^{88}Y - Comments on evaluation of decay data
by V.P. Chechev and N.K. Kuzmenko

The first DDEP evaluation of ^{88}Y decay data was done by E. Schönfeld in 1998 with minor update in 2004 (2004BeZR). The current evaluation has been completed in June 2015 with a literature cut-off by the same date.

1. DECAY SCHEME

The structure of the adopted decay scheme of ^{88}Y is based on the ENSDF evaluation by McCutchan and Sonzogni NDS (2014Mc01). ^{88}Y disintegrates by the electron capture and β^+-transition to the ^{88}Sr excited levels. Below the Q-value of 3622.6 keV there are two additional levels at 3486.6 and 3522.8 keV. They are not shown in the decay scheme because they are not populated in the disintegration of ^{88}Y. Up to now these levels were observed only in other disintegration processes, for example in the decay of ^{88}Rb (17.77 min).

An EC or β + transition to the ground state of ^{88}Sr were also not observed. This is due to the high order of forbiddenness of such transition (4- → 0+). Thus, the decay scheme of ^{88}Y adopted here is complete.

The spin, parity and half-life of the ^{88}Sr excited levels were adopted from the evaluation by 2014Mc01.

2. NUCLEAR DATA

Q^+ - value is from 2012 mass evaluation of Wang et al. (2012Wa38).

The recommended half-life of ^{88}Y is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{88}Y half-life (in days)

No	Author(s) and year	Reference	$T_{1/2}$	Method and comments
1	DuBridge and Marshall (1940)	1940Du09	105 (5)	Ionization chamber; *omitted* (too large uncertainty)
2	Peacock and Jones (1948)	1948Pe13	104	Ionization chamber; *omitted* (no uncertainty)
3	Ramaswamy and Jastram (1960)	1960Ra20	105	Ionization chamber; *omitted* (no uncertainty)
4	Wyatt *et al*. (1961)	1961Wy01	108.1 (3)	$4\pi\gamma$ ionization chamber; *omitted* (on the Chauvenet's criterion)
5	Anspach *et al*. (1965)	1965An07	106.52 (3)	$4\pi\gamma$ ionization chamber; *omitted* (superseded by 13)
6	Anspach *et al*. (1965)	1965An07	106.67 (3)	$4\pi\gamma$ ionization chamber; *omitted* (superseded by 13)

7	Grotheer *et al*. (1969)	1969Gr12	108.4 (9)	NaI(Tl)-detectors; *omitted* (on the Chauvenet's criterion)
8	Lagoutine *et al*. (1975)	1975La16	106.6 (4)	$4\pi\gamma$ ionization chamber; *omitted* (superseded by 18)
9	Bormann *et al*. (1976)	1976Bo19	107.1 (14)	$4\pi\gamma$ ionization chamber
10	Konstantinov *et al*. (1977)	1977Ko**	107.15 (65)	$4\pi\gamma$ ionization chamber
11	Houtermans *et al*. (1980)	1980Ho17	106.612 (50)	$4\pi\gamma$ ionization chamber; original uncertainty of 0.014 has been increased to 0.050 to ensure that the "weight" of this measurement would not exceed of the "weights" (26%) of two most recent values (18 and 20).
12	Debertin *et al*. (1982)	1982DEYX	106.64 (8)	Ge(Li) detector; *omitted* (superseded by 14)
13	Hoppes *et al*. (1982)	1982HOZJ	106.64 (5)	$4\pi\gamma$ ionization chamber; *omitted* (superseded by 15)
14	Walz *et al*. (1983)	1983Wa26	106.66 (6)	$4\pi\gamma$ ionization chamber
15	Unterweger *et al*. (1992)	1992Un01	106.626 (44)	$4\pi\gamma$ ionization chamber; *omitted* (superseded by 17)
16	Martin *et al*. (1997)	1997Ma75	106.65 (13)	$4\pi\gamma$ ionization chamber
17	Unterweger (2002)	2002Un02	106.63 (4)	4π ionization chamber; *omitted* (superseded by 19)
18	Amiot *et al*. (2005)	2005Am03	106.63 (5)	$4\pi\gamma$ ionization chamber
19	Fitzgerald (2012)	2012Fi12	106.62 (4)	$4\pi\gamma$ ionization chamber; *omitted* (superseded by 20)
20	Unterweger and Fitzgerald (2014)	2014Un01	106.63 (5)	$4\pi\gamma$ ionization chamber
Recommended value			**106.63 (5) d**	**LWM**

Values 1-3 from very early measurements (1940-1960) have been omitted as they are much less accurate. Values 5, 6, 8, 12, 13, 15, 17, 19 were not used because they were replaced ultimately by later results of the same laboratory.

Values 4, 7 have been rejected by the LWEIGHT computer program based on the Chauvenet's criterion. An unweighted average of the remained seven values is 106.78 (9) d. A weighted average is 106.632 d. The LWEIGHT program using the limitation of relative statistical weight method (LWM) has chosen the weighted average with the internal uncertainty of 0.025 d. The external uncertainty is 0.011 d. The ratio of the reduced χ^2 / $(\chi^2)_{crit}$ is 0.2/2.8. The smallest experimental uncertainty of 0.05 d has been adopted for the uncertainty of the recommended value.

Thus, the recommended value of ^{88}Y half-life is **106.63 (5) days.** It can be compared with an earlier evaluation of 106.626 (21) (2004BeZR).

The measurements with the largest contributions to the weighted average are listed in Table 1a.

Table 1a. The measured values having the largest contributions to the weighted average of ^{88}Y half-life.

	Houtermans *et al.* (1980)	Walz *et al.* (1983)	Amiot *et al.* (2005)	Unterweger and Fitzgerald (2014)
$T_{1/2}$ (d)	106.612 (50)	106.66 (6)	106.63 (5)	106.63 (5)
Weight	26%	18%	26%	26%

2.1. Electron Capture and β^+ Transitions

The electron capture and the β^+ emission probabilities, $P_{\varepsilon+}$ and $P_{\beta}{}^{+}$, have been deduced from the transition intensity balance for ^{88}Sr each level (Table 2). The energies, spins, parities and half-lives of levels have been adopted from 2014Mc01.

Table 2. ^{88}Sr levels populated in the ^{88}Y decay

Level	Energy (keV)	Spin and parity	Half-life	P_{ε} (%)	$P_{\beta+}$ (%)
0	0	0+	Stable	-	-
1	1836.090 (8)	2+	0.154 (8) ps	5.7 (3)	0.21 (1)
2	2734.137 (8)	3–	0.70 (5) ps	94.3 (3)	-
3	3218.489 (22)	2+	0.154 (10) ps	0.023 (4)	-
4	3584.784 (19)	5–	0.14 (4) ns	0.048 (18)	-

A positron transition to the ground state was not observed. However, sufficient energy for a positron transition is available for a transition to the 1836 keV level. The emission probability of these positrons was determined to be 0.203 (16) % by Barkov *et al*. (1974BaYZ) and that agrees well with the adopted value, 0.21 (1) %, calculated from the theoretical EC/β+ ratio of 25.6 (8) for an unique first forbidden transition interpolated from the table of Gove and Martin (1971Go40).

The maximum beta energy of the β^+ spectrum was found by Antonewa *et al*. (1979An36) to be 764.6 (15) keV corresponding to a Q value of 3622.6 (15) keV.

The log *ft* values, the fractional atomic shell electron capture probabilities and the average β+ energy have been calculated with the LOGFT code.

2.2. Gamma Transitions and Internal Conversion Coefficients

The gamma-ray transition probabilities Pγ+ce were calculated from the gamma ray emission probabilities, the total conversion coefficients, and the adopted internal pair creation coefficients.

Table 3. Comparison of the theoretical and experimental internal conversion coefficients for two most intense gamma-lines.

	$\alpha_K \times 10^{-4}$	$\alpha_T \times 10^{-4}$	K/L+M+…	
898 keV	2.73 (4) E1(+M2) δ= - 0.002 (9)	3.07 (5)	8.01 (16)	Theory, BrIccFO adopted value
	2.5 (3)	2.8 (3)	8.0 (2)	1971Al06
	3.01 (21)	3.45 (24)	7.0 (5)	1966Ha07
		3.4 (7)		1952Me50
1836 keV	1.45 (2) E2	1.63 (2)	7.80 (16)	Theory, BrIccFO adopted value
		1.7 (4)		1971Al06
	1.24 (16)	1.40 (16)	7.8 (3)	1966Ha07

Adopted ICC(s) are theoretical values interpolated by the BrIcc computer program based on BrIccFO approximation (2008Ki07). The multipolarities and mixing ratios δ have been taken from 2014Mc01 (Adopted Levels and Gammas). The mixing ratio parameter for the 898 keV transition was evaluated by Müller (1988) in 1988Mu09 to be δ = − 0.002 (9), i.e. this transition is an almost pure E1 transition.

The adopted internal pair creation coefficients, α_π, have been calculated with the BrIcc computer program. The experimental values were determined by Allan (1971Al06) as follows: α_π = 0.000 23 (3) for gamma-ray with energy of 1836 keV and α_π = 0.000 33 (5) for gamma-ray with energy of 2734 keV and can be compared with the adopted theoretical values of 0.000 230 (4) and 0.000 440 (7), respectively.

3. ATOMIC DATA

SAISINUC software has been used to determine the atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities).

4. ELECTRON AND POSITRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the electron binding energies.

The absolute emission probabilities of the conversion electrons have been deduced using recommended Pγ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program [2000Sc47].

The number of electron-positron pairs per 100 disintegrations have been obtained using the adopted α_π values.

β^+ average energies have been calculated using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-ray Emissions

The absolute emission probabilities of Sr KX- and LX- rays have been calculated using the EMISSION computer program [2000Sc47]. The adopted total KX-ray emission probability of 60.5 (5) % can be compared with the measured value of 61.5 (6) % (1994Ko34).

5.2. Gamma ray emissions

The energies of gamma rays in ^{88}Sr have been calculated from the level energies taking into account the recoil energy.

The measured relative intensities and the adopted values obtained with the LWEIGHT code are listed in Table 4 (see also 2004BeZR).

Table 4. Experimental and adopted relative gamma-ray intensities in decay of ^{88}Y

N		**γ850.6**	**γ898.0**	**γ1382.4**	**γ1836.1**	**γ2734.1**	**γ3218.4**
1	Peelle (1960Pe23)	-	94.0 (7)	-	100	0.597 (25)	-
2	Shastry and Bhattacharyya (1964Sh16)	-	91*	3*	100	0.97*	0.03*
3	Sakai *et al*. (1966Sa08)	-	-	-	100	0.63 (4)	0.0095 (3)*
4	Schötzig *et al*. (1973Sc40)	-	94.9 (5)*	-	100	-	-
5	Ardisson *et al*. (1974Ar12)	0.066 (13)	92.0 (7) [a]	0.021 (6)	100	0.724 (70)	0.0071 (20)
6	Heath (1974HeYW)	-	92.1*	-	100	0.54 (9)	0.007*
7	Antoneva *et al*. (1979An36)	0.030 (4)	92.2 (37)	0.014 (3)	100	-	-

N		**γ850.6**	**γ898.0**	**γ1382.4**	**γ1836.1**	**γ2734.1**	**γ3218.4**
8	Yoshizawa *et al*. (1980Yo05)	-	94.4 (3)	-	100	-	-
9	Debertin *et al*.(1982DeYX)	-	95.2 (5)*[b]	-	100	-	-
10	Hoppes *et al*. (1982HoZJ)	-	94.9 (4)	-	100	-	-
11	Schötzig (1990Sc08)	-	94.8 (9)	-	100	-	-
	Adopted	**0.048 (18)**	**94.3 (3)**	**0.016 (3)**	**100**	**0.612 (25)**	**0.0071 (20)**

*indicates the value omitted from the current analysis
[a] adopted in 1974Ar12 from the measurement by Jardine (1971Ja21)
[b] 1977 measurement result by Debertin *et al.*

The experimental values 2, 6 from Shastry and Bhattacharyya (1964Sh16) and Heath (1974HeYW), respectively, marked by asterisks were not taken into account because leak of uncertainties.

Adopted values:

- for **γ850 keV**: the evaluated value has been obtained by LWM with values 5 and 7. The LWEIGHT code has increased the original uncertainty of 1979An36 to 0.013 to ensure the relative weight of this measurement would not exceed 50%; the ratio of the reduced $\chi^2 / (\chi^2)_{crit}$ is 3.8/6.6.

- for **γ898 keV**: the values 2 and 6 have not been taken into account because of the lack of uncertainties and the values 4 and 9 are superseded by value 11. The value of the relative intensity of 92.2 (37) for this gamma line, referred to as Antoneva *et al*. (1979An36), has been calculated by the evaluators from the measured ratio $P(ce_K; \gamma_{1,0}) / P(ce_K; \gamma_{2,1}) = 0.576\ (20)$ in 1979An36 (where $P(ce_K; \gamma) = \alpha_K \times P\gamma$ is the probability of K-conversion electron emission) by using the current theoretical values of α_K. The evaluated value has been obtained by LWM with values 1, 5, 7, 8, 10 and 11. The ratio of the reduced $\chi^2 / (\chi^2)_{crit}$ is 2.8/3.0.

- for **γ2734 keV**: the evaluated value has been obtained by LWM with values 1, 3, 5 and 6**.** The ratio of the reduced $\chi^2 / (\chi^2)_{crit}$ is 1.2/3.8.

- for **γ3522 keV**: upper limit of Pγ (3522 keV)/Pγ (1836 keV) < 0.001 has been taken from Ardisson et al. (1974Ar12);

- for **γ484 keV**: upper limit of Pγ (484 keV)/Pγ (1836 keV) < 9×10^{-4} has been taken from Antoneva et al. (1979An36).

The normalization factor (**0.99346 (25)**) to convert the adopted relative gamma ray intensities to absolute emission probabilities has been deduced from the gamma ray transition intensity balance for the ground state assuming no direct electron capture or beta plus feeding to the ground state.

5. ENERGY CONSERVATION

The total average energy of 3622 (7) keV per decay, calculated from the current evaluated data, corresponds well to the available energy of 3622.6 (15) keV (Q) from the atomic mass tables (2012Wa38), confirming the consistency of the decay scheme and the reliability of this evaluation.

6. REFERENCES

1940Du09 L. A. DuBridge and J. Marshall, Phys. Rev. 58 (1940) 7. [$T_{1/2}$]

1948Pe13 W. C. Peacock, J. W. Jones, Report AECD, 1812 (1948). [$P_{\beta+}$, $T_{1/2}$]

1952Me50 F.R.Metzger, H.C.Amacher, Phys.Rev. 88, 147 (1952). [Experimental ICC]

1960Pe23 R. W. Peelle, report ORNL, 3016 (1960), 110. [$P\gamma$]

1960Ra20 M. K. Ramaswamy and P. S. Jastram, Nucl. Phys. 19 (1960) 243. [$T_{1/2}$]

1961Wy01 E. I. Wyatt, S. A. Reynolds, T. H. Handley, W. S. Lyon, H. A. Parker, Nucl. Sci. Eng. 11, 74 (1961). [$T_{1/2}$]

1964Sh16 S. Shastry and R. Bhattacharyya, Nucl. Phys. 55 (1964) 397. [$P\gamma$]

1965An07 S. C. Anspach, L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, C. N. Smith, Report NP-15663 (1965). [$T_{1/2}$]

1966Sa08 M. Sakai, T. Yamazaki, J. M. Hollander, Nucl. Phys. 84 (1966) 302. [$P\varepsilon$, $P\gamma$]

1966Ha07 J. H. Hamilton, S. R. Amtey, B. van Nooijen, A. V. Ramayya, J. J. Pinajian, Phys. Lett. 19 (1966) 682. [Experimental ICC]

1969Gr12 H. H. Grotheer, J. W. Hammer, K. W. Hoffmann, Z. Phys. 225 (1969) 293. [$P_{\beta+}$]

1971Al06 C. J. Allan, Nucl. Instrum. Methods 91 (1971) 117. [α_π]

1971Go40 N. B. Gove and M. J. Martin, Nuclear Data Tables 10 (1971) 205. [$P\varepsilon$ /$P_{\beta+}$]

1971Ja21 L. J. Jardine, Nucl. Instrum. Methods 96 (1971) 259. [$P\gamma$]

1973Sc40 U. Schötzig, K. Debertin, H.M. Weiss, PTB Mitt. 83, 307 (1973) [$P\gamma$]

1974Ar12 G. Ardisson, S. Laribi, C. Marsol, Nucl. Phys A223 (1974) 616. [$P\gamma$]

1974BaYZ A. V. Barkow, W. M. Winogradow, A. W. Solotawin, W. M. Makarow, T. M. Usypko, Program and abstracts of 24. Conference on nuclear spectroscopy and nuclear structure, Kharkov, 29 Jan. -1 Feb.1974, AN SSSR, Moscow, 1974, 58. [β^+, α_π]

1974HeYW R. L. Heath, Gamma-ray Spectrum Catalogue, USAEL, Rep. ANCR 1000-2 (1974). [$E\gamma$, $P\gamma$]

1975La16 F. Lagoutine, J. Legrand, C. Bac, Int. J. Appl. Radiat. Isot. 26 (1975) 131. [$T_{1/2}$]

1976Bo19 M. Bormann, H.-K. Feddersen, H.-H. Hölscher, W. Scobel and H. Wagner, Z. Physik A277 (1976) 203. [$T_{1/2}$]

1977Ko** A. A. Konstantinov, T. E. Sazonowa and S. W. Sepman, Conference: 27. Annual conference on nuclear spectroscopy and nuclear structure, Tashkent, USSR, 22-25 March 1977, p.6. [$T_{1/2}$]

1979An36 N. M. Antoneva, V. M. Vindgradov, E. P. Grigorev, P. P. Dmitriev, A. V. Zolotavin, G. S. Katykhin, N. Krasnov, V. N. Makarov, Bull. Ac. Sci.USSR, Phys. Ser. 43 (1979) 155. [$P_{\beta+}$, α_π , $P\gamma$]

1980Ho17 H. Houtermans, O. Milosevic, F. Reichel, Int. J. Appl. Radiat. Isot. 31 (1980) 153. [$T_{1/2}$]

1980Yo05 Y. Yoshizawa, Y. Iwata, T. Kaku, T. Katoh, J. Ruan, T. Kojima, Y. Kawada, Nucl. Instr. and Meth.174 (1980) 109. [$P\gamma$]

1982DeYX K. Debertin, U. Schötzig, K. F. Walz, National Bureau of Standards, Washington, D.C., Report NBS-SP- 626 (1982) 101. [$T_{1/2}$, $P\gamma$]

1982HoZJ D. D. Hoppes, J. M. R. Hutchinson, F. J. Schima, M. P. Unterweger, National Bureau of Standards, Washington, D.C., Report NBS-SP-626 (1982) 85. [$T_{1/2}$, $P\gamma$]

1983Wa26 K. F. Walz, K. Debertin and H. Schrader, Int. J. Appl. Radiat. Isot. 34 (1983) 1191. [$T_{1/2}$]

1988Mu09 H.-W. Muller, Nucl. Data Sheets 54 (1988) 1. [Gamma-ray multipolarities and mixing ratios]

1990Sc08 U. Schötzig, Nucl. Instrum. Methods Phys. Res. A286 (1990) 523. [$P\gamma$].

1992Un01 M.P. Unterweger, D.D. Hoppes, F.J. Schima, Nucl. Instrum. Methods Phys. Res. A312 (1992) 349. [$T_{1/2}$]

1994Ko34 A. A. Konstantinov, T. E. Sazonova, S. V. Sepman, A. V. Zanevsky, N. I. Karmalitsyn, Nucl. Instrum. Methods Phys. Res. A339 (1994) 200. [P_{KX}]

1997Ma75 R. H. Martin, K. I. W. Burns, J. G. V. Taylor, Nucl. Instrum. Methods Phys. Res. A390 (1997) 267. [$T_{1/2}$]

2000Sc47 E. Schönfeld and H. Janβen. Appl. Radiat. Isot. 52 (2000) 595. [X-ray and Auger electron emission probabilities]

2002Un02 M.P. Unterweger, Appl. Radiat. Isot. 56, 125 (2002). [$T_{1/2}$]

2004BeZR M.-M. Bé, V. Chiste, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Shönfeld, and R. Dersch, *Table of Radionuclides (Vol. 1 – A =1 to 150).* Bureau International des Poids et Mesures, 2004. ^{88}Y. P. 153-160. [Previous ^{88}Y decay data evaluation by DDEP collaboration]

2005Am01 M. N. Amiot, J. Bouchard, M.-M. Bé, J. B. Adamo, Appl. Rad. Isotop. 62 (2005) 11. [$T_{1/2}$]

2008Ki07 T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor Jr., Nucl. Instrum. Methods Phys. Res. A589 (2008) 202. [BrIcc computer program]

2012Fi12 R. Fitzgerald. J. Res. Natl. Inst. Stand. Technol. 117 (2012) 80. [$T_{1/2}$]

2012Wa38 M. Wang, G. Audi, A.H. Wapstra, F.G. Kondev, M. MacCormick, X. Xu, B. Pfeiffer, Chin. Phys. C36 (2012) 1603. [Q]

2014Mc01 E. A. McCutchan, A. A. Sonzogni, Nucl.Data Sheets 115, 135 (2014). [Decay scheme structure, ^{88}Sr adopted levels and gammas, gamma-ray multipolarities]

2014Un01 M.P. Unterweger, R. Fitzgerald, Appl. Radiat. Isot. 87 (2014) 92. [$T_{1/2}$]