propagation).

The external uncertainty is given by the equation:

$$s_{\text{ext}}(a_w) = \left[\frac{\sum_i (a_i - a_w)^2 / u_{ci}^2}{(n-1) \sum 1/u_{ci}^2} \right]^{1/2}$$

The external variance $s_{\text{ext}}^2(a_w)$ includes the scatter of the data, and is based on the amount by which each a_i deviates from the mean when measured as a fraction of each given uncertainty u_{ci} .

A measure of the consistency of the data is given by the ratio :

$$s_{ext} / s_{int} = \sqrt{c^2 / (n-1)}$$

If this ratio is significantly greater than unity, at least one of the input data most probably has an underestimated u_{c_i} which should be increased.

VI- Activity measuring methods

Except two participants, who used an ionisation chamber and the Liquid Scintillation Counting method respectively, all the laboratories carried out the activity measurement by the mean of the $4\pi\beta\text{-}\gamma$ coincidence method.

1. $4\pi\beta\text{-}\gamma$ coincidence method

The methods of sources preparation are classical ones. The sources were prepared on gold-coated Vyns films except in one case where collodion films were preferred. Wetting agents, such as Ludox, Catanac, were added to the drops deposited and weighted using the pycnometer method. Then, the sources were, most of the time, dried under an infra red lamp. Participant number 5 used an unusual freeze-drying method. Details are reported in Table 1.

All laboratories used a gas-flow pressurized proportional counter in the electron channel, working at atmospheric pressure or under pressure from 0,1 to 0,9 MPa. The operating gas was pure methane or a (90 % Ar + 10 % CH₄) mixture.

In the gamma channel, one laboratory used a hyper-pure germanium (HPGe) detector, all of the others used a NaI(Tl) detector.

The main features of the experimental arrangements used are summarized in Table 2.

Uncertainties

The laboratories reported a detailed uncertainty budget, the main components being summarized in Table 3.

The major contributions come from: the counting statistics, the weighting, the decay scheme parameters and the extrapolation procedure. The relative importance of these contributions greatly varies in each laboratory.

Counting statistics :

The uncertainty budget contribution of this parameter varies from 0,05 % to 0,32 %. These figures mainly depend on the number of sources measured and on the counting rate. Five laboratories found a value less or equal to 0,1 %. Two laboratories obtained a value around 0,3 % ; one of them measured 4 sources with a counting time of 10×100 s and the other measured 20 sources during 3000 s.

Weighting :

The uncertainty budget for this parameter is in the range 0,05 % - 0,10 % for five participants but is equal to 0,01 % and 0,19 % for the two remaining laboratories, respectively.

Table 1. Zn-65, source preparation for activity measurements

Code Number	Ampoule	Number of samples	Dilution	Support	Count rate for γ channel (s^{-1})	Count rate for β channel (s^{-1})	Counting time ranging, (s)	Remarks
1	3	8		Gold-coated (with 20 % Pd) VYNS	100	4000	900 to 1800	
2	7	15 + 15	2,15 – 4,44	Gold-coated VYNS	400	1200	10 × 100	Drying 10 min under CH ₄ atmosphere
3	1	2	2,72	Glass ampoules (I.C.)				
4	6	11		Gold-coated collodion film + normal collodion film	300	2500	10000	Drying in vacuum dessicator after adding one drop of Ludox SM 15×10^{-4} solution
5	14	12		Gold-coated VYNS	20	4000 - 7000	20000	Freeze-drying
6	9	20		Gold-coated VYNS	40	500	5 × 500	Catanac, Drying under infra red lamp
7	5	4		Gold-coated VYNS	106	1990	10 × 100	Ludox, Drying under infra red lamp
8	8	20		Gold-coated VYNS	700	1500	3000	
9	10	8		15 mL Ultima Gold + 1 mL H ₂ O			600 × 7	LS sources Quenching agent: CCl ₄

Table 2. Euromet 721 -- Zn-65. Main parameters of the 4pb-g coincidence methods and others

Code number	Electrons channel	Photons Channel	Resolving time (μ s)/ dead time (μ s)	Correction for Decay Scheme Parameters	Extrapolation Efficiency function %	Other information
1	4 π pill-box type proportional counter (90% Ar + 10% CH4) 0,9 MPa 4P-PP-MX-NA-GR-CO	1 NaI(Tl) detector d 76 mm, h 76 mm	1,092/8,069	No	72	
2	4 π proportional counter CH4 atmospheric pressure 4P-PC-MX-NA-GR-CO	NaI(Tl) detector d 76,2 mm, h 76,2 mm	2,01/6,107	No	34	
4	4 π proportional counter (90% Ar + 10% CH4) 0,4 MPa	NaI(Tl) detector d 76 mm, h 76 mm	1,60/5,00		55	
5	4 π proportional counter 90 % Ar + 10 %CH4 atmospheric pressure 4P-PC-MX-GH-GR-AC	HPGe d 49 mm, vol. 67 cm ³	Extended (β) & 50 (γ)	PK value and branching ratio		Anti coincidences counting
6	4 π proportional counter (90% Ar + 10% CH4) Atmospheric pressure	NaI(Tl) detector d 102 mm, h 95 mm	0,74/1,65		56	by feeding in two independent sets of random pulses, the resolving time was calculated from the knowledge of the accidental coincidence rate
7	4 π pill-box type proportional counter CH4 atmospheric pressure 4P-PC-BP-NA-GR-CO	NaI(Tl) detector d 76 mm, h 75 mm	1,06/10	yes	30	
8	Gas flow 0,1 MPa (90% Ar + 10% CH4) 0,1 MPa	NaI(Tl) detector d 76 mm, h 76 mm	1/5	yes	51	
3	Calibrated Ionisation Chamber 4P-IC-GR-00-00-00					IC calibrated by a Zn-65 solution standardized by 4 π (β ,A,X)- γ coincidences method in 2003
9						LSC, Ciemat-Nist method

Decay scheme parameters :

Three laboratories applied a correction taking these parameters into account and two explicitly reported a budget around 0,1 %.

Extrapolation procedure :

Except for two laboratories, this item gives the largest contribution to the final uncertainty. It varies from 0,01 % to 0,34 % following the participating laboratory.

2. Other methods

A laboratory used a well-type ionisation chamber previously calibrated with a Zn-65 solution standardized using a $4\pi(\beta, A, X)\text{-}\gamma$ coincidence method. Two glass ampoules were made.

The Ciemat-Nist liquid scintillation method has been used by another participant.

Uncertainties

These are equal to 0,34 % (CI) and 0,9 % (LSC) respectively. The main component comes from the extrapolation procedure.

3. Influence of half-life

Participant 1 sent two series of results associated with two different half-life values.

1. with $T_{1/2} = 243,94$ (21) d, the activity of the solution was found equal to $860,2$ (18) kBq g^{-1}
2. with $T_{1/2} = 244,06$ (10) d, the activity of the solution was found equal to $860,1$ (18) kBq g^{-1} (adopted value)

The difference between the two activity values is greatly less than the uncertainty, therefore the influence of the half-life value can be considered negligible.

Participant 9, despite the recommendations, used a half-life of 244,26 (26) d, i.e. 0,08 % greater than the adopted value. The used of the recommended half-life value would have resulted in an activity concentration value higher by 0,024 % than that reported by the participant. Due to the above conclusion and an uncertainty of 0,9 % on the activity value (854 (8) kBq g^{-1}), the results sent by this participant were accepted in this exercise.

4. Results

The Zn-65 decay scheme seems simple, nevertheless in a first analysis the results sent by the participants were very discrepant, so they were asked to check them. The second analysis led to results in better agreement. The results of the comparison are showed in Table 4.

However, the final uncertainty, in all cases, is less than 0,5 % which seems optimistic in view of the overall exercise.

Since each laboratory reported a detailed uncertainty budget a rough sketch of analysis was made. But, it is difficult to clearly conclude, as parts of the different components of the uncertainty could have been included in a contribution or in another one, depending on the method of extrapolation used. The final uncertainty is linked with the high "metrological" quality of the source and the duration of the counting time.

Table 3. Zn-65. Uncertainty budget in the 4pb-g coincidence methods and LSC

Code Number	Counting statistics %	weighting %	Dead time	counting time %	Background %	Decay scheme parameters %	Half-life %	Extrapolation %	Others	Total Uncertainty %
1	0,10	0,19	<0,02		0,02		0,01	0,01	0,01	0,20
2	0,08	0,01	0,01	0,01	0,04		0,01	0,23	0,03	0,26
4	0,10	0,10	0,10	0,01	0,03		0,01	0,17		0,25
5	0,05	0,05		0,01	< 0,02	0,13	< 0,02	0,34		0,37
6	0,06	0,05	0,01	< 0,01	0,05	0,05	0,05	0,1	0,15 (shape of extrapolation)	0,22
7	0,32	0,05	0,015	0,001	0,1 ; 0,1 (γ) ; (4 π PC)		0,041	0,22		0,42
8	0,3	0,06	<0,01	0,01	0,06	0,1	0,02	0,32		0,34
9	0,1	0,1	0,1	0,05	0,005	0,23	0,02	0,8	0,1 (stability)	0,9

Table 4. Euromet 721 -- Zn-65. Activity measurement results				
Code Number	Method	Activity	Uc	Rel. Uc
		kBq/g		%
1 - A	4 π β - γ coincidence counting	860,2	1,8	0,2
1	4 π β - γ coincidence counting	860,1	1,8	0,2
2	4 π (PC)e,X- γ coincidence counting	858,2	2,3	0,26
3	Calibrated Ionisation Chamber	866,881	3,253	0,38
4	4 π (PPC)e,X- γ coincidence counting with efficiency variation	864,9	2,2	0,27
5	4 π β (PC)- γ anticoincidence method	856,8	3,2	0,37
6	4 π (PC)e,X- γ coincidence counting using voltage reduction method	858,82	1,89	0,22
7	4 π (PC) β - γ coincidence counting with efficiency extrapolation	860,0	3,6	0,42
8	4 π (PC)e,X- γ coincidence counting	855,33	2,91	0,34
9	LSC using Ciemat-Nist method	854	8	0,9
Mean Value		860	1,2	0,13

Furthermore, as this radionuclide decays by electron capture, it seems that corrections due to undetected low energy x-rays and Auger electrons should be applied, in the case of measurements by the coincidence counting method. The range of this correction depends on the ratio of the sub shell capture probabilities (P_K and P_L) of the two electron capture transition branches to the excited level and to the ground state in the daughter nuclide, as explained in Funck *et al.* (1983). Only three laboratories applied this correction, see *Decay scheme parameters*.

(E.Funck and A.Nylandstedt Larsen. *Int. J. Appl. Radiat. Isot.* 34,3 (1983) 565.

Influence from low energy x-rays and Auger electrons on ^{40}K coincidence measurements of electron-capture-decaying nuclides.)

Table 5 lists the unweighted and weighted means for the results obtained by all methods (data set S1) and for the results obtained by the coincidence counting method only (data set S2 and S3) ; U_c is the standard deviation in the case of the unweighted mean and the external uncertainty (see §5) in the case of the weighted mean.

After processing the data set S2, the value of 864,9 (22) is declared outlier by applying the Chauvenet's criterion. The data set S3 is then used, without this value.

Table 5. Zn-65, unweighted and weighted means of activity measurements results

	S1		S2		S3	
	All methods (9 results)		Coincidence Counting method (7 results)		Coincidence Counting method (6 results)	
	A (kBq g ⁻¹)	U_c (kBq g ⁻¹)	A (kBq g ⁻¹)	U_c (kBq g ⁻¹)	A (kBq g ⁻¹)	U_c (kBq g ⁻¹)
Unweighted mean	859,4	1,4	859,2	1,2	858,2	0,8
Weighted mean	860,0	1,2	859,6	1,1	858,6	1,0

In the three cases the set of results are consistent. The influence of the two values obtained by ionisation chamber and liquid scintillation counting is very low due to their large uncertainties compared to the others (data set S1 compared to data set S2).

VII- Photon emission intensities determination

Nine participants carried out measurements of the intensity of the 1115-keV gamma emission, at least. Seven of them, sent results for the intensity of the 511-keV photon emission which comes from the beta plus annihilation. Only two participants measured the x-ray emission intensities.

1. Experimental arrangements

All the participants used a coaxial type germanium detector (HPGe) to measure the gamma emission intensities. One participant used a planar HPGe and another a Si(Li) in order to measure the x-ray emissions.

Main features of the experimental set-up are listed in Table 6.

2. Analysis procedure

Table 7 shows the list of radionuclides with their emitted x- or γ -rays used as standards, by each participant, to work out the efficiency response of the detector.

Table 6. Description of detection systems and their geometry arrangements							
Code Number	Type	Volume (cm ³) d (cm) x t (cm)	FWHM (keV) at 5,9/122,0/ 1332,5 keV	Composition and thickness of the window (cm)	Crystal to window Source to detector (cm)	Collimator : composition and dimensions (cm)	Sources used d (cm) / m (mg)
1	HP-Ge coaxial n type	127 5,09 x 6,25	0,84/ # / 1,92	Be - 0,05	0,3 18,5		2 0,3 / ~ 10
2	HP-Ge coaxial	58 6,3 x 5,9	# /0,838/ 1,78	Al - 0,05	0,5 25		5 point sources 3,5 / ~ 25
3	HP-Ge coaxial p type	263,7 6,49 x 7,97	# / 0,90/ 1,90	Al - 0,1	0,4 10		3 1,75 / ~ 24 -- 32
4	HP-Ge coaxial p type	365 6,90 x 9,89	# / 1,02/ 1,84	Mg - 0,15	0,4 25		5 0,7 / ~ 10 -- 34
4	HP-Ge coaxial p type	173 5,69 x 6,91	# / 0,74/ 1,73	Al - 0,127	0,3 15		
5	HP-Ge	95,35 4,8 x 5,27	0,53 / # / 1,73	Be - 0,05	0,3 10,35		6 0,4 - 0,7 / ~ 19 - 57
5	Si(Li)	0,3 x 0,17	0,155/##	BN - 0,15 µm	0,3 5,092		6 0,2 - 0,4 / 18 - 57
6	HP-Ge coaxial n type	43,3 x 40,0	0,714 / # / 1,79	Be - 0,5	3 10		10 d 0,5 -- 1,0
7	HP-Ge coaxial p type	112,5 5,3 x 5,1	# / 1,1 / 2,0	Al - 0,05	0,7 44,5 and 0,1		6 3 / ~ 5 -- 22
8	HP-Ge coaxial n type	34,6 4,91 x 5,74	# / # 1,85		0,3 41,8		7 1 - 1,3 / ~ 90 -- 125
9	HP-Ge coaxial p type	141 5,85 x 5,35	#/0,9/2,0	Al - 0,1	0,5 14,6	Cd 0,2 x 1,0	8 0,3 - 0,5 / 12 - 105
9	HP-Ge planar n type	148 8,00 x 3,00	0,6/0,9/2,4	Carbon ep - 0,11	0,6 12,1		
9	HP-Ge planar	7,6 2,55 x 1,5	0,17/0,35/#	Be - 0,015	0,5 8,2		

Table 7. X- and gamma ray lines used for efficiency calibration

Nuclide	Energy (keV)	Code number											
		1	2	3	4	5 (1)	5 (2)	6	7	8	9 (1)	9 (2)	9 (3)
Mn-54	5,47						y						y
Fe-55	6,0	y					y						
Co-57	6,5	y					y						
Am-241	12						y						y
Sr-85	13 & 15	y											
Am-241	14						y						y
Y-88	14 & 16	y											
Co-57	14,4	y					y						
Sr-85	15	y											
Y-88	15,8	y											
Am-241	18												y
Nb-93m	17 & 19	y											
Am-241	21												y
Cd-109	22,1	y											
Sn-113	24,1	y											
Cd-109	25,0	y											
Am-241	26,3	y					y						y
Sn-113	27,4	y											
I-125	27,4	y											
Ba-133	30,9	y											
I-125	31,1	y											
Cs-134	32,1	y											
Cs-137	32,1	y											y
Ce-139	33,1	y											
Ba-133	35,1	y											
I-125	35,5	y											
Cs-137	36,4	y											
Cs-137	37,3	y											y
Ce-139	37,8	y											
Ce-139	38,7	y											
Eu-152	39,9	y											
Pb-210	46,5	y											
Ba-133	53,2	y											
Am-241	59,5	y	y						y		y	y	y
Hg-203	70,8	y											
Hg-203	72,9	y											
Ba-133	79,6	y											
I-131	80,2	y											
Ba-133	81	y											
Hg-203	82,5	y											
Cd-109	88	y	y							y			
Eu-152	121,8	y	y	y	y	y			y				
Co-57	122,1	y	y	y	y	y				y	y	y	
Eu-154	123												
Co-57	136,5	y		y		y				y			
Ba-133	160,6					y							
Ce-139	165,9	y	y			y				y			
Sb-125	176,4				y								
Ho-166m	184,4			y	y								
Ho-166m	190,7			y									
Ir-192	205,8					y							
Ho-166m	214,8 & 215,9			y									
Ba-133	223,3			y									
Ra-226	242,0	y											

Table 7. X- and gamma ray lines used for efficiency calibration

Nuclide	Energy (keV)	Code number											
		1	2	3	4	5 (1)	5 (2)	6	7	8	9 (1)	9 (2)	9 (3)
Eu-152	244,7	y	y		y				y		y	y	
Eu-154	247				y								
Sn-113	255,1	y	y										
Ho-166m	259,7			y									
Ba-133	276,4	y		y	y	y			y				
Hg-203	279,2	y											
Ho-166m	280,4			y	y								
I-131	284,3	y											
Ra-226	295,2	y											
Eu-152	295,9			y									
Ir-192	296				y								
Ho-166m	300,7			y									
Ba-133	302,9	y		y	y	y			y				
Ir-192	308				y	y							
Ir-192	316				y	y							
Cr-51	320,1	y								y			
Ho-166m	339,8			y									
Eu-152	344,3	y	y	y	y	y			y		y	y	
Ra-226	351,9	y											
Ba-133	356,0	y		y	y	y			y				
I-131	364,5	y											
Eu-152	367,8			y									
Ba-133	383,9	y		y	y	y			y				
Sn-113	391,7	y	y		y								
Ho-166m	410,9			y	y								
Eu-152	411 & 416			y		y							
Sb-125	427				y								
Eu-152	444,0			y		y			y				
Ag-110m	446,8					y							
Ho-166m	449,8 & 451,5			y									
Sb-125	463,0				y								
Ir-192	468,0				y	y							
Cs-134	475,3					y							
Ir-192	484,8					y							
Sr-85	514,0	y	y						y	y			
Ho-166m	529,8			y	y								
Cs-134	563 & 569			y	y	y							
Bi-207	569,0				y								
Ho-166m	571,0			y									
Eu-152	586,3			y									
Eu-154	591,0			y									
Sb-125	600			y									
Ir-192	604				y	y							
Cs-134	604,7	y				y				y			
Sb-125	606				y								
Ra-226	609,3	y											
Ir-192	612				y	y							
Ag-110m	620,4					y							
Sb-125	635				y								
I-131	637,0	y											
Eu-152	656,5			y									
Ag-110m	658,0					y							
Cs-137	661,7	y	y	y	y	y			y	y	y	y	
Ho-166m	670,5			y	y								
Eu-152	671 & 675 & 679			y									

Table 7. X- and gamma ray lines used for efficiency calibration

Nuclide	Energy (keV)	Code number											
		1	2	3	4	5 (1)	5 (2)	6	7	8	9 (1)	9 (2)	9 (3)
Ag-110m	677,6					y							
Ag-110m	687 & 689					y							
Eu-152	688,7			y									
Ag-110m	706,7					y							
Ho-166m	711,7			y	y								
Ag-110m	744,3					y							
Eu-154	756			y									
Ag-110m	763,9					y							
Eu-152	764,9 & 768,9			y									
Eu-152	778,9	y	y	y	y	y			y		y	y	
Cs-134	795,9	y				y				y			
Cs-134	802,0	y				y							
Ho-166m	810,3			y	y								
Ag-110m	818,0					y							
Ho-166m	830,6			y	y								
Mn-54	834,8	y	y		y	y				y	y	y	
Eu-152	867,4			y		y							
Eu-154	873			y									
Ag-110m	884,7					y							
Y-88	898,0	y	y			y				y			
Eu-152	919,4			y									
Eu-152	926,3 & 930,6			y									
Ag-110m	937,5					y							
Ho-166m	950,9			y									
Eu-152	964,1	y	y	y	y	y			y		y	y	
Eu-154	996				y								
Eu-154	1004				y								
Cs-134	1038,6					y							
Bi-207	1063				y								
Eu-152	1084 & 1086 & 1090			y	y	y					y	y	
Eu-152	1112,1	y		y	y	y			y				
Ho-166m	1120,3			y									
Ra-226	1120,3	y											
Ho-166m	1146,8			y									
Co-60	1173,2	y	y	y	y	y			y	y	y	y	
Eu-152	1213			y		y					y	y	
Eu-154	1274				y								
Na-22	1274,5	y							y	y			
Eu-152	1292,8 & 1299,2			y									
Co-60	1332,5	y	y	y		y			y	y	y	y	
Cs-134	1365,2					y							
Ag-110m	1384,3					y							
Eu-152	1408,0	y	y	y	y	y			y		y	y	
Ag-110m	1475,8					y							
Ag-110m	1505,0					y							
Ag-110m	1562,3					y							
Ra-226	1764,5	y											
Bi-207	1770				y								
Y-88	1836,1	y	y			y				y			
Ra-226	2204,2	y											
Ra-226	2447,9	y											

Table 8. Zn-65, efficiency interpolation and peak analysis methods

Code Number	Efficiency interpolation	Peak analysis
1	Linear least square fit with cubic spline functions	a) Gaussian fit, background determined between -3σ to $+3 \sigma$ and limited by a linear extrapolation from range : between -6σ to -3σ (at lower energy) and linear extrapolation from $+3 \sigma$ to $+6 \sigma$ (at higher energy), with a step at peak energy. b) Sum of channel contents, reduced by background determined by method a)
2	Dual curve, polynomial regression of 4 th degree. Experimental points and curve were used only for detector model verification. Efficiency was calculated by Monte Carlo method (MCNP)	Net peak area was determined as a full number of impulses in a peak region and continuum was subtracted. Six channels from both sides of the peak and step function were used for continuum subtraction.
3	The efficiency curve as function of energy for the spectrometer was obtained using fifth-degree polynomial.	For the determination of peak area (net counts), at first, the zone of interest was divided in a total peak and a normal background peak region. After subtracting the normal background, the net area was determined by simple integration between each limit manually or automatically defined.
4	The energy region between the knee value (about 110 keV) and 1500 keV was fitted using the inverse third polynomial function, $y = y_0 + a/x + b/x^2 + c/x^3$	The background spectrum was subtracted from each sample spectrum first of all, and the ROI of the peak was selected manually. Two additional background levels for the left (lower) and right (higher) sides of the peak were prepared by averaging the counts outside of the ROI and were subtracted from the background-subtracted spectrum by bisecting the ROI. The net count of the peak was then obtained by summing the counts within the ROI.
5	Gamma : Polynomial function adjusted with the experimental points. Degree of the polynom : 4 X-ray : fit of a theoretical function including absorbing layers and detector geometry	Gamma : Ground subtracted by the trapezium method. X-ray : peak fitting using a Voigt shape (COLEGRAM software)
6	Linear fit in a log-log plot	Gaussian fit using the Canberra GENIE software.
7	The computer code EFFIGIE.exe, developed by LNHB/BNM-CEA, Saclay, France, was used.	The net area of the peaks was determined by using the software provided by the manufacturer of the equipment (CANBERRA AccuSpec ver. 7.3c). For the multiplets analysis (1115 keV – ⁶⁵ Zn and 1120 keV – ²¹⁴ Bi from the background) the computer code COLEGRAM (LNHB/BNM-CEA, Saclay, France) was used.
8	Fitting to the function of $\ln(E(x))=a+b*\ln(x)$ where 796 keV < x < 1333 keV , these nuclides are used to obtain wider range of efficiency curve.	A background curve was calculated using background regions of 20 channels that were both sides of the peak. The net peak counts were obtained by subtracting background counts from gross counts.
9	A quadratic polynomial was used to fit the efficiency curve (log-log) using the data from ¹³⁷ Cs, ⁵⁴ Mn and ⁶⁰ Co.	The analysis was done by using the Gammavision-32 (Ortec). It was considered better instead of fitting the peaks to simply integrate the counts under the peaks and subtract a linear background.

A short description of the efficiency interpolation peak analysis method is given in Table 8. Most of the laboratories determined a typical background calculated taking into account both sides of the region of interest (ROI). The net count of the peak was obtained by summing the channel contents within the ROI and subtracting the background spectrum.

The main applied corrections were due to pile-up and dead-time losses (Table 9).

Table 9. Main corrections applied for photon intensity measurements

Code Number	Coincidence Summing effect	Absorption by the screens between sample and detector	Self Absorption	Pile-up	Escape peak
1	yes	No (*)	No	yes	No
2	no	no	no	yes	no
3	no	no	no	no	no
4	no	no	no	yes	no
5	no	no	no	no	no
6	yes	yes	no	yes	no
7	no	no	no	no	no
8	yes	no	no	yes	no
9	yes	yes	yes	yes	no

(*) Included in efficiency calibration

3. Uncertainties

The laboratories reported a detailed uncertainty budget, the main components are summarized in Tables 10, 11, 12.

a) 1115-keV photon emission

The main components of the uncertainty come from the uncertainty on the efficiency and from the uncertainty on the activity value. The uncertainty components were added quadratically. The final uncertainty is given for one combined standard uncertainty.

The uncertainties determined by the participants are in the range 0,5 % - 1,3 %.

Table 10. Uncertainty budget in the photon emission intensity results for the 1115-keV line, in %.

Code Number	Counting Stat.	Peak area	Efficiency	Correction factor	Others	Activity Uncertainty	Total Uncertainty %
1	0,1	0,18	0,47	0,03		0,20	0,56
2	0,041	0,03	0,6	0,01		0,26	0,66
3	0,04		0,38	0,2		0,38	0,57
4	0,07	0,01	0,4	0,01	0,14	0,27	0,49
5	0,1	0,1	0,3			0,37	0,5
6	0,17	0,1	1,1	0,05		0,22	1,14
7	-	1,1	0,69		0,067	0,42	1,3
8	0,1	0,2	0,8	0,1		0,34	0,9
9 - 1	0,05	0,1	0,6	0,01		0,9	1,1
9 - 2	0,05	0,1	0,9	0,01		0,9	1,3
							WM : 0,9

b) 511-keV photon emission

Part of the ^{65}Zn decay occurs by emission of positrons. Most of them slow down to thermal velocity in the material surrounding the source and then annihilate with an electron and produce two 511-keV photons. Therefore, as a first approximation the 511-keV photon emission intensity is 2 times $P(\beta^+)$. The main correction to this relationship is that some of the positrons annihilate before they reach thermal energies. In this case the two photons have energies that differ from 511 keV and produce a continuous photon spectrum. This is called annihilation-in-flight.

In γ -ray spectrometry, this phenomenon has the effect of removing, from the 511-keV peak, a fraction of the annihilation photons, the magnitude of this effect depends on the material in which the β^+ are stopped. (see e.g. Shizuma, 1980)

(Shizuma, K., Hamanaka, S., Yoshizawa, Y. (1980)

Continuous radiation spectra of positron annihilation in flight. J. Phys. Soc. Japan **49**, 847.)

Seven participants sent results for this particular emission.

The β^+ have a certain range in the matter, they can annihilate in the radioactive source but also elsewhere in the surrounding (e.g. in the source cover foil, in the source holder, etc.) so, the source geometry, for this particular emission, cannot be regarded as a point source geometry.

In order to stop the positrons in a precise volume and to have the annihilation quanta generated in a known position, two laboratories (5 and 9) used a specific geometry arrangement. Participant 5 encapsulated the source in a small 1-mm thick lead cell ; participant 9 covered the source with 1-mm thick aluminium disk on both sides.

Four laboratories (1, 2, 5 and 9) took into account the annihilation-in-flight phenomenon, three of them (1, 5 and 9) reported 0,2 %, 0,34% and 0,5 % corrections respectively. Participant 2 used a peak region wider than for other peaks.

Table 11. Uncertainty budget in the photon emission intensity results for the 511-keV line, in %.

Code Number	Counting Stat.	Peak area	Efficiency	Correction factor	Annihilation	Others	Activity Uncertainty	Total Uncertainty %
1	0,2	0,6	0,52	0,03	0,2		0,20	0,87
2	0,1	0,6		0,01		-	0,26	0,7
3	0,24	-	0,37	0,20		-	0,38	0,62
4	0,22	0,25	0,40	0,01			0,27	0,59
5	0,2	0,1	0,5	0,1	0,34	0,1	0,37	0,7
7	-	1,65	1,94			0,059	0,42	1,4 (mean)
9	0,2	0,1	1,2	0,1	No		0,9	1,5
9	0,2	0,1	1	0,1			0,9	1,4
								WM 1,4

c) 344 and 770-keV photon emissions

Due to their weak intensities these emissions are difficult to measure. Only two laboratories (2 and 9) reported relative values with uncertainties varying from 8 to 50 %.

d) X-ray emissions

It must be noted that only two laboratories (5 and 9) carried out measurements of the x-ray emission intensities. The K x-ray energies of the Copper (^{65}Zn daughter) are in the 8-keV energy range, i.e. in a region where there are no confident standard emission intensities for detector calibration. The efficiency calibration was done, for the two participants, by fitting the available efficiency standard data. The uncertainty on the detector efficiency is then of the order of several percent.

The total reported uncertainties by the two participants are in the range 5 – 10 %, the main component comes from the uncertainty on the detector efficiency.

Table 12. Uncertainty budget in the x-ray emission intensity results, in %.

Code Number	Counting Stat.	Peak area	Efficiency	Correction factor	Others	Activity Uncertainty	Total Uncertainty %
5	0,69	0,2	5	< 0,1	0,1	0,37	5,1
9	0,1	0,5	9		1	0,9	9,1

4. Results

a) 1115-keV photon emission

Table 13 lists the 1115-keV photon emission intensity, per one decay, obtained by the participants from their own activity measurement result (columns 2, 3, 4) with the combined standard uncertainty calculated as the square root of the combined variance. The last line gives the weighted mean and the external uncertainty. In this case, all the input values can be thought as independent.

In columns 5, 6, 7 and in columns 8, 9, 10 ; the gamma intensity and the uncertainty given by each participant were recalculated with the mean activity values determined from all the measured values (data set 1) and from the values given by the coincidence counting technique (data set 3) respectively. It must be pointed out that, in these two cases, the input values are correlated, a component of correlation should be added to the standard uncertainty.

Taking into account that :

- the relative uncertainties deduced in columns 7 and 10, after gamma intensity recalculations, are worse than those in column 4 ;
- a factor of correlation is introduced when the same activity value is used for all the participants ;
- there is a good agreement between the three results within their respective uncertainty limits ;

Only the original values sent by the participants (i.e. columns 2, 3, 4) will be used in the following.

Moreover this set of values is consistent, with a reduced χ^2 of 0,79 ; then the adopted result, in this exercise, for the 1115-keV emission intensity is 0,5021 (10) per one disintegration.

Table 13. 1115-keV photon emission intensity, final results. Weighted mean and external uncertainty.

Code	Participant activity			$A = 860,0 \pm 1,2 \text{ kBq g}^{-1}$			$A = 858,6 \pm 1,0 \text{ kBq g}^{-1}$		
	Intensity	Uc	Rel.Uc %	Intensity	Uc	Rel.Uc %	Intensity	Uc	Rel.Uc %
1	0,5015	0,0028	0,56	0,5016	0,0027	0,54	0,5024	0,0027	0,53
2	0,5010	0,0033	0,66	0,5000	0,0032	0,64	0,5008	0,0032	0,64
3	0,5060	0,0029	0,57	0,5100	0,0023	0,45	0,5109	0,0023	0,44
4	0,5034	0,0025	0,49	0,5063	0,0022	0,44	0,5071	0,0022	0,43
5	0,4984	0,0025	0,5	0,4965	0,0018	0,36	0,4974	0,0018	0,35
6	0,5005	0,0057	1,14	0,4998	0,0056	1,13	0,5006	0,0056	1,12
7	0,4962	0,0065	1,3	0,4962	0,0061	1,24	0,4970	0,0061	1,24
8	0,507	0,005	0,9	0,5042	0,0043	0,84	0,5051	0,0042	0,84
9	0,503	0,005	0,9	0,4995	0,0015	0,29	0,5003	0,0014	0,28
W Mean	0,5021	0,0010	0,20	0,5014	0,0016	0,32	0,5022	0,0016	0,31
$c^2/n-1$	0,79			3,67			3,71		

(Remark on the above tables : when using the weighted mean activity value to re calculate the photon emission intensity, the individual uncertainties decrease, but the spreading of the whole set of values increases, as shown by the reduced χ^2 .)

Figure 1 gives the diagram for the activity measurement results and for the 1115-keV gamma emission intensity results.

b) 511-keV photon emission

As explained above, this particular γ -ray cannot be treated as the other ones.

The reported values (1, 2, 5, 9) which take into account the annihilation-in-flight are in good agreement. The weighted mean and the standard uncertainty for these four values are, per one disintegration : $0,02842 \pm 0,00013$

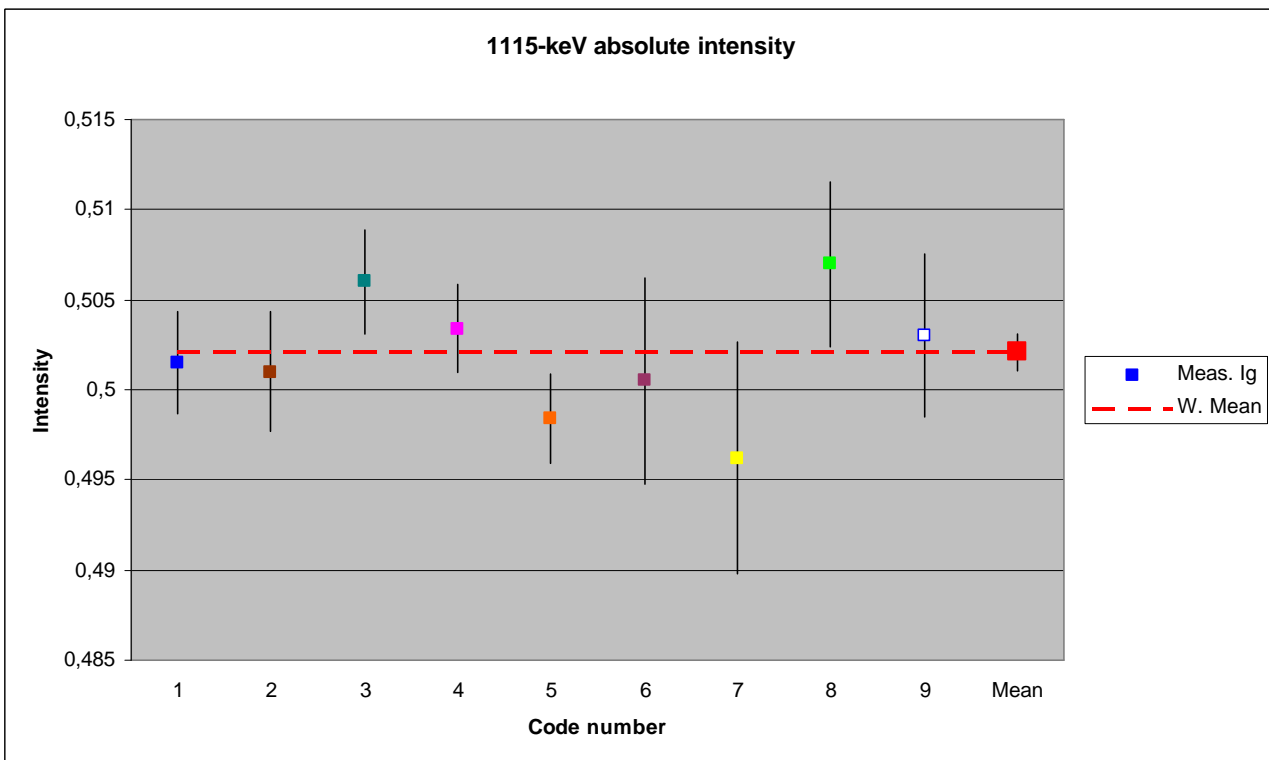
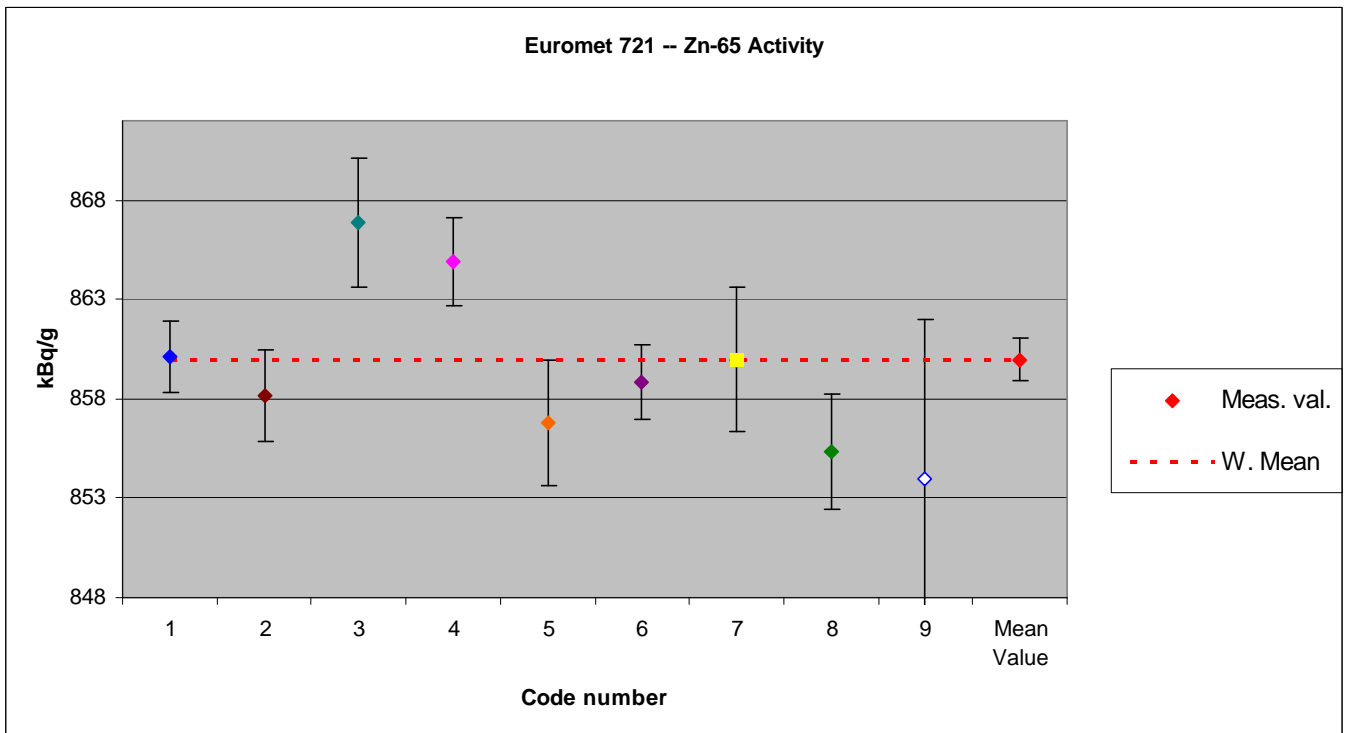
Table 15. 511-keV photon emission intensities

Code	Intensity	Uc	Rel.Uc	Correction for annihilation, in %
1	0,0281 *	0,0003	0,87	0,2
2	0,02841 *	0,00027	0,95	Wider peak region
3	0,0275	0,00017	0,62	
4	0,0300	0,00018	0,59	
5	0,02848 *	0,00020	0,7	0,34
7	0,0286	0,0004	1,4	
9	0,0288 *	0,0004	1,4	0,5

(*) taking annihilation-in-flight into account, magnitude given in the last column.

Additional 511-keV gamma photons are created by electron-positron pair creation as the internal pair creation coefficient is of the order of 10^{-6} , this emission is negligible.

Figure 1 : Zn-65 activity measurement results and 1115-keV gamma intensity results



c) 344 and 770-keV photon emissions

Three laboratories (1, 2 and 9) reported results for these weak emissions.

One participant (1) gave absolute values in terms of detection and decision limits ; the two other participants carried out measurements in relative values taking the 1115-keV as the reference line.

Participant 2 activated a zinc (99,99%) foil by thermal neutrons and obtained a Zn-65 activity of the order of 10 MBq, this made it possible to obtain better uncertainties.

Table 14 : Intensity per one disintegration, in absolute value (1) and in relative values (2, 9)

Code	344-keV			770-keV		
	Intensity			Intensity		
1	< 0,000 091	Detection limit		< 0,000 15	Detection limit	
1	< 0,000 14	Decision limit		< 0,000 23	Decision limit	
Relative values	Intensity	Uc	Rel.Uc %	Intensity	Uc	Rel.Uc %
2	0,000 050 67	0,000 003 65	7,2	0,000 053 58	0,000 004 39	8,2
9	0,000 022	0,000 008 6	39	0,000 03	0,000 017	57

d) X-ray emissions

Two laboratories (5 and 9) carried out specific measurements of the x-ray emission intensities. The two results are not, or are just, consistent within their uncertainty limits.

The solution sent to the participants contained a high carrier concentration nevertheless it seems that this did not affect the results. Participant 5 carried out measurements with six sources of various masses (see Table 6) without observing a quantifiable correction for auto-absorption.

Table 16. X-ray emission intensity results.

Code	K α			K β		
	Intensity	Uc	Rel. Uc %	Intensity	Uc	Rel.Uc %
5	0,321	0,016	5,1	0,0450	0,0023	5,1
9	0,39	0,035	9,1	0,052	0,0047	9,1

As far as the reported x-ray emission intensity measured values are scarce in the literature; as far as it exists a lot of values of the K β /K α ratio. A brief comparison is made in Table 17, the evaluated K β /K α ratio is from Schönfeld (1996).

(Schönfeld, E., Janssen, H. 1996 Nucl. Instrum. Meth. Phys. Res. **A369**, 527.)

Table 17. Comparison of the K β /K α ratio

Code	K β /K α	
		Uc
5	0,140	0,009
9	0,133	0,017
Eval. Value	0,1391	0,0014

VIII- Findings for the Euromet 721 exercise

Nine laboratories participated and sent results of measurements, showing their interest for that kind of international exercise.

Several difficulties appeared in measuring the activity of the solution or in measuring the photon emission intensities.

As most of the participants used the coincidence counting method to measure the activity, corrections due to undetected low energy x-rays and Auger electrons should be applied. Only three laboratories applied this correction.

However, the final reported uncertainty, in all cases, is less than 0,5 % which seems optimistic in view of the overall exercise.

Considering the gamma emission intensity measurement, in a first study, most of the participants did not see that the 511-keV emission requires a particular analysis.

So that, it appears that the ^{65}Zn activity and decay scheme parameters are not so easy to measure in spite of a simple decay scheme.

The 1115-keV gamma emission is much easier to measure and all the participants sent results. The reported uncertainties are in the range 0,5 % - 1,3 %. The total set of values is consistent.

One participant carried out specific experiment in order to measure the relative emission intensities of the weak gamma-rays and two others tried to manage the difficulty in determining the x-ray emission intensities.

Using the results obtained in this exercise and, taking into account the other previously published studies, the ^{65}Zn decay data are re-evaluated in the second part of this report.

PART B - Decay data evaluation

⁶⁵Zn - Comments on evaluation of decay data by M.M. Bé, V. Chisté and R. G. Helmer

1 Decay scheme

This evaluation was originally completed in September 1996. New evaluation was completed in January 2005 taking into account results obtained as a part of a specific exercise dedicated to the ⁶⁵Zn activity and emission intensity measurements managed by the Euromet organization.

The decay scheme is complete since only two excited levels in ⁶⁵Cu below the decay energy are populated. Also, there is excellent agreement between the total decay energy of 1352.1 (19) keV computed from the evaluated decay scheme and the Q value of 1352.1 (3) keV.

2 Nuclear Data

Q = 1352.1 (3) value is from Audi *et al.* (2003Au03).

The measured ⁶⁵Zn half-life values, in days, are as follow:

245.0 (8)	1953To17	
243.5 (8)	1957Ge07	
246.4 (22)	1957Wr37	outlier
243.1 (7)	1965An07	replaced by 1982HoZJ
244.12 (12)	"	replaced by 1982HoZJ
242.78 (19)	"	omitted from analysis
243 (4)	1968Ha47	
258 (4)	1972Cr02	omitted from analysis
246 (5)	"	"
251 (6)	"	"
252 (6)	"	"
244.0 (2)	1972De24	replaced by 2004Va02
244.52 (7)	1973Vi13	Uncertainty given per 3 σ
244.3 (4)	1974Cr05	
243.75 (12)	1975La16	replaced by 2003Lu06
244.2 (1)	1982HoZJ	replaced by 1992Un01
243.97 (8)	1982DeYX	replaced by 1983Wa26
243.9 (3)	1983Wa26	replaced by 2004Sc04
244.16 (10)	1992Un01	(or 2002Un02)
244.15 (10)	2003Lu06	
243.66 (9)	2004Sc04	
243.8 (3)	2004Va02	

244.01 (9) Adopted

The four values of 1972Cr02 were omitted because they were not intended as $T_{1/2}$ measurements, but rather to determine the origin of certain γ -rays.

The very small uncertainty, 0.07 (3.3 σ), given by 1973Vi13 appears unrealistic when compared to the other quoted uncertainties at the same period of time, at least this uncertainty value should be increased. Moreover, this result is far from the mean and the published paper not detailed enough, so this result is omitted from analysis.

The value of 1957Wr37 was found outlier according to the Chauvenet's criterion.

As a rule, only one result per laboratory is retained in order to avoid possible correlation.

Then, the weighted average of the remaining eight values is 244.01 with an internal uncertainty of 0.05, an external uncertainty of 0.09 and, a reduced- χ^2 of 3.11 (the critical reduced- χ^2 is 2.60), no input value has more than 50% of the weight. The Lweight program suggested to expand the uncertainty to 0.31 in order to include the most precise value of 243.66 within its range.

But a small increased of the uncertainty given by 2004Sc04 from 0.09 to 0.11 leads to a reduced- χ^2 of 2.48 less than the critical one, then the Lweight program recommended the internal uncertainty as final uncertainty.

With these results in mind, the evaluator has chosen the weighted average and the external uncertainty.

2.1 Electron Capture Transitions

The ϵ branch to the 770-keV level is 2nd forbidden. From the log ft systematics (1973Ra10), the expected log ft value is > 11.0 and the corresponding $I_{\epsilon}(0)$ is $< 0.003\%$.

The P_K etc. values are computed from the Schönfeld tables (1995ScZY) for allowed transitions.

Level energy (keV) =	0	1115
P_K (S)	0.8853 (16)	0.8794 (17)
P_L (S)	0.0977 (15)	0.1027 (16)

The total branching ratios to each level were computed from the measured I_{γ} and adopted theoretical conversion coefficients.

The total branching ($\epsilon + \beta^+$) to the ground state is 49.77 (11) %. From the 511-keV gamma emission intensity measurements, the β^+ transition probability is deduced as 1.421 (7) % (see § Photon emissions).

The LOGFT program gives the theoretical ϵ/β^+ ratio as 34.03 (18). Using the ($\epsilon + \beta^+$) branching to the ground state as 49.77 (11) % ; the β^+ transition probability is then 1.42 (1)%. This value is in good agreement with the experimental observations.

From the LOGFT program, the theoretical ϵ_K/β^+ ratio is calculated as 29.86. This value can be compared with the corresponding experimental values of:

28.0 (32)	1953Pe14
30.3 (12)	1963Ta04
27.7 (15)	1968Ha47
31.3 (20)	1977Bo10
30.7 (11)	1984ScZP
30.3 (10)	1990Ku11

The measured 1115 γ/β^+ ratio is 35.1 (17) (1968Ha47).

For comparison with the adopted value for the β^+ transition probability of 1.421 (7)%, the measured values are :

I_{β^+} (%)	
1959Gl55	1.70 (10)
1962Be28	1.2 (3)
1963Ta04	1.40 (4)
1972De24	1.46 (2)

Comments on evaluation

2.2 Gamma Transitions

The multipolarities are from the adopted γ -ray data (deduced from Coulomb excitation study and angular correlation data) in the journal Nuclear Data Sheets (1993Bh04).

The internal-conversion coefficients are interpolated from the tables of Band (2002Ba85). Mixing ratio of the 1115-keV transition is from Krane (1976Kr09). The ICC values for this high energy transition is very low so the influence of the uncertainty for the mixing ratio is negligible.

For the 1115-keV transition, the total and K-shell values of $1.85 (7) \times 10^{-4}$ and $1.66 (6) \times 10^{-4}$ respectively, evaluated by Hansen (1985HaZA) from measured values are in excellent agreement with the theoretical ones.

From the theoretical tables of 1979Sc31, the internal-pair-formation coefficients are $\alpha_{\pi}(1115, M1) = 1.2 \times 10^{-6}$ and $\alpha_{\pi}(1115, E2) = 1.6 \times 10^{-6}$, so $\alpha_{\pi}(1115) = 1.3 \times 10^{-6}$. This value is about 1% of the internal-conversion coefficient and therefore is negligible.

3 Atomic Data (Cu, Z=29)

Data are from 1996Sc06.

4.1 Electron Emission

The β^+ intensity to the ground state was deduced from the measured intensity of the 511-keV gamma ray.

4.2 Photon Emissions

The γ -ray energies are from the evaluation of Helmer *et al.* (2000He14) for the 1115-keV line where the values are on a scale on which the strong line from the decay of ¹⁹⁸Au is 411.80205 (17); from level energy differences for the 344-keV line; and from ⁶⁵Cu Adopted γ data in Nuclear Data Sheets (1993Bh04) and based on data from ⁶⁵Ni β^- decay for 770-keV line.

Photon emission intensities are deduced from the Euromet exercise results (2005Be**) and from other published values.

Absolute measured intensities of the 1115-keV line

	I (1115) (%)	Uc	
1959Gl55	51.3	3.0	
1960Go	46		
1963Ta04	50.7	0.5	
1966Ra21	51.3	1.5	
1968Ha47	52.4	1.0	Outlier
1972De24	50.75	0.10	Replaced by Euromet participant
1973Po10	49.3	0.8	
1982DeYX	50.39	0.26	replaced by 1990Sc08
1990Sc08	50.2	0.4	Replaced by Euromet participant
2003Lu06	49.76	0.21	Replaced by Euromet participant
Euromet-01	50.15	0.28	
Euromet-02	50.10	0.33	
Euromet-03	50.60	0.29	
Euromet-04	50.34	0.25	
Euromet-05	49.84	0.25	
Euromet-06	50.05	0.57	
Euromet-07	49.62	0.65	
Euromet-08	50.7	0.5	
Euromet-09	50.3	0.5	
Adopted	50.22	0.11	

The first part of the above Table lists the results published in various journals and the second part lists the values obtained as a part of the Euromet exercise (2005Be*).

The value from 1968Ha47 is omitted as outlier due to application of the Chauvenet's criterion. The results from 1972De24, 1990Sc08 and 2003Lu06 have been superseded by the results obtained by laboratories which have participated in the present Euromet exercise.

The LRSW analysis of the remaining 13 values gives a reduced χ^2 of 0.77 so the weighted mean of 50.22 and the internal uncertainty of 0.11, are adopted as final result.

344- and 770-keV Relative g-ray emission intensities :

γ -ray energy (keV)	I(344)	I(770)	I(1115)
1960Ri06	≤ 0.5	≤ 1	100
1968St05	0.0060 (6)		100
Euromet-02	0.005067 (365)	0.005358 (439)	100
Euromet-09	0.00220 (86)	0.003 (17)	100
Adopted relative	0.005067 (365)	0.005358 (439)	100
Adopted absolute	0.00254 (18)	0.00269 (22)	50.22 (11)

The adopted relative values are those given by the participant 2 in the Euromet exercise. This participant activated Zinc (99.99 %) foil by thermal neutrons and obtained a Zn-65 activity of the order of 10 MBq, so he had a better counting statistic and then a better uncertainty.

511-keV photon emission

This particular emission is due to the annihilation of the β^+ positrons in the source and in the surrounding material (annihilation-in-flight). In γ -ray spectrometry, this phenomenon has the effect of removing, from the 511-keV peak, a fraction of the annihilation photons, the magnitude of this effect depends on the material in which the β^+ are stopped and then must be calculated by each experimentalist.

reference	Intensity (%)	Uc	Correction for annihilation, in %
1990Sc08	2.84*	0.04	0.5
Euromet-01	2.81 *	0.03	0.2
Euromet-02	2.841 *	0.027	Wider peak region
Euromet-03	2.75	0.017	
Euromet-04	3.00	0.018	
Euromet-05	2.848 *	0.020	0.34
Euromet-07	2.86	0.04	
Euromet-09	2.88 *	0.04	0.5

(*) taking annihilation-in-flight into account, magnitude given in the last column.

Reference 1990Sc08 is superseded by one of the Euromet participant. The weighted mean and standard uncertainty of the four values taking annihilation-in-flight into account, are : 2.842 ± 0.013 %.

The emission of additional 511-keV photons created by electron-positron pair creation is negligible (see § Gamma transitions).

X-ray emissions and Auger electron emissions

From the gamma-ray emission intensities, the internal conversion coefficients, the electron capture probabilities and electron capture sub shell probabilities, the X-ray and Auger electron emission intensities have been deduced.

Calculated K X-ray are compared with the measured values in the following table.

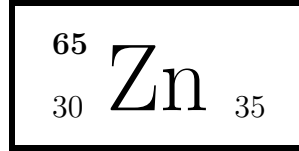
Reference	K α		K β		KX	
	Intensity	Uc	Intensity	Uc	Total	Uc
1963Ta19					40.0	0.6
1968Ha47					39.27	0.26
1968Ba**					38.66	0.17
1973Mu**					38.0	1.0
Euromet-05	32.1	1.6	4.50	0.023	36.6	1.6
Euromet-09	39	3.5	5.2	0.47	44.2	3.5
Weighted mean					38.87	0.22
Calculated	34.7	0.4	4.82	0.07	39.5	0.4

The weighted mean of the KX measured values (except Euromet-09 which is outlier) is lower than the calculated value deduced from the decay scheme. They barely agree within their uncertainty limits.

6 References

- 1953Pe14 - J. F. Perkins, S. K. Haynes, Phys. Rev. **92**(1953)687 [ϵ/β^+]
 1953To17 - J. Tobailem, J. Phys. Radium **14**(1953)553 [$T_{1/2}$]
 1957Ge07 - K. W. Geiger, Phys. Rev. **105**(1957)1539 [$T_{1/2}$]
 1957Wr37 - H. W. Wright, E. I. Wyatt, S. A. Reynolds, W. S. Lyon, T. H. Handley, Nuclear Sci. Eng. **2**(1957)427 [$T_{1/2}$]
 1959Gl55 - G. I. Gleason, Phys. Rev. **113**(1959)287 [P_{β^+} , P_{γ}]
 1960Go - W. M. Good, W. C. Peacock, Bull. Amer. Phys. Soc. Abstract B4 (1960) 680 [P_{γ}]
 1960Ri06 - R. A. Ricci, G. Chilosi, G. Varcaccio, G. B. Vingiani, R. van Lieshout, Nuovo cimento **17**(1960)523 [P_{γ}]
 1962Be28 - D. Berenyi, Phys. Letters **3**(1962)142 [P_{β^+}]
 1963Ta04 - J. G. V. Taylor, J. S. Merritt, Phys. Can. **19**(1963) No. 3, 17, abstract 4.5 [P_{γ}]
 1963Ta19 - J. G. V. Taylor, J. S. Merritt, Proc. Int. Conf. role of atomic electrons in nuclear transformations, Warsaw, CONF-233 (1963) 465 [XK]
 1965An07 - S. C. Anspach, L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, C. N. Smith, NP-15663(1965) [$T_{1/2}$]
 1966Ha07 - J. H. Hamilton, S. R. Amtey, B. van Nooijen, A. V. Ramayya, J. J. Pinajian, Phys. Letters **19**(1966)682 [α , α_K]
 1966Ra21 - P. S. Rao, Curr. Sci. **35**(1966)384 [P_{γ}]
 1968Ba** - W. Bambynek, D. Reher, Z. Physik **214**(1968)374 [XK]
 1968Ha47 - J. W. Hammer, Z. Physik **216**(1968)355 [$T_{1/2}$, P_{γ}]
 1968St05 - P. H. Stelson, Nucl. Phys. **A111**(1968)331 [P_{γ}]
 1972Cr02 - D. F. Crisler, H. B. Eldridge, R. Kunselman, C. S. Zaidins, Phys. Rev. **C5**(1972)419 [$T_{1/2}$]
 1972De24 - E. De Roost, E. Funck, A. Spornol, R. Vaninbrouckx, Z. Phys. **250**(1972)395 [ϵ/β^+ , P_{γ} , $T_{1/2}$]
 1973Po10 - W. P. Poenitz, A. Devolpi, Int. J. Appl. Radiat. Isotop. **24**(1973)471 [P_{γ}]
 1973Ra10 - S. Raman, N.B. Gove, Phys. Rev. **C7** (1973) 1995 [$lg ft$]
 1973Vi13 - C. J. Visser, J. H. M. Karsten, F. J. Haasbroek, P. G. Marais, Agrochemophysica **5**(1973)15 [$T_{1/2}$]
 1973Mu** - A. Mukerji, L. Chin, Atlanta Conf. Proc. AEA-CONF-720404 (1973) 164 [XK]

- 1974Cr05 - P. J. Cressy, Jr., Nucl. Sci. Eng. **55**(1974)450 [$T_{1/2}$]
1975La16 - F. Lagoutine, J. Legrand, C. Bac, Int. J. Appl. Radiat. Isotop. **26**(1975)131 [$T_{1/2}$]
1976Kr09 - K.S. Krane, S.S. Rosenblum, W.A. Steyert. Phys. Rev. C14, (1976) 650 [δ]
1977Bo10 - H. E. Bosch, J. Davidson, M. Davidson, L. Szybisz, Z. Phys. **A280**(1977)321 [ϵ/β^+]
1979Sc31 - P. Schluter, G. Soff, At. Data Nucl. Data Tables **24**(1979)509 [α_π]
1982DeYX - K. Debertin, U. Schötzig, K. F. Walz, NBS-SP-626(1982)101 [P_γ]
1982HoZJ - D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger, NBS-SP-626(1982)85 [$T_{1/2}$]
1983Wa26 - K. F. Walz, K. Debertin, H. Schrader, Int. J. Appl. Radiat. Isotop. **34**(1983)1191 [$T_{1/2}$]
1984ScZP - W.-D. Schmidt-Ott, J. Lauerwald, U. Bosch, H. Dornhofer, U. J. Schrewe, H. Behrens, 7th Proc. Intern. Conf. Atomic Masses Fund. Constants, Darmstadt-Seeheim (1984)210 [ϵ/β^+]
1985HaZA - H. H. Hansen, European App. Res. Rept. Nucl. Sci. Technol. **6**, No.4 (1985)777 [α , α_K]
1990Ku11 - V. Kunze, W.-D. Schmidt-Ott, H. Behrens, Z. Phys. **A337**(1990)169 [ϵ/β^+]
1990Sc08 - U. Schötzig, Nucl. Instrum. Methods Phys. Res. **A286**(1990)523 [P_{β^+} , P_γ]
1991BaZS - W. Bambynek, T. Barta, R. Jedlovsky, P. Christmas, N. Coursol, K. Debertin, R. G. Helmer, A. L. Nichols, F. J. Schima, Y. Yoshizawa, report IAEA-TECDOC-619 (1991) [P_γ evaluation]
1992Un01 - M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instr. Meth. **A312**(1992)349 [$T_{1/2}$]
1993Bh04 - M. R. Bhat, Nucl. Data Sheets **69**(1993)209 [multipolarities, mixing ratios, J^π]
1995ScZY - E. Schönfeld, report PTB-6.33-95-2 (1995) [P_K , P_L , P_M theory]
1996Sc06 - E. Schönfeld, H. Janßen, Nucl. Instr. Meth. **A369**(1996)527 [ω_K , ω_L , Auger emis. prob.]
2000He14 - R. G. Helmer and C. van der Leun, Nucl. Instr. Meth. **A450**(2000)35 [E_γ]
2002Ba85 - I.M.Band, M.B.Trazhaskovskaya, C.W.Nestor, S.Raman. At. Data and Nucl. Data Tables 81, 1&2 (2002) 1 [ICC]
2002Un02 - M.P. Unterweger, Applied Radiation Isotopes 56 (2002) 125 [$T_{1/2}$]
2003Lu06 - A. Luca, M.-N. Amiot, J. Morel, Applied Radiation Isotopes 58 (2003) 607 [$T_{1/2}$]
2003Au03 - G. Audi, A. H. Wapstra, C.Thibault. Nucl. Phys. **A729**(2003)337 [Q]
2004Sc04 - H. Schrader, Applied Radiation Isotopes 60 (2004) 317 [$T_{1/2}$]
2004Va02 - R. Van Ammel, S. Pommé, G. Sibbens, Applied Radiation Isotopes 60 (2004) 337 [$T_{1/2}$]
2005Be** - M.-M.Bé, Euromet 721, Report CEA, to be published.



1 Decay Scheme

Zn-65 disintegrates by electron capture to the 1115 keV excited level and by electron capture and beta plus emission to the ground state level of Cu-65.

Le Zn-65 se désintègre par capture électronique vers le niveau excité de 1115 keV du Cu-65 et par capture électronique et émission bêta plus vers le niveau fondamental.

2 Nuclear Data

$$T_{1/2}({}^{65}\text{Zn}) : 244,01 \text{ (9) d}$$

$$Q^+({}^{65}\text{Zn}) : 1352,1 \text{ (3) keV}$$

2.1 Electron Capture Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>	P_K	P_L	P_{M+}
$\epsilon_{0,2}$	236,5 (3)	50,23 (11)	Allowed	5,89	0,8794 (17)	0,1027 (16)	0,0179
$\epsilon_{0,0}$	1352,1 (3)	48,35 (11)	Allowed	7,46	0,8853 (16)	0,0977 (15)	0,017

2.2 β^+ Transitions

	Energy keV	Probability × 100	Nature	lg <i>ft</i>
$\beta_{0,0}^+$	329,9 (3)	1,421 (7)	Allowed	7,46

2.3 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ $\times 100$	Multipolarity	α_K (10^{-3})	α_L (10^{-3})	α_T (10^{-3})
$\gamma_{2,1}(\text{Cu})$	344,95 (20)	0,00256 (18)	[E2]	5,55 (17)	0,569 (19)	6,20 (19)
$\gamma_{1,0}(\text{Cu})$	770,64 (9)	0,00269 (22)	M1+0,9%E2	0,345 (10)	0,0343 (10)	0,384 (12)
$\gamma_{2,0}(\text{Cu})$	1115,549 (2)	50,23 (11)	M1+16,0%E2	0,166 (6)	0,0162 (5)	0,184 (7)

3 Atomic Data

3.1 Cu

ω_K	:	0,454	(4)
$\bar{\omega}_L$:	0,0097	(4)
n_{KL}	:	1,357	(4)

3.1.1 X Radiations

	Energy keV	Relative probability
X_K	$K\alpha_2$	8,02792
	$K\alpha_1$	8,04787
	$K\beta_1$	8,90539
	$K\beta_5''$	8,9771
		100
		}
		}
		21,05
X_L	$L\ell$	0,811
	$L\alpha$	0,929 – 0,93
	$L\beta$	0,932 – 1,022

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K	KLL	6,76 – 7,12
	KLX	7,76 – 8,05
	KXY	8,73 – 8,90
Auger L	0,7 – 1,0	346

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e _{AL}	(Cu)	0,7 - 1,0	126,6 (7)
e _{AK}	(Cu)		47,5 (4)
	KLL	6,76 - 7,12	}
	KLX	7,76 - 8,05	}
	KXY	8,73 - 8,90	}
$\beta_{0,0}^+$	max:	329,9 (3)	1,421 (7)
$\beta_{0,0}^+$	avg:	143,1 (1)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV	Photons per 100 disint.	
XL	(Cu)	0,811 — 1,022	1,305 (21)	
XK α_2	(Cu)	8,02792	11,76 (13)	} K α
XK α_1	(Cu)	8,04787	22,91 (22)	}
XK β_1	(Cu)	8,90539	}	K' β_1
XK β_5''	(Cu)	8,9771	}	

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{2,1}(\text{Cu})$	344,95 (20)	0,00254 (18)
γ^\pm	511	2,842 (13)
$\gamma_{1,0}(\text{Cu})$	770,64 (9)	0,00269 (22)
$\gamma_{2,0}(\text{Cu})$	1115,539 (2)	50,22 (11)

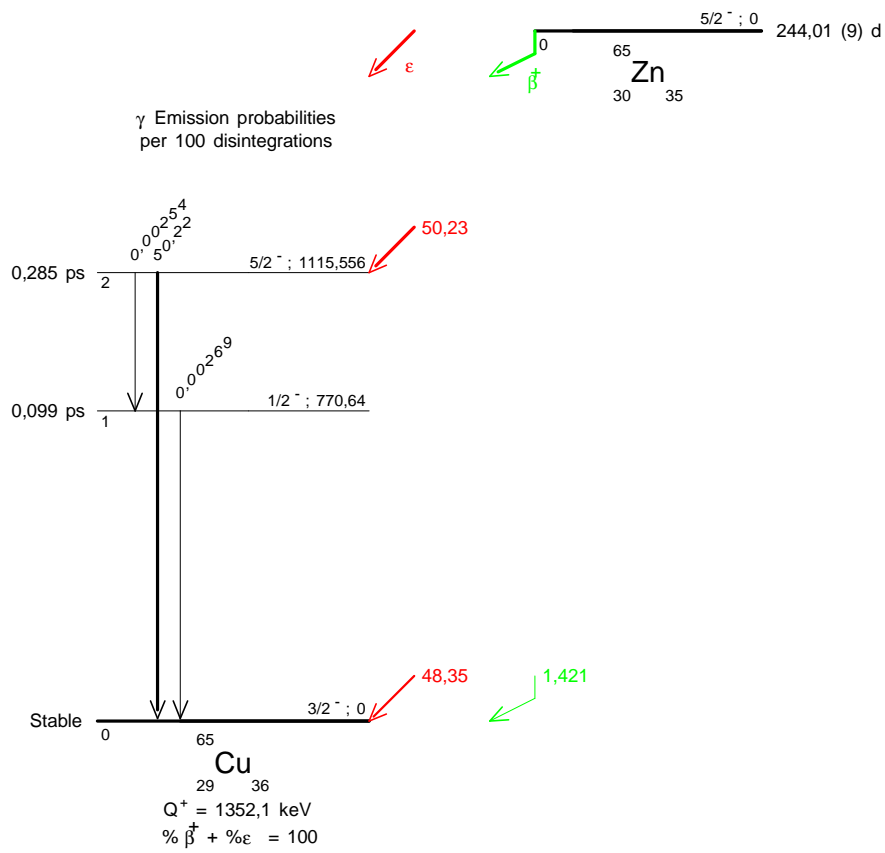
6 Main Production Modes

- $$\left\{ \begin{array}{l} \text{Zn} - 64(n,\gamma)\text{Zn} - 65 \quad \sigma : 0,76 \text{ (2) barns} \\ \text{Possible impurities : Cu} - 64, \text{ Cu} - 67, \text{ Zn} - 69\text{m} \end{array} \right.$$
- $$\left\{ \begin{array}{l} \text{Cu} - 65(p,n)\text{Zn} - 65 \\ \text{Possible impurities : Cu} - 67, \text{ Co} - 60 \end{array} \right.$$

7 References

- J.F.PERKINS, S.K.HAYNES. Phys. Rev. 92 (1953) 687
(Electron Capture/Beta plus Ratio)
- J.TOBALEM. J. Phys. Radium 14 (1953) 553
(Half-life)
- K.W.GEIGER . Phys. Rev. 105 (1957) 1539
(Half-life)
- H.W.WRIGHT, E.I.WYATT, S.A.REYNOLDS, W.S.LYON, T.H.HANDLEY. Nucl. Sci. Eng. 2 (1957) 427
(Half-life)
- G.I.GLEASON. Phys. Rev. 113 (1959) 287
(Gamma ray emission probabilities)
- W.M.GOOD, W.C.PEACOCK. Bull. Amer. Phys. Soc. Abstract B4 (1960) 680
(Gamma ray emission probabilities)
- R.A.RICCI, G.CHILOSI, G.VARCACCIO, G.B.VINGIANI, R.VAN LIESHOUT. Nuovo Cim. 17 (1960) 523
(Gamma ray emission probabilities)
- D.BERENYI. Phys. Lett. 3 (1962) 142
(Beta plus emission probabilities)
- J.G.V.TAYLOR, J.S.MERRITT. Phys. Can., Abstract 4.5 19 (1963) 3,17
(Gamma ray emission probabilities)
- J.V.G.TAYLOR, J.S.MERRITT. Proc. Int. Conf. Role of atomic electrons in Nuclear transformations, Warsaw CONF-233 (1963) 465
(K X-ray emission intensities)
- S.C.ANSPACH, L.M.CAVALLO, S.B.GARFINKEL, J.M.R.HUTCHINSON, C.N.SMITH. NP-15663 (1965)
(Half-life)
- P.S.RAO. Curr. Sci. 35 (1966) 384
(Gamma ray emission probabilities)
- J.H.HAMILTON, S.R.AMTEY, B.VAN NOOIJEN, A.V.RAMAYYA, J.J.PINAJIAN. Phys. Lett. 19 (1966) 682
(ICC)
- J.W.HAMMER. Z. Phys. 216 (1968) 355
(Half-life, Gamma ray emission probabilities)
- W.BAMBYNEK, D.REHER. Z. Physik 214 (1968) 374
(K X-ray emission intensities)
- P.H.STELSON. Nucl. Phys. A111 (1968) 331
(Gamma ray emission probabilities)
- D.F.CRISLER, H.B.ELDRIDGE, R.KUNSELMAN, C.S.ZAIDINS. Phys. Rev. C5 (1972) 419
(Half-life)
- E.DE ROOST, E.FUNCK, A.SPERNOL, R.VANINBROUKX. Z. Phys. 250 (1972) 395
(Gamma ray emission probabilities, Half-life)
- A.MUKERJI, L.CHIN. Atlanta Conf. Proc. AEA-CONF-720404 (1973) 164
(K X-ray emission intensities)
- S.RAMAN, N.B.GOVE. Phys. Rev. C7 (1973) 1995
(lg ft)
- C.J.VISSER, J.H.M.KARSTEN, F.J.HAASBROEK, P.G.MARAIS. Agrochemophysica 5 (1973) 15
(Half-life)
- W.P.POENITZ, A.DEVOLPI. Int. J. Appl. Radiat. Isotop. 24 (1973) 471
(Gamma ray emission probabilities)
- P.J.CRESSY JR. Nucl. Sci. Eng. 55 (1974) 450
(Half-life)

- F.LAGOUTINE, J.LEGRAND, C.BAC. Int. J. Appl. Radiat. Isotop. 26 (1975) 131
(Half-life)
- K.S.KRANE, S.S.ROSENBLUM, W.A.STEYERT. Phys. Rev. C14 (1976) 650
(Mixing ratio)
- H.E.BOSCH, J.DAVIDSON, M.DAVIDSON, L.SZYBISZ. Z. Phys. A280 (1977) 321
(Electron Capture/Beta plus Ratio)
- P.SCHLUTER, G.SOFF. At. Data. Nucl. Data Tables 24 (1979) 509
(Internal pair formation coefficient)
- D.D.HOPPE, J.M.R.HUTCHINSON, F.J.SCHIMA, M.P.UNTERWEGER. NBS-SP-626 (1982) 85
(Half-life)
- K.DEBERTIN, U.SCHÖTZIG, K.F.WALZ. NBS-SP-626 (1982) 101
(Gamma ray emission probabilities)
- K.F.WALZ, K.DEBERTIN, H.SCHRADER. Int. J. Appl. Radiat. Isotop. 34 (1983) 1191
(Half-life)
- W.-D.SCHMIDT-OTT, J.LAUERWALD, U.BOSCH, H.DORNHOFER, U.J.SCHREWE, H.BEHRENS. 7th Proc. Intern. Conf. Atomic Masses Fund. Constants Darmstadt-Seeheim (1984) 210
(Electron Capture/Beta plus Ratio)
- H.H.HANSEN. European App.Res.Rept.Nucl.Sci.Technol. 6,4 (1985) 777
(ICC)
- U.SCHÖTZIG. Nucl. Instrum. Methods A286 (1990) 523
(Gamma ray and Beta plus, emission probabilities)
- V.KUNZE, W.-D.SCHMIDT-OTT, H.BEHRENS. Z. Phys. A337 (1990) 169
(Electron Capture/Beta plus Ratio)
- M.P.UNTERWEGER, D.D.HOPPE, F.J.SCHIMA. Nucl. Instrum. Methods A312 (1992) 349
(Half-life)
- M.R.BHAT. Nucl. Data Sheets 69 (1993) 209
(Multipolarities, Mixing Ratio, Spin and Parity)
- E.SCHÖNFELD. Report PTB-6.33-95-2 (1995)
(PK, PL, PM theory)
- E.SCHÖNFELD, H.JANSSEN. Nucl. Instrum. Methods A 369 (1996) 527
(K and L fluorescence yields, Auger electron emission probabilities)
- R.G.HELME, C.VAN DER LEUN. Nucl. Instrum. Methods A450 (2000) 35
(Gamma ray energies)
- M.P.UNTERWEGER. Appl. Rad. Isotopes 56 (2002) 125
(Half-life)
- I.M.BAND, M.B.TRAZHASKOVSKAYA, C.W.NESTOR, S.RAMAN. At. Data Nucl. Data Tables 81, 1-2 (2002) 1
(Theoretical ICC)
- A.LUCA, M.-N.AMIOT, J.MOREL. Appl. Rad. Isotopes 58 (2003) 607
(Half-life)
- G.AUDI, A.H.WAPSTRA, C.THIBAUT. Nucl. Phys. A729 (2003) 337
(Q)
- H.SCHRADER. Appl. Rad. Isotopes 60 (2004) 317
(Half-life)
- R. VAN AMMEL, S.POMMÉ, G.SIBBENS. Appl. Rad. Isotopes 60 (2004) 337
(Half-life)
- M.-M.BÉ. Report CEA to be published (2005)
(Gamma-ray emission intensities)



Conclusions for the overall exercise

Nine laboratories participated and sent results of measurements, showing their interest for that kind of international exercise.

From the nine new values of the 1115-keV gamma ray intensity and from other published values, a new intensity value has been determined.

The final adopted emission intensity (50.22 (11) %) is less than the commonly adopted one (50.60 (22) %) and, must lead to derivate activity values higher than those previously obtained, reducing the difference, with other techniques of measurement, to 1%. Moreover, the uncertainty on the emission intensity value has been divided by a factor of two.

The better determination of the weak gamma emission intensities and of the 511-keV photon emission has also contributed to establish a consistent decay scheme data.

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