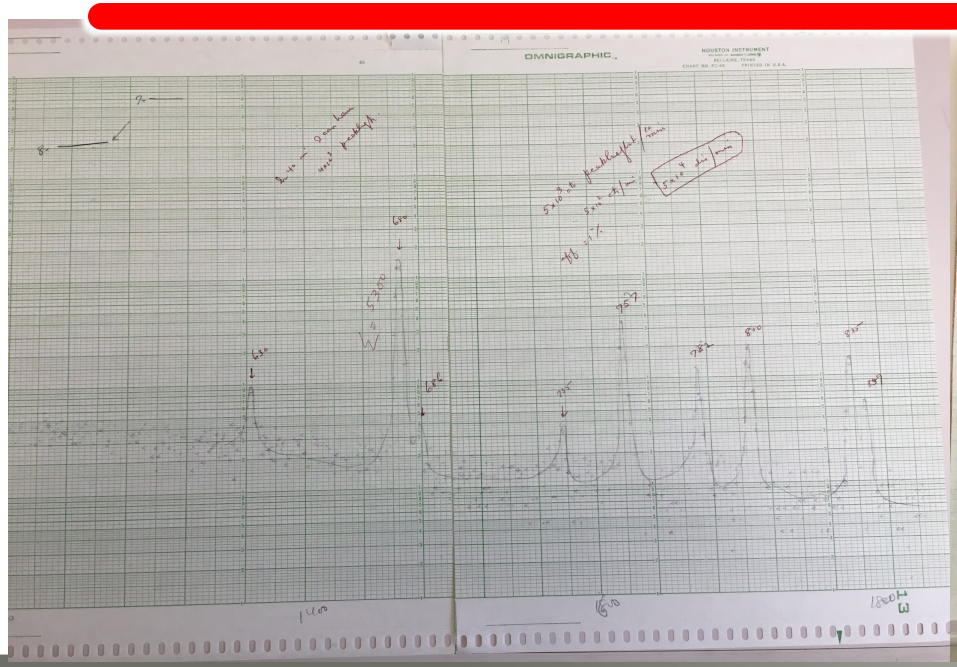
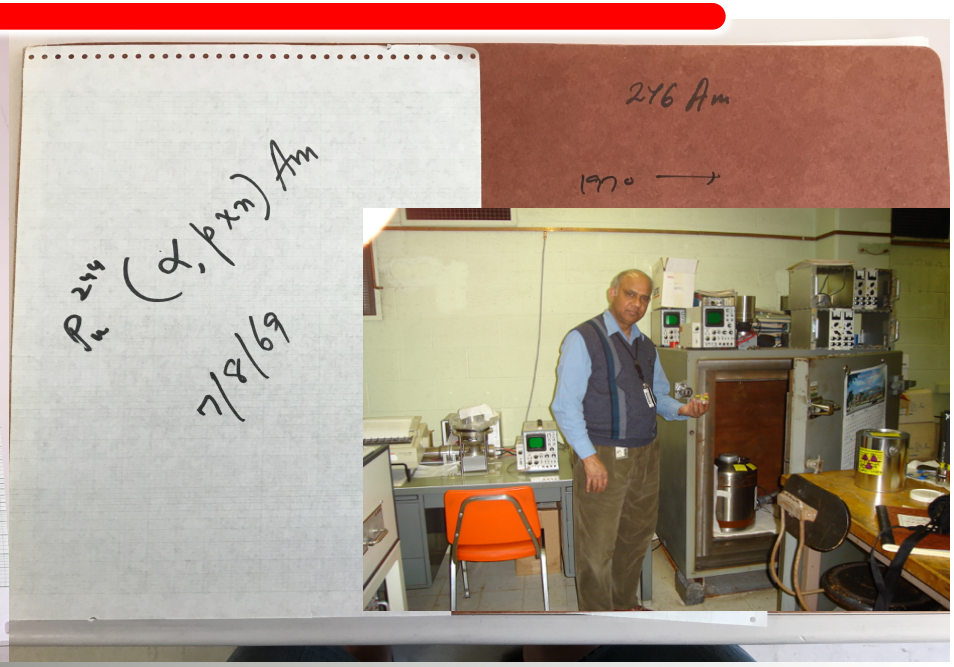
Nuclear Archaeology: Properties of K isomers in ^{244,246}Cm populated in β^- decays of ^{244,246}Am

with I. Ahmad & J. Greene (ANL)

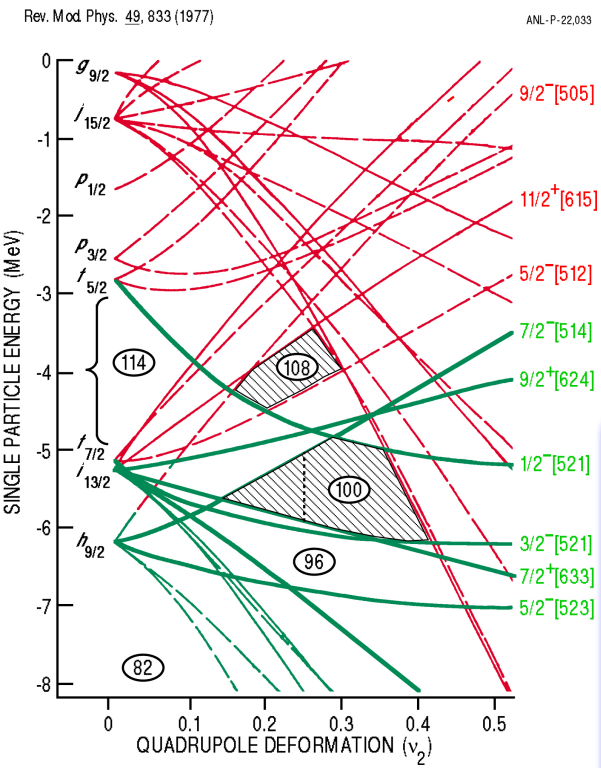
partial results were published by A. Robinson et al. PRC 78 (2008) 034308

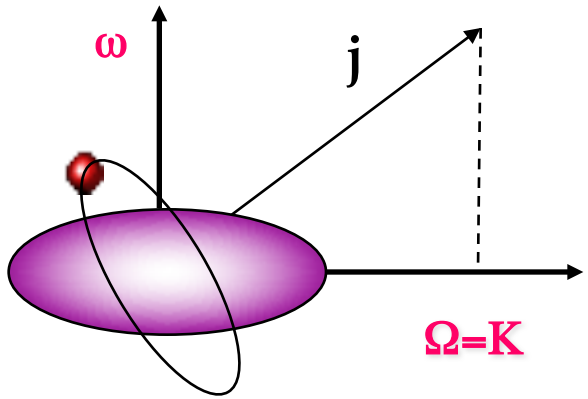


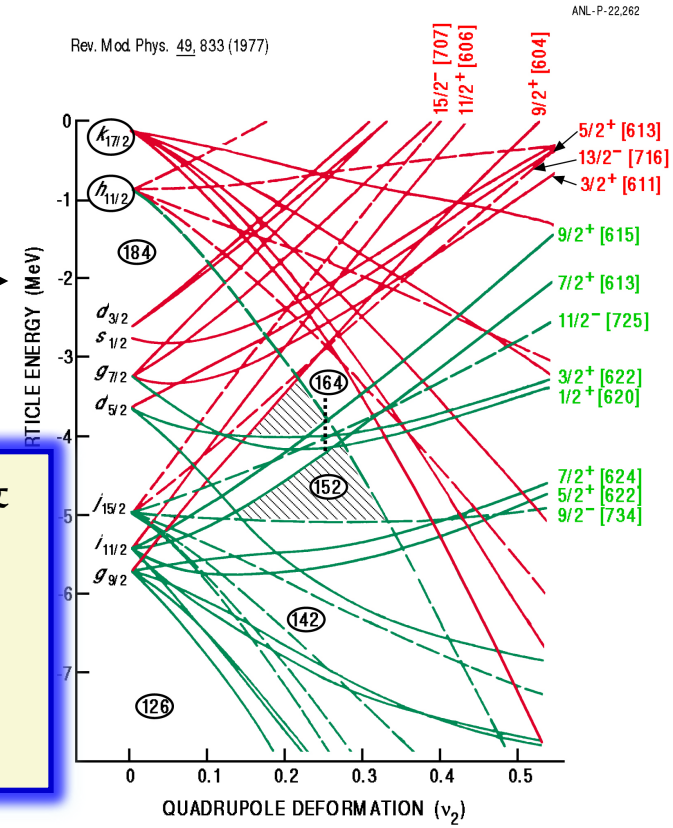


Trans-fermium region near Z=100 & N=152

Well-deformed nuclei with axially-symmetric shape







- ✓ single-particle structure & subshell closures
- ✓ collectivity, pairing and residual nucleon-nucleon interactions

High-K orbitals near the Fermi surface

N=150-152: ν 5/2[622], 7/2[624], 7/2[613], 9/2[734]

Z=100-104: π 5/2[523],5/2[642],7/2[633],7/2[514],9/2[624]

- ✓ competing mqp states & K- isomers
- ✓ high-K, α or β decaying states in odd-odd nuclei

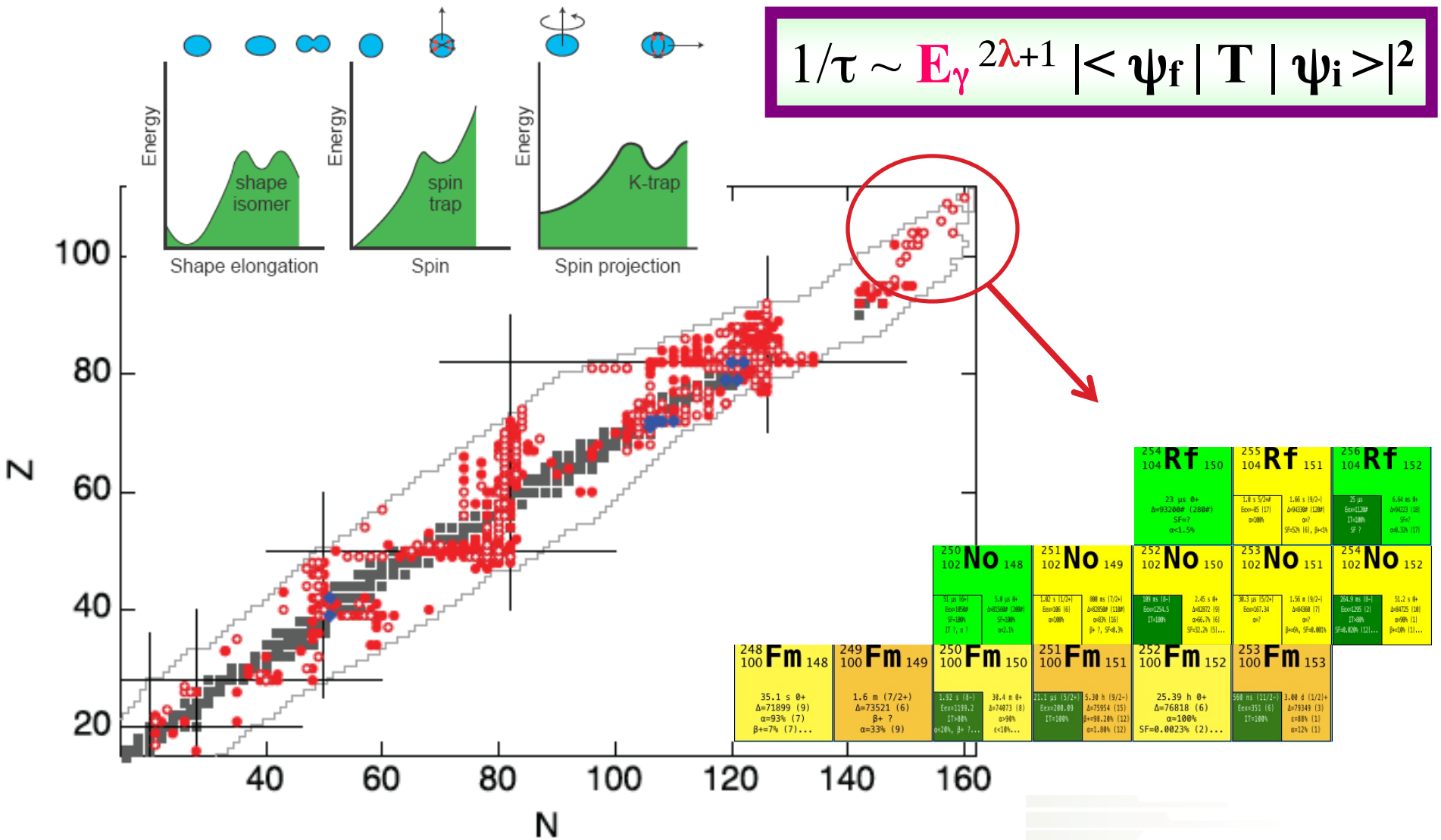
IOP Publishing

Rep. Prog. Phys. **79** 07630

Review of metastable states in heavy nuclei

G D Dracoulis[1,4], P M Walker[2] and F G Kondev[3]

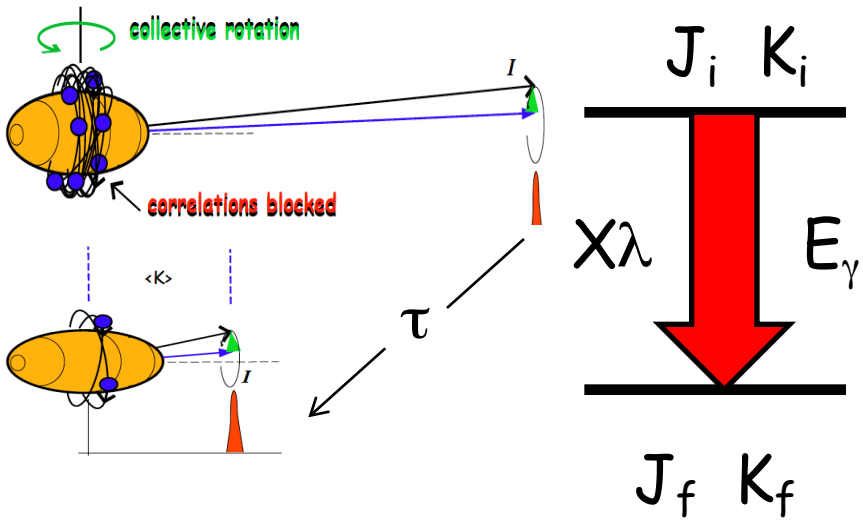
$$1/\tau \sim E_\gamma^{\,2\lambda+1} \, |\langle \psi_f \,|\, T \,|\, \psi_i \rangle|^2$$



Atomic Data and Nuclear Data Tables 103–104 (2015) 50–105

Configurations and hindered decays of K isomers in deformed nuclei with $A > 100$

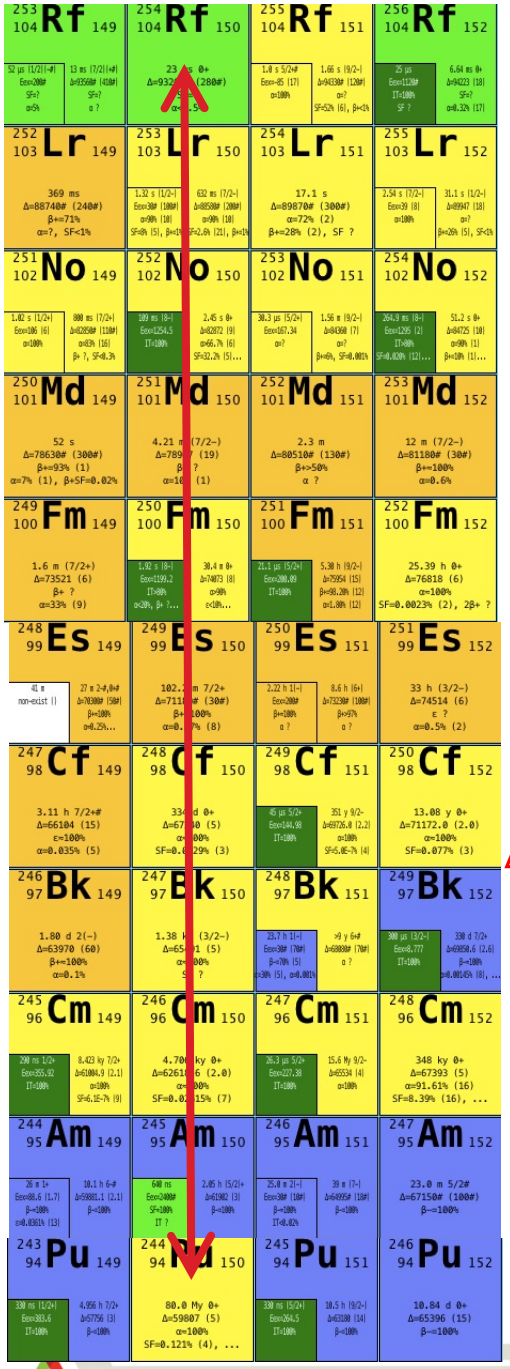
F.G. Kondev [a,*], G.D. Dracoulis [b,1], T. Kibédi [b]



- ✓ transition of multipolarity Xλ can only change the K projection by at most λ.
- ✓ the shortfall is the degree of "forbiddenness" $\nu = \Delta K - \lambda$.

- ✓ hindrance $F_w = \tau_\gamma / \tau_W$ & reduced hindrance $f_\nu = F_w^{1/\nu}$
  rule of thumb -> Fw increase by 100 per a unit of ν
- ✓ $Fw = F_0 x f_0^\nu$
  - F_0 – intrinsic part
  - f_0^ν – K-forbidden part

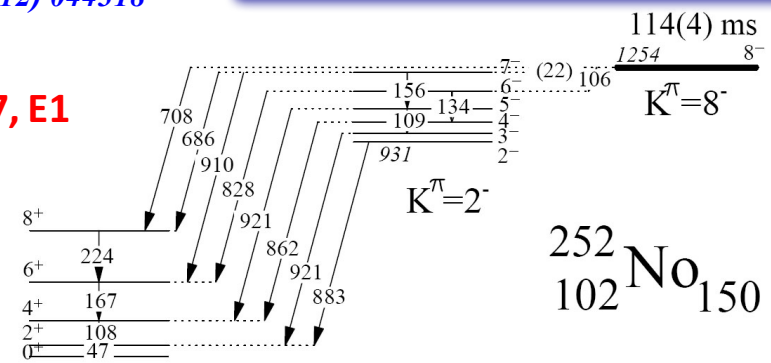
  ADNDT2015 -> Fw increase by ~6-9 per a unit of ν



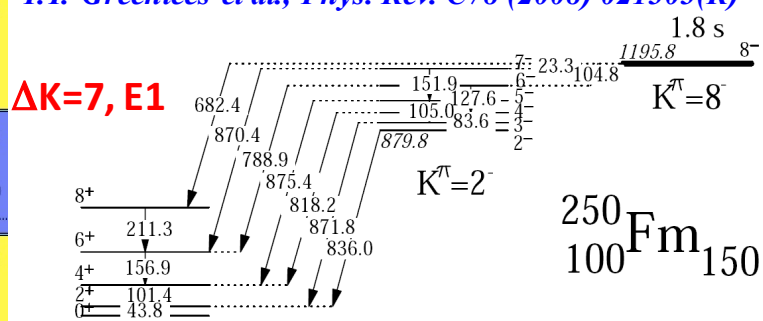
N=150 Isotones
Z=94, 96, (98), 100, 102 & 104

$K^{\pi}=8^-$, 2-qp state
$\nu^2(7/2[624],9/2[734])$

A. Robinson et al., Phys. Rev. C78 (2008) 034308
B. Sulignano et al., Eur. Phys. J. A33 (2008) 327
B. Sulignano et al., Phys. Rev. C86 (2012) 044318



P.T. Greenlees et al., Phys. Rev. C78 (2008) 021303(R)



- ✓ multiple branches from the isomers – but not precise BR for the decays to the $K^{\pi}=2^-$ band
- ✓ collective bands associated with the isomers – characterization of the configurations

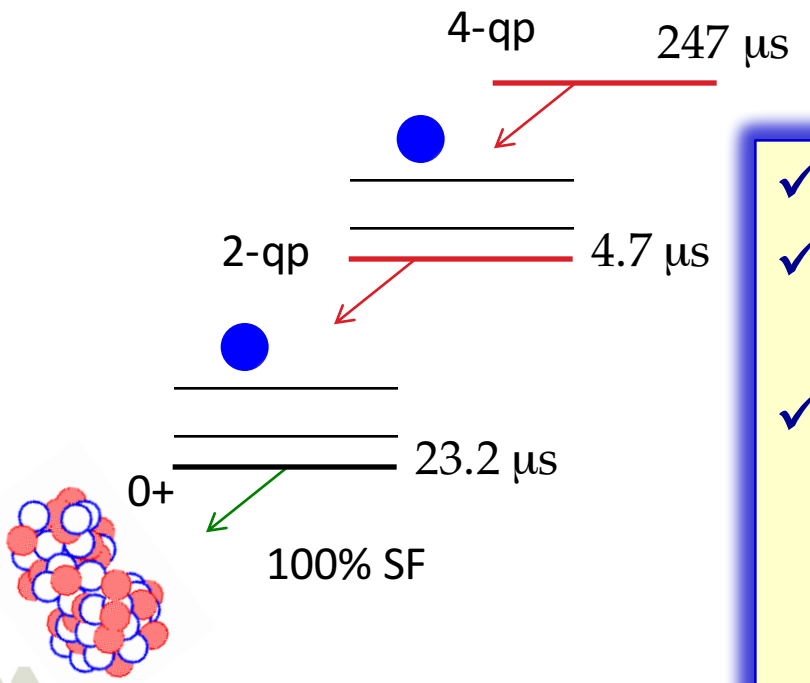
PRL 115, 132502 (2015) PHYSICAL REVIEW LETTERS week ending 25 SEPTEMBER 2015

Decay and Fission Hindrance of Two- and Four-Quasiparticle *K* Isomers in ^{254}Rf

H. M. David,[1] J. Chen,[1,‡] D. Seweryniak,[1,†] F. G. Kondev,[1] J. M. Gates,[2] K. E. Gregorich,[2] I. Ahmad,[1] M. Albers,[1,§] M. Alcorta,[1,∥] B. B. Back,[1] B. Baartman,[2] P. F. Bertone,[1,¶] L. A. Bernstein,[3] C. M. Campbell,[2] M. P. Carpenter,[1] C. J. Chiara,[4,1] R. M. Clark,[2] M. Cromaz,[2] D. T. Doherty,[5,**] G. D. Dracoulis,[6,*] N. E. Esker,[2] P. Fallon,[2] O. R. Gothe,[2] J. P. Greene,[1] P. T. Greenlees,[7] D. J. Hartley,[8] K. Hauschild,[9] C. R. Hoffman,[1] S. S. Hota,[10,††] R. V. F. Janssens,[1] T. L. Khoo,[1] J. Konki,[7] J. T. Kwarsick,[2] T. Lauritsen,[1] A. O. Macchiavelli,[2] P. R. Mudder,[2] C. Nair,[1] Y. Qiu,[10] J. Rissanen,[2] A. M. Rogers,[1,‡‡] P. Ruotsalainen,[7,‡‡] G. Savard,[1] S. Stolze,[7] A. Wiens,[2] and S. Zhu[1]

experiments at ANL & LBNL

^{254}Rf (Z=104; N=150)



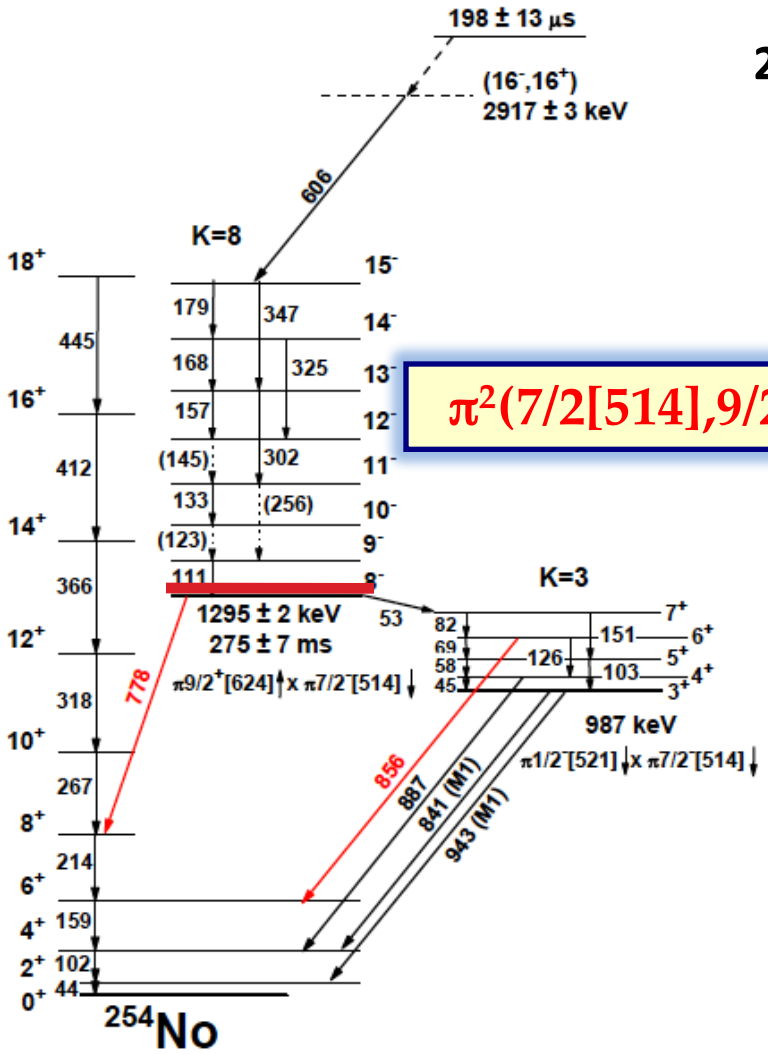
- ✓ discovery of 2-qp & 4-qp isomers
- ✓ 4-qp isomer is longer-lived than the ground state (100% SF)
- ✓ lack of good spectroscopy data prevents characterization of the observed structures – aided by systematics & model predictions

Reliable assignments require detailed spectroscopy!

F.P. Hesberger et al. (2010) @GSI & R.-D. Herzberg et al. (2006) @JYFL & S. Tandel at al. (2006) @ANL

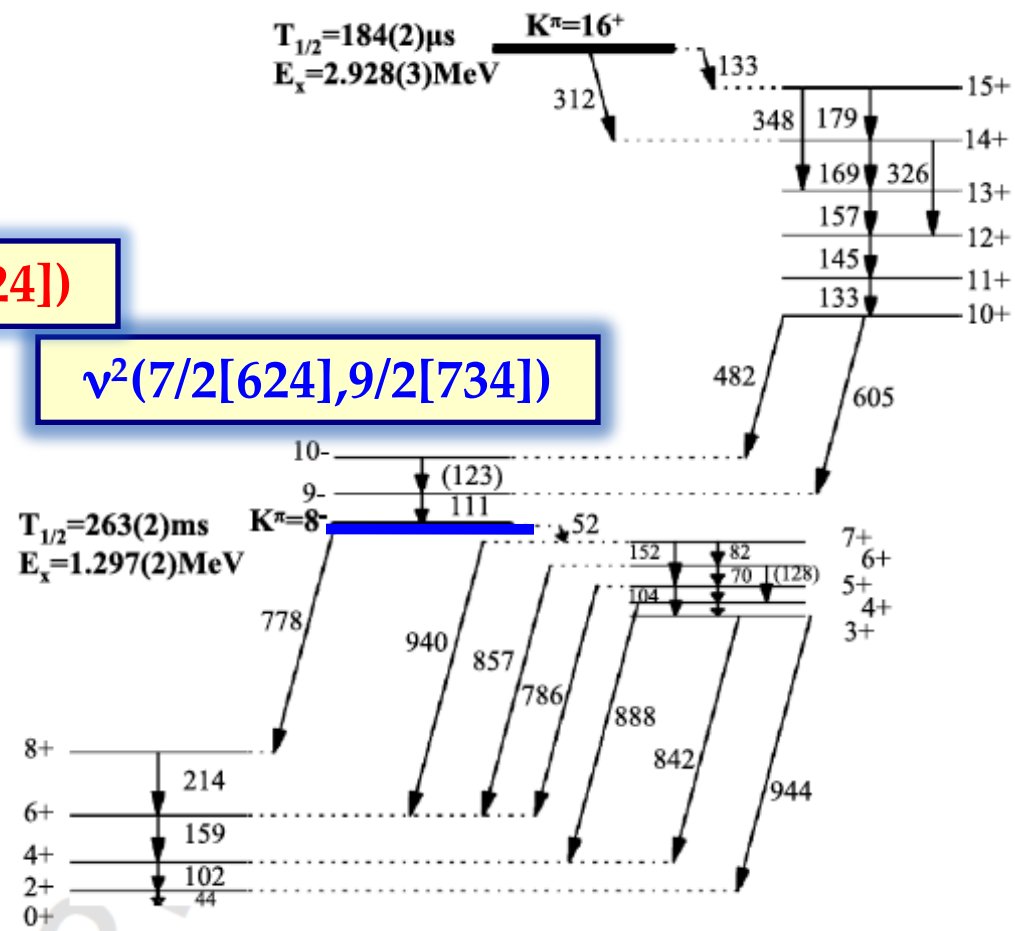
^{254}No

R.M. Clark et al. (2010) @LBNL

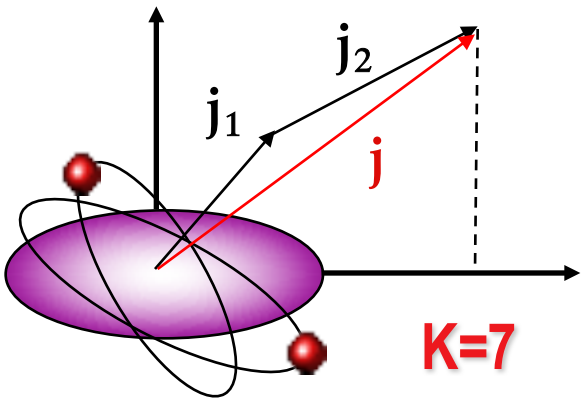


π^2(7/2[514],9/2[624])

ν^2(7/2[624],9/2[734])



Beta decay of odd-odd nuclei

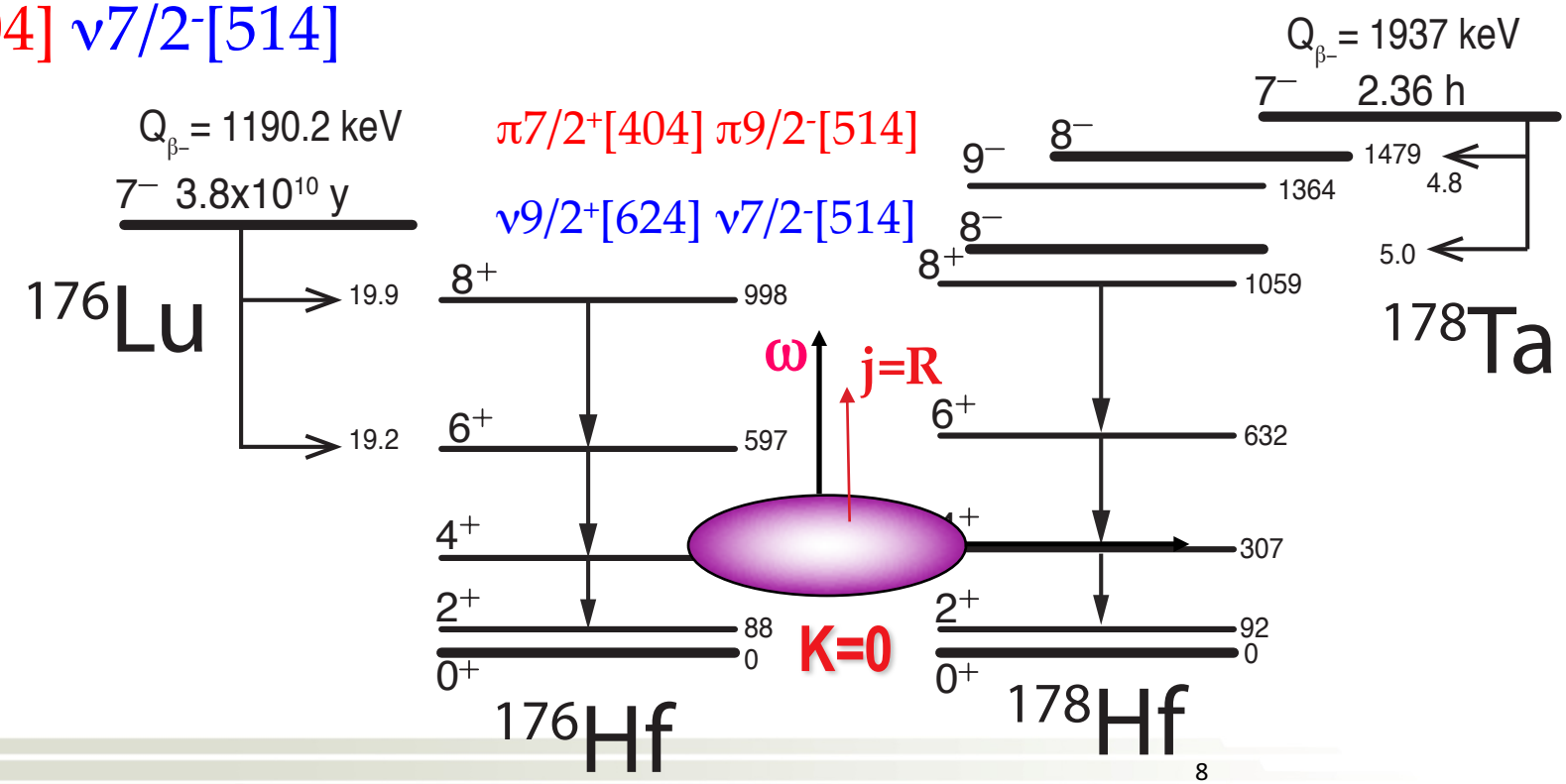


$\pi 7/2^+[404]$ $\nu 7/2^-[514]$

$$\log ft = (\log ft)_{sp} \times P^2 \times HF$$

$\pi 9/2^-[514]$ <- $\nu 7/2^-[514]$: *log* ft =4.4 (spin-flip)

$\pi 7/2^+[404]$ -> $\nu 9/2^+[624]$: *log* ft =6.7



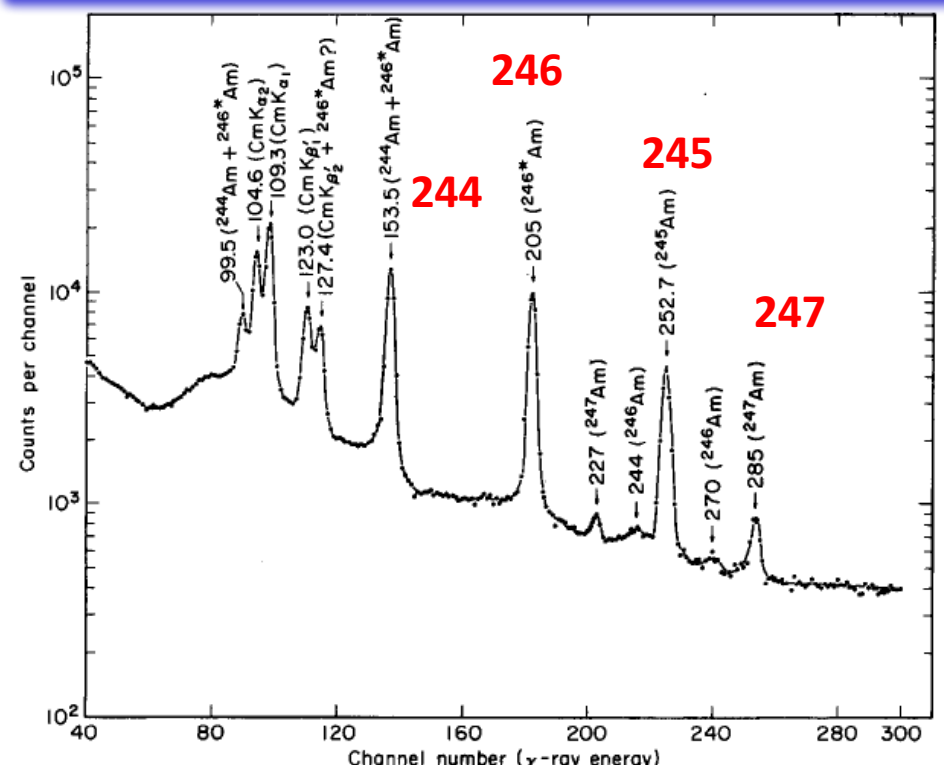
J. inorg. nucl. Chem., 1968, Vol. 30, pp. 1345 to 1352. Pergamon Press. Printed in Great Britain.

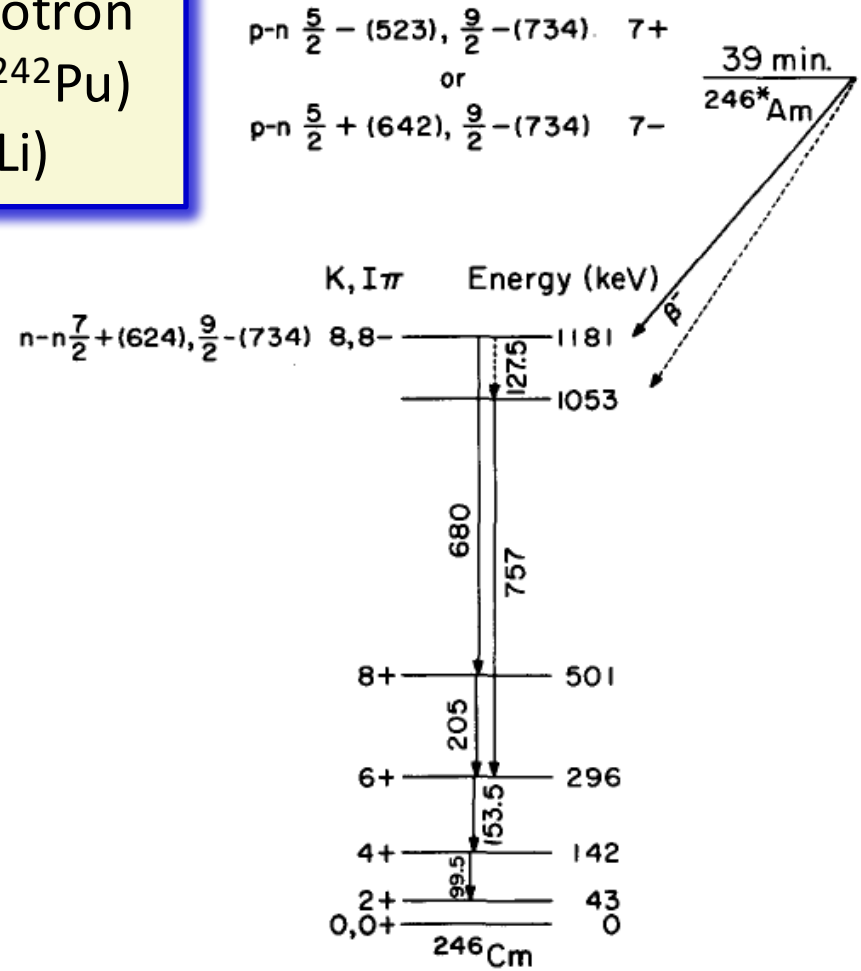
NUCLEAR PROPERTIES OF ^{246}Am AND ^{247}Am*

P. R. FIELDS, I. AHMAD, R. K. SJOBLOM, R. F. BARNES and E. P. HORWITZ
Chemistry Division, Argonne National Laboratory, Argonne, Illinois

α + ^{244}Pu (pxn) → ^{244,245,246,247}Am

- ✓ 42 MeV from the Argonne 60-in cyclotron
- ✓ 74.2% enriched ^{244}Pu target (25.3% ^{242}Pu)
- ✓ chemically purified samples & 1 Ge(Li)





NUCLEAR INSTRUMENTS AND METHODS 102 (1972) 373–378; © NORTH-HOLLAND PUBLISHING CO.

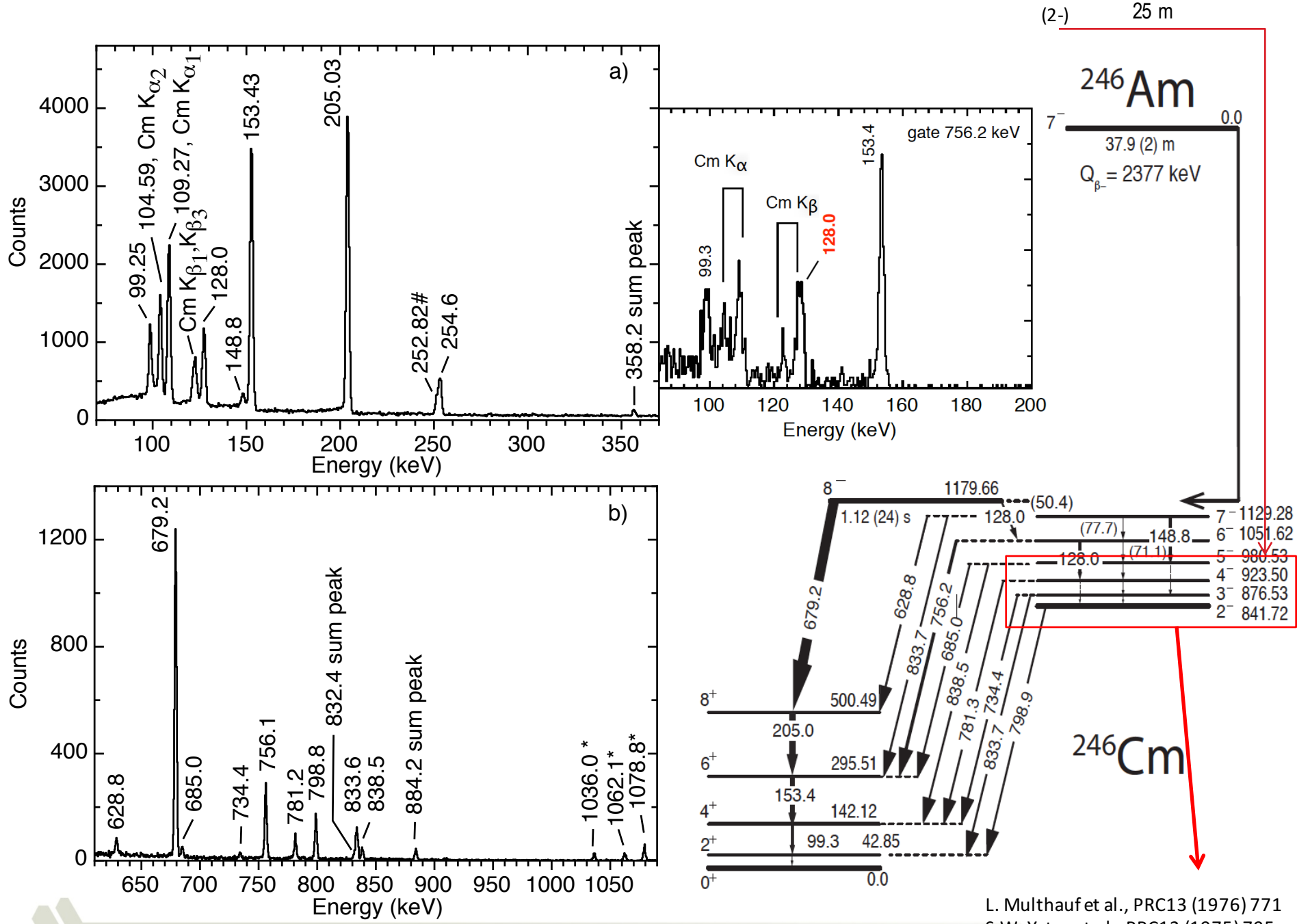
PREPARATION OF NUCLEAR RESEARCH MATERIALS WITH A LABORATORY-TYPE ISOTOPE SEPARATOR

J. LERNER

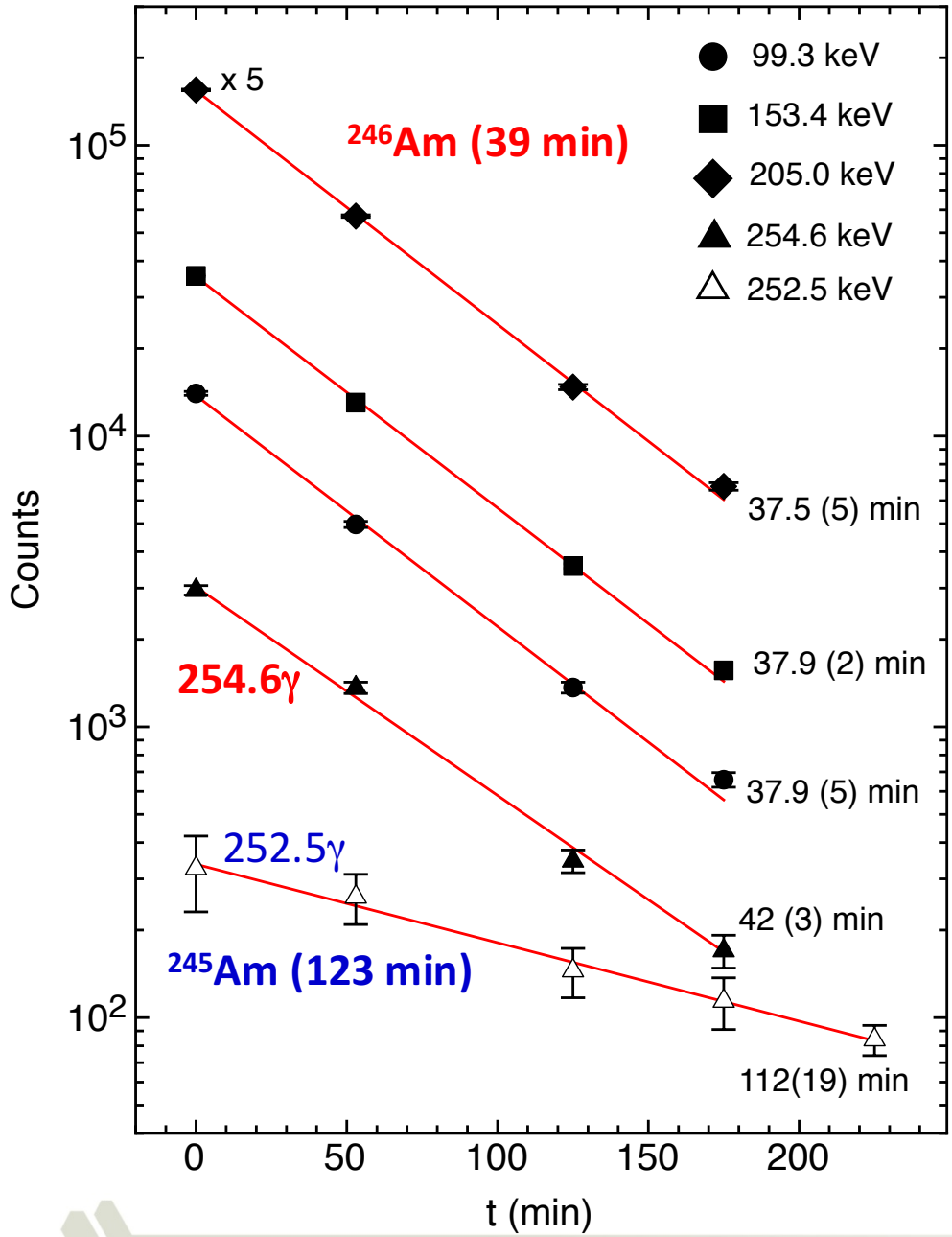
Argonne National Laboratory, Argonne, Illinois, U.S.A.

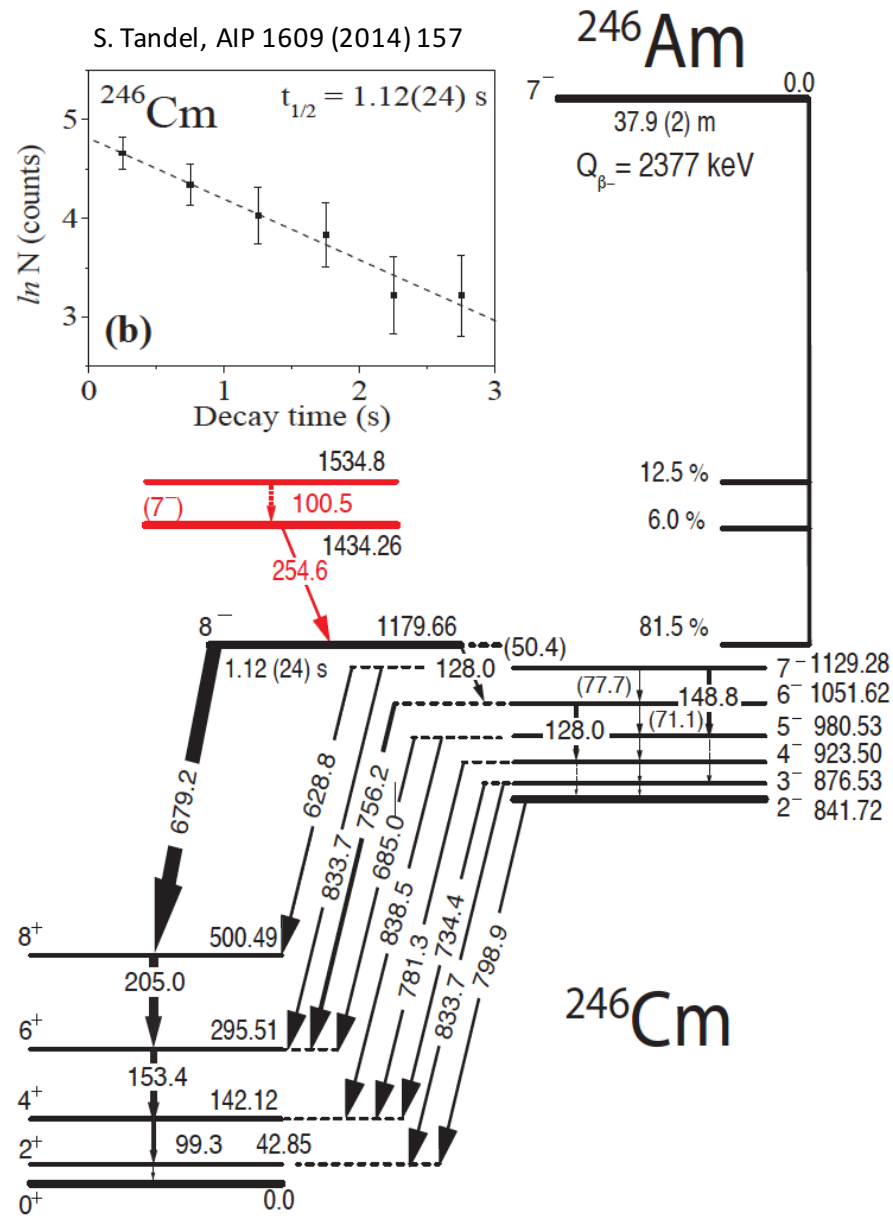
α + ^{244}Pu (pxn) → ^{244,245,246,247}Am

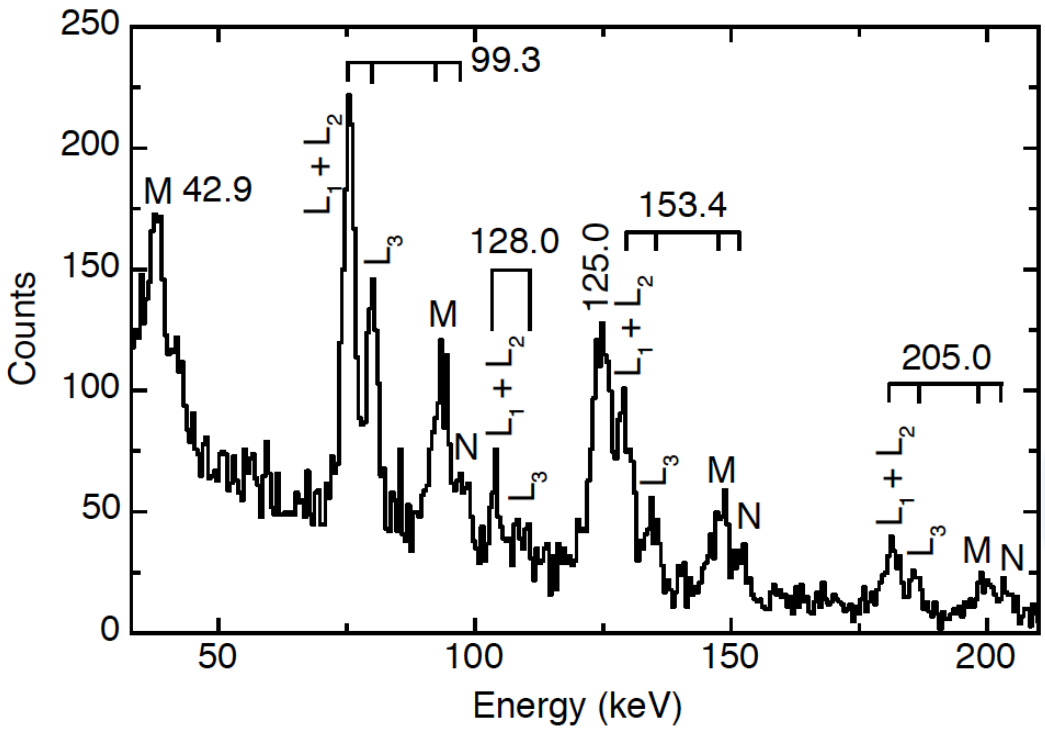
- ✓ chemically purified & run through the isotope mass separator
- ✓ ^{246}Am (25 min) was ~5% of the total activity
- ✓ 4-cm^3 and 25-cm^3 Ge(Li) – singles and γ–γ coincidences
- ✓ a cooled Si(Li) detector – singles γ and CE & CE-γ coin

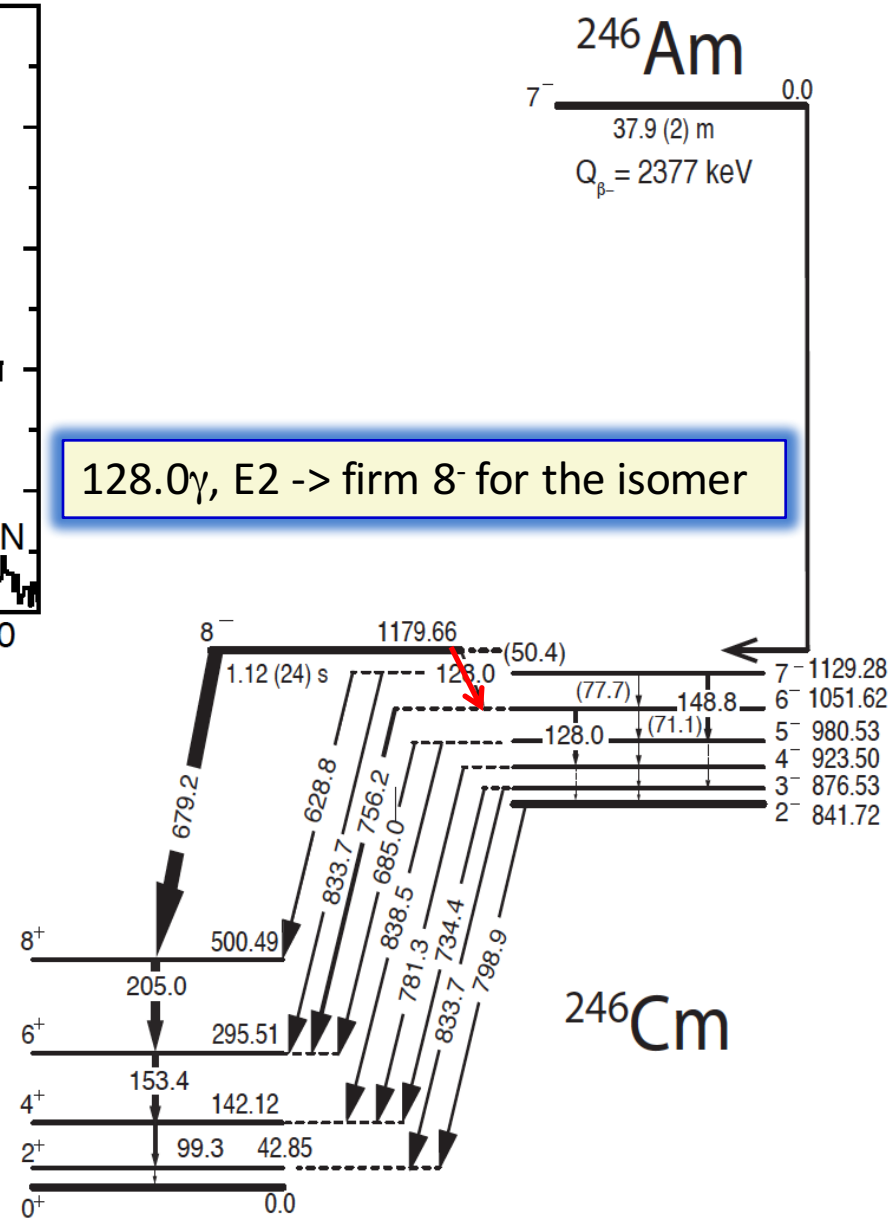


L. Multhauf et al., PRC13 (1976) 771
S.W. Yates et al., PRC12 (1975) 795


x 5
246Am (39 min)
99.3 keV
153.4 keV
205.0 keV
254.6 keV
252.5 keV
37.5 (5) min
37.9 (2) min
37.9 (5) min
42 (3) min
112(19) min
254.6γ
252.5γ
245Am (123 min)
Counts
t (min)


S. Tandel, AIP 1609 (2014) 157
246Cm
t1/2 = 1.12(24) s
ln N (counts)
(b)
Decay time (s)
246Am
37.9 (2) m
Qβ- = 2377 keV
12.5 %
6.0 %
81.5 %
1534.8
100.5
1434.26
254.6
1179.66
1.12 (24) s
679.2
628.8
833.7
756.2
685.0
838.5
781.3
734.4
833.7
798.9
(50.4)
128.0
(77.7)
148.8
(71.1)
128.0
7− 1129.28
6− 1051.62
5− 980.53
4− 923.50
3− 876.53
2− 841.72
500.49
205.0
295.51
153.4
142.12
99.3
42.85
0.0
246Cm





Type	Expt.	Theory		
		E1	M1	E2
L1+L2	3.1 (3)	0.044	2.5	2.9
L3	**1.5 (2)**	0.012	0.011	**1.5**
(L1+L2)/L3	**2.0 (4)**	3.3	227	**1.9**

Configurations and *log* ft values

$\pi 5/2^+[642]$ $\nu 9/2^-[734]$

MQP blocking calculations

$\nu^2 8^-$: $\nu^2(7/2[624],9/2[734])$

$\nu^2 7^-$: $\nu^2(5/2[622],9/2[734])$

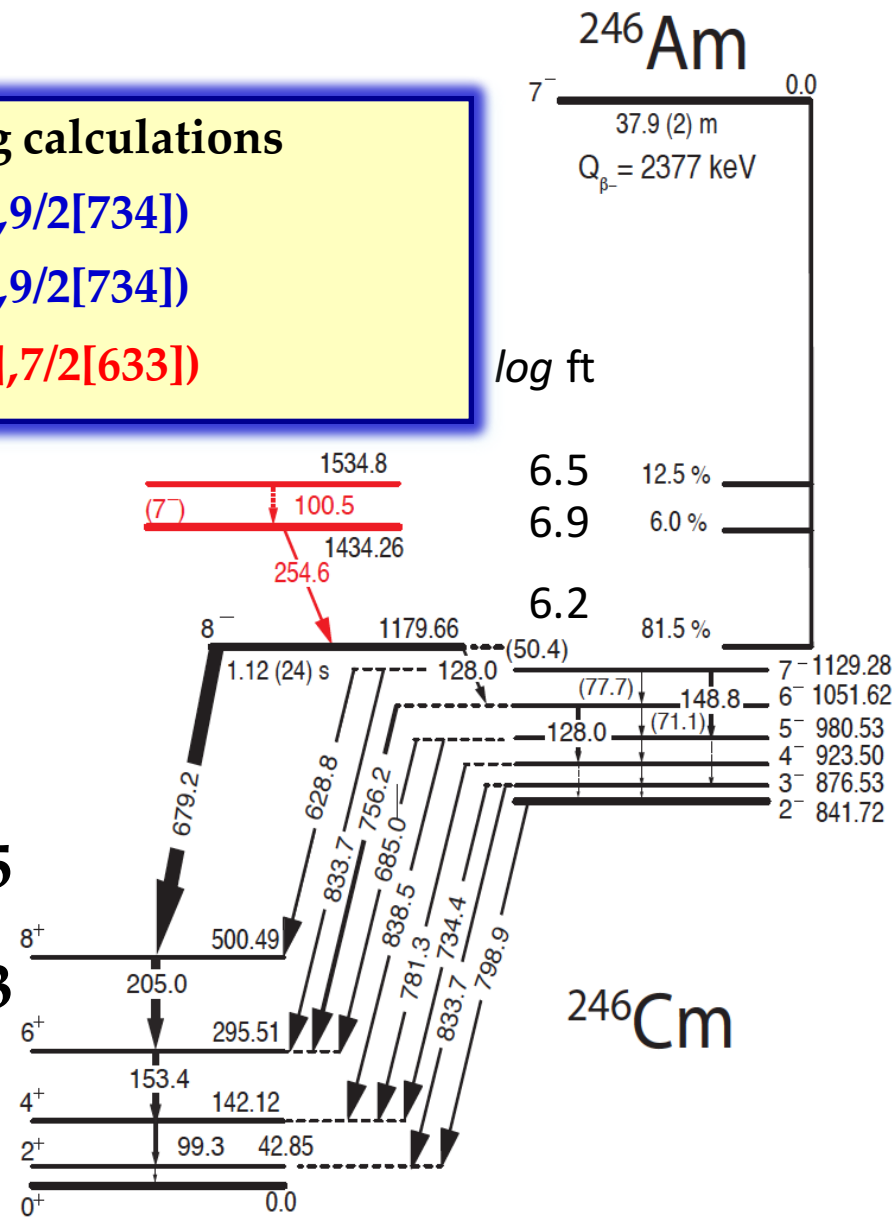
$\pi^2 6^+$: $\pi^2(5/2[642],7/2[633])$

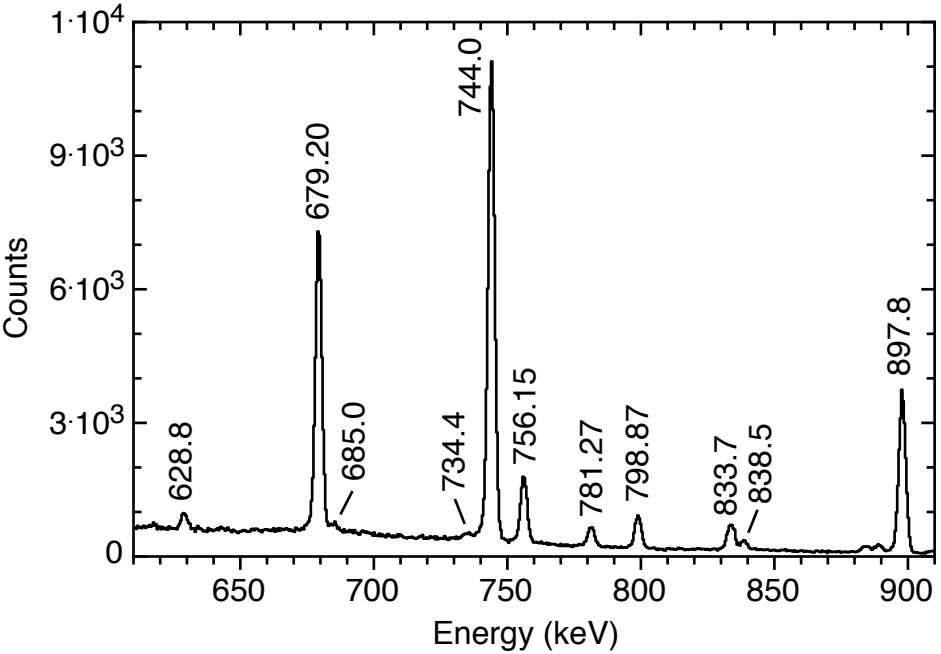
$\nu 5/2^+[622]$ $\nu 9/2^-[734]$

$\nu 7/2^+[624]$ $\nu 9/2^-[734]$

$\pi 5/2^+[642]$ -> $\nu 5/2^+[622]$: ***log* ft =6.5**

$\pi 5/2^+[642]$ -> $\nu 7/2^+[624]$: ***log* ft =6.3**





$\pi 5/2^-[523]$ $\nu 7/2^+[624]$

^{244}Am

6^- 0.0

10.1 h

β^-_0

log ft =5.6

6^+ 1040.20

34 (2) ms

$\nu 5/2^+[622]$ $\nu 7/2^+[624]$

538.4

744.0

897.8

$\pi 5/2^-[523]$ -> $\nu 5/2^+[622]$: *log* ft =5.8

8^+ 501.82

205.6

6^+ 296.23

153.9

4^+ 142.37

2^+ 99.4

42.97

0.0

0^+

^{244}Cm

~30 % uncertainty

S.E. Vanderbosch, P.Day, NP30 (1962) 177; BR

P.G. Hansen et al., NP45 (1963) 410; $T_{1/2}$, BR~30%

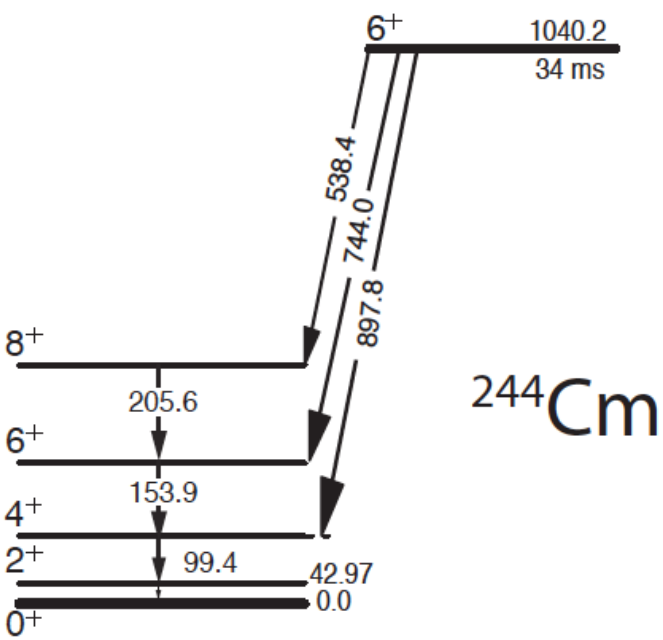
R. Hoff et al., PRC29 (1984) 618; BR~30%

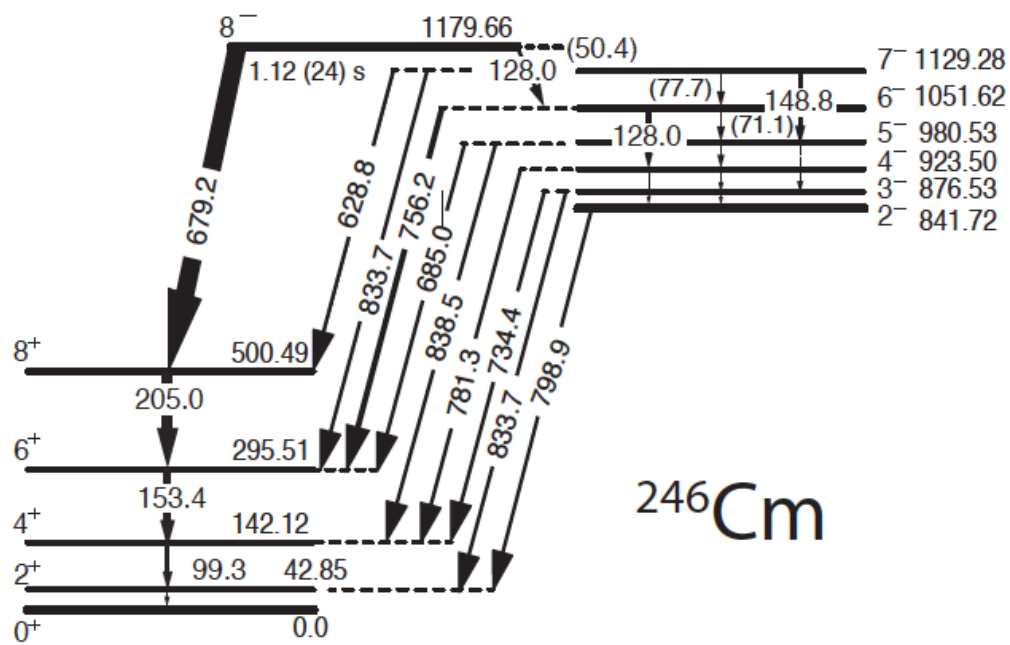
Branching Intensities & Hindrances

E_γ	Mult	I_γ	ν	f_ν
538.4	**E2**	**1.0 (3)**	**4**	**440 (30)**
744.0	M1	100 (1)	4	283 (6)
897.0	**E2**	**44.9 (6)**	**4**	**323 (5)**

E_γ	Mult	I_γ	ν	f_ν
50.4	M1	0.46 (7)	5	298 (15)
128.0	**E2**	**6.0 (5)**	**4**	**115 (6)**
679.2	**E1**	**100.0 (8)**	**7**	**166 (5)**

- ✓ mixing with the 8- member of the $K^\pi=2^-$ band (ΔE~30 keV)
- ✓ possible role of the octupole correlations – $K^\pi=8^-$: $j_{15/2}, g_{9/2}$; $\Delta j=\Delta l=3$





Conclusions & Outlook

- a wealth of experimental data are needed to understand the structure of heavy elements – K isomers provide complementary & useful information on single-particle structures, pairing, deformation, etc.

- decay of high-K, odd-odd nuclei is a powerful tool to populate & study properties of configuration-related multi-quasiparticle states in very heavy nuclei

- detailed spectroscopy is important in order to establish quantum properties and to characterize the observed structures

- the E2 decay from the K^{π}=8- isomer to the $K^{\pi}=2^{-}$ octupole band in ^{246}Cm is much faster compared to equivalent decays in ^{244}Cm. Reliable data on such decays in ^{250}Fm and ^{252}No are also needed

- when are we going to solve the ^{254}No puzzle? If the γ-ray spectroscopy cannot do it (I believe it CAN!), the laser spectroscopy is a promising tool …