

Recent α decay half-lives and analytic expression predictions including superheavy nuclei

G. Royer, H.F. Zhang

► **To cite this version:**

G. Royer, H.F. Zhang. Recent α decay half-lives and analytic expression predictions including superheavy nuclei. Physical Review C, American Physical Society, 2008, 77, pp.037602. 10.1103/PhysRevC.77.037602 . in2p3-00264500

HAL Id: in2p3-00264500

<http://hal.in2p3.fr/in2p3-00264500>

Submitted on 10 Apr 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Recent α decay half-lives and analytic expression predictions including the superheavy nuclei

G. Royer^{1*} and H.F. Zhang²

¹ *Laboratoire Subatech, UMR: IN2P3/CNRS-Université-Ecole des Mines,
4 rue A. Kastler, 44307 Nantes Cedex 03, France and*

² *School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, People's Republic of China*

(Dated: April 10, 2008)

New recent experimental α -decay half-lives have been compared with the results obtained from previously proposed formulae depending only on the mass and charge numbers of the α emitter and the Q_α value. For the heaviest nuclei they are also compared with calculations using the Density-Dependent M3Y (DDM3Y) effective interaction and the Viola-Seaborg-Sobiczewski (VSS) formulae. The correct agreement allows to provide predictions for the α decay half-lives of other still unknown superheavy nuclei from these analytic formulae using the extrapolated Q_α of Audi, Wapstra and Thibault [1].

PACS numbers: 23.60.+e, 21.10.Tg

The α decay process was described in 1928 [2, 3] in terms of a quantum tunnelling through the potential barrier separating the mother nucleus energy and the total energy of the separated α particle and daughter nucleus. To describe the α emission two different approaches have been developed. The cluster-like theories suppose that the α particle is preformed in the nucleus with a certain preformation factor while the fission-like approaches consider that the α particle is formed progressively during the very asymmetric fission of the parent nucleus. The experimental investigation cannot unambiguously distinguish these two formation modes. However the possible one-body configurations play a minor role since in the quasi-molecular decay path investigated in the α decay process the potential barrier is governed by the balance between the repulsive Coulomb forces and the attractive proximity forces and the Q_α value; consequently the barrier top is more external and lower than the pure Coulomb barrier and corresponds to two separated fragments. The difference between the two approaches appears mainly in the way the decay constant is determined. In the unified fission models [4, 5] the decay constant λ is the product of the constant assault frequency ν_0 and the barrier penetrability P while in the preformed cluster models [6, 7] a third factor is introduced : the cluster preformation probability P_0 .

Before the theoretical explanation and description of the α decay process, Geiger and Nuttall [8] observed a dependence of the α decay partial half-life $T_{1/2,\alpha}^{expt}$ on the mean α particle range for a fixed radioactive family and Geiger-Nuttall plots are now an expression of $\log_{10}T_\alpha$ as a function of $ZQ^{-1/2}$. Since, different new relations have been proposed [5, 9, 10, 11, 12, 13] to calculate $\log_{10}T_\alpha$ from the measured kinetic energy of the α particle via $E_\alpha = Q_\alpha A_d / (A_\alpha + A_d)$ or from Q_α given or extrapolated from mass formulae or tables.

Recently, isotopes of the elements 112, 113, 114, 115, 116 and 118 have been synthesized in fusion-evaporation reactions using ^{209}Bi , $^{233,238}\text{U}$, $^{242,244}\text{Pu}$, ^{243}Am , $^{245,248}\text{Cm}$ and ^{249}Cf targets with ^{48}Ca and ^{70}Zn beams and observed via their α decay cascades [14, 15, 16, 17, 18, 19, 20]. These recent experimental results have led to new theoretical studies on the α decay; for example within the relativistic mean field theory [21], the DDM3Y interaction [22, 23], the generalized liquid drop model (GLDM) [24, 25] and Skyrme-Hartree-Fock mean-field model [26]. The predicted half-lives against α decay of these transuranium nuclei obtained with a semiempirical formula taking into account the magic numbers have also been compared with the analytical superasymmetric fission model results and the universal curves and the experimental data [13].

In previous studies [5, 27] both theoretical description and analytical formulas were presented for the α emission. Within a generalized liquid drop model including the proximity effects between the α particle and the daughter nucleus and adjusted to reproduced the experimental Q value the α emission half-lives were deduced from the WKB barrier penetration probability as for a spontaneous asymmetric fission. The RMS deviation between the theoretical and experimental values of $\log_{10}T_\alpha$ was 0.63 for a data set of 373 emitters having an α branching ratio close to one and 0.35 for the subset of 131 even-even nuclides. A fitting procedure led to the following empirical formulas respectively for the 131 even(Z)-even(N), 106 even-odd, 86 odd-even and 50 odd-odd nuclei . A and Z are the mass and charge numbers of the mother nucleus. The rms deviation are respectively 0.285, 0.39, 0.36 and 0.35.

$$\log_{10} [T_{1/2}(s)] = -25.31 - 1.1629A^{1/6}\sqrt{Z} + \frac{1.5864Z}{\sqrt{Q_\alpha}}, \quad (1)$$

*Electronic address: royer@subatech.in2p3.fr

$$\log_{10} [T_{1/2}(s)] = -26.65 - 1.0859A^{1/6}\sqrt{Z} + \frac{1.5848Z}{\sqrt{Q_\alpha}}, \quad (2)$$

$$\log_{10} [T_{1/2}(s)] = -25.68 - 1.1423A^{1/6}\sqrt{Z} + \frac{1.592Z}{\sqrt{Q_\alpha}}, \quad (3)$$

$$\log_{10} [T_{1/2}(s)] = -29.48 - 1.113A^{1/6}\sqrt{Z} + \frac{1.6971Z}{\sqrt{Q_\alpha}}. \quad (4)$$

Since new α decays have been observed and their partial α decay half-lives $T_{1/2,\alpha}^{expt}$ have been measured [16, 17, 18, 19, 20, 26, 28, 29, 30, 31, 32, 33]. They are compared in the Tables 1 and 2 with the calculated values from the above-mentioned formulae using the measured Q_α values. The table 2 displays also the results obtained with the DDM3Y effective interaction [22, 23], the GLDM [5, 24] and the Viola-Seaborg formulae with Sobiczewski constants [9, 10].

A quite good agreement appears in the table 1 in the whole mass range confirming the accuracy of the formulas (1-4) and their usefulness for new predictions. The table 2 focuses on the heaviest elements for which the uncertainties both on the experimental Q value and α decay half-lives are larger since only some α cascades have been observed. The results obtained with the DDM3Y effective interaction agree with the experimental data as the ones calculated from the GLDM and largely better than the VSS calculations which give systematically longer half-lives. This shows that a GLDM taking account the proximity effects, the mass asymmetry and

quasi-molecular shapes is sufficient to reproduce the α decay potential barriers when the experimental Q_α value is known and proves that the double folding potential obtained using M3Y effective interaction supplemented by a zero-range potential for the single-nucleon exchange is also very appropriate to describe the α decay process. The DDM3Y results are on an average slightly larger than the experimental data while the GLDM values are slightly lower than the measured values. The values obtained using the formulae (1-4) and, then, only A , Z and Q_α are close to the values derived from the DDM3Y interaction and in agreement with the still rough experimental data. The fact that the partial α decay half-lives of these superheavy elements follow these simple formulae seems to prove that the experimental data are consistent with the formation of a cold and relatively compact composite nuclear system. The shell effects are implicitly contained in the Q_α value but difficult to disentangle.

Thus predictions of the partial α decay half-lives of still unknown superheavy nuclei within the formulas (1-4) seem reliable and are displayed in the table 3. The values obtained using the GLDM and the VSS expressions are also given for comparison. The assumed α decay energies are calculated from the atomic mass evaluation of Audi et al. [1] since the agreement with the experimental data on the mass of the known heaviest elements is very satisfactory. It may be useful for future experimental assignment and identification.

In conclusion, formulae already presented to determine the partial α decay half-lives have been checked on new experimental data in the whole mass range and the correct agreement allows to provide predictions for the partial α decay half-lives of still unknown superheavy nuclei.

-
- [1] G. Audi, A.H. Wapstra, and C. Thibault, Nucl. Phys. **A 729**, 337 (2003).
[2] G. Gamow, Z. Phys. **51**, 204 (1928).
[3] E.U. Condon and R.W. Gurney, Nature **122**, 439 (1928).
[4] D.N. Poenaru, M. Ivascu, A. Sandulescu, and W. Greiner, Phys. Rev. C **32**, 572 (1985).
[5] G. Royer, J. Phys. G **26**, 1149 (2000).
[6] S.S. Malik and R.K. Gupta, Phys. Rev. C **39**, 1992 (1989).
[7] A. Ludu, A. Sandulescu, and W. Greiner, Int. J. Mod. Phys. E **1**, 169 (1992).
[8] H. Geiger and J.M. Nuttall, Phil. Mag. **22**, 613 (1911).
[9] V. E. Viola and G. T. Seaborg, J. Inorg. Nucl. Chem. **28**, 741 (1966).
[10] A. Sobiczewski, Z. Patyk, and S. Cwiok, Phys. Lett. B **224**, 1 (1989).
[11] B.A. Brown, Phys. Rev. C **46**, 811 (1992).
[12] D.N. Poenaru and W. Greiner, In *Nuclear decay Modes* (Institute of Physics, Bristol, 1996), p.275.
[13] D.N. Poenaru, I.H. Plonski, and W. Greiner, Phys. Rev. C **74**, 014312 (2006).
[14] S. Hofmann and G. M \ddot{u} nzenberg, Rev. Mod. Phys. **72** 733 (2000).
[15] Yu.Ts. Oganessian *et al.*, Phys. Rev. Lett. **83** 3154 (1999) ; Eur. Phys. J. A **5**, 63 (1999) 63 ; Nature **400** 242 (1999).
[16] Yu.Ts. Oganessian *et al.*, Phys. Rev. C **69**, 021601(R) (2004); Phys. Rev. C **69**, 054607 (2004); Phys. Rev. C **70**, 064609 (2004).
[17] Yu.Ts. Oganessian *et al.*, Phys. Rev. C **71**, 029902(E) (2005); Phys. Rev. C **72**, 034611 (2005); Phys. Rev. C **74**, 044602 (2006).
[18] S. Hofmann *et al.*, Eur. Phys. J. A. **32**, 251 (2007).
[19] Yu. Ts. Oganessian *et al.*, Phys. Rev. C **76**, 011601(R) (2007).
[20] K. Morita *et al.*, J. Phys. Soc. Jpn **76**, 045001 (2007).
[21] M. M. Sharma, A. R. Farhan, and G. M \ddot{u} nzenberg, Phys. Rev. C **71**, 054310 (2005).
[22] D. N. Basu, J. Phys. G: Nucl. Part. Phys. **30**, B35 (2004).
[23] P. R. Chowdhury, D. N. Basu, and C. Samanta, Phys. Rev. C **75** 047306 (2007).
[24] H.F. Zhang, W. Zuo, J.Q. Li, and G. Royer, Phys. Rev. C **74**, 017304 (2006).
[25] H.F. Zhang and G. Royer, Phys. Rev. C **76**, 047304 (2007).

- [26] J.C. Pei, F.R. Xu, Z.J. Lin, and E.G. Zhao, Phys. Rev. C **76**, 044326 (2007).
- [27] R. Moustabchir and G. Royer, Nucl. Phys. A **683**, 266 (2001).
- [28] A.N. Andreyev *et al.*, Eur. Phys. J. A **6**, 381 (1999).
- [29] F. Garcia, O. Rodriguez, M. Gonçalves, S.B. Duarte, O.A.P. Tavares, and F. Guzman, J. Phys. G **26**, 755 (2000).
- [30] H. Mahmud *et al.*, Phys. Rev. C **62**, 057303 (2000).
- [31] H. Kettunen *et al.*, Phys. Rev. C **63**, 044315 (2001).
- [32] D. Seweryniak *et al.*, Phys. Rev. C **73**, 061301(R) (2006).
- [33] A.P. Leppänen *et al.*, Phys. Rev. C **75**, 054307 (2007).

TABLE I: Comparison between recently known experimental α decay half-lives and results obtained with the formulae (1-4).

Nucleus	Q_{α}^{expt} (MeV)	$T_{1/2,\alpha}^{expt}$ (s)	$T_{1/2,\alpha}^{Formulae}$ (s)	Nucleus	Q_{α}^{expt} (MeV)	$T_{1/2,\alpha}^{expt}$ (s)	$T_{1/2,\alpha}^{Formulae}$ (s)
^{105}Te	4.900(0.050)	$0.70_{-0.17}^{+0.25} \times 10^{-6}$	$0.37_{-0.13}^{+0.21} \times 10^{-6}$	^{156}Er	3.486	2.3×10^{10}	1.6×10^{10}
^{158}Yb	4.172	4.3×10^6	2.7×10^6	^{160}Hf	4.902	1.9×10^3	1.9×10^3
^{174}Hf	2.497	6.3×10^{22}	4.55×10^{23}	^{158}W	$6.612_{-0.003}^{+0.003}$	$1.5_{-2}^{+2} \times 10^{-3}$	$1.21_{-0.03}^{+0.03} \times 10^{-3}$
^{168}W	4.507	1.6×10^6	3.1×10^6	^{162}Os	$6.767_{-0.003}^{+0.003}$	$1.9_{-2}^{+2} \times 10^{-3}$	$2.33_{-0.05}^{+0.06} \times 10^{-3}$
^{164}Os	6.475	4.2×10^{-2}	2.2×10^{-2}	^{166}Pt	7.286	3.0×10^{-4}	2.85×10^{-4}
^{168}Pt	6.997	2.0×10^{-3}	2.2×10^{-3}	^{170}Pt	6.708	1.4×10^{-2}	2.0×10^{-2}
^{172}Hg	7.525	4.2×10^{-4}	2.7×10^{-4}	^{174}Hg	7.233	2.1×10^{-3}	2.0×10^{-3}
^{188}Hg	4.705	5.3×10^8	2.0×10^8	^{178}Pb	7.790	2.3×10^{-4}	2.1×10^{-4}
^{180}Pb	7.415	5.0×10^{-3}	2.75×10^{-3}	^{184}Pb	6.774	6.1×10^{-1}	3.6×10^{-1}
^{186}Pb	6.470	1.2×10^1	4.7×10^0	^{188}Pb	6.109	2.7×10^2	1.3×10^2
^{190}Pb	5.697	1.8×10^4	8.7×10^3	^{192}Pb	5.221	3.6×10^6	2.1×10^6
^{194}Pb	4.738	9.8×10^9	1.3×10^9	^{188}Po	$8.087_{-0.025}^{+0.025}$	$4.0_{-1.5}^{+2.0} \times 10^{-4}$	$1.1_{-0.17}^{+0.19} \times 10^{-4}$
^{189}Po	$7.703_{-0.020}^{+0.020}$	$5.0_{-1}^{+1} \times 10^{-3}$	$3.0_{-0.4}^{+0.4} \times 10^{-3}$	^{190}Po	7.693	2.5×10^{-3}	1.5×10^{-3}
^{192}Po	$7.319_{-0.011}^{+0.011}$	$2.9_{-0.8}^{+1.5} \times 10^{-2}$	$2.2_{-0.2}^{+0.2} \times 10^{-2}$	^{210}Po	5.407	1.2×10^7	1.0×10^6
^{196}Rn	$7.616_{-0.009}^{+0.009}$	$4.4_{-0.9}^{+1.3} \times 10^{-3}$	$1.36_{-0.09}^{+0.09} \times 10^{-2}$	^{198}Rn	7.349	6.5×10^{-2}	9.56×10^{-2}
^{202}Ra	8.020	2.6×10^{-3}	3.63×10^{-3}	^{204}Ra	7.636	5.9×10^{-2}	5.5×10^{-2}
^{210}Th	8.053	1.7×10^{-2}	1.3×10^{-2}	^{212}Th	7.952	3.6×10^{-2}	2.4×10^{-2}
^{218}U	$8.773_{-0.009}^{+0.009}$	$5.1_{-1.0}^{+1.7} \times 10^{-4}$	$4.0_{-0.2}^{+0.2} \times 10^{-4}$	^{220}U	10.30	6.0×10^{-8}	5.8×10^{-8}
^{224}U	8.620	7.0×10^{-4}	8.2×10^{-4}	^{226}U	7.701	5.0×10^{-1}	5.67×10^{-1}
^{228}Pu	7.950	2.0×10^{-1}	5.13×10^{-1}	^{230}Pu	7.180	1.0×10^2	2.71×10^2
^{238}Cm	6.62	2.3×10^5	3.3×10^5	^{258}No	8.151	1.2×10^2	5.4×10^1
^{258}Rf	9.25	9.2×10^{-2}	1.03×10^{-1}	^{260}Rf	8.901	1.0×10^0	1.0×10^0
^{266}Hs	10.34	2.3×10^{-3}	2.1×10^{-3}	^{270}Hs	9.02	2.2×10^1	1.03×10^1
^{270}Ds	11.2	1.0×10^{-4}	6.7×10^{-4}	$^{282}\text{113}$	$10.63_{-0.08}^{+0.08}$	$7.3_{-2.9}^{+13.4} \times 10^{-2}$	$4.27_{-1.7}^{+2.8} \times 10^{-2}$

TABLE II: Comparison between recent experimental α decay half-lives and results obtained with the DDM3Y effective interaction [22, 23], the GLDM [5, 24], the formulae (1-4) and the VSS expressions [9, 10].

Nucleus	Q_{α}^{expt} (MeV)	$T_{1/2,\alpha}^{expt}$	$T_{1/2,\alpha}^{DDM3Y}$	$T_{1/2,\alpha}^{GLDM}$	$T_{1/2,\alpha}^{Formulae}$	$T_{1/2,\alpha}^{VSS}$
$^{294}\text{118}$	11.81 ± 0.06	$1.8_{-1.3}^{+75}$ ms	$0.66_{-0.18}^{+0.23}$ ms	$0.15_{-0.04}^{+0.05}$ ms	$0.39_{-0.11}^{+0.15}$ ms	$0.64_{-0.18}^{+0.24}$ ms
$^{293}\text{116}$	10.67 ± 0.06	53_{-19}^{+62} ms	206_{-61}^{+90} ms	$22.81_{-7.06}^{+10.22}$ ms	308_{-93}^{+136} ms	1258_{-384}^{+557} ms
$^{292}\text{116}$	10.80 ± 0.07	18_{-6}^{+16} ms	39_{-13}^{+20} ms	$10.45_{-3.45}^{+5.65}$ ms	27_{-9}^{+14} ms	49_{-16}^{+26} ms
$^{291}\text{116}$	10.89 ± 0.07	$6.3_{-2.5}^{+11.6}$ ms	$60.4_{-20.1}^{+30.2}$ ms	$6.35_{-2.08}^{+3.15}$ ms	89_{-30}^{+46} ms	$336.4_{-113.4}^{+173.1}$ ms
$^{290}\text{116}$	11.00 ± 0.08	15_{-6}^{+26} ms	$13.4_{-5.2}^{+7.7}$ ms	$3.47_{-1.26}^{+1.99}$ ms	$8.9_{-3.3}^{+5.4}$ ms	$15.2_{-5.6}^{+9.0}$ ms
$^{288}\text{115}$	10.61 (6)	87_{-30}^{+105} ms	409 ms	$94.7_{-28.9}^{+41.9}$ ms	582_{-187}^{+278} ms	997_{-303}^{+442} ms
$^{287}\text{115}$	10.74 (9)	32_{-14}^{+155} ms	49 ms	$46.0_{-19.1}^{+33.1}$ ms	53_{-22}^{+38} ms	207_{-85}^{+149} ms
$^{289}\text{114}$	9.96 ± 0.06	$2.7_{-0.7}^{+1.4}$ s	$3.8_{-1.2}^{+1.8}$ s	$0.52_{-0.17}^{+0.25}$ s	$6.1_{-2.0}^{+3.0}$ s	$26.7_{-8.7}^{+13.1}$ s
$^{288}\text{114}$	10.09 ± 0.07	$0.8_{-0.32}^{+0.32}$ s	$0.67_{-0.27}^{+0.37}$ s	$0.22_{-0.08}^{+0.12}$ s	$0.52_{-0.19}^{+0.30}$ s	$0.98_{-0.40}^{+0.56}$ s
$^{287}\text{114}$	10.16 ± 0.06	$0.51_{-0.10}^{+0.18}$ s	$1.13_{-0.40}^{+0.52}$ s	$0.16_{-0.05}^{+0.08}$ s	$1.79_{-0.57}^{+0.85}$ s	$7.24_{-2.61}^{+3.43}$ s
$^{286}\text{114}$	10.35 ± 0.06	$0.16_{-0.03}^{+0.07}$ s	$0.14_{-0.04}^{+0.06}$ s	$0.05_{-0.02}^{+0.02}$ s	$0.11_{-0.03}^{+0.05}$ s	$0.19_{-0.06}^{+0.08}$ s
$^{284}\text{113}$	10.15 (6)	$0.48_{-0.17}^{+0.58}$ s	$1.55_{-0.48}^{+0.72}$ s	$0.43_{-0.13}^{+0.21}$ s	$2.4_{-0.80}^{+1.2}$ s	$4.13_{-1.31}^{+1.94}$ s
$^{283}\text{113}$	10.26 (9)	100_{-45}^{+490} ms	$201.6_{-84.7}^{+164.9}$ ms	222_{-96}^{+172} ms	234_{-100}^{+180} ms	937_{-402}^{+719} ms
$^{285}\text{112}$	9.29 ± 0.06	34_{-9}^{+17} s	75_{-26}^{+41} s	$13.22_{-4.64}^{+7.25}$ s	127_{-44}^{+69} s	592_{-207}^{+323} s
$^{283}\text{112}$	9.67 ± 0.06	$4.0_{-0.7}^{+1.3}$ s	$5.9_{-2.0}^{+2.9}$ s	$0.95_{-0.32}^{+0.48}$ s	$9.6_{-3.2}^{+4.9}$ s	$41.3_{-13.8}^{+20.9}$ s
$^{280}\text{111}$	9.87 (6)	$3.6_{-1.3}^{+4.3}$ s	$1.9_{-0.6}^{+0.9}$ s	$0.69_{-0.23}^{+0.33}$ s	$3.1_{-1.05}^{+1.6}$ s	$5.70_{-1.84}^{+2.74}$ s
$^{279}\text{111}$	10.52(16)	170_{-80}^{+810} ms	$9.6_{-5.7}^{+14.8}$ ms	$12.4_{-7.6}^{+19.9}$ ms	$10.9_{-6.7}^{+17.8}$ ms	$45.3_{-27.6}^{+73.1}$ ms
$^{279}\text{110}$	9.84 ± 0.06	$0.18_{-0.03}^{+0.05}$ s	$0.40_{-0.13}^{+0.18}$ s	$0.08_{-0.02}^{+0.04}$ s	$0.65_{-0.21}^{+0.31}$ s	$2.92_{-0.94}^{+1.4}$ s
$^{276}\text{109}$	9.85 (6)	$0.72_{-0.25}^{+0.87}$ s	$0.45_{-0.14}^{+0.23}$ s	$0.19_{-0.06}^{+0.08}$ s	$0.65_{-0.22}^{+0.33}$ s	$1.44_{-0.46}^{+0.68}$ s
$^{275}\text{109}$	10.48 (9)	$9.7_{-4.4}^{+46}$ ms	$2.75_{-1.09}^{+1.85}$ ms	$4.0_{-1.6}^{+2.8}$ ms	$3.2_{-1.3}^{+2.3}$ ms	$13.7_{-5.6}^{+9.6}$ ms
$^{275}\text{108}$	9.44 ± 0.07	$0.15_{-0.06}^{+0.27}$ s	$1.09_{-0.40}^{+0.73}$ s	$0.27_{-0.10}^{+0.16}$ s	$1.9_{-0.72}^{+1.2}$ s	$8.98_{-3.38}^{+5.49}$ s
$^{272}\text{107}$	9.15 (6)	$9.8_{-3.5}^{+11.7}$ s	$10.1_{-3.4}^{+5.4}$ s	$5.12_{-1.58}^{+2.8}$ s	$17.6_{-6.4}^{+10.2}$ s	$33.8_{-11.6}^{+17.9}$ s
$^{271}\text{106}$	8.65 ± 0.08	$2.4_{-1.0}^{+4.3}$ min	$1.0_{-0.5}^{+0.8}$ min	$0.33_{-0.16}^{+0.28}$ min	$1.8_{-0.8}^{+1.5}$ min	$8.6_{-3.9}^{+7.3}$ min

TABLE III: Predicted α -decay half-lives using the GLDM, the formulae (1-4) and the VSS formulae. The α decay energies are taken from the extrapolated data of Audi et al. [1].

$\frac{A}{Z}$	Q	$T_{1/2}^{GLDM}$	$T_{1/2}^{form.}$	$T_{1/2}^{VSS}$	$\frac{A}{Z}$	Q	$T_{1/2}^{GLDM}$	$T_{1/2}^{form.}$	$T_{1/2}^{VSS}$	$\frac{A}{Z}$	Q	$T_{1/2}^{GLDM}$	$T_{1/2}^{form.}$	$T_{1/2}^{VSS}$
²⁹³ ₁₁₈	12.30	77 μ s	187 μ s	592 μ s	²⁹² ₁₁₇	11.60	1.30 ms	6.47 ms	13.33 ms	²⁹¹ ₁₁₇	11.90	0.29 ms	0.32 ms	1.23 ms
²⁹¹ ₁₁₅	10.00	4.33 s	4.8 s	21.9 s	²⁹⁰ ₁₁₅	10.30	0.62 s	4.2 s	6.86 s	²⁸⁹ ₁₁₆	11.70	0.43 ms	1.05 ms	3.63 ms
²⁸⁹ ₁₁₅	10.60	97.4 ms	113 ms	482 ms	²⁸⁷ ₁₁₃	9.34	102 s	99.4 s	461 s	²⁸⁶ ₁₁₃	9.68	9.44 s	61.5 s	92.5 s
²⁸⁵ ₁₁₄	11.00	5.1 ms	12 ms	44.6 ms	²⁸⁵ ₁₁₃	10.02	0.99 s	1.0 s	4.35 s	²⁸⁴ ₁₁₂	9.30	64.7 s	25.1 s	47.3 s
²⁸³ ₁₁₁	8.96	6.01 min	5.5 min	25.73 min	²⁸² ₁₁₂	9.96	0.772 s	0.297 s	0.516 s	²⁸² ₁₁₁	9.38	18.6 s	99.8 s	158.4 s
²⁸¹ ₁₁₂	10.28	0.102 s	0.2 s	0.786 s	²⁸¹ ₁₁₁	9.64	3.12 s	2.72 s	11.96 s	²⁸¹ ₁₁₀	8.96	3.05 min	4.6 min	22.47 min
²⁸⁰ ₁₁₂	10.62	13.3 ms	25.4 ms	8.62 ms	²⁸⁰ ₁₁₁	9.98	0.335 s	1.43 s	2.79 s	²⁷⁹ ₁₁₂	10.96	2.06 ms	3.88 ms	14.1 ms
²⁷⁹ ₁₀₉	8.70	10.35 min	7.72 min	36.32 min	²⁷⁸ ₁₁₂	11.38	0.223 ms	0.083 ms	0.121 ms	²⁷⁸ ₁₁₁	10.72	3.89 ms	12.5 ms	30.9 ms
²⁷⁸ ₁₁₀	10.00	148.5 ms	51.8 ms	89.8 ms	²⁷⁸ ₁₀₉	9.10	31 s	143 s	240 s	²⁷⁷ ₁₁₂	11.62	0.069 ms	0.12 ms	0.402 ms
²⁷⁷ ₁₁₁	11.18	0.323 ms	0.28 ms	1.073 ms	²⁷⁷ ₁₁₀	10.30	23.1 ms	39 ms	162 ms	²⁷⁷ ₁₀₉	9.50	1.89 s	1.48 s	6.61 s
²⁷⁷ ₁₀₈	8.40	49.7 min	65.25 min	330.3 min	²⁷⁶ ₁₁₀	11.32	0.157 ms	0.39 ms	1.11 ms	²⁷⁶ ₁₀₉	10.60	4.03 ms	1.47 ms	2.35 ms
²⁷⁶ ₁₀₈	8.80	131 s	40.6 s	75 s	²⁷⁵ ₁₁₁	11.55	51.5 μ s	42.3 μ s	152 μ s	²⁷⁵ ₁₁₀	11.10	0.26 ms	0.43 ms	1.65 ms
²⁷⁴ ₁₁₁	11.60	41.4 μ s	88.1 μ s	258 μ s	²⁷⁴ ₁₁₀	11.40	55.5 μ s	19.5 μ s	28.7 μ s	²⁷⁴ ₁₀₉	10.50	3.67 ms	9.84 ms	26.8 ms
²⁷⁴ ₁₀₈	9.50	0.92 s	0.3 s	0.51 s	²⁷⁴ ₁₀₇	8.50	9.94 min	48.45 min	70.98 min	²⁷³ ₁₁₁	11.20	0.33 ms	0.29 ms	0.96 ms
²⁷³ ₁₁₀	11.37	0.067 ms	0.11 ms	0.39 ms	²⁷³ ₁₀₉	10.82	0.61 ms	0.5 ms	1.96 ms	²⁷³ ₁₀₈	9.90	69.4 ms	101 ms	441.6 ms
²⁷³ ₁₀₇	8.90	28.8 s	21.1 s	92.8 s	²⁷² ₁₁₀	10.76	1.97 ms	0.697 ms	0.94 ms	²⁷² ₁₀₉	10.60	2.34 ms	5.74 ms	15.02 ms
²⁷² ₁₀₈	10.10	21.7 ms	6.9 ms	10.9 ms	²⁷² ₁₀₆	8.30	24.9 min	6.38 min	11.4 min	²⁷¹ ₁₁₀	10.87	1.12 ms	1.79 ms	5.86 ms
²⁷¹ ₁₀₉	10.14	37.5 ms	29.9 ms	105.6 ms	²⁷¹ ₁₀₈	9.90	79.2 ms	109.7 ms	441.7 ms	²⁷¹ ₁₀₇	9.50	0.499 s	0.338 s	1.40 s
²⁷⁰ ₁₁₀	11.20	0.199 ms	0.067 ms	0.083 ms	²⁷⁰ ₁₀₉	10.35	10.7 ms	30 ms	65 ms	²⁷⁰ ₁₀₈	9.30	4.48 s	1.4 s	2.02 s
²⁷⁰ ₁₀₇	9.30	2.0 s	6.25 s	11.9 s	²⁷⁰ ₁₀₆	9.10	3.59 s	0.99 s	1.66 s	²⁷⁰ ₁₀₅	8.20	24.38 min	94.58 min	140.53 min
²⁶⁹ ₁₀₉	10.53	3.75 ms	3.12 ms	10.25 ms	²⁶⁹ ₁₀₈	9.63	0.48 s	0.68 s	2.52 s	²⁶⁹ ₁₀₇	8.84	55.9 s	39 s	144.5 s
²⁶⁹ ₁₀₆	8.80	32.5 s	37.5 s	167.9 s	²⁶⁹ ₁₀₅	8.40	4.96 min	3.01 min	12.93 min	²⁶⁸ ₁₁₀	11.92	6.3 μ s	1.84 μ s	2.1 μ s
²⁶⁸ ₁₀₉	10.73	1.28 ms	3.07 ms	7.15 ms	²⁶⁸ ₁₀₈	9.90	85.7 ms	28.6 ms	37.7 ms	²⁶⁸ ₁₀₇	9.08	9.86 s	35.4 s	55.5 s
²⁶⁸ ₁₀₆	8.40	12.1 min	3.4 min	5.1 min	²⁶⁸ ₁₀₅	8.20	25.4 min	102.7 min	140.5 min	²⁶⁸ ₁₀₄	8.10	23.8 min	5.88 min	10.2 min
²⁶⁷ ₁₁₀	12.28	1.3 μ s	1.57 μ s	4.4 μ s	²⁶⁷ ₁₀₉	10.87	0.61 ms	0.49 ms	1.49 ms	²⁶⁷ ₁₀₈	10.12	22.1 ms	32.9 ms	112.5 ms
²⁶⁷ ₁₀₇	9.37	1.33 s	0.97 s	3.36 s	²⁶⁷ ₁₀₆	8.64	1.9 min	2.25 min	9.3 min	²⁶⁷ ₁₀₅	7.90	330 min	205 min	787 min
²⁶⁷ ₁₀₄	7.80	315 min	306 min	1494 min	²⁶⁶ ₁₀₉	10.996	0.32 ms	0.69 ms	1.63 ms	²⁶⁶ ₁₀₈	10.336	6.26 ms	2.16 ms	2.64 ms
²⁶⁶ ₁₀₇	9.55	0.41 s	1.21 s	2.21 s	²⁶⁶ ₁₀₅	8.19	29.0 min	121.8 min	152.5 min	²⁶⁶ ₁₀₄	7.50	81.47 h	20.09 h	31.30 h
²⁶⁵ ₁₀₉	11.07	0.223 ms	0.178 ms	0.498 ms	²⁶⁵ ₁₀₇	9.77	99.7 ms	74.4 ms	241 ms	²⁶⁵ ₁₀₅	8.49	2.70 min	1.76 min	6.43 min
²⁶⁵ ₁₀₄	7.78	6.58 h	6.58 h	29.65 h	²⁶⁴ ₁₀₇	9.97	29.9 ms	74.1 ms	151 ms	²⁶⁴ ₁₀₆	9.21	1.99 s	0.60 s	0.77 s
²⁶⁴ ₁₀₅	8.66	46.1 s	154 s	232 s	²⁶⁴ ₁₀₄	8.14	19.2 min	5.03 min	7.36 min	²⁶³ ₁₀₈	10.67	1.03 ms	1.52 ms	4.45 ms
²⁶³ ₁₀₇	10.08	15.5 ms	11.6 ms	34.9 ms	²⁶³ ₁₀₅	9.01	3.65 s	2.4 s	8.27 s	²⁶³ ₁₀₄	8.49	72.7 s	76.8 s	324.7 s
²⁶² ₁₀₇	10.30	4.42 ms	9.51 ms	20.5 ms	²⁶² ₁₀₆	9.60	160.4 ms	47.5 ms	56.7 ms	²⁶² ₁₀₅	9.01	4.06 s	10.9 s	18.2 s
²⁶² ₁₀₄	8.49	82.6 s	20.6 s	27.9 s	²⁶¹ ₁₀₇	10.56	1.04 ms	0.74 ms	2.07 ms	²⁶¹ ₁₀₆	9.80	44.8 ms	56.1 ms	183.9 ms
²⁶¹ ₁₀₅	9.22	0.96 s	0.60 s	1.92 s	²⁶⁰ ₁₀₇	10.47	1.77 ms	3.58 ms	7.62 ms	²⁶⁰ ₁₀₄	8.90	4.09 s	1.08 s	1.35 s
²⁵⁹ ₁₀₆	9.83	39.4 ms	50.5 ms	152.3 ms	²⁵⁹ ₁₀₅	9.62	69.0 ms	45.9 ms	136.7 ms	²⁵⁹ ₁₀₄	9.12	0.89 s	0.93 s	3.38 s
²⁵⁸ ₁₀₆	9.67	114 ms	36.1 ms	36 ms	²⁵⁸ ₁₀₅	9.48	0.18 s	0.42 s	0.74 ms	²⁵⁸ ₁₀₄	9.25	380 ms	103 ms	120 ms
²⁵⁷ ₁₀₅	9.23	1.0 s	0.67 s	1.8 s	²⁵⁷ ₁₀₄	9.04	1.66 s	1.76 s	5.88 s	²⁵⁶ ₁₀₅	9.46	230 ms	522 ms	848 ms
²⁵⁶ ₁₀₄	8.93	3.78 s	1.04 s	1.09 s	²⁵⁵ ₁₀₅	9.72	42.9 ms	28.9 ms	72.4 ms	²⁵⁵ ₁₀₄	9.058	1.57 s	1.69 s	5.19 s
²⁵⁴ ₁₀₄	9.38	181 ms	51.9 ms	50.5 ms	²⁵³ ₁₀₄	9.55	63.1 ms	68.3 ms	195.0 ms					