In-beam and decay studies of high-K states in heavy nuclei

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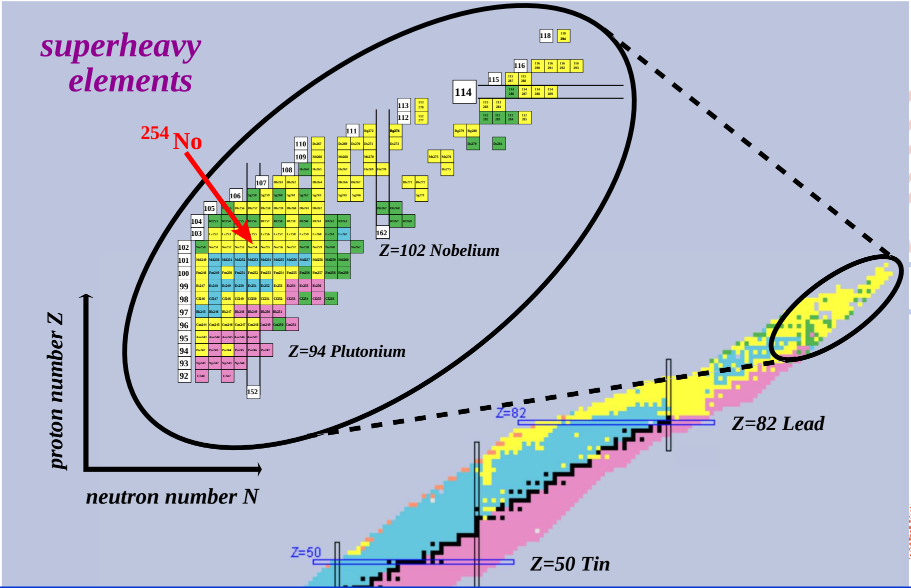
Collaborators

Surrey Isomer Workshop
19.5.2010
University of Surrey, U.K.

Outline

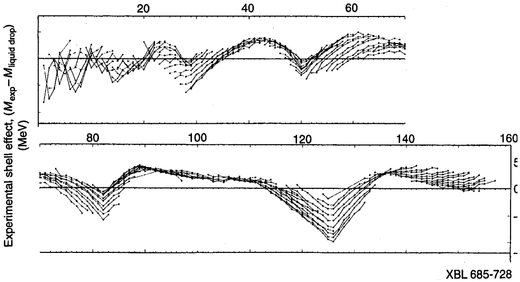
Superheavy Elements - Current Status

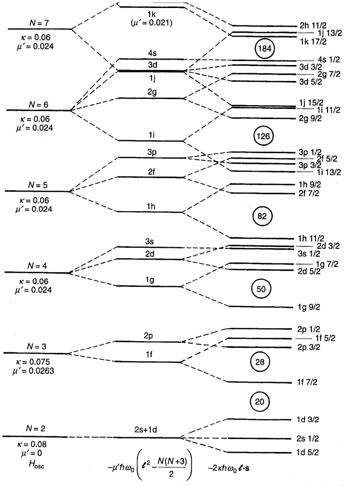


Superheavy Elements

Enhanced Stability - Shell Effects

- Nucleus not simply a liquid drop
- Evidence e.g. from masses
- Enhanced stability at 2,8,20,28,50,82,(126)
- Confining potential - gaps in energy level spectrum
- Reproduction of Magic Numbers - l^2 and $l.s$ terms

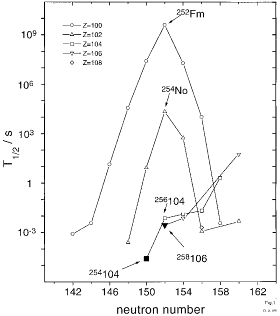


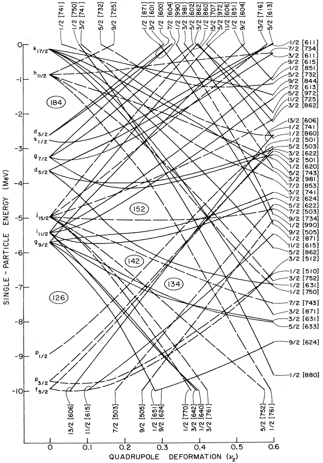


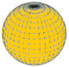
Superheavy Elements

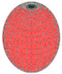
Enhanced Stability - Shell Effects

- Majority of nuclei not spherical
- Effect of deformation?
- Deformed shell gaps
- Enhanced stability e.g. at N=142,152

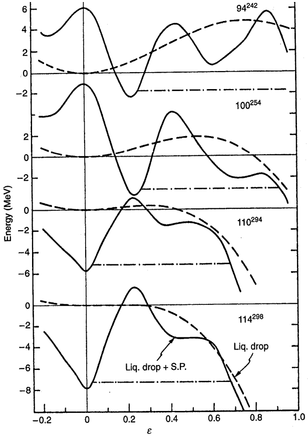


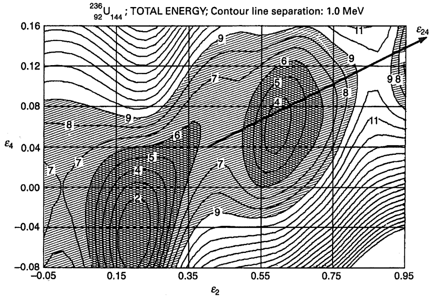




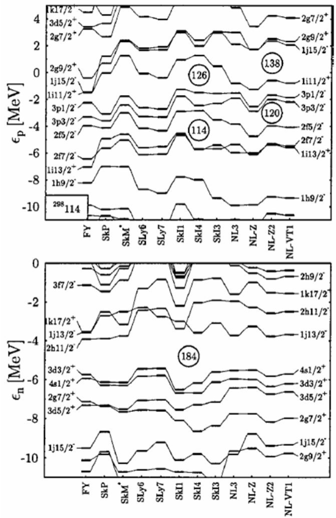


Superheavy Elements





Motivation: Constraining Theory

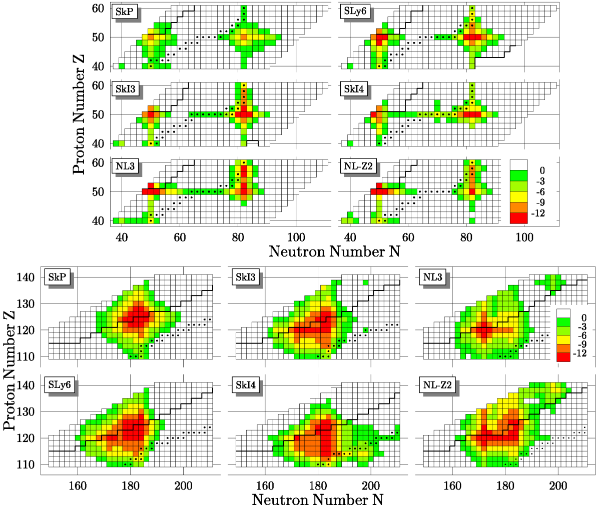


M. Bender et al., PRC60, 034304 (1999)

Self-Consistent Theories

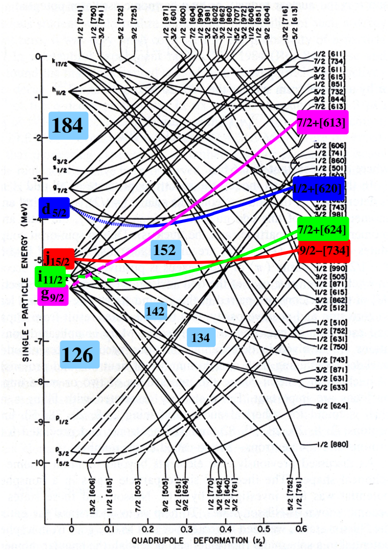
- Calculations based on realistic effective nucleon-nucleon interaction
- e.g. Skyrme
- Allows results to be traced back to interaction
- Difficult in Macroscopic-Microscopic calculations
- Need experimental data to determine correct ordering
- Will provide better predictions of properties of SHE
- Location of next proton shell gap?

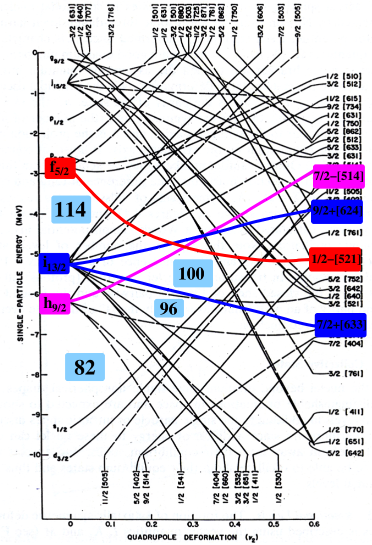
Shell stabilisation without magic gaps



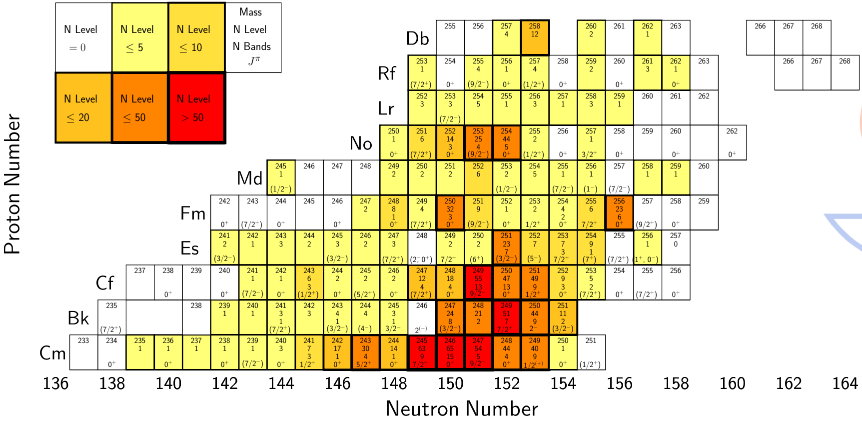
M. Bender, W. Nazarewicz, P.-G. Reinhard, PLB 515, 42 (2001)

Single-Particle Orbitals in Region of ^{254}No



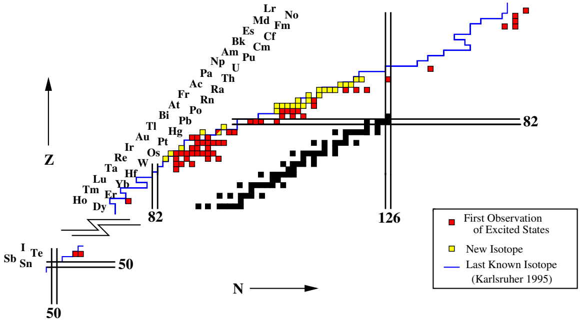


Motivation: ENSDF 2007



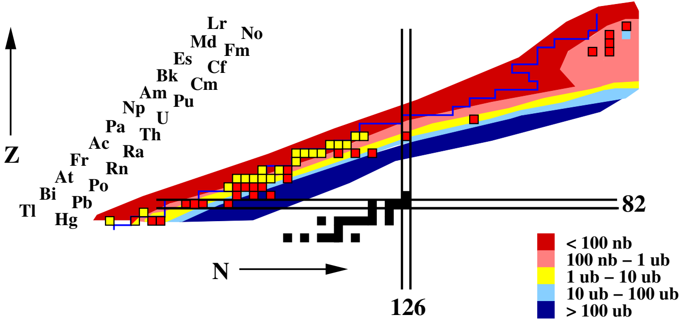
R.-D.Herzberg and P.T.Greenlees, Prog. Part. Nuc. Phys. 61, 674 (2008)

Regions of Study at JYFL



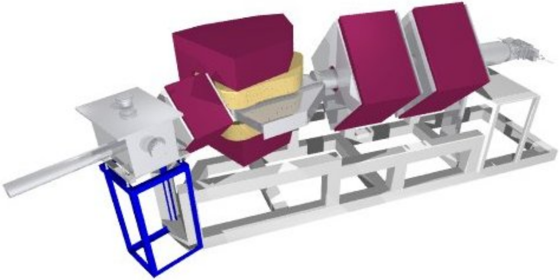
- Shell-stabilized transfermium nuclei
- Shape co-existence in light Pb and Po region
- Proton dripline nuclei
- K-isomerism in the A=140 region
- Nuclei close to ^{100}Sn

Spectroscopy of Heavy Nuclei



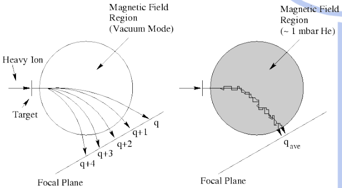
- Decreasing cross-section with increasing Z, decreasing N
- Increased fission probability (Z^2/A)
- Typical limit for γ^n measurements > 100 μb
- Need channel selection

The RITU Gas-filled Recoil Separator

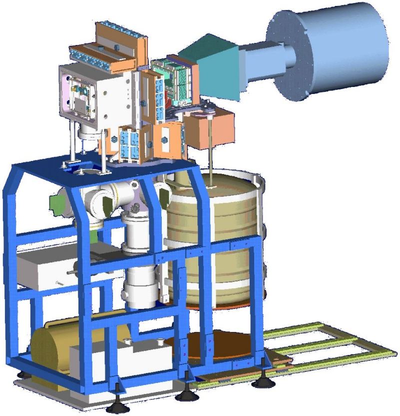


M.Leino et al., NIM **B99**, 653 (1995)

- High Efficiency
- Low mass resolution
- Charge and Velocity Focussing



The GREAT Spectrometer

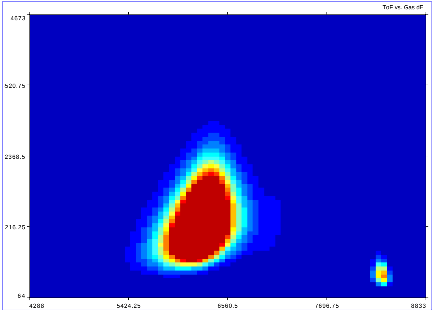


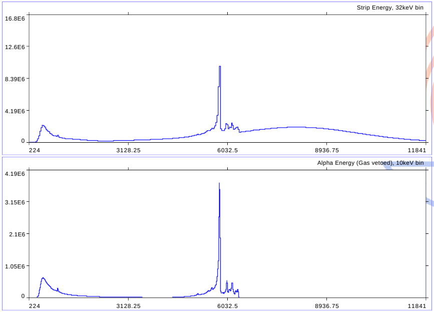
- UK Universities + Daresbury
- 2×60 mm $\times$ 40 mm DSSSD
- 28×28 mm $\times$ 28 mm PIN Diodes
- 24×12 Segmented Planar Ge
- Compton-Suppressed 16-fold Segmented Clover Ge
- Position Sensitive MWPC
- Total Data Readout (TDR) Acquisition System

R.D.Page et al., NIM **B204**, 634 (2003)

Particle Identification

$$^{36}\mathrm{Ar} + {}^{144}\mathrm{Sm} \Rightarrow {}^{180}\mathrm{Hg}^*$$

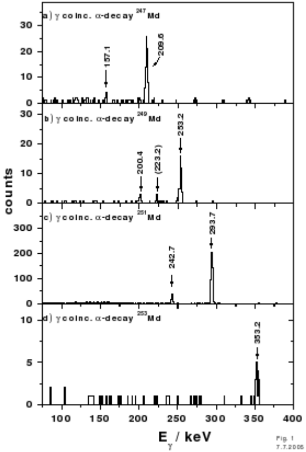


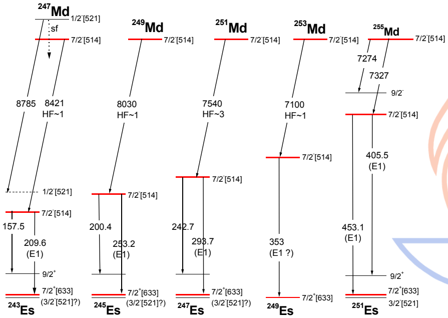


P. Rahkila

Decay spectroscopy at SHIP

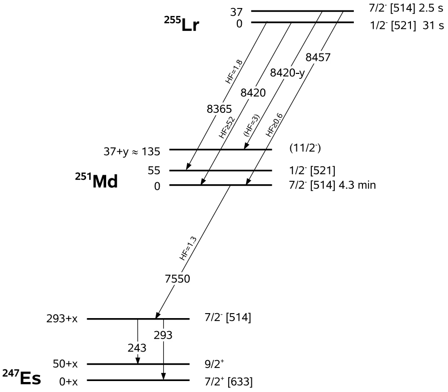
F.P.Heßberger et al. EPJA 23, 233 (2005)

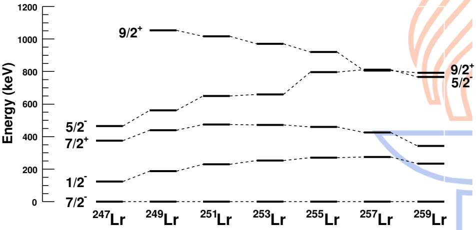




- Trace separation of states from 4 spherical shells:
- $\pi[521]1/2^-$ $(2f_{5/2})$
- $\pi[514]7/2^-$ $(1h_{9/2})$
- $\pi[633]7/2^+$ $(1i_{13/2})$
- $\pi[521]3/2^-$ $(2f_{7/2})$

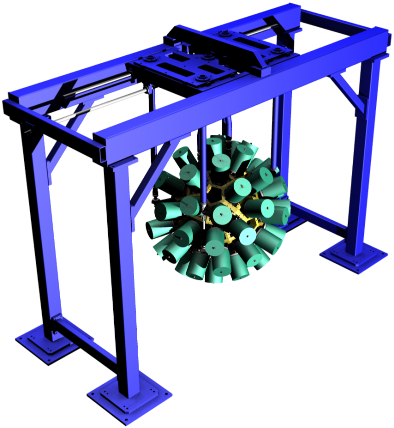
Decay spectroscopy of ^{255}Lr



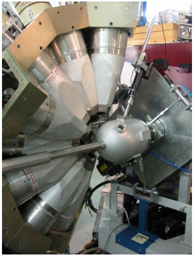


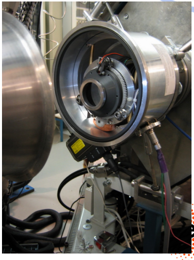
$^{48}Ca + ^{209}Bi \Rightarrow ^{255}Lr + 2n$, $\sigma \simeq 300$ nb, A.Chatillon et al., EPJA **30** 397 (2006)

The JUROGAM Germanium Array



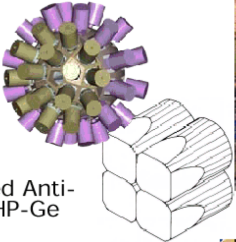
- 43 Phase I and GASP-type Ge detectors - EUROBALL and U.K.-France loan pool
- Total Photopeak Efficiency 4.2% @ 1.3 MeV
- Software Compton suppression
- Autofill system built by University of York, part of GREAT
- Target chamber built by IReS Strasbourg, allows use of rotating target wheel
- Modified EUROGAM support structure



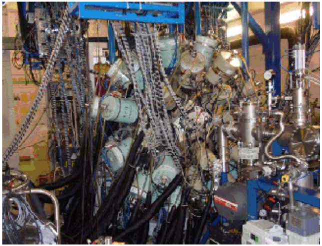


The JUROGAM II Germanium Array

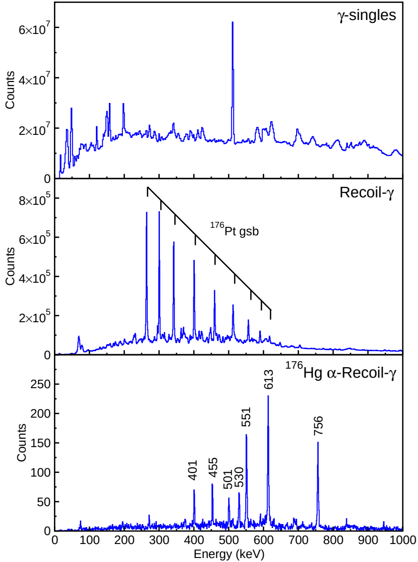
JUROGAM II
October 2008



- 24 Clover + 15 Tapered Anti-Compton suppressed HP-Ge detectors
- Increased efficiency (ε_{ph}= 4.2% → ~6.3% / 1.3 MeV)
- Coincidence efficiency
- Digital electronics : Increased count rates (x5), lower thresholds
- Efficient and Versatile
- Gammapool resource approved to end of 2010

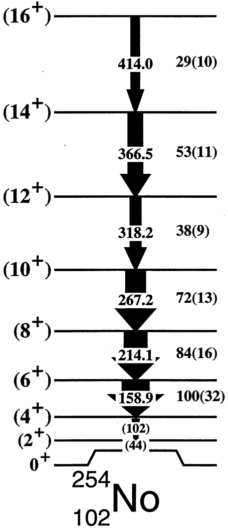


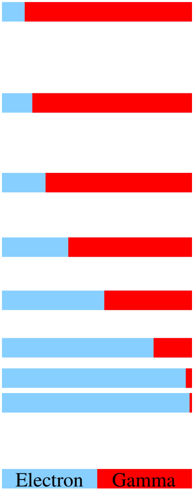
Power of Recoil-Decay Tagging:



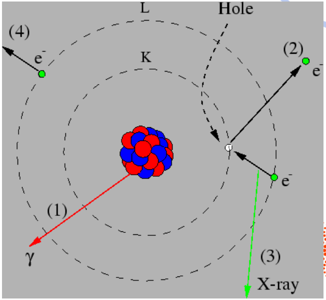
- Typical beam intensity: 6.25×10^{10} pps
- Total Gamma Ray Counting Rate: 450 kHz
- Our record - 10 nb
- 3 reactions/hour
- 1 in 10^9 selectivity

Internal Conversion



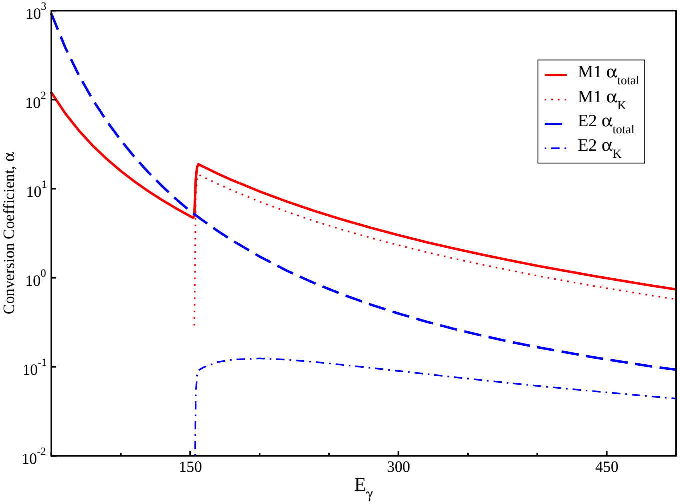


- $E_i = E_\gamma - B_i$;
  $i = K, L_I, L_{II}, .., M_V, ..$
- $\alpha_{tot} = \frac{N_e}{N_\gamma} = \alpha_K + \alpha_L + \ldots$
- $\alpha \propto \frac{Z^3}{n^3 E_\gamma^{2.5}}$
- α increases strongly with multipolarity
- α larger for magnetic transitions



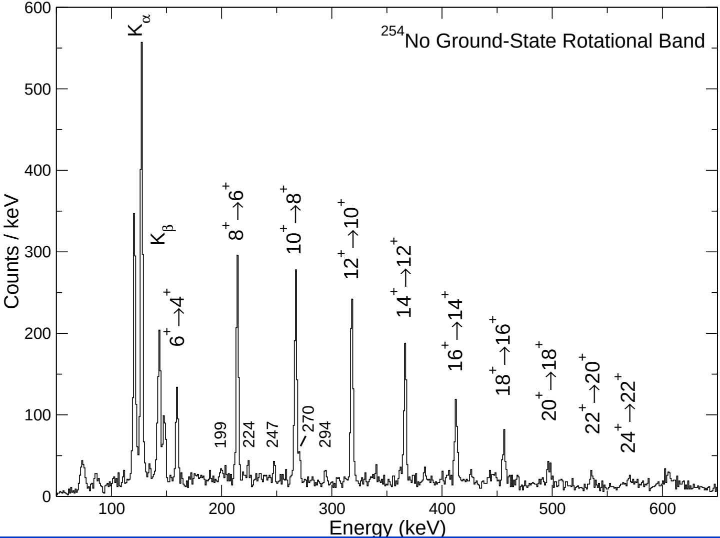
Internal Conversion

Z=103 M1 and E2 internal conversion coefficients

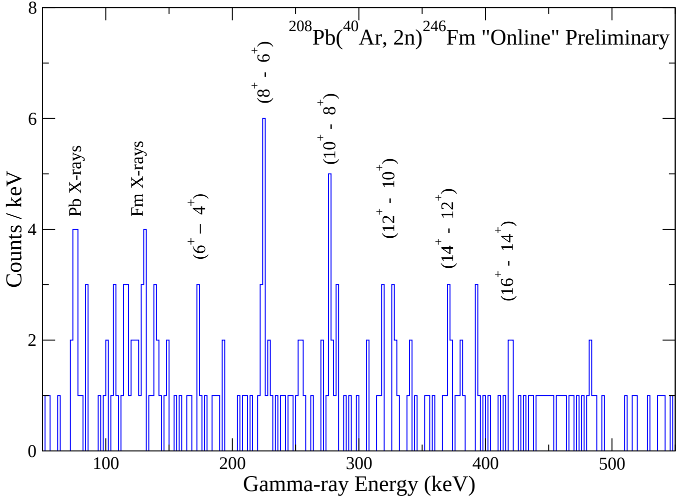


In-beam γ-ray Spectroscopy of ^{254}No - JUROGAM

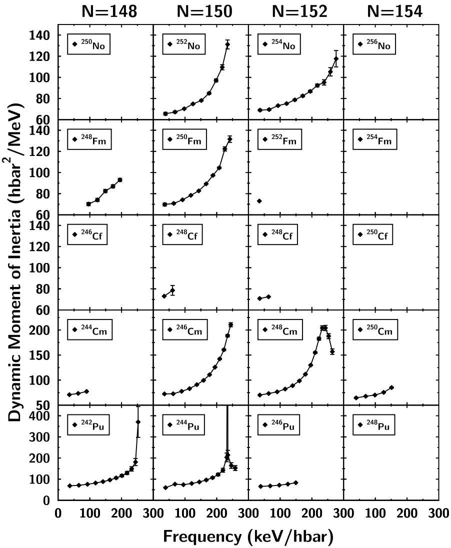
Unpublished spectrum,see also S. Eeckhaudt, P.T. Greenlees et al., EPJA **26**, 227 (2005)



New limit for in-beam spectroscopy in heavy nuclei

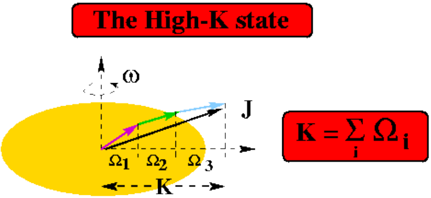


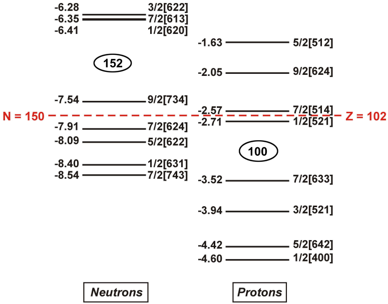
Moment of Inertia Systematics (Even-Even Nuclei)



- Confirmed deformed nature of nuclei around ^{254}No
- Showed fission barrier robust with spin ($> 20\hbar$)
- Faster alignment at N=150 compared to N=152 ($\pi i_{13/2}$, $\nu j_{15/2}$)
- Excellent testing ground for theory; e.g.
  Egido and Robledo, PRL **85** 1198 (2000),
  Duguet et al., NPA **679**, 427 (2001),
  Bender et al., NPA **723**, 354 (2003),
  Afanasjev et al., PRC **67**, 024309 (2003)

K-Isomerism in ^{254}No and ^{250}Fm





- Transition forbidden if: $\Delta K \leq L$
- Degree of forbiddenness $\nu = \Delta K - L$
- Information on pairing gap, Δ and single-particle energies, ϵ_i
- $E = \sqrt{(\epsilon_i - \lambda)^2 + \Delta^2} + \sqrt{(\epsilon_j - \lambda)^2 + \Delta^2}$
- Studies at focal plane - clean environment
- Often full decay path to ground state can be delineated

K-Isomerism in ^{254}No and ^{250}Fm

PHYSICAL REVIEW C VOLUME 7, NUMBER 5 MAY 1973

Isomeric States in ^{250}Fm and ^{254}No†

Albert Ghiorso, Kari Eskola,* Pirkko Eskola,* and Matti Nurmia
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
(Received 30 November 1972)

- Isomeric states in ^{254}No and ^{250}Fm first postulated by Ghiorso et al., PRC7 (1973) 2032
- *The transfer of the ^{250}Fm atoms from the wheel onto the movable detectors must then be caused by the feeble recoil resulting from the isomeric transition or other accompanying γ rays and conversion electrons in the cascade that leads to the ground state. For a 500 keV γ ray the recoil energy of a ^{250}Fm atom is about 0.5 eV.*

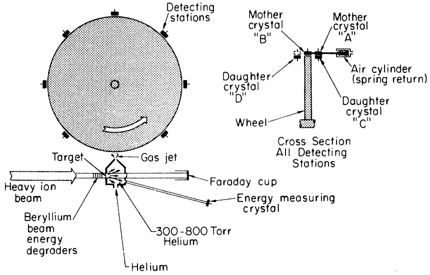
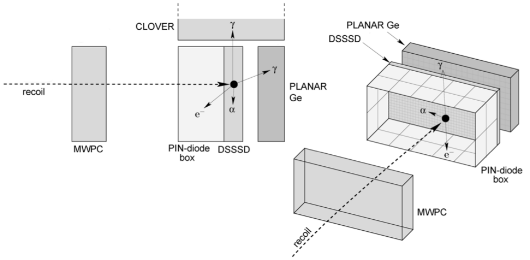
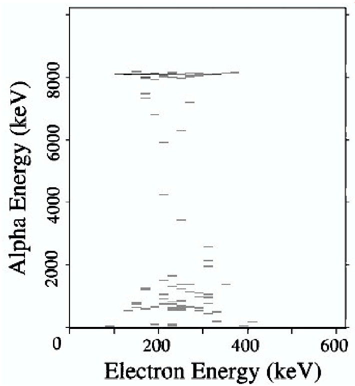


FIG. 1. A schematic diagram of the seven-detector-station system. The cross section at right shows the arrangement of the two movable mother detectors and the two stationary daughter detectors.

K-Isomerism in ^{254}No

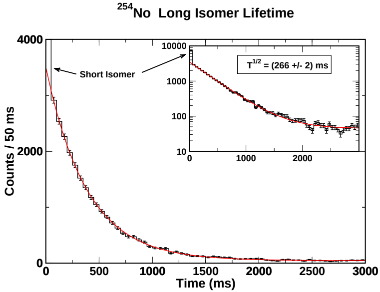
- Isomeric state with half-life 280 ms first postulated by Ghiorso et al., PRC7 (1973) 2032
- Powerful method proposed by Jones, NIM A488 (2002) 471
- Low-energy transitions highly converted, look for Recoil-electron-α correlated chains in DSSSD

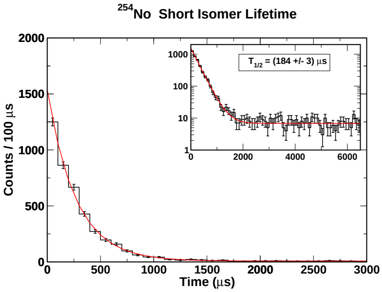




K-Isomerism in ^{254}No

^{48}Ca + ^{208}Pb $\Rightarrow$ ^{254}No + 2n, RITU+GREAT, R.-D. Herzberg et al., Nature **442**, 896-899 (2006)
Correlated recoil-electron time differences

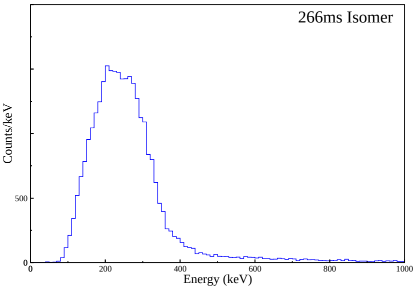




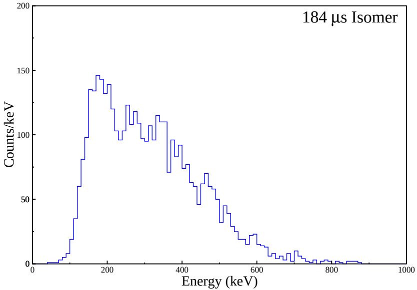
K-Isomerism in ^{254}No

$^{48}Ca + ^{208}Pb \Rightarrow ^{254}No + 2n$, RITU+GREAT, R.-D. Herzberg et al. , Nature **442**, 896-899 (2006)
Correlated recoil-electron spectra

Slow Isomer



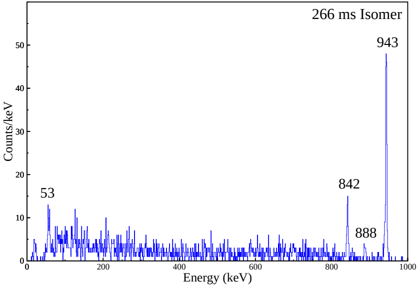
Fast Isomer



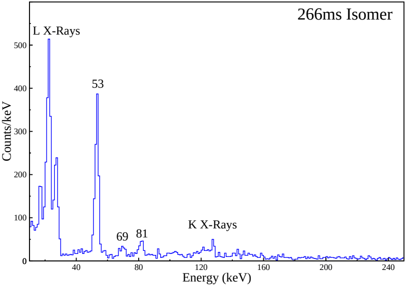
K-Isomerism in ^{254}No - 266ms Isomer

^{48}Ca + ^{208}Pb $\Rightarrow$ ^{254}No + 2n, RITU+GREAT, R.-D. Herzberg et al., Nature **442**, 896-899 (2006)
Correlated recoil-electron γ coincidences

Clover Ge Spectra

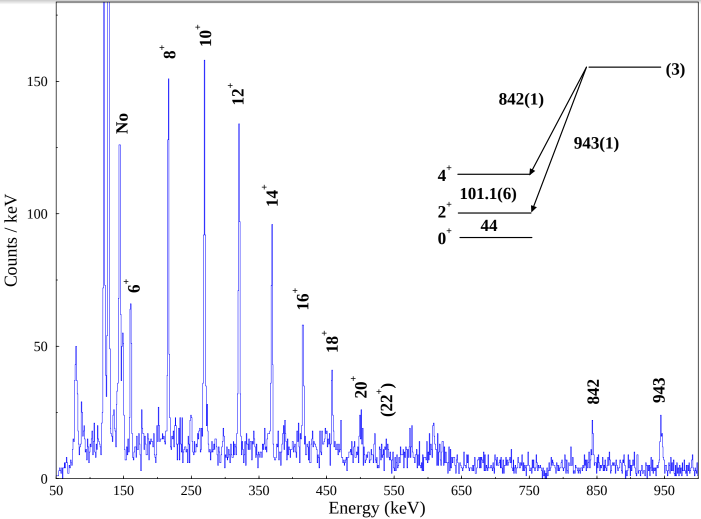


Planar Ge Spectra



In-beam γ-ray Spectroscopy of ^{254}No

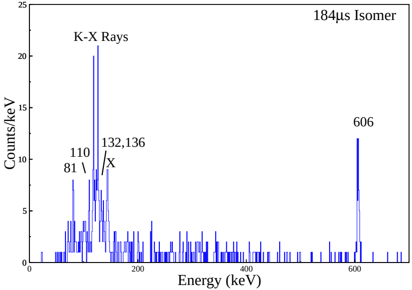
$^{48}Ca + ^{208}Pb \Rightarrow ^{254}No + 2n$, S. Eeckhaudt et al., EPJA **26**, 227 (2005)



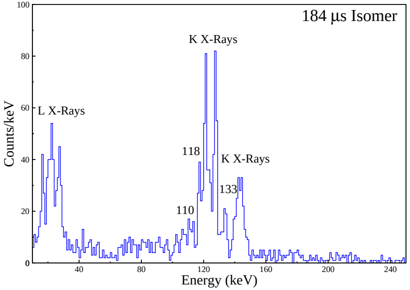
K-Isomerism in ^{254}No - 184μs Isomer

^{48}Ca + ^{208}Pb $\Rightarrow$ ^{254}No + 2n, RITU+GREAT, R.-D. Herzberg et al., Nature **442**, 896-899 (2006)
Correlated recoil-electron γ coincidences

Clover Ge Spectra

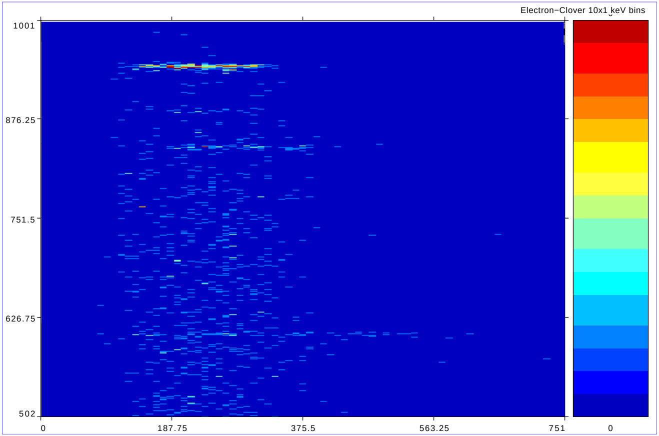


Planar Ge Spectra



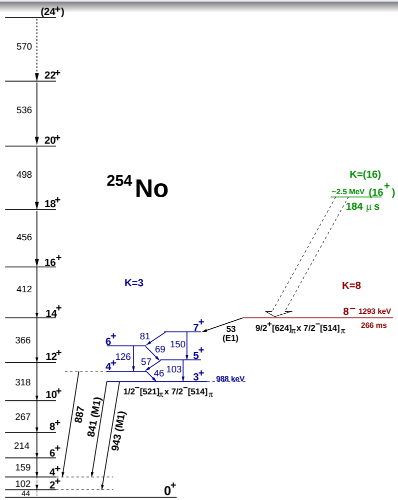
K-Isomerism in ^{254}No

Electron - Clover Coincidences



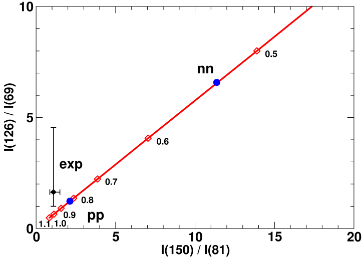
K-Isomerism in ^{254}No

R.-D. Herzberg et al., Nature **442**, 896-899 (2006)
S.K. Tandel et al., PRL **97**, 082502 (2006)



Determined Configurations:

3^{+} - p[514]7/2$^{-}\otimes$p[521]1/2^{-}
8^{-} - p[514]7/2$^{-}\otimes$p[624]9/2^{+}
53keV E1 ΔK=5: f_{ν} = 804



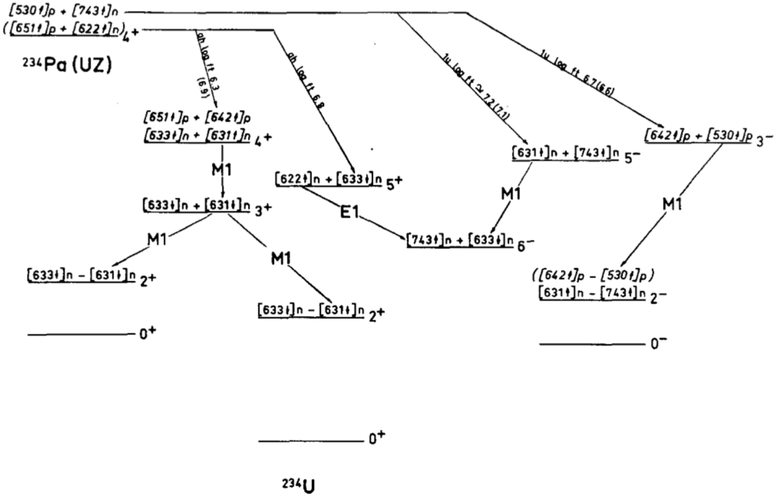
Hindered E1 transitions in ^{234}U

Table 6
Hindrance factors F_W of K-forbidden transitions

Initial state half-life	K_i I_i^π	K_f I_f^π	E_γ (keV)	ML	Gamma-ray half-life exp. (s)	Gamma-ray half-life s.p.e. (s)	F_W	ν	f_W
1421.0 keV 3.3×10^{-5} s	6 6$^-$	2 4$^-$	351.6	E2	14.3×10^{-4}	0.12×10^{-8}	1.2×10^{6}	2	11×10^{2}
		2 5$^-$	293.5	E2	3.1×10^{-4}	0.31×10^{-8}	1.0×10^{5}	2	3.2×10^{2}
		2 6$^-$	226.15	E2	2.1×10^{-4}	1.1×10^{-8}	1.9×10^{4}	2	1.4×10^{2}
		2 7$^-$	144.35	E2	57×10^{-4}	9.9×10^{-8}	5.8×10^{4}	2	2.4×10^{2}
		2 5$^-$	293.5	M1	6.1×10^{-4}	0.88×10^{-12}	6.9×10^{8}	3	8.8×10^{2}
		2 6$^-$	226.15	M1	3.6×10^{-4}	1.9×10^{-12}	1.9×10^{8}	3	5.7×10^{2}
		2 7$^-$	144.35	M1	57×10^{-4}	7.4×10^{-12}	7.7×10^{8}	3	9.2×10^{2}
		2 5$^+$	(328.3)	E1	29×10^{-4}	0.5×10^{-14}	5.8×10^{11}	3	8.3×10^{3}
		2 6$^+$	248.8	E1	3.4×10^{-4}	1.15×10^{-14}	3.0×10^{10}	3	3.1×10^{3}
		2 7$^+$	159.1	E1	17×10^{-4}	4.3×10^{-14}	4.0×10^{10}	3	3.4×10^{3}
1194.7 keV a) 4.9×10^{-11} s	2 6$^-$	0 6$^+$	899.3	E1	1.8×10^{-10}	2.4×10^{-16}	7.5×10^{5}	1	7.5×10^{5}
1127.6 keV a) 2.6×10^{-11} s	2 5$^-$	0 4$^+$	(984.5)	E1	1.3×10^{-10}	1.9×10^{-16}	6.9×10^{5}	1	6.9×10^{5}
		0 6$^+$	832.4	E1	0.45×10^{-10}	3.0×10^{-16}	1.5×10^{5}	1	1.5×10^{5}
1069.4 keV a) 8.3×10^{-11} s	2 4$^-$	0 4$^+$	(926.7)	E1	3×10^{-10}	2.2×10^{-16}	1.4×10^{6}	1	14×10^{5}
1024.2 keV a) 5.6×10^{-11} s	2 3$^-$	0 2$^+$	(980.9)	E1	2.4×10^{-10}	1.9×10^{-16}	1.4×10^{6}	1	14×10^{5}
		0 4$^+$	(881.1)	E1	1.4×10^{-10}	2.6×10^{-16}	5.4×10^{5}	1	5.4×10^{5}
989.8 keV b)	2 2$^-$	0 2$^+$	946.3	E1		2.1×10^{-16}	(6.3×10^{2})	1	(6.2×10^{2})
1496.1 keV c)	3 3$^+$	0 2$^+$	1453	M1		7.3×10^{-15}	(1.4×10^{2})	2	(0.12×10^{2})
		0 4$^+$	1354	M1		9.0×10^{-15}	(6.5×10^{1})	2	(0.08×10^{2})

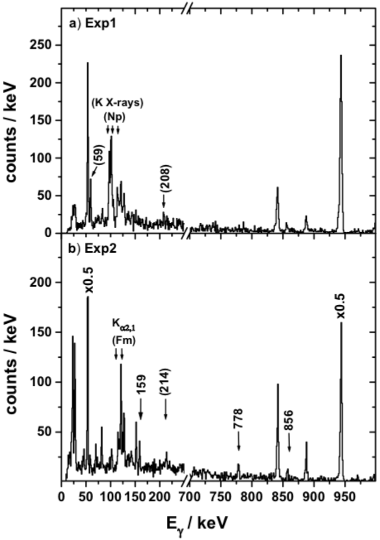
Bjornholm et al, NPA **118**, 261 (1968)

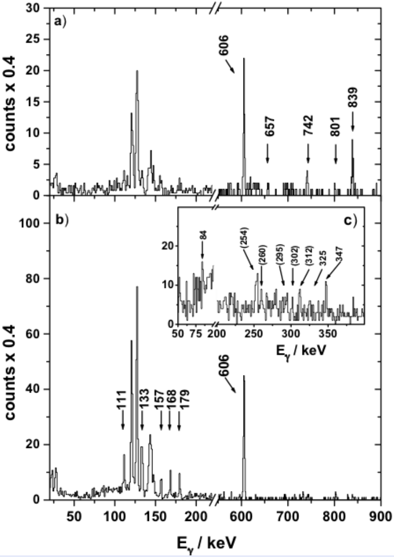
Hindered E1 transitions in ^{234}U



Bjornholm et al, NPA **118**, 261 (1968)

K-Isomerism in ^{254}No





GSI/SHIP Data - F.P. Hessberger et al., EPJA **43**, 55 (2010)

K-Isomerism in ^{254}No

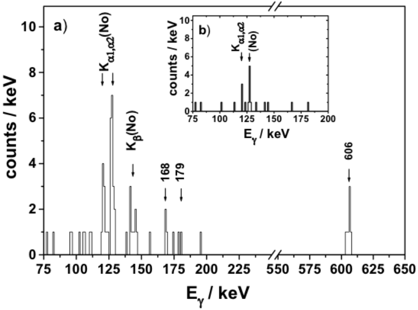


Fig. 6. Spectrum of γ events: a) in prompt coincidence with the E = 133.3 keV line; b) in coincidence with the E = 133.3 keV or the E = 605.7 keV line and K X-rays ("triple coincidences").

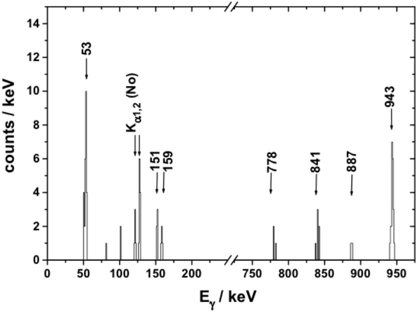
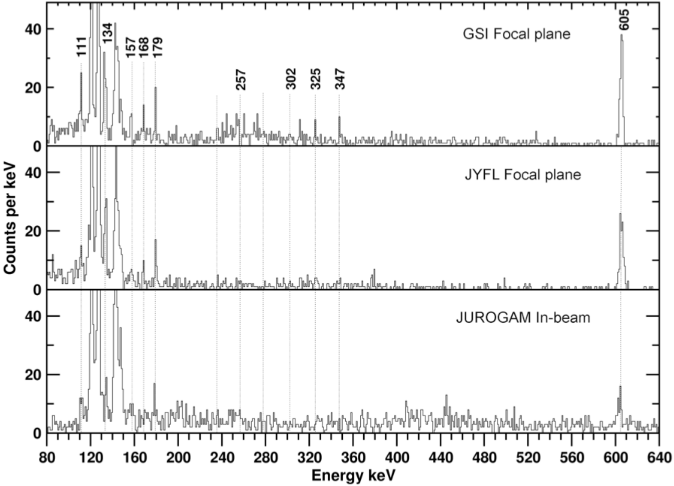


Fig. 7. Spectrum of γ events from ^{254m1}No (γ1) following γ decays of ^{254m2}No (γ2) within $\Delta t(\gamma1\text{-}\gamma2) \leq 1$ s and being correlated to the same evaporation residue.

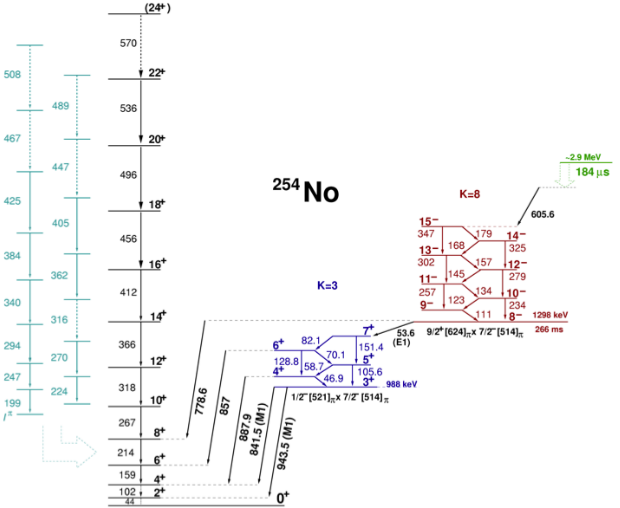
GSI/SHIP Data - F.P. Hessberger et al., EPJA **43**, 55 (2010)

K-Isomerism in ^{254}No



GSI/SHIP + JUROGAM Data - F.P. Hessberger et al., EPJA **43**, 55 (2010)
C.Gray-Jones, Thesis, University of Liverpool

K-Isomerism in ^{254}No

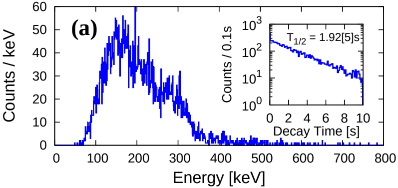


F.P. Hessberger et al., EPJA **43**, 55 (2010) / C.Gray-Jones, Thesis, University of Liverpool

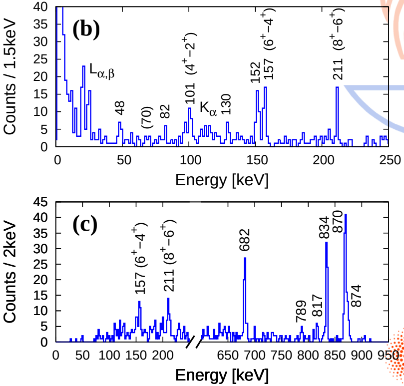
778 keV E1 ΔK=8: f_ν = 219

K-Isomerism in ^{250}Fm

^{48}Ca + ^{204}HgS $\Rightarrow$ ^{250}Fm + 2n,JUROGAM+RITU+GREAT, P.T. Greenlees et al., PRC **78**, 021301(R) (2008)



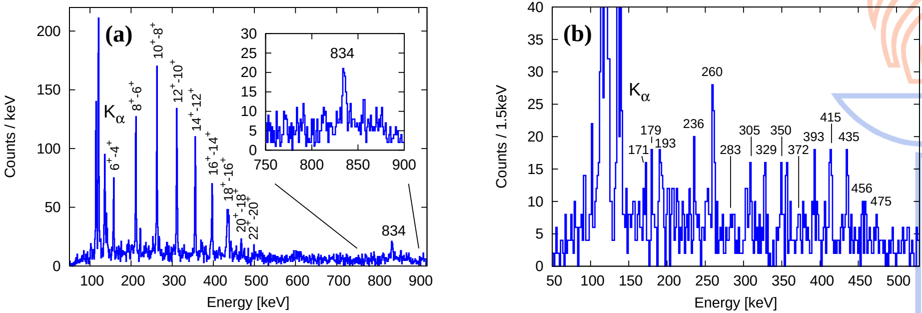
Focal Plane Gamma Rays



K-Isomerism in ^{250}Fm

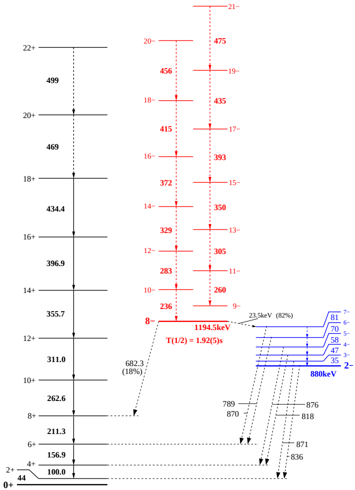
^{48}Ca + ^{204}HgS $\Rightarrow$ ^{250}Fm + 2n,JUROGAM+RITU+GREAT, P.T. Greenlees et al., PRC **78**, 021301(R) (2008)

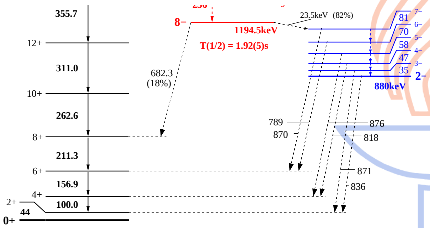
Ground State Band | Isomer-Tagged Transitions



K-Isomerism in ^{250}Fm

^{250}Fm: P.T. Greenlees et al. PRC **78**, 021301(R) (2008)





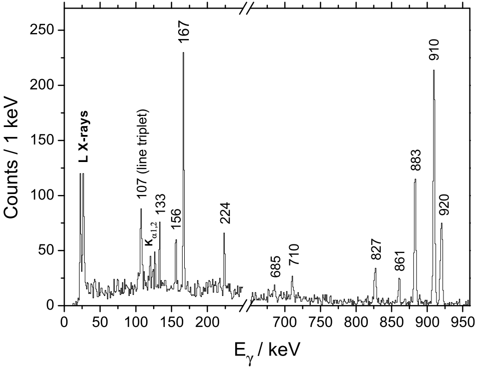
8^{-} - $\nu[624]7/2^{+} \otimes \nu[734]9/2^{-}$

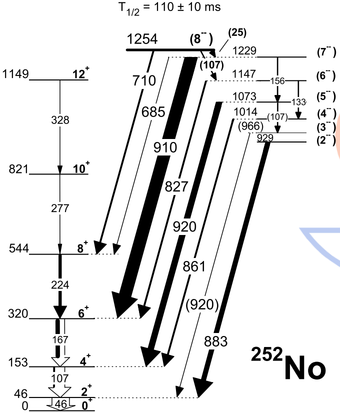
2^{-} - $\nu[622]5/2^{+} \otimes \nu[734]9/2^{-}$ dominates

682 keV E1 ΔK=8: $f_{\nu} = 213$

23.5 keV M1 ΔK=6: $f_{\nu} = 192$

K-Isomerism in ^{252}No





SHIP Focal Plane Data
B.Sulignano et al., EPJA **33**, 327 (2007)
ANL data: A.Robinson et al., PRC **78**, 034308 (2008)

710 keV E1 ΔK=8: f_ν = 170
25 keV M1 ΔK=6: $f_\nu \simeq 100$

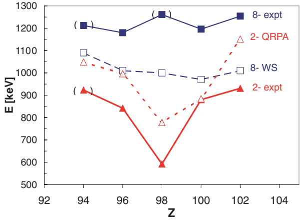
Known 2QP K-Isomers in Region

Nucleus	K^π	$T_{1/2}$	E_x	Decay Mode	Configuration
^{270}Ds	$9^-,10^-$	6 ms	$\simeq$1.13 MeV	α	9^- - $\nu[725]11/2^-\otimes\nu[613]7/2^+$ 10^- -$\nu[725]11/2^-\otimes\nu[615]9/2^+$
^{256}Rf	6,7?	25 μs	$\simeq$1.120 MeV	γ	??
^{256}Rf	10-12?	17 μs	$\simeq$1.400 MeV	γ	??
^{254}No	8^-	266 ms	1.293 MeV	γ	8^- - $\pi[514]7/2^-\otimes\pi[624]9/2^+$
^{252}No	8^-	110 ms	1.254 MeV	γ	8^- - $\nu[624]7/2^+\otimes\nu[734]9/2^-$
^{250}No	6^+?	42 μs	??	SF,γ?	6^+ - $\nu[622]5/2^+\otimes\nu[624]7/2^+$
^{256}Fm	7^-	70 ns	1.425 MeV	γ,SF	7^- - $\pi[633]7/2^+\otimes\pi[514]7/2^-$
^{250}Fm	8^-	1.92 s	1.195 MeV	γ	8^- - $\nu[624]7/2^+\otimes\nu[734]9/2^-$
^{248}Fm	??	$\simeq$8 ms	??	γ	??
^{246}Cm	8^-	??	1.179 MeV	γ	8^- - $\nu[624]7/2^+\otimes\nu[734]9/2^-$
^{244}Cm	6^+	34 ms	1.040 MeV	γ	6^+ - $\nu[622]5/2^+\otimes\nu[624]7/2^+$

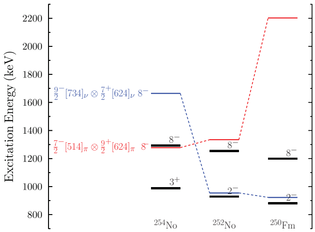
- References: See R.-D.Herzberg and P.T.Greenlees, Prog. Part. Nuc. Phys. 61, 674 (2008)
- ^{256}Rf: H.B.Jeppesen et al., PRC **79**, 031303(R) (2009)
- 3QP isomer in ^{255}Lr (Dubna/GSI/JYFL/Berkeley). Also in ^{253}No
- New transfer reaction data also forthcoming from Lovell/ANL for Cm and Cf isotopes

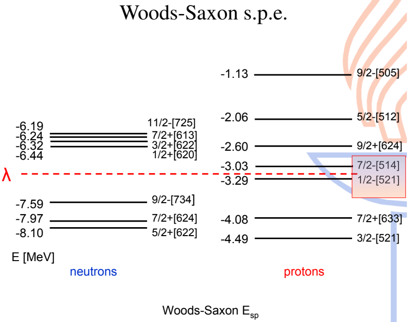
Systematics of 2 quasi-particle states

N=150: A.Robinson et al., PRC **78**, 034308 (2008)



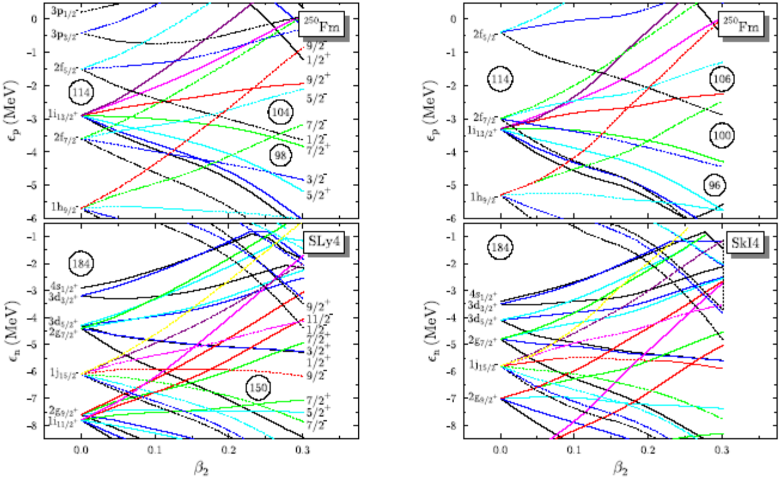
N=150/152: P.T.Greenlees et al., PRC **78**, 021303(R) (2008)





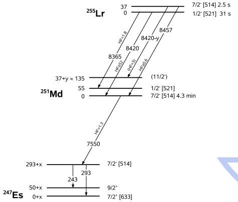
Self-Consistent Calculations

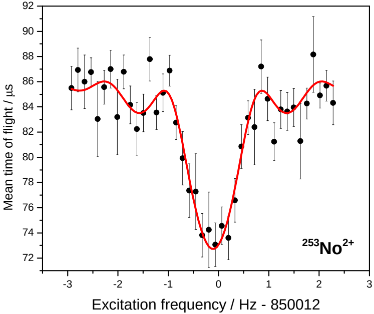
Taken from Talk of Paul-Henri Heenen (http://nuclear1.paisley.ac.uk/SHEworkshop/)



Direct Mass Measurements at SHIPTRAP

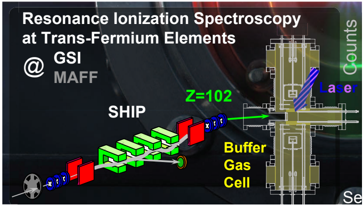
M. Block et al., Nature **463**, 785 (2010)

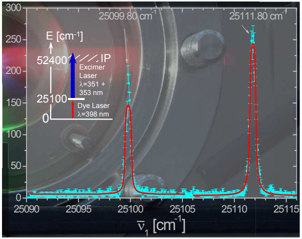




- Measured ^{252,253,254}No
- Ties down masses in decay chains of ^{269,270}Ds
- Information missing from decay studies
- Measure Q-value for parent-daughter
- Possibilities to extract isomeric beams?

Optical spectroscopy of heaviest elements





Sewtz et al., PRL90

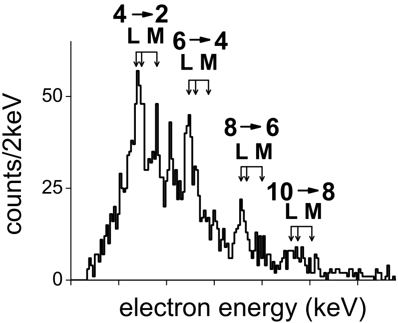
- Sample of ^{255}Fm produced at ORNL
- Breeding of ^{255}Es from ^{246}Cm
- Sample transported to Germany (about 10^{11} atoms)
- Isotope Shift and Hyperfine Spectroscopy
- Similar reactions as for decay/in-beam
- Heavily dependent on atomic theory

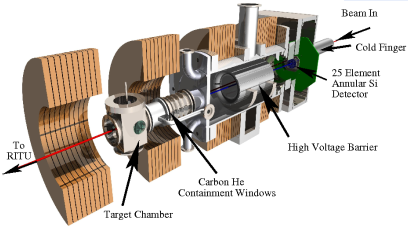
Conversion-Electron Spectroscopy of ^{254}No

VOLUME 89, NUMBER 20 PHYSICAL REVIEW LETTERS 11 NOVEMBER 2002

Conversion Electron Cascades in $^{254}_{102}$No

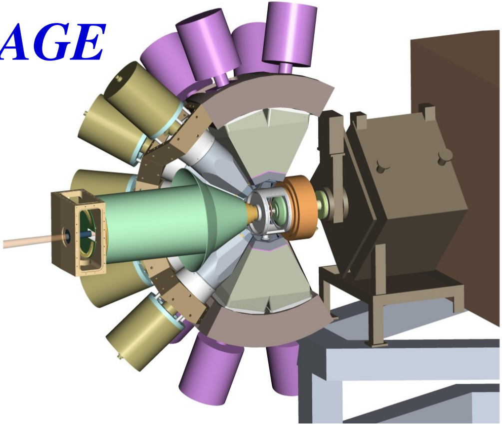
P. A. Butler,[1] R. D. Humphreys,[1] P. T. Greenlees,[2] R.-D. Herzberg,[1] D. G. Jenkins,[1] G. D. Jones,[1] H. Kankaanpää,[2] H. Kettunen,[2] P. Rahkila,[2] C. Scholey,[1,2] J. Uusitalo,[2] N. Amzal,[1] J. E. Bastin,[1] P. M. T. Brew,[1] K. Eskola,[3] J. Gerl,[4] N. J. Hammond,[1] K. Hauschild,[5] K. Helariutta,[4] F.-P. Heßberger,[4] A. Hürstel,[5] P. M. Jones,[2] R. Julin,[2] S. Juutinen,[2] A. Keenan,[2] T.-L. Khoo,[6] W. Korten,[5] P. Kuusiniemi,[2] Y. Le Coz,[5] M. Leino,[2] A.-P. Leppänen,[2] M. Muikku,[2] P. Nieminen,[2] S. W. Ødegård,[7] T. Page,[1] J. Pakarinen,[2] P. Reiter,[8] G. Sletten,[9] Ch. Theisen,[5] and H.-J. Wollersheim[4]

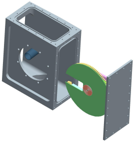


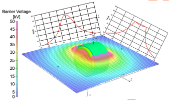


The SAGE Spectrometer

SAGE







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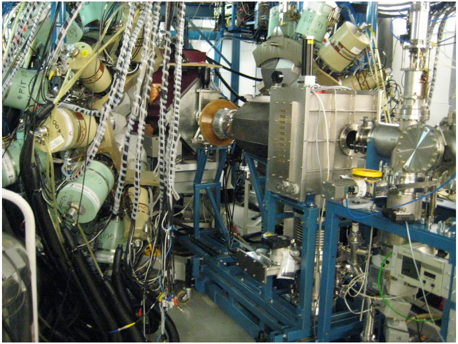
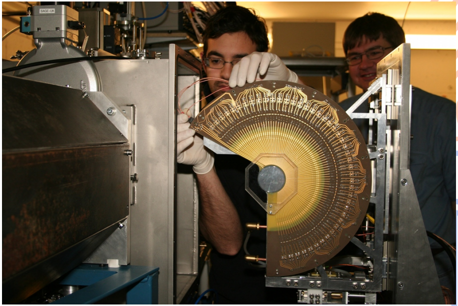
The SAGE Spectrometer





Summary

- A wealth of complementary data are needed to understand the structure of heavy elements
- Decay properties, reaction cross-sections, masses, spins, moments of inertia,..
- Reliable assignments require detailed spectroscopy
- K-isomers can provide these assignments
- Data show that deformed shell gaps not well reproduced in SC calculations
- Still much to be done (both experiment and theory)
- Mass and Laser Measurements will bring new information
- Lots of new developments ongoing (SAGE, TASCA, S^3, GARIS2,...) - should start to produce exciting new data soon

Collaborators in Recent JYFL Papers

nature Vol 442|24 August 2006|doi:10.1038/nature05069

LETTERS

Nuclear isomers in superheavy elements as stepping stones towards the island of stability

R.-D. Herzberg[1], P. T. Greenlees[2], P. A. Butler[1], G. D. Jones[1], M. Venhart[3], I. G. Darby[1], S. Eeckhaudt[2], K. Eskola[4], T. Grahn[2], C. Gray-Jones[1], F. P. Hessberger[5], P. Jones[2], R. Julin[2], S. Juutinen[2], S. Ketelhut[2], W. Korten[6], M. Leino[2], A.-P. Leppänen[2], S. Moon[1], M. Nyman[2], R. D. Page[1], J. Pakarinen[1,2], A. Pritchard[1], P. Rahkila[2], J. Sarén[2], C. Scholey[2], A. Steer[2], Y. Sun[7], Ch. Theisen[6] & J. Uusitalo[2]

PRL 102, 212501 (2009) PHYSICAL REVIEW LETTERS week ending 29 MAY 2009

γ-Ray Spectroscopy at the Limits: First Observation of Rotational Bands in ^{255}Lr

S. Ketelhut,[1,*] P. T. Greenlees,[1] D. Ackermann,[2] S. Antalic,[3] E. Clément,[4] I. G. Darby,[5,†] O. Dorvaux,[6] A. Drouart,[4] S. Eeckhaudt,[1] B. J. P. Gall,[6] A. Görgen,[4] T. Grahn,[1,‡] C. Gray-Jones,[5] K. Hauschild,[7] R.-D. Herzberg,[5] F. P. Heßberger,[2] U. Jakobsson,[1] G. D. Jones,[5] P. Jones,[1] R. Julin,[1] S. Juutinen,[1] T.-L. Khoo,[8] W. Korten,[4] M. Leino,[1] A.-P. Leppänen,[1,§] J. Ljungvall,[4] S. Moon,[5] M. Nyman,[1] A. Obertelli,[4] J. Pakarinen,[1,‡] E. Parr,[5] P. Papadakis,[5] P. Peura,[1] J. Piot,[6] A. Pritchard,[5] P. Rahkila,[1] D. Rostron,[5] P. Ruotsalainen,[1] M. Sandzelius,[9] J. Sarén,[1] C. Scholey,[1] J. Sorri,[1] A. Steer,[10] B. Sulignano,[4] Ch. Theisen,[4] J. Uusitalo,[1] M. Venhart,[3,†] M. Zielinska,[11] M. Bender,[12,13] and P.-H. Heenen[14]

RAPID COMMUNICATION

PHYSICAL REVIEW C 78, 021303(R) (2008)

High-K structure in ^{250}Fm and the deformed shell gaps at $N = 152$ and $Z = 100$

P. T. Greenlees,[1,*] R.-D. Herzberg,[2] S. Ketelhut,[1] P. A. Butler,[2] P. Chowdhury,[3] T. Grahn,[1] C. Gray-Jones,[2] G. D. Jones,[2] P. Jones,[1] R. Julin,[1] S. Juutinen,[1] T.-L. Khoo,[4] M. Leino,[1] S. Moon,[2] M. Nyman,[1] J. Pakarinen,[2] P. Rahkila,[1] D. Rostron,[2] J. Sarén,[1] C. Scholey,[1] J. Sorri,[1] S. K. Tandel,[3] J. Uusitalo,[1] and M. Venhart[5]

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Eur. Phys. J. A 26, 227–232 (2005)
DOI 10.1140/epja/i2005-10163-6

THE EUROPEAN PHYSICAL JOURNAL A

Evidence for non-yrast states in ^{254}No

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Eur. Phys. J. A 30, 397–411 (2006)
DOI 10.1140/epja/i2006-10134-5

THE EUROPEAN PHYSICAL JOURNAL

Spectroscopy and single-particle structure of the odd-Z heavy elements ^{255}Lr, ^{251}Md and ^{247}Es

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