^{138}La - Comments on evaluation of decay data by X. Mougeot, M.M. Bé

This evaluation was completed in November 2013 with literature available at this date included. The updated evaluation was done in June 2016 to account for the recent publication 2016Qu01.

Decay Scheme

^{138}La decays by electron capture and β^- disintegrations to the first excited level of ^{138}Ba and of ^{138}Ce respectively.

Q_{EC} and $Q_{\beta-}$ values for ^{138}La decay were adopted from Wang *et al.* (2012Wa38).
It should be noted that for the EC decay there exists one estimate of the Q_{EC} value: 1590 (40) keV, cited as 1620 (15) in 2012Wa38, which is far from the adjusted value of 1740,0 (34) keV resulting from a least-square calculation.
For the β^- decay, a maximum energy of 205 (10) keV and 370 (40) keV were determined by 1957Gl20 and 1970ElZR leading to a $Q_{\beta-}$ of 1015 (14) keV and of 1158 (40) keV respectively. The adjusted value in 2012Wa38 is 1047 (10) keV and was deduced from two mass measurements for ^{138}La and ^{138}Ce respectively. A new endpoint energy of 264,0 (43) keV was determined in 2016Qu01, corresponding to a $Q_{\beta-}$ of 1052,7 (43) keV. Following a private communication with G. Audi, the final value adopted here is $Q_{\beta-}$ = 1051,7 (40) keV. This value will be included within the next atomic mass evaluation.

The spins, parities and level energies are based on the mass-chain evaluation of Sonzogni (2003So13).

Half-life

The experimental half-life values used to calculate the recommended value are listed in the following table:

References	10^{11} a	uc (10^{11} a)	Comments
Pringle (1951Pr**)	2,0		Omitted
Mulholland (1952Mu04)	0,66		Omitted
Turchinetz (1956Tu17)	1,0	0,1	Omitted – comparison with ^{40}K (A_γ =3,4)
Glover (1957Gl20)	1,16	0,11	Omitted – comparison with ^{40}K (A_γ =3,47)
Ellis (1972El02)	1,56	0,3	Omitted – comparison with ^{40}K (A_γ =3,25)
Marsol (1972Ma31)	1,27	0,18	Omitted – comparison with ^{40}K
Taylor (1979Ta21)	1,28	0,12	Omitted – comparison with ^{40}K (A_γ =3,26)
Sato (1981Sa42)	1,03	0,03	Omitted – comparison with ^{40}K, uc = 3%
Norman (1983No02)	1,06	0,03	WM of 1,07 (3) from mixed source with ^{40}K and 0,97 (12) direct measurement
De Ruyter (1966De04)	1,04	0,03	Original uc = 0,014 multiplied by 2
Cesana (1977Ce**)	1,29	0,12	uc = 10% to account for systematic component, outlier
Norman (1983No02)	0,97	0,12	Direct measurement
Dalmasso (1994Da**)	1,14	0,05	Direct measurement
Nir-El (1997Ni12)	1,01	0,023	Direct measurement, original uc = 0,01 increased to limit its weight to 50%

Bernabei (2005Be73)	1,07	0,06	Direct measurement
Crit (χ^2)	3,32		
χ^2 /(n-1)	1,56		
UWM	1,046		
WM	1,036		
uc(WM)int. :	0,016		
uc(WM)ext. :	0,020		
Adopted	**1,036 (20)**		

The six first results listed in the above table were derived from the comparison of the specific activity in ^{138}La of a lanthanum crystal with the specific activity of ^{40}K. The resulting values depend on the ^{40}K decay data which are not always the same in the various publications, and, when they are, the results are no longer independent. For these reasons these six values have not been used in the evaluation.
The six remaining results were obtained from direct measurement of the ^{138}La activity and calculation of the number of ^{138}La atoms. In this set, the value of Cesana was found to be an outlier. The original uncertainty of De Ruyter (1966De04) has been multiplied by 2, to account for a systematic component. The adopted value for Norman (1983No02) is the one obtained by direct measurement. The uncertainty given by Nir-El (1997Ni12) was increased from 0,01 to 0,023 to limit its weight to 50%, the resulting uncertainty of about 2% seems reasonable for a measurement of such a long half-life.
This set of five data adopted for statistical processing is consistent. The adopted value is the weighted mean with the external uncertainty (the lowest experimental uncertainty is 0,01), that is:
$T_{1/2}$ = 103,6 (20) 10^9 a.

From this latter value and the branching ratios obtained below, a value of 2,33 (6) 10^{-12} a^{-1} for the partial decay constant λ_β is derived. It can be compared with the value of 2,37 (10) 10^{-12} a^{-1} determined by geophysical methods (2000Ta24).

Gamma Transition probabilities and Internal Conversion Coefficients

The γ transitions with energy 1435 and 788 keV respectively are of pure E2 character.
The adopted ICC are the theoretical values interpolated by the BrIcc program (2008Ki07) from the tables of Band *et al.* (2002Ba85).

Electron Capture transition

- The electron capture probability to the 1435 keV level is deduced from the decay scheme balance.
$P_{EC} = I\gamma_{1435} (1 + \alpha_T)$ = 65,2 (6) %.

Reference	L/K	uc	Comments
Mandal (1984Ma46)	0,48	0,16	P_K = 0,676 (10)
Quarati (2012Qu02)	0,44	0,044	
Logft	0,43		
Quarati (2012Qu02) - theoretical	0,402		P_K = 0,69 ; P_L = 0,277 ; P_M = 0,032
Quarati (2016Qu01) – experimental	0,391	0,003	M/K = 0,102 (3) ; M/L = 0,261 (9)
Quarati (2016Qu01) - theoretical	0,405	0,007	M/K = 0,0915 (17) ; M/L = 0,226 (7)

- The K/L capture ratio was measured by Mandal (1984Ma46) and Quarati (2012Qu02, 2016Qu01). Their results are in good agreement with the theoretical values calculated, for this 2nd unique forbidden transition, by the Logft program and Quarati.

- The atomic sub shell electron capture probabilities and the *lg ft* values are calculated with the LOGFT program.

β^- transition

The probability of the β^- transition to the 788 keV level is deduced from the decay scheme balance.
$P_{\beta-} = 100 - P_{EC} = 34{,}8\ (6)$ %.
An experimental shape factor was extracted from Quarati's data as the deformation to be applied on an allowed shape (see Fig. 1):

$$C(W) = 1 - 55{,}435 \times W + 9{,}53\ /\ W + 68{,}53 \times W^2 - 24{,}565 \times W^3$$

The maximum energy of the β^- spectrum was deduced from the new $Q_{\beta-}$ value to be 263,0 (40) keV. The mean β^- energy was calculated by using the experimental shape factor from 2016Qu01 to be 91,1 (21) keV.

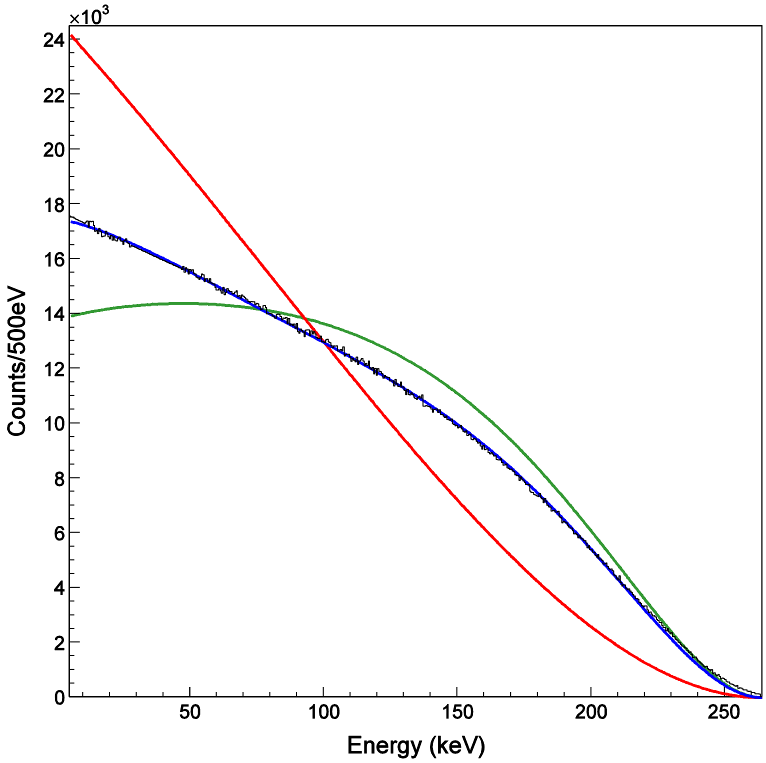

Figure 1 – La-138 β^- spectrum: measurement from 2016Qu01 (black); usual 2nd forbidden unique calculation (green); allowed spectrum (red); allowed spectrum distorted by the extracted experimental shape factor (blue – hidden by experimental spectrum).

Gamma Rays

The gamma ray energies are deduced from level energies.

Absolute γ ray intensities

The measured gamma ray intensities are:

References	**I_{g788} (%)**	**uc (%)**	**I_{g1435} (%)**	**uc (%)**	**Comments**
Turchinetz (1956Tu17)	47	5	53	5	omitted
Glover (1957Gl20)	30		70		omitted
Ellis (1972El02)	33		67		omitted
Cesana (1977Ce**)	35,1	1,9	64,9	1,9	Derived from partial $T_{1/2}$ ratio
Sato (1981Sa42)	33,8	2,0	65,9	2,0	Derived from partial $T_{1/2}$ ratio
Norman (1983No02)	33,1	2,0	66,9	2,0	Derived from partial $T_{1/2}$ ratio
De Ruyter (1966De04)	37,0	1,2	63,0	1,2	Derived from Iγ ratio; original uc = 0,6 multiplied by 2
Marsol (1972Ma31)	32,1	1,8	67,9	1,8	Direct measurement
Nir-El (1997Ni12)	35,0	0,8	65,0	0,8	Derived from Iγ ratio; original uc = 0,4 multiplied by 2
Crit. χ^2	3,32		3,02		
χ^2 /(n-1)	1,65		1,29		
UWM	34,20		65,6		
WM	**34,908**		**65,053**		
uc(WM)int.	0,571		0,547		
uc(WM)ext.	0,734		0,622		
Adopted	**34,7 (6)**		**65,1 (6)**		

- *1435 keV gamma intensity*

Six values of the 1435 keV gamma intensity have been used, as they were derived from ratios some parameters, such as $T_{1/2}$(^{40}K), cancel out.
The original uncertainty of De Ruyter (1966De04) has been multiplied by 2, to account for a systematic component. The uncertainty given by Nir-El (1997Ni12) was increased to limit its weight to 50%.
This set of the six data adopted for the statistical processing is consistent, the weighted mean is 65,1 (6) %.

- *788 keV gamma intensity*

From the statistical processing of the six values above the weighted mean is 34,9 (6) %. But with $P_{(\gamma+ce)}$ = $P_{\beta-}$ = 100 - P_{EC} = 34,8 (6) % and the adopted internal conversion coefficients, the Iγ (788) intensity must be equal to 34,7 (6) %. This latter value is adopted.

Atomic Data

The X-ray and Auger electron emission intensities are derived from the decay scheme parameters by using the program Emission, the derived total K X-ray intensities is 41,6 (5) %.
A K X-ray intensity of 0,4 X-ray s^{-1} g^{-1} of natural Lanthanum was observed in an old publication (Pringle *et al.* (1951Pr**)).

References

The program LOGFT, National Nuclear Data Center, September 3, 2002.

1951Pr** Phys.Rev. 84, 1006 (1951), R.W.Pringle *et al.*; *A further study of the natural activity of Lanthanum*

1952Mu04 Phys.Rev. 85, 144 (1952), G.L.Mulholland, T.P.Kohman; *Possible Natural Radioactivity of Neodymium*

1956Tu17 Phys.Rev. 103, 1000 (1956), W.Turchinetz, R.W.Pringle; *Decay Scheme of* La^{138}

1957Gl20 Phil.Mag. 2, 49 (1957), R.N.Glover, D.E.Watt; *The Natural Radioactivity of Lanthanum*

1966De04 Physica 32, 991 (1966), A.W.De Ruyter, A.H.W.Aten, Jr., A.Van Dulmen, C.Krol-Koning, E.Zuidema; *Specific Gamma Emission of Natural Potassium and Lanthanum*

1972El02 Nucl.Phys. A179, 540 (1972), J.L.Ellis, H.E.Hall, Jr.; *Decay of Naturally Occurring* ^{138}La

1972Ma31 C.R.Acad.Sci., Ser.B, 274, 904 (1972), C.Marsol, F.Armanet, G.Ardisson ; *Étude de la Désintégration du Nucléide Naturel* ^{138}La *(*$T_1/_2$*=1, 27.10*^{11} *années)*

1977Ce** Analytical Chemistry, Vol 49, 8 (1977) 1156, A. Cesana, M. Terrani; *Gamma-ray activity determination in large volume samples with a Ge-Li detector*

1979Ta21 J.Phys.Soc.Jpn. 47, 1395 (1979), H.W.Taylor, R.J.Bauer; *A Note on the Decay of* ^{138}La

1981Sa42 Radiochem.Radioanal.Lett. 46, 145 (1981), J.Sato, T.Hirose; *Half-Life of* ^{138}La

1983No02 Phys.Rev. C27, 1321 (1983), E.B.Norman, M.A.Nelson; *Half-Life and Decay Scheme of* ^{138}La

1984Ma46 J.Phys.(London) G10, 1765 (1984), A.M.Mandal, A.P.Patro; *(L+M+...)/K Capture Ratio in the Decay of* ^{138}La

1994Da** Applied Radiation Isotopes 45, 3, 388 (1994), J. Dalmasso, G. Barci-Funel, G. Ardisson; *Reinvestigation of the Decay of the Naturally Occurring Nuclide* ^{138}La

1997Ni12 Radiochim.Acta 77, 191 (1997), Y.Nir-El; *Determination of the Half-Life and Gamma-Ray Emission Probability of* ^{138}La

2002Ba85 At.Data Nucl.Data Tables 81, 1 (2002), I.M.Band, M.B.Trzhaskovskaya, C.W.Nestor, Jr., P.O.Tikkanen, S.Raman; *Dirac-Fock Internal Conversion Coefficients*

2003So13 Nucl.Data Sheets 98, 515 (2003), A.A.Sonzogni ; *Nuclear Data Sheets for A = 138*

2005Be73 Nucl.Instrum.Methods Phys.Res. A555, 270 (2005), R.Bernabei, P.Belli, F.Montecchia, F.Nozzoli, A.d'Angelo, F.Cappella, A.Incicchitti, D.Prosperi, S.Castellano, R.Cerulli, C.J.Dai, V.I.Tretyak; *Performances and potentialities of a* $LaCl_3$*:Ce scintillator*

2008Ki07 Nucl.Instrum.Methods Phys.Res. A589, 202 (2008), T.Kibédi, T.W.Burrows, M.B.Trzhaskovskaya, P.M.Davidson, C.W.Nestor, Jr.; *Evaluation of theoretical conversion coefficients using BrIcc*

2000Ta24 Physical Review C 62, 017601-1 (2000), Masaharu Tanimizu

2012Qu02 Nucl.Instrum.Methods Phys.Res. A683, 46 (2012), F.G.A.Quarati, I.V.Khodyuk, C.W.E.van Eijk, P.Quarati, P.Dorenbos; *Study of* ^{138}La *radioactive decays using* $LaBr_3$ *scintillators*

2012Wa38 Chin.Phys.C 36, 1603 (2012), M.Wang, G.Audi, A.H.Wapstra, F.G.Kondev, M.MacCormick, X.Xu, B.Pfeiffer; *The AME2012 atomic mass evaluation (II). Tables, graphs and references*

2016Qu01 Applied Radiation Isotopes 109, 172-176 (2016), F.G.A.Quarati, P.Dorenbos, X. Mougeot; *Experiments and theory of* ^{138}La *radioactive decay*

2016Au Priv. Comm., G. Audi, *Atomic Mass Evaluation 2016* [Q]