Workshop on
NUCLEAR STRUCTURE AND DECAY DATA EVALUATION

Trieste, April 4 – 15, 2005
Trieste, November 17 – 28, 2003
Edgardo Browne

Decay Data

1. Statistical treatment of data
2. Properties of the parent nucleus
3. Gamma rays
4. Decay scheme normalization
5. Beta particles
6. Electron capture
7. Alpha particles
8. Level structure and decay scheme

1. Statistical treatment of data

- Weighted and unweighted averages
- Limits
- Discrepant data
- Limitation of relative statistical weight method

2. **Properties of the parent nucleus**

- Energy, spin/parity, half-life, Q-value

3. Gamma rays

- Energy (E_γ)
- Relative intensity (I_γ)
- Multipolarity and mixing ratio (δ)
- Internal conversion coefficient (α_i)
- Total transition intensity [$I_\gamma (1 + \alpha)$]
- Absolute intensity (%I_γ)

4. Beta particles

- Relative intensity (I_β), absolute intensity (%I_β)
- Average energy (I_{avg})
- Log *ft*
- Energy (E_β)

5. Electron capture

- Relative probability (I_{ε}), absolute probability (%I_{ε})
- Relative sub-shell probabilities (P_K, P_L, P_M, P_N)
- Log *ft*

6. Alpha particles

- Energy (E_α)
- Relative intensity (I_α), absolute intensity (%I_α)
- Hindrance factor (HF)

7. Level structure and decay scheme

- Level energy (E)
- Level spin/parity ($J\pi$), particle configuration (CONF)
- Level half-life ($T_{1/2}$)
- Decay scheme normalization

1. Statistical treatment of data

- Average, Weighted Average (weight = $1/\sigma_i^2$)
- Limits (given by authors: <10; changed by evaluator: 5 *5*)
- Confidence level for limits deduced by evaluators from transition intensity balances (Tom Burrows will talk about this matter.)
- Discrepant data – Limitation of Relative Statistical Weight (LWEIGHT)

Averages

Unweighted

$x(\text{avg}) = 1 / n \sum x_i$

$\sigma_{x(\text{avg})} = [\,1 / n\,(n-1)\ \sum (x(\text{avg}) - x_i)^2]^{1/2}$ Std. dev.

Weighted

$x(\text{avg}) = W \sum x_i / \sigma_{xi}^2\ ;\quad W = 1 / \sum \sigma_{xi}^{-2}$

$\chi^2 = \sum (x(\text{avg}) - x_i)^2 / \sigma_{xi}^2$ Chi sqr.

$\chi_\nu^2 = 1 / (n-1)\ \sum (x(\text{avg}) - x_i)^2 / \sigma_{xi}^2$ Red. Chi sqr

$\sigma_{x(\text{avg})} =$ larger of $W^{1/2}$ and $W^{1/2}\chi_\nu$. Std. dev.

Limits

B_m = measured value

σ = Standard deviation

B_0 = True value

Example: -2 ± 3

For a Gaussian distribution the formulas to convert measured values to limits are:

$B_0 < B_m + 1.28\,\sigma$ (90% confidence limit); Example: < 1.84

$B_0 < B_m + 1.64\,\sigma$ (95% confidence limit); Example: < 2.92

$B_0 < B_m + 2.33\,\sigma$ (99% confidence limit); Example; < 4.99

Discrepant Data

Simple definition: A set of data for which $\chi_\nu^2 > 1$.

But, χ_ν^2 has a Gaussian distribution, i.e. it varies with the degrees of freedom ($n - 1$).

Better definition: A set of data is discrepant if χ_ν^2 is greater than χ_ν^2 (critical). Where χ_ν^2 (critical) is such that there is a 99% probability that the set of data is discrepant.

Limitation of Relative Statistical Weight Method

For discrepant data ($\chi^2_\nu > \chi^2_\nu$(critical)) with at least three sets of input values, we apply the *Limitation of Relative Statistical Weight* method. The program identifies any measurement that has a relative weight >50% and increases its uncertainty to reduce the weight to 50%. Then it recalculates χ^2_ν and produces a new average and a best value as follows:

If $\chi^2_\nu \leq \chi^2_\nu$(critical), the program chooses the weighted average and its uncertainty (the larger of the internal and external values).

If $\chi^2_\nu > \chi^2_\nu$(critical), the program chooses either the weighted or the unweighted average, depending on whether the uncertainties in the average values make them overlap with each other. If that is so, it chooses the weighted average and its (internal or external) uncertainty. Otherwise, the program chooses the unweighted average. In either case, it may expand the uncertainty to cover the most precise input value

2. Properties of the parent nucleus

- Level energy (keV): 0.0, 328.0 *25*, 942 *4*, 0.0 + X
- Spin/parity: 1/2+, (3/2+), 5-, 6(+), (5/2-,7/2-)
- Half-life: 3.8 d *2*, 432.2 y *7*, 2 m, 35 ms *10*, ~3 s, 1.2×10^{15} y
- Units: (sidereal) y (= 365.25636 d), d, h, m, s, ms, ms, ns, ps, fs, …
- Q-value (keV): 2003Au03 (G. Audi et al., Nucl. Phys. A729, 337 (2003))
- Theoretical values: 1997Mo25 (P. Moller et al., At. Nucl. Data Tables 66, 131 (1997)

3. Gamma rays

1. Energy (keV)

- Weighted average from radioactive decay
- Very precise measurements (e.g. bent crystal)
- Recommended standards for energy calibration:

  Helmer and Van der Leun (Nucl. Instr. and Meth. in Phys. Res. **A450**, 35 (2000)
- Not observed, but expected (From level energy difference)
- Deduced from conversion electron energies (Give atomic electron binding energy)
- Multiplets:

  Broader peak in spectrum

  Known levels involved

2000He14

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Nuclear Instruments and Methods in Physics Research A 450 (2000) 35–70

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Section A

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Recommended standards for γ-ray energy calibration (1999)

R.G. Helmer[a,*], C. van der Leun[b,*]

[a]Idaho Accelerator Center, Idaho State University, Pocatello, Idaho, USA
[b]R.J. Van de Graaff Laboratorium, Utrecht University, P.O. Box 80,000, 3508 TA Utrecht, The Netherlands

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- Uncertainties: Statistical

Give (in comments) estimate of systematic errors.

When uncertainties are known to include systematic errors, no result from weighted average should have an uncertainty smaller than the smallest on the input uncertainty.

No uncertainty should be smaller than the uncertainty in the calibration standard.

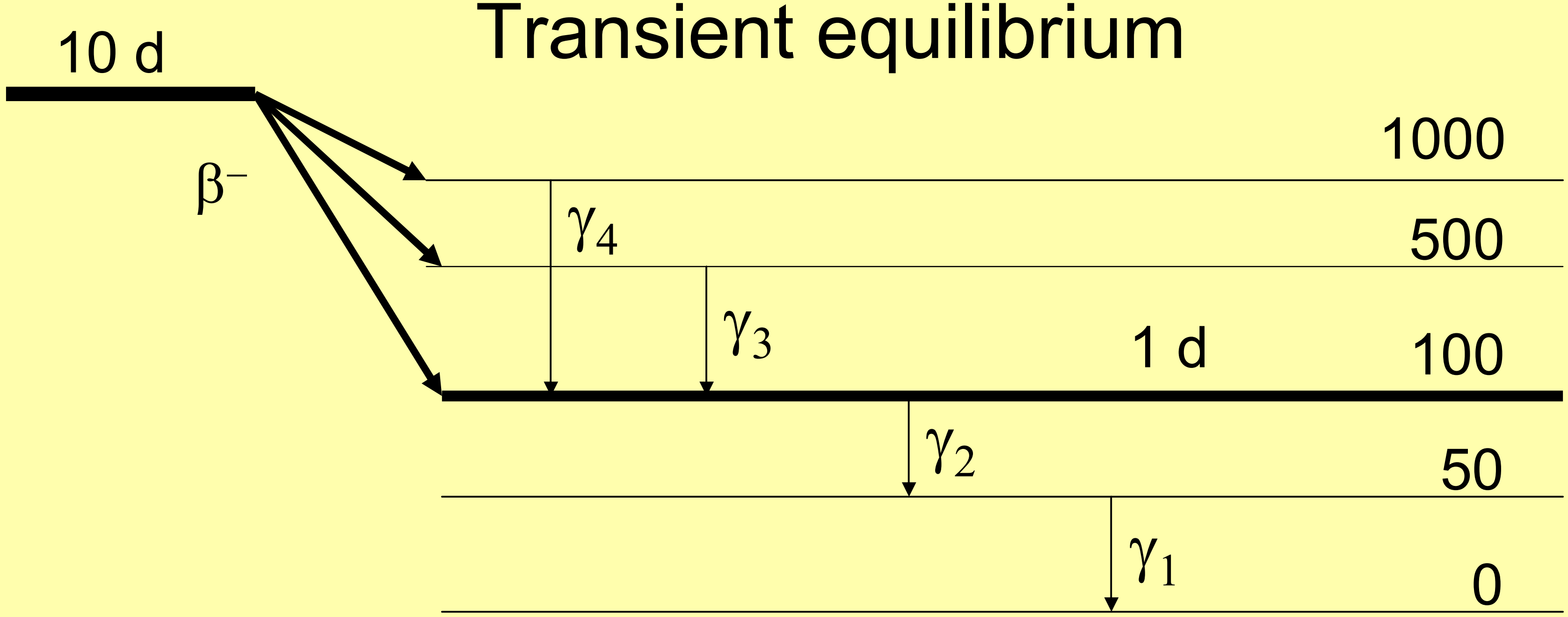
Uncertainties larger than *25* should be rounded off.

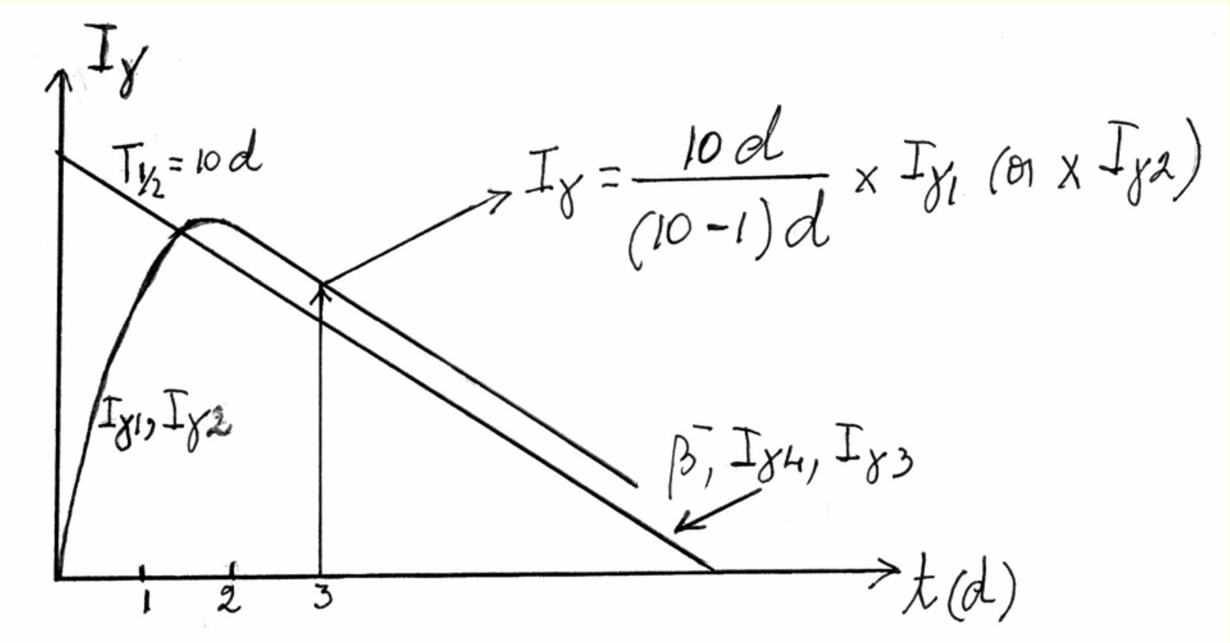
Author	ENSDF
351.53 ± 0.25	351.53 *25*
351.53 ± 0.30	351.5 *3*
8346 ± 29	83.5E2 *3*

2. Relative intensity

- Weighted average from radioactive decay
- Use 100 for the most intense gamma ray.
- Use a limit for an expected (but unobserved) γ ray.
- Use total transition intensity (TI) if this is the only quantity measured, or deduced from transition intensity balance. If α_T is known, then deduce and give I_γ.
- Limits are acceptable (e.g. $I_\gamma < A$), but $I_\gamma = ½ A ± ½ A$ is preferable (for calculating transition intensity balances).
- Intensity from an isomer in the daughter nucleus should not be given if such intensity is time dependant. Include a comment giving the percent feeding to the isomer, and explain the reason for not giving I_γ.

Transient equilibrium





3. Multipolarity and mixing ratio (δ)

- From conversion electron data. If I_K and I_γ were used to determine α_K, explain normalization between electron and photon intensity scales. Conversion electron sub-shell ratios.
- From γ-ray angular correlations ($\gamma(\theta)$). Notice that $\gamma(\theta)$ determines *only* the L component of the γ-ray character, thus mult.= D, D+Q, etc. $T_{1/2}$(exp.) may be used to rule out choices. For example, Q=M2 and D+Q=E1+M2.

Multipolarity and mixing ratio (δ) from conversion electron data

- Using experimental conversion coefficients

$$\delta^2 = \text{E2 } \gamma\text{-ray intensity / M1 } \gamma\text{-ray intensity} = I_\gamma(E2)/I_\gamma(M1) \;\ldots.\; (\,1\,)$$

$$I_\gamma(M1) + I_\gamma(E2) = I_\gamma \;\ldots.\; (\,2\,)$$

From equations (1) and (2) we obtain:

$$I_\gamma(M1) = I_\gamma / 1 + \delta^2, \text{ and } I_\gamma(E2) = I_\gamma\, \delta^2 / 1 + \delta^2$$

Conversion electron intensity: $I_e = I_e(M1) + I_e(E2)$

Experimental conversion coefficient

$$\alpha(\exp) = I_e / I_\gamma = 1/ I_\gamma\, [I_\gamma(M1) \times \alpha(M1)^{th} + I_\gamma(E2) \times \alpha(E2)^{th}]$$

$$\text{or, } \alpha(\exp) = 1/ I_\gamma\, [I_\gamma / 1 + \delta^2 \times \alpha(M1)^{th} + I_\gamma\, \delta^2 / 1 + \delta^2 \times \alpha(E2)^{th}]$$

$$\boxed{\delta^2 = (\alpha(M1)^{th} - \alpha(\exp)) / (\alpha(\exp) - \alpha(E2)^{th})}$$

$$\%M1 = 100/1 + \delta^2, \quad \%E2 = 100\, \delta^2 / 1 + \delta^2$$

- <u>Using experimental electron sub-shell ratios</u>

$$R(exp) = I_e(L1)/ I_e(L3)$$

Then

$$\boxed{\delta^2 / 1 + \delta^2 = A / [\alpha(E2,L1)^{th} - \alpha(M1,L1)^{th} + R(exp)\ (\alpha(M1,L3)^{th} - \alpha(E2,L3)^{th})]}$$

where

$$\boxed{A = R(exp)\ \alpha(M1,L3)^{th} - \alpha(M1,L1)^{th}}$$

- Consistency of entries for α and δ:

For a single multipolarity the δ field should be blank.

For $\delta < V$:

Give *only* dominant multipolarity and corresponding α. Give $\delta < V$ in a comment, or

give both multipolarities and $\delta < V$ in the δ field. Calculate α from $\delta = ½ V ± ½ V$.

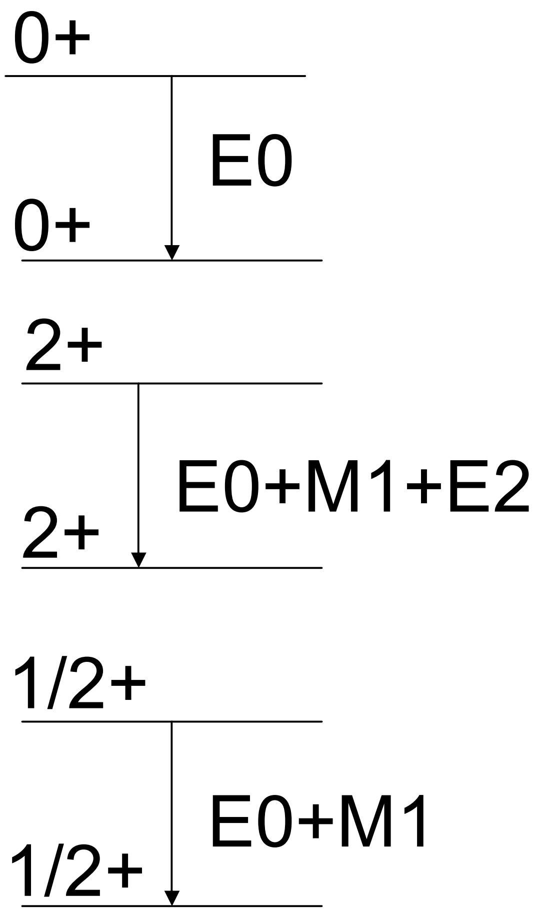
Examples: E2+M3 with $\delta < 0.5$ should preferably be entered as E2, whereas M1+E2 with $\delta < 0.5$, as M1+E2 ($\delta = 0.25 ± 0.25$).

M1, E2 is not the same as M1+E2.

- Assumed multipolarity

[M1], [E2], [M1+E2], [M4], etc.

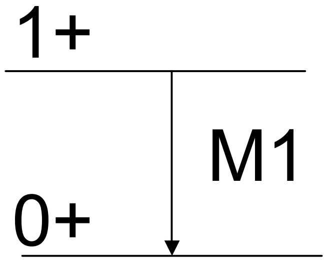
More about multipolarities



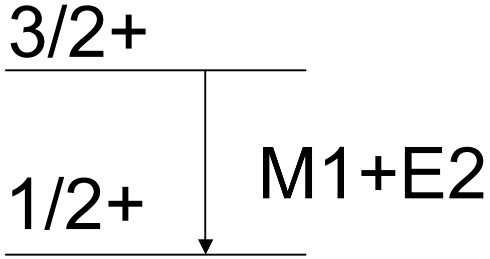
$0 \le \ell \le 0$; $\ell = 0$

$0 \le \ell \le 2$; $\ell = 0, 1, 2$

$0 \le \ell \le 1$; $\ell = 0, 1$



$1 \le \ell \le 1\ ;\ \ \ell = 1$



$1 \le \ell \le 2\ ;\ \ \ell = 1,\ 2$

4. Internal conversion coefficients

- Theoretical values:

  From Hager and Seltzer (1968Ha53) for K, L_i, M_i shells, and $Z \geq 30$

  From Dragoun et al. (1971Dr11) for N, O, … shells.

  From Dragoun et al. (1971Dr09) for N_i shells.

  From Band et al. (1976Ba63) for $E_\gamma \leq 6000$ keV, Z=3, 6, 10, and $14 \leq Z \leq 30$.

  From Trusov (1972Tr09) for $E_\gamma > 2600$ keV.

  From Hager and Seltzer (1969Ha61), K/L_1, L_1/L_2, for E0 transitions.

New Calculation of Conversion Coefficients

Dirac-Fock Internal Conversion Coefficients

I.M. Band, M.B. Trzhaskovskaya, C.W. Nestor, Jr.,
P.O. Tikkanen, and S. Raman

Atomic Data and Nuclear Data Tables **81**, 1 (2002)

(To be discussed by Tom Burrows)

- Experimental values:

For very precise values ($\leq$ 3% uncertainty).

E_{γ} = 661 keV ; ^{137}Cs (α_K=0.0902 $\pm$ 0.0008, M4)

Nuclear penetration effects.

^{233}Pa β^- decay to ^{233}U.

E_{γ} = 312 keV almost pure M1 from electron sub-shell ratios.

However α_K(exp) = 0.64 $\pm$ 0.02.

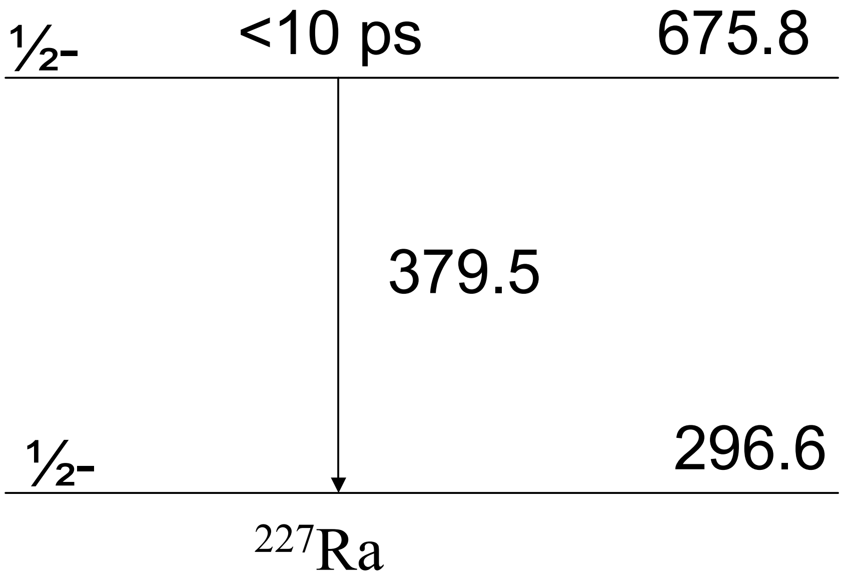
($\alpha_K{}^{th}$(M1)=0.78, $\alpha_K{}^{th}$(E2)=0.07)

For mixed E0 transitions (e.g., M1+E0).

^{227}Fr β^- ^{227}Ra

E_γ = 379.1 keV (M1+E0); α(exp) = 2.4 ± 0.8

α^{th}(M1) = 0.40; α^{th}(E2) = 0.08



½- <10 ps 675.8

379.5

½- 296.6

^{227}Ra

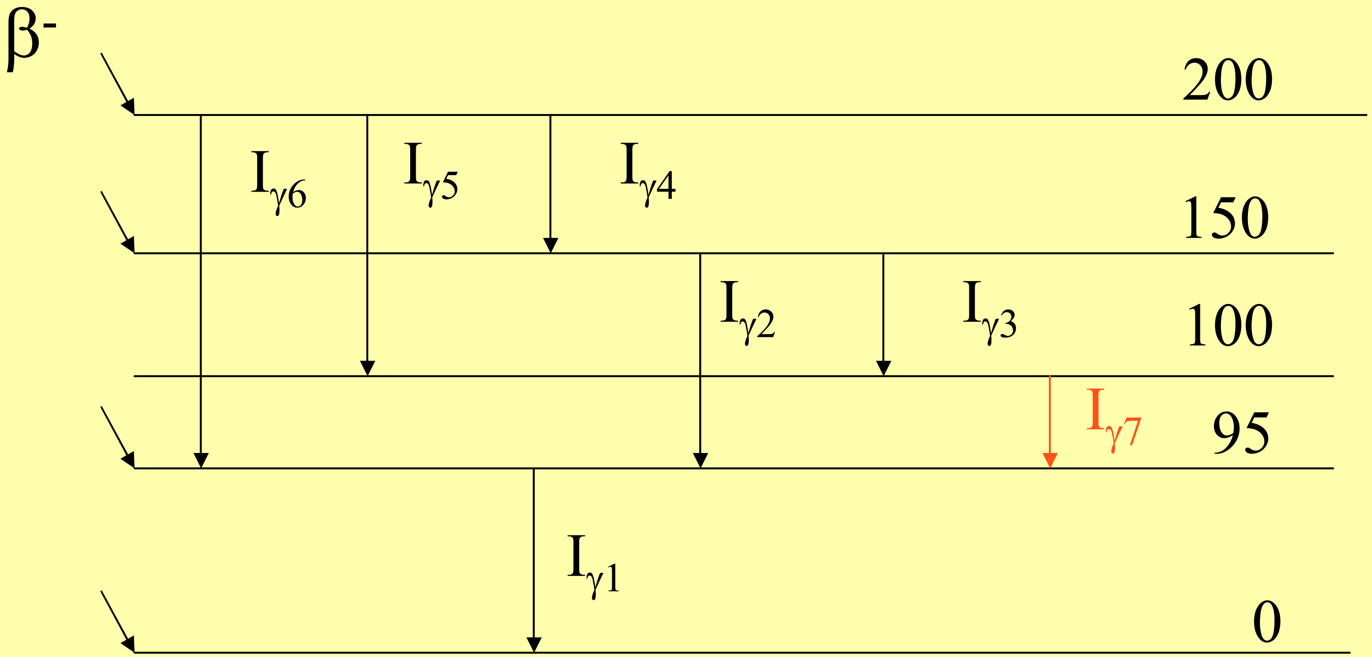
- Total transition intensity

The TI field should be used *only* if TI (rather than I_γ) is the measured or deduced quantity. Usual cases are:

TI deduced from transition intensity balance.

TI = ΣI_i(ce), if I_γ is known to be negligible. If not, but conversion coefficient is known, then deduced and give I_γ.

Total intensity from transition-intensity balance



$TI(\gamma_7) = TI(\gamma_5) + TI(\gamma_3)$

If $\alpha(\gamma_7)$ is known, then

$I\gamma_7 = TI(\gamma_7) / [1 + \alpha(\gamma_7)]$

5. Absolute intensities

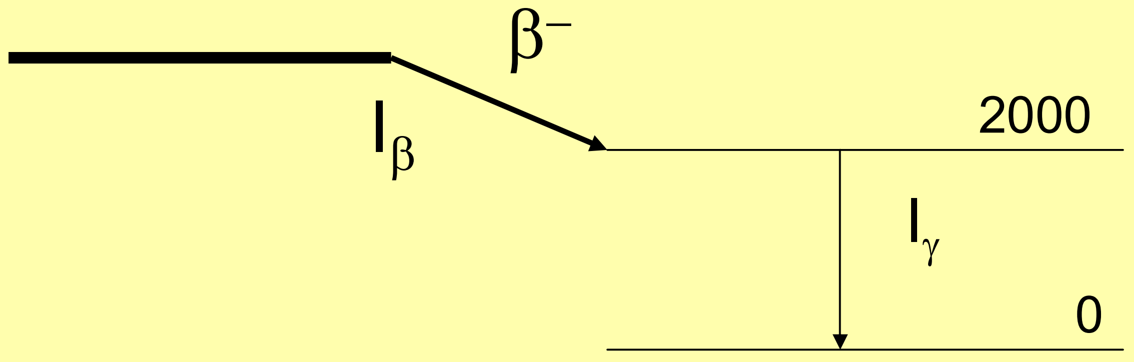
   “Intensities per 100 disintegrations of the parent nucleus”

- Measured (Photons from β^-, $\varepsilon+\beta^+$, and α decay)

  Simultaneous singles measurements

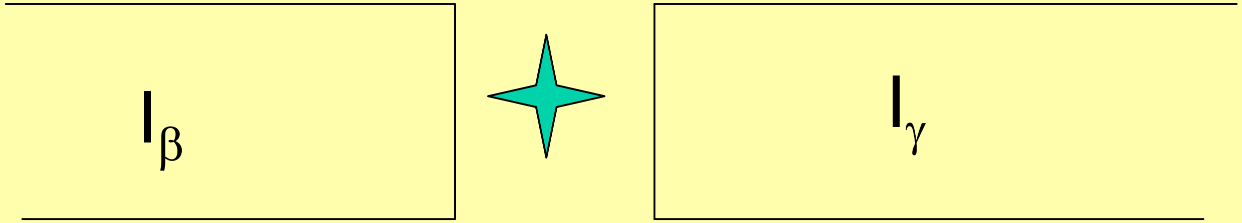
  Coincidence measurements

Absolute γ-ray intensity



$$\gamma(\%) = I_\gamma \,/\, I_\beta = 100\%$$

Simultaneous singles measurement



I_β: β^- intensity corrected for detector efficiency

I_γ: γ-ray intensity corrected for detector efficiency

I_γ / I_β = absolute γ-ray intensity

Units: photons per β^- (or per 100 β^-) disintegrations

4. Decay scheme normalization

Rel. int.	Norm. factor	Abs. Int.
I_γ	NR × BR	$\%I_\gamma$
I_T	NT × BR	$\%I_T$
I_β	NB × BR	$\%I_\beta$
I_ε	NB × BR	$\%I_\varepsilon$
I_α	NB × BR	$\%I_\alpha$

BR: Factor for converting intensity per 100 *decays through this decay branch*, to intensity per 100 *decays of the parent nucleus*

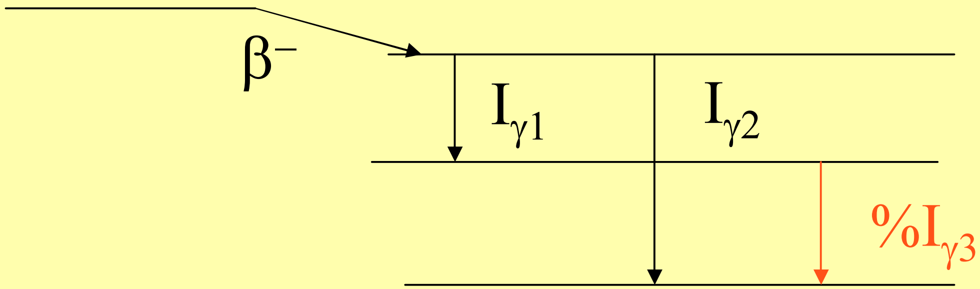
NR: Factor for converting relative I_γ to I_γ per 100 decays through this decay branch.

NT: Factor for converting relative TI to TI per 100 decays through this decay branch.

NB: Factor for converting relative β^- and ε intensities to intensities per *100 decays of this decay branch*.

Normalization Procedures

1. Absolute intensity of one gamma ray is known ($\%I_\gamma$)



Relative intensity $I_\gamma \pm \Delta I_\gamma$

Absolute intensity $\%I_\gamma \pm \Delta\%I_\gamma$

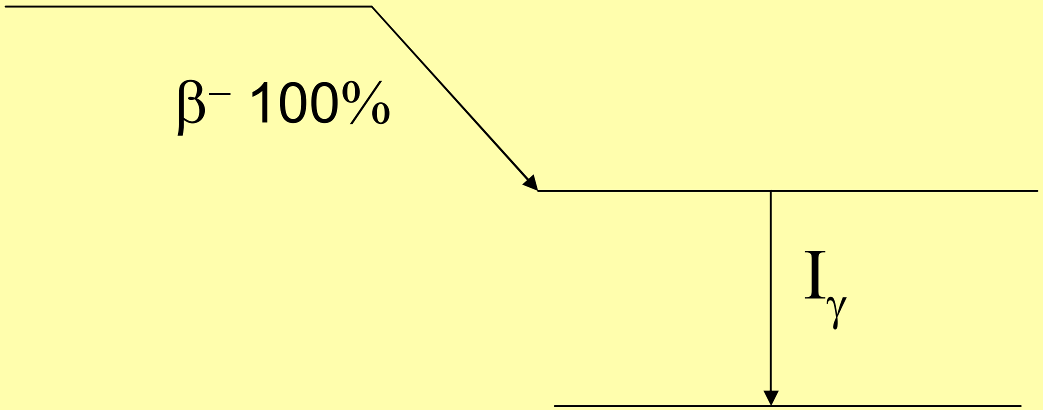
Normalization factor $N = \%I_\gamma / I_\gamma$

Uncertainty $\Delta N = [(\Delta\%I_\gamma / \%I_\gamma)^2 + (\Delta I_\gamma / I_\gamma)^2]^{1/2} \times N$

Then $\%I_{\gamma 1} = N \times I_{\gamma 1}$

$\Delta\%I_{\gamma 1} = [(\Delta N/N)^2 + +(\Delta I_\gamma / I_\gamma)^2]^{1/2} \times I_{\gamma 1}$

2. From Decay Scheme



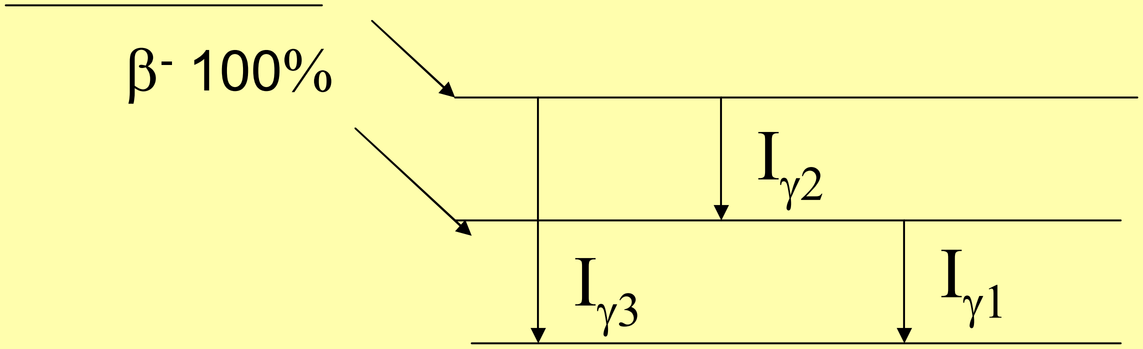
Iγ: Relative γ-ray intensity; α: total conversion coefficient

$$N \times I_\gamma \times (1 + \alpha) = 100\%$$

Normalization factor $N = 100/\ I_\gamma \times (1 + \alpha)$

Absolute γ-ray intensity $\%\ I_\gamma = N \times I_\gamma = 100/\ (1 + \alpha)$

Uncertainty $\Delta\%\ I_\gamma = 100 \times \Delta\alpha/(1 + \alpha)^2$



Normalization factor $N = 100 / I_{\gamma 1}(1 + \alpha_1) + I_{\gamma 3}(1 + \alpha_3)$

$\% I_{\gamma 1} = N \text{ x } I_{\gamma 1} = 100 \text{ x } I_{\gamma 1} / I_{\gamma 1}(1 + \alpha_1) + I_{\gamma 3}(1 + \alpha_3)$

$\% I_{\gamma 3} = N \text{ x } I_{\gamma 3} = 100 \text{ x } I_{\gamma 3} / I_{\gamma 1}(1 + \alpha_1) + I_{\gamma 3}(1 + \alpha_3)$

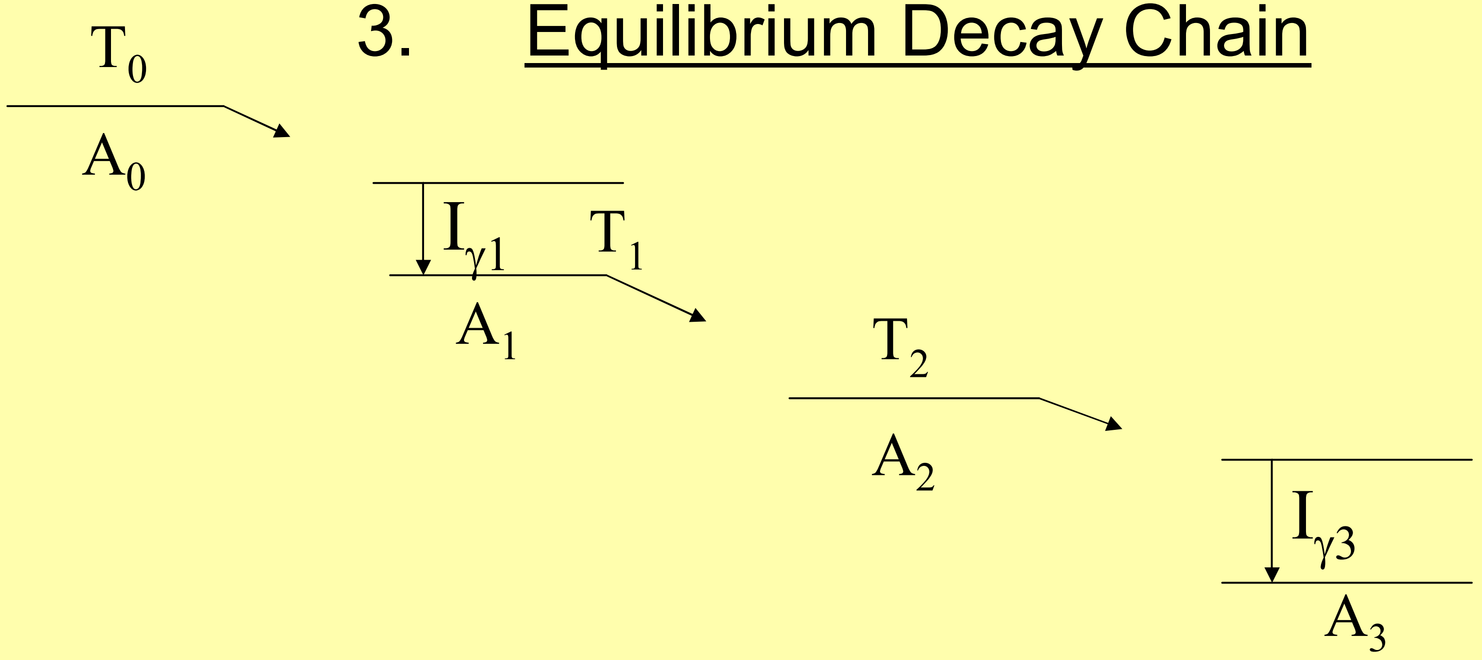
$\% I_{\gamma 2} = N \text{ x } I_{\gamma 2} = 100 \text{ x } I_{\gamma 2} / I_{\gamma 1}(1 + \alpha_1) + I_{\gamma 3}(1 + \alpha_3)$

Calculate uncertainties in $I_{\gamma 1}$, $I_{\gamma 2}$, and $I_{\gamma 3}$. Use 3% fractional uncertainty in α_1 and α_3.

See Nucl. Instr. and Meth. **A249**, 461 (1986).

To save time use computer program GABS

3. Equilibrium Decay Chain



$T_0 > T_1$, T_2 are the radionuclide half-lives,

For $t = 0$ only radionuclide A_0 exists,

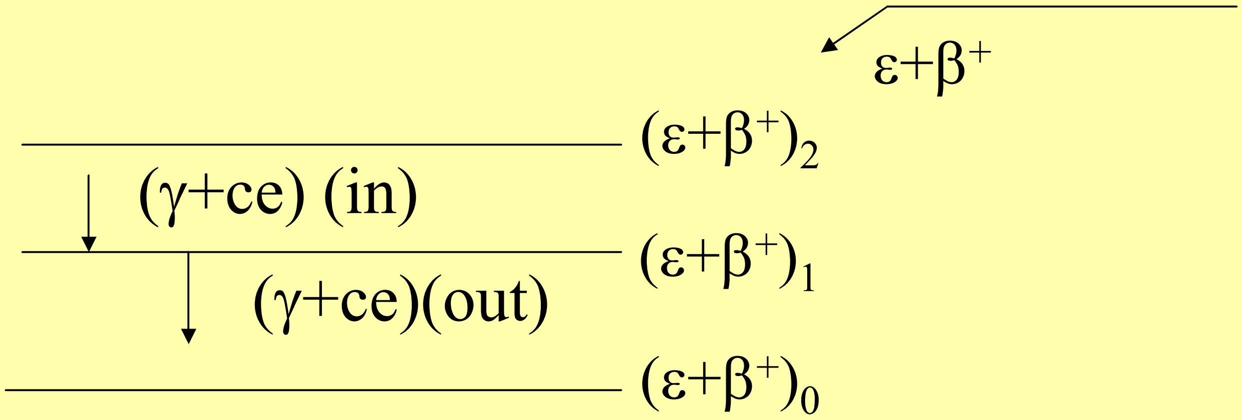
$\% I_{\gamma 3}$, $I_{\gamma 3}$, and $I_{\gamma 1}$ are known.

Then, at equilibrium

$\% I_{\gamma 1} = (\% I_{\gamma 3}/I_{\gamma 3}) \times I_{\gamma 1} \times (T_0/(T_0 - T_1) \times (T_0/(T_0 - T_2)$

Normalization factor $N = \% I_{\gamma 1}/ I_{\gamma 1}$

4. Annihilation radiation intensity is known



$I(\gamma\pm)$ = Relative annihilation radiation intensity

X_i = Intensity imbalance at the ith level = (γ+ce) (out) – (γ+ce) (in)

$r_i = \varepsilon_i / \beta^+_i$ theoretical ratio to ith level

$X_i = \varepsilon_i + \beta^+_i = \beta^+_i\ (1 + r_i)$, therefore $\beta^+_i = X_i / 1 + r_i$

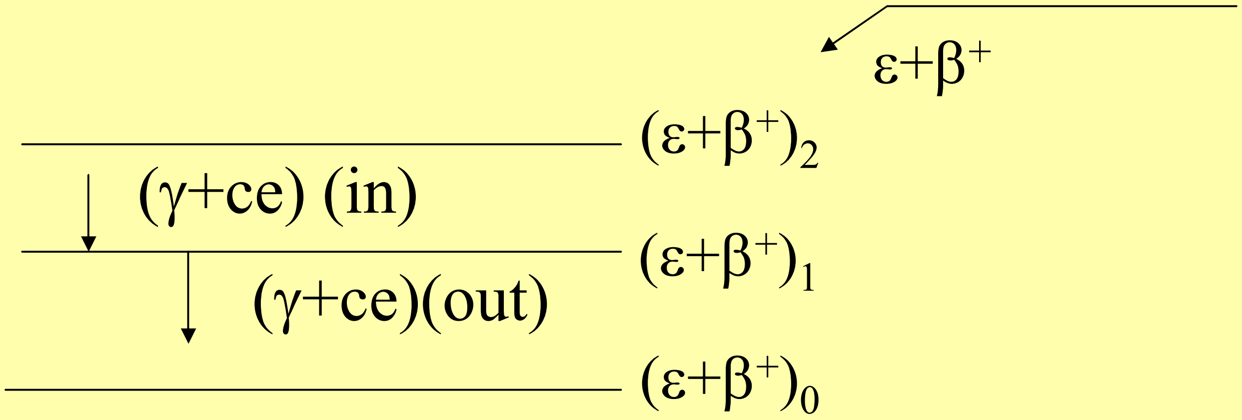
$$2\,[X_0 / (1 + r_0) + \Sigma\, X_i / (1 + r_i)] = I(\gamma\pm) \;\ldots\ldots\ldots\; (1)$$

$$[X_0 + \Sigma\, I_{\gamma i}\, (\gamma + ce) \text{ to gs }]\, N = 100 \;\ldots\ldots\ldots.\; (2)$$

Solve equation (1) for X_0 (rel. gs feeding).

Solve equation (2) for N (normalization factor).

5. X-ray intensity is known



$\varepsilon+\beta^+$

$(\varepsilon+\beta^+)_2$

$(\gamma+ce)$ (in)

$(\varepsilon+\beta^+)_1$

$(\gamma+ce)$(out)

$(\varepsilon+\beta^+)_0$

I_K = Relative Kx-ray intensity

X_i = Intensity imbalance at the ith level = $(\gamma+ce)$ (out) – $(\gamma+ce)$ (in)

$r_i = \varepsilon_i / \beta^+_i$ theoretical ratio to ith level

$X_i = \varepsilon_i + \beta^+_i$, so $\varepsilon_i = X_i r_i / 1 + r_i$ (atomic vacancies); ω_K=K-fluorsc.yield

P_{Ki} = Fraction of the electron-capture decay from the K shell

$$I_K = \omega_K\,[\varepsilon_0 \times P_{K0} + \Sigma\, \varepsilon_i \times P_{Ki}]$$

$$I_K = \omega_K\,[P_{K0} \times X_0 r_0 / (1 + r_0) + \Sigma\, P_{Ki} \times X_i r_i / 1 + r_i] \ldots (1)$$

$$[X_0 + \Sigma\, I_i(\gamma + ce) \text{ to gs}]\, N = 100 \;\ldots.\; (2)$$

Solve equation (1) for X_0, equation (2) for N.

5. Beta particles

1. Energy (keV)

- Give E_β(max) *only* if experimental value is so accurate that it could be used as input to mass adjustment.
- Do not give E_β(avg.), program LOGFT calculates its value.

2. Absolute intensity (%I_β, per 100 decays of the parent nucleus)

- Give experimental value, if used for normalizing the decay scheme.
- Give absolute value deduced from γ-ray transition intensity balance (Program GTOL).

3. Log*ft*

Usually authors assign spins and parities. Nevertheless,

verify that the relevant log*ft* values are consistent with their assignments.

6. Electron capture

- Give $(I_{\varepsilon}+I_{\beta+})$ feedings deduced from γ-ray transition intensity balance. Program LOGFT calculates (from theory) ε and β^+ probabilities.
- Program LOGFT calculates (from theory) sub-shell (P_K, P_L, P_M, …) probabilities.
- Give (in comments) x-ray intensities. These are useful for normalizing or testing the decay scheme.

7. Alpha particles

- Energy (keV)

Most measurements are relative to a line from a standard radionuclide. Include this information in a comment.

Use Ritz's (At. Data and Nucl. Data Tables **47**, 205 (1991)) evaluated E_α and I_α when no new values are available.

- Intensity

Give intensities preferably "per 100 α decays" (NB=1), and a branching factor BR to convert them to "per 100 decays of the parent nucleus.

- Hindrance factor

HF= experimental $T_{1/2}(\alpha)$/theoretical $T_{1/2}(\alpha)$. The theoretical value is from 1947Pr17 (M.A. Preston). The assumption is that 0^+ to 0^+ α transitions from even-even nuclei are the fastest (HF=1). These transitions are used to determine the radius parameter r_0 (See 1998Ak04, Y.A. Akovali). Use program ALPHAD.

Favored alpha-particle transition

- HF < 4
- Takes place between levels with the same spin and parity

The radius parameter r_0

(Y. Akovali, Oak Ridge)

- <u>Odd-N nucleus (Z, A)</u>

  $r_0(Z, N) = [r_0(Z, N-1) + r_0(Z, N+1)]/2$

- <u>Odd-Z nucleus (Z, A)</u>

  $r_0(Z, N) = [r_0(Z-1, N) + r_0(Z+1, N)]/2$

- <u>Odd-Odd nucleus (Z, A)</u>

  $r_0(Z, N) = [r_0(Z, N-1) + r_0(Z, N+1)]/2 =$

  $[r_0(Z-1, N+1)+r_0(Z-1, N-1)+r_0(Z+1, N+1) +r_0(Z+1, N-1)]/4$

Example

^{219}Rn $\Rightarrow$ ^{215}Po (Odd-N)

r_0 (Z=84, N=131) = [r_0(84, 130) + r_0(84, 132)] /2

From 1998Ak04:

r_0(84,214) = 1.559 *8*

r_0(84,216) = 1.5555 *2,* therefore

$\boxed{r_0 \text{ (Z=84, N=131) = 1.557}}$

Use Table 1 – “Calculated r_0 for even-even nuclei” (1998Ak04). Insert R0= … in *comment* record:

CA HF R0=…

Run program ALPHAD to calculate hindrance factors.

8. Level structure and decay scheme

Deduce best γ-ray energies
and relative intensities

Calculate conversion coefficients (HSICC)

Normalize radiation intensities
to and absolute scale (GABS)

Deduce level energies and decay branchings (GTOL)

Calculate: logft values (LOGFT),
alpha decay hindrance factors (ALPHAD)

Workshop on
NUCLEAR STRUCTURE AND DECAY DATA EVALUATION

Model exercise

Trieste, April 4 – 15, 2005
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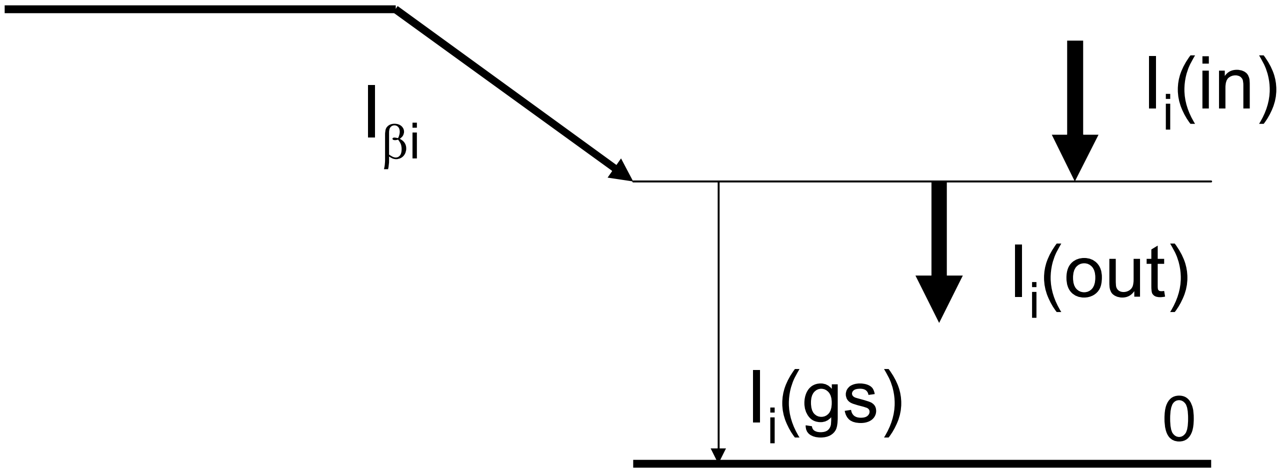
Edgardo Browne

γ-ray transition intensity balance



The corresponding normalization factor is

$N = 100 / \Sigma[\, I_i(out) + I_i(gs) - I_i(in)] =$

$100 / \Sigma[\, I_i(out) - I_i(in)] + \Sigma\, I_i(gs)$, but

$\Sigma[\, I_i(out) - I_i(in)] = 0$, therefore

$N = 100 / \Sigma\, I_i(gs)$

^{233}Pa β^- decay

$I_\gamma(312) = 38.6\ (5)\ \%$ (experimental value, Gehrke et al.)

$\Sigma I(\gamma+ce)\ (gs) = 102\ (2)\ \%$

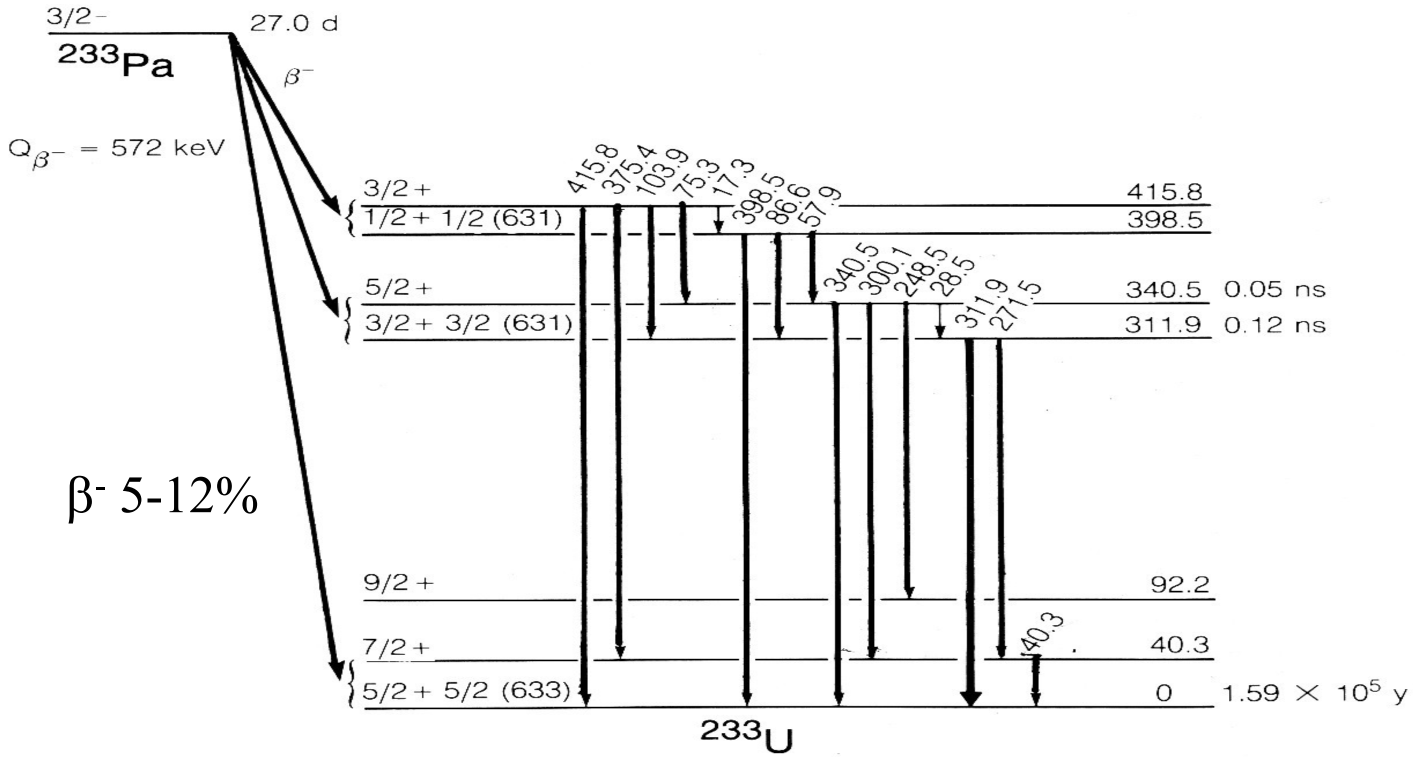


Fig. 1. Simplified ^{233}Pa decay scheme from ref. [1]).

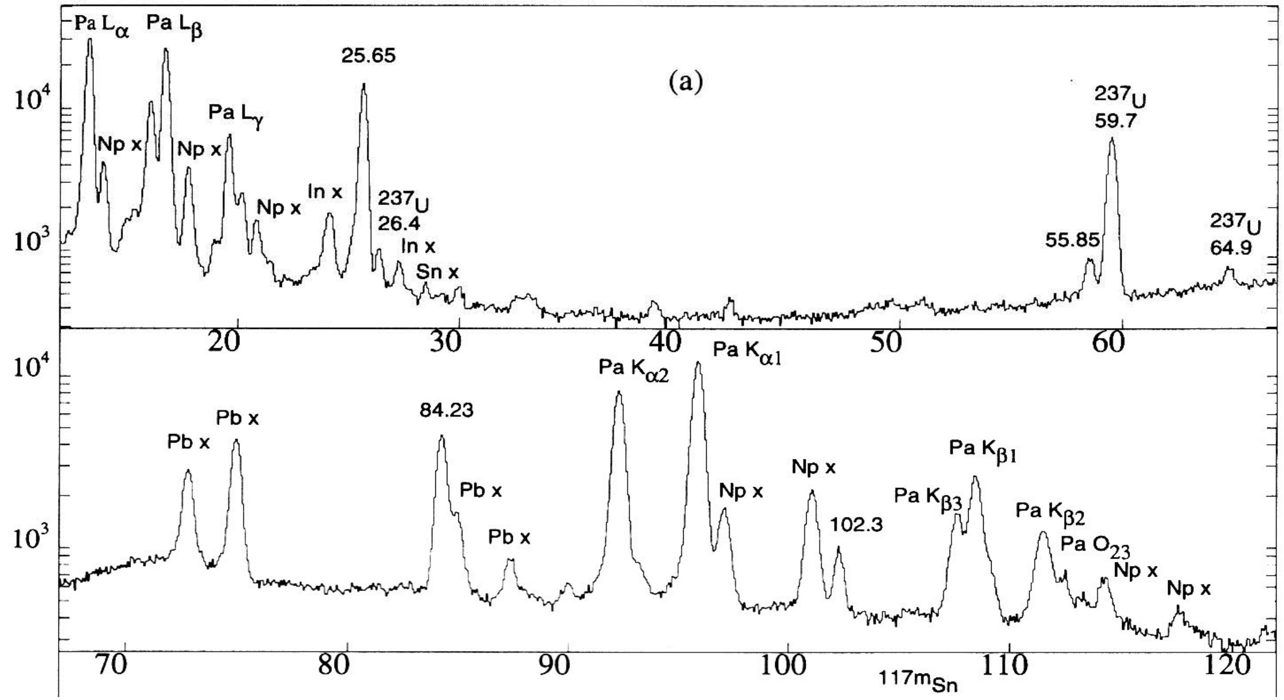
What went wrong?

E_γ(keV)	**α_T(exp.)**	**α_T(theo. M1)**
300	0.83 (2)	1.04
312	0.79 (2)	0.96
340	0.61 (2)	0.75

Answer: Nuclear penetration effects

Using X rays to normalize a decay scheme

^{231}U γ-ray spectrum



$I_\gamma(25)=100\ (6)$

$I_\gamma(84)=50\ (3)$

$I_{KX}=390\ (14)$

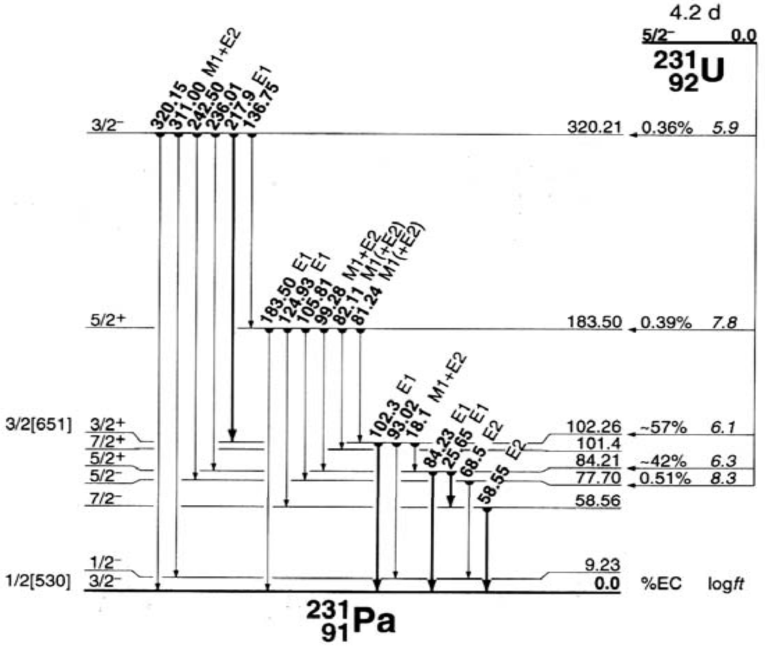


Fig. 4. ^{231}U electron-capture decay scheme. Gamma rays measured in this work are shown with thicker arrows; other data are from refs. [3,11]. Electron-capture branches per 100 decays of ^{231}U and log *ft* values are from gamma-ray transition probability balances (see Table 3).

EC(K)/EC(Total) = 0.59

$\omega_K = 0.972$

B_K=115.6 keV, thus most K-x rays originate from vacancies produced by the electron-capture process.

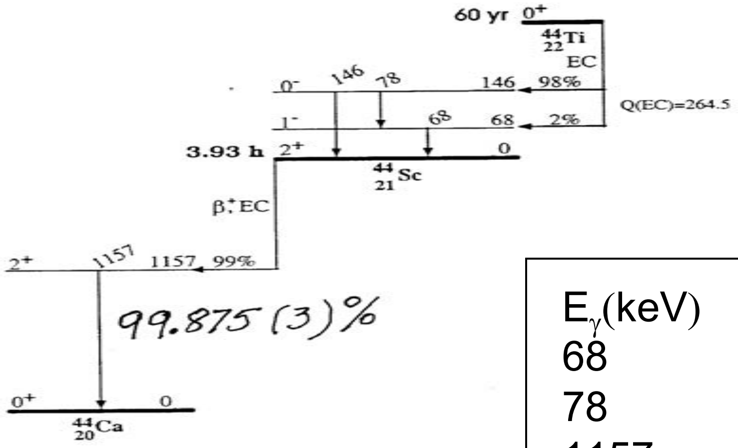
Total vacancies = I_{KX} EC(Total) / ω_K EC(K) = 680 (33)

Normalization factor N = 100 / 680 (33) = 0.147 (7)

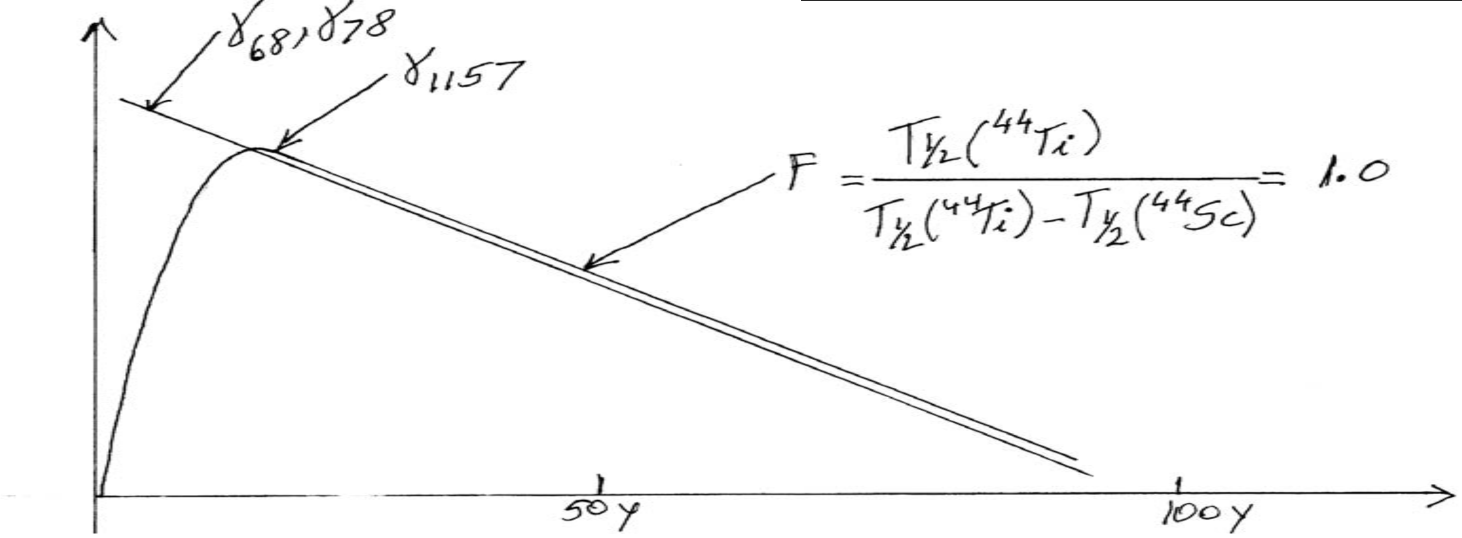
$I_\gamma(25)=100\ (6) \times 0.147\ (7) = 15\ (1)\%$

$I_\gamma(84)=50\ (3) \times 0.147\ (7) = 7.5\ (6)\%$

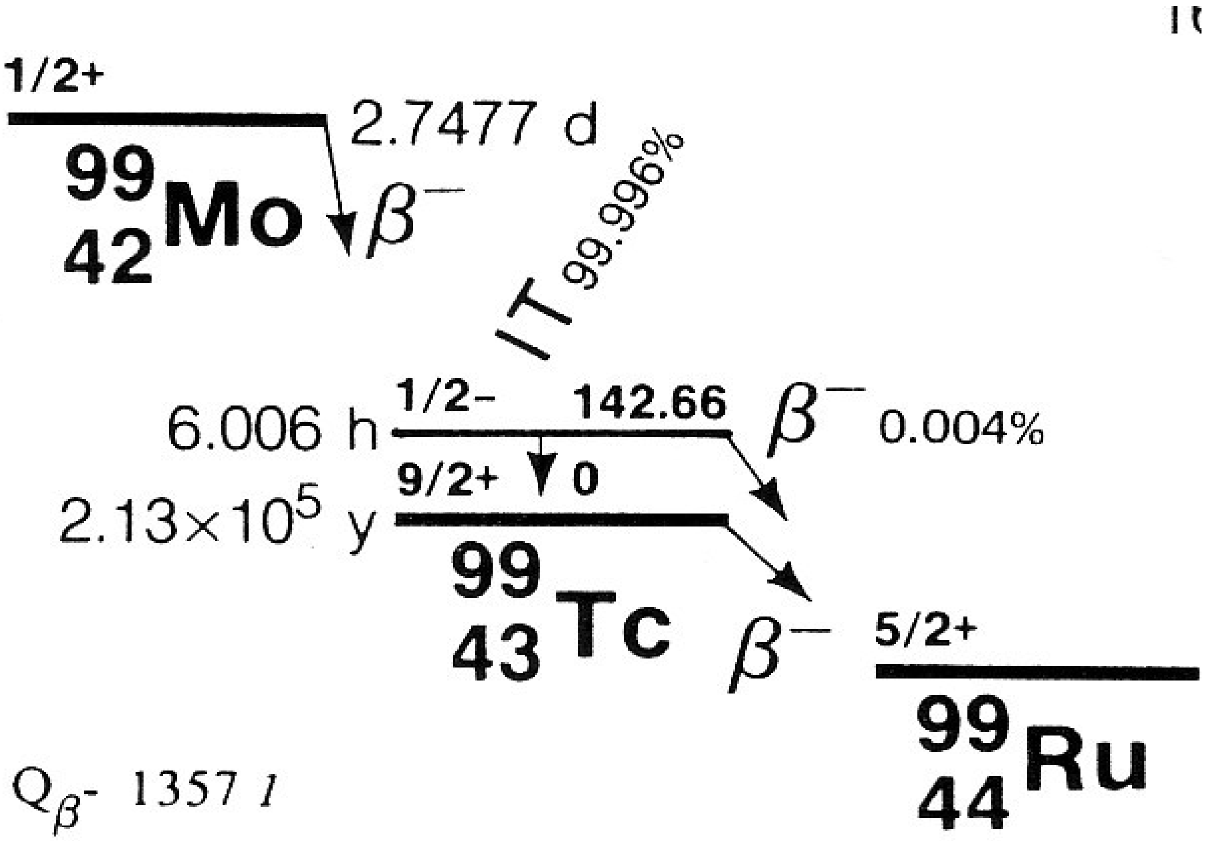
^{44}Ti electron capture decay

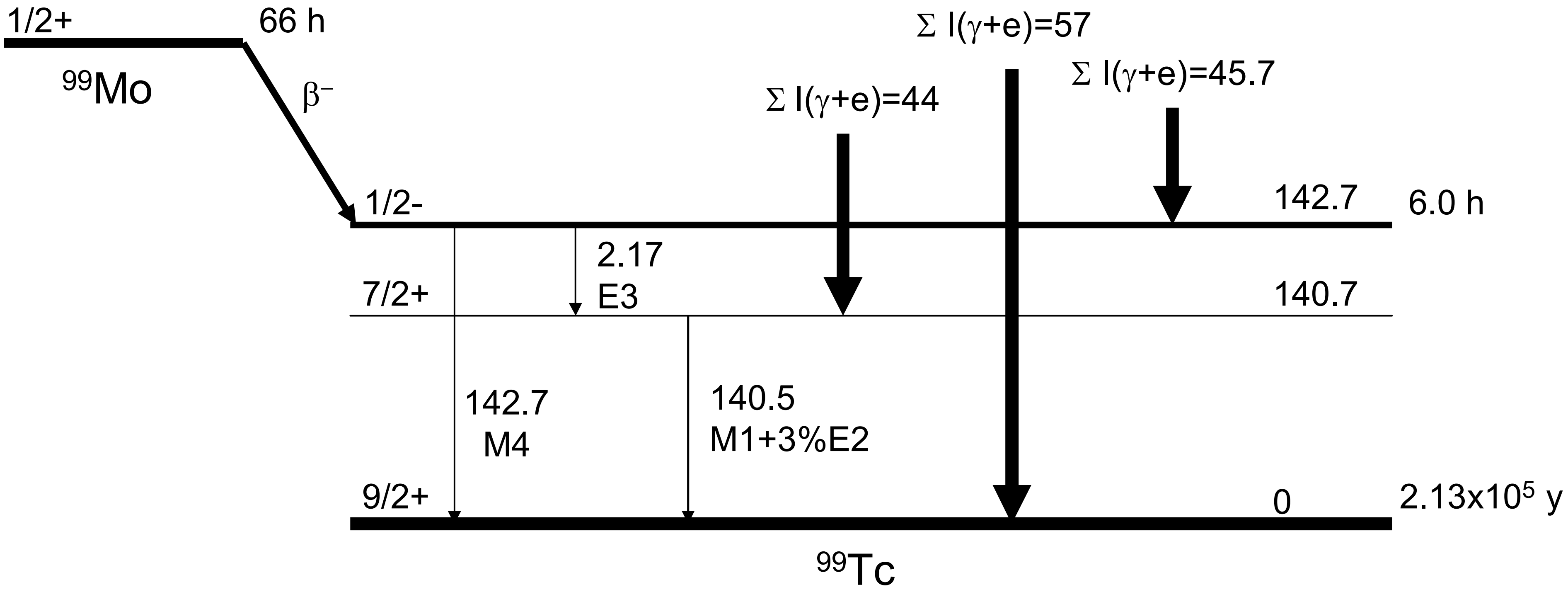


E_γ(keV)	I_γ (rel)	I_γ(%)
68	100 (1)	96.6 (10)
78	94.2 (8)	91.0 (8)
1157	103.4 (10)	99.875 (3)



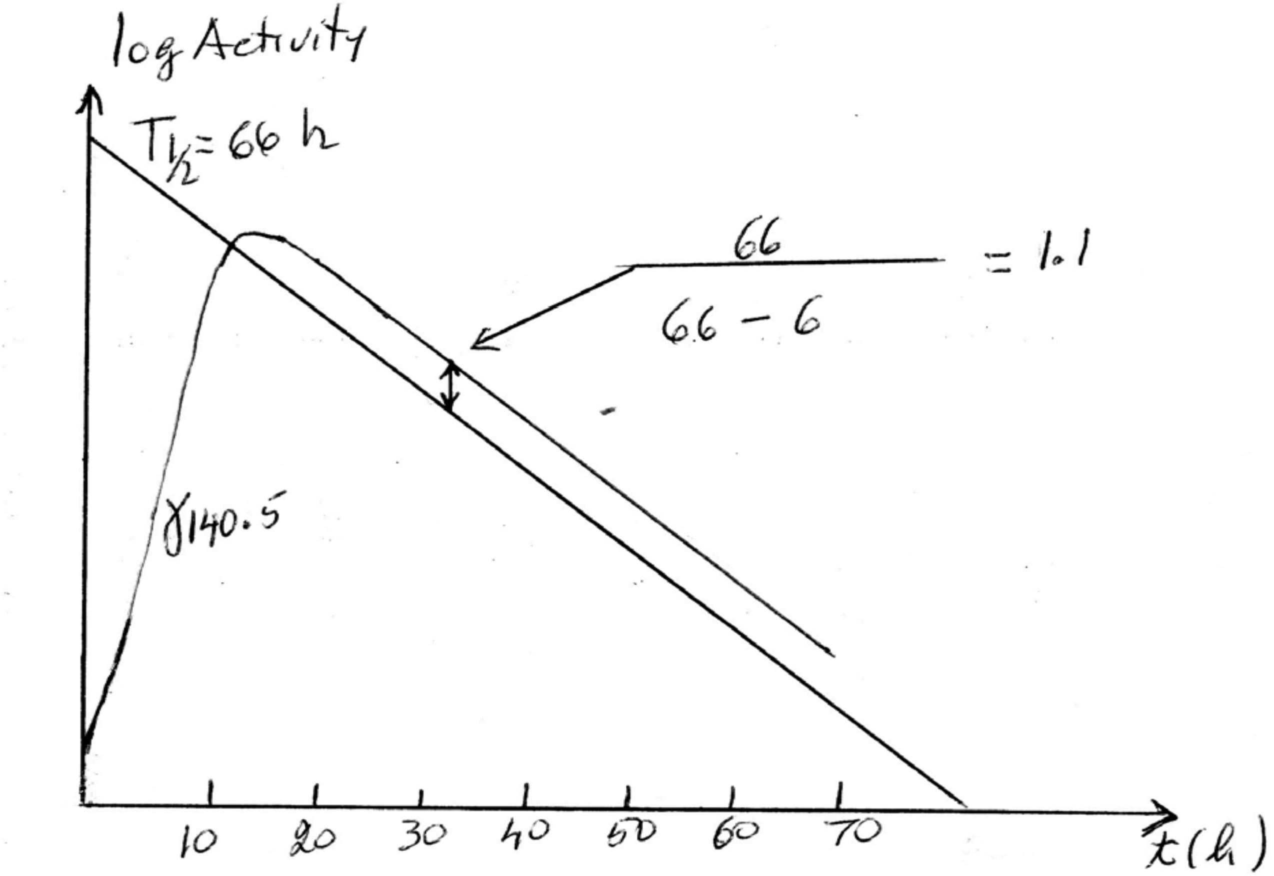
$$^{99}\text{Mo}(2.75\text{ d}) \xrightarrow{\beta^-} {}^{99m}\text{Tc}(6.0\text{ h}) \xrightarrow{\text{IT}} {}^{99}\text{Tc}(2.1\text{x}10^5\text{ y})$$

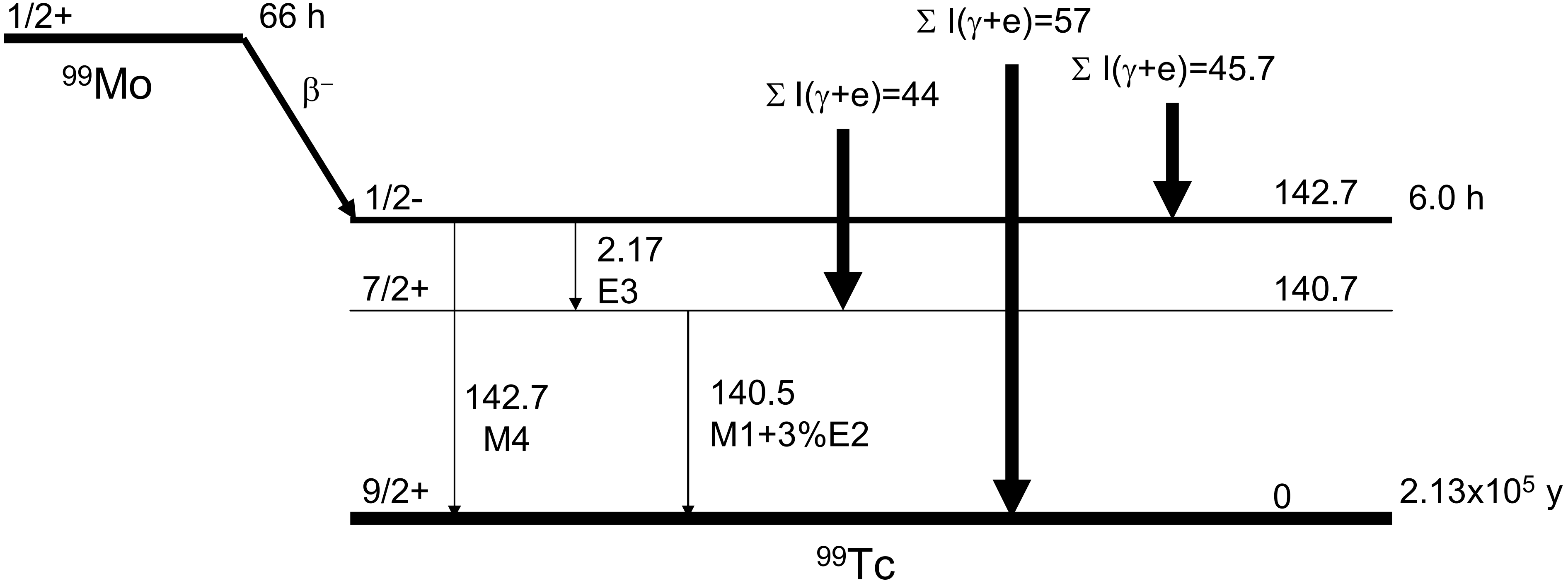




Equilibrium Intensities

E_γ(keV)	I_γ	α	$I_{\gamma+ce}$
140.5	742 (11)	0.114 (3)	827 (12)
142.7	0.17 (2)	40.9 (12)	7.3 (7)


log Activity
$T_{1/2} = 66$ h
$\frac{66}{66-6} = 1.1$
γ140.5
10
20
30
40
50
60
70
t (h)



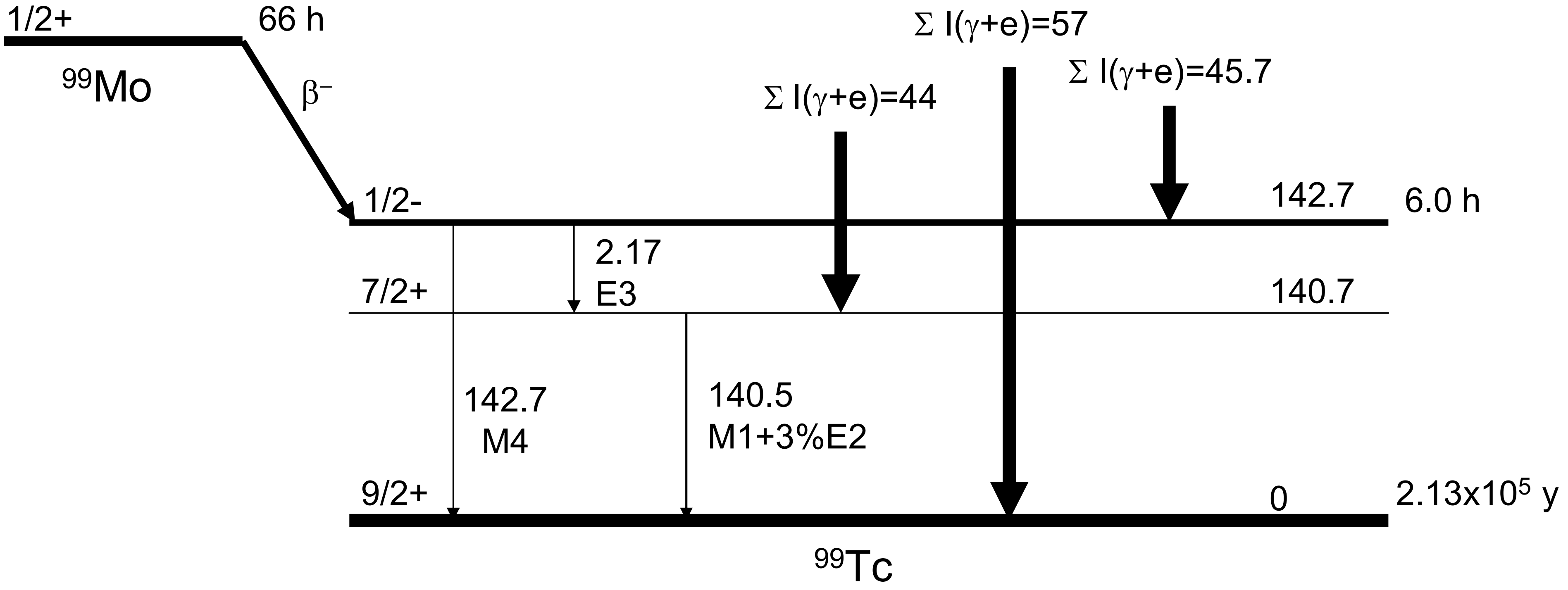
Decay Scheme Normalization

$$[I(\gamma+ce)(142.7)/1.1 + I(\gamma+ce)(140.5)/1.1 + \Sigma I(\gamma+ce)_{gs}] \times N = 100$$

$$[7.3\ (7)/1.1 + 827\ (12)/1.1 + 57.0\ (8)] \times N = 100$$

$$N = 100/816\ (11) = 0.1226\ (17)$$

So, $I_{\gamma}(\%)(140.5) = 742\ (11) \times 0.1226\ (7) = 91.0\ (\mathbf{3})\%$



β^- feeding to 142.7-keV level

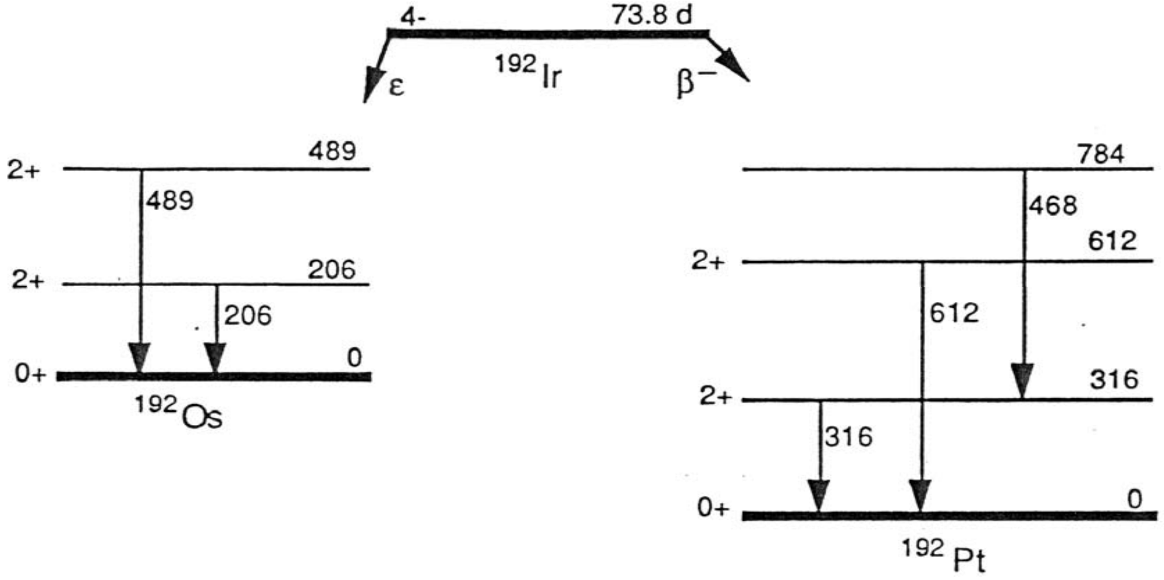
$$I_{\beta-} = I(\gamma+ce)(142.7)/1.1 + I(\gamma+ce)(2.17)/1.1 - \Sigma I(\gamma+ce)_{142.7}$$

$$I(\gamma+ce)(140.5)/1.1 - I(\gamma+ce)(2.17)/1.1 - \Sigma I(\gamma+ce)_{140.5} = 0$$

$$I_{\beta-} = 668$$

So, $I_{\beta-}(\%) = 668 \times 0.1226 = 82.0\%$

^{192}Ir β^{-} and electron capture decay



E_γ(keV)	I_γ	α	$I_\gamma (1+\alpha)$	
206	4.01 (6)	0.305 (9)	5.23 (8)	
489	0.527 (9)	0.0242 (7)	0.540 (9)	Σ= 5.77 (8)
316	100.0 (5)	0.085 (3)	108.5 (6)	
468	57.76 (20)	0.0294 (9)	58.43 (20)	
612	6.365 (25)	0.0155 (5)	6.464 (25)	Σ= 114.9 (6)

The normalization factor is:

$N = 100 / [I_\gamma(489)\ (1+\alpha_{489}) + I_\gamma(206)\ (1+\alpha_{206}) + I_\gamma(316)\ (1+\alpha_{316}) + I_\gamma(612)\ (1+\alpha_{612})]$

$= 100 / 120.7\ (7) = 0.828\ (5)$

$$\boxed{N = 0.828\ (5)}$$

The electron capture (ε) and β^- decay branchings are:

$\varepsilon = 100\ [I_\gamma(489)\ (1+\alpha_{489}) + I_\gamma(206)\ (1+\alpha_{206})]\ /120.7\ (7) =$

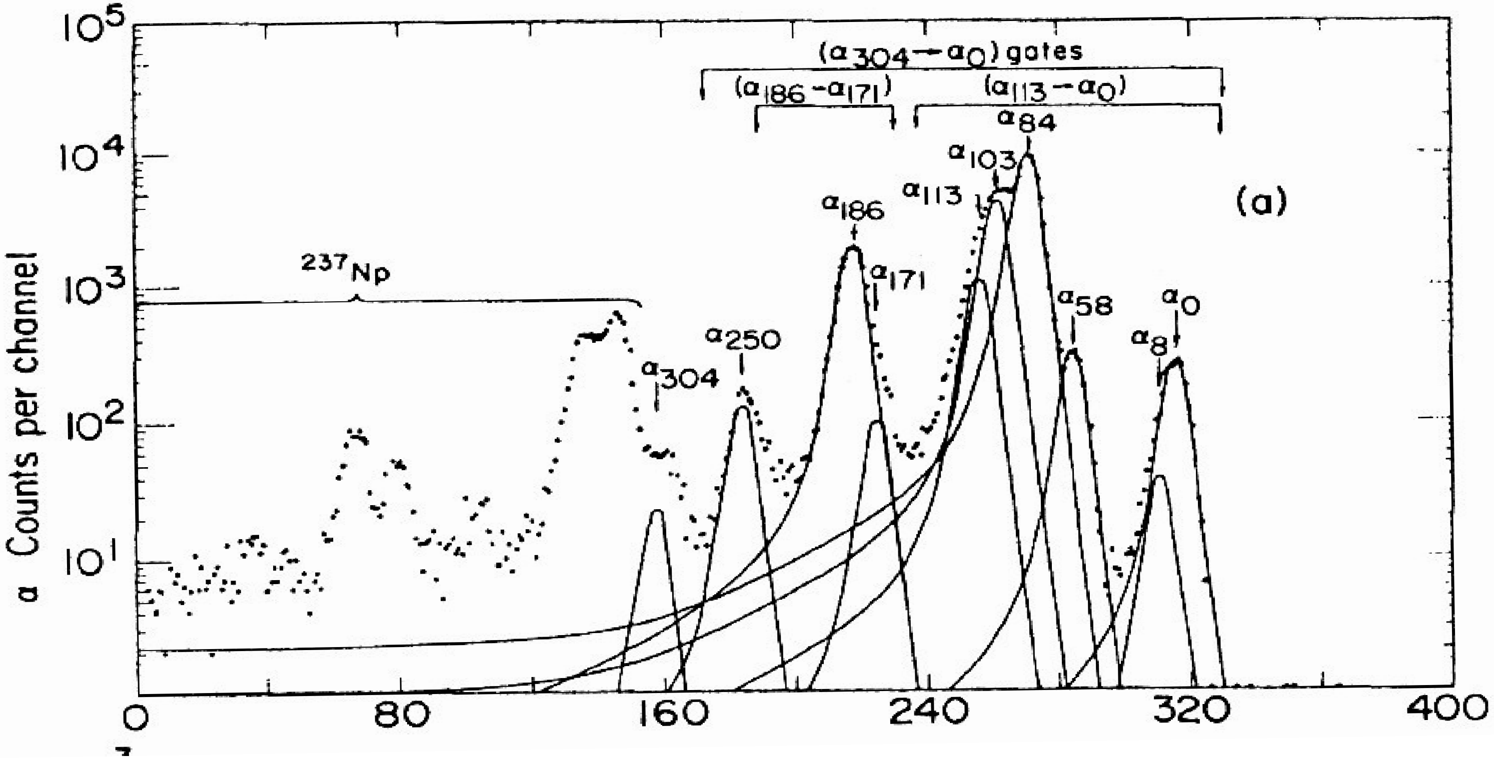
$100 / [1 + (I_\gamma(316)\ (1+\alpha_{316}) + I_\gamma(612)\ (1+\alpha_{612})/(I_\gamma(489)\ (1+\alpha_{489}) + I_\gamma(206)\ (1+\alpha_{206})) =$

$100 / [1 + 114.9\ (6)/5.77\ (8)] = 100 / 20.9\ (3) = 4.78\ (7)\%$

$\beta^- = 100 - EC = 100 - 4.78\ (7) = 95.22\ (7)\%$

$$\boxed{\begin{array}{l} \beta^- = 95.22\ (7)\% \\ \varepsilon = 4.78\ (7)\% \end{array}}$$

^{235}Np Alpha-Particle Spectrum

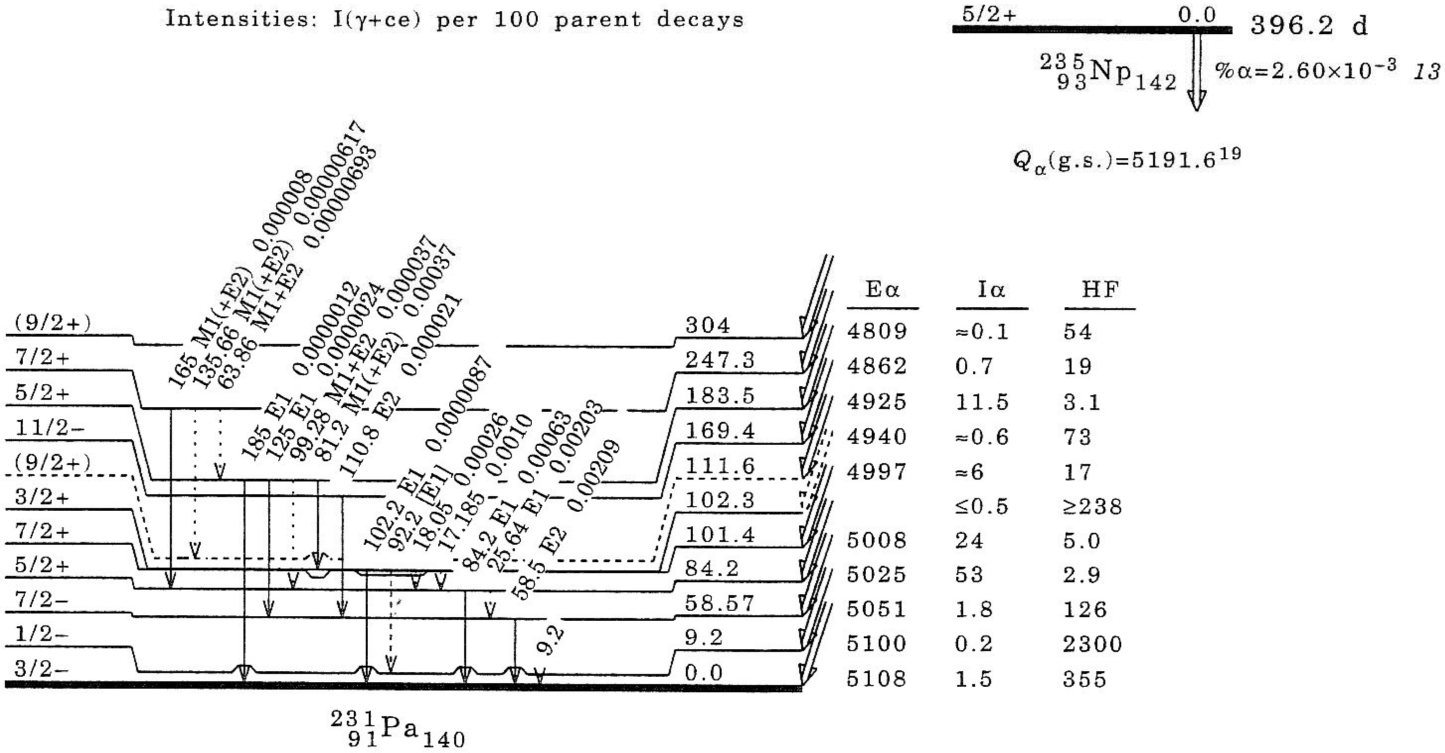


^{235}Np Alpha Decay Scheme

^{235}Np α Decay 1973Br12 (continued)

Decay Scheme

Intensities: I(γ+ce) per 100 parent decays



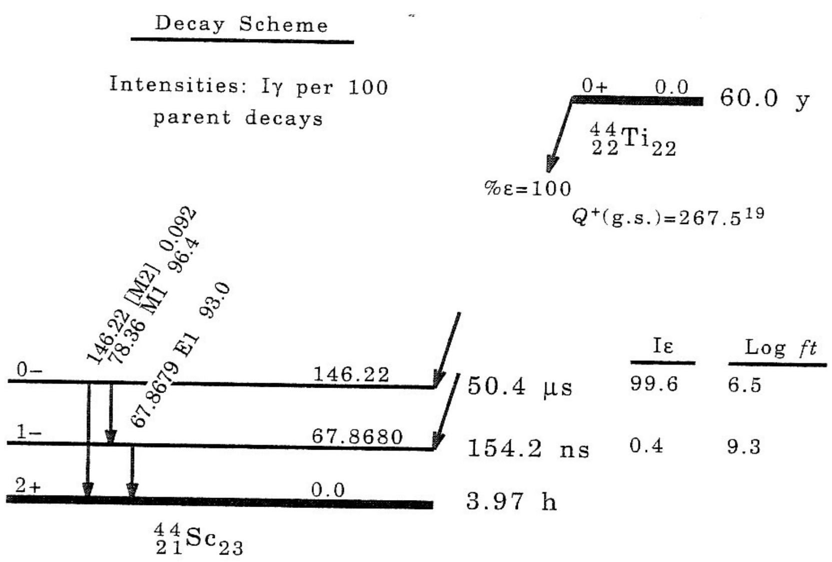
Eα	Iα	HF
4809	≈0.1	54
4862	0.7	19
4925	11.5	3.1
4940	≈0.6	73
4997	≈6	17
	≤0.5	≥238
5008	24	5.0
5025	53	2.9
5051	1.8	126
5100	0.2	2300
5108	1.5	355

^{235}Np Alpha-particle intensities

E_{α}(keV)	E_{lev}(keV)	I_{α}(spec.)	I_{α}(bal.)
4809	304	~0.1	
4862	247	0.7 (1)	0.8 (2)
4925	183	11.5 (5)	16 (3)
4940	169	~0.6	0.8 (3)
4997	112	~6	
5008	101	24 (8)	33 (10)
5025	84	53 (8)	51 (12)
5051	58	1.8 (3)	~2
5100	9	0.2	
5108	0	1.5 (2)	

Preparing ENSDF Data Sets

^{44}Sc ENSDF Data Set



```
44SC    44TI EC DECAY
44TI  P 0            0+                60.0 Y    11             267.5     19
44SC  N 0.964      13         1.0
44SC  L 0            2+               3.97 H    4
44SC  L 67          1-                154.2 NS  8
44SC  G 67.8679   14   96.5 16    E1                   0.0845
44SCS G KC=   0.0766  $LC=   0.00664
44SC  L 146         0-                50.4 US   7
44SC  G 78.36      3  100.0 11    M1                   0.0302
44SCS G KC=   0.0273  $LC=   0.00243
44SC  G 146.22     3  0.095 3    [M2]                  0.0460
44SCS G KC=   0.0414  $LC=   0.00385
```

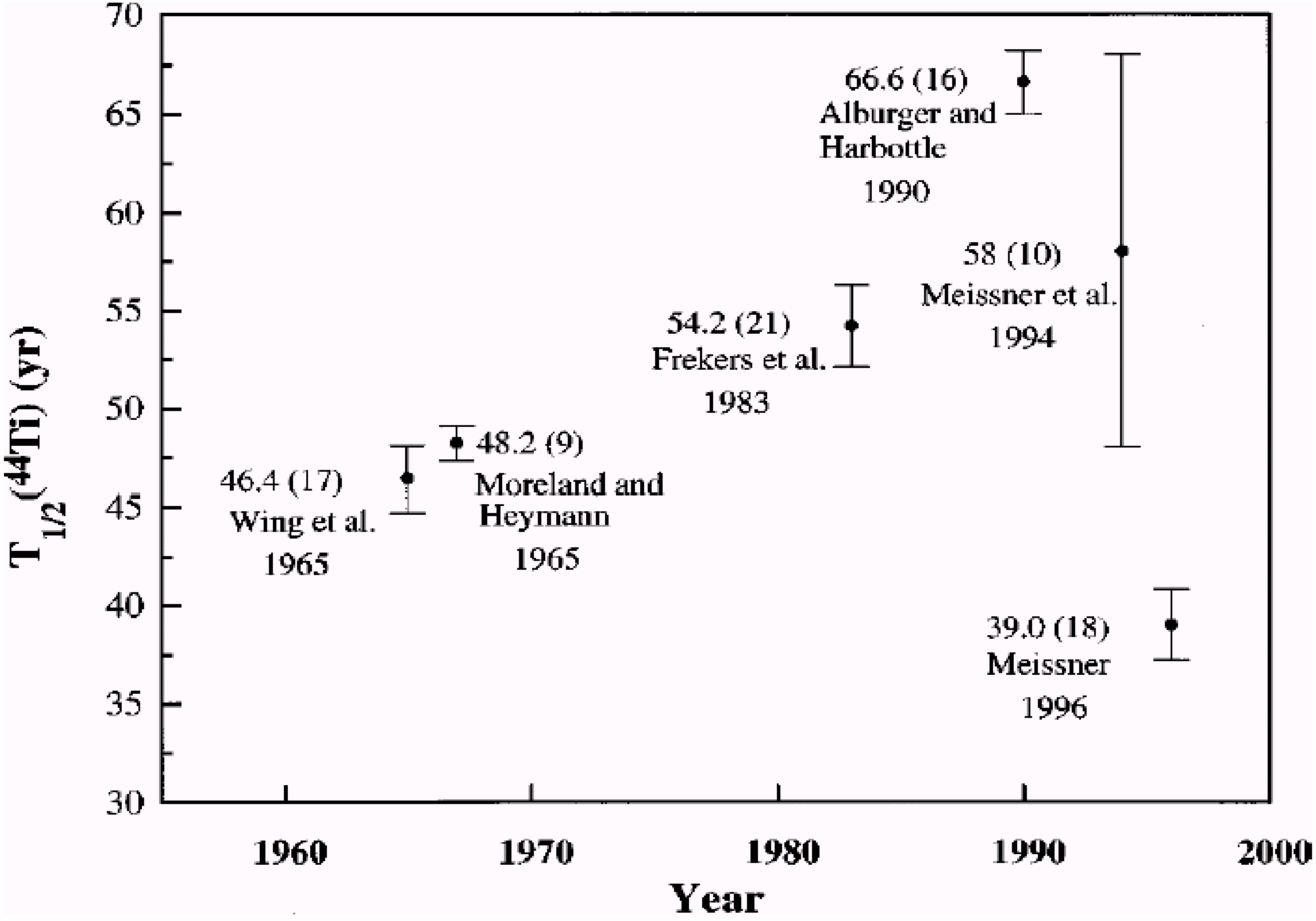


FIG. 2. Summary of previously reported values for the half-life of ^{44}Ti. Numbers in parentheses represent the 1σ uncertainties in the least significant digit(s).

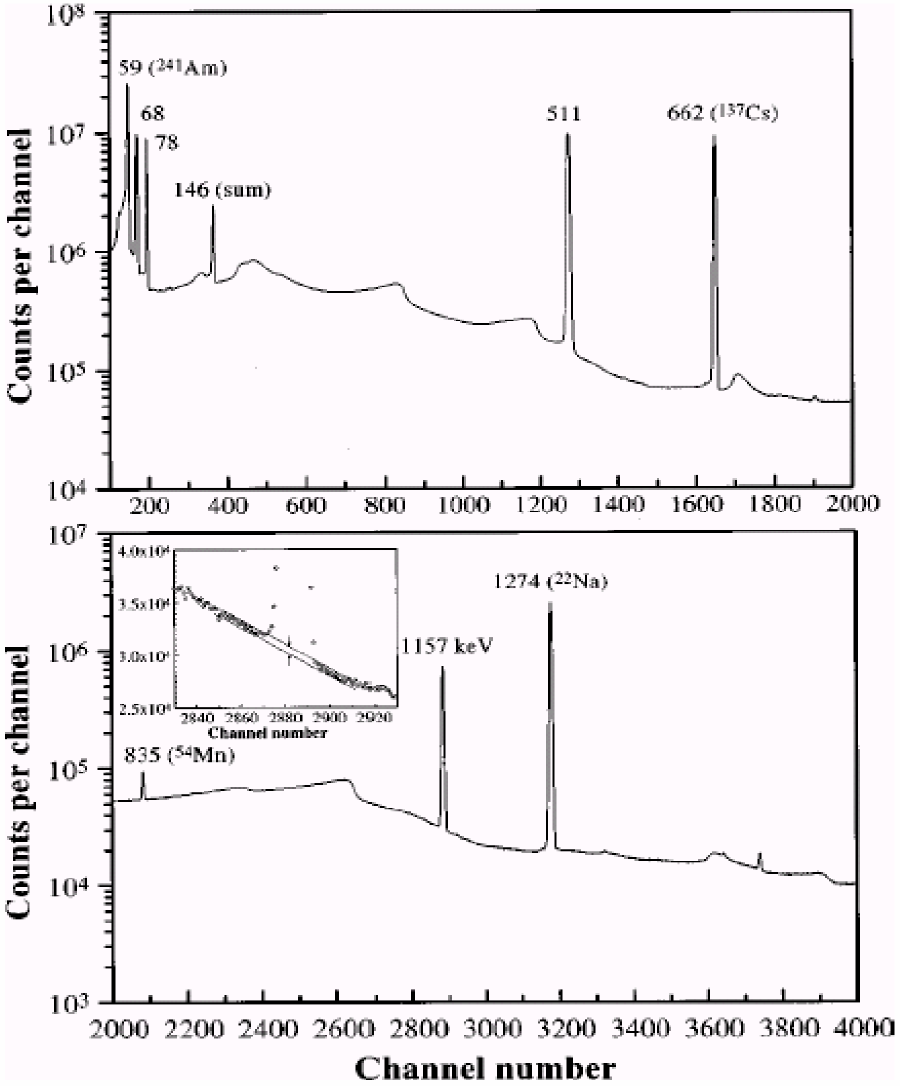


FIG. 4. γ-ray spectrum accumulated in 10 days of counting the mixed source of ^{44}Ti, ^{241}Am, ^{137}Cs, and ^{22}Na. All energies are in keV. Peaks labeled only by energy are from the decay of ^{44}Ti. The inset illustrates the background under the 1157-keV peak. The arrows indicate a ±1% systematic background uncertainty.

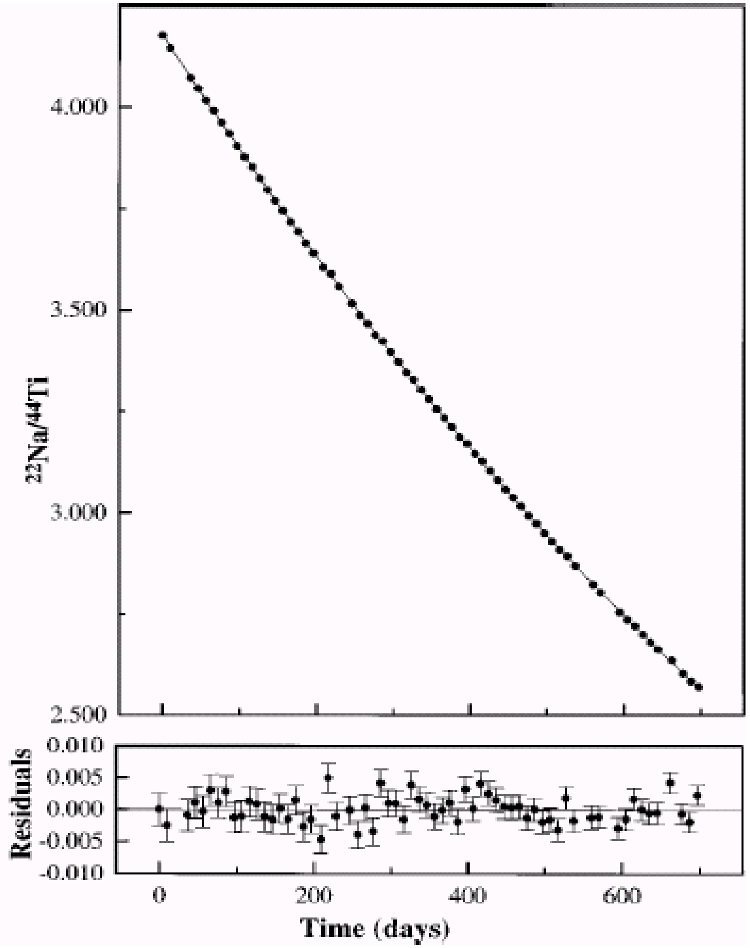


FIG. 5. The upper part of this figure shows the decrease in the ratio between the peak areas of the 1274-keV (^{22}Na) and 1157-keV (^{44}Ti) γ rays as a function of time. The curve going through the data is the result of a least-squares fit of an exponentially decreasing function of time. The ^{44}Ti half-life determined from this fit is 61.5(9) yr and $\chi^2/\nu=1.1$. The lower panel shows the residuals to this fit.

^{44}Ti Half-life (LWEIGHT)

```
             44Ti Half-life Measurements

INP. VALUE  INP. UNC.     R. WGHT  chi**2/N-1 REFERENCE
.607000E+02 .120E+01      .141E+00  .826E-01   99Wi01
.590000E+02 .600E+00 MIN *.563E+00* .479E+00   98Ah03
.603000E+02 .130E+01      .120E+00  .163E-01   98Go05
.620000E+02 .200E+01      .507E-01  .214E+00   98No06
.666000E+02 .160E+01      .792E-01  .348E+01   90Al11
.542000E+02 .210E+01      .460E-01  .149E+01   83Fr27

No. of Input Values N= 6  CHI**2/N-1=  5.76  CHI**2/N-1(critical)=  3.00

UWM   :.604667E+02  .164796E+01
WM    :.599288E+02  .450317E+00(INT.)  .108057E+01(EXT.)

INP. VALUE  INP. UNC.     R. WGHT  chi**2/N-1 REFERENCE
.607000E+02 .120E+01      .161E+00  .563E-01   99Wi01
.590000E+02 .681E+00     *.500E+00* .487E+00   98Ah03
* Input uncertainty increased .114E+01 times *
.603000E+02 .130E+01      .137E+00  .663E-02   98Go05
.620000E+02 .200E+01      .580E-01  .188E+00   98No06
.666000E+02 .160E+01      .907E-01  .334E+01   90Al11
.542000E+02 .210E+01      .526E-01  .156E+01   83Fr27

No. of Input Values N= 6  CHI**2/N-1=  5.63  CHI**2/N-1(critical)=  3.00
UWM   :.604667E+02  .164796E+01
WM    :.600634E+02  .481846E+00(INT.)  .114378E+01(EXT.)
LWM   :.600634E+02  .114378E+01   Min. Inp. Unc.=.600000E+00
LWM has used weighted average   and external uncertainty
```

Recommended value: 60.0 (11) y

^{44}Sc ENSDF Data Set (GTOL)

	TI	TI	TI	NET FEEDING	
LEVEL	(OUT)	(IN)	(NET)	(CALC)	(USE)
0.0	0.000	104.8 18	-104.8 18	-1.0 17	0.0
67.8679 14	104.7 18	103.0 12	1.6 21	1.6 21	0.6 11
146.224 22	103.1 12	0.000	103.1 12	99.4 11	99.4 11

```
44SC    44TI EC DECAY
44TI  P 0            0+               60.0 Y    11             267.5     19
44SC  N 0.964      13         1.0
44SC  L 0            2+               3.97 H    4
44SC  L 67.8679   141-                154.2 NS  8
44SC  E                           0.6     11
44SC  G 67.8679    14  96.5 16    E1                   0.0845
44SCS G KC=   0.0766  $LC=   0.00664
44SC  L 146.224   220-                50.4 US   7
44SC  E                           99.4    11
44SC  G 78.36       3  100.0 11   M1                   0.0302
44SCS G KC=   0.0273  $LC=   0.00243
44SC  G 146.22      3  0.095 3   [M2]                  0.0460
44SCS G KC=   0.0414  $LC=   0.00385
```

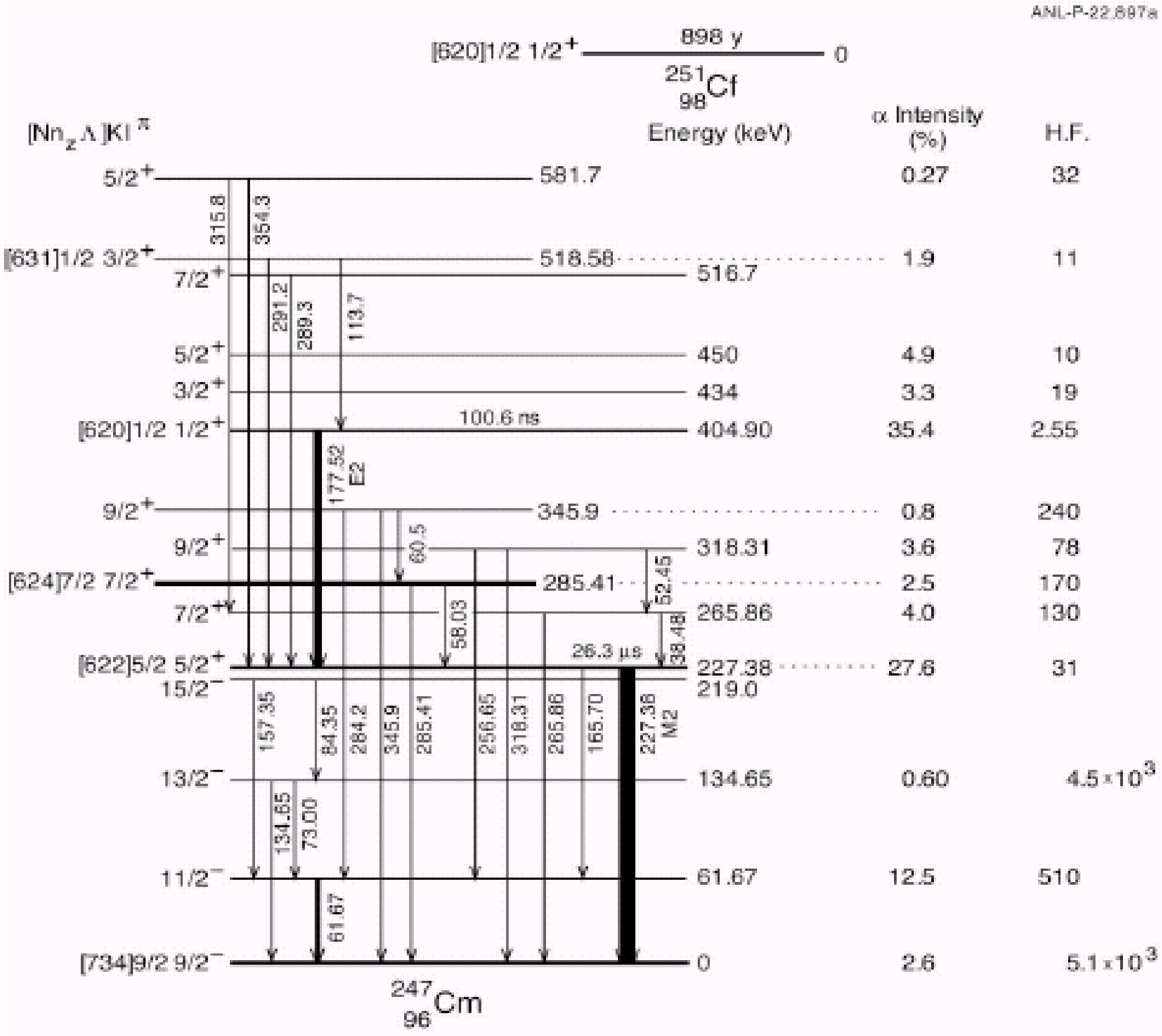
^{44}Sc ENSDF Data Set (LOGFT)

```
44SC    44TI EC DECAY
44TI  P 0            0+               60.0 Y    11             267.5     19
44SC  N 0.964     13          1.0
44SC  L 0            2+               3.97 H    4
44SC  L 67.8679   141-                 154.2 NS 8
44SC  E                          0.6  11   9.2   8
44SCS E  CK=0.8910 $CL=0.09309 $CM+=0.01592
44SC  G 67.8679   14   96.5 16    E1                   0.0845
44SCS G KC=   0.0766  $LC=   0.00664
44SC  L 146.224   220-                 50.4 US  7
44SC  E                         99.4  11  6.509 17
44SCS E  CK=0.8883 $CL=0.09533 $CM+=0.016352 18
44SC  G 78.36      3  100.0 11    M1                   0.0302
44SCS G KC=   0.0273  $LC=   0.00243
44SC  G 146.22     3  0.095 3    [M2]                  0.0460
44SCS G KC=   0.0414  $LC=   0.00385
```

New Exercise
Trieste, April 4 – 15, 2005

PHYSICAL REVIEW C **68**, 044306 (2003)

Energy levels of ^{247}Cm populated in the α decay of $^{251}_{98}$Cf


ANL-P-22,897a
[620]1/2 1/2+
898 y
0
$^{251}_{98}$Cf
[Nn$_z$Λ]KI$^\pi$
Energy (keV)
α Intensity (%)
H.F.
5/2+ 581.7 0.27 32
[631]1/2 3/2+ 518.58 1.9 11
7/2+ 516.7
5/2+ 450 4.9 10
3/2+ 434 3.3 19
[620]1/2 1/2+ 404.90 35.4 2.55
100.6 ns
9/2+ 345.9 0.8 240
9/2+ 318.31 3.6 78
[624]7/2 7/2+ 285.41 2.5 170
7/2+ 265.86 4.0 130
[622]5/2 5/2+ 227.38 27.6 31
26.3 μs
15/2− 219.0
13/2− 134.65 0.60 4.5×10^3
11/2− 61.67 12.5 510
[734]9/2 9/2− 0 2.6 5.1×10^3
315.8
354.3
291.2
289.3
113.7
177.52 E2
60.5
52.45
58.03
38.48
157.35
84.35
284.2
345.9
285.41
256.65
318.31
265.86
165.70
227.38 M2
134.65
73.00
61.67
$^{247}_{96}$Cm

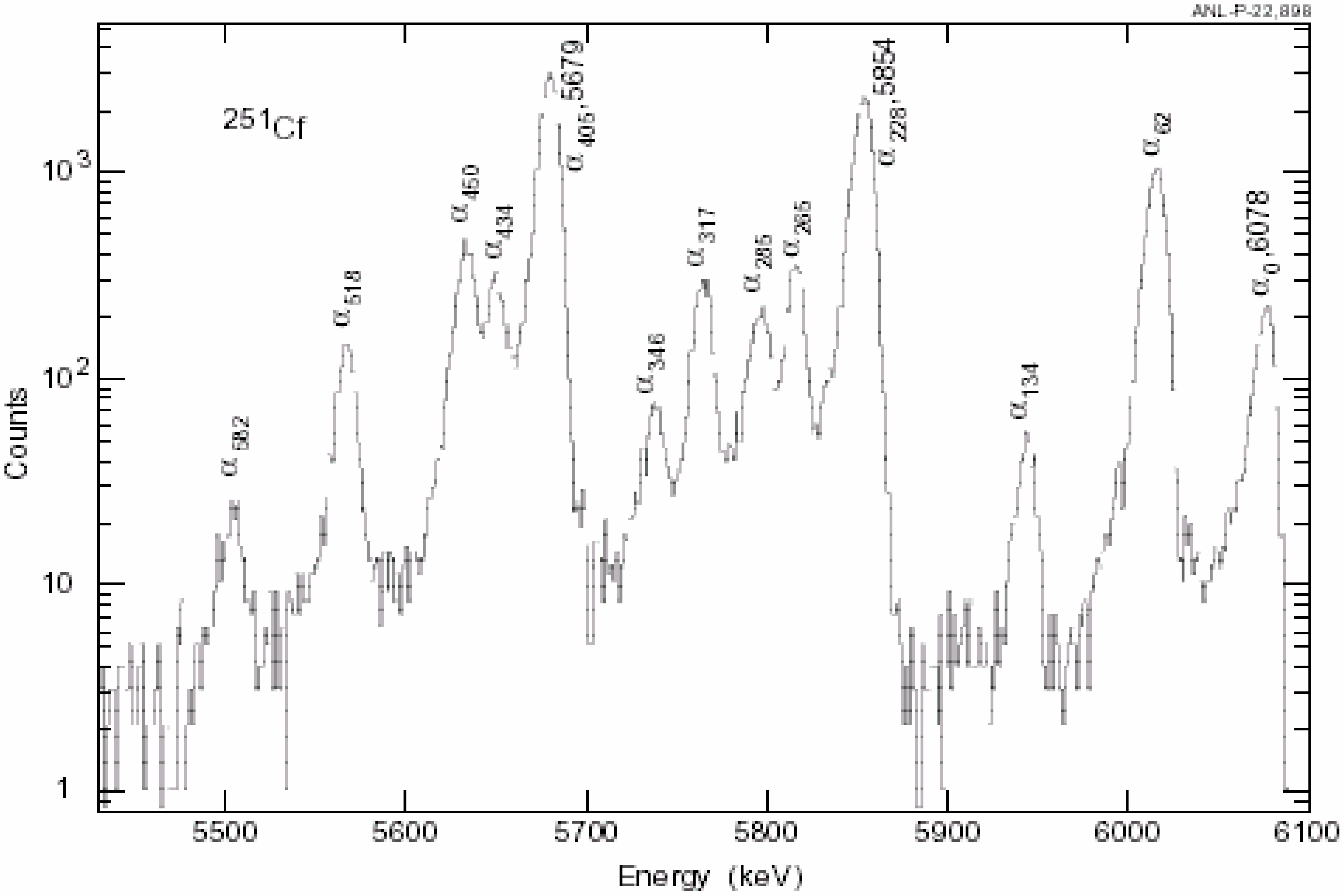

ANL-P-22,898
251Cf
α582
α518
α450
α434
α405,5679
α346
α317
α285
α265
α228,5854
α134
α62
α0,6078
10³
10²
10
1
Counts
5500
5600
5700
5800
5900
6000
6100
Energy (keV)

TABLE I. ^{251}Cf α groups.

Energy (MeV)	Excited state energy (keV)	Intensity (%)	Hindrance factor[a]
6.078±0.002	0	2.6±0.1	5.1×10^3
6.017±0.002	62	12.5±0.3	5.1×10^2
5.946±0.002	134	0.60±0.06	4.5×10^3
5.854±0.002	228	27.6±0.5	31
5.817±0.002	265	4.0±0.2	1.3×10^2
5.798±0.002	285	2.5±0.2	1.7×10^2
5.766±0.002	317	3.6±0.2	78
5.738±0.002	346	0.8±0.1	2.4×10^2
5.679±0.002	405	35.4±0.5	2.55
5.651±0.002	434	3.3±0.2	19
5.635±0.002	450	4.9±0.2	10
5.568±0.002	518	1.9±0.1	11
5.505±0.002	582	0.27±0.05	32

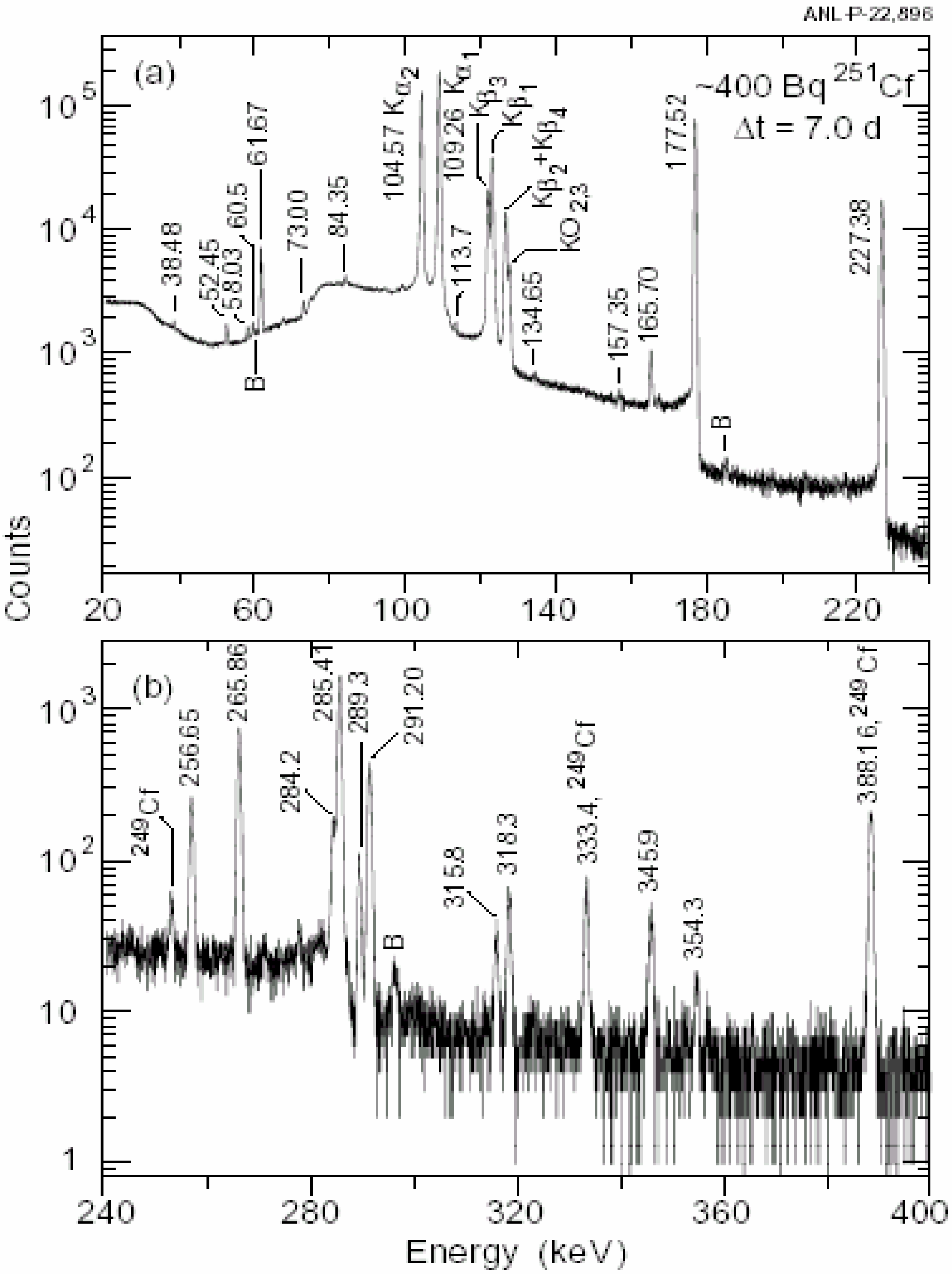

ANL-P-22,896
(a)
~400 Bq ^{251}Cf
Δt = 7.0 d
38.48
52.45
58.03
60.5
61.67
B
73.00
84.35
104.57 K_{α_2}
109.26 K_{α_1}
K_{β_3}
K_{β_1}
$K_{\beta_2}+K_{\beta_4}$
KO_{23}
113.7
134.65
157.35
165.70
177.52
B
227.38
10^5
10^4
10^3
10^2
Counts
20
60
100
140
180
220
(b)
^{249}Cf
256.65
265.86
284.2
285.41
289.3
291.20
B
315.8
318.3
333.4, ^{249}Cf
345.9
354.3
388.16, ^{249}Cf
10^3
10^2
10
1
240
280
320
360
400
Energy (keV)

TABLE III. ^{251}Cf γ rays.

Energy (keV)	Intensity (%)	Transitions Initial→Final
38.48±0.05	0.038±0.006	265.86→227.38
52.45±0.05	0.048±0.005	318.31→265.86
58.03±0.05	0.024±0.005	285.41→227.38
60.5±0.1	0.010±0.003	345.9→285.41
61.67±0.05	0.40±0.03	61.67→0
73.00±0.08	0.040±0.005	134.65→61.67
84.35±0.08	0.040±0.005	219.0→134.65
104.57±0.02	12.6±0.7	Cm $K\alpha_2$
109.26±0.02	19.8±1.0	Cm $K\alpha_1$
113.7±0.1	0.024±0.005	518.58→404.90
122.31±0.02+		Cm $K\beta_3$
123.40±0.02	7.7±0.5	Cm $K\beta_1$
127.01±0.04+		Cm $K\beta_2+K\beta_4$
128.00±0.05	2.6±0.2	Cm $KO_{2,3}$
134.65±0.08	0.014±0.003	134.65→0
157.35±0.08	0.020±0.004	219.0→61.67
165.70±0.05	0.12±0.01	227.38→61.67
177.52±0.02	17.3±0.9	404.90→227.38
227.38±0.02	6.8±0.3	227.38→0
256.65±0.08	0.13±0.01	318.31→61.67
265.86±0.08	0.43±0.03	265.86→0
284.2±0.1	0.12±0.01	345.9→61.67
285.41±0.08	1.13±0.09	285.41→0
289.3±0.1	0.070±0.007	516.7→227.38
291.20±0.08	0.30±0.03	518.58→227.38
315.8±0.1	0.024±0.003	581.7→265.86
318.3±0.1	0.050±0.005	318.31→0
345.9±0.1	0.043±0.004	345.9→0
354.3±0.1	0.013±0.002	581.7→227.38

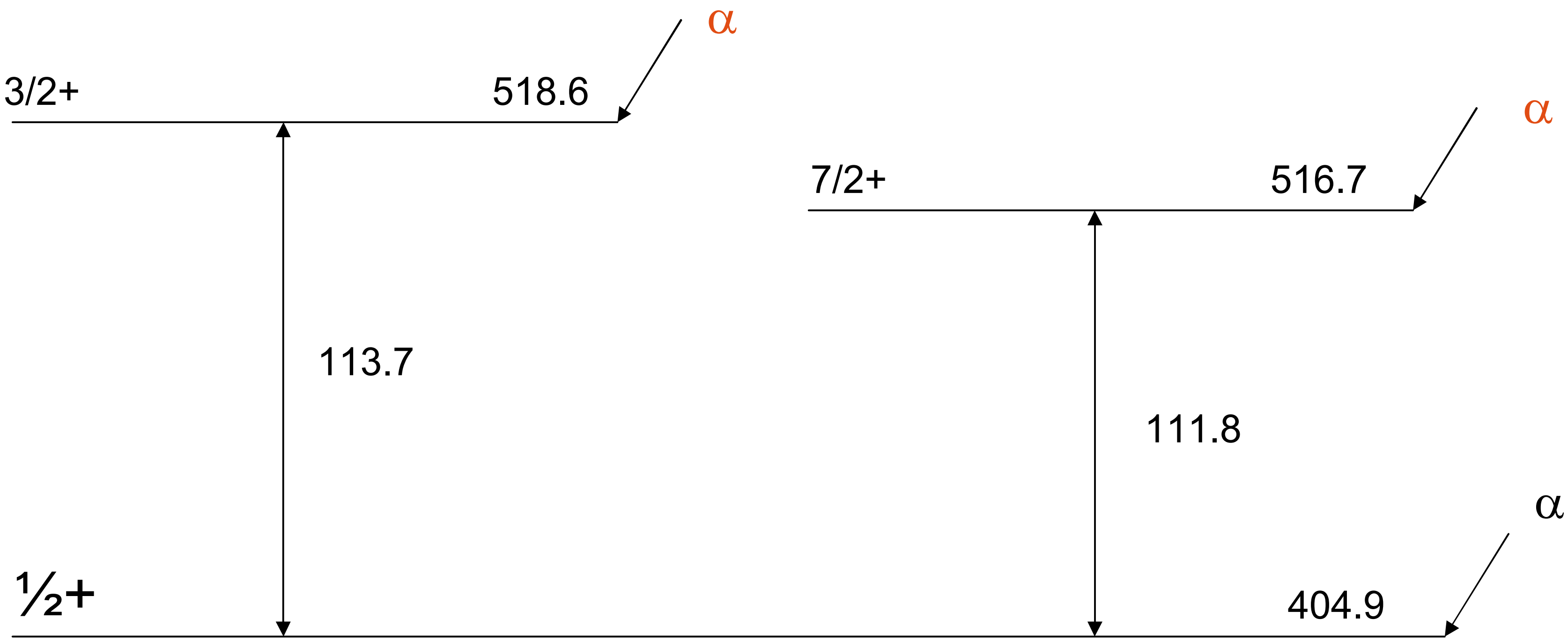
TABLE II. ^{251}Cf conversion electron data.

Transition energy (keV)	Shell	Energy (keV)	Intensity (%)	Conversion coefficient	Theory	Mixing ratio δ	Multipolarity
38.48	$L+M+\cdots$			183 ± 31[a]	$122(M1), 1833(E2)$	0.19 ± 0.05	$M1+3.6\%E2$
52.45	$L+M+\cdots$			70 ± 10[a]	$49.3(M1), 410(E2)$	0.25 ± 0.06	$M1+5.7\%E2$
58.03	$L+M+\cdots$			80 ± 19[a]	$36.7(M1), 256(E2)$	0.50 ± 0.08	$M1+20\%E2$
60.5	$L+M+\cdots$			62 ± 21[a]	$32.6(M1), 208(E2)$	0.45 ± 0.12	$M1+17\%E2$
61.67	L_1+L_2	37.4	9.4 ± 1.0	23.5 ± 3.1	$22.8(M1), 78.7(E2)$	0.11 ± 0.025	
	L_3	43.0	1.3 ± 0.3	3.3 ± 0.8	$0.096(M1), 56.7(E2)$	0.24 ± 0.03	
	$M+N$	55.5	4.5 ± 0.6	11.0 ± 1.7	$7.7(M1), 53(E2)$	0.28 ± 0.07	$M1+7\%E2$
73.00	$L+M+\cdots$			40 ± 16[a]	$18.7(M1), 84.3(E2)$	0.69 ± 0.14	$M1+32\%E2$
165.7	L_1+L_2	141.7	1.8 ± 0.3	15 ± 3	$15.6(E3)$		$E3$
	L_3	146.6	0.8 ± 0.3	6.7 ± 2.6	$5.6(E3)$		
177.52	K	49.3	3.3 ± 0.5	0.19 ± 0.03	$0.17(E2)$		
	L_1+L_2	153.7	12.3 ± 1.2	0.71 ± 0.08	$0.73(E2)$		$E2$
	L_3	158.6	5.3 ± 0.5	0.31 ± 0.03	$0.31(E2)$		
	$M+N$	171.8	7.1 ± 0.7	0.41 ± 0.05	$0.40(E2)$		
227.38	K	99.1	41 ± 3	6.0 ± 0.5	$7.9(M2), 0.27(E3)$	0.58 ± 0.05	$M2+25\%E3$
	L_1+L_2	202.9	18.4 ± 1.9	2.7 ± 0.3	$2.76(M2), 3.26(E3)$		
	L_3	208.2	2.8 ± 0.3	0.41 ± 0.05	$0.28(M2), 0.91(E3)$		
	$M+N$	221.1	10.4 ± 1.1	1.53 ± 0.17	$1.13(M2), 1.73(E3)$		

[a] Deduced from decay scheme γ-ray and α-particle intensity balance.

ENSDF Dataset (1)

```
247CM    251CF A DECAY                 2003AH07
251CF  P 0.0          1/2+             898 Y     44             6175.8    10
247CM  N 1.0         1.0       1.0
247CM  L 0.0          9/2-             1.56E+7 Y 5
247CM  A 6078      2  2.6    1
247CM  L 62           11/2-
247CM  A 6017      2 12.5    3
247CM  G 61.67     5  0.40   3 M1+E2     0.24    3
247CM  L 135          13/2-
247CM  A 5946      2  0.60   6
247CM  G 73.00     8 0.040   5 M1+E2     0.69     14
247CM  G 134.65    8  0.014  3   [E2]
247CM  L 219           15/2-
247CM  G 84.35     8 0.040   5 [M1+E2]
247CM  G 157.35    8 0.020   4 [E2]
247CM  L 227          5/2+             26.3 US   3
247CM  A 5854      2 27.6    5
247CM  G 165.70    5 0.12    1  E3
247CM  G 227.38    2  6.8    3  M2+E3    0.58    5
247CM  L 266         (7/2+)
247CM  A 5817      2  4.0    2
247CM  G 38.48     5 0.038   6 (M1+E2)   0.19    5
247CM  G 265.86    8  0.43   3 [E1]
247CM  L 285         (7/2+)
247CM  A 5798      2  2.5    2
247CM  G 58.03     5 0.024   5 (M1+E2)   0.50    8
247CM  G 285.41    8  1.13   9   [E1]
247CM  L 318          9/2+
247CM  A 5766      2  3.6    2
247CM  G 52.45     5 0.048   5 (M1+E2)   0.25    6
247CM  G 256.65    8 0.13    1 [E1]
247CM  G 318.3     1 0.050   5 [E1]
247CM  L 346         (9/2+)
247CM  A 5738      2 0.8     1
247CM  G 60.5      1 0.010   3 (M1+E2)   0.45    12
247CM  G 284.2     1 0.12    1 [E1]
247CM  G 345.9     1 0.043   4 [E1]
```



$516.7 - 404.9 = 111.8$ keV

$518.6 - 404.9 = 113.7$ keV

$E_{\alpha}(516.7 + 518.6) = 5568$ keV

$E_{\alpha}(404.9) = 5679.3$ keV

$Q(516.7) = 5679.3 \times 251/247 - 111.8 = 5659.5$ keV

$E_{\alpha}(516.7) = 5659.5 \times 247/251 =$ 5569 keV

$Q(518.6) = 5679.3 \times 251/247 - 113.7 = 5657.6$ keV

$E_{\alpha}(518.6) = 5657.6 \times 247/251 =$ 5567 keV

ENSDF Dataset (2)

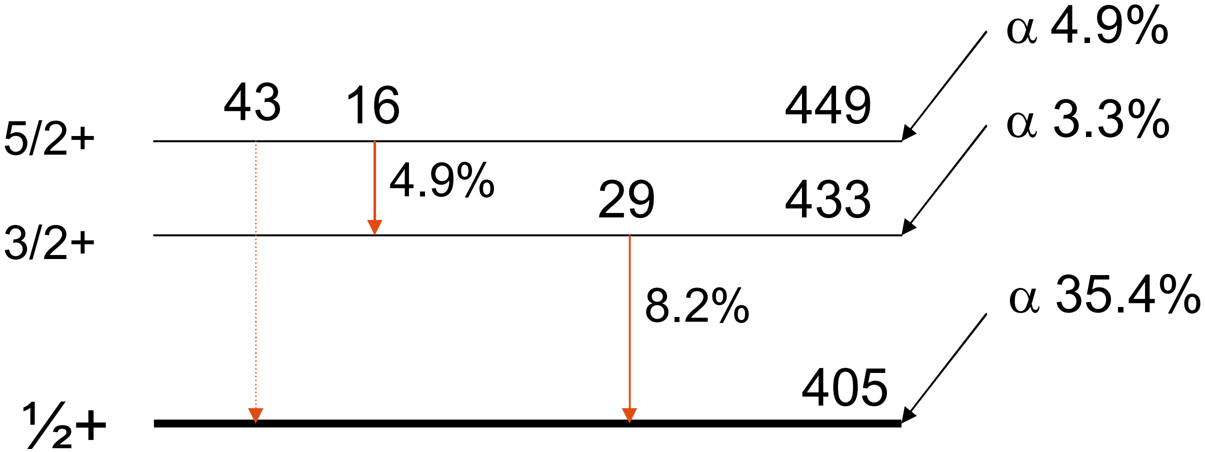
```
247CM  L 405          1/2+             100.6 NS  6
247CM  A 5679.3    1635.4    5
247CM  G 177.52    2  17.3   9  E2
247CM  L 434         (3/2+)
247CM  A 5651      2   3.3   2
247CM  G 28        5           [M1+E2]                          8.2       3
247CM  L 450       2 (5/2+)
247CM  A 5635      2   4.9   2
247CM  G 16        5           [M1+E2]                          4.9       2
247CM  G 44                                                                    S
247CM  L 517          (7/2+)
247CM  A 5569      2   1.9   LE
247CM cA E         from E|a(404.9 level)=5679.3 {I16} and the energy difference
247CM2cA between 516.7 and 404.9 levels (recoil energy is taken into account).
247CM3cA E|a=5568 {I2}, measured by 2003Ah07, is assumed by the evaluator to be
247CM4cA a doublet, feeding the 516.7- and 518.58-keV levels.
247CM cA IA        1.9 {I1} was measured by 2003Ah07 for the doublet.
247CM  G 289.3     1 0.070   7 [M1+E2]
247CM  L 519          (3/2+)
247CM  A 5567      2   1.9   LE
247CM cA E         from E|a(404.9 level)=5679.3 {I16} and the energy difference
247CM2cA between 518.6 and 404.9 levels (recoil energy is taken into account).
247CM  G 113.7     1 0.024   5 [M1+E2]
247CM  G 291.20    8 0.30    3 [M1+E2]
247CM  L 582         (5/2+)
247CM  A 5505      2  0.27   5
247CM  G 63        5           [M1+E2]                          0.21      5
247CM  G 315.8     1 0.024   3 [M1+E2]
247CM  G 354.3     1 0.013   2 [M1+E2]
```

Program HSICC (1)

```
247CM    251CF A DECAY                 2003AH07
251CF  P 0.0          1/2+             898 Y     44             6175.8    10
247CM  N 1.0         1.0       1.0
247CM  L 0.0          9/2-             1.56E+7 Y 5
247CM  A 6078      2  2.6    1
247CM  L 62           11/2-
247CM  A 6017      2 12.5    3
247CM  G 61.67     5  0.40   3 M1+E2     0.24    3       39.2 22
247CMS G LC=29.0 16$MC=7.4 5$NC+=2.82 18
247CM  L 135          13/2-
247CM  A 5946      2  0.60   6
247CM  G 73.00     8 0.040   5 M1+E2     0.69     14      40   6
247CMS G LC=29 5$MC=7.8 13$NC+=3.0 5
247CM  G 134.65    8  0.014  3   [E2]                    5.06
247CMS G KC=0.156$LC=3.52$MC=0.99$NC+=0.389
247CM  L 219           15/2-
247CM  G 84.35     8 0.040   5 [M1+E2]                    27
247CMS G LC=20 11$MC=5 4$NC+=2.1 13
247CM  G 157.35    8 0.020   4 [E2]                      2.62
247CMS G KC=0.178$LC=1.76$MC=0.495$NC+=0.193
247CM  L 227          5/2+             26.3 US   3
247CM  A 5854      2 27.6    5
247CM  G 165.70    5 0.12    1  E3                       31.2
247CMS G KC=0.243$LC=21.7$MC=6.60$NC+=2.65
247CM  G 227.38    2  6.8    3  M2+E3    0.58    5       10.6  2
247CMS G KC=6.0 3$LC=3.35 4$MC=0.93 2$NC+=0.364 6
247CM  L 266         (7/2+)
247CM  A 5817      2  4.0    2
247CM  G 38.48     5 0.038   6 (M1+E2)   0.19    5      1.8E2  4
247CMS G LC=135 25$MC=35 7
247CM  G 265.86    8  0.43   3 [E1]                     0.0571
247CMS G KC=0.0446$LC=0.0094$MC=0.00229$NC+=0.00084
247CM  L 285         (7/2+)
247CM  A 5798      2  2.5    2
247CM  G 58.03     5 0.024   5 (M1+E2)   0.50    8        80  12
247CMS G LC=58 8$MC=15.6 23$NC+=6.0 9
247CM  G 285.41    8  1.13   9   [E1]                   0.0489
247CMS G KC=0.0383$LC=0.00795$MC=0.00194$NC+=0.00071
247CM  L 318          9/2+
247CM  A 5766      2  3.6    2
247CM  G 52.45     5 0.048   5 (M1+E2)   0.25    6        71  11
247CMS G LC=52 8$MC=13.4 22$NC+=5.1 9
247CM  G 256.65    8 0.13    1 [E1]                     0.0617
247CMS G KC=0.0481$LC=0.0102$MC=0.00249$NC+=0.00091
247CM  G 318.3     1 0.050   5 [E1]                     0.0387
247CMS G KC=0.0304$LC=0.00620$MC=0.00151$NC+=0.00055
```

Program HSICC (2)

```
247CM  L 346          (9/2+)
247CM  A 5738       2 0.8     1
247CM  G 60.5       1 0.010   3 (M1+E2)   0.45    12       62  14
247CMS G LC=45 10$MC=12 3$NC+=4.6 11
247CM  G 284.2      1 0.12    1 [E1]                    0.0494
247CMS G KC=0.0386$LC=0.00803$MC=0.00196$NC+=0.00072
247CM  G 345.9      1 0.043   4 [E1]                    0.0324
247CMS G KC=0.0256$LC=0.00515$MC=0.00125$NC+=0.00046
247CM  L 405           1/2+             100.6 NS  6
247CM  A 5679.3     1635.4    5
247CM  G 177.52     2  17.3   9  E2                      1.61
247CMS G KC=0.168$LC=1.04$MC=0.291$NC+=0.113
247CM  L 434          (3/2+)
247CM  A 5651       2   3.3   2
247CM  G 28         5           [M1+E2]                 4.E3  58.2       3
247CMS G L/T=0.73 23$M/T=0.20 21
247CM  L 450        2 (5/2+)
247CM  A 5635       2   4.9   2
247CM  G 16         5           [M1+E2]                1.9E4 194.9       2
247CMS G M/T=0.75 19
247CM  G 44                                                                     S
247CM  L 517           (7/2+)
247CM  A 5569       2   1.9   LE
247CM cA E         from E|a(404.9 level)=5679.3 {I16} and the energy difference
247CM2cA between 516.7 and 404.9 levels (recoil energy is taken into account).
247CM3cA E|a=5568 {I2}, measured by 2003Ah07, is assumed by the evaluator to be
247CM4cA a doublet, feeding the 516.7- and 518.58-keV levels.
247CM cA IA        1.9 {I1} was measured by 2003Ah07 for the doublet.
247CM  G 289.3      1 0.070   7 [M1+E2]                 1.0   8
247CMS G KC=0.7 7$LC=0.21 7$MC=0.052 15$NC+=0.020 6
247CM  L 519           (3/2+)
247CM  A 5567       2   1.9   LE
247CM cA E         from E|a(404.9 level)=5679.3 {I16} and the energy difference
247CM2cA between 518.6 and 404.9 levels (recoil energy is taken into account).
247CM  G 113.7      1 0.024   5 [M1+E2]                  8    3
247CMS G LC=5.7 19$MC=1.5 6$NC+=0.60 25
247CM  G 291.20     8 0.30    3 [M1+E2]                 1.0   7
247CMS G KC=0.7 7$LC=0.20 7$MC=0.051 15$NC+=0.020 6
247CM  L 582          (5/2+)
247CM  A 5505       2  0.27   5
247CM  G 63         5           [M1+E2]                1.0E2  70.21      5
247CMS G L/T=0.72 19$M/T=0.20 16$N/T=0.08 7
247CM  G 315.8      1 0.024   3 [M1+E2]                 0.8   6
247CMS G KC=0.6 5$LC=0.16 6$MC=0.040 13$NC+=0.015 5
247CM  G 354.3      1 0.013   2 [M1+E2]                 0.6   5
247CMS G KC=0.4 4$LC=0.11 5$MC=0.028 11$NC+=0.011 4
```


α 4.9%
α 3.3%
α 35.4%
43
16
449
5/2+
4.9%
29
433
3/2+
8.2%
405
½+

Report from GTOL

```
                RI           RI           RI           TI           TI           TI              NET FEEDING
LEVEL        (OUT)        (IN)           (NET)        (OUT)         (IN)           (NET)        (CALC)        (INPUT)

    0.0        0.000          8.9  4      -8.9  4     0.000           97  5       -97  5            3  5   2.6     1
       Upper limit (90% C.L.) estimates:
         Method 1:     9.80
         Method 2:     9.10
  61.67  4      0.40  3     0.430 19     -0.03  4      16.1 16       5.8  5      10.2 17         10.2 17  12.5     3
 134.66  6     0.054  6     0.040  5     0.014  8       1.7  4       1.1  7       0.6  8          0.6  8   0.60     6
       Upper limit (90% C.L.) estimates:
         Method 1:     1.63
         Method 2:     1.54
 219.02  7     0.060  7     0.000        0.060  7       1.2  7     0.000             1.2  7          1.2  7
       Upper limit (90% C.L.) estimates:
         Method 1:     2.05
         Method 2:     2.03
227.379 19       6.9  3      17.7  9     -10.8 10        83  5        55  4        28  6           28  6  27.6     5
 265.86  4      0.47  3     0.072  6      0.40  4       7.3 19       3.5  7       3.8 20          3.8 20    4.0     2
       Upper limit (90% C.L.) estimates:
         Method 1:     6.40
         Method 2:     6.38
 285.41  5      1.15  9     0.010  3      1.14  9       3.1  5      0.63 24       2.5  6          2.5  6    2.5     2
 318.31  5     0.228 13     0.000        0.228 13       3.6  7     0.000             3.6  7          3.6  7    3.6     2
 345.89  6     0.173 12     0.000        0.173 12      0.80 24     0.000            0.80 24         0.80 24  0.8      1
 404.90  3      17.3  9     0.024  5      17.3  9      45.2 25       8.4  4        37  3           37  3  35.4     5
    433  4     0.000        0.000        0.000              8.2  3      4.90 20       3.3  4          3.3  4    3.3     2
  448.9 10     0.000        0.000        0.000             4.90 20     0.000            4.90 20         4.90 20    4.9     2
 516.68 11     0.070  7     0.000        0.070  7      0.14  6     0.000            0.14  6         0.14  6    1.9     LE
 518.59  7      0.32  3     0.000         0.32  3      0.82 24      0.21  5      0.61 24         0.61 24    1.9     LE
 581.67  8     0.037  4     0.000        0.037  4      0.27  6     0.000            0.27  6         0.27  6   0.27     5
```

Program GTOL (1)

```
247CM    251CF A DECAY                  2003AH07
251CF  P 0.0          1/2+             898 Y     44             6175.8    10
247CM  N 1.0         1.0       1.0
247CM  L 0.0          9/2-             1.56E+7 Y 5
247CM  A 6078      2  2.6    1 5080
247CM  L      61.67 4 11/2-
247CM  A 6017      2 12.5    3 512
247CM  G 61.67     5  0.40   3 M1+E2     0.24    3       39.2 22
247CMS G LC=29.0 16$MC=7.4 5$NC+=2.82 18
247CM  L     134.66 6 13/2-
247CM  A 5946      2  0.60   6 4460
247CM  G 73.00     8 0.040   5 M1+E2     0.69     14      40   6
247CMS G LC=29 5$MC=7.8 13$NC+=3.0 5
247CM  G 134.65    8  0.014  3   [E2]                    5.06
247CMS G KC=0.156$LC=3.52$MC=0.99$NC+=0.389
247CM  L     219.02 7  15/2-
247CM  G 84.35     8 0.040   5 [M1+E2]                    27  16
247CMS G LC=20 11$MC=5 4$NC+=2.1 13
247CM  G 157.35    8 0.020   4 [E2]                      2.62
247CMS G KC=0.178$LC=1.76$MC=0.495$NC+=0.193
247CM  L    227.37919 5/2+             26.3 US   3
247CM  A 5854      2 27.6    5 31.3
247CM  G 165.70    5 0.12    1  E3                       31.2
247CMS G KC=0.243$LC=21.7$MC=6.60$NC+=2.65
247CM  G 227.38    2  6.8    3  M2+E3    0.58    5       10.6  2
247CMS G KC=6.0 3$LC=3.35 4$MC=0.93 2$NC+=0.364 6
247CM  L     265.86 4(7/2+)
247CM  A 5817      2  4.0    2 134
247CM  G 38.48     5 0.038   6 (M1+E2)   0.19    5      1.8E2  4
247CMS G LC=135 25$MC=35 7
247CM  G 265.86    8  0.43   3 [E1]                     0.0571
247CMS G KC=0.0446$LC=0.0094$MC=0.00229$NC+=0.00084
247CM  L     285.41 5(7/2+)
247CM  A 5798      2  2.5    2 168
247CM  G 58.03     5 0.024   5 (M1+E2)   0.50    8        80  12
247CMS G LC=58 8$MC=15.6 23$NC+=6.0 9
247CM  G 285.41    8  1.13   9   [E1]                   0.0489
247CMS G KC=0.0383$LC=0.00795$MC=0.00194$NC+=0.00071
247CM  L     318.31 5 9/2+
247CM  A 5766      2  3.6    2 77
247CM  G 52.45     5 0.048   5 (M1+E2)   0.25    6        71  11
247CMS G LC=52 8$MC=13.4 22$NC+=5.1 9
247CM  G 256.65    8 0.13    1 [E1]                     0.0617
247CMS G KC=0.0481$LC=0.0102$MC=0.00249$NC+=0.00091
247CM  G 318.3     1 0.050   5 [E1]                     0.0387
247CMS G KC=0.0304$LC=0.00620$MC=0.00151$NC+=0.00055
```

Program GTOL (2)

```
247CM  L     345.89 6(9/2+)
247CM  A 5738      2 0.8     1 244
247CM  G 60.5      1 0.010   3 (M1+E2)   0.45    12       62  14
247CMS G LC=45 10$MC=12 3$NC+=4.6 11
247CM  G 284.2     1 0.12    1 [E1]                     0.0494
247CMS G KC=0.0386$LC=0.00803$MC=0.00196$NC+=0.00072
247CM  G 345.9     1 0.043   4 [E1]                     0.0324
247CMS G KC=0.0256$LC=0.00515$MC=0.00125$NC+=0.00046
247CM  L     404.90 3 1/2+             100.6 NS   6
247CM  A 5679.3    1635.4    5 2.6
247CM  G 177.52    2  17.3   9  E2                       1.61
247CMS G KC=0.168$LC=1.04$MC=0.291$NC+=0.113
247CM  L        433 4(3/2+)
247CM  A 5651      2   3.3   2 19.2
247CM  G 28        5           [M1+E2]                   4.E3  58.2       3
247CMS G L/T=0.73 23$M/T=0.20 21
247CM  L      448.910(5/2+)
247CM  A 5635      2   4.9   2 10.5
247CM  G 16        5           [M1+E2]                  1.9E4 194.9       2
247CMS G M/T=0.75 19
247CM  G 44                                                                    S
247CM  L     516.6811 (7/2+)
247CM  A 5569      2   1.9   LE11      GE
247CM cA E         from E|a(404.9 level)=5679.3 {I16} and the energy difference
247CM2cA between 516.7 and 404.9 levels (recoil energy is taken into account).
247CM3cA E|a=5568 {I2}, measured by 2003Ah07, is assumed by the evaluator to be
247CM4cA a doublet, feeding the 516.7- and 518.58-keV levels.
247CM cA IA        1.9 {I1} was measured by 2003Ah07 for the doublet.
247CM  G 289.3     1 0.070   7 [M1+E2]                   1.0   8
247CMS G KC=0.7 7$LC=0.21 7$MC=0.052 15$NC+=0.020 6
247CM  L     518.59 7 (3/2+)
247CM  A 5567      2   1.9   LE11      GE
247CM cA E         from E|a(404.9 level)=5679.3 {I16} and the energy difference
247CM2cA between 518.6 and 404.9 levels (recoil energy is taken into account).
247CM  G 113.7     1 0.024   5 [M1+E2]                    8    3
247CMS G LC=5.7 19$MC=1.5 6$NC+=0.60 25
247CM  G 291.20    8 0.30    3 [M1+E2]                   1.0   7
247CMS G KC=0.7 7$LC=0.20 7$MC=0.051 15$NC+=0.020 6
247CM  L     581.67 8(5/2+)
247CM  A 5505      2  0.27   5 32
247CM  G 63        5           [M1+E2]                  1.0E2  70.21      5
247CMS G L/T=0.72 19$M/T=0.20 16$N/T=0.08 7
247CM  G 315.8     1 0.024   3 [M1+E2]                   0.8   6
247CMS G KC=0.6 5$LC=0.16 6$MC=0.040 13$NC+=0.015 5
247CM  G 354.3     1 0.013   2 [M1+E2]                   0.6   5
247CMS G KC=0.4 4$LC=0.11 5$MC=0.028 11$NC+=0.011 4
```

Program AlphaD (Alpha Hindrance factors)

```
            98      251.                                                                  DATE RUN 23-FEB- 5
Q ALPHA     E TOTAL    ALPHA HALF LIFE      RADIUS       RZERO      TOTAL HALF LIFE     ALPHA BRANCH
 6.1758     6.2154          3.280E+05 D     9.3638E-13   1.4924     8.980E+02 Y         1.000E+00

ENERGY LEVEL      ABUNDANCE       CALC. HALF LIFE       HINDRANCE FACTOR

   0.00           2.60E-02             2.48E+03                5.08E+03
  61.67           1.25E-01             5.13E+03                5.12E+02
 134.66           6.00E-03             1.23E+04                4.46E+03
 227.38           2.76E-01             3.80E+04                3.13E+01
 265.86           4.00E-02             6.13E+04                1.34E+02
 285.41           2.50E-02             7.83E+04                1.68E+02
 318.31           3.60E-02             1.18E+05                7.69E+01
 345.89           8.00E-03             1.68E+05                2.44E+02
 404.90           3.54E-01             3.59E+05                2.58E+00
 433.00           3.30E-02             5.17E+05                1.92E+01
 448.90           4.90E-02             6.36E+05                1.05E+01
 516.68           1.90E-02             1.56E+06                1.11E+01
 518.59           1.90E-02             1.60E+06                1.08E+01
 581.67           2.70E-03             3.74E+06                3.25E+01
```