Examining the north-west limit of octupole correlations in the light-actinide region using α-decay spectroscopy

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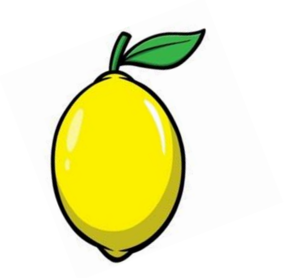
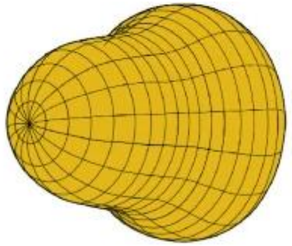
Deformed nuclei





Spherical nucleus (a_{00})

Quadrupole deformed nuclei (a_{20})

Octupole deformed nucleus (a_{30})

λ = multipole order

$\lambda = 0$: Monopole, volume oscillation
$\lambda = 1$: Dipole, centre of mass shift
$\lambda = 2$: Quadrupole, axially asymmetric
$\lambda = 3$: Octupole, reflection asymmetric

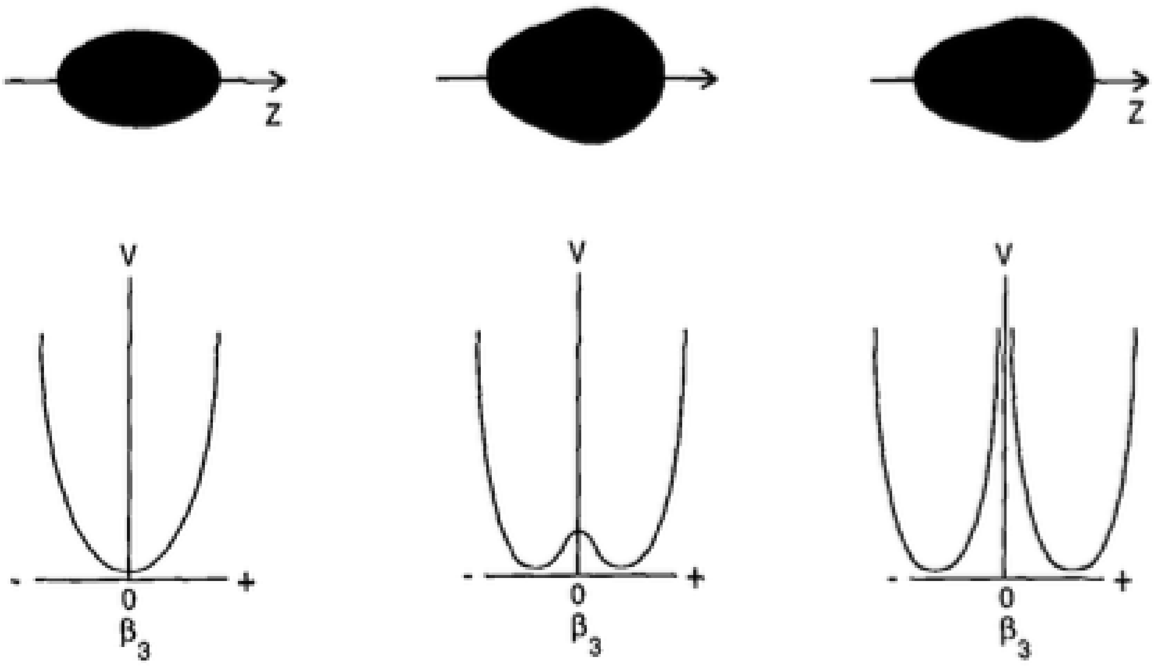
$$R(\theta, \phi) = R_0\left(1 + \sum_{\lambda,\mu} a_{\lambda\mu} Y_\lambda^\mu\right)$$

μ = Orientation of deformation

Reflection-asymmetric nuclei

Characteristic properties:

- Interleaving opposite-parity energy levels in even-even nuclei
- Parity doublets in odd-mass nuclei
- Enhanced E1 transitions
- Large E3 transition probabilities

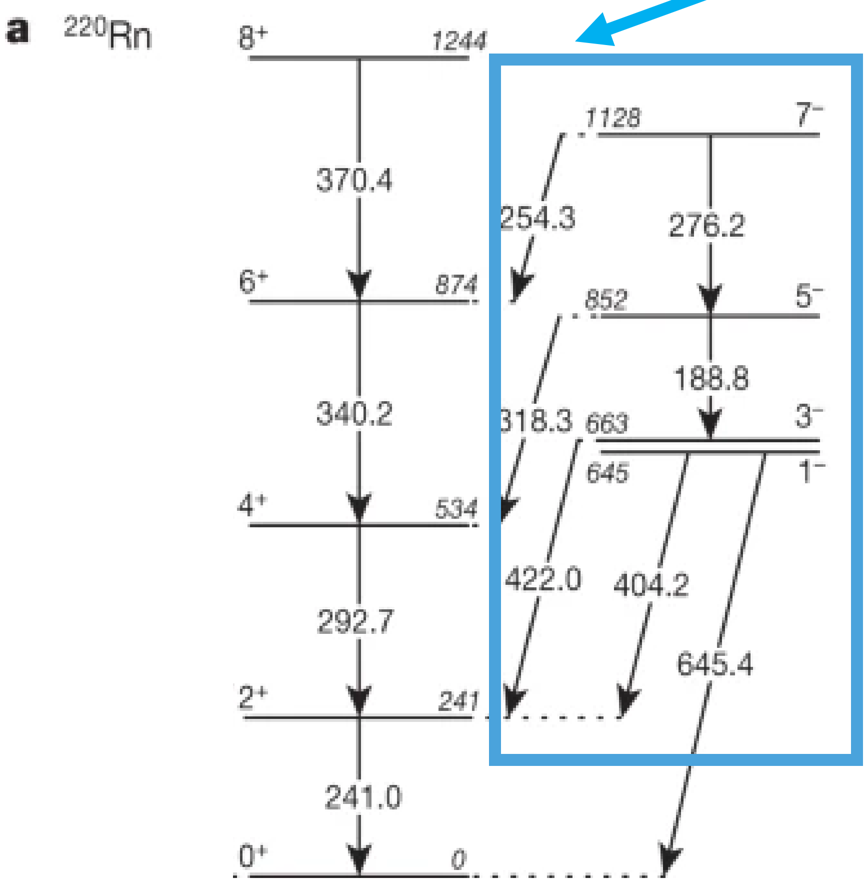


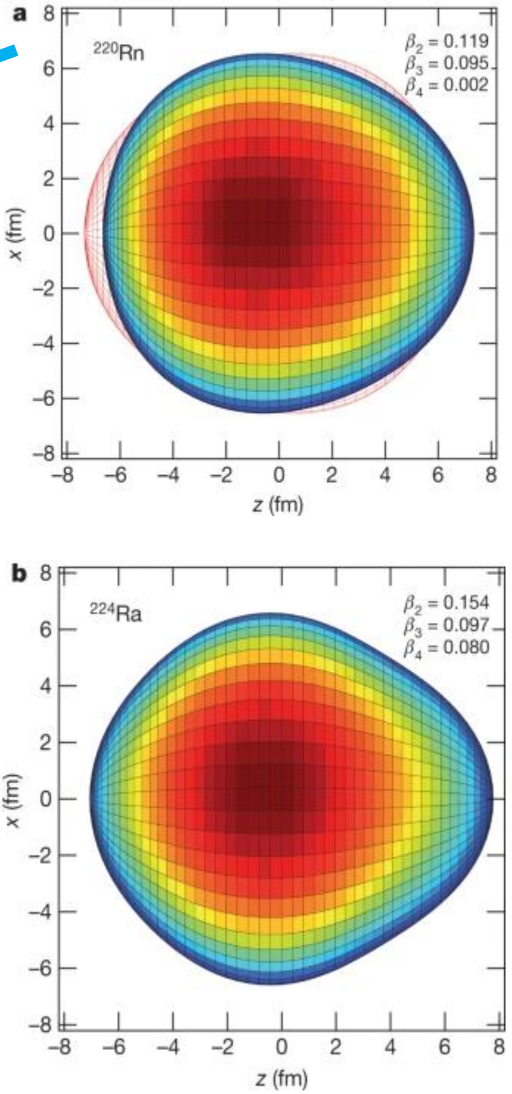
Vibrational octupole Transitional octupole Rigid octupole

I. Ahmed and P. A. Butler, Ann. Rev. Nucl. Part. Sci **43,** 72 (1990)

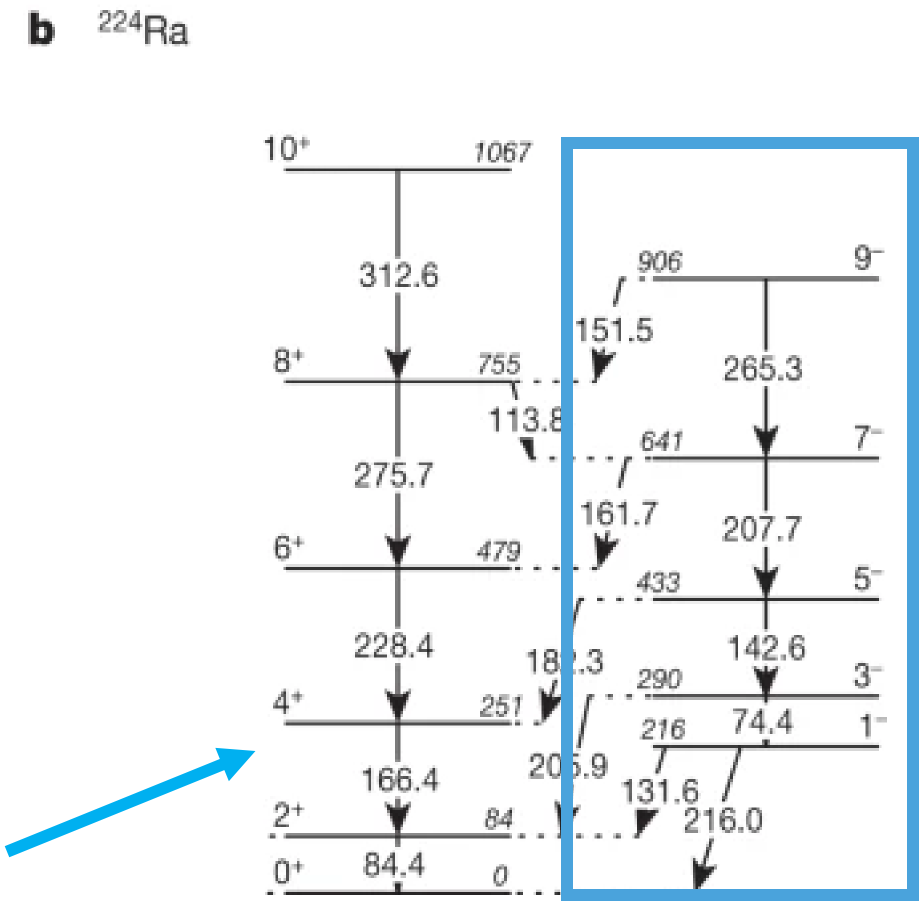
Reflection-asymmetric nuclei

Vibrational





Rigid



L. P. Gaffney et al. Nature, 497(7448):199-204, 2013.

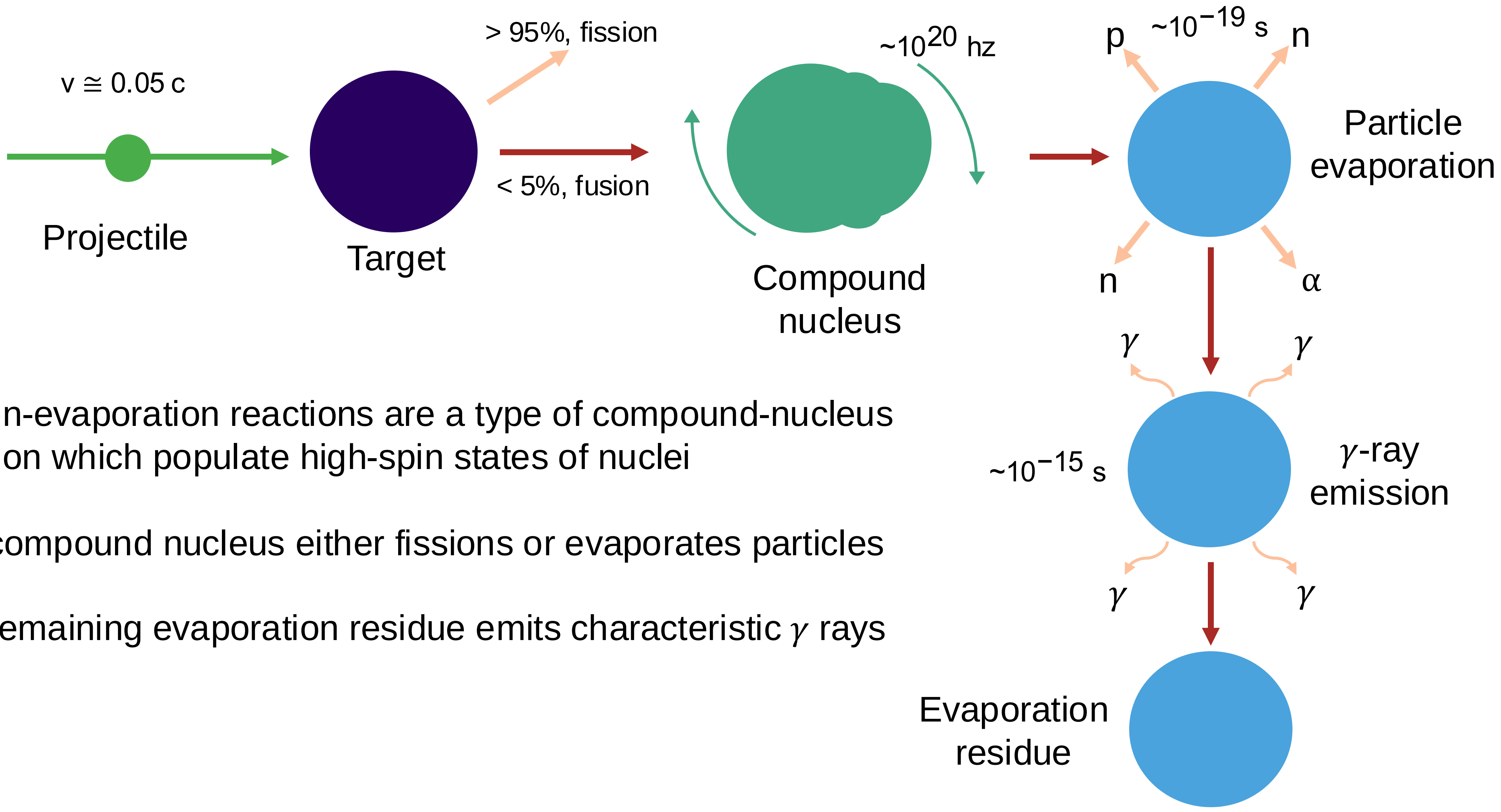
Region of octupole deformation

- Part of the chart of nuclides where octupole correlations have been predicted and identified
- Even-even nuclei predicted to posses asymmetrically-deformed ground states marked in red
- Nuclei being studied marked in blue
- Green boundary marks region of odd-*A* octupole deformed nuclei
- Boundary in north-west of region is unknown

	N = 129	130	131	132	133	134	135	136	137
Z = 94 (Pu)	223 -		225 -		227 -		229 -		231 -
Z = 93 (Np)		223 $9/2^-$		225 -		227 -		229 -	
Z = 92 (U)	221 $9/2^+$		223 -		225 -		227 $(3/2^+$		229 $3/2^+$
Z = 91 (Pa)		221 $9/2^-$		223 -		225 $5/2^-$		227 $5/2^-$	
Z = 90 (Th)	219 $9/2^+$		221 $7/2^+$		223 $5/2^+$		225 $3/2^+$		227 $1/2^+$
Z = 89 (Ac)		219 $9/2^-$		221 $5/2^-$		223 $5/2^-$		225 $3/2^-$	
Z = 88 (Ra)	217 $9/2^+$		219 $7/2^+$		221 $5/2^+$		223 $3/2^+$		225 $1/2^+$

Y. Cao et al., Phys. Rev. C 102, 024311 (2020).

Fusion-evaporation reactions



- Fusion-evaporation reactions are a type of compound-nucleus reaction which populate high-spin states of nuclei
- The compound nucleus either fissions or evaporates particles
- The remaining evaporation residue emits characteristic γ rays

Experimental details

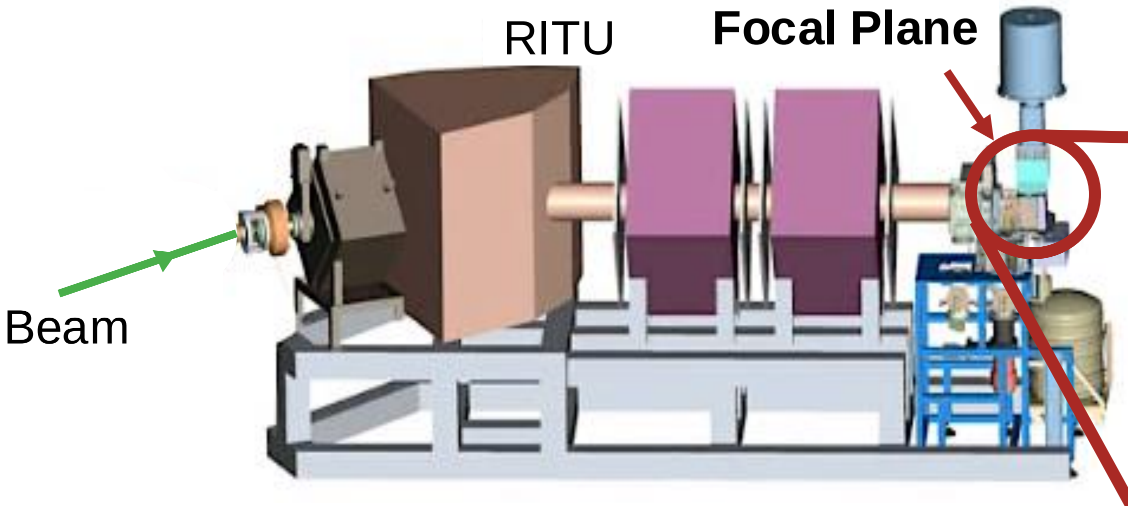
Reaction	Beam E (MeV)	Beam I (pnA)	σ (nb)	$T_{1/2}$	Run time (hrs)
$^{208}Pb(^{22}Ne, 7n)^{223}U$	148	200	300	18 µs	~ 39
$^{209}Bi(^{22}Ne, 6n)^{225}Np$	136	200	36	3.6 ms	~ 43
$^{209}Bi(^{22}Ne, 4n)^{227}Np$	112	140	300	510 ms	~ 20

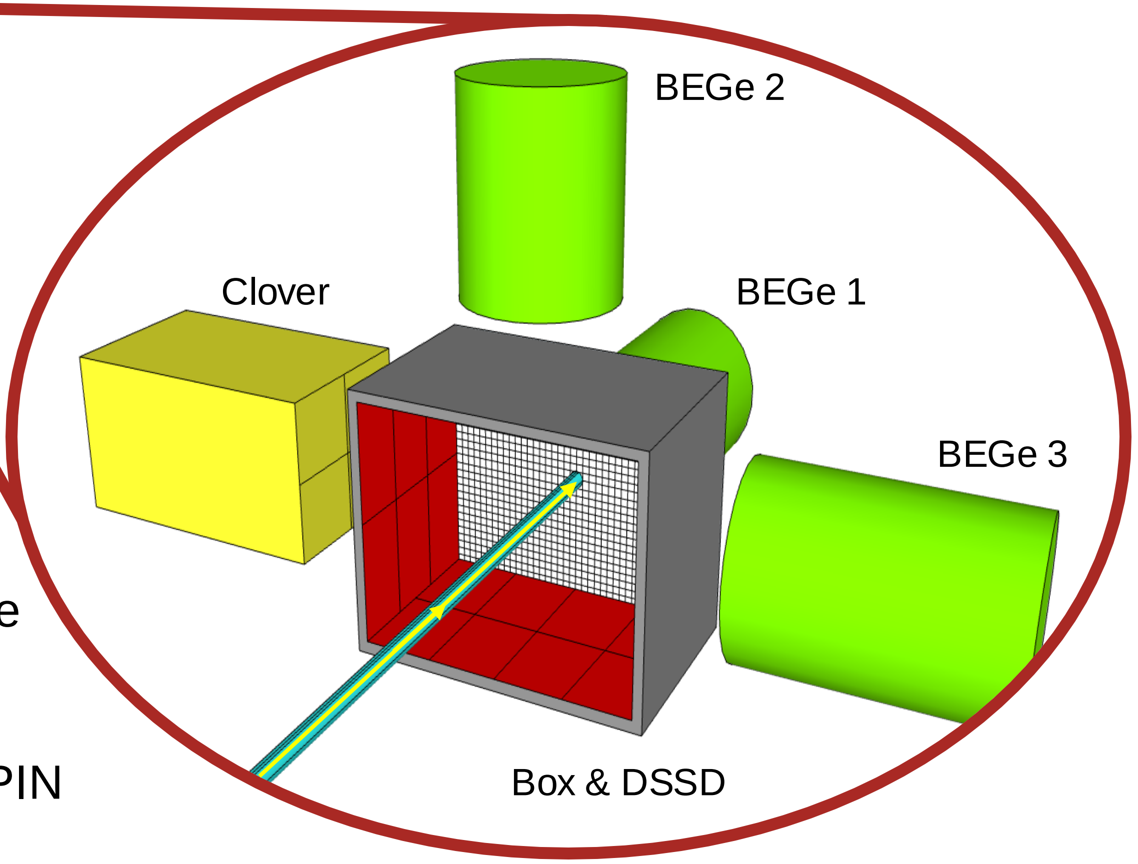
- Carried out at the Accelerator Laboratory at the University of Jyväskylä, Finland (JYFL)
- Similar reactions have been used in previous experiments at JYFL
- Production cross section for ^{227}Np reported by Andreyev et al
- Production cross section for ^{225}Np and ^{223}U estimated using statistical-model code Alice

A. N. Andreyev et al., Z. Phys. A 337, 229 (1990).

Experimental setup

- PIN diodes detect alpha particles which travel out of the DSSD

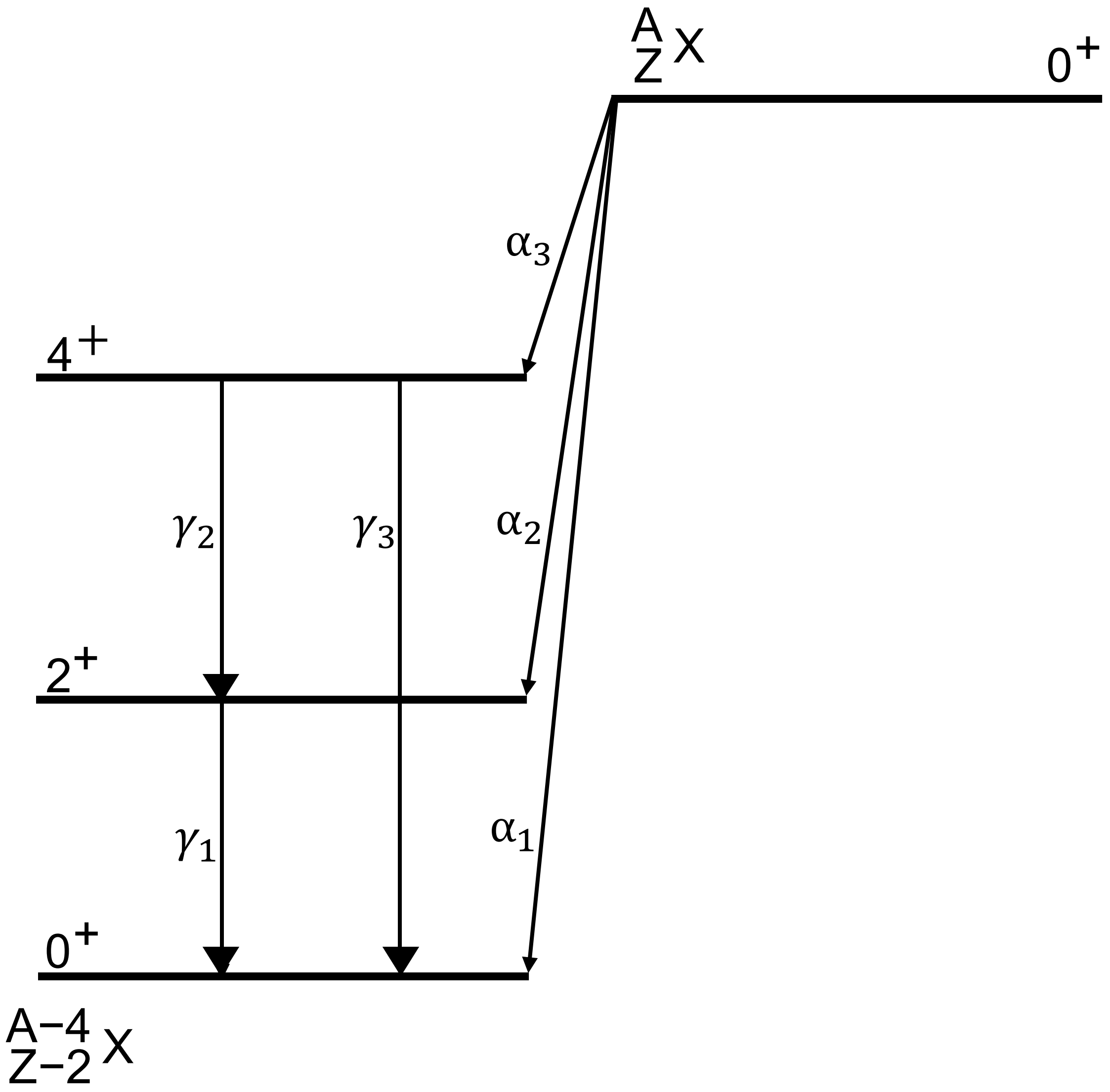




- RITU is a gas-filled recoil separator
- Evaporation residues are implanted into the DSSD at the focal plane
- 3 BEGe and 1 clover detector surround the DSSD and PIN diode box

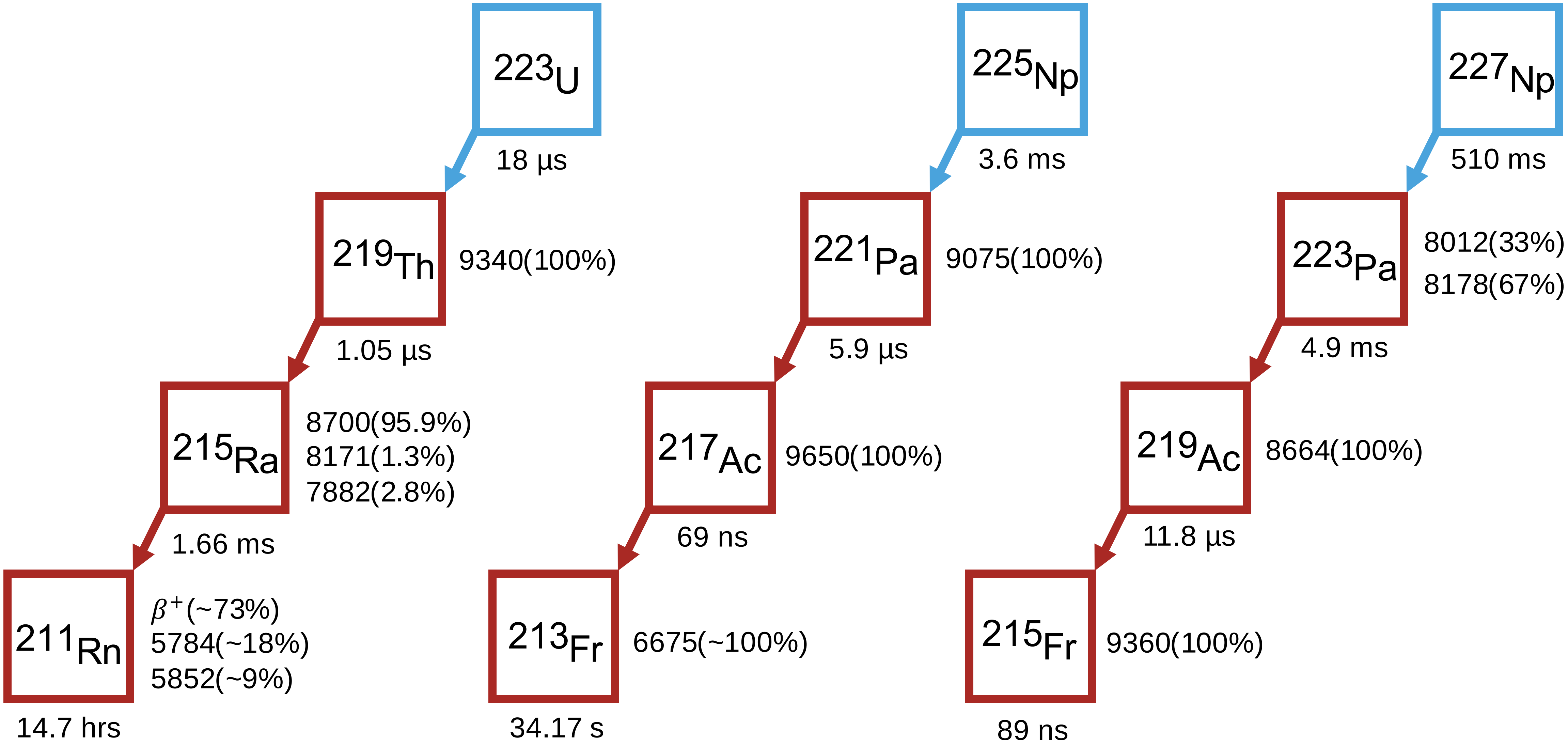
α-decay spectroscopy

- Cross sections are too low for γ-ray spectroscopy
- Energy of α particles can be measured
- Branching ratio of α-decay branches can be determined
- α-decay hindrance factors can be established
- α-γ coincidences; investigate α-decaying fine structure
- Establishment of ground-state spins

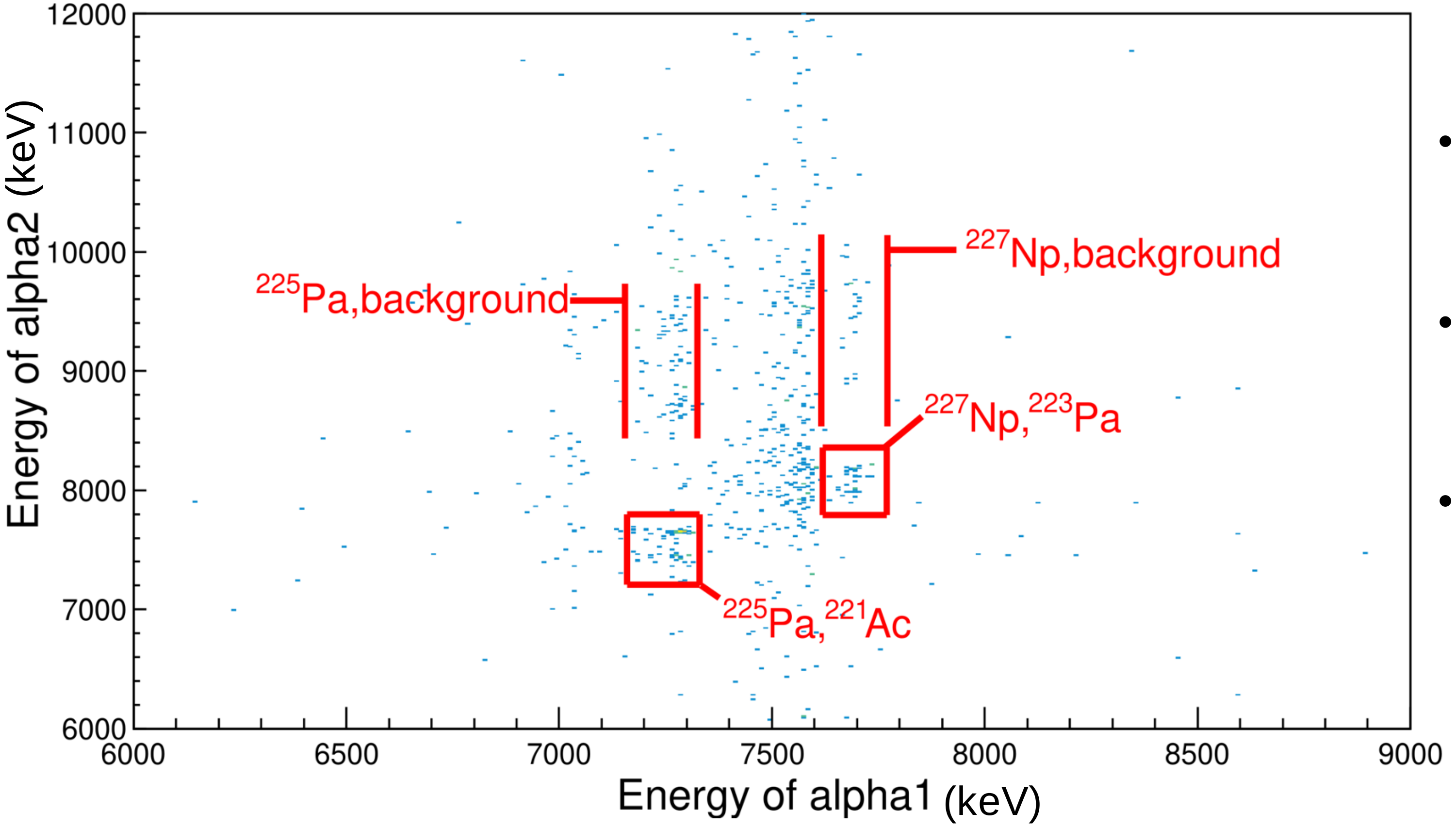


E. Parr et al., Physical Review C 102, 054335 (2020)

α-decay chains



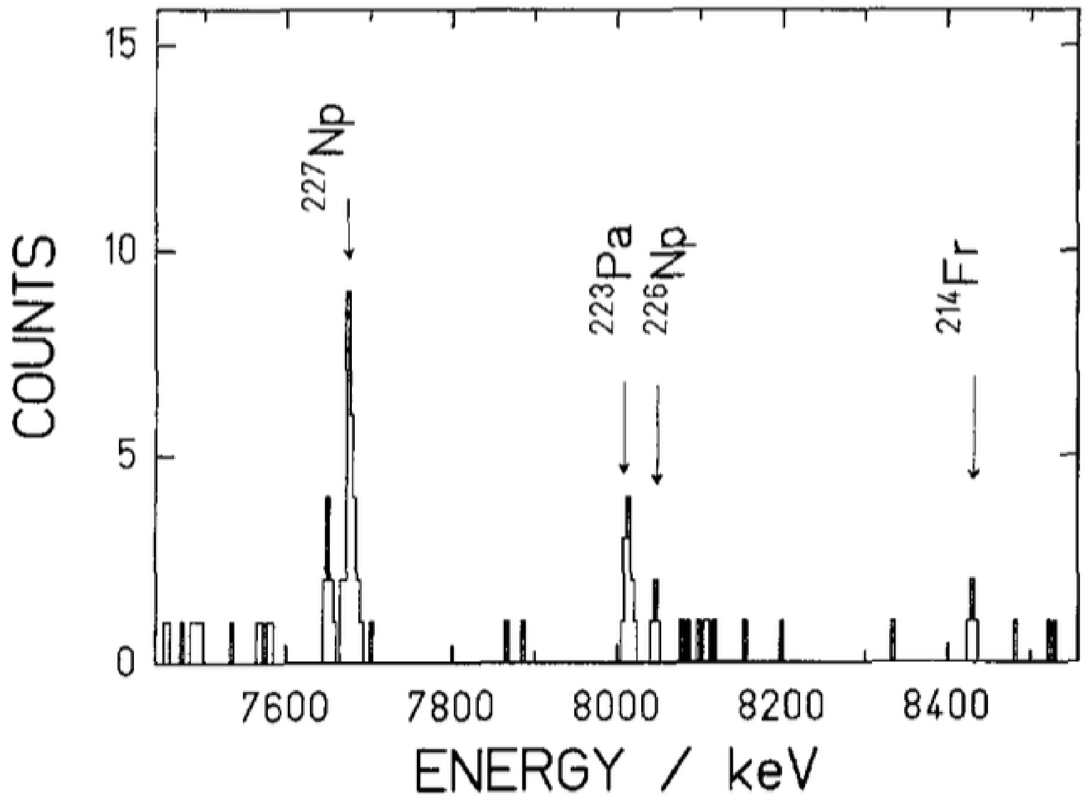
^{227}Np analysis



- Alpha1-alpha2 spectrum, time gated for $7t_{1/2}(^{227}\mathrm{Np})$ and $7\ t_{1/2}(^{223}\mathrm{Pa})$
- Some coincidences between ^{227}Np, ^{223}Pa and ^{225}Pa, ^{221}Ac
- Difficulties in resolving recoils; recoils sometimes overlap with alpha particles

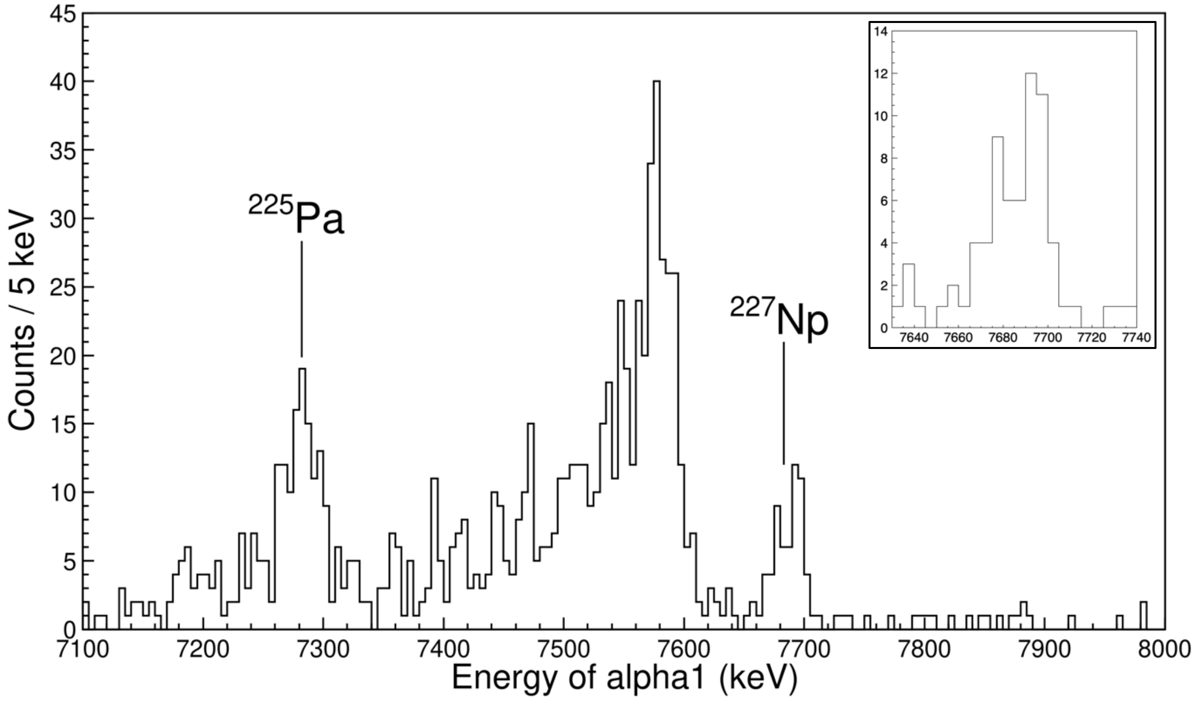
^{227}Np analysis

Previous study – V. Ninov et al., Z. Phys. A **336**, 473 (1990)



α-particle energies: 7677(20) keV and 7650(20) keV

This study



Tentative α-particle energies: 7694(11) keV and 7678(11) keV

Conclusions & future analysis

- The region of octupole correlations in the light actinides is not well defined
- Obtain information about the ground-state spin and α-decaying fine structure of $^{227,225}Np$ and ^{223}U
- Two alpha decays of ^{227}Np have been tentatively identified
- Correlation of decay chains to be improved
- Hindrance factors can compare ^{227}Np ground state with other odd-A nuclei in the isotonic chain
- This analysis will be carried out for ^{225}Np and ^{223}U

B. J. M. Hogg[1], J. M. Keatings[1], A. D. Briscoe[2], E. Parr[2], J. F. Smith[1], B. Alayed[2], K. Auranen[3], H. Ayatollahzadeh[1], V. Bogdanoff[3], P. A. Butler[2], R. Chapman[1], T. Grahn[3], P. T. Greenlees[3], H. Joukainen[3], R. Julin[3], H. Jutila[3], H. Kokkonen[3], M. Leino[3], J. Louko[3], M. Luoma[3], A. McCarter[2], J. Ojala[3], R. D. Page[2], J. Pakarinen[3], P. Rahkila[3], P. Ruotsalainen[3], J. Saren[3], M. Satrazani[2], J. Uusitalo[3], D. White[1] and T. Wonderley[2].

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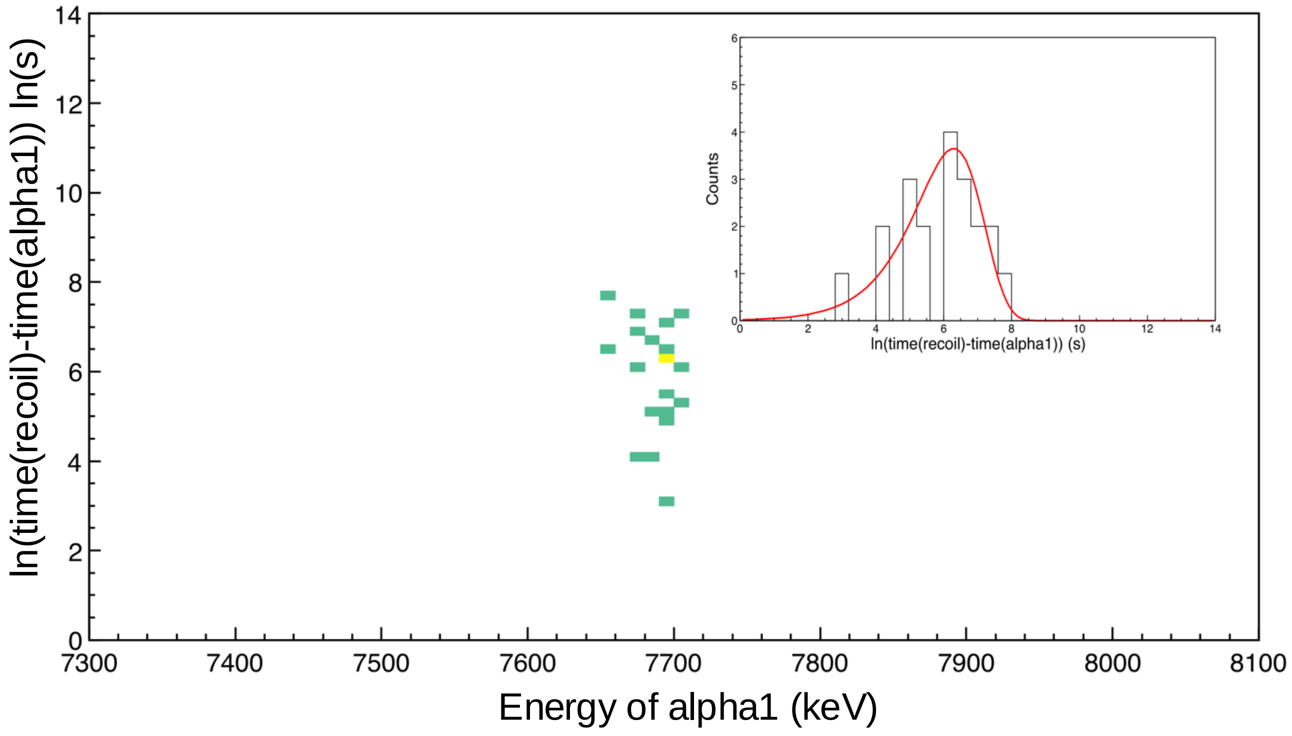
^{227}Np analysis



	Ninov et al.	This study
Alpha particle energies (keV)	7677(20)	7694 (11)
	7650(20)	7678 (11)
Measured half life (ms)	510 (60)	720 (140)

These are tentative results. The analysis is ongoing.

K.-H. Schmidt, The European Physical Journal A 8, 141 (2000).