^{140}Ba - Comments on evaluation of decay data by R. G. Helmer

1 Decay Scheme

There are 34 reported levels in ^{140}La below the ß$^-$ decay energy, so some levels in addition to the six reported here may be weakly populated in this decay.

2 Nuclear Data

Q value is from Audi and Wapstra 1995 mass evaluation (1995Au04).

The half-life values available are, in days:

12.80	(5)	1965Si17
12.789	(6)	1971Ba28
12.746	(10)	1982DeYX, replaced by 1983Wa26
12.753	(2)	1982HoZJ, replaced by 1992Un01 and 2002Un02
12.739	(22)	1983Wa26
12.751	(5)	1983Wa26
12.7527	(23)	1992Un01 and 2002Un02
12.753	(4)	Adopted value

The value of 1971Ba28 disagrees with all of the later values, so the evaluator increased its uncertainty from 0.006 to 0.020. In the Limitation of Relative Statistical Weight, LRSW, method (1985ZiZY, 1992Ra09), the uncertainty of 1992Un01 is increased from 0.0023 to 0.0047 to reduce its weight from 81% to 50%. Then, the weighted average is 12.753 days with a σ_{int} of 0.003, a reduced-χ^2 of 1.17, and an σ_{ext} of 0.004; these values are adopted. If the original uncertainty for the 1971Ba28 value is used, the reduced-χ^2 is 10.3.

2.1 b$^-$ Transitions

The probabilities for the β^- branches are from the intensity balances from the γ-ray transitions; this is straightforward because one has a direct measurement of some of the γ-ray emission probabilities (1977De34, 1975Ha50, and 1976Li06). The limits for the very weak β^- branches are:

Level (keV)	Comment
0	This is a nonunique 3rd forbidden transition. The log *ft* systematics of 1998Si17 list only one nonunique 3rd forbidden β^- decay and it has a log *ft* of 17.5. If we assume that this class of decays all have log *ft* $\geq$ 15, the corresponding $I_{\beta-}$ is $\leq$ 1.10^{-5} %.
63	Similarly, this β^- branch is unique 3rd forbidden for which 1973Ra10 lists log *ft* values of 18.1 and 20.9. (The corresponding values in 1998Si17 are the log $f^{3u}t$ values of 20.7 and 21.4.). If we assume that this class has log *ft*>18, $I_{\beta -}$ is < 1 10^{-8} %. The intensity balance from the adopted decay scheme gives 0.00019 % (16). This nonzero value, at the 1σ level, suggests that either (1) the true $P_\gamma(63)$ and $\alpha(63)$ are both at the low end of the 1σ range, or (2) there is a very weak γ ray from either the 467 (an M3 γ) or 581 level (an E4 γ) to the 63 level. Such a γ ray would only need to be about 1% as intense as the weakest γ rays reported in this energy

region.

2.2 g Transitions

The multipolarities are from the adopted γ data in the Nuclear Data Sheets (1994Pe19). Mixing is 0.010% (6) E2 for 13-keV gamma; mixing is less than or equal to 0.008% E2 for 29-keV gamma; mixing is less than or equal to 0.064% E2 for 162 gamma; mixing is less than or equal to 1% E2 for 304-keV gamma.

See sect. 4.2 for comments on the γ-ray and level energies and the normalization of relative photon emission probabilities to absolute values.

3 Atomic Data

The data are from Schönfeld and Janßen (1996Sc06).

3.1 and 3.2

The desired data were computed by RADLST with the Schönfeld atomic data (1996Sc06, 1996ScZX).

4 Emissions

4.1 Electron Emission

Data were computed by the RADLST program, except the average β^- energies are from the LOGFT program.

4.2 Photon Emission

The level energies were computed from a least-squares fit to the measured γ-ray energies, corrected for recoil, which simultaneously includes all of the individual values from 1990Me03, 1982Ad02, 1970Ju04, 1970Ke09 (including values quoted from 1961Ge01), 1969Ka33, and 1966Mo16; plus the 537-keV value from 1979Bo26; and excluding the 30-keV value from 1966Mo16 and all unplaced lines. γ rays of 183 and 275 keV are reported by 1990Me03, but their nuclide assignment was questionable, so they have been omitted. The uncertainties in the deduced level and γ-ray energies include a factor of the square root of the reduced-χ^2 value.

The γ-ray energies from these references are:

1990Me03	1982Ad02	1979Bo26	1970Ke09	1961Ge01	1970Ju04 *	1969Ka33	1966Mo16
	13.85(5)			13.846(15)			
29.961(5) 8	29.955(2)				29.9653(7)		30.45(3)
63.185(6) *							
99.49(2)							
113.514(31)	113.55(3)		113.56(3)	113.54(3)			
118.837(3)	118.905(22)			118.84(3)	118.81 (5)	118.84(12)	119.0(5)
132.687(1)	132.716(14)			132.69(3)	132.68 (3)	132.84(12)	
162.660(1)	162.672(2)	162.369(6) ?			162.656(3)	162.64(5)	163.10(9)
183.83(9)							
275.18(18)							
304.849(3)	304.874(7)		304.840(20)		304.83(3)	304.83(6)	304.82(3)
418.44(4)							
423.722(1)	423.732(4)		423.69(3)	423.70(9)		423.81(8)	423.69(4)
437.575(2)	437.589(9)		437.55(3)	437.50(9)		437.60(3)	437.55(5)
						467.57(5)	
537.261(9)	537.311(3)	537.261(33)	537.250(20)	537.17(10)		537.32(8)	537.38(3)
551.08(4)	551.2(5)						

* from ^{139}La(n,γ)

The reduced-χ^2 = 6.0 for this fit, which implies that the uncertainties are generally too small by a factor of 2.4, or more likely, for some energies the uncertainties are too small by a larger factor. Since a major portion of this reduced-χ^2 value is from the data of 1990Me03, their uncertainties of 0.001 keV were increased to 0.002 keV and the fit repeated. The reduced-χ^2 value was then 5.2 and the χ^2 value is 259. These large values can result from inconsistencies between the values for one γ ray and/or inconsistencies between different γ rays. These cases are illustrated in the following table which shows the conflicts within the values for the 118, 162, and 537 keV, whereas for the 304- and 423-keV lines, only one values has a large contribution to the χ^2 value. The lines in this table provide 172 to the χ^2 value of 259.

Reference	E_γ [a]	ΔE_γ	final E_γ	δ/σ [b]
1990Me03	118.837 (3)	0.068 (22)	118.849 (4)	-3.9
1982Ad02	118.905 (22)			+2.6
1990Me03	162.660 (2)	0.012 (3)	162.6628 (24)	-1.4
1982Ad02	162.672 (2)	0.016 (4)		+4.6
1970Ju04	162.656 (3)	0.44 (9)		-2.3
1966Mo16	163.10 (9)			+4.9
1990Me03	304.849 (3)	0.025 (8)	304.872 (4)	-7.8
1982Ad02	304.874 (7)			+0.2
1990Me03	423.722 (2)	0.010 (4)	423.721 (4)	+0.6
1982Ad02	423.732 (4)			+2.8
1990Me03	537.261 (9)	0.050 (10)	537.303 (6)	-4.7
1982Ad02	537.311 (3)			+2.6

[a] Difference between the E_γ on the line and the one on the next line.
[b] δ is (E_γ - final E_γ) and s is the uncertainty in E_γ.

This method of analysis does not give an average value for each individual line from the data for that line. Rather, the final γ-ray energies are computed from the deduced level energies, corrected for recoil. This also means that precise energies are obtained for some γ rays for which no precise measuremenrs have been made.

The adopted energies are: 13.849 (4), 29.9656 (15), 63.184 (13), 99.479 (13), 113.582 (7), 118.849 (4), 132.6972 (25), 162.6628 (24), 304.872 (4), 423.721 (4), 437.569 (3), 537.303 (6), and 551.152 (8) keV.

For the relative γ-ray emission probabilities, the following data were used. Many values have been scaled from their original normalizations. All the values of 1966Mo16 are omitted since they do not have uncertainties. Several lines from 1969Ka33 are not included here because they have not been reported again; these are at 144, 177, 498, 512, 602, 637, and 661 keV. The weighted averages from the LRSW method have been adopted.

γ-ray energy (keV	1991Ch05	1990Me03	1982Ad02	1977Ge12	1977De34	1976Li06	1975Ha50	1970Ke09	1969Ka33	Adopted
L x	54.1(22)		32(6)							53 (7)
13.8	4.69(12)	5.0(7)	4.9(6)						7.2(25)	4.71(12)
29.9	58.4(10)	61.0(40)	60(3)					55(8)	72(12)	58.7(9)
K a	6.10(18)		6.5(5)						10.0(20)	6.4 (5)
K ß	1.47(7)		1.60(15)						<2.0(3)	1.49 (6)
43.8	0.054(7)		<0.007					<0.005		
63.1		0.00012(6)								0.00012(6)
99.4		0.00008(5)								0.00008(5)
113.6	0.072(6)	0.066(5)	0.077(16)					0.074(8)		0.070(3)
118.9	0.25(1)	0.250(3)	0.27(3)				1.56(16)	0.28(3)	0.21(2)	0.248(7)
132.7	0.81(2)	0.83(2)	0.90(8)				2.14(31)	0.84(5)	0.83(7)	0.824(13)
162.7	25.3(3)	25.45(29)	28.0(8)	26.4(8)	25.5(3)	25.9(7)	27.6(16)	25.1(10)	28.4(9)	25.65 (26)
304.9	17.54(15)	17.6(2)	17.8(5)	17.67(18)	17.63(21)	18.5(7)	17.9(19)	17.2(7)	17.3(7)	17.61(9)
418.4		0.015(1)	<0.04							
423.7	12.65(12)	12.7(1)	12.8(5)	12.73(14)	12.92(16)	13.0(6)	14.8(12)	12.7(5)	12.8(6)	12.74(6)
437.6	7.91980	7.91(4)	7.80(25)	7.82(9)	7.91(16)	8.5(5)	8.9(4)	7.8(3)	7.8(4)	7.90(4)
467.7	0.29(3)	<0.002	<0.01							
537.3	100(1)	100.0(3)	100(-)	100.0(10)	100.0(9)	100.0(23)	100.0(23)	100.0(20)	100	100.0
551.2	0.028(4)	0.0128(8)	0.027(9)							0.020 (8)
848.9			0.02							

For the lines at 43.8 and 467 keV, there are limits that are much lower than the other reported values, so they are not included in the decay scheme. Other lines that are not adopted are 418 and 848 for which only one value has been reported.

These relative emission probabilities have been scaled by **0.2439 (22)** to obtain absolute values based on the measured γ-emission rates for five lines and the source activity by 1977De34. Other normalization factors are 0.257 (6) (1975Ha50) and 0.236 (5) (1976Li06) where both were determined for the 1596 line from ^{140}La decay. The discrepancy between the latter two values is 9% and may result from difficulties in determining the γ efficiency at 1596 keV where there is a dearth of efficiency calibration lines. If the three values are averaged, the weighted mean is dominated by the 1977De34 value and is 0.2442 with σ_{int}=0.0019 and σ_{ext}=0.0036.

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