Alpha decay of nuclei interesting for synthesis of $Z = 119, 120$

isotopes

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Abstract

Four groups (even-even, even-odd, odd-even and odd-odd) of heavy and super-heavy nuclei are of interest for the synthesis of the isotopes with $Z = 119, 120$. We report calculations of $\alpha$ decay half-lives using four models: AKRA (Akrawy); ASAF (Analytical Super-Asymmetric Fission); UNIV (Universal Formula), and semFIS (Semi-empirical formula based on Fission Theory). We compare the experimental $Q_\alpha$ values either with AME16 atomic mass evaluation (whenever available) and with the theoretical model WS4, able to give masses of not yet measured nuclides. For $^{92,94}$Sr cluster radioactivity of $^{300,302}$120 we predict a branching ratio relative to $\alpha$ decay of -0.10 and 0.49, respectively, meaning that it is worth trying to detect such kind of decay modes in competition with $\alpha$ decay.

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I. INTRODUCTION

Super-heavy (SH) nuclei with atomic number Z up to 118, have been produced by two kinds of fusion reactions: (1) almost cold fusion (with one evaporated neutron) at GSI Germany and RIKEN Japan based on the doubly magic target $^{208}$Pb or its neighbour $^{209}$Bi, and (2) hot fusion (with three or four evaporated neutrons) at JINR Dubna Russia and Livermore Nat. Lab. USA with the, quite expensive, $^{48}$Ca projectile.

From the attempts to synthesize $Z = 119,120$ isotopes, we selected 21 even-even (e-e), 21 even-odd (e-o), 4 odd-even (o-e), and 5 odd-odd (o-o) $\alpha$ emitters. Some of them are reported from experiments with different values of $Q_\alpha$ or half-life $T_{1/2}$. Consequently the total number of cases is larger: 29 e-e, 58 e-o, 5 o-e, and 9 o-o. To these we also added few (3 e-e, 10 o-e, and 4 o-o) other nuclides, members of the $\alpha$ decay chains of $^{300,302}$120, $^{299,301}$120, $^{297}$119 and $^{300}$119, namely 273Bh$_{107}$, 277Mt$_{109}$, 281,283,284Rg$_{111}$, 285,287,288Nh$_{113}$, 289,291,292Mc$_{115}$, 294Bh$_{116}$, 293,295,296Ts$_{117}$, 296,298O$_{118}$. We express the half-lives in decimal logarithm of the values in seconds, $T = \log_{10} T_{1/2}$ (s). Whenever possible we rely on the latest (AME16) atomic mass evaluation in order to calculate $Q_\alpha$. The following nuclides are not available on AME16 evaluation: e-e $^{278}$Hs$_{108}$; $^{282}$Ds$_{110}$; $^{284}$Fl$_{114}$; $^{290}$Fl$_{114}$; $^{294}$Fl$_{114}$; $^{300}$120 and $^{302}$120; e-o $^{277}$Hs$_{108}$; $^{299}$120 and $^{301}$120; o-e $^{297}$119 and o-o $^{278}$Bh$_{107}$; $^{283}$Mt$_{109}$; $^{286}$Rg$_{111}$; $^{290}$Nh$_{113}$ and $^{300}$119. In this way, there is no o-o nuclide remaining on the AME16 table. For nuclides not available in this table we use the model W4, which was found to be the best among 20 models. Also, in the same Ref., it is mentioned that “SemFIS2 formula is the best one to predict the alpha-decay half-lives ... In addition, the UNIV2 formula with fewest parameters and ... work well in prediction on the SHN alpha-decay half-lives”. We shall use semFIS, UNIV, ASAF and AKRA. A computer program gives us the possibility to improve the parameters of the ASAF model in agreement with a given set of experimental data. The UNIV (universal curve) model was updated in 2011. Nevertheless, for $^{297,299}$119 nuclei we couldn’t get the Q-values by using the model W4, hence in these particular cases the model KTUY05 have been used. Interesting developments concerning alpha decay, cluster radioactivity, spontaneous fission and proton radioactivity have been recently made.

In the decay modes we are studying, a parent nucleus, $^{A}$Z, disintegrates with emission of...
a light particle, $^{A_e}Z_e$, and a heavy daughter $^{A_d}Z_d$

$$A Z \rightarrow ^{A_e}Z_e + ^{A_d}Z_d$$ (1)

The kinetic energy of the $\alpha$ particle is related to Q-value by the relationship

$$E_k = QA_d/A$$ (2)

and Q-value is calculated from the atomic masses using the Einstein’s relationship

$$Q = [M_p - (M_e + M_d)]mc^2$$ (3)

where $c$ is the speed of light.

ASAF, fragmentation theory developed by the Frankfurt School, and other models have been used to predict cluster radioactivities [21]. For some isotopes of SHs, with $Z > 121$, there is a good chance for cluster decay modes to compete [37, 39].

In the following section, models, we shall give some informations concerning the AKRA, ASAF, UNIV, and semFIS models. Then in section, released energy, we shall compare the experimental values of $Q_\alpha$ with those obtained from AME16 and W4. In the section, results, we shall compare the half-lives obtained with the four models, with experimental data. In conclusion and outlook we evaluate how useful is any of the four models, and what to do in order to improve the present situation.

II. MODELS

The half-life of a parent nucleus $AZ$ against the split into a cluster $^{A_e}Z_e$ and a daughter $^{A_d}Z_d$

$$T = [(h \ln 2)/(2E_\alpha)]exp(K_{ov} + K_s)$$ (4)

is calculated by using the WKB quasiclassical approximation, according to which the action integral is expressed as

$$K = \frac{2}{\hbar} \int_{R_a}^{R_b} \sqrt{2B(R)[E(R) - Q]}dR$$ (5)

with $B = \mu$ — the reduced mass, $K = K_{ov} + K_s$ (overlapping and separated fragments), and $E(R)$ is the total deformation energy. $R_a, R_b$ are the turning points, defined by

$$E(R_a) - Q = E(R_b) - Q = 0$$ (6)
A. AKRA

In Ref. [22] a new formula was introduced, derived by adding few parameters to the one developed by G. Royer [16]. Three experimental data sets have been used: A (130 e-e, 119 e-o, 109 o-e, and 96 o-o), set B (188 e-e, 147 e-o, 131 o-e, and 114 o-o), and set C with 136 e-e, 84 e-o, 76 o-e, and 48 o-o alpha emitters. The set A was developed by one of us (DA), the set B belongs to DNP’s group, and the set C was taken from G. Royer [16]; few Q-values have been updated using the AME16 evaluation of experimental atomic masses [12]. Comparison with ASAF, UNIV, and semFIS will be made using both A, B and C data sets.

The Royer formula [16] is defined as

\[ T_{1/2} = a + bA^{1/6} \sqrt{Z} + \frac{cZ}{\sqrt{Q_\alpha}} \]  

with initial parameters \( a = -27.657; -28.408; -27.408, \) \( b = -24.763, \) \( c = -0.966; -0.920; -1.038, \) \( d = 0.907, \) \( e = 1.522; 1.519; 1.581; 1.410 \) for e-e, e-o, o-e, and o-o, respectively. The rms standard deviation for 130 e-e, 119 e-o, 109 o-e, and 96 o-o was \( \sigma = 0.560, 1.050, 0.871, \) and 0.926, respectively.

The new relationship is obtained by introducing \( I = (N - Z)/A \) and the new parameters \( d \) and \( e \):

\[ T_{1/2} = a + bA^{1/6} \sqrt{Z} + \frac{cZ}{\sqrt{Q_\alpha}} + dI + eI^2 \]  

where for the comprehensive set B the parameters \( a, b, c, d, e \) are given in Table V.

Before optimization, with our set of 580 \( \alpha \) emitters, and the initial values of the parameters \( a = -27.989, b = -0.940, c = 1.532, d = -5.747, e = 11.336 \) for even-even nuclei we got the following values of rms standard deviations, \( \sigma = 0.5547 \). After optimization for e-e emitters, with \( a = -27.837, b = -0.94199975, c = 1.5343, d = -5.7004, e = 8.785 \) the agreement was improved: \( \sigma = 0.540 \).

By ruling with the optimized set of 21 e-e, 21 e-o, 13 o-e and 9 o-o \( \alpha \) emitters, we adjusted only the value of parameter \( e \), in order to get the best fit. The parameters have been \( a = -27.949, -28.215, -26.594, -23.936, b = -0.94199975, -0.861, -1.107, -0.891, c = 1.5343, 1.53774, 1.557, 1.404, d = -5.7004, -21.145, 15.149, -12.420 \) and \( e = 22.560, -18.200, -77.700, 33.000 \). We got for even-even nuclei the rms standard deviation, \( \sigma_{ee} = 2.9892, \) for even-odd \( \sigma_{eo} = 8.0620, \) for odd-even \( \sigma_{oe} = 3.8810, \) and for odd-odd \( \sigma_{oo} = 1.366 \).
B. ASAF

We replace in eq. (5) \( E(R) - Q \) by \( [E(R) - E_{\text{corr}}] - Q \). \( E_{\text{corr}} \) is a correction energy similar to the Strutinsky shell correction, also taking into account the fact that Myers-Swiatecki’s liquid drop model (LDM) overestimates fission barrier heights, and the effective inertia in the overlapping region is different from the reduced mass. The turning points of the WKB integral are:

\[
R_a = R_i + (R_t - R_i)[(E_v + E^*)/E_0^b]^{1/2}
\]

\[
R_b = R_i E_c [1/2 + [1/4 + (Q + E_v + E^*)E_i/E_c^2]^{1/2}]/(Q + E_v + E^*)
\]

where \( E^* \) is the excitation energy concentrated in the separation degree of freedom, \( R_i = R_0 - R_e \) is the initial separation distance, \( R_t = R_e + R_d \) is the touching point separation distance, \( R_j = r_0 A_j^{1/3} \) \((j = 0, e, d; \ r_0 = 1.2249 \text{ fm}) \) are the radii of parent, emitted and daughter nuclei, and \( E_0^b = E_i - Q \) is the barrier height before correction. The interaction energy at the top of the barrier, in the presence of a non negligible angular momentum, \( l \hbar \), is given by:

\[
E_i = E_c + E_t = e^2 Z_e Z_d / R_t + \hbar^2 l(l + 1)/(2 \mu R_t^2)
\]

The two terms of the action integral \( K \), corresponding to the overlapping \( (K_{ov}) \) and separated \( (K_s) \) fragments, are calculated by analytical formulas (approximated for \( K_{ov} \) and exact for \( K_s \) in case of separated spherical shapes within the LDM):

\[
K_{ov} = 0.2196 (E_0^b A_e A_d / A)^{1/2} (R_t - R_i) \left[ \sqrt{1 - b^2} - b^2 \ln \frac{1 + \sqrt{1 - b^2}}{b} \right]
\]

\[
K_s = 0.4392 [(Q + E_v + E^*) A_e A_d / A]^{1/2} R_b J_{rc} ; \ b^2 = (E_v + E^*)/E_0^b
\]

\[
J_{rc} = (c) \arccos \sqrt{(1 - c + r)/(2 - c)} - [(1 - r)(1 - c + r)]^{1/2}
+ \sqrt{1 - c} \ln \left[ \frac{2\sqrt{(1 - c)(1 - r)(1 - c + r) + 2 - 2c + cr}}{r(2 - c)} \right]
\]

where \( r = R_t/R_b \) and \( c = r E_c / (Q + E_v + E^*) \). In the absence of the centrifugal contribution \((l = 0)\), one has \( c = 1 \).

The choice \( E_v = E_{corr} \) allows to get a smaller number of parameters. Owing to the exponential dependence, any small variation of \( E_{corr} \) induces a large change of \( T \), and thus plays a more important role compared to the preexponential factor variation due to \( E_v \). Shell
and pairing effects are included in $E_{corr} = a_i(A_e)Q$ ($i = 1, 2, 3, 4$ for even-even, odd-even, even-odd, and odd-odd parent nuclei). For a given cluster radioactivity there are four values of the coefficients $a_i$, the largest for even-even parent and the smallest for the odd-odd one (see figure 1 of [19]). The shell effects for every cluster radioactivity is implicitly contained in the correction energy due to its proportionality with the Q value. Since 1984, the ASAF model results have been used to guide the experiments and to stimulate other theoretical works.

In the present case we obtained the following rms standard deviations: $\sigma_{ee} = 3.397$, for even-odd $\sigma_{eo} = 8.458$, for odd-even $\sigma_{oe} = 4.056$, and for odd-odd $\sigma_{oo} = 1.663$

C. UNIV (Universal Formula)

In cluster radioactivity and $\alpha$-decay the (measurable) decay constant $\lambda = \ln 2/T$, can be expressed as a product of three (model dependent) quantities

$$\lambda = \nu SP_s$$

(15)

where $\nu$ is the frequency of assaults on the barrier per second, $S$ is the preformation probability of the cluster at the nuclear surface, and $P_s$ is the quantum penetrability of the external potential barrier. The frequency $\nu$ remains practically constant, the preformation differs from one decay mode to another but it is not changed very much for a given radioactivity, while the general trend of penetrability follows closely that of the half-life.

The preformation probability can be calculated within a fission model as a penetrability of the internal part of the barrier, which corresponds to still overlapping fragments. One may assume as a first approximation, that preformation probability only depends on the mass number of the emitted cluster, $S = S(A_e)$. The next assumption is that $\nu(A_e, Z_e, A_d, Z_d) = \text{constant}$. In this way it was obtained a single straight line universal curve on a double logarithmic scale

$$\log T = -\log P_s - 22.169 + 0.598(A_e - 1)$$

(16)

where

$$-\log P_s = c_{AZ} \left[ \arccos \sqrt{r} - \sqrt{r(1-r)} \right]$$

(17)
with \( c_{AZ} \) = 0.22873\((\mu_A Z_d Z_e R_b)^{1/2} \), \( r = R_t / R_b, R_t = 1.2249(A_d^{1/3} + A_e^{1/3}) \), \( R_b = 1.43998 Z_d Z_e / Q \), and \( \mu_A = A_d A_e / A \).

Sometimes this universal curve is misinterpreted as being a Geiger-Nuttal plot. Nowadays by Geiger-Nuttal diagram one understands a plot of \( \log T \) versus \( ZQ^{-1/2} \), or versus \( Q^{-1/2} \). For \( \alpha \)-decay of even-even nuclei, \( A_e = 4 \), one has

\[
\log T = -\log P_s + c_{ee}
\]

(18)

where \( c_{ee} = \log S_\alpha - \log \nu + \log(\ln 2) = -20.375 \). We can find new values for \( c_{ee} \) and we also can extend the relationship to even-odd, odd-even, and odd-odd nuclei, by fitting a given set of experimentally determined alpha decay data.

By adjusting every time the additive constant \( c_{ee} \) we obtained the following rms standard deviations: \( \sigma_{ee} = 2.952 \) when \( c_{ee} = 1.420 \), \( \sigma_{eo} = 8.146 \) when \( c_{eo} = -1.600 \), \( \sigma_{oe} = 3.989 \) when \( c_{oe} = -0.700 \), and \( \sigma_{oo} = 1.548 \) when \( c_{oe} = 1.392 \).

D. semFIS (Semiempirical relationship based on fission theory of \( \alpha \)-decay)

Mainly the \( Z \) dependence was stressed by all formulae, in spite of strong influence of the neutron shell effects. The neighborhood of the magic numbers of nucleons is badly described by all these relationships. The SemFIS formula based on the fission theory of \( \alpha \)-decay gives

\[
\log T = 0.43429 K_s \chi - 20.446
\]

(19)

where

\[
K_s = 2.52956 Z_{da}[A_{da} / (A_Q \alpha)]^{1/2} [\arccos \sqrt{x} - \sqrt{x}(1 - x)] ;
\]

\[
x = 0.423 Q_\alpha (1.5874 + A_{da}^{1/3}) / Z_{da}
\]

(20)

and the numerical coefficient \( \chi \), close to unity, is a second-order polynomial

\[
\chi = B_1 + B_2 y + B_3 z + B_4 y^2 + B_5 y z + B_6 z^2
\]

(21)

in the reduced variables \( y \) and \( z \), expressing the distance from the closest magic-plus-one neutron and proton numbers \( N_i \) and \( Z_i \):

\[
y \equiv (N - N_i) / (N_{i+1} - N_i) ; \quad N_i < N \leq N_{i+1}
\]

(22)
\[ z \equiv (Z - Z_i)/(Z_{i+1} - Z_i) \; ; \; Z_i < Z \leq Z_{i+1} \tag{23} \]

with \( N_i = \ldots, 51, 83, 127, 185, 229, \ldots \), \( Z_i = \ldots, 29, 51, 83, 115, \ldots \), and \( Z_{da} = Z - 2 \), \( A_{da} = A - 4 \). The coefficients \( B_i \) are obtained by fit with experimental data, using a computer program making automatically the best fit [29]. Better agreement with experimental results are obtained in the region of superheavy nuclei by introducing other values of the magic numbers plus one unit for protons (suggesting that the next magic number of protons could be 126 instead of 114): \( Z_i = \ldots, 83, 127, 165, \ldots \).

Practically for even-even nuclei, the increased errors in the neighborhood of \( N = 126 \), present in all other cases, are smoothed out by SemFIS formula using the second order polynomial approximation for \( \chi \). They are still present for the strongest \( \alpha \)-decays of some even-odd and odd-odd parent nuclides. In fact for non-even number of nucleons the structure effects became very important, and they should be carefully taken into account for every nucleus, not only globally. An overall estimation of the accuracy, gives the standard rms deviation of log \( T \) values:

\[ \sigma = \left\{ \sum_{i=1}^{n} [\log(T_i/T_{exp})]^2/(n-1) \right\}^{1/2} \tag{24} \]

The partial \( \alpha \)-decay half-lives plotted in this figure are lying in the range of \( 10^{-7} \) to \( 10^{25} \) seconds. One can see the effect of the spherical and deformed neutron magic numbers of the daughter nuclei \( N_d = 126, 152, 162 \) particularly clear for even-even and even-odd nuclides. For the large set of alpha emitters the following values of the rms errors have been obtained: log \( T \): 0.19 for SemFIS formula; 0.33 for the universal curve; 0.39 for ASAF model, and 0.43 for numerical superasymmetric (NuSAF) model.

There are many parameters of the SemFIS formula introduced in order to reproduce the experimental behaviour around the magic numbers of protons and neutrons, which could be a drawback in the region of light and intermediate alpha emitters.

We succeeded to obtain \( \sigma_{ee} = 3.178 \) when \( B1 = 0.993119, B2 = -0.0046700, B3 = 0.017009, B4 = 0.045030, B5 = 0.018101, B6 = -0.025097, \sigma_{eo} = 9.453 \) when \( B1 = 1.017560, B2 = -0.113054, B3 = 0.019057, B4 = 0.147320, B5 = 0.230300, B6 = -0.101528, \sigma_{oe} = 4.439 \) when \( B1 = 1.000560, B2 = 0.010783, B3 = 0.050671, B4 = 0.013918, B5 = 0.0043657, B6 = -0.079999, \) and \( \sigma_{oo} = 2.885 \) when \( B1 = 1.004470, B2 = -0.160056, B3 = 0.264857, B4 = 0.212332, B5 = 0.292664, B6 = -0.401158. \)
III.  RELEASED ENERGY

A.  AME16 and W4

The results obtained with AME16 are showing good agreement with experimental data, particularly for e-e emitters, followed by o-e ones.

The largest error (over |0.1|) is obtained for: $^{253}Es_{99}$, $^{269,271}Sg_{106}$, $^{273,275}Hs_{108}$, $^{277,279,281}Ds_{110}$, $^{283,285}Cn_{112}$, $^{287}Nh_{113}$, $^{285,286,287,288,289}Fl_{114}$, $^{290,291,292,293}Lv_{116}$, and $^{294,295}Og_{118}$. The best result (under |0.01|) is obtained for $^{281,284,281,285}Cn_{112}$, $^{287,288,289}Fl_{114}$, $^{290}Lv_{116}$, $^{294}Og_{118}$, and the almost perfect $^{291}Lv_{116}$. Some of the nuclides appear both on the wrong and the best side, because the input data may be different for the same emitter.

From the results obtained with W4 atomic masses one can see the worst results (dq over 1 unit) for $^{253}Es_{99}$, $^{265,267}Rf_{104}$, $^{269,271,273}Sg_{106}$, $^{278}Bh_{107}$, $^{273,275,277,278}Hs_{108}$, $^{282}Mt_{109}$, $^{277,279,281,282}Ds_{110}$, $^{286}Rg_{111}$, $^{281,283,285}Cn_{112}$, $^{287}Nh_{113}$, $^{284,285,286,287,288,289,290,291,293,294}Fl_{114}$, $^{290,291,292,293}Lv_{116}$, and $^{294,295}Og_{118}$. The best result is obtained for $^{281,282,285}Cn_{112}$, $^{286,287,288}Fl_{114}$, $^{290,292}Lv_{116}$, $^{291}Lv_{116}(dq = -0.954E - 06!!)$, and $^{294}Og_{118}$.

Selected data with the best values are given in the following tables: XIX, XIX, and XIX. The corresponding results are given in the XIV. If we look at the figures I and II it is very clear that Q-values are very well reproduced, but generally speaking for the half-lives the errors may rich many orders of magnitude (9!!!), except few cases: $^{282,284}Cn_{112}$ and $^{288}Fl_{114}$ (dT under 1) plus $^{284,286,294}Fl_{114}$, $^{292,294}Og_{118}$ and the evident case of those who have no experimental data $^{300,302,120}$ (dT few units) for e-e nuclei; $^{273,275}Hs_{108}$, $^{279}Ds_{110}$, $^{281}Cn_{112}$, $^{287,289}Fl_{114}$, $^{293}Lv_{116}$ (dT under 1) plus $^{277}Hs_{108}$, $^{291}Lv_{116}$, $^{295}Og_{118}$, $^{299,301,120}$ for e-o; $^{277}Hs_{108}$, $^{277}Ds_{110}$, $^{277}Hs_{108}$, $^{277}Ds_{110}$, $^{297,299,119}$ (dT few units) for o-e, and $^{290,300,119}$. The differences $DQ = Q_4 - Q_{exp}$ between $Q_4$, or $Q_{K Tu Y 0 5}$ when $Q_4$ is not available are generally speaking quite small, except for the following cases: $DQ = -4.721, -5.339$ MeV, respectively, for $^{288}Fl_{114}$ out of 13 e-e nuclides. For 18 e-o α emitters is much simpler to give few cases with small $DQ = -0.725, -0.605$ for $^{275,277}Hs_{108}$ Particularly large $DQ = -4.948$ is observed for $^{279}Ds_{110}$. Similarly for 4 odd-even nuclides the only one with small $DQ = 0.283$ is $^{253}Es_{99}$. For 9 of the α emitters we found AME16 data, which are given in the table LXX.

In the following part we shall study the behaviour of the optimized values of Q and T;
just one line for every nucleus, despite the fact that we can miss some excited states in this way. The motivation would be that we are mainly interested in transitions between the ground state states.

IV. CLUSTER RADIOACTIVITIES

We give in tables VI–VIII the cluster emission with Q-values calculated using W4 model, and half-lives with ASAF model. The Q-values are plotted in figure 1 and the differences $T_{semFis} - T_{exp}$ in figure 2. The most interesting results are those obtained for the heaviest nuclides: $^{300,302}120$ with branching ratios $B_\alpha = -0.10$ and 0.49, respectively, $^{299,301}120$ with $B_\alpha = -1.49$ and -1.17, $^{297,299}119$ with $B_\alpha = -1.99$ and -3.21, and $^{300}119$ with $B_\alpha = -3.75$.

V. Q-VALUES

Compare experiments with AME16 and W4. Differences $\Delta Q = Q_{th} - Q_{exp}$, and rms standard deviations, $\sigma_{AME16}$ and $\sigma_{W4}$.

$$\log_{10} T_\alpha (s) = -57.5 \log_{10} R_\alpha (cm) + C$$

where $C$ depends on the series, e.g. $C = 41$ for the $^{238}U$ series. One has approximately $R_\alpha = 0.325E_\alpha^{3/2}$ in which the kinetic energy of $\alpha$ particles, $E_\alpha$, is expressed in MeV and the range in air, $R$, in cm. This relationship is now of historical interest; the effect of atomic number, $Z$, upon decay rate is obscured. The one-body theory of $\alpha$-decay can explain it and to a good approximation produces a formula with an explicit dependence on the $Z$ number. Nowadays, very often a diagram of $\log T_\alpha$ versus $ZQ^{-1/2}$ is called Geiger-Nuttal plot.

There are many semiempirical relationships allowing to estimate the disintegration period if the kinetic energy of the emitted particle $E_\alpha = QA_d/A$ is known. $Q$ is the released energy and $A_d, A$ are the mass numbers of the daughter and parent nuclei. Alpha-decay half-life of an even-even emitter can also be easily calculated by using the universal curves or the analytical supersymmetric (ASAF) model. Some of these formulae were only derived for a limited region of the parent proton and neutron numbers. Their parameters have been determined by fitting a given set of experimental data. Since then, the precision of the measurements was increased and new $\alpha$-emitters have been discovered.
The description of data in the neighborhood of the magic proton and neutron numbers, where the errors of the other relationships are large, was improved by deriving a new formula based on the fission theory of $\alpha$-decay \cite{17}. A computer program \cite{29} allows to change automatically the fit parameters, every time a better set of experimental data is available. There are many alpha emitters, particularly in the intermediate mass region, for which both the Q-values and the half-lives are well known \cite{11, 12}. Initially it was used a set of 376 data (123 even-even (e-e), 111 even-odd (e-o), 83 odd-even (o-e), and 59 odd-odd (o-o)) on the most probable (ground state to ground state or favored transitions) $\alpha$-decays, with a partial decay half-life

$$T_{\alpha} = \frac{100}{b_{\alpha}}\left(\frac{100}{i_{p}}\right)T_{t}$$

(26)

where $b_{\alpha}$ and $i_{p}$, expressed in percent, represent the branching ratio of $\alpha$-decay in competition with all other decay modes, and the intensity of the strongest $\alpha$-transition, respectively.

In the region of superheavy nuclei the majority of researchers prefer to use Viola-Seaborg formula. Recently for nuclei with $Z = 84 - 110$ and $N = 128 - 160$, for which both $Q_{exp}^{\alpha}$ and $T_{exp}$ experimental values are available, new optimum parameter values \cite{35} have been determined. The average hindrance factors for 45 o-e ($Z = 85 - 107$), 55 e-o ($Z = 84 - 110$), and 40 o-o ($Z = 85 - 111$, $N = 129 - 161$) nuclei were determined to be $C_{V}^{p} = 0.437$, $C_{V}^{n} = 0.641$, and $C_{V}^{pn} = 1.024$. In this way $T_{exp}$ were reproduced by the Viola-Seaborg formula within a factor of 1.4 for e-e, 2.3 for o-e, 3.7 for e-o and 4.7 for o-o nuclei, respectively.

Since 1979 one of us (DNP) considered $\alpha$ decay a supersymmetric fission process. Consequently a new semiempirical formula for the alpha decay halflives \cite{17} was a straightforward finding. The analytical and numerical supersymmetric fission (ASAF \cite{18} and NUSAF) models were used together with fragmentation theory developed by the Frankfurt School, and with penetrability calculations like for $\alpha$ decay, to predict cluster (or heavy particle) radioactivity \cite{20, 21}. The extended calculations, e.g. \cite{19} have been used to guide the experiments and as a reference for many theoretical developments. A series of books and chapters in books, e.g. \cite{23, 27} are also available. A computer program \cite{29} gives us the possibility to improve the parameters of the ASAF model in agreement with a given set of experimental data. The UNIV (universal curve) model was updated in 2011 \cite{36}.

The interest for $\alpha$D is strongly simulated by the search for heavier and heavier superheavies (SHs) — nuclides with $Z > 103$, produced by fusion reactions, who may be identified easily if a chain of $\alpha$D leading to a known nucleus may be measured. Recently it was shown

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that for superheavy nuclei with atomic numbers $Z > 121$ \cite{37,39} $\alpha$D may be stronger than CD or spontaneous fission.

A very interesting result was reported by Y.Z. Wang et al. \cite{15}, who compared 18 such formulae in the region of superheavy nuclei. They found: “SemFIS2 formula is the best one to predict the alpha-decay half-lives ... In addition, the UNIV2 formula with fewest parameters and the VSS, SP and NRDX formulas with fewer parameters work well in prediction on the SHN alpha-decay half-lives ...”

VI. COMPARISON OF RESULTS OBTAINED WITH THE NEW FORMULA, SEMFIS, UNIV, AND ASAP.

We present the results obtained using the four models. A global indicator for a given model could be the weighted mean value

$$\sigma_{newF}^B = \frac{21\sigma_{e-e} + 21\sigma_{e-o} + 13\sigma_{o-e} + 9\sigma_{o-o}}{64} = 4.6065 \quad (27)$$

Similarly for the other models

$$\sigma_{ASAF} = \frac{21\sigma_{e-e} + 21\sigma_{e-o} + 13\sigma_{o-e} + 9\sigma_{o-o}}{64} = 4.9477 \quad (28)$$

$$\sigma_{UNIV} = \frac{21\sigma_{e-e} + 21\sigma_{e-o} + 13\sigma_{o-e} + 9\sigma_{o-o}}{64} = 4.6476 \quad (29)$$

$$\sigma_{semFIS} = \frac{21\sigma_{e-e} + 21\sigma_{e-o} + 13\sigma_{o-e} + 9\sigma_{o-o}}{64} = 5.4519 \quad (30)$$

The rms standard deviations obtained with all models are compared in table III.

From the results in table III, we may say that, unexpectedly semFIS came this time on the last global position. AKRA is the best, followed by UNIV and ASAP. Once again, we may see how important could be the experimental set of data we are dealing with. In order to make it very clear how much the result may depend on the quality of experimental data we reproduce from a previous publication \cite{38}:

$$\sigma_{semFIS534} = \frac{173\sigma_{e-e} + 134\sigma_{e-o} + 123\sigma_{o-e} + 104\sigma_{o-o}}{534} = 0.40803 \quad (31)$$
VII. POSSIBLE CHAINS OF HEAVIEST SHS

We may predict the results shown in the table II and figures 3,4 for αD and in table I for cluster radioactivities.

VIII. CONCLUSIONS

The accuracy of the new formula was increased after optimization of the five parameters in the order: a; e; d; c, and b. The SemFIS formula taking into account the magic numbers of nucleons, the analytical super-asymmetric fission model and the universal curves may be used to estimate the alpha emitter half-lives in the region of superheavy nuclei. The dependence on the proton and neutron magic numbers of the semiempirical formula may be exploited to obtain informations about the values of the magic numbers which are not well known until now.

We introduced a weighted mean value of the rms standard deviation, allowing to compare the global properties of a given model. In this respect for the set B the order of the four models is the following: semFIS; UNIV; newF, and ASAF.

The quality of experimental data was also tested, as one can see by comparing the three sets (A, B, C). The set B with large number of emitters (580) gives the best global result. It is followed by the set A (454) three times and the set C (344). Despite its simplicity in comparison with semFIS the new formula, presented in this article, behaves quite well, competing with the others well known relationships discussed in the Ref. [15].

We made few predictions concerning possible αD decay chains of future SHs. For $^{92,94}$Sr cluster radioactivity of $^{300,302}$120 we predict a branching ratio relative to α decay of -0.10 and 0.49, respectively, meaning that it is worth trying to detect such kind of decay modes in competition with α decay.

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FIG. 1. The differences of $Q_4 - Q_{exp}$ in four groups of nuclides versus the daughter number of neutrons, $N_d$. 
FIG. 2. The decimal logarithm of the difference of $T_{semFis} - T_{exp}$ in four groups of nuclides versus the daughter number of neutrons, $N_d$.

**TABLE I. Possible Cluster decay modes in competition with $\alpha$ decay for the Heaviest SHs.**

| Parent | Emitted | $E_e$(MEV) | $T_e$ ($\mu$s) | $B_\alpha$ |
|--------|---------|------------|----------------|-----------|
| 300 120 | $^{92}$Sr | 175.677 | 1.86 | -0.10 |
| 302 120 | $^{94}$Sr | 175.916 | 5.50 | 0.49 |
FIG. 3. Few possible alpha decay chains of even-even SH emitters. We give the kinetic energy (MeV) and the half-life of the parent nucleus.
FIG. 4. Few possible alpha decay chains of odd-mass SH emitters. We give the kinetic energy (MeV) and the half-life of the parent nucleus.
### TABLE II. Possible Chains of $\alpha$ decay for the Heaviest SHs.

| Parent | $E_\alpha$ (MeV) | $T_\alpha$ |
|--------|------------------|------------|
| 297 119 | 12.046           | 0.200 ms   |
| 293 117 | 11.029           | 9.330 ms   |
| 289 115 | 10.377           | 85.10 ms   |
| 285 113 | 9.886            | 513 ms     |
| 281 111 | 9.631            | 692 ms     |
| 277 109 | 9.570            | 251 ms     |
| 273 107 | 8.927            | 5 s        |
| 299 119 | 12.526           | 18.6 $\mu$s|
| 295 117 | 10.914           | 18.2 ms    |
| 291 115 | 10.178           | 316 ms     |
| 287 113 | 9.406            | 15 s       |
| 283 111 | 9.060            | 42 s       |
| 300 119 | 12.278           | 6.46 ms    |
| 296 117 | 11.209           | 64.6 ms    |
| 292 115 | 9.912            | 5 min 31s  |
| 288 113 | 9.493            | 25 min 49s |
| 284 111 | 8.760            | 6days 6h 27 min |
| 300 120 | 13.131           | 64.6 $\mu$s|
| 296 118 | 11.486           | 1.20 ms    |
| 292 116 | 10.597           | 34.7 ms    |
| 288 114 | 9.932            | 617 ms     |
| 284 112 | 9.406            | 4.9 s      |
| 302 120 | 12.597           | 1.70 ms    |
| 298 118 | 11.931           | 0.117 ms   |
| 294 116 | 10.439           | 112 ms     |
| 290 114 | 9.613            | 5.5 s      |
| 286 112 | 9.149            | 31.6 s     |
TABLE III. Comparison of rms standard deviations. $\sigma$, obtained with different models.

| Parity | AKRA | ASAF | UNIV | semFIS |
|--------|------|------|------|--------|
| e-e    | 2.989| 3.397| 2.952| 3.177  |
| e-o    | 8.062| 8.458| 8.146| 9.453  |
| o-e    | 3.881| 4.056| 3.988| 4.439  |
| o-o    | 1.366| 1.663| 1.547| 2.885  |
| Global | 4.606| 4.948| 4.648| 5.4519 |

TABLE IV. Half-lives, $\log_{10} T_\alpha(s)$, of few nuclides, as given in the Ref. [34].

| A | Z | $\log_{10} T_\alpha(s)$ |
|---|---|--------------------------|
| 252 | 100 | 4.961 |
| 269 | 106 | 2.681 |
| 273 | 108 | -0.041 |
| 277 | 110 | -1.658 |
| 281 | 110 | 1.076 |
| 281 | 112 | -0.432 |
| 285 | 112 | 1.505 |
| 285 | 114 | -0.328 |
| 287 | 114 | -0.284 |
| 289 | 114 | 0.380 |
| 291 | 116 | -1.553 |
| 293 | 116 | -1.097 |
| 253 | 99  | 6.248 |
TABLE V. Optimization of coefficients using the set B.

| Group | n   | σ   | a             | b           | c            | d            | e            |
|-------|-----|-----|---------------|-------------|--------------|--------------|--------------|
| e-e   | 188 | 0.540 | -27.837       | -0.94199975 | 1.5343       | -5.7004      | 8.785        |
| e-o   | 147 | 0.678 | -28.2245      | -0.8629     | 1.53774      | -21.145      | 53.890       |
| o-e   | 131 | 0.522 | -26.8005      | -1.10783    | 1.5585       | 14.8525      | -30.523      |
| o-o   | 114 | 0.840 | -23.6354      | -0.891      | 1.404        | -12.4255     | 36.9005      |

TABLE VI. Cluster radioactivities of even-even emitters. Q-values obtained using W4 model, and half-lives with ASAF model.

| A  | Z  | $A_e$ | $Z_e$ | $Q_c$ (MeV) | $\log_{10} T_c$ (s) | $B_a = T_\alpha - T_c$ |
|----|----|-------|-------|-------------|----------------------|------------------------|
| 252| 100| 48    | 20[Ca]| 145.85      | 23.63                | -20.88                 |
| 278| 108| 72    | 28[Ni]| 216.64      | 16.76                | -15.51                 |
| 282| 110| 74    | 28[Ni]| 223.06      | 15.21                | -12.89                 |
| 282| 112| 74    | 30[Zn]| 245.52      | 9.29                 | -10.24                 |
| 284| 112| 76    | 30[Zn]| 245.30      | 8.91                 | -8.23                  |
| 284| 114| 78    | 32[Ge]| 264.41      | 6.71                 | -9.18                  |
| 286| 114| 80    | 32[Ge]| 264.23      | 6.18                 | -7.22                  |
| 288| 114| 80    | 32[Ge]| 264.72      | 5.12                 | -5.33                  |
| 290| 114| 82    | 32[Ge]| 263.89      | 5.30                 | -4.56                  |
| 294| 114| 82    | 32[Ge]| 258.17      | 10.81                | -7.31                  |
| 292| 116| 84    | 34[Se]| 284.64      | 0.55                 | -2.01                  |
| 294| 118| 86    | 36[Kr]| 303.81      | -2.45                | -0.87                  |
| 300| 120| 92    | 38[Sr]| 321.36      | -5.73                | -0.10                  |
| 302| 120| 94    | 38[Sr]| 320.04      | -5.26                | 0.49                   |
TABLE VII. Cluster radioactivities of even-odd emitters. Q-values obtained using W4 model, and half-lives with ASAF model.

| A  | Z  | $A_e$ | $Z_e$ | $Q_c$ (MeV) | $\log_{10} T_c(s)$ | $B_\alpha = T_\alpha - T_c$ |
|----|----|------|------|-------------|----------------|-----------------------------|
| 265| 104| 55   | 22[Ti]| 165.27      | 26.71           | -22.00                      |
| 267| 104| 61   | 24[Cr]| 175.93      | 28.83           | -24.30                      |
| 269| 106| 64   | 26[Fe]| 195.84      | 24.94           | -22.56                      |
| 271| 106| 65   | 26[Fe]| 195.65      | 24.86           | -23.00                      |
| 273| 108| 68   | 28[Ni]| 216.27      | 20.25           | -20.30                      |
| 275| 108| 70   | 28[Ni]| 216.20      | 19.97           | -18.98                      |
| 277| 108| 71   | 28[Ni]| 216.04      | 19.76           | -17.35                      |
| 279| 110| 71   | 28[Ni]| 225.09      | 15.77           | -15.84                      |
| 281| 110| 72   | 28[Ni]| 223.55      | 17.05           | -14.59                      |
| 279| 110| 71   | 28[Ni]| 225.09      | 15.77           | -15.84                      |
| 281| 112| 74   | 30[Zn]| 245.18      | 12.15           | -12.59                      |
| 283| 112| 76   | 30[Zn]| 244.79      | 12.00           | -10.47                      |
| 285| 112| 77   | 30[Zn]| 244.08      | 12.26           | -8.81                       |
| 287| 114| 80   | 32[Ge]| 264.49      | 8.04            | -6.56                       |
| 289| 114| 81   | 32[Ge]| 263.78      | 8.22            | -5.94                       |
| 291| 116| 84   | 34[Se]| 284.42      | 3.58            | -5.01                       |
| 293| 116| 85   | 34[Se]| 283.13      | 4.34            | -5.15                       |
| 295| 118| 87   | 36[Kr]| 303.06      | 0.50            | -2.73                       |
| 299| 120| 91   | 38[Sr]| 321.48      | -2.70           | -1.49                       |
| 301| 120| 93   | 38[Sr]| 320.58      | -3.86           | -1.17                       |
TABLE VIII. Cluster radioactivities of odd-even and odd-odd emitters. Q-values obtained using W4 model, and half-lives with ASAF model.

| A  | Z  | $A_e$ | $Z_e$ | $Q_c$ (MeV) | $\log_{10} T_c$(s) | $B_{\alpha} = T_{\alpha} - T_c$ |
|----|----|-------|-------|-------------|------------------|------------------|
| 253| 99 | 46    | 18[Ar]| 129.54      | 25.87            | -19.44           |
| 277| 108| 71    | 18[Ar]| 216.04      | 19.76            | -17.35           |
| 108| 71 | 28[Ni]| 225.98| 15.24       | 17.49            |
| 113| 79 | 31[Ga]| 254.02| 8.97        | -7.80            |
| 119| 89 | 37[Rb]| 311.65| -1.71       | -1.99            |
| 119| 91 | 37[Rb]| 310.63| -1.52       | -3.21            |
| 107| 73 | 28[Ni]| 211.19| 22.73       | -15.79           |
| 109| 71 | 27[Co]| 208.28| 25.44       | -17.78           |
| 111| 78 | 29[Cu]| 230.34| 18.88       | -12.76           |
| 113| 81 | 31[Ga]| 251.27| 13.45       | -9.30            |
| 300| 119| 92    | 37[Rb]| 309.74      | 1.56             | -3.75            |

TABLE IX. Best results obtained with AME16 for $\alpha$ emitters.

| A  | Z  | $Q_{exp}$ (MeV) | $Q_2$ (MeV) | $DQ = Q_2 - Q_{exp}$ (MeV) |
|----|----|-----------------|-------------|-----------------------------|
| 282| 112| 10.10           | 10.10       | 0.899E-02                   |
| 288| 114| 10.10           | 10.10       | -0.201E-02                  |
| 290| 116| 11.00           | 11.0        | -0.801E-02                  |
| 292| 116| 10.80           | 10.80       | -0.200E-02                  |
| 294| 118| 11.80           | 11.80       | -0.900E-02                  |
| 281| 112| 10.40           | 10.40       | 0.900E-02                   |
| 285| 112| 9.32            | 9.32        | -0.300E-02                  |
| 287| 114| 10.20           | 10.20       | -0.500E-02                  |
| 291| 116| 10.90           | 10.90       | -0.954E-06                  |
TABLE X. Best results obtained with W4 for α emitters.

| A  | Z  | $Q_{exp}$ (MeV) | $Q_4$ (MeV) | $DQ = Q_4 - Q_{exp}$ | $\log_{10}T_{semFIS}$ | $\log_{10}T_{ASAF}$ | $DT = T_{semFIS} - T_{ASAF}$ |
|----|----|----------------|-------------|----------------------|--------------------------|--------------------------|-----------------------------|
| 282| 112| 10.10          | 10.10       | 0.899E-02            | -1.35                    | -0.952                   | 0.236                       |
| 288| 114| 10.10          | 10.10       | -0.201E-02           | -0.702                   | -0.211                   | 0.155                       |
| 290| 116| 11.10          | 11.10       | -0.801E-02           | -2.47                    | -2.02                    | 3.27                        |
| 292| 116| 10.80          | 10.80       | -0.200E-02           | -1.97                    | -1.46                    | 0.319                       |
| 294| 118| 11.80          | 11.80       | -0.900E-02           | -3.84                    | -3.31                    | 0.319                       |
| 281| 112| 10.40          | 10.50       | 0.900E-02            | -1.63                    | -0.442                   | 0.479                       |
| 285| 112| 9.32           | 9.32        | -0.300E-02           | 1.49                     | 3.45                     | 0.229                       |
| 287| 114| 10.20          | 10.20       | -0.500E-02           | -0.299                   | 1.47                     | 0.208                       |
| 289| 114| 9.97           | 9.97        | -0.801E-02           | 0.208                    | 0.228                    | 0.228                       |
| 291| 116| 10.90          | 10.90       | -0.954E-06           | -1.62                    | -1.43                    | 0.592                       |
TABLE XI. Selected best input data with half-lives in decimal logarithm of the $T_{1/2}$ expressed in seconds, $lgT = \log_{10} T_{1/2}(s)$. Even-even $\alpha$ emitters.

| Crt. nb. | A  | Z  | $N_d$ | $T_{med}$ | Q (MeV) | $T_{min}$ | $T_{max}$ | $lgT_{med}$ | $lgT_{min}$ | $lgT_{max}$ | $\Delta T$ |
|---------|----|----|-------|-----------|---------|-----------|-----------|-------------|-------------|-------------|------------|
| 1       | 240| 96 | 142   | $2.3328 \times 10^6$ | 6.398   |           |           | 6.368       |             |             |            |
| 2       | 246| 98 | 146   | $1.2852 \times 10^5$ | 6.862   |           |           | 5.109       |             |             |            |
| 3       | 248| 98 | 148   | $2.87712 \times 10^7$ | 6.361   |           |           | 7.459       |             |             |            |
| 4       | 250| 98 | 150   | $9.83923 \times 10^9$ | 6.128   |           |           | 9.993       |             |             |            |
| 5       | 252| 100| 150   | $9.0 \times 10^4$    | 7.153   |           |           | 4.954       |             |             |            |
| 6       | 278| 108| 168   | 690.0                 | 8.8     | 380.0     | 3990.0    | 2.839       | 2.580       | 3.601       | 1.021      |
| 7       | 282| 110| 170   | 67.0                  | 8.96    | 37.0      | 387.0     | 1.826       | 1.568       | 2.588       | 1.020      |
| 8       | 284| 112| 170   | 0.118                 | 9.605   | 0.101     | 0.142     | -0.928      | -0.996      | 0.148       |            |
| 9       | 286| 112| 172   | 640.                  | 8.793   | 340.      | 3740.     | 2.806       | 2.531       | 3.573       | 1.041      |
| 10      | 284| 114| 168   | 0.002                 | 10.76   | 0.0013    | 0.0047    | -2.699      | -2.886      | -2.328      | 0.558      |
| 11      | 286| 114| 170   | 0.166                 | 10.65   |           |           | -0.780      |             |             |            |
| 12      | 288| 114| 172   | 0.644                 | 14.795  | 0.547     | 0.782     | -0.191      | -0.262      | -0.107      | 0.155      |
| 13      | 290| 114| 174   | 21.0                  | 9.846   | 11.0      | 122.0     | 1.322       | 1.041       | 2.086       | 1.045      |
| 14      | 294| 114| 178   | 0.002                 | 10.760  |           |           | -2.699      |             |             |            |
| 15      | 290| 116| 172   | 0.0083                | 11.005  | 0.0064    | 11.9      | -3.495      | -3.658      | -3.237      | 0.421      |
| 16      | 292| 116| 174   | 0.0128                | 10.776  | 0.0095    | 0.0198    | -1.893      | -2.022      | -1.703      | 0.319      |
| 17      | 294| 118| 174   | 0.0022                | 11.835  | 0.0012    | 12.7      | -2.658      | -2.921      | 1.104       |            |
| 18      | 300| 120| 178   | 0.0                   | 13.308  |           |           | -5.83       |             |             |            |
| 19      | 302| 120| 180   | 0.0                   | 12.766  |           |           | -4.77       |             |             |            |
TABLE XII. Selected best input data with half-lives in decimal logarithm of the $T_{1/2}$ expressed in seconds, $lgT = \log_{10} T_{1/2}(s)$. Even-odd $\alpha$ emitters.

| Crt. nb. | $A$ | $Z$ | $N_d$ | $T_{med}$ (s) | Q (MeV) | $T_{min}$ (s) | $T_{max}$ (s) | $lgT_{med}$ | $lgT_{min}$ | $lgT_{max}$ | $\Delta T$ |
|----------|-----|-----|-------|--------------|---------|--------------|--------------|------------|------------|------------|----------|
| 1        | 265 | 104 | 159   | 61.          | 6.398   | 39.00        | 145.0        | 1.785      | 1.591      | 2.161      | 0.570    |
| 2        | 267 | 104 | 161   | 4608.        | 6.862   | 2808.        | 12996.       | 3.664      | 3.448      | 4.114      | 0.665    |
| 3        | 269 | 106 | 161   | 185.0        | 6.361   | 117.0        | 439.0        | 2.267      | 2.068      | 2.642      | 0.574    |
| 4        | 273 | 108 | 163   | 0.765        | 7.153   | 0.00         | 0.00         | -0.116     | 1.806      | 2.283      | 0.477    |
| 5        | 275 | 108 | 165   | 0.201        | 10.175  | 0.00         | 0.00         | -0.873     | -0.396     | 0.477      | 0.00     |
| 6        | 277 | 108 | 167   | 0.0031       | 9.605   | 1.70         | 18.0         | -2.509     | 0.230      | 1.255      | 1.025    |
| 7        | 279 | 110 | 167   | 0.290        | 10.795  | 0.243        | 0.359        | -0.538     | -0.614     | -0.445     | 0.169    |
| 8        | 281 | 110 | 169   | 13.0         | 10.365  | 10.30         | 17.50        | 1.114      | 1.013      | 1.243      | 0.230    |
| 9        | 279 | 110 | 167   | 0.290        | 14.795  | 0.00         | 0.00         | -0.538     | 1.013      | 1.243      | 0.230    |
| 10       | 281 | 112 | 167   | 0.128        | 11.005  | 0.085        | 0.256        | -0.893     | -1.071     | -0.592     | 0.479    |
| 11       | 283 | 112 | 169   | 308.0        | 16.115  | 219.0        | 520.0        | 2.489      | 2.340      | 2.716      | 0.376    |
| 12       | 285 | 112 | 171   | 28.9         | 11.835  | 23.0         | 39.00        | 1.461      | 1.362      | 1.591      | 0.229    |
| 13       | 287 | 114 | 171   | 0.540        | 10.025  | 0.440        | 0.710        | -0.268     | -0.357     | -0.149     | 0.208    |
| 14       | 289 | 114 | 173   | 1.870        | 7.805   | 1.49         | 2.52         | 0.272      | 0.173      | 0.401      | 0.228    |
| 15       | 291 | 116 | 173   | 0.0180       | 7.885   | 0.00         | 0.00         | -1.745     | -1.959     | -1.367     | 0.592    |
| 16       | 293 | 116 | 175   | 0.0570       | 8.645   | 0.0390       | 0.103        | -1.244     | -1.409     | -0.987     | 0.422    |
| 17       | 295 | 118 | 175   | 0.261        | 8.895   | 0.00         | 0.00         | -0.583     | -1.409     | -0.987     | 0.422    |
| 18       | 299 | 120 | 177   | 3.7          | 13.14   | 0.00         | 0.00         | 0.568      | -1.009     | 0.020      | 1.029    |
| 19       | 301 | 120 | 179   | 0.0          | 12.939  | 0.00         | 0.00         | -3.86      | 0.00       | 0.00       | 0.00     |
TABLE XIII. Selected best input data with half-lives in decimal logarithm of the $T_{1/2}$ expressed in seconds, $\lg T = \log_{10} T_{1/2}$ (s). Odd-even and odd-odd $\alpha$ emitters. For $^{297,299,119}$ we have used the KTUY mass model [30].

| Crt. nb. | A   | Z   | $N_d$ | $T_{med}$ | Q (MeV) | $T_{min}$ | $T_{max}$ | $\lg T_{med}$ | $\lg T_{min}$ | $\lg T_{max}$ | $\Delta T$ |
|----------|-----|-----|-------|-----------|---------|-----------|-----------|----------------|----------------|----------------|-----------|
| 1        | 253 | 99  | 152   | 1771200   | 6.398   | 0.        | 0.        | 6.248          | 0.             | 0.             | 0.         |
| 2        | 277 | 108 | 167   | 0.0031    | 6.862   | 1.7       | 18.       | -2.509         | 0.230          | 1.255          | 1.02      |
| 3        | 277 | 110 | 165   | 0.0041    | 6.361   | 0.        | 0.        | -2.387         | 0.             | 0.             | 0.         |
| 4        | 287 | 113 | 172   | 14.00     | 6.128   | 0.        | 0.        | 1.146          | 0.             | 0.             | 0.         |
| 5        | 297 | 119 | 176   | 12.210    | 11.285  | 0.        | 0.        | -3.70          | 0.             | 0.             | 0.         |
| 6        | 299 | 119 | 178   | 12.696    | 11.475  | 0.        | 0.        | -4.73          | 0.             | 0.             | 0.         |
| 7        | 278 | 107 | 169   | 690.0     | 7.900   | 380.      | 3990.     | 2.839          | 2.580          | 3.601          | 0.         |
| 8        | 282 | 109 | 171   | 67.0      | 8.83    | 0.        | 0.        | 1.826          | 0.             | 0.             | 0.         |
| 9        | 286 | 111 | 173   | 642.      | 8.67    | 0.        | 0.        | 2.808          | 0.             | 0.             | 0.         |
| 10       | 290 | 113 | 175   | 2.0       | 9.71    | 0.        | 0.        | 0.301          | 0.             | 0.             | 0.         |
| 11       | 300 | 119 | 179   | 0.        | 12.444  | 0.        | 0.        | -2.19          | 0.             | 0.             | 0.         |

TABLE XIV. Best results obtained with selected $\alpha$ emitters. Q-values given by W4 model.

| n | parity | $\sigma_Q$ | $\sigma_{T-ASAF}$ |
|---|--------|------------|--------------------|
| 16| e-e    | 0.489      | 0.448              |
| 19| e-o    | 0.171      | 1.280              |
| 4 | o-e    | 0.356      | 0.986              |
| 4 | o-o    | 0.463      | 2.920              |