Decay Data

- ☐ decay data are very rich source of nuclear structure information & are of importance to many other areas
  - ✓ nuclear structure – often offer the best quantities, because the complexity of spectra is reduced
  - ✓ astrophysics – especially on the “r-process” side – neutron-rich nuclei
  - ✓ atomic masses – proton-rich ($Q\alpha$ & Qp); neutron-rich ($Q\beta-$)
  - ✓ applications of nuclear science

Plan

Today: $\alpha-$ and $\beta-$decays - isomers (IT decay) on Friday

Introduction

❑ Decay Data

✓ experimental results obtained following $\alpha-$, β−-, $\beta+$, EC, IT, p, cluster, etc. decay processes

❑ Evaluated Decay Data

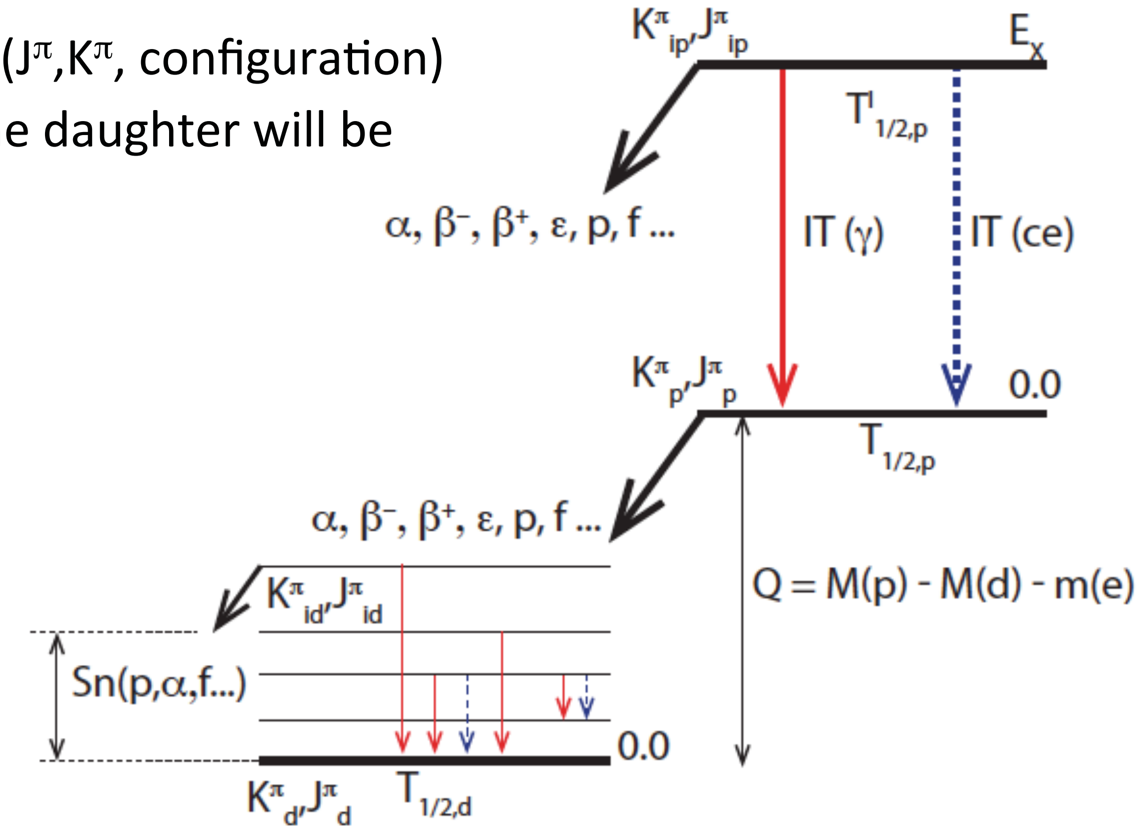
✓ Recommended (best) values for nuclear levels and decay radiation properties, deduced by the evaluator using all available experimental data & theoretical calculations (conv. coefficients)

Myth: decay data evaluation deals only with decay data – many properties come from other decays and reactions (adopted level properties), e.g $E\gamma$, $I\gamma$, MR, ICC, …

Introduction – cont.

- structure of the parent state (J^π,K^π, configuration)
  - ✓ controls which states of the daughter will be populated

- **excitation energy**
- **quantum numbers and their projections**
- **lifetime**
- **decay modes & branching ratios**

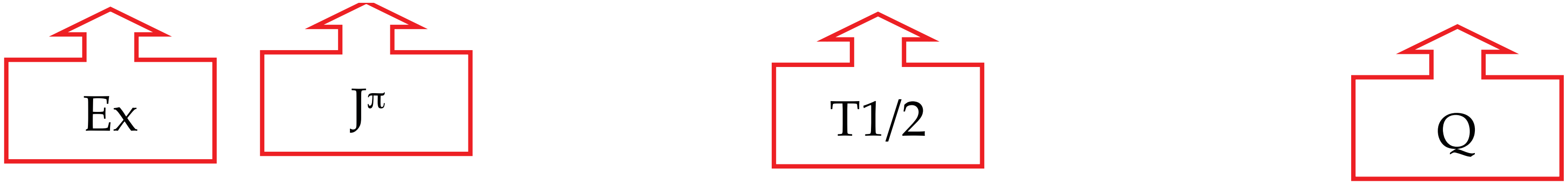


- Q-value – defines the energetics of the decay
  - ✓ controls the lifetime of the parent
  - ✓ the window of daughter states available

Introduction – cont.

- every decay dataset MUST have a Parent record

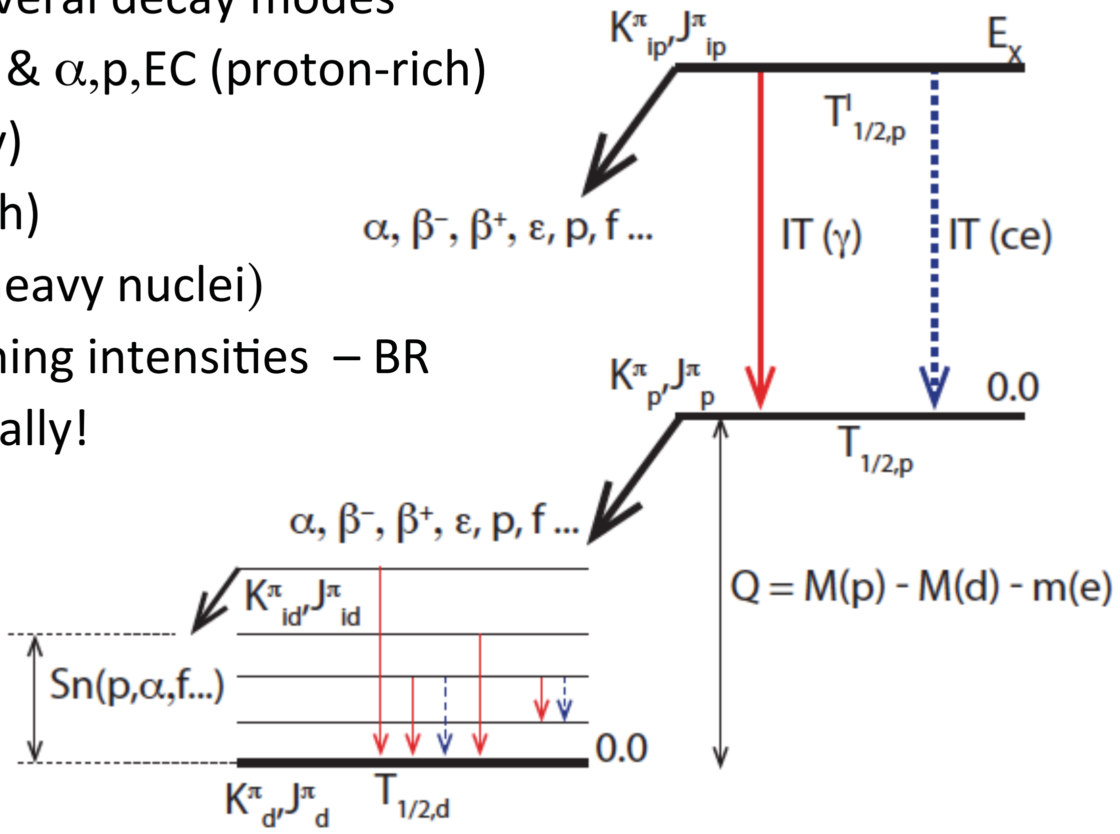
```
206TL    206HG B- DECAY                1970AS05,1968WO08        08NDS   200805
206TL  H TYP=FUL$AUT=F.G. KONDEV$CIT=NDS 109, 1527 (2008)$CUT=31-Jan-2008$

206TL c  1968Wo08: {+206}Hg produced by {+208}Pb(p,3p) reaction and isotope
206TL2c  separation. |b{+-} measured in proportional counter, ce in Si(Li)
206TL2c  detectors, |g singles and |g|g coincidences in NaI and Ge detector,
206TL3c  and |g|b{+-} coincidences with NaI and Si(Li) detectors.

206TL c  1970As05: {+206}Hg produced by {+208}Pb(p,3p) reaction with E(p)=600
206TL2c  MeV. |g singles measured with Ge detector, lifetime measured with
206TL3c  plastic scintillators.
206TL c  Other: 1969Ha03: survey measurement of level lifetimes using 600 MeV
206TL2c  proton beam on Pb target with isotope separation. Measured limit for
206TL3c  T{-1/2}(305|g).

206HG  P 0          0+                  8.32 M     7             1308     20
```



```
206HG CP T$From 1111AAyy ...
```

Introduction – cont.

- nuclear state can decay via several decay modes
  - ✓ IT & β^- (neutron-rich) or IT & α,p,EC (proton-rich)
  - ✓ β^- & EC (near the stability)
  - ✓ α & p or α & EC (proton-rich)
  - ✓ α & SF or α & β^- (^{255}Es) (heavy nuclei)
- one needs to know the branching intensities – BR
  - ✓ not a trivial job experimentally!

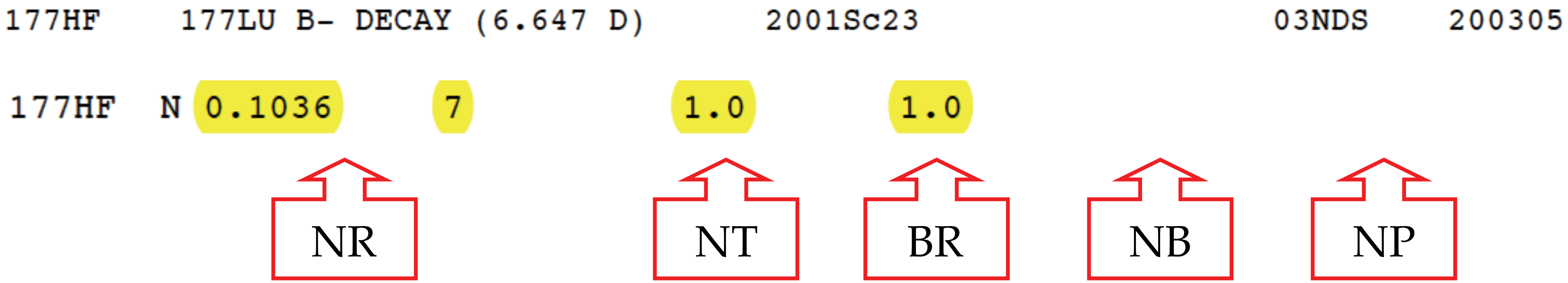


%I = Intensity/100 parent decays

- usually the experiments provide relative emission probabilities – absolute measurements are difficult & rare
  - ✓ convert relative to absolute emission probabilities using the properties of the decay scheme – NORMALIZATION

Introduction – cont.

❑ **every decay dataset MUST have a Normalization record**



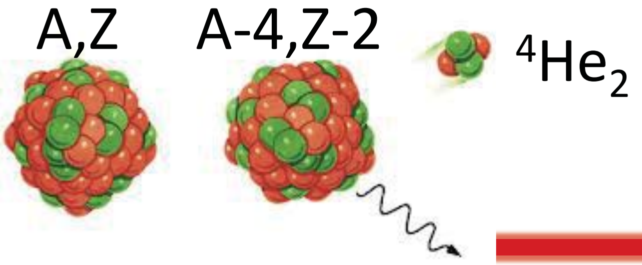
```
177HF    177LU B- DECAY (6.647 D)       2001Sc23                   03NDS    200305

177HF  N 0.1036    7           1.0       1.0
```

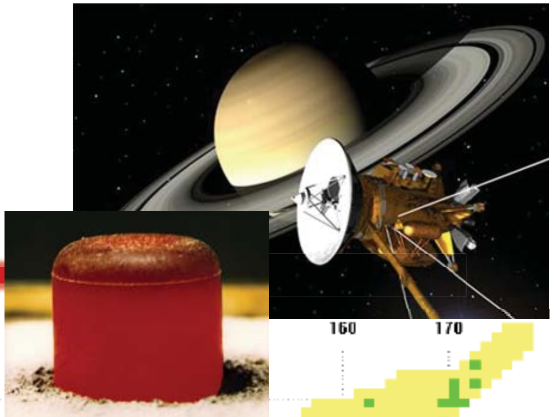
NR NT BR NB NP

Relative Intensity	**Normalization factor**	**Absolute Intensity**
Iγ x	NR x BR	= %Iγ
Iγ (tot) x	NT x BR	= %Iγ (tot)
Iβ (or α or ε) x	NB x BR	= %Iβ (or α or ε)
Iβn (or εp …) x	NP x BR	= %Iβn (or εp …)

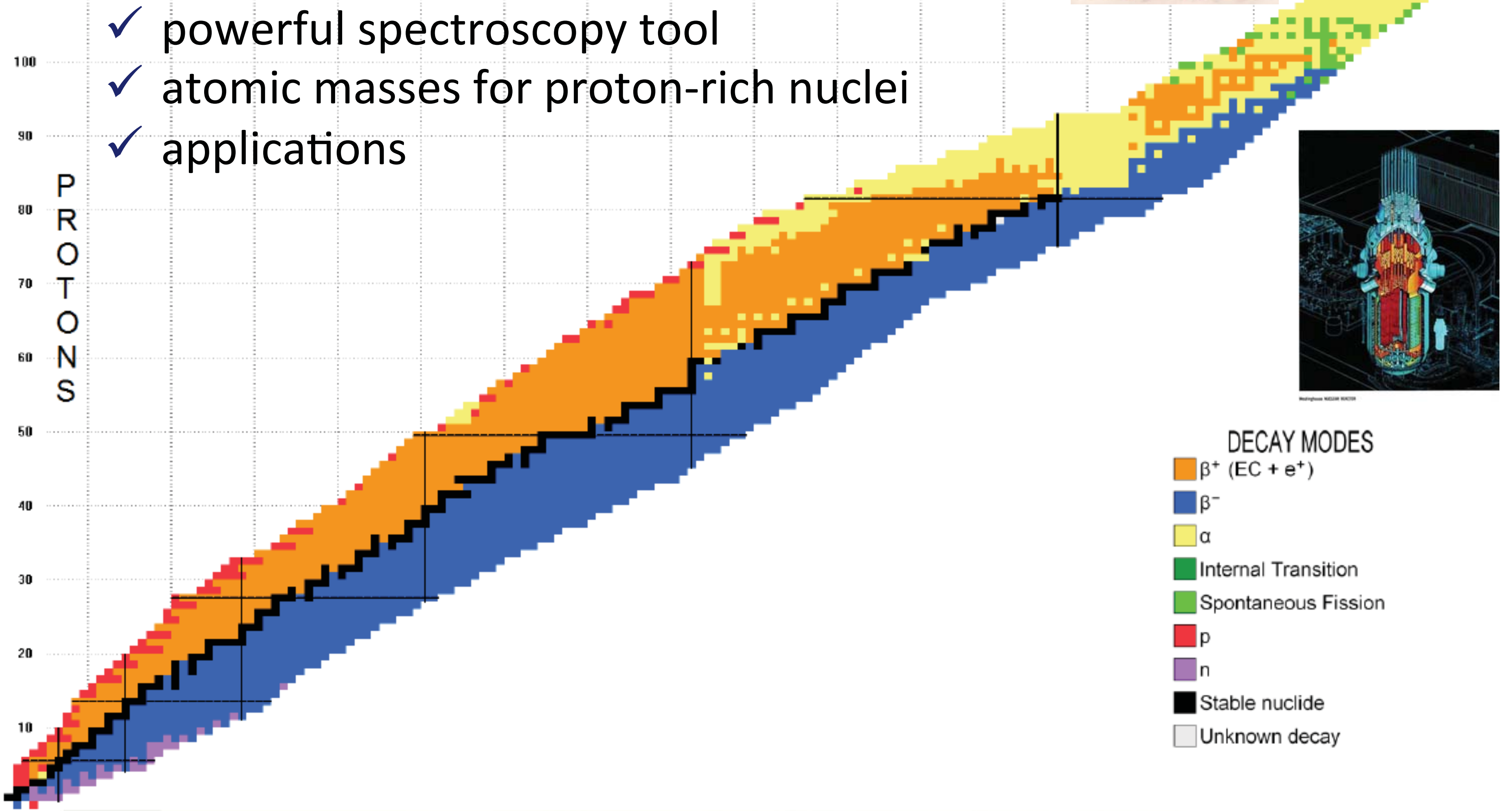
```
177HF cN NR$Using absolute |g ray intensity for the 208.3662|g of 10.36% {I7}
177HF2cN from 2001Sc23
```

α−decay





- ✓ powerful spectroscopy tool
- ✓ atomic masses for proton-rich nuclei
- ✓ applications



α−decay – cont.

$$|I_i - I_f| \le l_\alpha \le |I_i + I_f|$$

$$\pi_i \pi_f = (-1)^{l_\alpha}$$

even-even nuclei:

0+ -> 0+; l_α=0

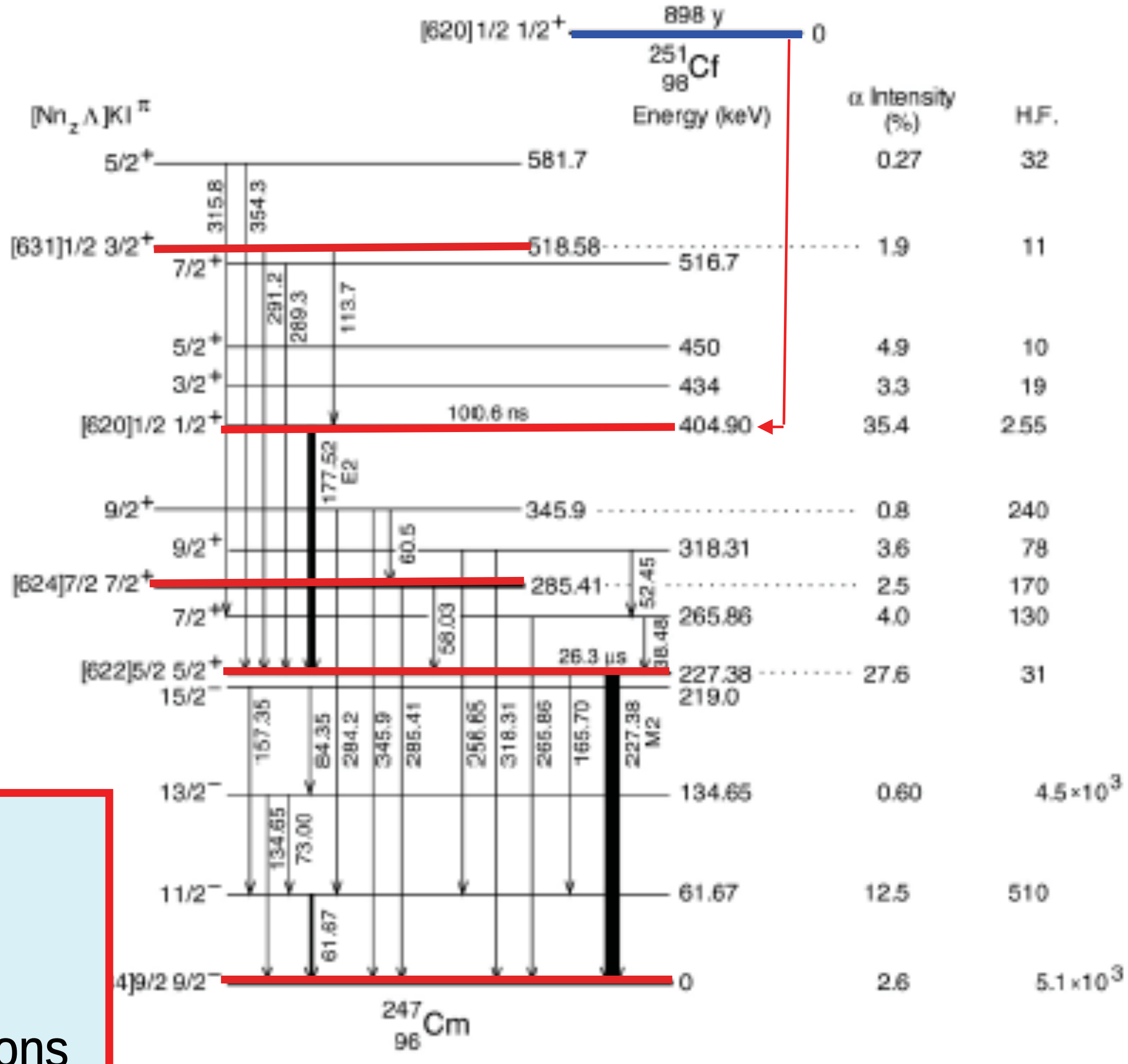
odd-A:

1/2+ -> 1/2+; l_α=0,~~1~~

1/2+ -> 3/2+; l_α=~~1~~,2

1/2+ -> 9/2-; l_α=~~4~~,5

- ☐ Strong dependence on l_α
- ✓ fastest decay for l_α=0
- ☐ Configuration dependence
- ✓ fastest for the same configurations

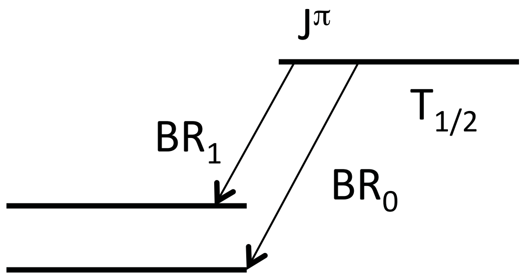


I. Ahmad et al., Phys. Rev. C68 (2003) 044306

Hindrance Factor in α−decay

HF < 4 – favorite decay (fast)

$$HF_i = \frac{t_{1/2}^{\alpha_i}(\exp)}{t_{1/2}^{\alpha_i}(th)} = \frac{T_{1/2}(\exp)/BR_i}{t_{1/2}^{\alpha_i}(th)}$$



$t_{1/2}^{\alpha_i}(th)$ M.A. Preston, Phys. Rev. 71 (1947) 865

$$t_{1/2}^{\alpha} = \ln 2 \boxed{\frac{r_0}{2v}} \frac{\mu^2(H_l^2 + K_l^2) + \tan^2\alpha_0(C_l^2 + S_l^2) + 2\mu\tan\alpha_0(C_lK_l - S_lH_l)}{\mu^2\tan\alpha_0(H_lC_l + K_lS_l)Q_l} e^{+2\omega_0}$$

- ✓ depends on r_0 and Q(α) - nuclear radius: $R=r_0 \times A^{1/3}$ $\quad v = \sqrt{2E_\alpha / m_\alpha}$

$$Q_{\alpha i} = Q_{\alpha 0} - E_i = [m(A,Z) - m(A-4,Z-2) - m_\alpha] - E_i$$

from AME12

$$Q_{\alpha 0} = E_{\alpha 0} \times \frac{m(A,Z)}{m(A-4,Z-2)} = E_{\alpha 0} \times \left(1 + \frac{4}{(A-4)}\right)$$

$E_{\alpha 0}$, $Q_{\alpha 0}$ in keV

$$Q_{\alpha 0} = \frac{2 \times m(A,Z) \times E_{\alpha 0}}{m(A-4,Z-2) + \sqrt{m(A-4,Z-2)^2 - 2 \times m(A,Z) \times E_{\alpha 0}}} \approx E_{\alpha 0} \times \left(1 + \frac{4.0015}{(A-4)}\right) + 0.15$$

relativistic formula

Hindrance Factor in α–decay – cont.

- Odd-N nucleus (Z, A)

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

- Odd-Z nucleus (Z, A)

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

- Odd-Odd nucleus (Z, A)

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

^{209}Rn(Z=86) $\Rightarrow$ ^{205}Po (Z=84, A=121) (Odd-N) $\Rightarrow$ ^{204}Po (84,120) and ^{206}Po (84,122)

$$r_0\ (84, 121) = [r_0(84, 120) + r_0(84, 122)]\ /2$$

From neighboring even-even nuclei (also 1998Ak04) – use r0 for even-even nuclei:

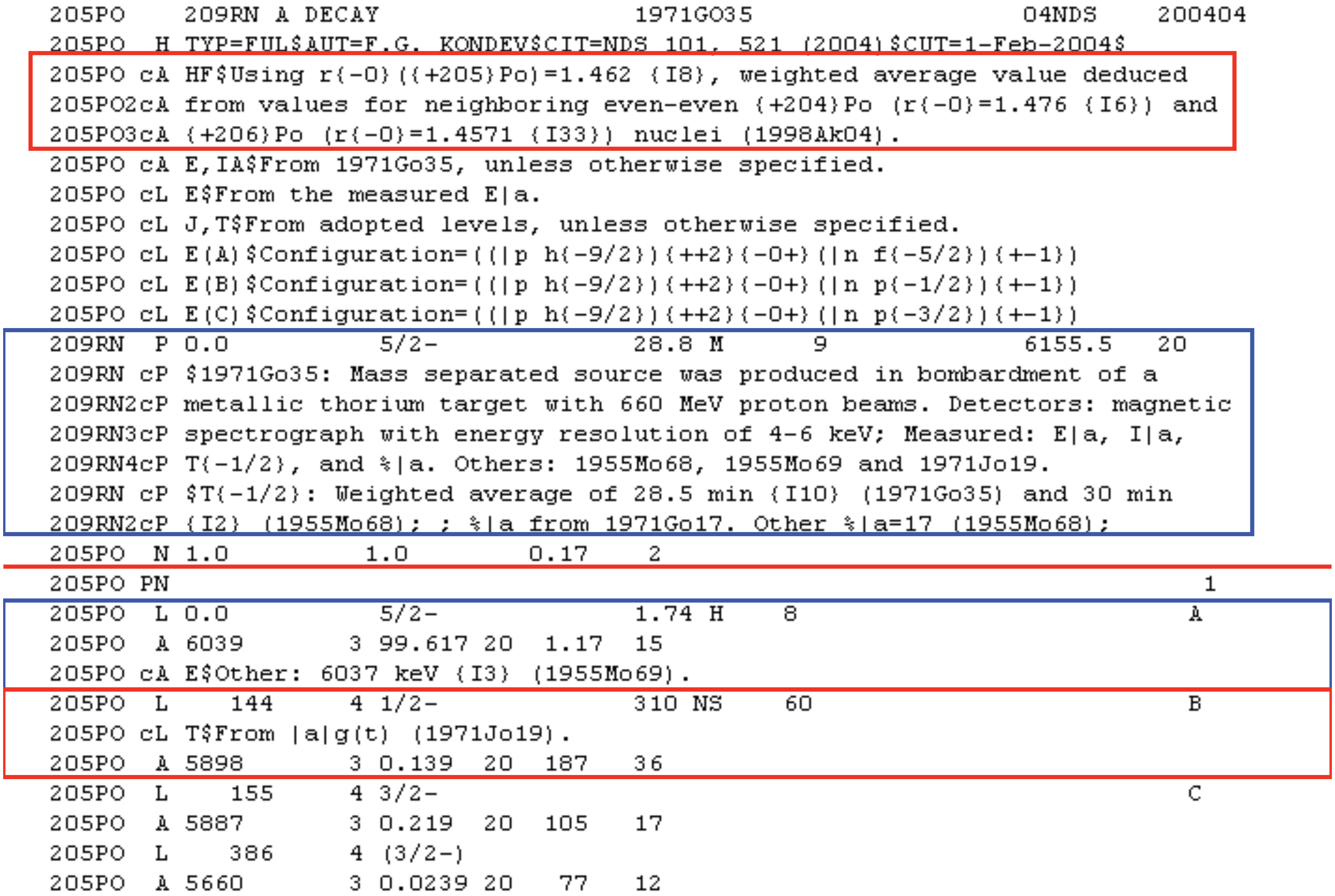
$$r_0(84,120) = 1.476\ \mathit{6}$$

$$r_0(84,122) = 1.4571\ \mathit{33}$$

weighted average: r_0 (84, 121) = 1.462 8

- insert r0= … in A (alpha) *comment* record (CA):

205PO CA HF\$r0=1.462 8, weighted average of 1.476 6 (204PO) and …



```
205PO    209RN A DECAY                 1971GO35                  04NDS    200404
205PO  H TYP=FUL$AUT=F.G. KONDEV$CIT=NDS 101, 521 (2004)$CUT=1-Feb-2004$
205PO cA HF$Using r{-0}({+205}Po)=1.462 {I8}, weighted average value deduced
205PO2cA from values for neighboring even-even {+204}Po (r{-0}=1.476 {I6}) and
205PO3cA {+206}Po (r{-0}=1.4571 {I33}) nuclei (1998Ak04).
205PO cA E,IA$From 1971Go35, unless otherwise specified.
205PO cL E$From the measured E|a.
205PO cL J,T$From adopted levels, unless otherwise specified.
205PO cL E(A)$Configuration=((|p h{-9/2}){++2}{-0+}(|n f{-5/2}){+-1})
205PO cL E(B)$Configuration=((|p h{-9/2}){++2}{-0+}(|n p{-1/2}){+-1})
205PO cL E(C)$Configuration=((|p h{-9/2}){++2}{-0+}(|n p{-3/2}){+-1})
209RN  P 0.0          5/2-             28.8 M    9             6155.5   20
209RN cP $1971Go35: Mass separated source was produced in bombardment of a
209RN2cP metallic thorium target with 660 MeV proton beams. Detectors: magnetic
209RN3cP spectrograph with energy resolution of 4-6 keV; Measured: E|a, I|a,
209RN4cP T{-1/2}, and %|a. Others: 1955Mo68, 1955Mo69 and 1971Jo19.
209RN cP $T{-1/2}: Weighted average of 28.5 min {I10} (1971Go35) and 30 min
209RN2cP {I2} (1955Mo68); ; %|a from 1971Go17. Other %|a=17 (1955Mo68);
205PO  N 1.0         1.0        0.17    2
205PO PN                                                                     1
205PO  L 0.0          5/2-             1.74 H    8                          A
205PO  A 6039       3 99.617 20  1.17  15
205PO cA E$Other: 6037 keV {I3} (1955Mo69).
205PO  L    144     4 1/2-             310 NS    60                         B
205PO cL T$From |a|g(t) (1971Jo19).
205PO  A 5898       3 0.139  20  187   36
205PO  L    155     4 3/2-                                                  C
205PO  A 5887       3 0.219  20  105   17
205PO  L    386     4 (3/2-)
205PO  A 5660       3 0.0239 20   77   12
```

^{209}Rn α Decay 1971Go35

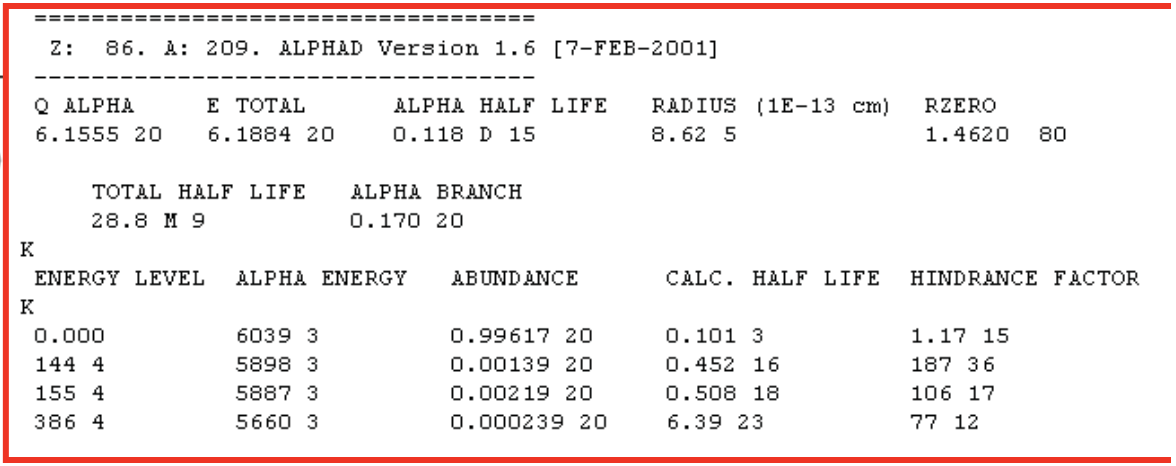
Parent ^{209}Rn: E=0.0; Jπ=5/2−; $T_{1/2}$=28.8 min 9; Q(g.s.)=6155.5 20; %α decay=17 2.

^{209}Rn: 1971Go35: Mass separated source was produced in bombardment of a metallic thorium target with 660 MeV proton beams. Detectors: magnetic spectrograph with energy resolution of 4–6 keV; Measured: Eα, Iα, $T_{1/2}$, and %α. Others: 1955Mo68, 1955Mo69 and 1971Jo19.

^{209}Rn: $T_{1/2}$: Weighted average of 28.5 min 10 (1971Go35) and 30 min 2 (1955Mo68); ; %α from 1971Go17. Other %α=17 (1955Mo68).

^{205}Po Levels

alphad.rpt



```
==================================
 Z:  86. A: 209. ALPHAD Version 1.6 [7-FEB-2001]
----------------------------------
Q ALPHA      E TOTAL      ALPHA HALF LIFE     RADIUS (1E-13 cm)   RZERO
6.1555 20    6.1884 20    0.118 D 15          8.62 5              1.4620  80

    TOTAL HALF LIFE    ALPHA BRANCH
    28.8 M 9           0.170 20
K
 ENERGY LEVEL  ALPHA ENERGY   ABUNDANCE      CALC. HALF LIFE   HINDRANCE FACTOR
K
 0.000         6039 3         0.99617 20     0.101 3           1.17 15
 144 4         5898 3         0.00139 20     0.452 16          187 36
 155 4         5887 3         0.00219 20     0.508 18          106 17
 386 4         5660 3         0.000239 20    6.39 23           77 12
```

E(level)[†]	Jπ[‡]	$T_{1/2}$[‡]	
0.0[§]	5/2−	1.74 h 8	
144[#] 4	1/2−	310 ns 60	$T_{1/2}$: From αγ(t)
155[@] 4	3/2−		
386 4	(3/2−)		

[†] From the measured Eα.

[‡] From adopted levels, unless otherwise specified.

[§] Configuration=$((\pi h_{9/2})^{+2}_{0+}(\nu f_{5/2})^{-1})$.

[#] Configuration=$((\pi h_{9/2})^{+2}_{0+}(\nu p_{1/2})^{-1})$.

[@] Configuration=$((\pi h_{9/2})^{+2}_{0+}(\nu p_{3/2})^{-1})$.

α radiations

Eα[‡]	E(level)	Iα[‡][§]	HF[†]	Comments
5660 3	386	0.0239 20	77 12	
5887 3	155	0.219 20	105 17	
5898 3	144	0.139 20	187 36	
6039 3	0.0	99.617 20	1.17 15	Eα: Other: 6037 keV 3 (1955Mo69).

[†] Using $r_0(^{205}Po)$=1.462 8, weighted average value deduced from values for neighboring even–even ^{204}Po (r_0=1.476 6) and ^{206}Po (r_0=1.4571 33) nuclei (1998Ak04).

[‡] From 1971Go35, unless otherwise specified.

[§] For α intensity per 100 decays, multiply by 0.17 2.

α decay - Experiments

- ❑ magnetic spectrometers
- ❑ ionization chambers
- ❑ semiconductor detectors – mostly Si
  - ✓ Si(Au), PIPS, DSSD, …

- ❑ using radioactive sources (off-line)
  - ✓ when lifetimes are sufficiently long

- ❑ using nuclear reactions (on-line)
  - ✓ implanting on a catcher foil
  - ✓ implanting directly on the DSSD

absolute determinations of α energies **using the BIPM magnetic spectrometer with a semi-circle focusing of alpha-particles**. These measurements were performed in the 70's - 80’s for the **most intense alpha-transitions**

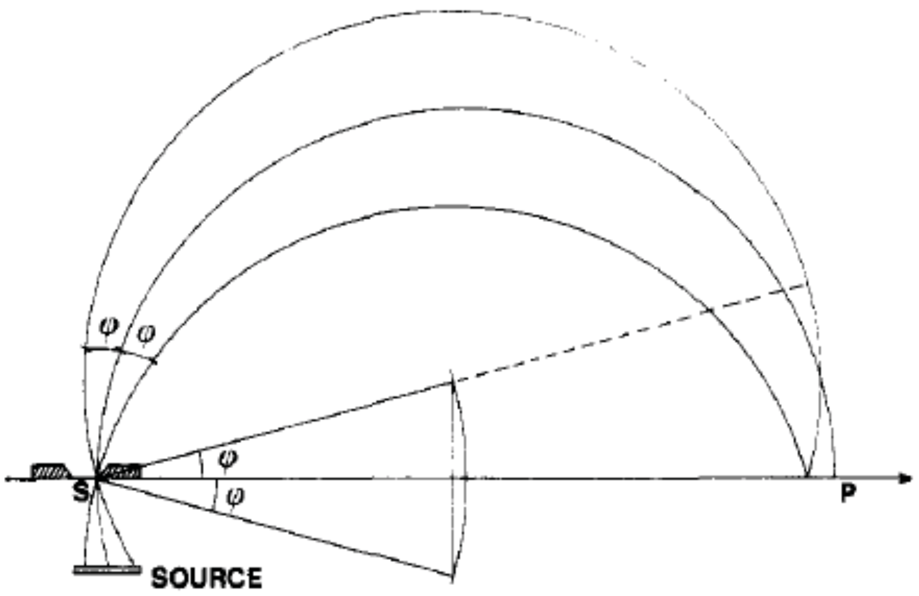
- ✓ **^{228}Th, ^{224,226}Ra, ^{220,222,219}Rn, ^{216,212,218,214,215}Po, ^{212}Bi, ^{227}Th, ^{223}Ra, ^{211}Bi, ^{253}Es, ^{242,244}Cm, ^{241}Am, ^{238}Pu – B. Grennberg, A. Rytz,** Metrologia 7, 65 (1971)
- ✓ **^{232}U, ^{240}Pu – D.J. Gorman, A. Rytz, H.V. Michel,** C. R. Acad. Sci., Ser. B 275, 291 (1972)
- ✓ **^{210}Po** - **D.J. Gorman, A. Rytz,** C. R. Acad. Sci., Ser. B 277, 29 (1973)
- ✓ **^{239}Pu** - **A. Rytz,** Proc. Intern. Conf. Atomic Masses and Fundamental Constants, 6th, East Lansing (1979)
- ✓ **^{236}Pu** - **A. Rytz, R.A.P. Wiltshire,** Nucl. Instrum. Methods 223, 325 (1984)
- ✓ **^{252}Cf, ^{227}Ac** - **A. Rytz, R.A.P. Wiltshire, M. King,** Nucl. Instrum. Methods Phys. Res. A253, 47 (1986).

Two parameters - the radius of curvature ρ and the mean magnetic induction **B.**

$$E(\alpha) = a\,(B\rho)^2 + b\,(B\rho)^4 + d\,(B\rho)^6$$

The factors **a, b, d** are derived from the latest adjustment of fundamental constants (**m_e, e and N_A**).

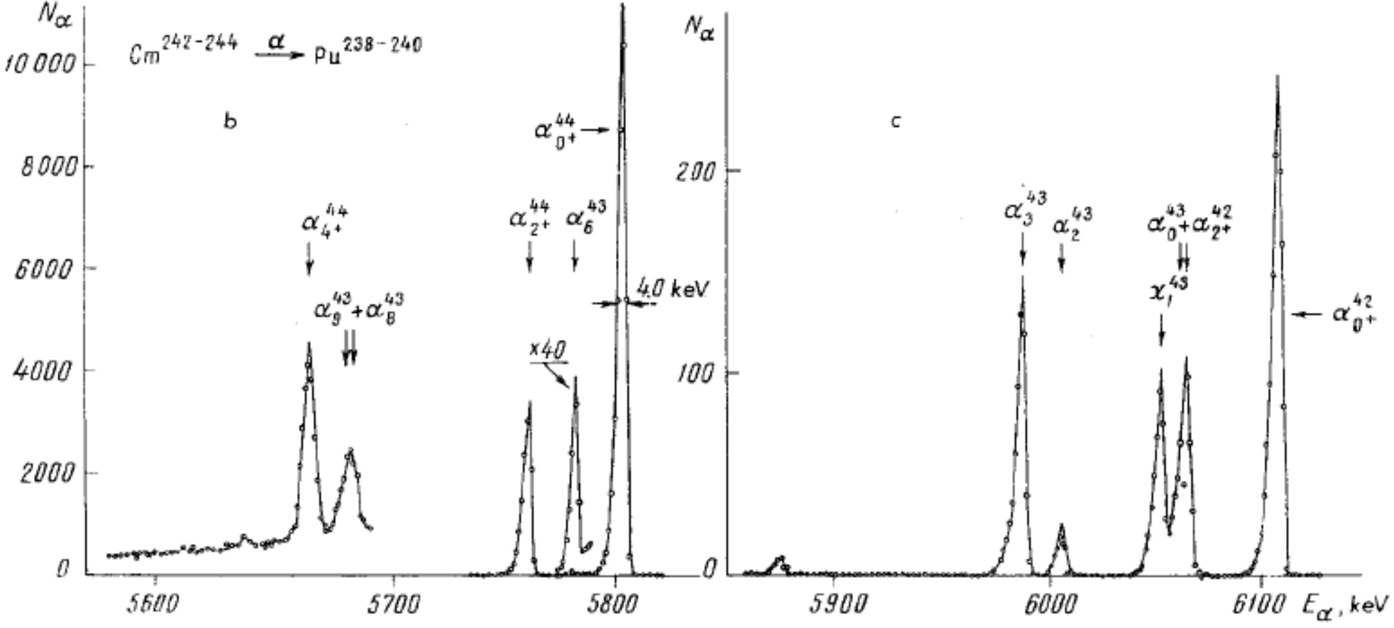
The components of systematic uncertainty are due to length measurements ($4.6\cdot10^{-5}$ E(α)), measurement of mean magnetic induction ($1.3\cdot10^{-5}$ E(α)) and combined effect of uncertainties of fundamental constants ($0.3\cdot10^{-5}$ E(α)), i.e. the total systematic uncertainty is ~$5\cdot10^{-5}$ E(α) or ~0.3 keV (**^{239}Pu**).



Magnetic $\pi\sqrt{2}$ α-spectrometers with high luminosity

In 1960's three such big magnetic α spectrometers were built in the Soviet Union – in Moscow (Baranov et al.), St. Petersburg (Dzhelepov et al.) and Dubna (Golovkov et al.).

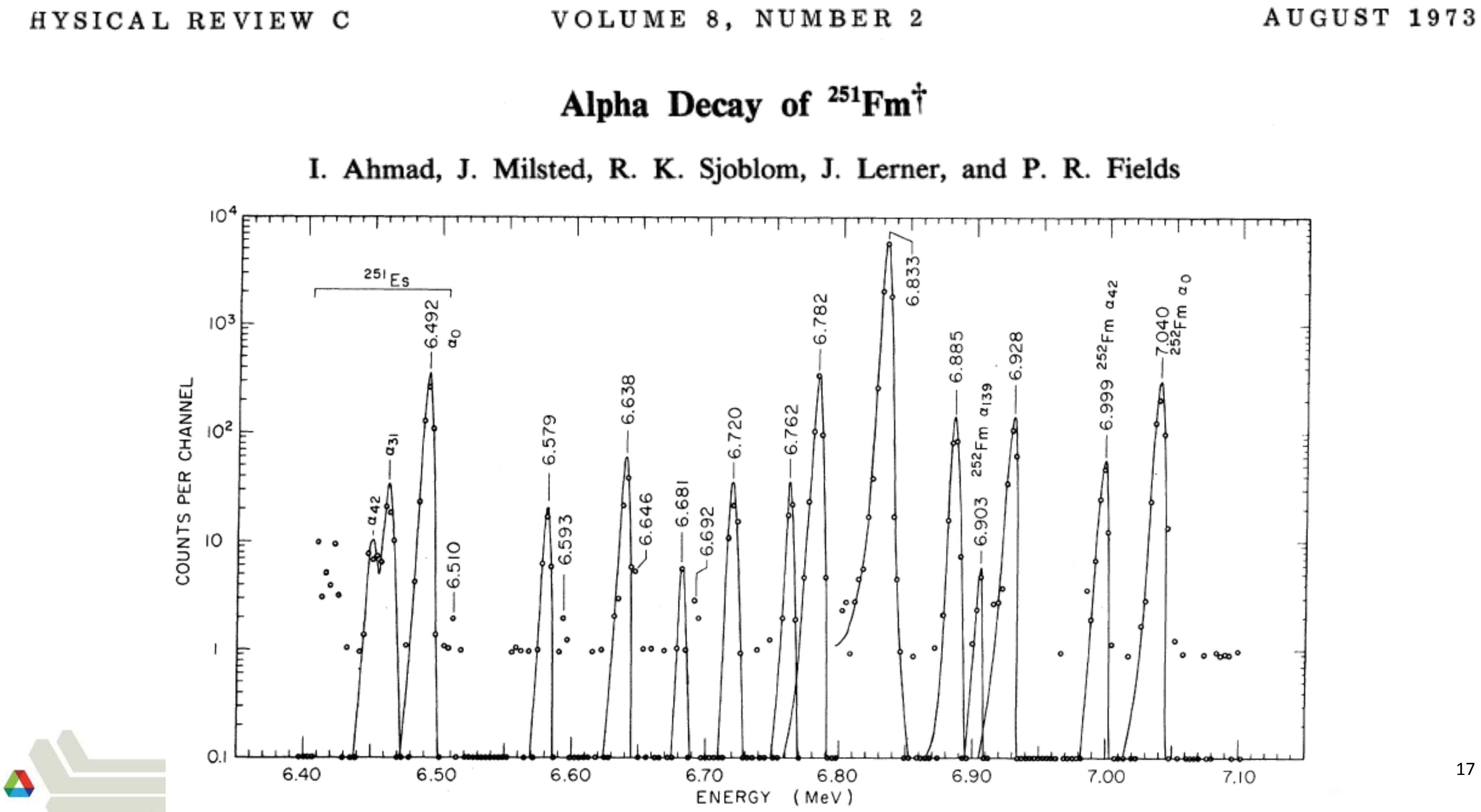
1.5 keV energy resolution



In respect of alpha-particle energies the measurements with $\pi\sqrt{2}$ magnetic spectrometers are relative – one needs to use alpha-energy "standards".

Argonne double-focusing magnetic spectrometer

- ✓ energy resolution (FWHM) of **5 keV**
- ✓ transmission efficiency of Ω=0.1 % for 6 MeV α−particles



HYSICAL REVIEW C VOLUME 8, NUMBER 2 AUGUST 1973

Alpha Decay of ^{251}Fm†

I. Ahmad, J. Milsted, R. K. Sjoblom, J. Lerner, and P. R. Fields

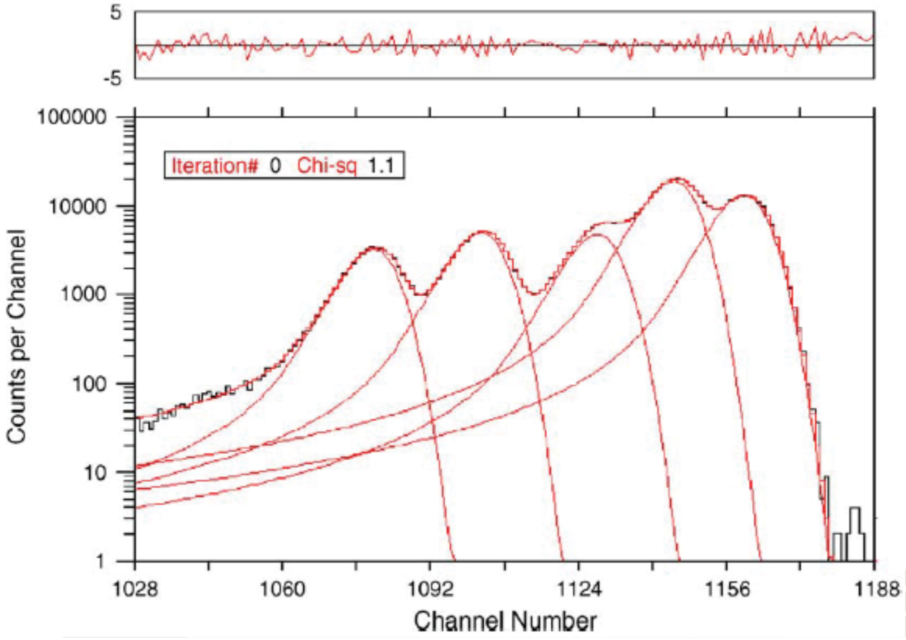
Semiconductor detectors

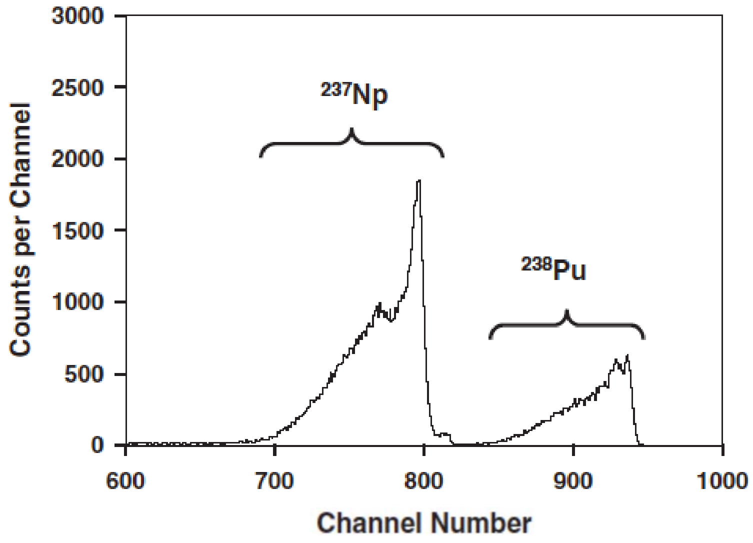
☐ **semiconductor detectors:** Passivated Implanted Planar Silicon (PIPS)

✓ energy resolution (FWHM) of **12 keV**

✓small geometrical efficiency of Ω=0.225% in order to minimize α−e-coincidence summing effects

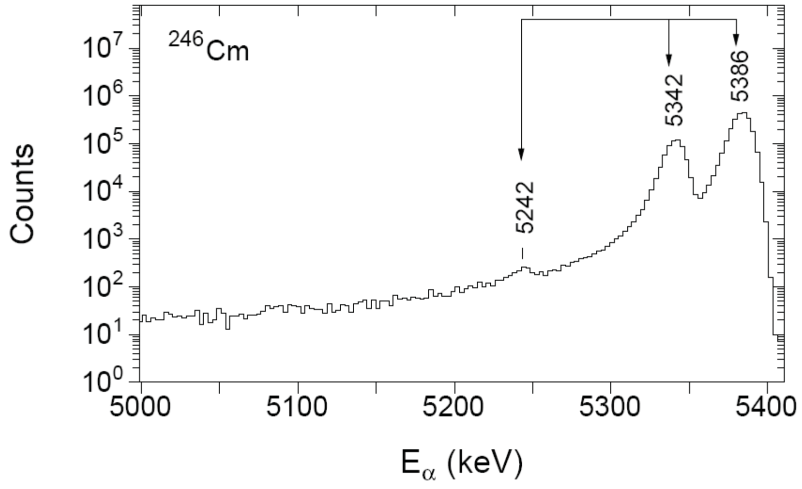
✓ thin and isotopically pure sources
✓ sophisticated data analysis

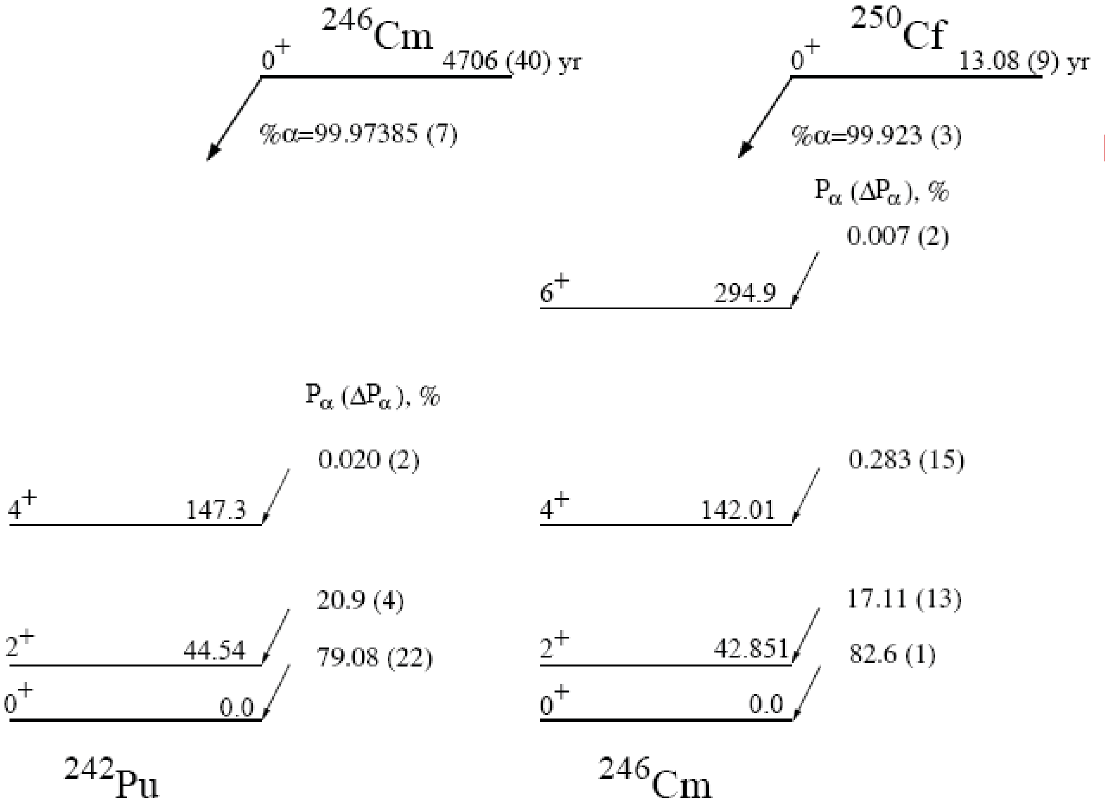




Harada et al. J. Nucl. Sci. and Techn. 43 (2006) 1289

Emission Probabilities





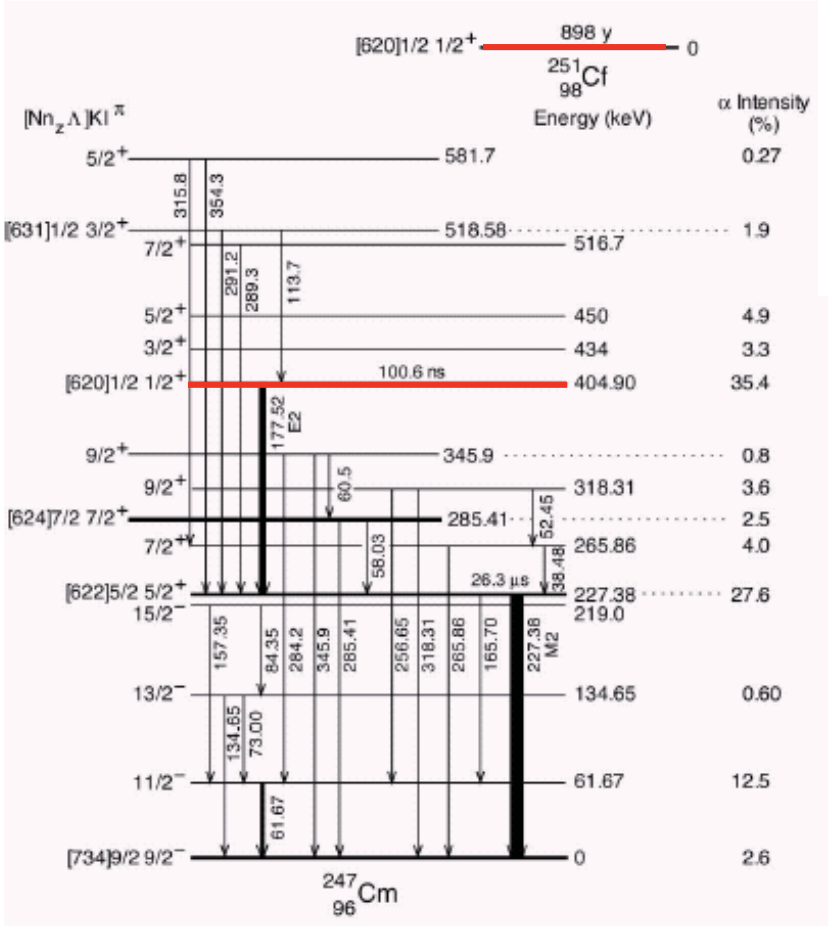
t_m= 23.0 *h* (0.06% geometry)

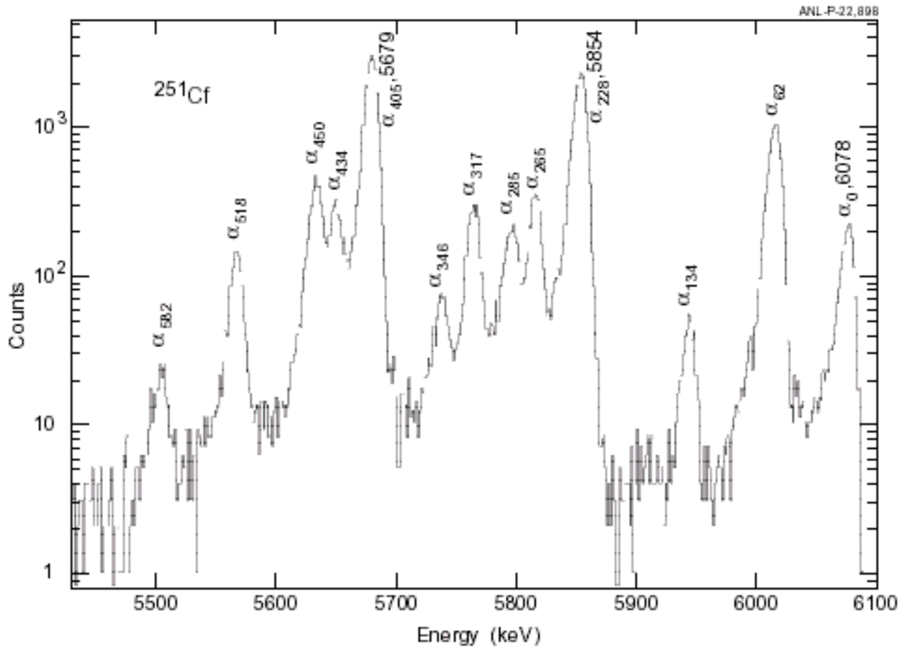
	$\alpha_{0.0}$		$\alpha_{44.5}$		$\alpha_{147.3}$	
Author	E_α, keV	P_α, %	E_α, keV	P_α, %	E_α, keV	P_α, %
Belov et al. (1963)	5387	78	5345	22	–	–
Dzhelepov et al. (1963)	5387 (4)	78 (5)	5345 (5)	22 (5)	–	–
Baranov et al. (1966)	5385	79	5342	21	–	–
Shatinskii (1984)	5386.5 (10)	82.2 (12)	5343.5 (10)	17.8 (12)	–	–
Present work	5386 (3)	79.08 (22)	5342 (3)	20.9 (4)	5242 (3)	0.020 (2)

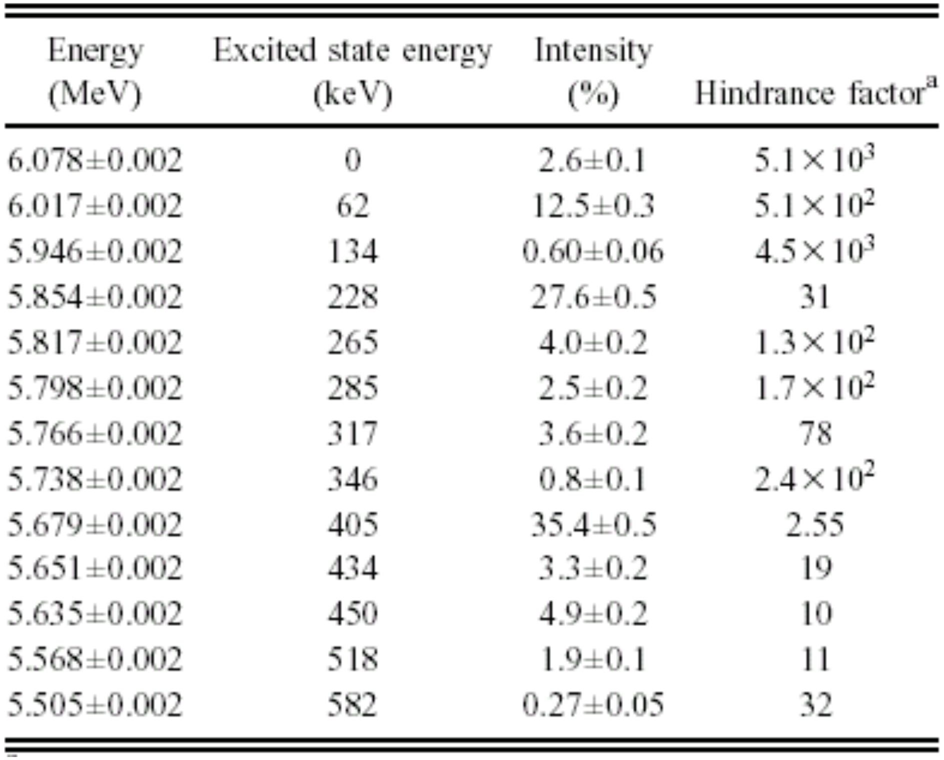
^{251}Cf α−decay

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

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



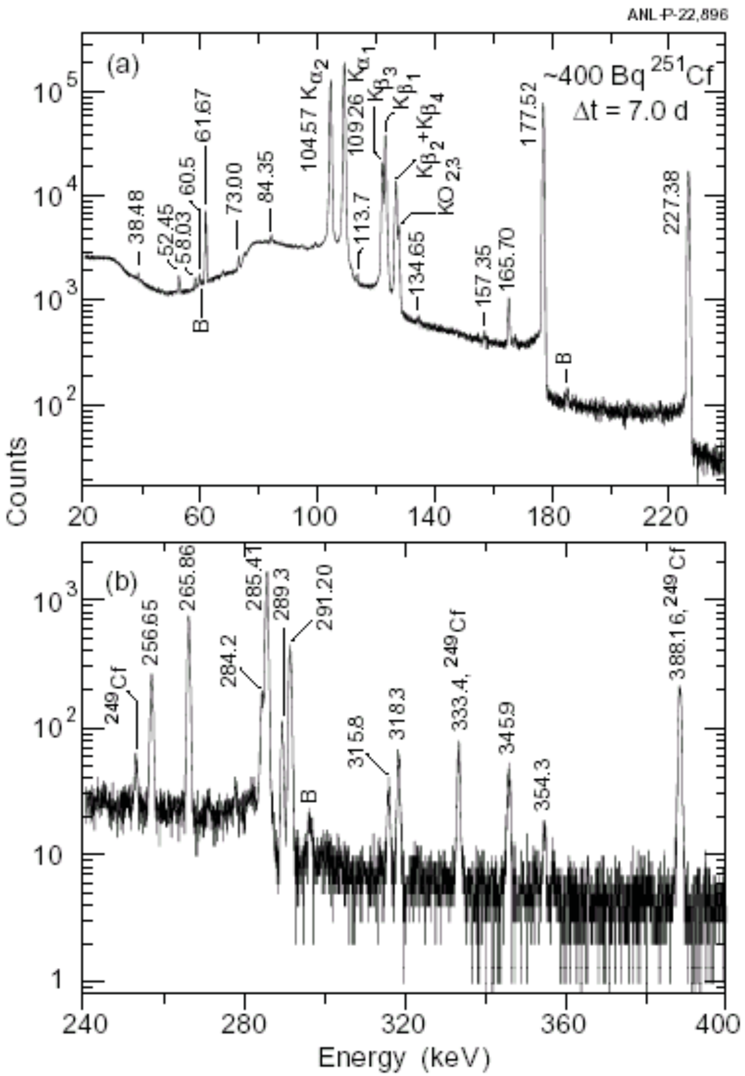


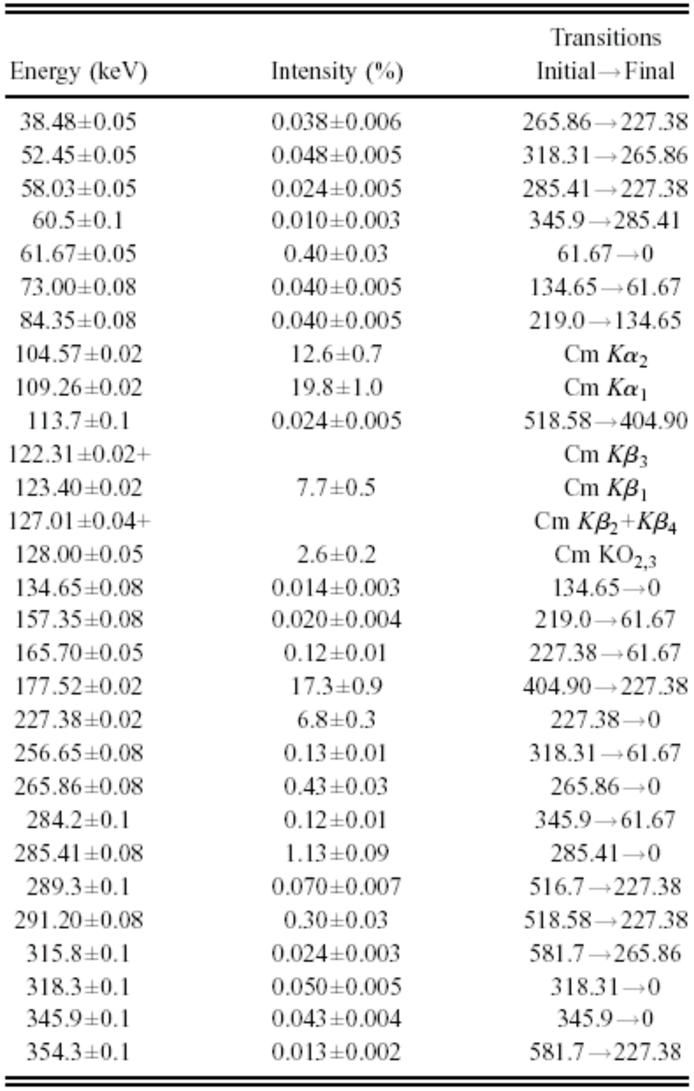


Energy (MeV)	Excited state energy (keV)	Intensity (%)	Hindrance factor[a]
6.078±0.002	0	2.6±0.1	5.1×10^3
6.017±0.002	62	12.5±0.3	5.1×10^2
5.946±0.002	134	0.60±0.06	4.5×10^3
5.854±0.002	228	27.6±0.5	31
5.817±0.002	265	4.0±0.2	1.3×10^2
5.798±0.002	285	2.5±0.2	1.7×10^2
5.766±0.002	317	3.6±0.2	78
5.738±0.002	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

I. Ahmad et al., Phys. Rev. C68 (2003) 044306

^{251}Cf α−decay – cont.

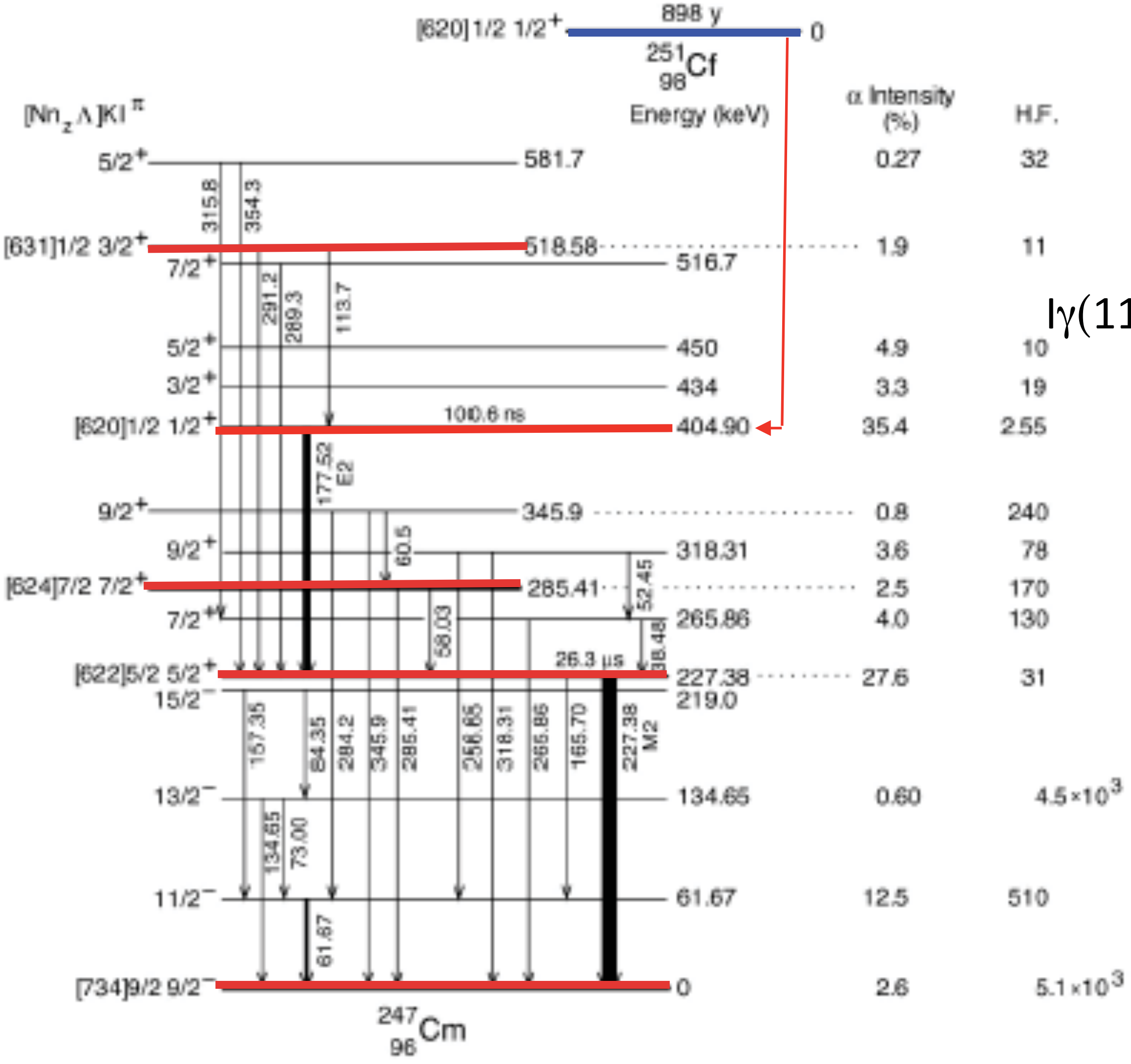




Energy (keV)	Intensity (%)	Transitions Initial→Final
38.48±0.05	0.038±0.006	265.86→227.38
52.45±0.05	0.048±0.005	318.31→265.86
58.03±0.05	0.024±0.005	285.41→227.38
60.5±0.1	0.010±0.003	345.9→285.41
61.67±0.05	0.40±0.03	61.67→0
73.00±0.08	0.040±0.005	134.65→61.67
84.35±0.08	0.040±0.005	219.0→134.65
104.57±0.02	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 $\mathrm{KO}_{2,3}$
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

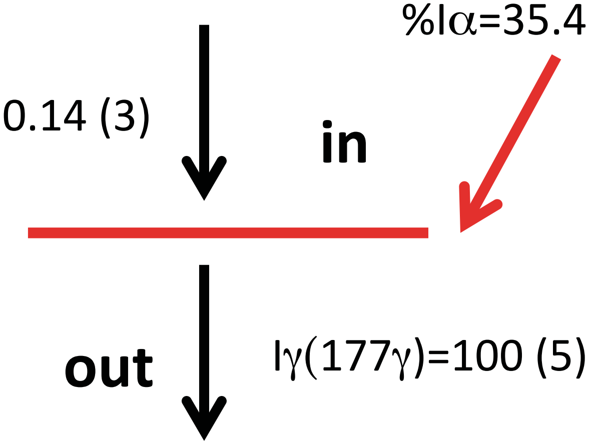
I. Ahmad et al., Phys. Rev. C68 (2003) 044306

^{251}Cf α−decay - normalization



I. Ahmad et al., Phys. Rev. C68 (2003) 044306

$TI(114\gamma)=I\gamma(114\gamma) \times (1+\alpha_T)$



%Iα=35.4 (5)

Iγ(114γ)=0.14 (3)

in

out

Iγ(177γ)=100 (5)

$TI(177\gamma)=I\gamma(177\gamma) \times (1+\alpha_T)$

N = (TI(177γ) – TI(114γ))/Iα=0.138 (7)

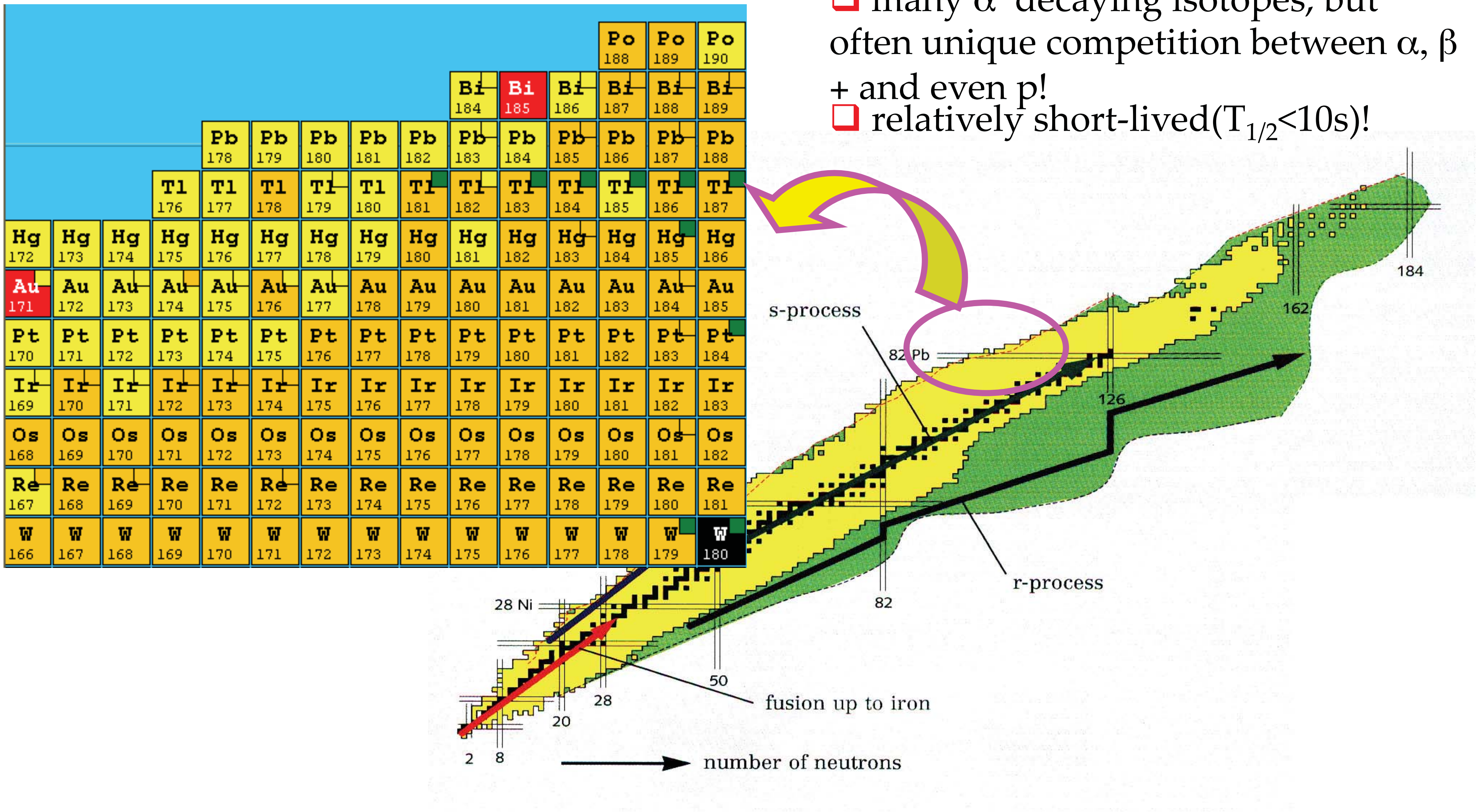
%Iγ(177γ)=13.8 (7), BUT …

17.3 (9) – 20% diff!

%Iγ(177γ)=14.4 (8) – 17% diff!

Spectroscopy near the proton drip line

- ❑ many α−decaying isotopes, but often unique competition between α, β^+ and even p!
- ❑ relatively short-lived($T_{1/2}$<10s)!

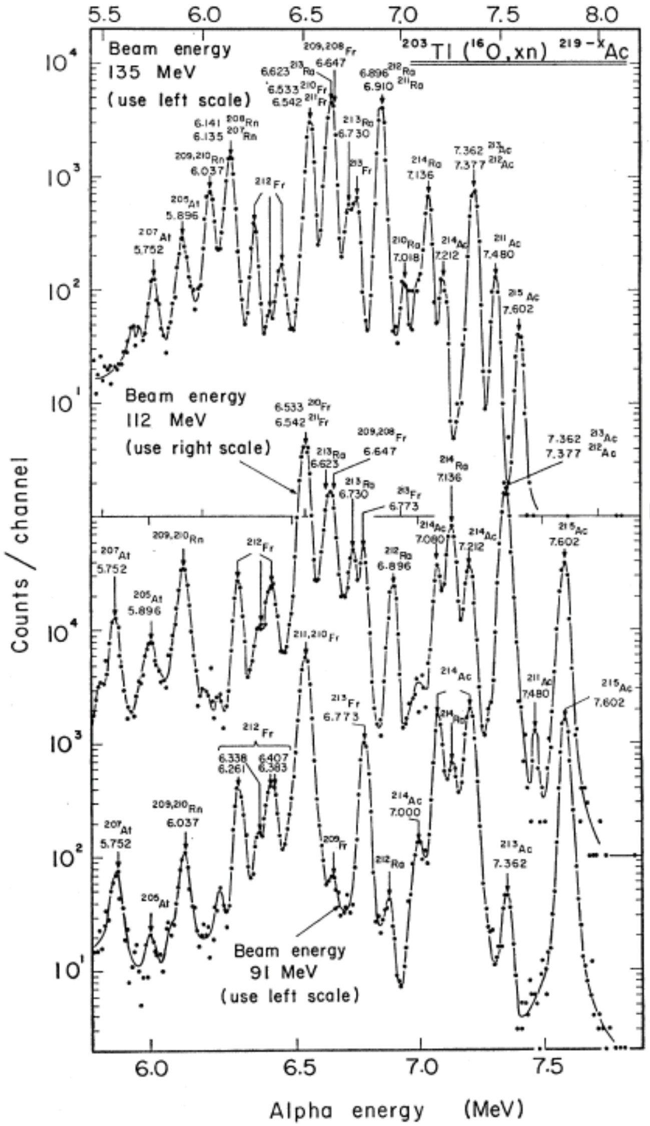


												Po 188	Po 189	Po 190
									Bi 184	Bi 185	Bi 186	Bi 187	Bi 188	Bi 189
				Pb 178	Pb 179	Pb 180	Pb 181	Pb 182	Pb 183	Pb 184	Pb 185	Pb 186	Pb 187	Pb 188
			Tl 176	Tl 177	Tl 178	Tl 179	Tl 180	Tl 181	Tl 182	Tl 183	Tl 184	Tl 185	Tl 186	Tl 187
Hg 172	Hg 173	Hg 174	Hg 175	Hg 176	Hg 177	Hg 178	Hg 179	Hg 180	Hg 181	Hg 182	Hg 183	Hg 184	Hg 185	Hg 186
Au 171	Au 172	Au 173	Au 174	Au 175	Au 176	Au 177	Au 178	Au 179	Au 180	Au 181	Au 182	Au 183	Au 184	Au 185
Pt 170	Pt 171	Pt 172	Pt 173	Pt 174	Pt 175	Pt 176	Pt 177	Pt 178	Pt 179	Pt 180	Pt 181	Pt 182	Pt 183	Pt 184
Ir 169	Ir 170	Ir 171	Ir 172	Ir 173	Ir 174	Ir 175	Ir 176	Ir 177	Ir 178	Ir 179	Ir 180	Ir 181	Ir 182	Ir 183
Os 168	Os 169	Os 170	Os 171	Os 172	Os 173	Os 174	Os 175	Os 176	Os 177	Os 178	Os 179	Os 180	Os 181	Os 182
Re 167	Re 168	Re 169	Re 170	Re 171	Re 172	Re 173	Re 174	Re 175	Re 176	Re 177	Re 178	Re 179	Re 180	Re 181
W 166	W 167	W 168	W 169	W 170	W 171	W 172	W 173	W 174	W 175	W 176	W 177	W 178	W 179	W 180

PHYSICAL REVIEW VOLUME 167, NUMBER 4 20 MARCH 1968

On-Line Alpha Spectroscopy of Neutron-Deficient Actinium Isotopes*

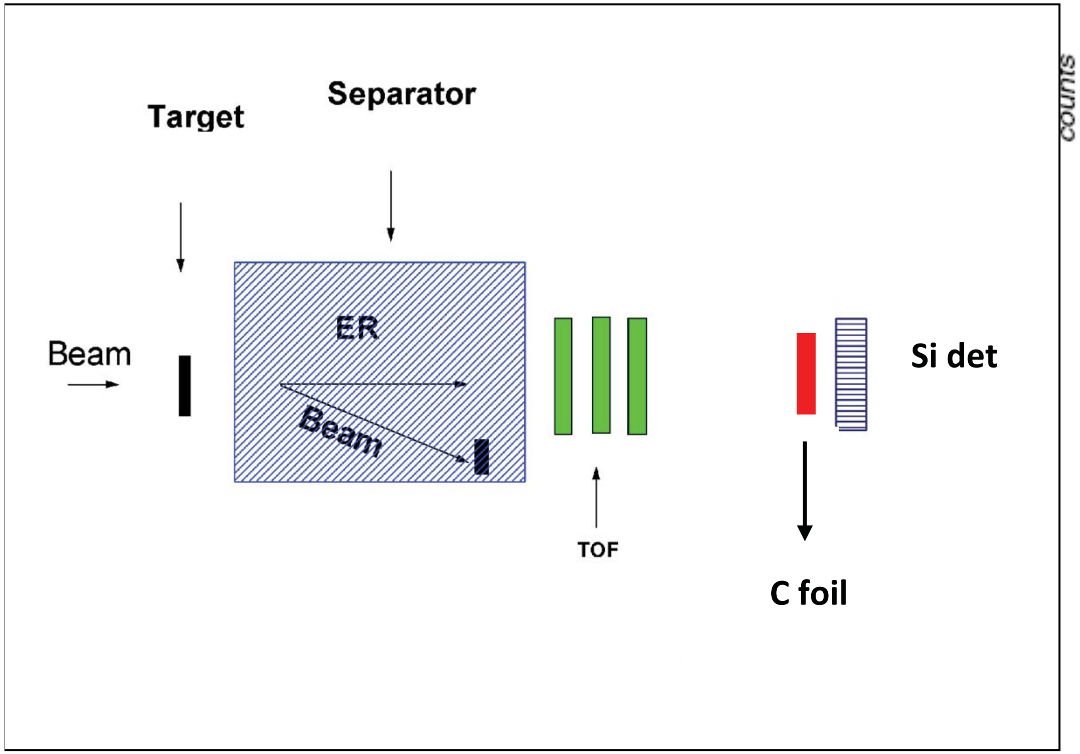
KALEVI VALLI, WILLIAM J. TREYTL,† AND EARL K. HYDE
Lawrence Radiation Laboratory, University of California, Berkeley, California

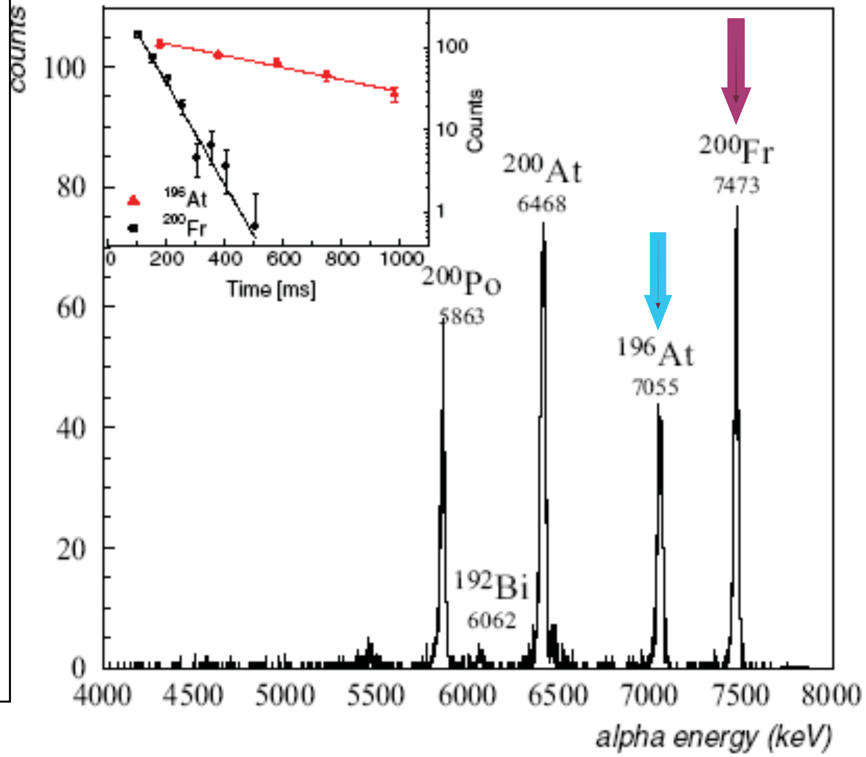


- ✓ using HI fusion reactions to produce various nuclei
- ✓ collect recoils on a catcher foil
- ✓ Si(Au) surface-barrier detector or PIPS

- ✓ using excitation function measurements for isotopic identification

No direct detector implantation





1 GeV pulsed proton beam on 51 g/cm2 ThCx target

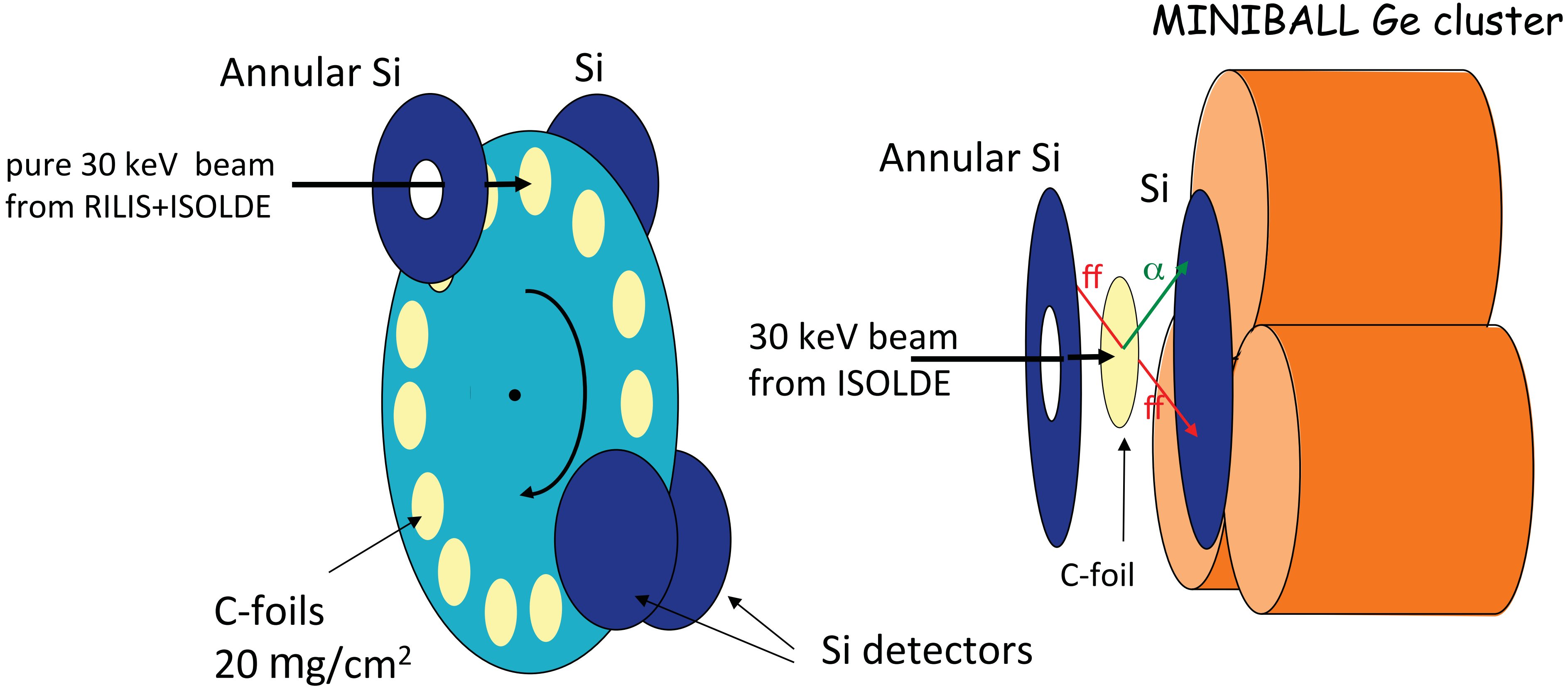
on-line mass separation (ISOLDE)/CERN

H. De Witte et al., EPJ A23 (2005) 243

Isotope	Energy (keV)	$T_{1/2}$	Reference
^{200}Fr	7473(12)	49(4) ms	this work
	7500(30)	570^{+270}_{-140} ms	[4]
	7468(9)	19^{+13}_{-6} ms	[5]

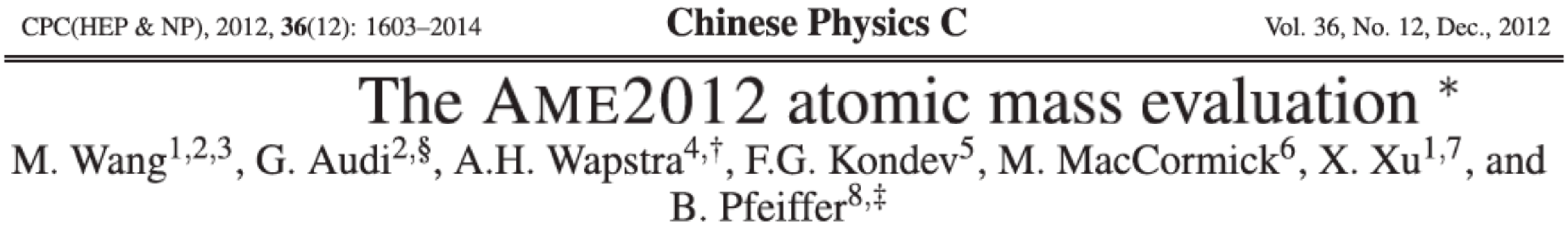
Windmill System (WM) at ISOLDE

A. Andreyev et al., PRL 105, 252502 (2010)



Setup: Si detectors from both sides of the C-foil

- Simple setup & DAQ: 4 PIPS (1 of them – annular)
- Large geometrical efficiency (up to 80%)
- 2 fold fission fragment coincidences
- ff-gamma coincidences
- Digital electronics



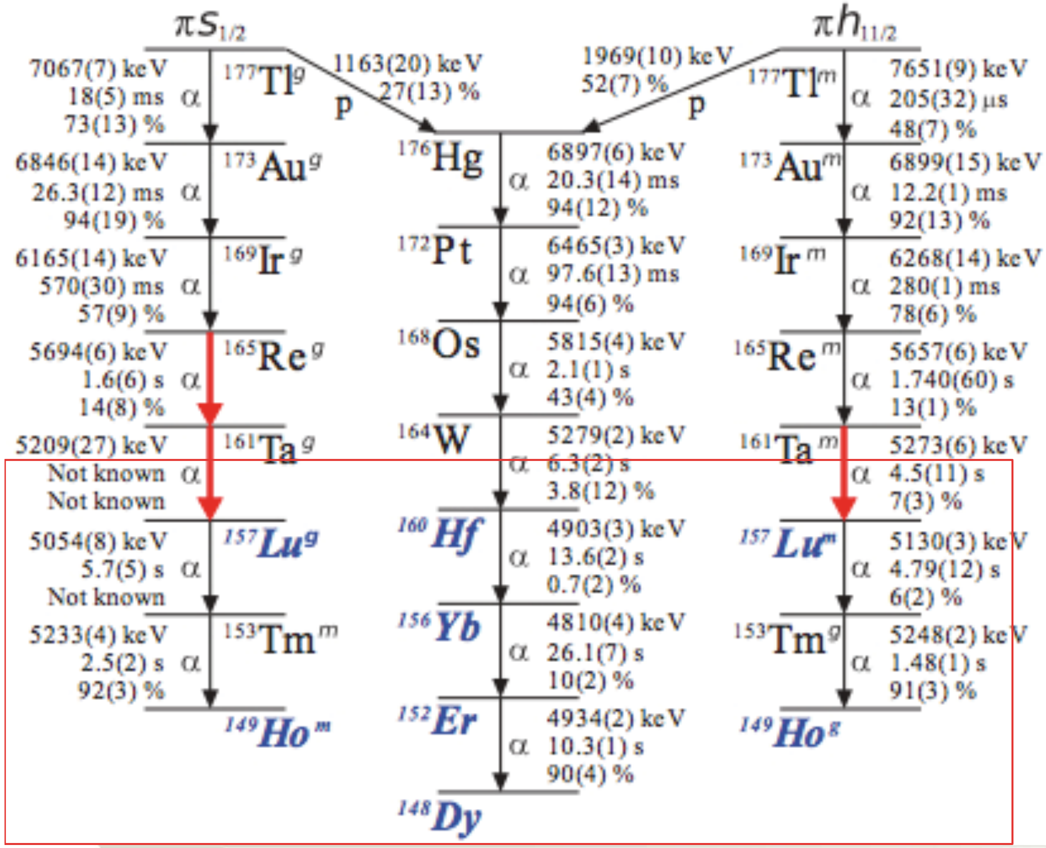
CPC(HEP & NP), 2012, **36**(12): 1603–2014 **Chinese Physics C** Vol. 36, No. 12, Dec., 2012

The AME2012 atomic mass evaluation *

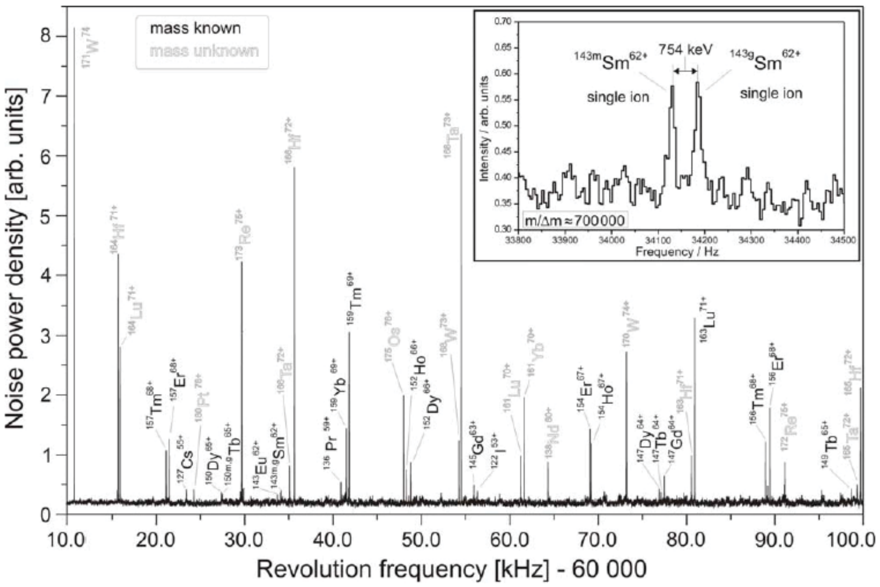
M. Wang[1,2,3], G. Audi[2,§], A.H. Wapstra[4,†], F.G. Kondev[5], M. MacCormick[6], X. Xu[1,7], and B. Pfeiffer[8,‡]

- ☐ define the mass surface at the drip-line

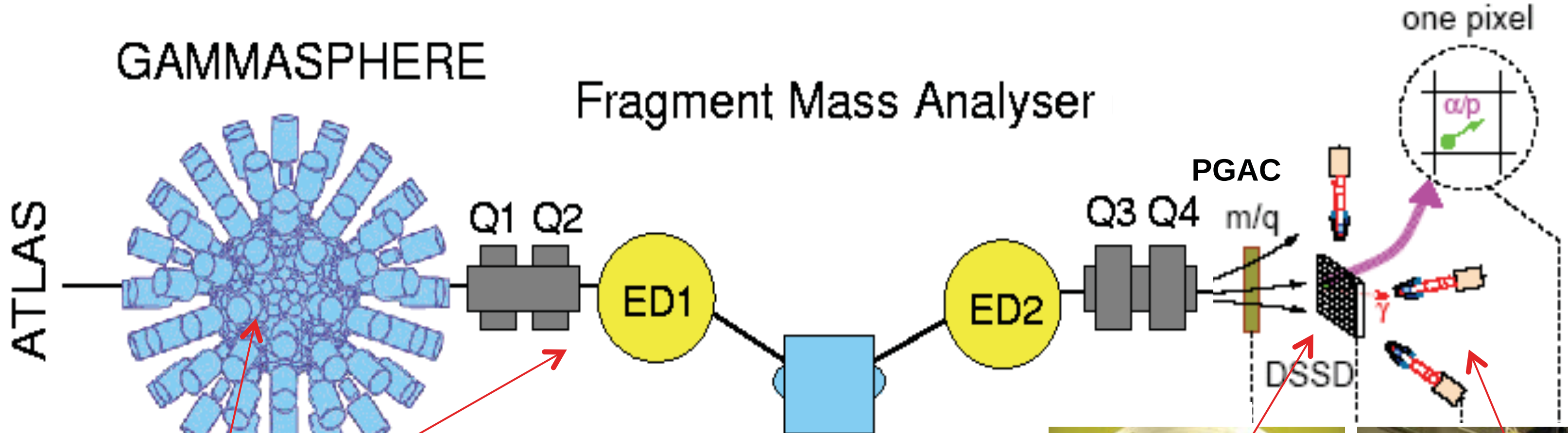
A. Thornthwaite et al., Phys. Rev. **C86** (2012) 064315

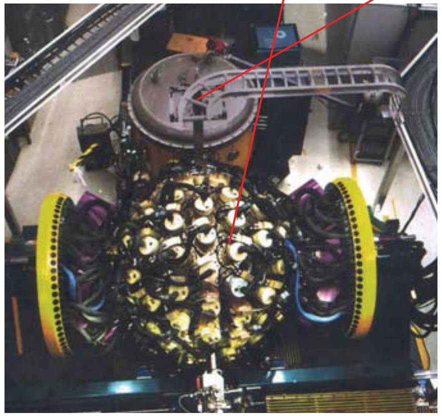


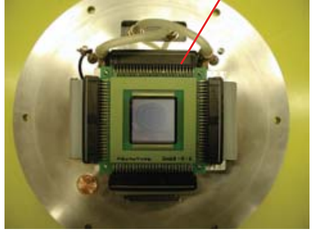
Y. Litvinov et al., Nucl. Phys. **A756** (2005) 3

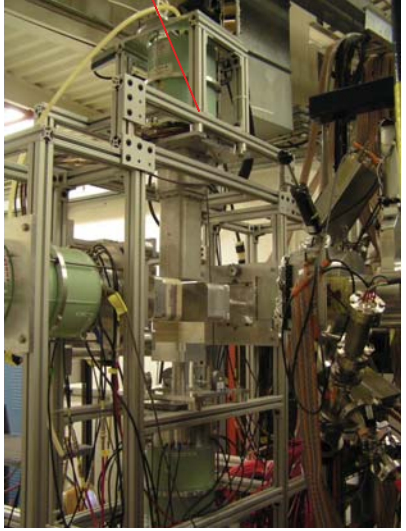


Experiments & Techniques







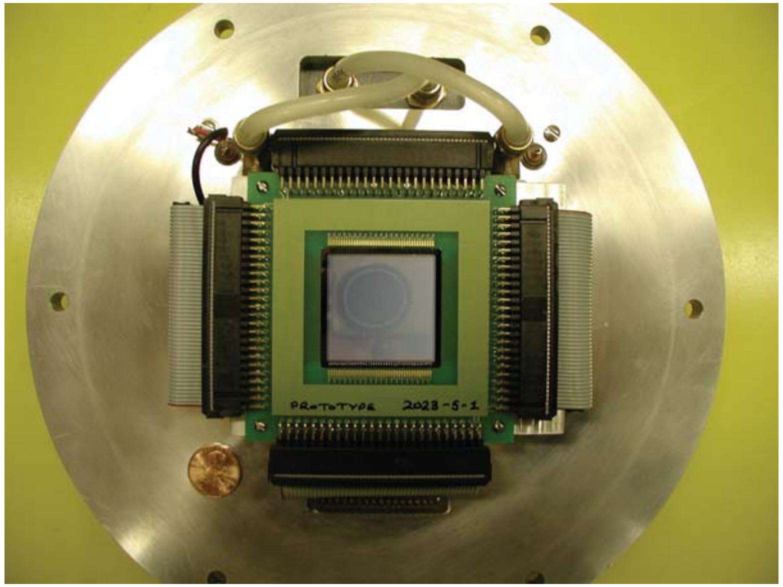


- ✓ ^{90}Zr + ^{90,92}Zr@^{180}Hg
- ✓ ^{90}Zr + ^{82}Mo@^{182}Pb
- ✓ ^{89}Y + ^{90}Zr@^{179}Au
- ✓ ^{84}Sr + $^{92\text{-}96}$Mo@$^{176\text{-}180}$Hg
- ✓ **^{89}Y + ^{92}Mo@^{181}Tl@375 MeV**

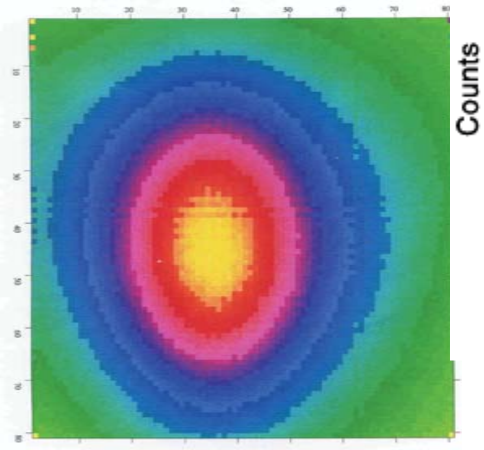
X-array

one “Super-Clover” &
four 70 X 70 mm Clovers

The Heart of RDT: the DSSD

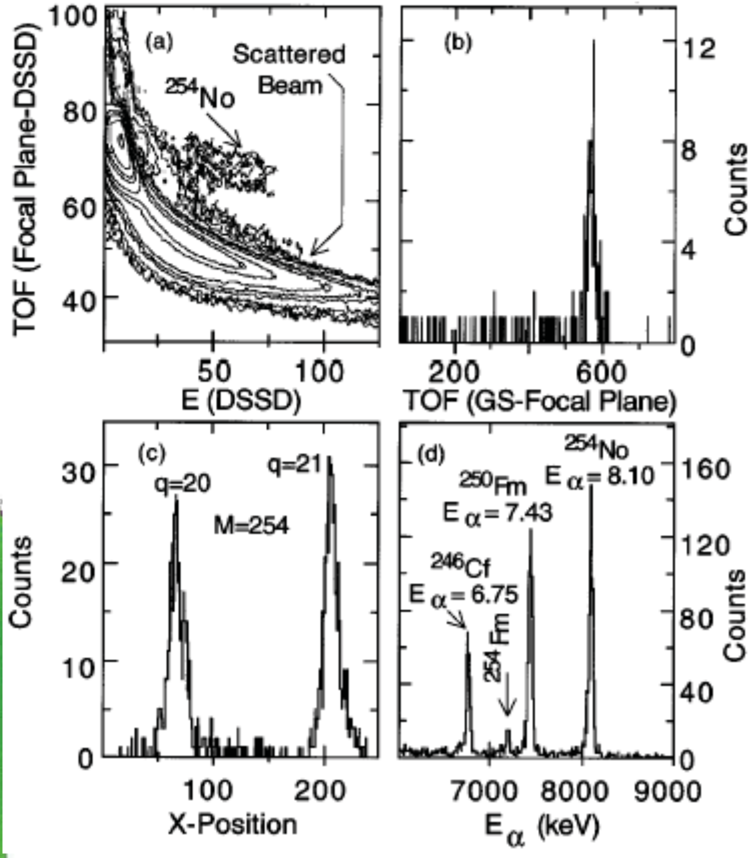


80 x 80 detector 300 μm strips,
Each with high, low, and delay line amplifiers, for implant, decay, and fast-decay recognition.



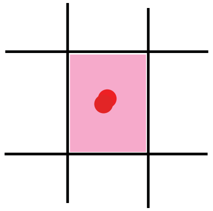
Data from DSSD showing implant pattern 40 cm beyond the focal plane

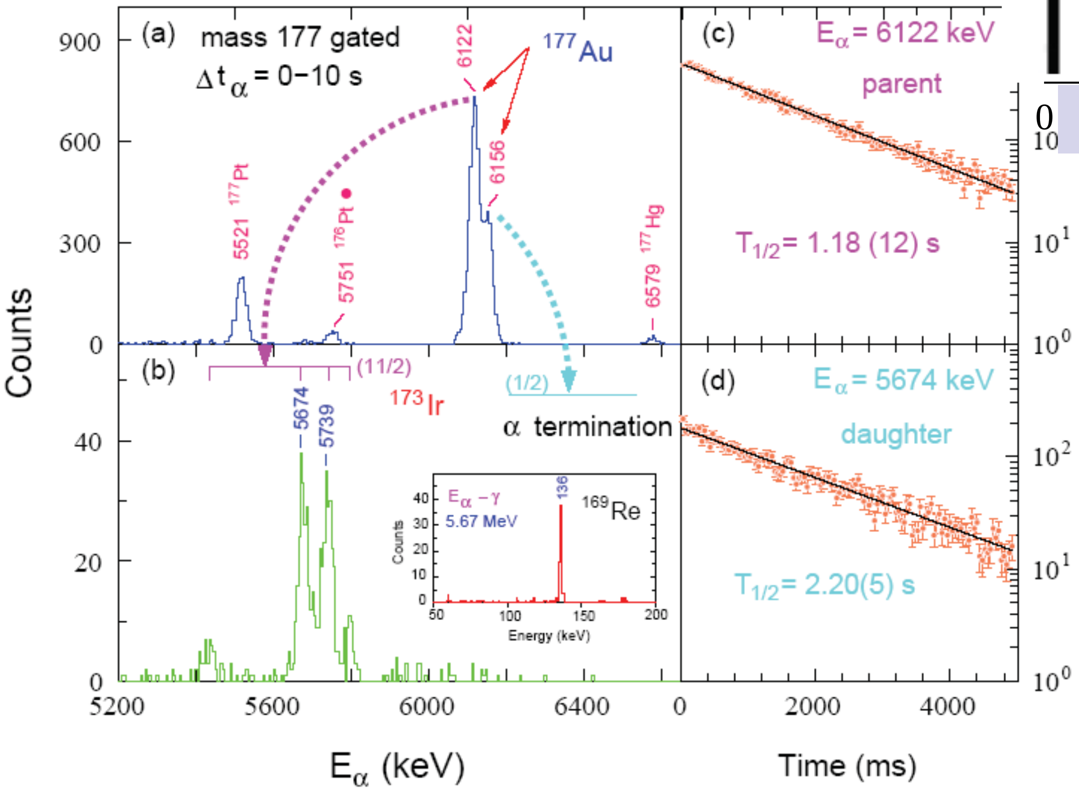
^{208}Pb(^{48}Ca,2n)^{254}No

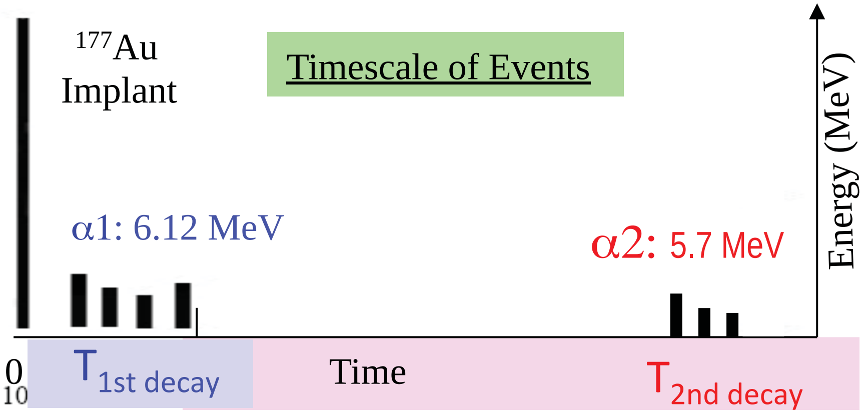


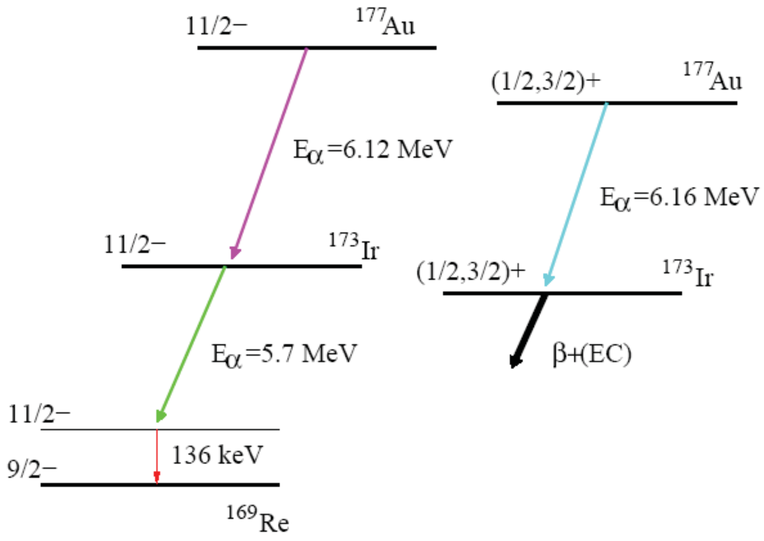
α1−α2 (parent-daughter) correlations

Implantation->Decay 1->Decay 2 within a single pixel



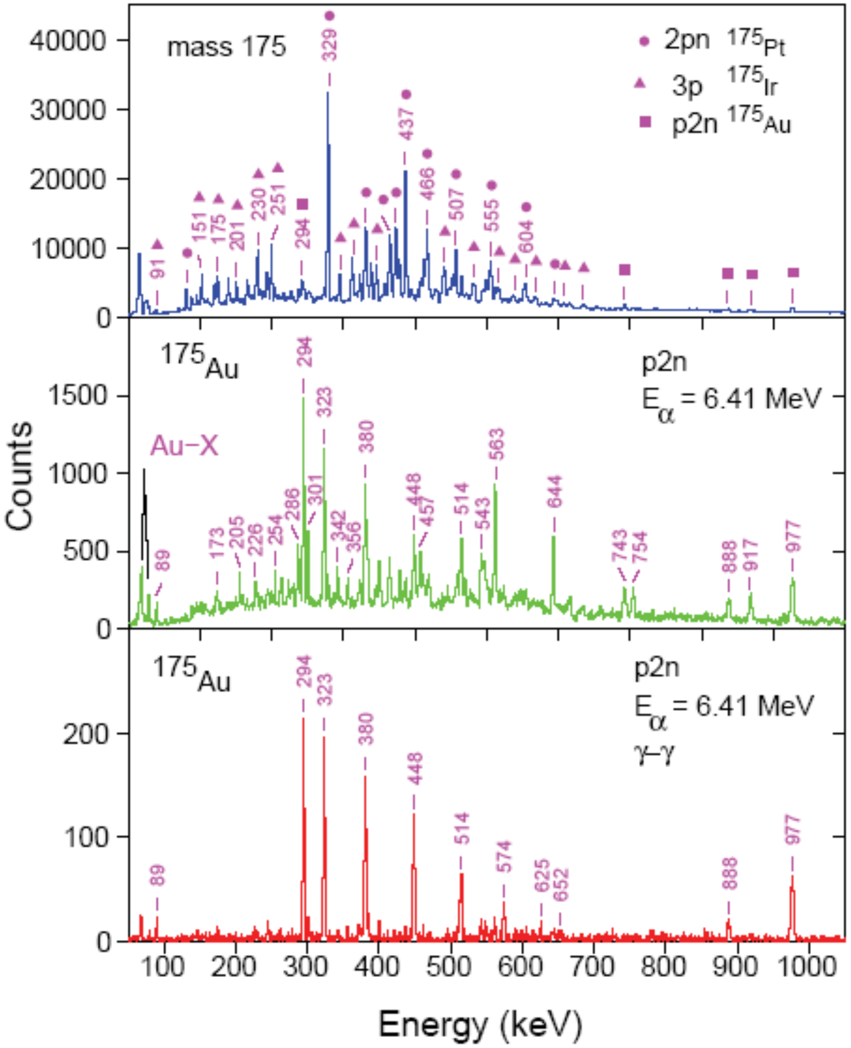






F.G. Kondev et al. Phys. Lett. B528 (2002) 221

Odd-Z Au (Z=79) isotopes –sample spectra



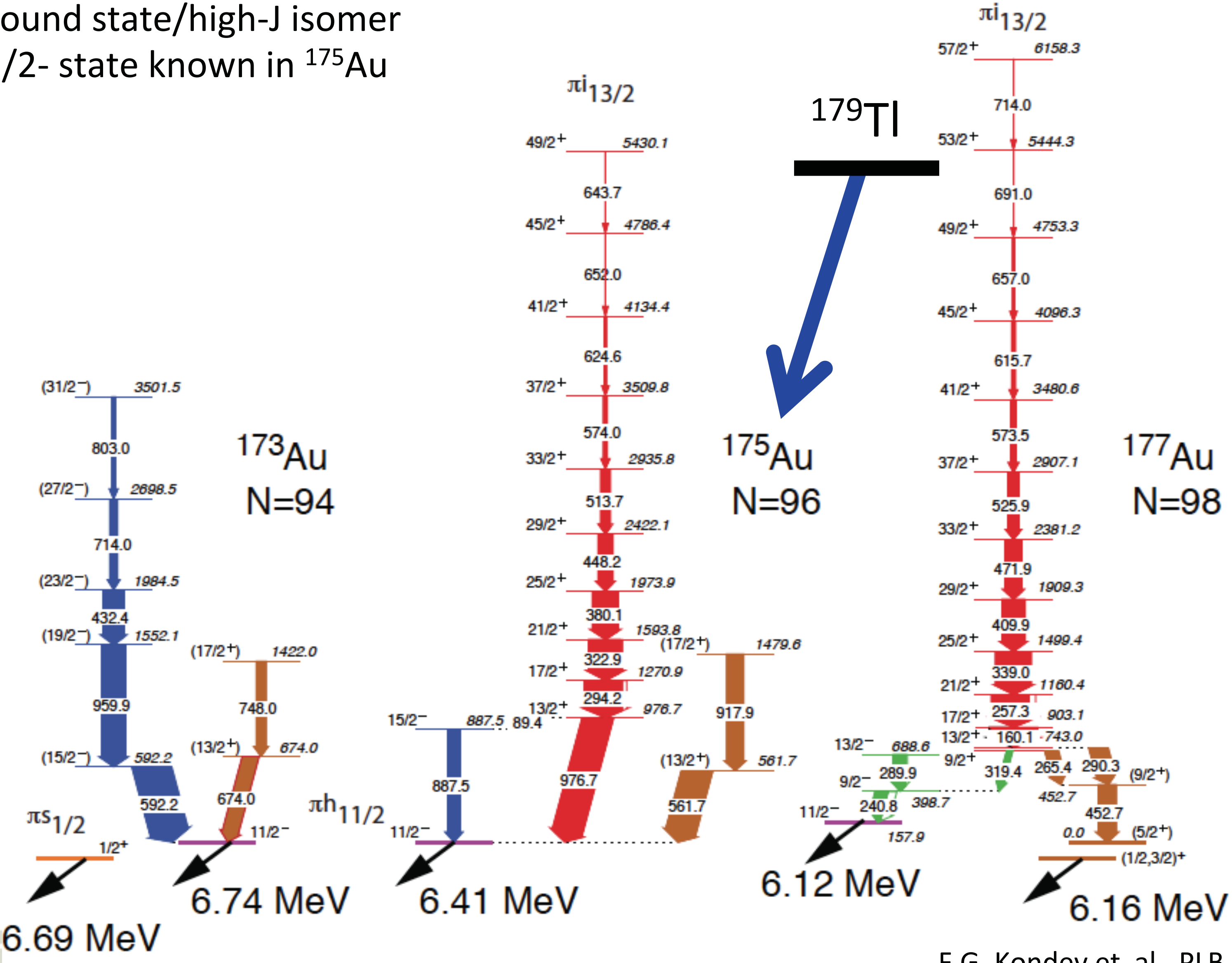
mass gated

channel gated

structure gated

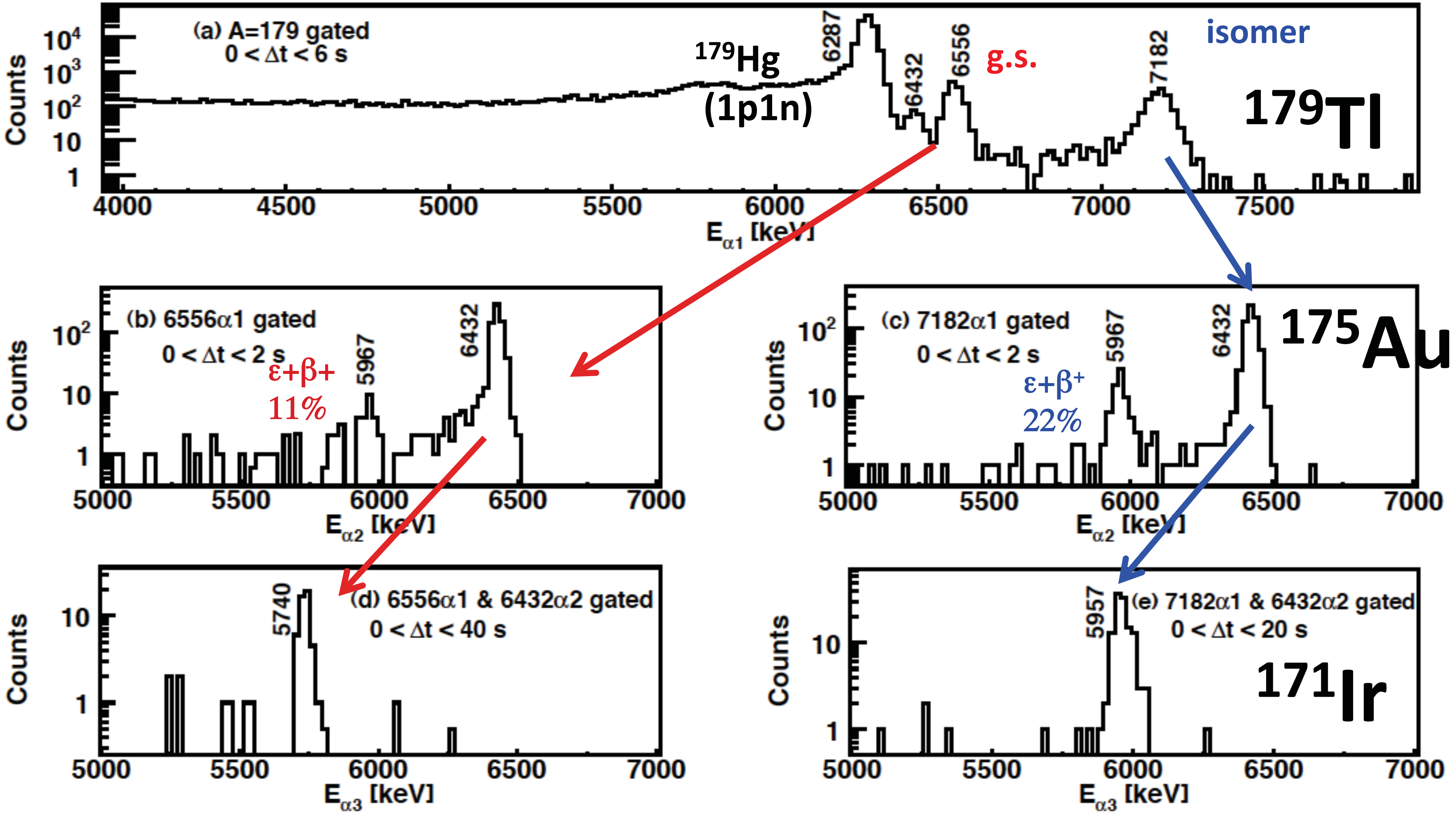
Neutron-deficient Au nuclei (Z=79)

- ☐ low-J ground state/high-J isomer
- ☐ only 11/2- state known in ^{175}Au



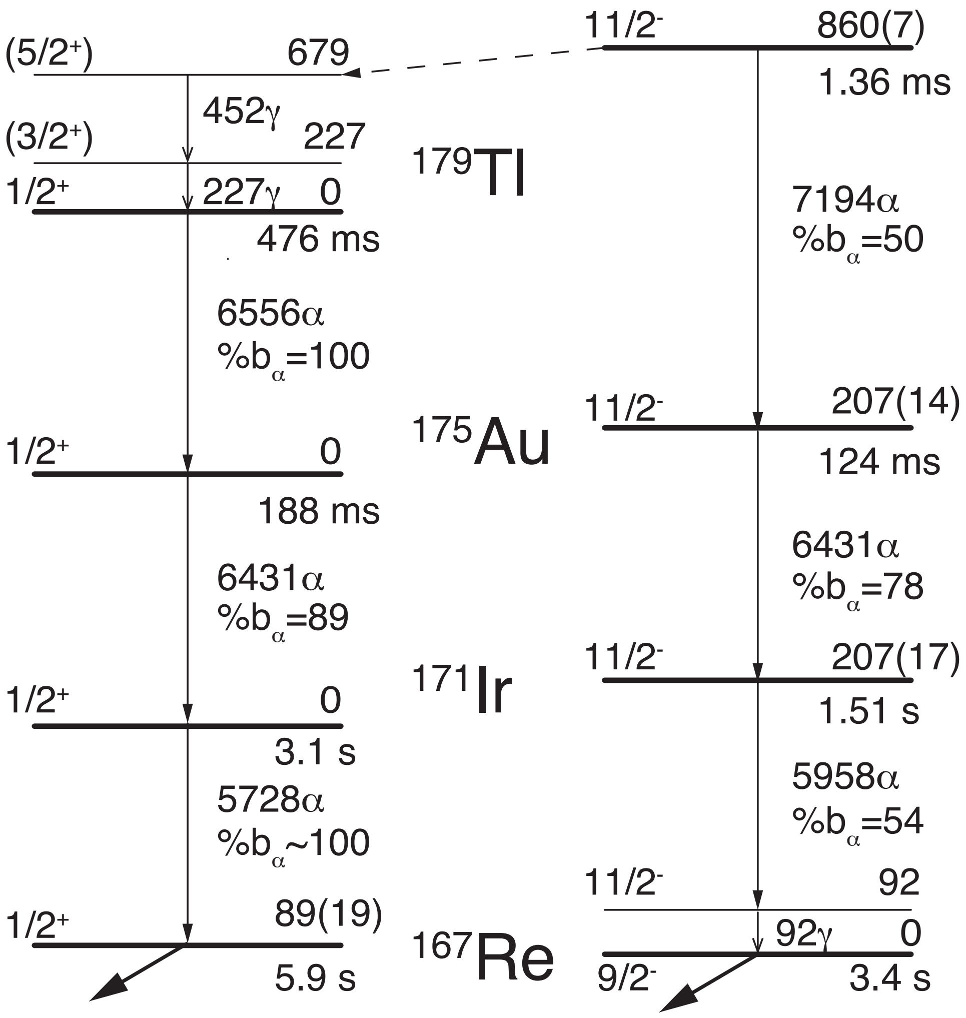
F.G. Kondev et al., PLB 512 (2001)

^{179}Tl: $\alpha-$decay properties



$$HF_i = \frac{T_{1/2}^{Exp}(\alpha_i)}{T_{1/2}^{Theory}} = \frac{T_{1/2}^{Exp} / BR_i}{T_{1/2}^{Theory}}$$

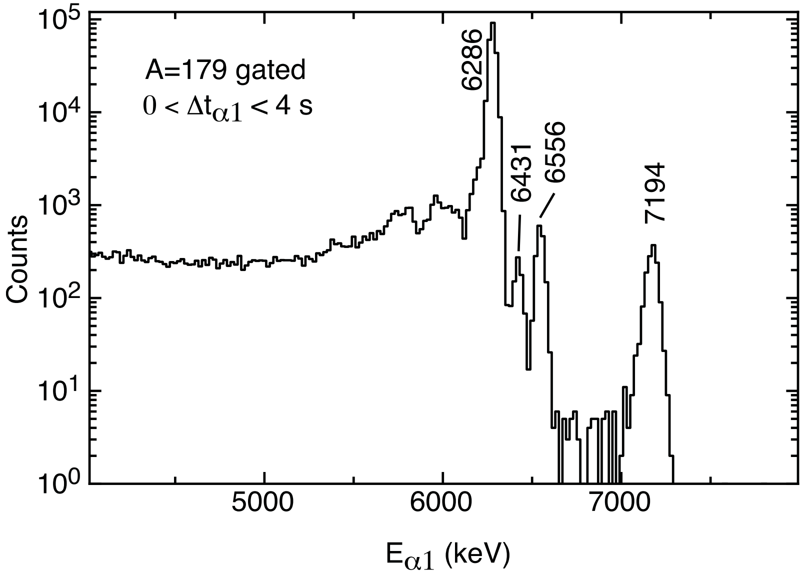
$T_{1/2}^{Theory}$ M.A. Preston, Phys. Rev. 71 (1947) 865



HF < 4 favorite (ΔL=0)decay

1/2+	11/2-
1.12 (6)	0.50 (3)
2.16 (17)	1.63 (19)
0.36 (6) $\%b_{\alpha}$~15%	2.2 (4)

^{179}Tl: lifetimes



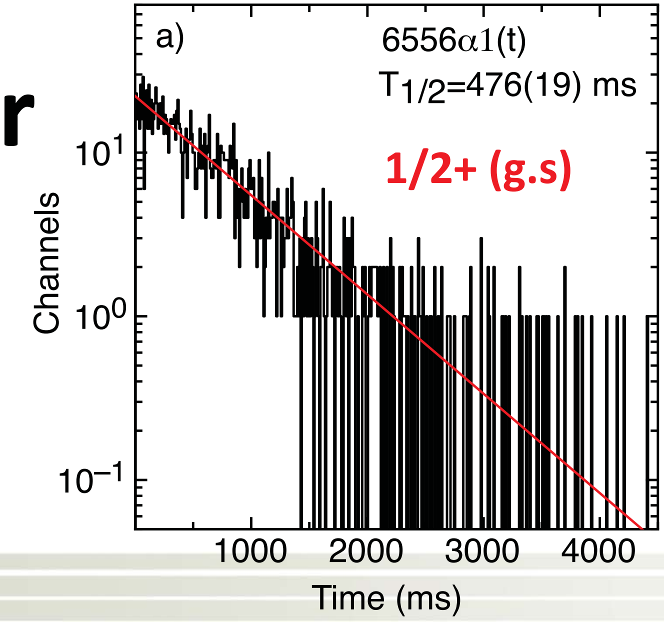
^{179}Tl – g.s.

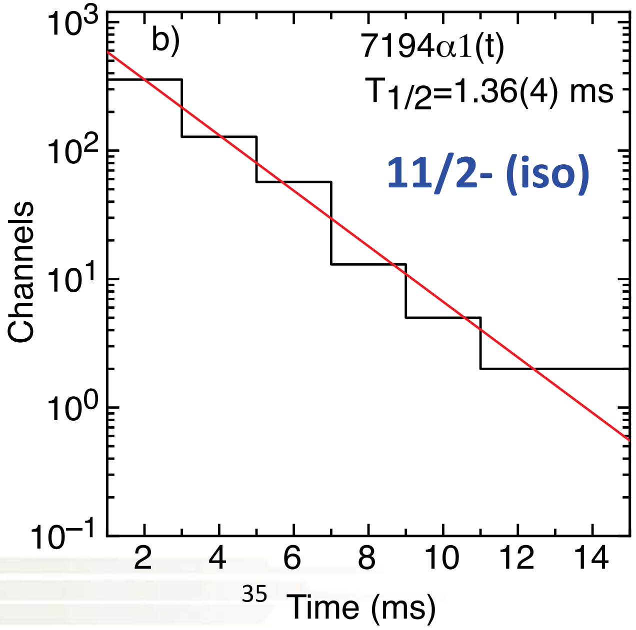
476 (19) ms
present

415 (55) ms – LBNL
230 (40) ms – ANL (1998)
160 (+90-40) ms – GSI (1993)

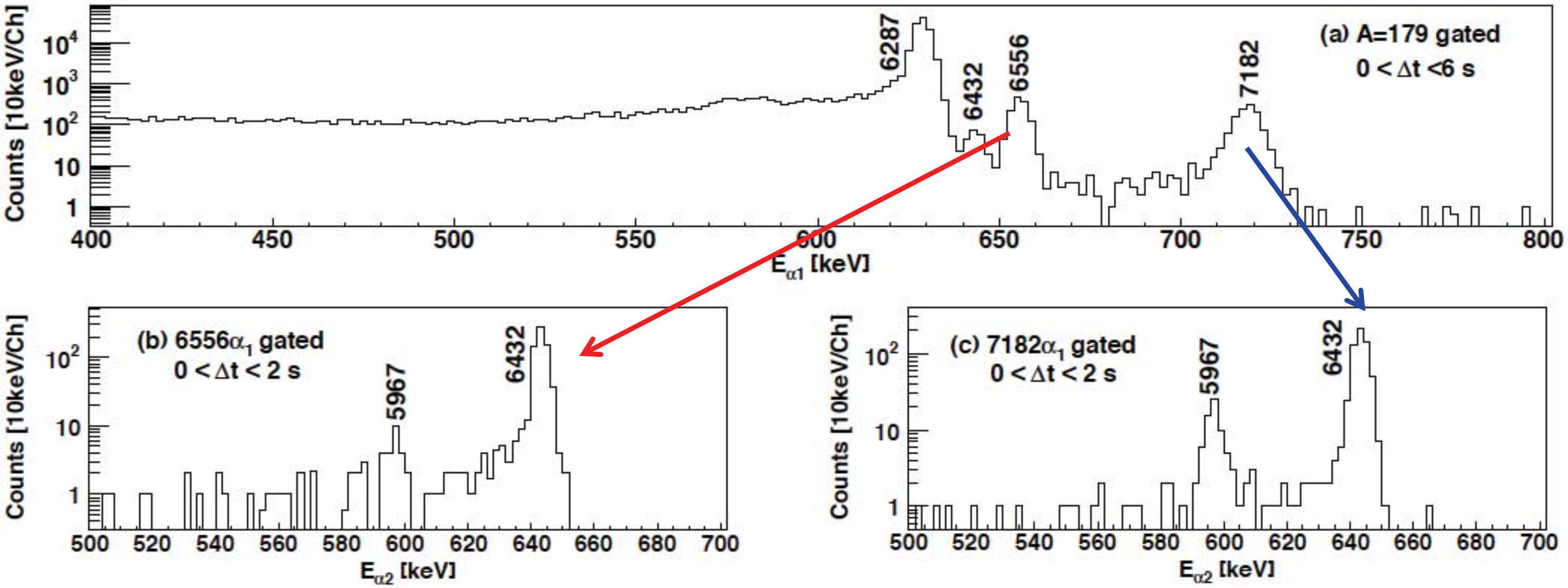
^{179}Tl – isomer

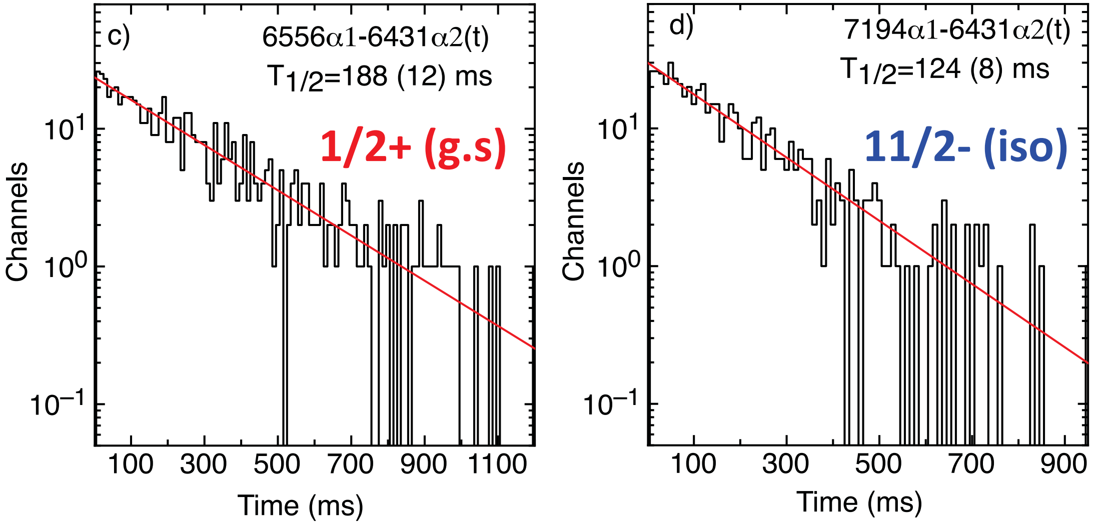
good agreement with
previous measurements





^{175}Au: lifetimes





similar, but not identical!

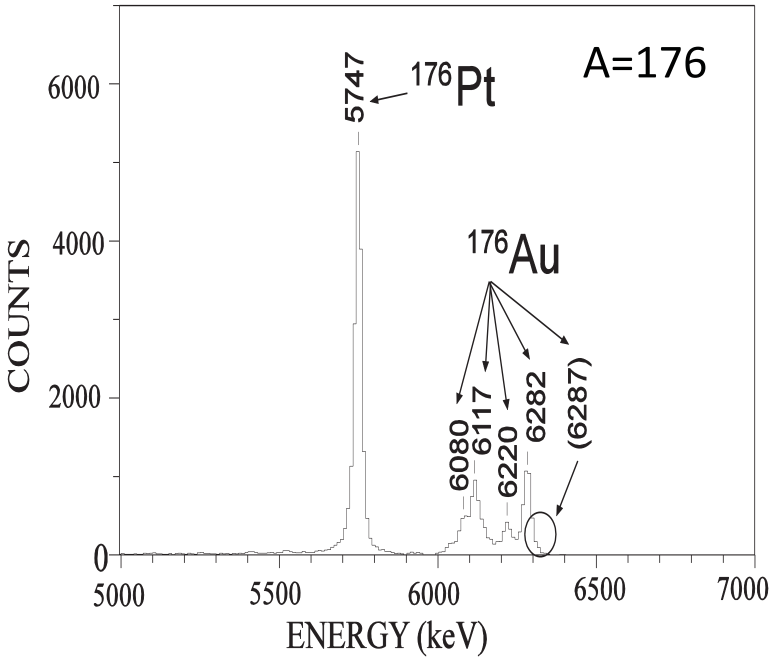
188 (12) ms – 124 (8) ms

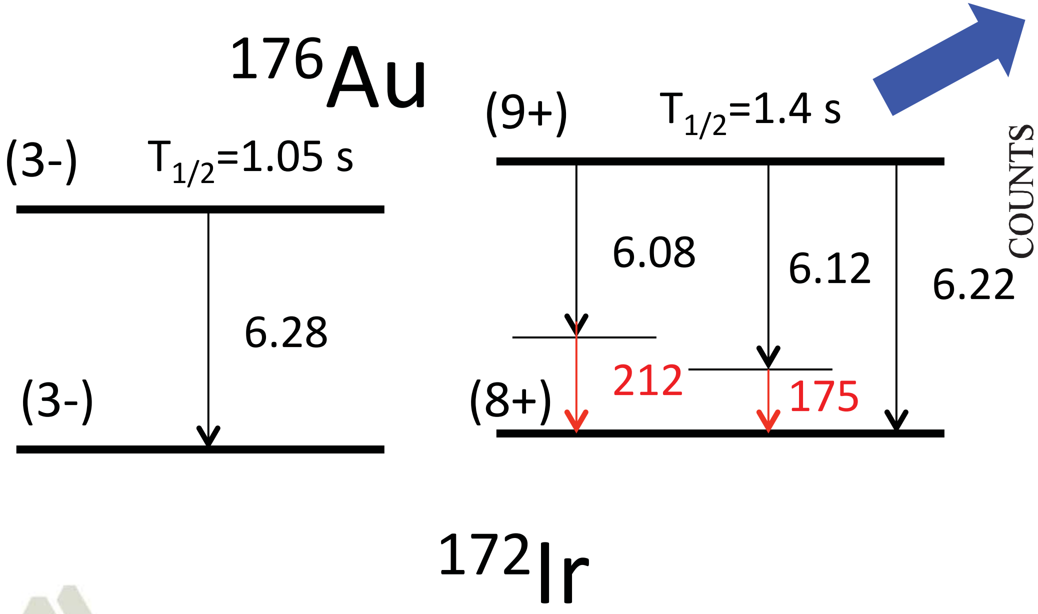
158 (3) ms using 6432α(t)

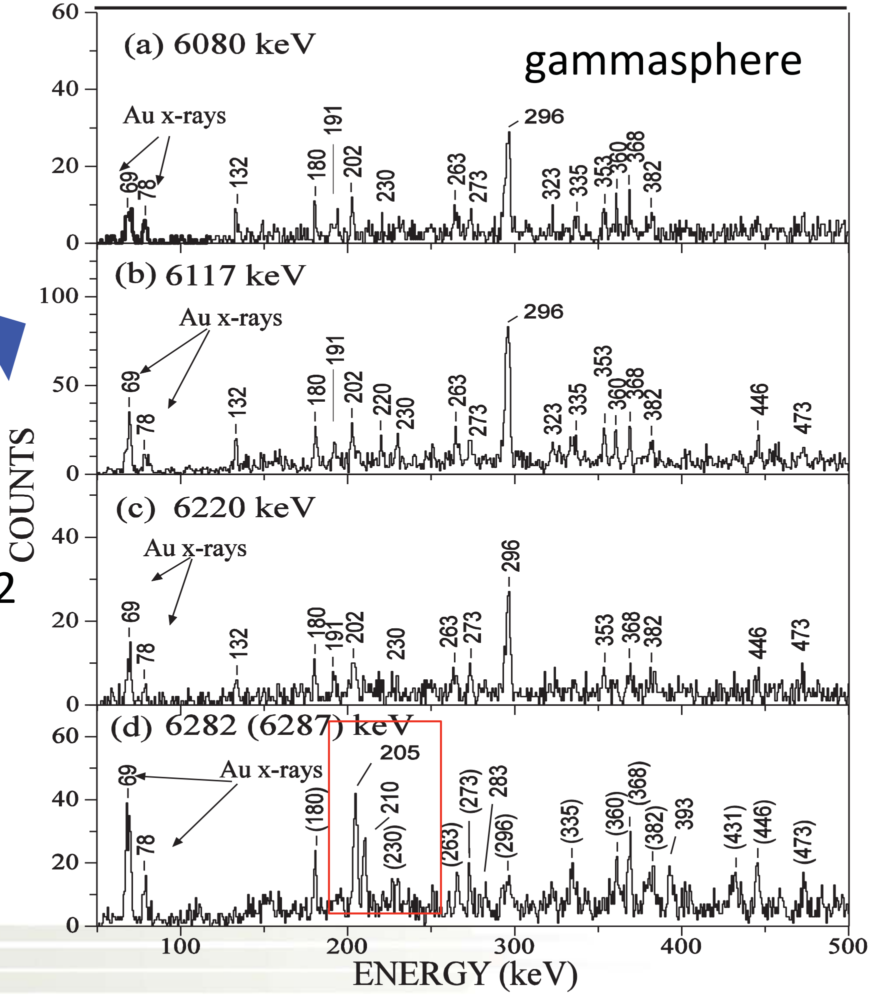
F.G. Kondev et al., PLB 512 (2001)

^{84}Sr + ^{94}Mo@^{178}Hg (pn)^{176}Au
Gammasphere & FMA

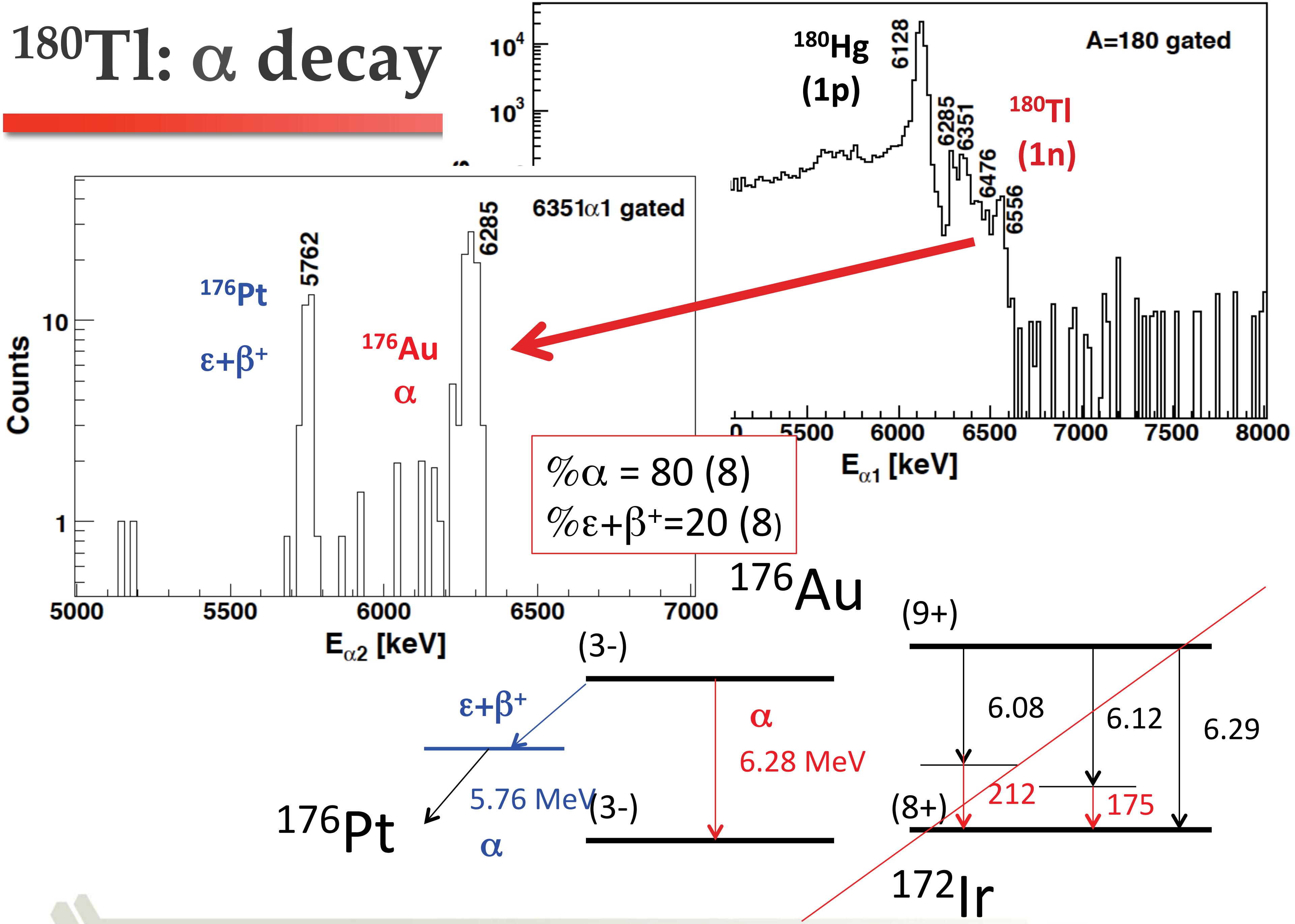
J.T.M. Goon, PhD thesis, UT





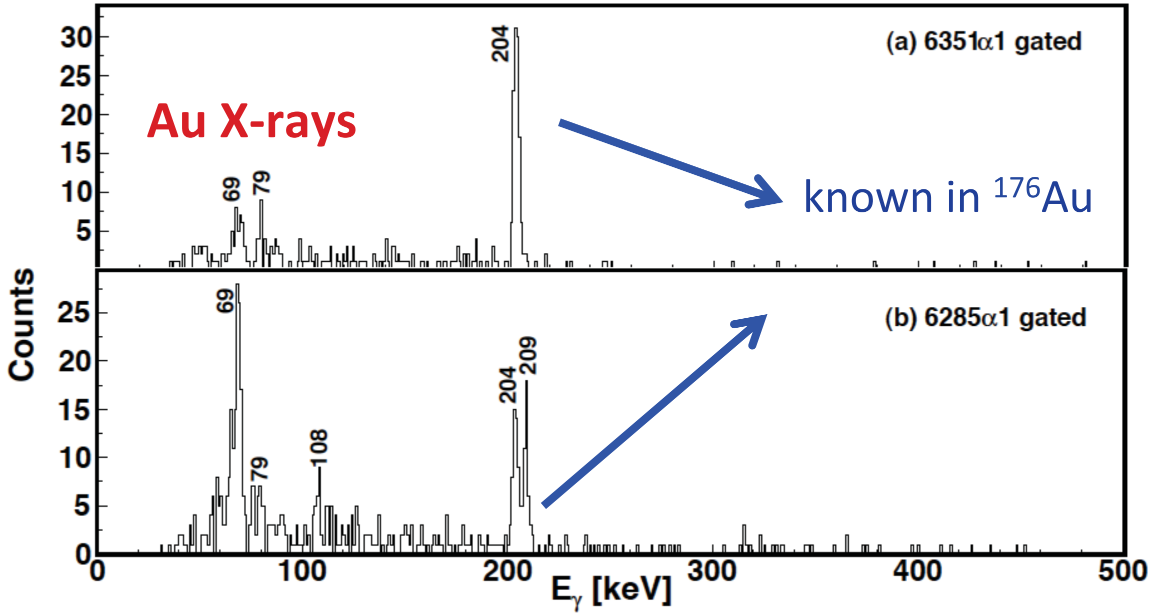


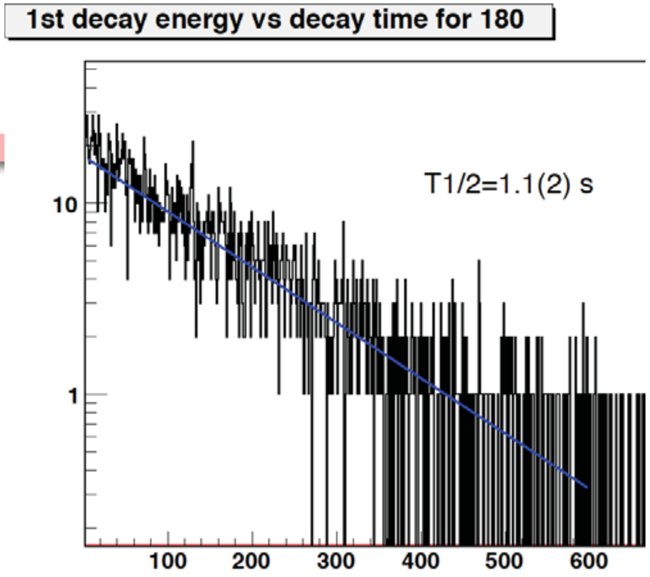
^{180}Tl: α decay

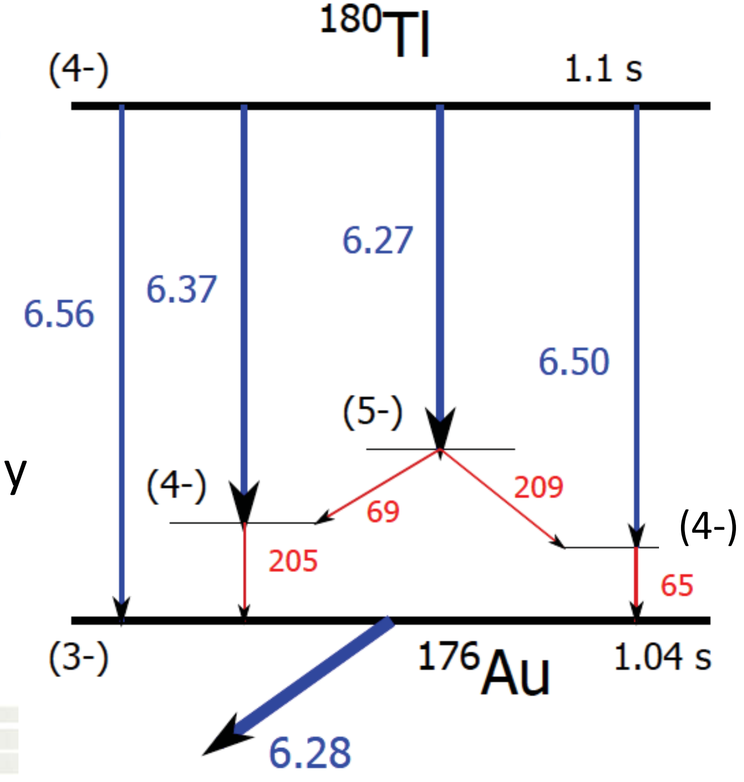


%α = 80 (8)
%ε+β^+=20 (8)

^{180}Tl: α−γ coincidences







- ✓ decay of a single state in ^{180}Tl

^{180}Tl:

I^{π}=**4-** and **5-**: $\pi 1/2^{+}$ ($s_{1/2}$) x $\nu 9/2^{-}$ ($h_{9/2}$) - favored α-decay

^{176}Au:

I^{π}=3- and 4-: $\pi 1/2^{+}$ ($s_{1/2}$) x $\nu 7/2^{-}$ ($f_{f/2}$)

Guidelines for evaluators

❑ Start with a collection of all references – NSR is very useful!

❑ Complete the ID record – provide information about the key references

  ✓ how the parent nuclide was produced, which techniques and equipment were used; what was the energy resolution of the spectrometer and what was actually measured

  ✓ mention other relevant references only by the NSR key number (for the benefit of the reader)

❑ Complete the Parent record

  ✓ Ex, J^{π} and T1/2 from "Adopted Levels" of the parent nuclide, BUT check for new data and reevaluate, if needed

  ✓ Qα from AME12 (2012Wa38)

❑ Deduce r0 (if not an even-even nuclide) and include it in the HF record

Guidelines for evaluators – cont.

NO GAMMA RAYS WERE MEASURED

- ☐ **Include measured Eα and Iα with the corresponding level**
  - ✓ if there is more than one reference you may use averages, BUT be careful – need to compare oranges with oranges, e.g. magnetic spectrometer (ΔE ~4 keV) vs Si (ΔE ~20 keV)
  - ✓ most measurements are relative to Eα from a standard radionuclide. If available, include this information in a comment.
  - ✓ use Ritz's (At. Data and Nucl. Data Tables 47, 205 (1991)) - evaluated Eα and Iα - when no new values are available.
  - ✓ renormalize Iα, so that SUM $I\alpha_i$ = 100 % - have a simple spreadsheet handy
  - ✓ provide comments on Eα and Iα , where appropriate
- ☐ **Complete the Normalization record – BR**
  - ✓ BR from Adopted levels of the parent, BUT check for new data are reevaluate, if needed

Guidelines for evaluators – cont.

GAMMA RAYS WERE MEASURED

- ☐ Include measured Eα and Iα (as in the earlier slide)
- ☐ Include measured Eγ and Iγ
  - ✓ if there is more than one reference you may use averages, BUT be careful – need to compare oranges with oranges
  - ✓ include Mult. & MR – use "Adopted gammas" or J^{π} differences if not available
  - ✓ include measured ICC and/or sub-shell ratios to support Mult. assignment or to deduce MR as a comment record to a corresponding G record
  - ✓ include T1/2 available for a particular level – usually αγ(t) coincidence data
- ☐ Run BrICC to deduce conversion electron coefficients
- ☐ Run GTOL – determine level energies and intensity balances
- ☐ Complete the Normalization record – NR and BR
  - ✓ NR - need to convert to %Iγ
  - ✓ BR from Adopted levels of the parent, BUT check for new data are reevaluate, if needed

Guideline for evaluators-cont.

- **Run FMTCHK – check that everything is OK**
- **Run ALPHAD - calculate HF**
- **Run RADLIST - check the decay scheme for consistency**

$$Qeff = \sum_{i=1}^{allBF} Q_i BF_i ; Qcalc = \sum_{j=1}^{all\gamma} E_{\gamma j} P_{\gamma j} + \sum_{k=1}^{all\beta} E_{\beta k} P_{\beta k} + \sum_{l=1}^{all\alpha} E_{\alpha l} P_{\alpha l} + etc. \quad Consistency = \left[\frac{Qeff - Qcalc}{Qeff} \right] \times 100\%$$