^{228}Ra – Comments on Evaluation of Decay Data by A. Luca

This evaluation was completed in June 2009. The literature available by December 31st, 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office). The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{228}Ra decays 100 % by beta minus particle emissions populating ^{228}Ac excited states. The decay scheme was studied by a few authors (1961To10, 1972HeYY, 1995So11). The most recent evaluation of the ^{228}Ra nuclear structure and decay data, published in Nuclear Data Sheets, was done by A. Artna-Cohen (1997). In the present evaluation, the spin, parity and energy of ^{228}Ac excited levels, and the multipolarities of the γ-ray transitions, have been adopted from the above mentioned A=228 ENSDF mass-chain evaluation (1997Ar08).

3. Nuclear Data

The adopted beta decay energy value Q(β) = 45.8 (7) keV, is from 2003Au03. This value is in very good agreement with the effective Q(β) value of 46 (6) keV, deduced from average radiation energies from the decay scheme data, by using the SAISINUC software, version 2008 April.

3.1. Half-life

In the literature, only three measured ^{228}Ra half-life ($T_{1/2}$) values are reported; these measurements are very old (the most recent is from 1962), so new half-life measurements are needed to improve the quality of the evaluation. The half-life values and their uncertainties are presented in Table 1; the value recommended by Curie et al. (1931), with an estimated uncertainty added by the evaluator, has been also included. A critical review of the half-life (weighted average of 7 values) from reference 1962Ma58, has been done here by using the computer code LWEIGHT, ver.4. The set of data is consistent and the recommended value, 5.75 years, with an uncertainty of 0.04 year, is the weighted average (LWM, χ^2_ν=4.6) of the three input values. The reference *Nuclear Science References* (NSR) keynumbers are:

Table 1 : ^{228}Ra Half-life values

$T_{1/2}$ (years)	Uncertainty of $T_{1/2}$ (years)	Reference
6.7	1	1931Cu01
5.7	0.2	1960Du11
5.75	0.04	1962Ma58

3.2. Beta transitions and emissions

The most complete reference reporting measurements of energy and emission intensities for ^{228}Ra beta minus transitions is 1995So11.

For this evaluation, the beta transitions energies were calculated from Q(β-) and the energies of the decay scheme levels. The intensities of the beta branches were deduced from γ-ray transition intensity balance at each level, with the exception of the lowest energy branch (12.7 keV maximum energy) which was adopted from the measurements reported in 1995So11; also, the intensity ratio of the two highest energy beta branches (39.1 keV and 39.5 keV) was adopted from the same reference.

Using the gamma-ray emission probabilities for the 13.52 keV and 12.88 keV photons measured by 1995So11, a new intensity value of the 25.6 keV beta branch was computed by the evaluator (see Table 2); this was done because the 20 % beta intensity gives a negative gamma-ray emission probability for the 12.88 keV photons, according to the intensity balance of the 20.19 keV ^{228}Ac excited level. The normalization condition of the beta emissions (the sum of the all the beta transitions intensities must be 100 %) was checked. The adopted energy and intensity values of the beta transitions, as well as their Log ft values are shown in Table 2.

Table 2: ^{228}Ra β^- Energies and Emission Probabilities

Level energy (keV)	$E_{\beta-}$ (keV)	Uncertainty $E_{\beta-}$ (keV)	Emission probability (%)	Emission probability (%), from 1995So11	Log ft
33.07	12.7	0.7	30 (10)	30 (10)	5.11
20.19	25.6	0.7	8.7 (9)	20 (6)	6.2
6.67	39.1	0.7	49 (10)	40 (10)	6.45
6.28	39.5	0.7	12 (10)	10	7.07

3.3. γ- transitions: γ rays and internal conversion electrons

The only paper that reports measurements of the γ-ray energies and some emission intensities following the ^{228}Ra decay (only for 13.52 keV and 12.88 keV) is 1995So11. Using the measured 13.52 keV gamma-ray emission probability of 1.6 % (with a 0.1 % estimated uncertainty, added by the evaluator), the 12.88 keV photons measured emission probability of 0.30 (6) % and the internal conversion coefficients, the corresponding absolute gamma-ray emission probabilities and their uncertainties were computed for all the γ rays, according to the intensity balance for each level; these data are given below in Table 3. The internal conversion coefficients were computed with the program BrIcc, version 2.2b/20-Jan-2009, using the "Frozen Orbitals" approximation.

Other possible gamma-ray transitions observed only by Sood et al. (1995So11), but were not placed in the level scheme, are: 15.15 keV, 15.5 keV, 16.2 keV and 30.6 keV.

Table 3: ^{228}Ra γ-ray Energies and Absolute Emission Probabilities

E_γ (keV)	Uncertainty E_γ (keV)	Absolute Emission Probability (%)	Uncertainty of absolute emission probability (%)	Total ICC (α_T) and uncertainty
6.28	0.03	$1.8 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	$6.68\ (19) \cdot 10^{6}$
6.67	0.02	$5.7 \cdot 10^{-5}$	$0.9 \cdot 10^{-5}$	$1.560\ (40) \cdot 10^{6}$
12.88	0.11	0.30	0.06	6.67 (18)
13.52	0.04	1.6	0.1	5.86 (10)
26.40	0.11	0.14	0.05	201 (4)

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield (ϖ_L) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v.3.10, 28-Jan-2003: 0.969 (4), 0.464 (18) and 0.799 (5) respectively.

4.1. Auger electrons and X-rays

Because the decay energy, Q, is very low, there are no electron emissions from the ^{228}Ac K-shell (Auger electrons or internal conversion electrons). The emission probability of the L Auger electrons (energy from 0.1 keV to 19.69 keV) was computed using the same EMISSION computer program: 12 (5) %. The energy range for the L Auger electrons was filled-in by the SAISINUC program, version 2008 April.

For the same reason mentioned above, there are no K X-rays emitted by ^{228}Ac, following the ^{228}Ra decay. The absolute emission probability values of the different groups of L X-rays (L_L, L_α, L_η, L_β and L_γ) were determined using the EMISSION program; the total L X-rays emission probability is 9.6 (19) %, for an energy range between 10.87 keV and 18.92 keV. The energy range values of the L X-rays groups are from the tables linked to SAISINUC. Neither measurements of X-ray energies nor of emission probabilities were found in the literature, in order to compare them with the results of this evaluation.

5. Main production mode

The main production mode of ^{228}Ra is by alpha-particle decay of the ^{232}Th nuclei (^{228}Ra is the daughter of ^{232}Th), present in important quantities in many natural ores.

6. References

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