Review of alpha-decay data from doubly-even nuclei

Y. A. AKOVALI

Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6371, USA*

RECEIVED

SEP 18 1996

OSTI

Abstract: Alpha-decay data from doubly-even nuclei throughout the periodic table are reviewed and evaluated. From these data, nuclear radius parameters are calculated by using the Preston formula for α -decay probabilities. The radius parameters for each element behave rather regularly as a function of neutron number. They show minima at the major closed shells, increase sharply for parents just above the closed shells, and decrease smoothly toward the next shell closure. The same trend is observed for α reduced widths calculated using the Rasmussen formalism. Any irregularity or large departure from this behavior indicates probable incorrect input data. This systematic behavior can also be utilized to estimate partial half-lives.

Alpha-hindrance factors, HF, defined as the ratios of experimental to theoretical partial half-lives of α transitions, are powerful tools in obtaining spectroscopic information about nuclear states. Various models have been introduced in order to understand the α -decay process and to calculate the penetrability of α particles through a barrier.

In one of the early models¹, a preformed α particle inside a nucleus was treated as being in a rectangular potential field with a depth of V_0 and an effective nuclear radius, $R=r_0 A^{1/3}$, where A is that of the daughter nucleus; for distances larger than this radius, the field is a Coulomb potential between α particle and daughter nucleus. The spin-independent part of the Preston equations¹ is used widely². The nuclear radius parameter R (or r_0) for an even-even nuclide is determined by defining the calculated transition probability for an α transition from parent's ground state to ground state in the daughter nucleus to be equal to the experimental transition rate, that is $HF=1.0$ for such a transition. In the calculation of hindrance factors for α transitions from odd and odd-odd nuclei, the radius parameters are chosen from the r_0 values for the neighboring even-even nuclei.

In a later model³, nuclear-barrier penetration was calculated by using an optical-model potential derived from the analysis of α -particle scattering data. A centrifugal barrier was added to the nuclear potential to take l dependence into account. The α -decay rates are discussed in terms of reduced widths, defined by $\delta^2 = \lambda h/P^2$ where P is the penetrability factor, λ is the decay constant and h is the Planck's constant. The Rasmussen formalism is used by many researchers⁴.

With a better understanding of the nuclear potential and with the availability of faster computing capabilities, interest in exploring the α -decay process has increased recently. There are numerous excellent theoretical studies where absolute transition rates have been calculated for various nuclei⁵. These studies will not be reviewed here; the reader is referred to papers given in Ref.5 and the earlier references quoted in them.

The purpose of this study is to provide a tool for estimating half-lives and α -decay branchings for not-yet-discovered nuclei, as well as to provide evaluated α -decay data for even-even nuclei. In this study, the experimental α -transition rates and their hindrance factors for all known even-even α emitters are examined. For calculations of hindrance factors, experimental half-lives of parent nuclei, α -decay branchings, α energies and relative α intensities are needed. All available data⁶ for these experimental quantities have been reviewed, evaluated and listed in Table 1. The nuclear radius parameters given in this table are calculated by using the Preston formula¹. As mentioned above, for α transitions from odd and odd-odd nuclei the radius parameters obtained from these r_0 parameters are to be used in the computation of hindrance factors. A systematic study of hindrance factors for α transitions between various orbitals has been done previously and rules for hindrance factors were deduced⁷.

The calculated radius parameters for all nuclides decrease gradually with increasing neutron number between closed shells; they reach minima at the $N=126$, the only major closed shell for α decaying nuclei, increase sharply just above this closed shell, and decrease again with increasing neutron number toward the next major shell with a slight minimum at the $N=152$ minor closed shell. A similar pattern has been observed⁴ for α reduced widths for these s-wave α transitions.

*The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-96OR22464. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

UM

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

The regular behavior of r_0 parameters (and δ^2s) is often utilized to calculate some unmeasured property of an observed α transition, such as its partial α half-life, or to predict some nuclear properties for yet unobserved α decays. In these cases, the r_0 parameter for a nucleus is obtained from the r_0 systematics by extrapolation or interpolation, and the desired properties are computed from this radius parameter. Examples below illustrate some of the methods used for (i) estimating the half-life of a nucleus; (ii) estimating branching ratio for α -decay; (iii) choosing the best half-life of a nucleus from various measured values.

- A 7428-keV α group following the $^{166}\text{Er}(^{36}\text{Ar}, \text{xn})$ reaction was observed⁸ and identified as decaying from neutron-deficient ^{196}Rn . The r_0 systematics suggests $r_0 = 1.56 \pm 0.02$, which leads to $T_{1/2}(7428\text{-keV } \alpha) = 7 \pm 3$ ms. The partial half-life of ^{196}Rn for β decay was estimated as ≈ 5 seconds from gross beta calculations⁹. These calculated partial half-lives predict that the α branching for ^{196}Rn is 99.9% and the β branching is $\approx 0.14\%$. The calculated half-life of 7 ms agrees well with the time difference of 5 ms measured between residues in $^{166}\text{Er}(^{36}\text{Ar}, \text{xn})$ reaction and the α detection⁸.

- In the decay of ^{228}Pu , only one α group with energy of 7810 keV has been observed¹⁰; its half-life has not been measured, and no other mode of decay has been detected. From a separate systematic study⁷ of hindrance factors for α 's to the first 2^+ states, the intensity of the 7810-keV α transition to the ground state of ^{224}U is deduced as 75%. From the radius parameter of $r_0 = 1.525 \pm 0.015$, the partial half-life for α decay is calculated to be 0.28 ± 0.10 seconds. Together with the partial half-life of 90 seconds for β decay⁹, the total half-life and α and β decay branchings of ^{228}Pu are predicted to be $T_{1/2} = 0.28 \pm 0.10$ seconds, 99.7% and 0.3%, respectively.

The r_0 values placed in parentheses in Table 1 are obtained from the systematics of radius parameters that are calculated in this work, and $T_{1/2}$ or α branchings listed in parentheses are the values computed using the corresponding r_0 values. It is hoped that this table will serve as a useful tool for analyzing new results and estimating the α -decay properties for nuclei in new regions to be studied.

The author is grateful to Mrs. Mary Ruth Lay for preparing the table and for editing the manuscript. The author wishes to thank Dr. Murray Martin for valuable discussions.

Table 1. Calculated r_0 parameters and the data used in calculations

Parent	Parent $T_{1/2}$	α -branching ratio	r_0 (daughter) (10^{-13} cm)		$E\alpha_0$ (keV)	$I \alpha$ (per 100 α)
^{106}Te	60 μs 30	1.0	1.70	4	4128 9	100
^{108}Te	2.1 s 1	0.49 4	1.632	14	3318 4	100
^{110}Te	18.6 s 8	(6.7×10^{-6})	(1.57	5)	2624 15	100
^{110}Xe	(0.05 s)	(0.87)	(1.70	6)	3745 15	100
^{112}Xe	2.7 s 8	0.008	1.64	9	3211 7	100
^{144}Nd	2.29×10^{15} y 16	1.0	1.596	9	1852.3 18	100
^{146}Sm	10.31×10^7 y 45	1.0	1.569	8	2455 4	100
^{148}Sm	8×10^{15} y 2	1.0	(1.554	26)	1932.3 12	100
^{148}Gd	74.6 y 30	1.0	1.570	3	3182.680 24	100
^{150}Gd	1.79×10^6 y 8	1.0	1.572	12	2734 7	100
^{150}Dy	7.17 m 5	0.36 5	1.566	10	4235.1 17	100
^{152}Gd	1.08×10^{14} y 8	1.0	1.574	7	2146.6 15	100
^{152}Dy	2.38 h 2	0.00108 11	1.584	13	3628 4	100
^{152}Er	10.3 s 1	0.91 4	1.567	4	4804.3 16	100
^{154}Dy	3.0×10^6 y 15	1.0	1.54	4	2870 5	100
^{154}Er	3.7 m 3	0.0047 13	1.551	24	4168 3	100
^{154}Yb	0.409 s 2	0.92 2	1.5570	25	5330.9 17	100
^{156}Yb	26 s 2	0.10 2	1.596	19	4687 4	100
^{156}Hf	23 ms 1	0.97 3	1.552	6	5873 4	100
^{158}Yb	1.60 m 10	0.000021 13	1.52	6	4065 8	100
^{158}Hf	2.85 s 7	0.44 3	1.562	7	5267 4	100

Table 1. Calculated r_0 parameters and the data used in calculations

Parent	Parent $T_{1/2}$	α -branching ratio	r_0 (daughter) (10^{-13} cm)		$E\alpha_0$ (keV)	$I \alpha$ (per 100 α)
^{158}W	0.9 ms 3	1.0	1.581	36	6437 30	100
^{160}Hf	13.6 s 2	0.007 2	1.548	20	4780 3	100
^{160}W	91 ms 5	0.87 8	1.557	10	5912 5	100
^{162}Hf	39.8 s 4	7×10^{-5} 1	1.576	13	4308 8	(>99.5)
^{162}W	1.3 s 1	0.46 3	1.569	9	5534 3	100
^{162}Os	1.7 ms 7	0.998	1.563	33	6618 10	100
^{164}W	6.0 s 3	0.038 12	1.567	24	5149.8 23	(>98.9)
^{164}Os	21 ms 1	0.990 10	1.553	13	6321 7	100
^{166}W	18.8 s 4	3×10^{-4} 1	1.509	25	4739 4	(>98)
^{166}Os	220 ms 7	0.72 13	1.558	16	5990 6	(>95.4)
^{166}Pt	0.3 ms 1	1.0	1.551	28	7110 15	100
^{168}Os	2.1 s 1	0.44 4	1.563	11	5676 4	(>94)
^{168}Pt	2.0 ms 4	1.0	1.554	17	6832 10	100
^{170}Os	8.1 s 10	0.085 34	1.550	37	5407 4	(97 3)
^{170}Pt	14.7 ms 5	(0.993 3)	1.562	9	6548 6	100
^{172}Os	19.2 s 9	0.011 2	1.569	20	5105 10	(95 5)
^{172}Pt	0.096 s 3	0.94 6	1.558	8	6314 4	(98 2)
^{174}Hf	2.0×10^{15} y 4	1.0	1.55	2	2437.4 25	(99.9 1)
^{174}Os	44 s 4	0.00020 10	1.53	4	4760 10	(>88.5)
^{174}Pt	0.90 s 1	0.67 6	1.546	11	6038 4	(>96.5)
^{176}Pt	7.5 s 35	0.40 3	1.551	24	5751.2 20	99.74 13
^{176}Hg	18 ms 10	(0.986 14)	1.55	3	6767 10	(>98)
^{178}Pt	21.1 s 20	0.046 31	1.544	30	5446 3	97.3 24
^{178}Hg	266 ms 25	0.95 +5-26	1.545	10	6430 6	(98 2)
^{180}Pt	52 s 3	0.0030 15	1.53	4	5140 10	(92 8)
^{180}Hg	2.56 s 2	0.48 5	1.533	8	6119 5	99.87 3
^{180}Pb	4 ms +4-2	1.0	1.53	5	7230 40	100
^{182}Pt	3.0 m 2	0.00031 7	1.533	26	4843 5	(>83)
^{182}Hg	10.83 s 6	0.152 8	1.522	5	5866 5	98.94 11
^{182}Pb	55 ms 40	1.0	1.51	6	6920 10	(>88.6)
^{184}Pt	17.3 m 2	1.7×10^{-5} 7	1.536	31	4502 10	(>87.8)
^{184}Hg	30.6 s 3	0.0126 20	1.512	11	5535 15	99.44 10
^{184}Pb	0.55 s 6	(>0.89)	1.505	13	6628 6	(>82.4)
^{186}Os	2.0×10^{15} y 11	1.0	1.49	3	2761.3 17	(>95)
^{186}Pt	2.2 h 2	1.4×10^{-6}	1.49	3	4230 20	(94 6)
^{186}Hg	1.38 m 7	1.8×10^{-4} 5	1.504	27	5094 15	(94 6)
^{186}Pb	4.83 s 5	(0.55 17)	(1.50	2)	6332 7	98.0 18
^{188}Pt	10.2 d 3	2.9×10^{-7} 5	1.470	17	3922 5	(95 5)
^{188}Hg	3.25 m 15	4.0×10^{-7} 8	1.481	28	4610 20	(96 4)
^{188}Pb	24 s 2	0.10 5	1.498	39	5983 5	99 1

Table 1. Calculated r_0 parameters and the data used in calculations

Parent	Parent $T_{1/2}$	α -branching ratio	r_0 (daughter) (10^{-13} cm)		$E\alpha_0$ (keV)	$I \alpha$ (per 100 α)
^{190}Pt	6.5×10^{11} y 3	1.0	1.474	10	3180 6	(98.5 15)
^{190}Pb	1.2 m 1	0.0021 7	1.462	25	5581 4	99.90 2
^{190}Po	2.0 ms +5-10	0.9987 13	1.54	4	7482 20	(99.5 5)
^{192}Pb	3.5 m 1	5.9×10^{-5} 6	1.500	9	5112 5	(99.8 2)
^{192}Po	0.034 s 3	0.995 5	1.511	8	7167 7	(99.6 4)
^{194}Pb	12.0 m 5	7.3×10^{-8} 29	1.432	23	4640 20	(99.9 1)
^{194}Po	0.392 s 4	0.93 7	1.511	6	6842 6	99.71 6
^{196}Po	5.8 s 2	0.94 5	1.511	6	6520 3	99.978 13
^{198}Po	1.76 m 3	0.57 2	1.4965	34	6182.0 22	99.9987 3
^{198}Rn	57 ms 9	0.994 6	1.551	10	7205 5	99.93 2
^{200}Po	11.5 m 1	0.111 3	1.4803	26	5861.9 18	100
^{200}Rn	1.06 s 2	0.86 14	1.516	9	6902.4 25	99.986 3
^{202}Po	44.7 m 5	0.0192 7	1.4719	31	5588.1 17	100
^{202}Rn	9.85 s 20	0.90 10	1.517	7	6639.5 19	99.9982 6
^{202}Ra	0.7 ms +33-3	1.0	1.60	+5-10	7860 60	100
^{204}Po	3.53 h 2	0.0066 1	1.4617	17	5377.1 12	100
^{204}Rn	1.24 m 3	0.73 1	1.5035	26	6418.9 25	100
^{204}Ra	45 ms +55-21	(0.997 3)	1.533	4	7488 12	(99 1)
^{206}Po	8.8 d 1	0.0545 5	1.4550	17	5223.7 15	100
^{206}Rn	5.67 m 17	0.63 6	1.492	7	6260.6 25	(99.96 4)
^{206}Ra	0.24 s 2	(0.97 3)	1.527	8	7272 5	(99.2 8)
^{208}Po	2.898 y 2	0.999958 4	1.4296	8	5114.9 14	99.99976 7
^{208}Rn	24.35 m 14	0.62 7	1.476	6	6140.1 17	99.953 4
^{208}Ra	1.3 s 2	(0.95 5)	1.495	14	7133 5	(99.5 5)
^{210}Pb	22.3 y 3	1.9×10^{-8} 8	1.449	42	3720 20	100
^{210}Po	138.4 d 1	1.0	1.40882	10	5304.33 7	99.99879 4
^{210}Rn	2.4 h 1	0.96 1	1.4571	33	6041 3	99.9944 3
^{210}Ra	3.7 s 2	(0.96 4)	1.487	6	7019 5	(99.7 3)
^{212}Po	0.299 μ s 2	1.0	1.5212	4	8784.86 12	100
^{212}Rn	23.9 m 12	1.0	1.4343	34	6264 3	99.950 5
^{212}Ra	13.0 s 2	(0.85 15)	1.467	10	6899.2 17	(99.85 15)
^{212}Th	30 ms +20-10	(0.997 3)	1.510	27	7802 10	(98.8 12)
^{214}Po	164.3 μ s 20	1.0	1.5394	6	7686.82 7	99.9895 6
^{214}Rn	0.27 μ s 2	1.0	1.532	6	9036 9	(99.95 5)
^{214}Ra	2.46 s 3	0.99941 4	1.4552	21	7137 3	(99.81 19)
^{214}Th	100 ms 25	(0.999 1)	1.492	16	7678 10	(99.5 5)
^{216}Po	0.145 s 2	1.0	1.5408	9	6778.3 5	99.9981 3
^{216}Rn	45 μ s 5	1.0	1.5649	8	8050 10	(99.6 4)
^{216}Ra	182 ns 10	1.0	1.541	5	9349 8	(99.97 3)
^{216}Th	0.028 s 2	1.0	1.466	6	7921 8	(99.5 5)

Table 1. Calculated r_0 parameters and the data used in calculations

Parent	Parent $T_{1/2}$	α -branching ratio	r_0 (daughter) (10^{-13} cm)	$E\alpha_0$ (keV)	$I\alpha$ (per 100 α)
^{218}Po	3.10 m 2	0.99980 2	1.5379 7	6002.35 9	99.9989 11
^{218}Rn	35 ms 5	1.0	1.559 8	7129.2 12	99.87 1
^{218}Ra	25.6 μ s 11	1.0	1.563 4	8389 6	(99.5 5)
^{218}Th	109 ns 11	1.0	1.554 9	9666 10	100
^{218}U	1.5 ms +73-7	1.0	1.46 +4-9	8625 25	(99.1 9)
^{220}Rn	55.6 s 1	1.0	1.5555 2	6288.08 10	99.89 2
^{220}Ra	17 ms 2	1.0	1.556 8	7457 7	99.0 4
^{220}Th	9.7 μ s 6	1.0	1.566 9	8790 20	(99.3 7)
^{222}Rn	3.8235 d 3	1.0	1.5487 2	5489.52 30	99.92 1
^{222}Ra	38.0 s 5	1.0	1.5423 23	6559 5	96.9 1
^{222}Th	2.8 ms 3	1.0	1.539 8	7982 8	97 1
^{224}Ra	3.66 d 4	1.0	1.5419 6	5685.37 15	94.91 7
^{224}Th	1.05 s 2	1.0	1.536 5	7170 10	79 2
^{224}U	0.7 ms +5-2	1.0	1.527 30	8466 12	(96 4)
^{226}Ra	1600 y 7	1.0	1.5397 4	4784.34 25	94.45 5
^{226}Th	30.57 m 10	1.0	1.5385 8	6336.8 10	75.5 3
^{226}U	0.30 s 10	1.0	1.529 18	7570 20	85 5
^{228}Th	1.912 y 2	1.0	1.5332 8	5423.15 22	72.2 11
^{228}U	9.1 m 2	0.975 25	1.524 9	6680 10	70 5
^{230}Th	7.538×10^4 y 30	1.0	1.5331 13	4687.0 15	76.3 3
^{230}U	20.8 d 21	1.0	1.531 5	5888.4 7	67.4 4
^{232}Th	1.40×10^{10} y 1	1.0	1.5361 22	4012.3 14	78.2 13
^{232}U	68.9 y 4	1.0	1.5288 6	5319.23 14	68.0 4
^{234}U	2.455×10^5 y 6	1.0	1.5216 5	4774.6 14	71.38 16
^{234}Pu	8.8 h 1	0.06 3	1.518 39	6202	68
^{236}U	2.342×10^7 y 3	1.0	1.527 3	4493.5 21	74 4
^{236}Pu	2.858 y 8	1.0	1.5103 3	5767.53 8	69.14 33
^{238}U	4.468×10^9 y 3	1.0	1.536 3	4198 3	79.0 27
^{238}Pu	87.7 y 1	1.0	1.5075 2	5499.03 20	70.91 10
^{240}Pu	6563 y 7	1.0	1.5168 3	5168.13 15	73.51 36
^{240}Cm	27 d 1	0.997 3	1.4949 18	6290.5 5	71.1 5
^{242}Pu	3.75×10^5 y 2	1.0	1.5143 9	4902.3 14	76.45 17
^{242}Cm	162.8 d 2	1.0	1.5013 10	6112.72 8	74.1 17
^{244}Pu	8.00×10^7 y 9	0.99879 4	1.5062 10	4589 1	80.6 8
^{244}Cm	18.1 y 1	1.0	1.4979 7	5804.77 5	76.4 12
^{244}Cf	19.4 m 6	1.0	1.5103 25	7209 4	75 3
^{246}Cm	4.76×10^3 y 4	0.999737 4	1.4946 10	5385.7 9	80.7 11
^{246}Cf	35.7 h 5	0.999996 2	1.4953 9	6750.0 10	79.3 10
^{248}Cm	3.48×10^5 y 6	0.9161 16	1.4963 8	5078.41 25	81.9 4
^{248}Cf	333.5 d 28	0.999971 3	1.4851 24	6258 5	80.0 10

Table 1. Calculated r_0 parameters and the data used in calculations

Parent	Parent $T_{1/2}$	α -branching ratio	r_0 (daughter) (10^{-13} cm)		$E\alpha_0$ (keV)	$I\alpha$ (per 100 α)
^{248}Fm	36 s 3	0.93 7	1.490	13	7870 20	80 20
^{250}Cf	13.08 y 9	0.99923 3	1.4836	5	6030.22 20	84.7 6
^{252}Cf	2.645 y 8	0.96908 8	1.50126	20	6118.10 4	84.3 3
^{252}Fm	25.39 h 5	0.999977 2	1.4670	8	7039 2	84.0 5
^{252}No	2.27 s 18	0.731 19	1.490	5	8415 6	83.6 20
^{254}Cf	60.5 d 2	0.00310 16	1.517	4	5833 5	83 1
^{254}Fm	3.240 h 2	0.999408 2	1.4888	8	7192.1 17	85.0 5
^{254}No	54 s 6	0.90 4	1.465	7	8093 14	86 2
^{256}Fm	157.6 m 13	0.081 3	1.500	3	6917 5	87.6 12
^{256}No	2.91 s 5	0.9950 6	1.4765	19	8448 6	87 2

* Research sponsored by the Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corporation for the U. S. Department of Energy under contract number DE-AC05-96OR22564.

¹M. A. Preston, Phys. Rev. **71** (1947) 865.

²See, for example, "General Policies" in Nuclear Data Sheets, first issue of every volume, p.vii

³J. O. Rasmussen, Phys. Rev. **113** (1959) 1593.

⁴See, for example, K. Toth, *et al.*, Phys. Rev. Lett. **53** (1984) 1623 for calculated reduced widths of s-wave α transitions; J. Wauters, *et al.*, Phys. Rev. Lett. **72** (1994) 1329 and R. D. Page, *et al.*, Phys. Rev. **C53** (1996) 660 for reduced widths relative to ground-state to ground-state transitions in even-even nuclei

⁵See, for example, the following references and the references therein:

A. Insolia, R. J. Liotta and E. Maglione, Europhysics Lett. **7** (1988) 209;

A. Raduta, *et al.*, Phys. Rev. **C44** (1991) 1929;

D. S. Delion, A. Insolia, R. J. Liotta, Phys. Rev. **C46** (1992) 1346;

S. M. Lenzi, *et al.*, Phys. Rev. **C48** (1993) 1463;

F. Hoyler, P. Mohr and G. Staudt, Phys. Rev. **C50** (1994) 2631;

B. Buck, Phys. Rev. **C51** (1995) 559;

A. Florescu and A. Insolia, Phys. Rev. **C52** (1995) 726.

⁶References for experimental data are obtained from recent references maintained by the National Nuclear Data Center at the Brookhaven National Laboratory. See S. Ramavaram, Nuclear Data Sheets **76**, Number 4 (1995) p. iv for instructions on on-line access to the Nuclear Structure References (NSR) file which contains accumulated up-to-date references and on access to the Evaluated Nuclear Structure Data File (ENSDF), and see p.489-702 of the same issue for references scanned during 1995

⁷Y. A. Ellis and M. R. Schmorak, Nucl. Data Sheets **B8** (1972) 345.

⁸K. Morita, *et al.*, Z. Phys. **A352** (1995) 7.

⁹K. Takahashi, M. Yamada, T. Kondoh, At. Data Nucl. Data Tables **12** (1973) 101.

¹⁰A. N. Andreyev, *et al.*, Z. Phys. **A347** (1994) 225.