^{153}Gd - Comments on evaluation of decay data by R. G. Helmer and E. Schönfeld

This evaluation was completed in 2001. It has been corrected in 2011. Q value and internal conversion coefficients were updated.

1 Decay Scheme

In addition to the 5 levels populated in the daughter nucleus, there may be a few others with $J \leq 7/2$ in ^{153}Eu, so the completeness of the scheme depends on the failure to observe other γ-rays.
There are some serious discrepancies and ambiguities in the data for some of these five levels.

The recent mass evaluations give the decay energy as 484 keV. However, several measurements of the K-capture probability to the 172-keV level of ^{153}Eu (1962Bl11, 1964Cr08, 1967Bo11, 1980Se01, and 1985Si03) have been interpreted to indicate that the decay energy is 235 to 245 keV. In an attempt to resolve this conflict, 1981Gr19 looked for the 166-keV γ-ray which de-excites the 269-keV level and reported an emission probability of 0.0003 (3) per 100 decays; so this result is not definitive since it allows 'no population' within the 1σ uncertainty. The problem with the K-capture probability measurements or their interpretation, if any, has not been resolved.

2 Nuclear Data

Q value is from Audi *et al.* (2011).

The half-life values available are, in days:

225	1949Ke01	as quoted in 1990Le13
236 (3)	1950He18	
200	1958An34	as quoted in 1990Le13
242 (1)	1963Ho15	
240.9 (6)	1970LyZZ	superseded by 1972Em01 2nd value
241.6 (2)	1972Em01	
240.9 (6)	1972Em01	
239.63 (4)	1982HoZJ	superseded by 1992Un01 value
226.7 (21)	1989Po21	
239.47 (7)	1992Un01	
240.4 (10)	Adopted value, from LRSW weighted average	

The weighted average of the six remaining values with uncertainties is 239.71 with σ_{int} of 0.07, a reduced-χ^2 of 30.0, and σ_{ext} of 0.36. In the Limitation of Relative Statistical Weight (LRSW) method (1985ZiZY, 1992Ra09), the uncertainty for the 1992Un01 value is increased from 0.07 to 0.185 so that its relative weight is reduced from 88 % to 50 %. The weighted average is then 240.44 with σ_{int} of 0.13, a reduced-χ^2 of 21.8, and σ_{ext} of 0.61. This method then increases the final uncertainty from 0.61 to 1.0 to include the most precise value, namely, 239.47. In this LRSW analysis, the values of 1972Em01 and 1992Un01 provide 43 % and 50 % of the relative weight, respectively. The values of 1972Em01, 1989Po21, and 1992Un01 contribute 6.7, 8.6, and 5.5, respectively, to the reduced-χ^2 value.

The value from 1989Po21 differs from this average by about 6σ. The omission of this value would not make a significant difference; in the LRSW analysis without this value the weighted average would only change to 240.49 with a reduced-χ^2 of 16.6. A more aggressive analysis would increase the uncertainties for the extreme values of 226.7 (21) and 241.6 (2) and thereby drive the result nearer the value of 1992Un01 and give a smaller final uncertainty. However, the evaluator feels that the larger uncertainty of 1.0 is justified by the large spread in the measured values. This large spread is illustrated by the fact that none of the 1σ ranges of the other five values overlap the value from 1992Un01.

2.1 Electron Capture Transitions

The probabilities for the ε branches are from the probability balances using the γ-ray transition probabilities at each level of the decay scheme. It is possible to derive the ε probabilities because one has a direct measurement of the 97-keV γ-ray emission probability (1990GeZZ). There is a question as to whether the 151-keV and 269-keV levels are fed in the ^{153}Gd decay; see the discussion in section 4.2. In the decay scheme adopted here, they are omitted.

2.2 Gamma Transitions

The multipolarities and mixing ratios are from the ^{153}Eu Adopted γ data in the Nuclear Data Sheets (1998He06). The internal conversion coefficients were derived from the Band *et al.* tables (2002Ba85) using the BrIcc program (2008Ki07) with the "frozen orbital" calculation.

3 Atomic Data

The atomic data are from 1996Sc06.

The relative K x-ray probabilities are from 1996Sc06.

The x-ray emission intensities (in %) as calculated from the decay scheme data are compared with the results of measurements reported in 1992Ch16 (the quoted uncertainties given per P = 0.95 have been divided by 3). They are consistent within the uncertainty limits.

	EMISSION	Measured
$K_{\alpha 2}$	34.2 (9)	33.1 (5)
$K_{\alpha 1}$	61.7 (18)	59.3 (8)
$K_{\beta 1}$	19.4 (6)	18.9 (3)
$K_{\beta 2}$	5.01 (17)	5.08 (7)

The EMISSION values were adopted.

The K Auger electron intensities are from EMISSION.

4.1 Electron Emission

Conversion electron intensities were calculated from the absolute γ intensities and the internal conversion coefficients.

4.2 Photon Emission

From the Helmer and van der Leun evaluation (2000He14), the curved-crystal spectrometer data for the decay of ^{153}Sm and ^{153}Gd give the energies for the γ-rays of 69.6, 75.4, 83.3, 89.4, 97.4, 103.1, and 172.8 keV on a scale on which the strong line from the decay of ^{198}Au is 411.802 05 (17) keV. In addition, the values from the ^{152}Eu(n,γ) study of 1970Mu04 have been adjusted to this energy scale and are used for the γ-rays at 54.1, 68.2, 96.8, 118.1, 151.6, 166.5, and 172.3 keV. The remaining two γ-ray energies, 14.0 and 19.8 keV, were computed from the deduced level energies.

The adopted values for the relative γ-ray emission probabilities were generally taken to be the weighted averages of the data in the table below. The values for several γ-rays are very discrepant (e.g., χ_R^2 greater than 3.0) and are discussed below. The uncertainties have been chosen by the evaluator as shown in the table. The relative γ-ray emission probabilities given in 1990GeZZ have not been included since they are the same as those in 1992Ch16.

The 21.2-keV γ-ray has not been placed in the scheme.

The values for the 19-keV γ-ray form two groups, namely, the large values of 0.089 (9), 0.072 (11) and 0.06 (2), and the small values of < 0.03, 0.019 (3) and 0.006 (1); so the weighted average does not give a useful value. If one assumes that there is no electron capture feeding of the 83-keV level, a requirement of an probability balance at this level gives the transition probability of the 19-keV γ-ray as 1.55 (14) in the units of the table 1. Then, with α(19,E2) = 3220 (50), the γ intensity is 1.55/3220 = 0.000 48 (5) in relative value. Also, from conversion electron data of 1963Gr09 (a private communication to the ENSDF system), I_{ce}(LM) =1.17 (in the table units), which, with α(19,E2) = 3220, gives the γ intensity of 0.0004.

The measured intensities of the γ-ray which are proposed to depopulate the 151-keV level are not consistent with those from other modes of populating this level (see the 1998He06 for the other modes of population). These values are:

E_γ	Relative I_γ			
	^{153}Sm β^-	(n,γ)	(d,3nγ)	^{153}Gd ε
54	17.1 (18)	26 (4)	25 (3)	330 (130)
68	11 (3)	21.0 (21)	326 (47)	
151	100 (13)	100 (8)	100 (17)	100 (16)

If the ε feeding of the 151-keV level in the ^{153}Gd decay is simply computed from the intensities of the 54- and 68-keV γ-rays, it is about 0.2 %. On the other hand, the log *ft* systematics for 2nd forbidden transitions (1998Si17) give log *ft* > 11.0 which corresponds to an upper limit of branch probability 0.02 %. (Also, the intensity data in the table on the next page for the 54- and 151-keV lines are quite discrepant, with reduced-χ^2 values of 121 and 9.1, respectively.) Therefore, no adopted values are given for the 54- and 68-keV γ-rays. [A good new measurement of the intensities of the weak lines is desirable.]

As noted in section 1, it is not known if the level at 269 keV in ^{153}Eu is populated in this decay. If it is, the depopulating γ-rays are at 96.8, 118.1, 166.5 and 172.3 keV as shown from other modes of population. From the reported intensity of the 166-keV γ-ray (1981Gr19), this level would be fed in 0.008 (8) % of the decays. This level is omitted here.

The relative γ-ray intensities were normalized to γ's per 100 decays based on the measured absolute intensity for the 97-keV line of 1990GeZZ as reported in 1992Ch16; this gives a scaling factor of 0.290 (8), where the published 2σ uncertainty has been divided by 2.

The relative intensities of the K x-rays, on the scale of the table below, are K_α = 333 (8) and K_β = 84.8 (24) as calculated from the decay scheme and 325 (5) and 82.6 (12), respectively, as adopted from the measured values in the table.

Table 1. **Relative Gamma emission Intensities**

γ-ray energy (keV)	1974HeYW	1974Se08	1985Si03	1988Su13	1988Ve05	1992Ch16	1992Ch44	1993Eg05	1995Ku34	Weighted average [e] value	σ_{int}	χ_R^2	σ_{ext}	σ_{LRSW}	Adopted value
K α_2						114 (2)[d]		114 (4)[d]							
K α		321 (11)	150 (4)[a]	340 (4)	313 (8)		302 (8)		323 (8)	325	(2)	4.5	(5)	(15)	331 (12)
K α_1						204 (4)[d]		208 (8)[d]							
K β_1'						65.2 (14)[d]		65 (3)[d]	69.2 (19)						
K β		78 (11)	32.9 (5)[a]	84.9 (8)	78.9 (11)		76.4 (21)			82.6	(5)	5.3	(12)	(23)	84 (3)
K β_2'						17.5 (4)[d]		17.5 (7)[d]	16.84 (26)						
14.0			0.054 (9)	0.146 (15)	0.09 (1)		0.11 (3)	0.10 (3)	0.051 (5)[g]	0.068	(4)	9.2	(13)	(17)	0.068 (17)
19.8			0.089 (9)	0.072 (11)	0.006 (1)[g]		0.06 (2)	< 0.03	0.019 (3)	0.018	(2)	27.5	(10)	[f]	0.0004[i]
21.2				0.07 (2)				< 0.03	0.078(16)	0.075	(12)	0.10	(12)	(12)	0.075 (12)[h]
54.1		<0.01	0.091 (3)	0.058 (8)					0.027 (2)[g]	0.057	(2)	121	(22)	(30)	
68.2		0.04 (1)		0.071 (11)	0.035 (14)		0.064 (17)		0.071(11)	0.056	(5)	2.2	(8)	(16)	
69.6	7.8 (2)	8.4 (3)	8.35 (32)	8.60 (15)	8.31 (13)	8.41 (22)	7.97 (20)		8.20 (26)	8.28	(7)	1.9	(10)	(10)	8.28 (10)
75.4	0.30 (3)	0.26 (8)	0.26 (8)	0.278 (31)	0.27 (1)[g]		0.28 (2)		0.26 (2)	0.272	(8)	0.25	(8)	(8)	0.272 (8)
83.3	0.80 (8)	0.70 (7)	0.69 (7)	0.67 (4)	0.69 (3)		0.66 (2)		0.71 (4)	0.680	(14)	0.68	(14)	(14)	0.680 (14)
89.4	0.30 (3)	0.23 (7)	0.23 (6)	0.218 (26)	0.22 (2)		0.29 (2)		0.22 (2)	0.245	(10)	2.12	(14)	(45)	0.245 (14)
97.4	100 (5)	100.	100.	100.	100.0	100 (3)	100.0 (15)	100.	100.0	100					100
103.1	73.5 (10)	71.0 (15)	71.1 (15)	74.8 (7)	69.6 (10)	73.4 (17)	73.7 (12)		72.1 (14)	72.9	(4)	3.2	(7)	(19)	72.9 (7)
151.6	0.0130 (13)	<0.06	0.31[b]	0.060 (15)	0.02 (1)		<0.010		0.021 (1)	0.0172	(9)	9.1	(27)	(38)	0.017 (4)[h]
172.8	0.130 (13)	0.10 (10)	0.28[c]	0.144 (26)	0.10 (2)		0.13 (1)		0.12 (1)	0.125	(6)	0.56	(6)	(6)	0.125 (6)

[a] Value is uniquely low, omitted from weighted average calculation.
[b] Value is uniquely high, omitted from weighted average calculation.
[c] No uncertainty, omitted from weighted average calculation.
[d] Sum of Kα_1 and Kα_2 and sum of Kβ_1' and Kβ_2' used in weighted average calculation.
[e] Limits are omitted from weighted average calculation.
[f] LRSW method gives unweighted average of 0.049 (43).
[g] LRSW method increased uncertainty in order to reduce relative weight to 50 %.
[h] Value is not consistent with one upper limit.
[i] Computed from γ-ray intensity balance at 83-keV level and α(19,E2) and from internal-conversion electron data and α(19,E2).

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