

**²¹²Bi – Comments on evaluation of decay data
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Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

²¹²Bi undergoes beta decay to ²¹²Po (BF = 64.07(7)%), and alpha decay to ²⁰⁸Tl (BF = 35.93(7)%). The alpha branching fraction was calculated as the weighted mean of the measurements of 1960Sc07, 1962Be09, 1962Fl03 and 1965Wa09, with the uncertainty increased to include the most precise value of 36.00(3)%.

| Reference | α -decay Branching Fraction (BF) % |
|-------------------|---|
| 1960Sc07 | 35.96(6) |
| 1962Be09 | 35.81(4) |
| 1962Fl03 | 36(1) |
| 1965Wa09 | 36.00(3)* |
| Recommended Value | 35.93(7) |

* Uncertainty increased slightly so that weighting does not exceed 0.5.

A reasonably consistent decay scheme has been constructed from a combination of alpha-particle studies by 1951Ry17 (two main emissions modified), 1960Wa14, and 1962Be09, and the gamma-ray measurements of 1960Sc07, 1962Be09, 1962Fl03, 1967Be19, 1968Yt02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05.

Nuclear Data

²²⁸Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ²³²Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (²²⁴Ra alpha decay to ²²⁰Rn; ²¹²Bi and ²⁰⁸Tl gamma-ray emissions).

Half-life

The recommended half-life is the unweighted mean of two somewhat elderly measurements (1914Le01 and 1961Ap03). Further studies are merited to determine this value with greater confidence.

| Reference | Half-life (min) |
|-------------------|-----------------|
| 1914Le01 | 60.480(52) |
| 1961Ap03 | 60.600(43) |
| Recommended Value | 60.54(6) |

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1986Ma17 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

The gamma-ray measurements of 1960Sc07, 1962Be09, 1962Fl03, 1967Be19, 1968Yt02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05 were used to determine the emission probabilities of the major gamma rays. These data have been measured relative to widely differing decay parameters: beta-decay mode, alpha-decay mode, per decay of ²¹²Bi (ie., absolute emission probabilities), and relative to the 583.19 and 2614.51 keV gamma rays of ²⁰⁸Tl. All of these measured data were adjusted to absolute emission probabilities when appropriate, and weighted mean values determined.

Absolute emission probabilities were estimated for the 180.2 and 1800.9 keV gamma rays in the beta-decay mode, and the 433.7, 492.7, 580.5, 620.4, 759 and 807 keV gamma rays in the alpha-decay mode. The latter values were derived from measurements of the low-intensity alpha-particle emission probabilities by 1960Wa14, and involved the introduction of uncertainty estimates that varied between 10% and 50% (depending on the number of significant figures quoted in the measurement of the relevant alpha emission probability).

Published Gamma-ray Emission Probabilities

| E_g (keV) | P_g | | | | | | | |
|----------------------------|----------------------|------------------------|---------------|---------------|---------------|---------------|---------------|---------------|
| | 1960Sc07 * | 1962Be09 | 1962Fl03 ‡ | 1967Be19 # | 1968Yt02 § | 1972DaZA § | 1978Av01 Δ | 1982Sa36 ¶ |
| 39.858(4) [α] | - | - | - | - | - | - | - | 0.9(1) |
| 180.2(2) [β] | - | - | - | - | - | - | - | - |
| 288.08(6) [α] | - | 0.775(40) [#] | - | 0.82(2) | - | 0.9(2) | 0.97(5) | 0.32(3) |
| 327.94(6) [α] | - | 0.299(23) [#] | - | 0.33(1) | - | 0.36(7) | - | - |
| 433.7(2) [α] | - | | - | 0.04(1) | - | ~ 0.025 | - | - |
| 452.8(1) [α] | - | | - | 0.84(2) | - | 0.88(17) | 1.10(6) | 0.42(5) |
| | | 1.18(5) [#] | | | | | | |
| 473.6(2) [α] | - | | - | 0.122(8) | - | 0.10(3) | - | - |
| 492.7(1) [α] | - | | - | < 0.008 | - | - | - | - |
| 580.5(3) [α] | - | - | - | - | - | - | - | - |
| 620.4(3) [α] | - | - | - | - | - | - | - | - |
| 727.33(1) [β] | 11.1(7) | | 11.8(24) | - | - | 17.6(17) | 21.0(8) | 6.9(4) |
| 759(1) [α] | - | 100 [†] | - | - | - | - | - | - |
| 785.37(9) [β] | 1.70(26) | | - | - | - | 2.8(6) | 3.26(16) | 1.01(7) |
| 807(1) [α] | - | - | - | - | - | - | - | - |
| 893.41(2) [β] | 0.66(7) | 4.9(3) [†] | 0.5(1) | - | - | 0.94(19) | - | 0.49(8) |
| 952.12(2) [β] | 0.16(4) | - | - | - | - | 0.46(9) | - | - |
| 1073.6(2) [β] | | | - | - | - | ~ 0.03 | - | - |
| | 0.99(8) | 10.1(4) [†] | | | | | | |
| 1078.63(11) [β] | | | 0.7(1) | - | - | 1.4(2) | - | - |
| 1512.70(8) [β] | 0.49(5) | 3.4(3) [†] | - | - | 0.99(15) | 0.8(1) | - | - |
| 1620.74(1) [β] | 2.81(20) | 20.0(6) [†] | 3.0(6) | - | 4.85(50) | 3.9(4) | - | - |
| 1679.45(1) [β] | - | - | - | - | 0.230(7) | 0.16(3) | - | - |
| 1800.9(2) [β] | | | | - | - | - | - | - |
| | 0.17(3) | 1.4(2) [†] | 0.5(1) | | | | | |
| 1805.96(10) [β] | | | | - | 0.41(10) | 0.25(5) | - | - |

Published Gamma-ray Emission Probabilities (cont.)

| E _g (keV) | P _g (cont.) | | | |
|-------------------------------|------------------------|-----------------------|-----------------------|-----------------------|
| | 1983Sc13 ^ψ | 1983Va22 ^ψ | 1984Ge07 ^Δ | 1992Li05 ^ψ |
| 39.858(4) [α] | - | - | 3.49(28) | - |
| 180.2(2) [β ⁻] | - | - | - | - |
| 288.08(6) [α] | 0.274(23) | - | 1.106(10) | 0.389(57) |
| 327.94(6) [α] | 0.120(4) | - | 0.423(20) | 3.23(12) |
| 433.7(2) [α] | - | - | - | - |
| 452.8(1) [α] | 0.256(23) | - | 1.191(11) | 0.370(49) |
| | | | | |
| 473.6(2) [α] | - | - | - | - |
| 492.7(1) [α] | - | - | - | - |
| 580.5(3) [α] | - | - | - | - |
| 620.4(3) [α] | - | - | - | - |
| 727.33(1) [β ⁻] | 6.56(15) | 7.00(18) | 21.63(13) | 6.93(18) |
| 759(1) [α] | - | - | - | - |
| 785.37(9) [β ⁻] | 1.07(5) | - | 3.62(4) | 1.05(5) |
| 807(1) [α] | - | - | - | - |
| 893.41(2) [β ⁻] | 0.352(36) | - | 1.25(6) | - |
| 952.12(2) [β ⁻] | - | - | - | - |
| 1073.6(2) [β ⁻] | - | - | - | - |
| | | | | |
| 1078.63(11) [β ⁻] | 0.58(4) | - | 1.85(6) | 0.555(41) |
| 1512.70(8) [β ⁻] | 0.276(42) | - | - | - |
| 1620.74(1) [β ⁻] | 1.38(8) | - | 4.88(10) | 1.44(9) |
| 1679.45(1) [β ⁻] | - | - | - | - |
| 1800.9(2) [β ⁻] | - | - | - | - |
| | | | | |
| 1805.96(10) [β ⁻] | - | - | - | - |

* Emission probabilities expressed in terms of ²¹²Bi β⁻ decay mode only.

† Emission probabilities expressed in terms of (727 + 785) keV gamma rays of ²¹²Bi.

‡ Emission probabilities relative to ²¹²Po α decay.

Emission probabilities expressed in terms of ²¹²Bi α decay mode only.

\$ Emission probabilities relative to P_γ(2614.51 keV) of ²⁰⁸Tl.

Δ Emission probabilities relative to P_γ(583.19 keV) of ²⁰⁸Tl.

¶ Emission probabilities relative to P_γ(238.63 keV) of ²¹²Pb specified as 0.430(20), compared with recommended value of 0.435(4).

ψ Absolute emission probabilities.

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ²¹²Bi

| E _g (keV) | P _g ^{abs} | | | | | | | |
|-------------------------------|-------------------------------|-----------|----------|----------|-----------------------|----------------------|----------|----------------------|
| | 1960Sc07 | 1962Be09 | 1962Fl03 | 1967Be19 | 1968Yt02 | 1972DaZA | 1978Av01 | 1982Sa36 |
| 39.858(4) [α] | - | - | - | - | - | - | - | 0.9(1) |
| 180.2(2) [β ⁻] | - | - | - | - | - | - | - | - |
| 288.08(6) [α] | - | 0.278(14) | - | 0.29(1) | - | 0.3(1) | 0.35(2) | 0.32(3) |
| 327.94(6) [α] | - | 0.107(8) | - | 0.12(1) | - | 0.13(3) | - | - |
| 433.7(2) [α] | - | | - | 0.014(4) | - | ~ 0.009 | - | - |
| 452.8(1) [α] | - | | - | 0.30(1) | - | 0.32(6) | 0.40(2) | 0.42(5) |
| | | 0.424(18) | | | | | | |
| 473.6(2) [α] | - | | - | 0.044(3) | - | 0.04(1) | - | - |
| 492.7(1) [α] | - | | - | < 0.003 | - | - | - | - |
| 580.5(3) [α] | - | - | - | - | - | - | - | - |
| 620.4(3) [α] | - | - | - | - | - | - | - | - |
| 727.33(1) [β ⁻] | 7.11(45) | | 7.6(15) | - | - | 6.3(6) | 7.6(3) | 7.0(4) |
| 759(1) [α] | - | [7.85] | - | - | - | - | - | - |
| 785.37(9) [β ⁻] | 1.09(17) | | - | - | - | 1.0(2) | 1.17(6) | 1.02(7) |
| 807(1) [α] | - | - | - | - | - | - | - | - |
| 893.41(2) [β ⁻] | 0.42(4) | 0.38(2) | 0.32(6) | - | - | 0.34(7) | - | 0.50(8) [§] |
| 952.12(2) [β ⁻] | 0.10(3) | - | - | - | - | 0.17(3) | - | - |
| 1073.6(2) [β ⁻] | | | - | - | - | ~ 0.01 | | - |
| | 0.63(5) | 0.79(3) | | | | | | |
| 1078.63(11) [β ⁻] | | | 0.45(6) | - | - | 0.50(7) | - | - |
| 1512.70(8) [β ⁻] | 0.31(3) | 0.27(2) | - | - | 0.36(5) | 0.29(4) | - | - |
| 1620.74(1) [β ⁻] | 1.80(13) | 1.57(5) | 1.9(4) | - | 1.74(18) | 1.4(1) | - | - |
| 1679.45(1) [β ⁻] | - | - | - | - | 0.083(3) [¶] | 0.06(1) | - | - |
| 1800.9(2) [β ⁻] | | | | - | - | - | - | - |
| | 0.11(2) | 0.11(2) | 0.32(6) | | | | | |
| 1805.96(10) [β ⁻] | | | | - | 0.15(4) | 0.09(2) [¶] | - | - |

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ²¹²Bi (cont.)

| E _g (keV) | P _g ^{abs} (cont.) | | | | Recommended Values* |
|----------------------|---------------------------------------|----------|------------------------|-----------------------|--------------------------|
| | 1983Sc13 | 1983Va22 | 1984Ge07 | 1992Li05 | |
| 39.858(4) [α] | - | - | 1.07(9) [¶] | - | 1.01(3) [‡] |
| 180.2(2) [β] | - | - | - | - | 0.003(1) |
| 288.08(6) [α] | 0.274(23) | - | 0.339(3) [¶] | 0.389(57) | 0.32(2) |
| 327.94(6) [α] | 0.120(4) [¶] | - | 0.129(6) | 3.23(12) ^ψ | 0.121(3) |
| 433.7(2) [α] | - | - | - | - | 0.0095(20) [‡] |
| 452.8(1) [α] | 0.256(23) | - | 0.365(3) [¶] | 0.370(49) | 0.34(3) |
| | | | | | |
| 473.6(2) [α] | - | - | - | - | 0.044(3) |
| 492.7(1) [α] | - | - | - | - | 0.04(1) [‡] |
| 580.5(3) [α] | - | - | - | - | 0.0010(2) [‡] |
| 620.4(3) [α] | - | - | - | - | 0.0038(6) [‡] |
| 727.33(1) [β] | 6.56(15) | 7.00(18) | 6.62(4) [¶] | 6.93(18) ^ψ | 6.74(12) |
| 759(1) [α] | - | - | - | - | 0.00036(18) [‡] |
| 785.37(9) [β] | 1.07(5) | - | 1.11(1) | 1.05(5) | 1.11(1) |
| 807(1) [α] | - | - | - | - | 0.000039(4) [‡] |
| 893.41(2) [β] | 0.352(36) | - | 0.383(18) | - | 0.38(1) |
| 952.12(2) [β] | - | - | - | - | 0.14(4) |
| 1073.6(2) [β] | - | - | - | - | 0.015(5) [#] |
| | | | | | |
| 1078.63(11) [β] | 0.58(4) | - | 0.566(18) [¶] | 0.555(41) | 0.55(2) |
| 1512.70(8) [β] | 0.276(42) | - | - | - | 0.29(1) |
| 1620.74(1) [β] | 1.38(8) | - | 1.49(3) [¶] | 1.44(9) | 1.51(3) |
| 1679.45(1) [β] | - | - | - | - | 0.07(1) |
| 1800.9(2) [β] | - | - | - | - | 0.004(2) |
| | | | | | |
| 1805.96(10) [β] | - | - | - | - | 0.12(3) |

* Weighted mean values adopted when appropriate; remainder derived from proposed decay scheme (see other footnotes).

† Determined directly from proposed decay scheme (calculated transition probability and total theoretical internal conversion coefficient).

‡ Calculated from low-intensity alpha-particle emission probabilities of 1960Wa14.

Estimated from the approximate measurement of 1972DaZA, and used to define P_γ for 180.2 and 1800.9 keV gamma rays.

¶ Uncertainty increased so that weighting does not exceed 50%.

§ Datum rejected as outlier, and not included in weighted mean analysis.

ψ Unresolved overlap with other gamma-ray emission(s); data not included in the weighted-mean analysis.

Multipolarities and Internal Conversion Coefficients

Many of the M1 + E2 gamma transitions in the alpha-decay mode were assumed to be close to 100%M1, based on the studies of 1978Av01 and 1982Be09. Specific exceptions to this assumption include:

- 99.55 %M1 + 0.45 %E2 for 288.08keV,
- 99.2 %M1 + 0.8 %E2 for 785.37 keV,
- 99.8 %M1 + 0.2 %E2 for 893.41 keV,
- 70 %M1 + 30 %E2 for 952.12 keV,
- 98.2 %M1 + 1.8 % E2 for 1078.63 keV,
- 90 %M1 + 10 %E2 for 1620.74 keV gamma rays.

Multipolarity Assignments

| Reference | E _g (keV) | Multipolarity |
|-----------|--------------------------------|-----------------------|
| 1978Av01 | 288.08(6) [α decay] | M1 + E2 |
| | 452.8(1) [α decay] | 72%M1 + 28%E2 |
| | 727.33(1) [β^- decay] | E2 |
| | 785.37(9) [β^- decay] | 98%M1 + 2%E2 |
| 1982Be09 | 785.37(9) [β^- decay] | 99.2%M1 + 0.8%E2 |
| | 893.41(2) [β^- decay] | M1 (+ \leq 0.25%E2) |
| | 952.12(2) [β^- decay] | 70%M1 + 30%E2 |
| | 1078.63(11) [β^- decay] | 98.2%M1 + 1.8%E2 |

Reasonable consistency was achieved from the proposed gamma-ray emission probabilities, internal conversion coefficients and alpha-particle emission probabilities. The 39.858 keV gamma ray is particularly important in the alpha branch, and further measurements are required to determine the emission probability of this transition with greater confidence. A value of 1.01(3)% (0.0101(3)) was adopted on the basis of the relevant alpha-particle emission probability, gamma-ray transition probability and a total internal conversion coefficient of 24.6(7).

Alpha-particle EmissionsEnergies

All alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies specified by 1986Ma17 and 1992Ar05, and Q-values were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

The main alpha-particle emission probabilities emitted directly by ²¹²Bi were calculated from the evaluated gamma-ray emission probabilities (see above) and theoretical internal conversion coefficients, combined with an alpha branching fraction of 0.3593(7). These data are in excellent agreement with the measured emission probabilities of the two main alpha transitions (1951Ry17, 1960Wa14 and 1962Be09), but deviate considerable for the low-intensity transitions that are poorly resolved. Under such circumstances, the low-intensity alpha-particle data of 60Wa14 were adopted when appropriate, while others were derived from the gamma-ray studies.

Alpha-particle Emission Probabilities

| E _a (keV) | P _a ^{rel} | | | P _a ^{abs} | |
|---------------------------|-------------------------------|------------|-----------|-------------------------------|---------------------------|
| | 1951Ry17 | 1960Wa14 | 1962Be09 | | Recommended Values* |
| 5298(1) | 0.016 | 0.00011(1) | - | - | 5298(1) |
| 5345(1) | 0.147 | 0.001 | - | - | 5345(1) |
| 5481.3(3) | - | 0.014 | ~ 0.04 | ~ 0.02 | 5481.3(3) |
| 5606.63(14) | 1.08 | 1.19 |) |) | 5606.63(14) |
| | | |) 1.35(6) |) 1.22(2) | |
| 5625.4(2) | - | 0.1625 |) |) | 5625.4(2) |
| 5768.27(10) | 1.67 | 1.78 | 1.63(11) | 1.67(2) | 5768.27(10) |
| 6050.92(4) | 69.86 [#] | 69.7 | 70.2(3) | 70.2(2) | 6050.92(4) |
| 6090.02(4) | 27.16 [#] | 27.1 | 27.0(5) | 26.8(2) | 6090.02(4) |
| 9498.79(12) [†] | - | - | - | - | 9498.79(12) [†] |
| 10432.95(12) [†] | - | - | - | - | 10432.95(12) [†] |
| 10552.1(3) [†] | - | - | - | - | 10552.1(3) [†] |

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities, theoretical internal conversion coefficients and alpha branching fraction of 0.3593(7), unless stated otherwise (expressed per 100 disintegrations of ²¹²Bi).

‡ Data reported by 1960Wa14 were adopted and adjusted for alpha branch; uncertainties were estimated when not quoted.

† Arises from $\beta^- \alpha$ decay (long-range alpha particles).

Data reported incorrectly; re-assigned by evaluator.

Alpha-particle emissions from the $\beta\alpha$ decay mode have been observed at energies greater than 9 MeV by 1951Ry17, 1962Be09 and 1965Le08. Some of the excited states of ²¹²Po populated by the beta of ²¹²Bi undergo subsequent alpha decay (in competition with the gamma-ray decay). These nuclear levels at 1800.9, 1679.45 and 727.33 keV emit high-energy alpha particles (energies of 10552.1, 10432.95 and 9498.79 keV, respectively). All measurements were expressed relative to 10⁶ emission probability for the 8785.18 keV alpha particle of ²¹²Po, but with no quoted uncertainties. These long-range alpha particles constitute part of the ²¹²Bi decay; and their emission probabilities were determined from the measurements of 1951Ry17, 1962Be09 and 1965Le08:

Alpha-particle Emissions ($\beta\alpha$ Decay)

| E_a (keV) | P_a^{rel} | | | |
|------------------------------------|-----------------|-----------------|-----------------|-----------------|
| | 1951Ry17 | 1962Be09 | 1965Le08 | Mean Value |
| [8785.18(11)]* | 10 ⁶ | 10 ⁶ | 10 ⁶ | 10 ⁶ |
| 9498.79(12) | 35 | 45 | 34 | 38 |
| 10432.95(13) | 20 | 17 | 10 | 16 |
| 10552.1(3) | 170 | 167 | 160 | 166 |
| Total α (of $\beta\alpha$) | 225 | 229 | 204 | 219(15) |

*²¹²Po alpha decay.

Total α emissions from $\beta\alpha$ decay have an estimated mean value of 219 relative to 10⁶ for the emission probability of the 8785.18 keV alpha particle of ²¹²Po, with an uncertainty of 15 to cover the range of measured data. Therefore, a mean value of 0.00014 was estimated for the $\beta\alpha$ branching fraction, combined with an uncertainty of approximately 7% ($BF(\beta\alpha) = 0.00014(1)$). Absolute alpha-particle emission probabilities for this small branch were calculated from the mean values and $BF(\beta\alpha)$.

Beta-particle Emissions

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1992Ar05 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities

The beta-particle emission probabilities were calculated from gamma-ray transition intensity balances, using the recommended gamma-ray emission probabilities and the theoretical internal conversion coefficients of 1978Ro22.

Beta-particle Emission Probabilities

| E_b (keV) | P_b | |
|-------------|----------|---------------------|
| | 1957Bu34 | Recommended Values* |
| 448(2) | 8.5 | 0.68(5) |
| 453(2) | - | 0.029(1) |
| 575(2) | - | 0.21(5) |
| 633(2) | 6 | 1.90(4) |
| 741(2) | - | 1.45(2) |
| 1527(2) | 10 | 4.58(21) |
| 2254(2) | 63 | 55.23(21) |

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities, theoretical internal conversion coefficients, beta branching fraction of 64.06(7) % and beta-alpha branching fraction of 0.00014(1) (expressed per 100 disintegrations of ²¹²Bi).

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

References

- 1914Le01 - F. V. Lerch, Verdampfungerscheinungen der ThB- und ThC-Verbindungen, Sitzber. Akad. Wiss., Wien, Math.-Naturw. Kl. Abt. Ila 123(1914)699. [Half-life]
- 1951Ry17 - A. Rytz, Nouvelles Expériences sur le Spectre Magnétique Alpha du Thorium C et des Longs Parcours du Thorium C', C. R. Acad. Sci. Paris 233(1951)790. [E_{α} , P_{α}]
- 1957Bu34 - J. Burde and B. Rozner, Beta Spectrum of Bi²¹² (ThC), Phys. Rev. 107(1957)531. [P_{β}]
- 1960Em01 - G. T. Emery and W. R. Kane, Gamma-ray Intensities in the Thorium Active Deposit, Phys. Rev. 118(1960)755. [P_{γ} , high-energy α]
- 1960Sc07 - G. Schupp, H. Daniel, G. W. Eakins and E. N. Jensen, Transition Intensities in the Tl²⁰⁸ Beta Decay, the Bi²¹² \rightarrow Po²¹² Decay Scheme, and the Bi²¹² Branching Ratio, Phys. Rev. 120(1960)189. [P_{γ} , BF]
- 1960Wa14 - R. J. Walen and G. Bastin-Scoffier, Spectre α du ²¹⁴Bi et Remarques sur Quelques Émetteurs α du Bi, Nucl. Phys. 16(1960)246. [P_{α}]
- 1961Ap03 - K. R. Applegate, E. M. Morimoto, M. Kahr and J. D. Knight, Redetermination of the Half-Life of Bismuth (ThC), J. Inorg. Nucl. Chem. 19(1961)375. [Half-life]
- 1962Be09 - G. Bertolini, F. Cappellani, G. Restelli and A. Rota, Excited States of Tl-208 and Po-212, Nucl. Phys. 30(1962)599. [P_{α} , P_{γ} , BF]
- 1962Fl03 - F. C. Flack and J. E. Johnson, The Gamma Radiation from ²¹²Po (ThC'), Proc. Phys. Soc. (London) 79(1962)10. [P_{γ} , BF]
- 1965Le08 - C-F. Leang, Spectres α de Long Parcours des Poloniums 214 (RaC') et 212 (ThC'), C. R. Acad. Sci. Paris 260(1965)3037. [high-energy α]
- 1965Wa09 - J. Walker and T. Salgir, The Branching Ratio of ²¹²Bi (ThC), Proc. Phys. Soc. (London) 86(1965)423. [BF]
- 1967Be19 - R. Benoit, G. Bertolini, F. Cappellani and G. Restelli, Decay of the Excited Levels of ²⁰⁸Tl, Nuovo Cimento 49B(1967)125. [P_{γ}]
- 1968Yt02 - C. Ythier, H. Forest, G. Ardisson and H. Maria, Sur le Rayonnement γ de Haute Énergie Accompagnant la Désintégration du Bismuth-212, C. R. Acad. Sci. Paris Series B 267(1968)1362. [P_{γ}]
- 1972DaZA - J. Dalmasso, Recherches sur le Rayonnement Gamma de Quelques Radioéléments Naturels Appartenant à la Famille du Thorium, PhD thesis, University of Nice (1972); J. Dalmasso, H. Maria and C. Ythier, Étude du Rayonnement γ du Thorium 228 et de ses Dérivés, et plus Particulièrement du Thallium 208 (ThC''), C. R. Acad. Sci. Paris 277B(1973)467. [P_{γ}]
- 1978Av01 - F. T. Avignone and A. G. Schmidt, γ -ray and Internal-conversion Intensity Studies of Transitions in the Decay of ²²⁸Th, Phys. Rev. C17(1978)380. [P_{γ} , multipolarity]
- 1978Ro22 - F. Rösel, H. M. Fries, K. Alder and H. C. Pauli, Internal Conversion Coefficients for all Atomic Shells, ICC Values for Z = 68-104, At. Data Nucl. Data Tables 21(1978)291-514. [ICC]
- 1982Be09 - B. Bengtson, H. L. Nielsen, N. Rud and K. Wilsky, Half-life of the α -emitting Excited 0⁺ State in ²¹²Po, Nucl. Phys. A378(1982)1. [Multipolarity]
- 1982Sa36 - S. Sadasivan and V. M. Raghunath, Intensities of Gamma Rays in the ²³²Th Decay Chain, Nucl. Instrum. Meth. 196(1982)561. [P_{γ}]
- 1983Sc13 - U. Schötzgig and K. Debertin, Photon Emission Probabilities per Decay of ²²⁶Ra and ²³²Th in Equilibrium with their Daughter Products, Int. J. Appl. Radiat. Isot. 34(1983)533. [P_{γ}]
- 1983Va22 - R. Vaninbrouckx and H. H. Hansen, Determination of γ -ray Emission Probabilities in the Decay of ²²⁸Th and its Daughters, Int. J. Appl. Radiat. Isot. 34(1983)1395. [P_{γ}]
- 1984Ge07 - R. J. Gehrke, V. J. Novick and J. D. Baker, γ -ray Emission Probabilities for the ²³²U Decay Chain, Int. J. Appl. Radiat. Isot. 35(1984)581. [P_{γ}]
- 1986Ma17 - M. J. Martin, Nuclear Data Sheets for A = 208, Nucl. Data Sheets 47(1986)797. [Nuclear structure, energies]
- 1992Ar05 - A. Artna-Cohen, Nuclear Data Sheets for A = 212, Nucl. Data Sheets 66(1992)171. [Nuclear structure, energies]
- 1992Li05 - W-J. Lin and G. Harbottle, Gamma-ray Emission Intensities of the ²³²Th Chain in Secular Equilibrium, of ²³⁵U and the Progeny of ²³⁸U, J. Radioanal. Nucl. Chem. 157(1992)367. [P_{γ}]
- 1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409. [Q values]
- 1996Sc06 - E. Schönfeld and H. Janßen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527. [X_K , X_L , Auger electrons]
- 1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]
- 1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]