^{51}Cr - Comments on evaluation of decay data by V.P. Chechev and N.K. Kuzmenko

The first DDEP evaluation of ^{51}Cr decay data was done by E. Schönfeld and R.G. Helmer in February 2001 with a minor error correction in 2004 (2004BeZR). The current evaluation was completed in March 2014 with a literature cut-off at the same date.

1. DECAY SCHEME

The structure of the adopted scheme of ^{51}Cr is based on the ENSDF evaluation by Huang (2006Hu10). ^{51}Cr disintegrates by electron capture to the ground state (90.1%) and lowest excited level (9.9%) of ^{51}V. The decay scheme is complete since these are the only states in ^{51}V below the decay energy which can be populated in this decay. The spin, parity and half-life of the ^{51}V excited level are from the evaluation by 2006Hu10.

2. NUCLEAR DATA

Q^- value is from the 2012 mass evaluation by Wang *et al.* (2012Wa38).

The recommended half-life of ^{51}Cr is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{51}Cr half-life (in days)

N	Author(s) and year	Reference	$T_{1/2}$	Method and comments
1	Walke and Thompson (1940)	1940Wa02	26.0 (10)	NaI(Tl) detector
2	Walke and Thompson (1940)	1940Wa02	26.5 (10)	Ionization chamber
3	Hopkins Jr. and Cunningham (1948)	1948Ho04	26	Ionization chamber; *omitted* – no uncertainty
4	Miller et al. (1948)	1948Mi12	27	Ionization chamber; *omitted* – no uncertainty
5	Lyon (1952)	1952Ly17	27.75 (30)	Ionization chamber
6	Kafalas and Irvine, Jr. (1956)	1956Ka33	27.9 (2)	Ionization chamber
7	Schumann and Jones (1956)	1956Sc87	27.8 (1)	Ionization chamber
8	Karavaev and Rusinova (1957)	1957Ka65	27.85 (2)	Ionization chamber
9	Karavaev and Rusinova (1957)	1957Ka65	28.04 (16)	Ionization chamber
10	Wright et al. (1957)	1957Wr37	27.75 (30)	Ionization chamber

11	Hontzeas and Yaffe (1963)	1963Ho17	27.82 (20)	Ionization chamber
12	Salisbury and Chalmers (1965)	1965Sa09	27.5	Ionization chamber; *omitted* – no uncertainty
13	Marias et al. (1964)	1964Ma56	27.701 (6)	Ionization chamber
14	Lagoutine et al. (1967)	1967LaZZ	27.7 (2)	NaI(Tl) detector; *omitted* as superseded by 19
15	Bormann et al. (1968)	1968Bo25	27.80 (51)	Ionization chamber
16	Merritt and Taylor (1969, 1970)	1969MeZV, 1970MeZQ	27.704 (3)	Ionization chamber
17	Walz and Schötzig (1970)	1970WaAA	27.679 (17)	Ionization chamber, *omitted* as superseded by 26
18	Emery et al. (1972)	1972Em01	27.76 (15)	Ionization chamber
19	Lagoutine (1973)	1973LaAA	27.721 (26)	Ionization chamber, *omitted* as superseded by 23
20	Araminovicz and Dresler (1973)	1973ArZI	28.1 (17)	Ionization chamber
21	Visser et al. (1973)	1973Vi13	27.750 (9)	4πγ ionization chamber
22	Tse et al. (1974)	1974Ts01	27.703 (8)	Ge(Li) detector
23	Lagoutine et al. (1975)	1975La16	27.720 (27)	NaI(Tl) detector
24	Houtermans et al. (1980)	1980Ho17	27.690 (5)	4πγ ionization chamber
25	Christmas (1982)	1982ChZF	27.71 (1)	4πγ ionization chamber
26	Hoppes et al. (1982)	1982HoZJ	27.73 (1)	4πγ ionization chamber; *omitted* as superseded by 28
27	Walz et al. (1983)	1983Wa26	27.710 (30)	4πγ ionization chamber
28	Unterweger et al. (1992)	1992Un01	27.7010 (12)	4πγ pressurized ionization chamber; *omitted* as superseded by 29
29	Unterweger et al. (2002)	2002Un01	27.6999 (13)	4πγ ionization chamber; *omitted* as superseded by 30
30	Fitzgerald (2012)	2012Fi12	27.7010 (12)	4πγ ionization chamber; *omitted* as superseded by 31
31	Unterweger and Fitzgerald (2014)	2014Un01	27.70 (3)	4πγ ionization chamber
Recommended value		**27.704 (4)**		

The three values (3, 4, 12) without uncertainties were omitted. The values 14, 17, 19, 26, 28, 29, 30 were not used because they were replaced ultimately by later results of the same laboratory. The values 1, 2, 6, 8, 9, 20 have been rejected by the LWEIGHT computer program based on Chauvenet's criterion.

The weighted average of the remaining 15 values is **27.7040 d**. The external uncertainty is 0.0034 d. The internal uncertainty is 0.0021 d. The smallest experimental uncertainty is 0.003 d. The largest contributions to the weighted average are from the values 16 (1969MeZV, 1970MeZQ) - 50% and 24 (1980Ho17) – 18%. The ratio of the reduced $\chi^2/(\chi^2)_{crit}$ is 2.6/2.1. The weighted average has been chosen with the external uncertainty.

The recommended value of ^{51}Cr half-life is **27.704 (4) days**.

2.1. Electron Capture

The electron capture transition energies have been obtained from Q^+ and the ^{51}V level energy, which has been adopted from Huang (2006Hu10) (see Table 2).

The electron capture probabilities, P_ε, have been deduced from the intensity balance for each level.

Table 2. ^{51}V levels populated in ^{51}Cr decay

Level	Energy (keV)	Multipolarity	Half-life	P_ε (%)
0	0	7/2-	Stable	90.09 (2)
1	320.0835 (4)	5/2-	184 (6) ps	9.91 (2)

The lg ft values and the fractional atomic shell electron capture probabilities have been calculated with the LOGFT code.

2.4. Gamma Transitions and Internal Conversion Coefficients

The gamma-ray transition probability has been deduced from its gamma-ray emission probability and the total ICC. The adopted ICC(s) are the theoretical values interpolated by the BrIcc computer program (2008Ki07) from the tables of Band et al. (2002Ba85). The multipolarity and the mixing ratio, $\delta = 0.465$ (20), have been taken from 2006Hu08. The adopted value of the mixing ratio, $\delta = +\ 0.465$ (20), is the weighted average of the measured values of + 0.43 (3) in ^{51}V(γ,γ'), + 0.52 (7) from pulsed beam in Coulomb excitation (1962Ri09, 1999Ka65), and 0.49 (3) calculated from the adopted B(E2) = 0.0132 (11) (the weighted average of 1960Ad01, 1962Ri09, 1971DaZM) and the level half- life.

3. ATOMIC DATA

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electron energies and relative probabilities) have been deduced by using the SAISINUC software.

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energy and the electron binding energies. The absolute emission probabilities of the conversion electrons have been deduced using recommended P_γ and ICC values. The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

5. PHOTON EMISSIONS

5.1. X-ray Emissions

The absolute emission probabilities of the vanadium KX- and LX- rays have been calculated using the EMISSION computer program. In Table 3 the calculated values are compared to the experimental data.

Table 3. Experimental and adopted KX - ray emission probabilities per 100 decays in the decay of ^{51}Cr.

	1994Ko34	2005Ya01	2010Mo01	**Adopted (calculated)**
XKα		20.36 (1)	20.0 (7)	20.2 (3)
XKβ			2.57 (9)	2.69 (7)
XK	23.2 (3)			22.9 (3)

5.2. Gamma ray emissions

The energies of gamma rays in ^{51}V have been adopted from 2006Hu08. The adopted γ-ray emission probability, P_γ, is based on the experimental results given in Table 4.

Table 4. Experimental and adopted γ-ray emission probabilities in the decay of ^{51}Cr.

N	**Pγ (%)**	**Reference**
1	9.8 (6)	1955Bu01
2	9 (1)	1955Co56
3	9.72 (15)	1963MeZZ
4	10.20 (63)	1965Dh01
5	9.75 (20)	1965Le24
6	10.2 (10)	1970Ri11
7	9.85 (9)	1980Sc07
8	10.30 (19)	1984Fi10
9	9.86 (8)	1991Ba11
10	9.96 (9)	1994Ko34

11	9.91 (1)	2005Ya01
12	9.87 (3)	2010Mo01
9.89 (2)		**Adopted**

The value of 1955Co56 was rejected by the LWEIGHT computer program based on Chauvenet's criterion. The value of 1984Fi10 was also rejected by the evaluators as an outlier. Its contribution to the total χ^2 was too large.

The evaluators have increased the uncertainty of value 11 (2005Ya01) from 0.01 to 0.025 in order to reduce its relative weight from 86% to 50%. The ratio of the reduced $\chi^2/(\chi^2)_{crit}$ is 0.5/2.4. The weighted average of the remaining ten values is **9.890**. The external uncertainty is 0.012. The internal uncertainty is 0.018. The smallest experimental uncertainty is 0.01.

The adopted value of Pγ (320 keV) is **9.89 (2) %.**

6. ENERGY CONSERVATION

The total average energy of 752.61 (29) keV, for one disintegration, calculated from the current evaluated data corresponds very well to the available energy of 752.62 (24) keV (Q^+) from the mass tables (2012Wa38) confirming the consistency of the decay scheme and the reliability of this evaluation.

7. REFERENCES

1940Wa02 H. Walke, F.C. Thompson, J. Holt, Phys. Rev. 57 (1940) 171. [$T_{1/2}$]

1948Ho04 H.H. Hopkins Jr, B.B. Cunningham, Phys. Rev. 73 (1948) 1406. [$T_{1/2}$]

1948Mi12 D.R. Miller, R.C. Thompson, B.B. Cunningham, Phys. Rev. 74 (1948) 347. [$T_{1/2}$]

1952Ly17 W.S. Lyon, Phys. Rev. 87 (1952) 1126. [$T_{1/2}$]

1955Bu01 M. E. Bunker, J. W. Starner, Phys. Rev. 97 (1955) 1272 and 99 (1955) 1906. [Pγ]

1955Co56 S. G. Cohen, S. Ofer, Phys. Rev. 100 (1955) 856. [Pγ]

1956Ka33 P.Kafalas, J.W.Irvine, Jr., Phys. Rev. 104 (1956) 703. [$T_{1/2}$]

1956Sc87 R.P. Schumann, M.E. Jones, A.C. Mewherter, J. Inorg. Chem. 3 (1956) 160. [$T_{1/2}$]

1957Ka65 G.M. Karavaev, S.A. Rusinova, Trudy Vsesoyuz. Nauch.-Issledovatel. Inst. Metrol. 30 (1957) 132. [$T_{1/2}$]

1957Wr37 H.W. Wright, E.I. Wyatt, S.A. Reynolds, W.S. Lyon, T.H. Handley, Nuc. Sci. Eng. 2 (1957) 427. [$T_{1/2}$]

1960AD01 B.M. Adams, D. Eccleshall, M.J.L. Yates, Proc. Conf. Reactions between Complex Nuclei, 2nd, Gatlinburg, A. Zucker, E.C. Halbert, F.T. Howard, Eds., John Wiley and Sons, Inc., New York, p.95 (1960). [measured B(E2), deduced δ]

1962RI09 R.C. Ritter, P.H. Stelson, F.K. McGowan, R.L. Robinson, Phys. Rev. 128, 2320 (1962). [measured B(E2), deduced δ]

1963Ho17 S. Hontzeas, L. Yaffe, Can. J. Chem. 41 (1963) 2194 [$T_{1/2}$]

1963MeZZ J.S. Merritt, J.G.V. Taylor, Report AECL-1778 (1963) 31. [Pγ]

1964Ma56 P.G. Marais, F.J. Haasbroek, J.H.M. Karsten, S. Afr. J. Agric. Sci. 7, 881 (1964). [$T_{1/2}$]

1965Dh01 K.C. Dhingra, U.C. Gupta, N.P.S. Sidhu, Current Sci. (India) 34 (1965) 504. [Pγ]

1965Le24 J. Legrand, Report CEA-R-2813 (1965). [Pγ]

1965Sa09 S.R. Salisbury, R.A. Chalmers, Phys. Rev. 140 (1965) B305. [$T_{1/2}$]

1967LaZZ F. Lagoutine, Y.Le Gallic, J. Legrand, Proc. Symp. Standardization of radionuclides, Vienna, Austria(1966), IAEA, Vienna, (1967) 603; CONF-661012. [$T_{1/2}$]

1968Bo25 M. Bormann, A. Behrend, I. Riehle, O. Vogel, Nucl. Phys. A115 (1968) 309. [$T_{1/2}$]

1969MeZV J.S. Merritt, J.G.V. Taylor, Report AECL-3512, p.30 (1969). See also 1980RuZY. [$T_{1/2}$]

1970MeZQ J.S. Merritt, J.G.V. Taylor, Report AECL-3668, p.50 (1970). See also 1980RuZY. [$T_{1/2}$]

1970Wa** K.F. Walz, U. Schötzig, Wissenschaftliche Abhandlungen der Phys.-Techn. Bundesanstalt 22 (1970) 76. [$T_{1/2}$]

1971DaZM W.G. Davies, J.S. Forster, I.M. Szoghy, D. Ward, Report AECL-3996, p.16 (1971) [measured B(E2)]

1972Em01 J.F. Emery, S.A. Reynolds, E.I. Wyatt, G.I. Gleason, Nucl. Sci. Eng. 48 (1972). 319 [$T_{1/2}$]

1973ArZI J. Araminowicz, J. Dresler, Report INR-1464 (1973) 14. [$T_{1/2}$]

1973De60 E. De Roost, F. Lagoutine, At. Energy Rev. 11 (1973) 642. [$T_{1/2}$]

1973La** F. Lagoutine, Priv. Comm. (quoted in 1973De60). [$T_{1/2}$]

1973Vi13 C.J. Visser, J.H.M. Karsten, F.J. Haasbroek, P.G. Marias, Agrochemophysica 5 (1973) 15. [$T_{1/2}$]

1974Ts01 C.W. Tse, J.N. Mundy, W.D. McFall, Phys. Rev. C 10 (1974) 838. [$T_{1/2}$]

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

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

1980RuZY A.R.Rutledge, L.V.Smith, J.S.Merritt, Report AECL-6692 (1980). [$T_{1/2}$]

1980Sc07 USchotzig, KDebertin, K.FWalz, Nucl. Instrum. Methods 169 (1980) 43. [Pγ]

1982ChZF P. Christmas, Report NBS-SP-626 (1982) 100. [$T_{1/2}$]

1982HoZJ D.D. Hoppes, J.M.R. Hutchinson, F.J. Schima, M.P. Unterweger, Report NBS-SP-626 (1982) 85. [$T_{1/2}$]

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

1984Fi10 S.A. Fisher, R.I. Hershberger, Nucl. Phys. A423 (1984) 121. [Pγ]

1991Ba11 T. Barta, L. Szücs, A. Zsinka, Appl. Radiat. Isot. 42 (1991) 490. [Pγ]

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

1994Ko34 A.A. Konstantinov, T.E. Sazonova, S.V. Sepman, A.V. Zanevsky, N.I. Karmalitsyn, Nucl. Instr. Meth. A339 (1994) 200. [Pγ, P_{XK}]

1999Ka65 H. Kaisera, P. von Brentanob, E. Caurierc et al., Nucl. Phys. A660 (1999) 41. [δ]

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

2002Ba85 I.M. Band, M.B. Trzhaskovskaya, C.W. Nestor Jr., P.O. Tikkanen, S. Raman. At. Data Nucl. Data Tables 81 (2002) 1. [Theoretical ICC]

2004BeZR M.-M. Bé, V. Chisté, 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. ^{51}Cr. p. 73. [Previous ^{51}Cr decay data evaluation]

2005Ya01 P. Yalcin, Y. Kurucu, Appl. Radiat. Isot. 62 (2005) 63. [Pγ, P_{XK}]

2006Hu10 X. Huang, Nucl. Data Sheets 107, 2131 (2006). [Decay Scheme, ^{51}V Adopted Levels and Gammas]

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]

2010Mo01 D.S. Moreira, M.F. Koskinas, I.M. Yamazaki, M.S. Dias, Appl. Radiat. Isot. 68 (2010) 596. [Pγ]

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

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

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