^{65}Zn - 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 ^{65}Zn activity and emission intensity measurements managed by the Euromet organization.

The decay scheme is complete since only two excited levels in ^{65}Cu 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 ^{65}Zn 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 $I_\varepsilon(0)$ 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 Iγ and adopted theoretical conversion coefficients.

The total branching (ε + β^+) 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 (ε + β^+) 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 :

	$I_{\beta+}$ (%)
1959Gl55	1.70 (10)
1962Be28	1.2 (3)

1963Ta04 1.40 (4)
1972De24 1.46 (2)

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 α_π(1115, M1) = 1.2 $\times 10^{-6}$ and α_π(1115,E2) = 1.6 $\times 10^{-6}$, so α_π(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 ^{198}Au is 411.80205 (17); from level energy differences for the 344-keV line; and from ^{65}Cu Adopted γ data in Nuclear Data Sheets (1993Bh04) and based on data from ^{65}Ni 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.

	Kα		Kβ		KX	
Reference	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

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