Alpha decay of neodymium isotopes

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Neodymium isotopes

Five of seven naturally occurring neodymium isotopes are potentially alpha unstable

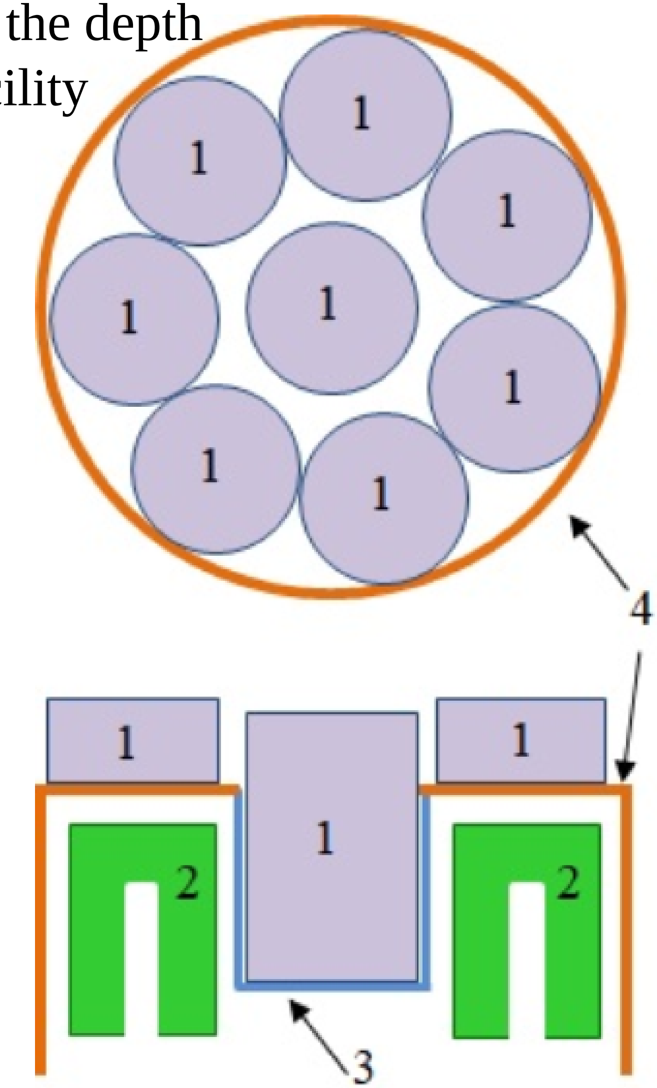
isotope	abundance (%)	decay mode, Q (keV)	$T_{1/2}$ (exp), y	$T_{1/2}$ (theor), y
^{143}Nd	12.173	α, 530.5	> 2×10^{17} [1]	1.0×10^{79} — 3.5×10^{92}
^{144}Nd	23.798	α, 1901.3	g.s. to g.s.: = $2.29(16)\times10^{15}$ [2]	2.3×10^{15} — 5.0×10^{15}
			to 1st excited ^{140}Ce 2^+ (1596.2 keV) level: —	7.8×10^{121} — 9.5×10^{121}
^{145}Nd	8.293	α, 1574.1	> 1×10^{17} [1, 3]	2.2×10^{22} — 4.9×10^{23}
^{146}Nd	17.189	α, 1182.1	g.s. to g.s.: —	2.0×10^{34} — 4.0×10^{34}
			to 1st excited ^{142}Ce 2^+ (641.3 keV) level: > 1.6×10^{18} [4]	5.8×10^{77} — 8.5×10^{77}
^{148}Nd	5.756	α, 599	—	6.1×10^{70} — 1.1×10^{71}
		2α, 1011.5	—	3.0×10^{172} — 8.0×10^{178} [5]

[1] G. Kauw, Untersuchungen an angereicherten Isotopen auf naturliche Alphastrahlung, Forschungsber. Landes Nordrhein-Westfalen No.1640 (1966).
[2] A.A. Sonzogni, Nuclear Data Sheets for A = 144, Nucl. Data Sheets 93 (2001) 599.
[3] E. Browne, J.K. Tuli, Nuclear Data Sheets for A = 145, Nucl. Data Sheets 110 (2009) 507.
[4] C. Stengl, H. Wilsenach, K. Zuber, First search for the α-decay of ^{146}Nd into the first excited state of ^{142}Ce, Int. J. Mod. Phys. E 24 (2015) 1550043.
[5] V.I. Tretyak, Spontaneous double alpha decay: First experimental limit and prospects of investigation, Nucl. Phys. At. Energy 22 (2021) 121.

Experiment

Total mass of all samples m(Nd_2O_3) = 2381 g (density ρ = 2.85 g/cm^3)

Ultra-low background HPGe-detector system GeMulti located at the depth of ~ 3600 m of water equivalent underground at the STELLA facility of the Gran Sasso underground laboratory of the INFN (Italy).



Passive shield:

1) low-radioactive copper 10 cm thick
2) 20 cm layer of lead

The Plexiglas box with the detector was flashed by high-purity nitrogen gas to eliminate environmental radon.

The live time of the measurements is 51237 h.

1. Nd_2O_3 source samples
2. two of four coaxial HPGe detectors (225 cm^3 each)
3. aluminium cup of the detector system endcap
4. copper walls of the endcap

α and 2α decays accompanied by γ quanta

γ quanta appear in α decay in the following cases:

1) if an excited level of a daughter nucleus is populated, with subsequent emission of deexcitation γ;
2) if daughter nucleus is unstable and decays further with emission of γ;

α decay:

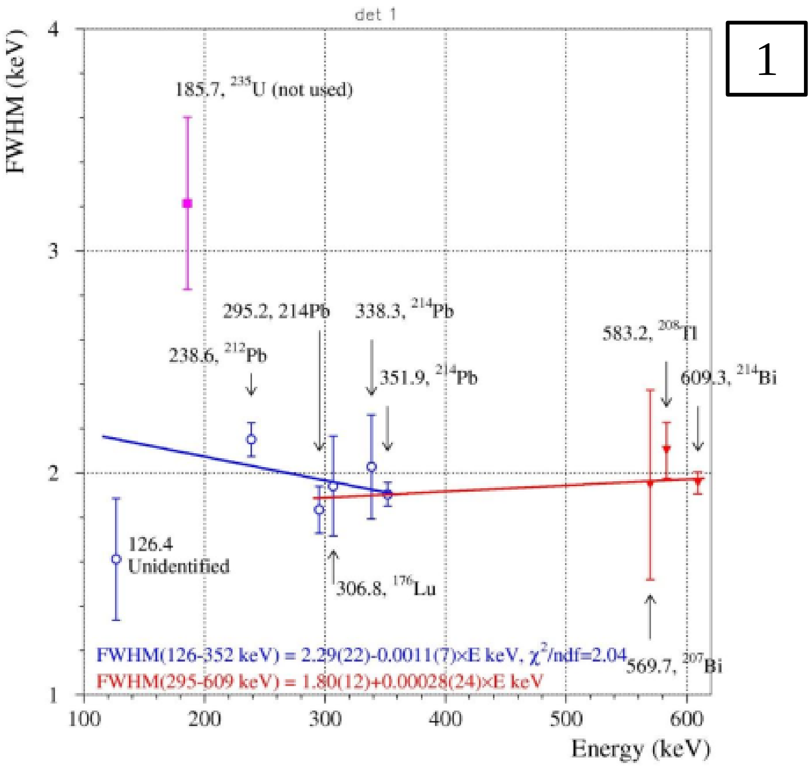
1) $^{143}Nd \to {}^{139}Ce \to {}^{139}La$
2) $^{144}Nd \to {}^{140}Ce$
3) $^{145}Nd \to {}^{141}Ce \to {}^{141}Pr$
4) $^{146}Nd \to {}^{142}Ce$
5) $^{148}Nd \to {}^{144}Ce \to {}^{144}Pr \to {}^{144}Nd$

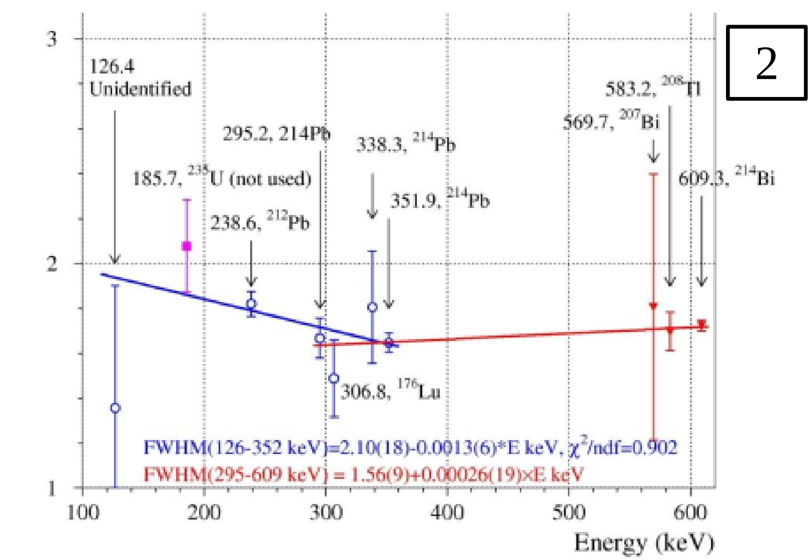
2α decay:

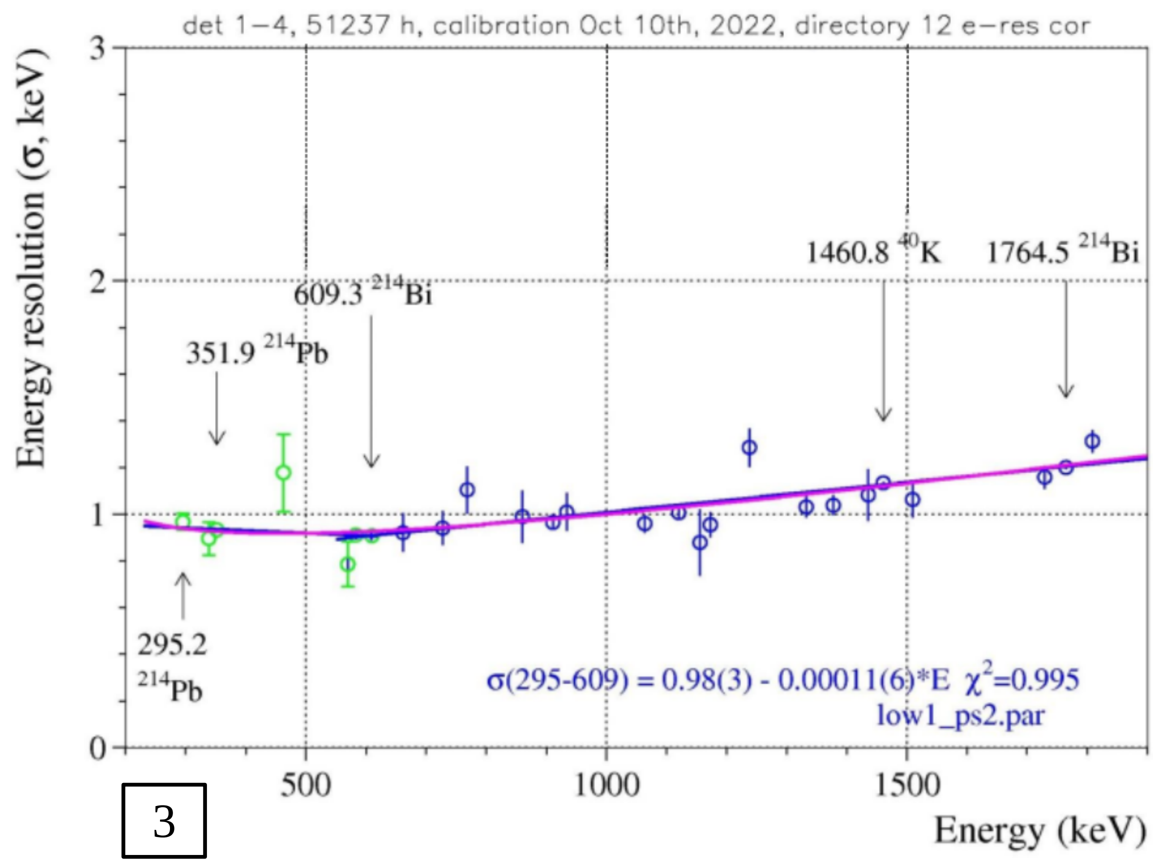
6) $^{148}Nd \to {}^{140}Ba \to {}^{140}La \to {}^{140}Ce$

In the cases 1, 3, and 5, daughter Ce isotopes are unstable and decay with emission of γ's. Decays 2 and 4 can be observed only in the case of decays to excited Ce level.

Energy resolution

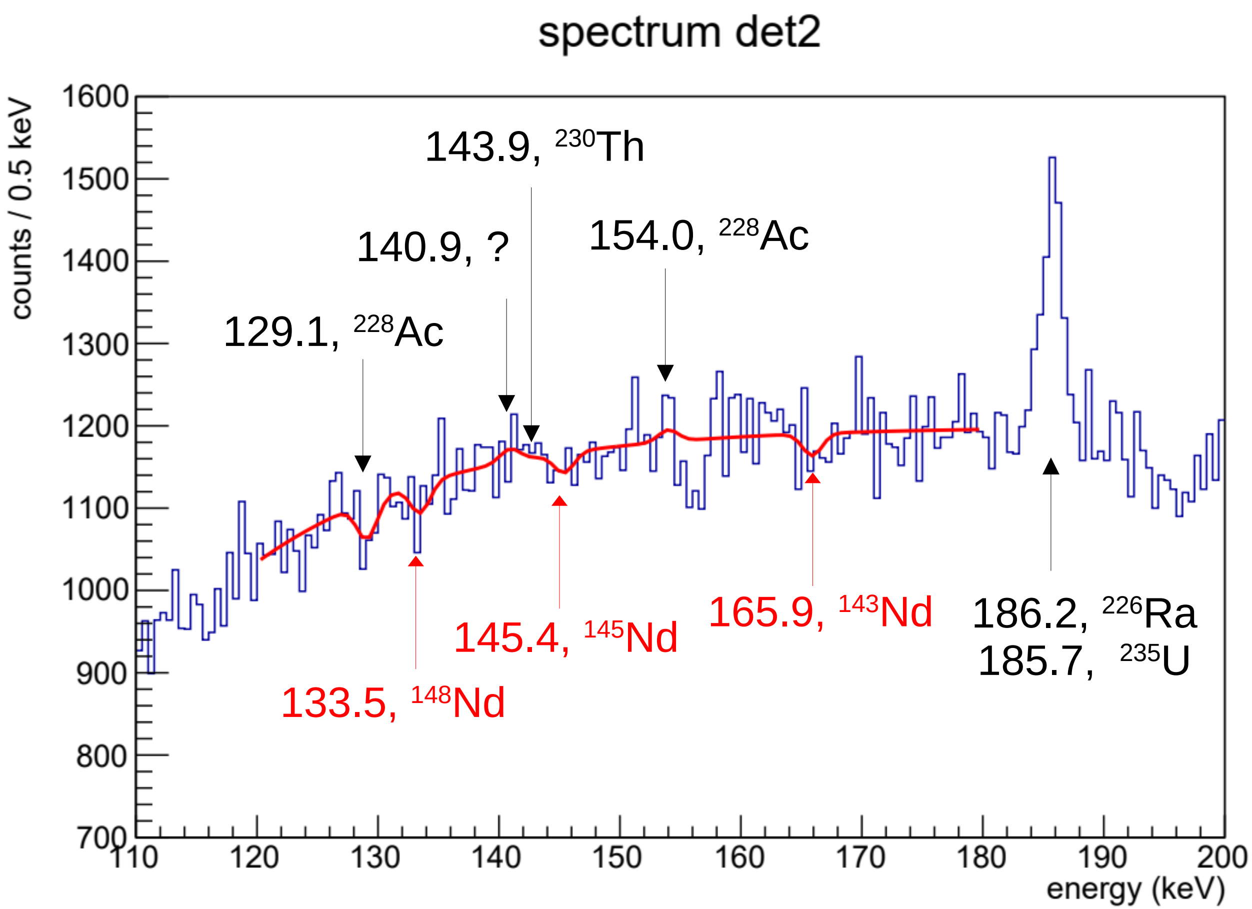






1. detector 1 FWHM dependence
2. detector 2 FWHM dependence
3. energy resolution of summarized spectrum of all detectors

Search for alpha decays of ^{143}Nd, ^{145}Nd, ^{148}Nd



μ (keV)	σ (keV)	S
129.1	0.82	-94 ± 45
133.5	0.82	-74 ± 46
140.9	0.82	32 ± 46
143.9	0.81	-2 ± 47
145.4	0.81	-49 ± 47
154.0	0.81	29 ± 44
165.9	0.80	-54 ± 43

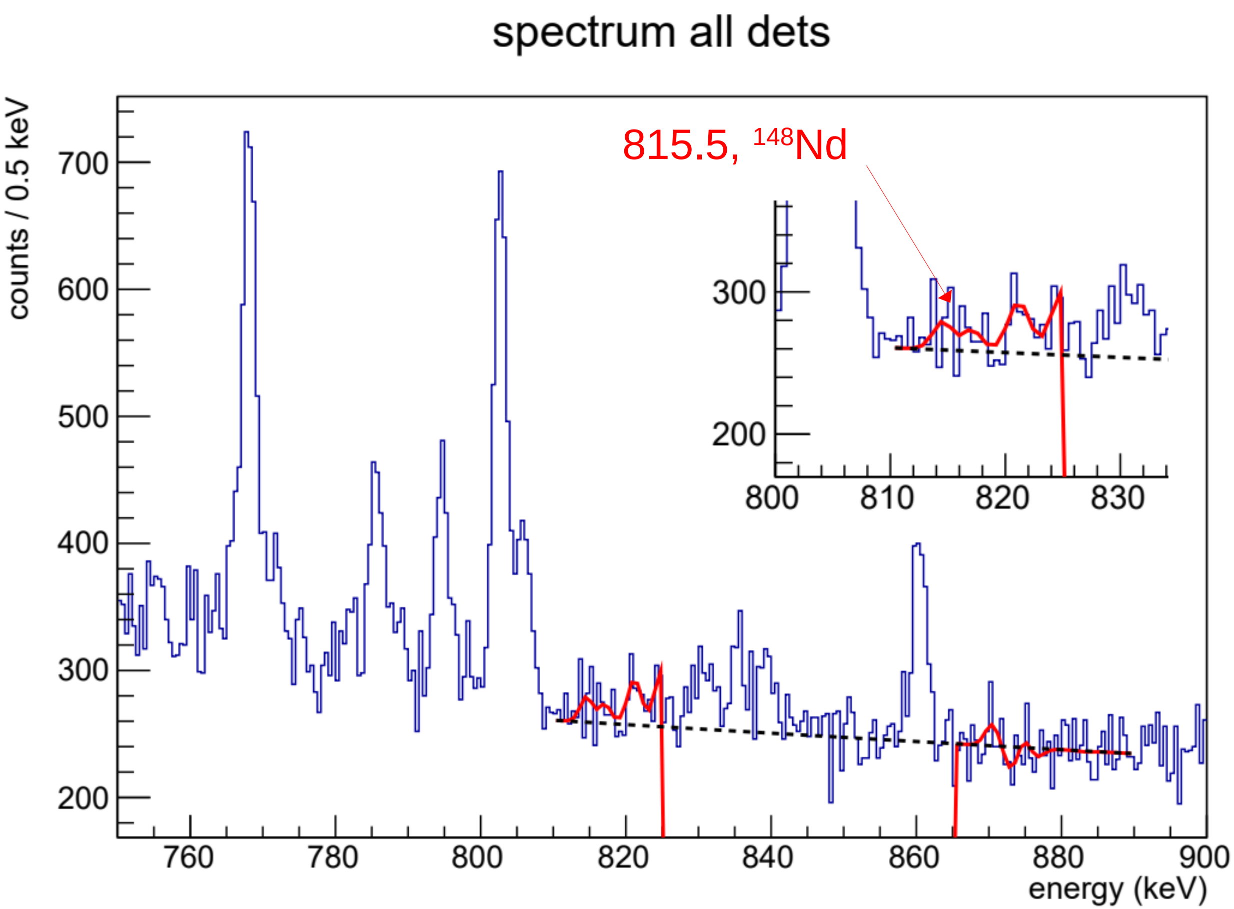
$$\chi^2/ndf = 130.18/110 = 1.18$$

Data measured over 51237 h by one of the detectors with low energy threshold

$$\lim T_{1/2} = \frac{\ln 2 \cdot N \cdot t \cdot eff \cdot \eta}{\lim S}$$

nuclide, decay channel	energy (keV)	lim S	$T_{1/2}$ (y)
^{143}Nd, α	165.9	29	> 1.4×10^{20}
^{145}Nd, α	145.4	37	> 6.2×10^{19}
^{148}Nd, α	133.5	24	> 2.2×10^{19}

Search for 2α decay of ^{148}Nd



μ (кеВ)	σ (кеВ)	S
814.92	0.96	76 ± 55
815.8	0.96	-63 ± 76
816.71	0.96	61 ± 53
821.18	0.96	87 ± 27
824.93	0.96	106 ± 33
870.46	0.97	42 ± 23
873.17	0.97	-48 ± 25
874.7	0.97	26 ± 27
876.5	0.97	-19 ± 24
883.3	0.97	-2 ± 23

$\chi^2/ndf = 85.36/67 = 1.27$

Sum energy spectrum measured by 4 detectors over 51237 h

nuclide, decay channel	energy (keV)	lim S	$T_{1/2}$ (y)
^{148}Nd, 2α	815.8	72	> 1.6×10^{20}

Summary

Decay	Q_α ($Q_{2\alpha}$) (keV)	Transition (energy of level (keV))	Energy of γ-quanta (keV)	best previous limit $T_{1/2}$, y	this work $T_{1/2}$, y
α decay					
$^{143}Nd \to {}^{139}Ce$	530.5	$7/2^+ \to 3/2^+$ (g.s.)	165.9	$> 2\times10^{17}$	$> 1.4\times10^{20}$
$^{144}Nd \to {}^{140}Ce$	1901.3	$0^+ \to 2^+$ (1596.2)	1596.2	—	in progress
$^{145}Nd \to {}^{141}Ce$	1574.1	$7/2^- \to 7/2^-$ (g.s.)	145.4	$> 1\times10^{17}$	$> 6.2\times10^{19}$
$^{146}Nd \to {}^{142}Ce$	1182.1	$0^+ \to 2^+$ (641.3)	641.3	$> 1.6\times10^{18}$	$> 3.5\times10^{21}$
$^{148}Nd \to {}^{143}Ce$	599	$7/2^+ \to 3/2^+$ (g.s.)	133.5	—	$> 2.2\times10^{19}$
2α decay					
$^{148}Nd \to {}^{140}Ba$	1011.5	$0^+ \to 0^+$ (g.s.)	537.3	—	$> 2.7\times10^{20}$

Conclusions

1) The search for alpha decays of naturally occurring neodymium isotopes was realized with low-background HPGe gamma spectrometry.

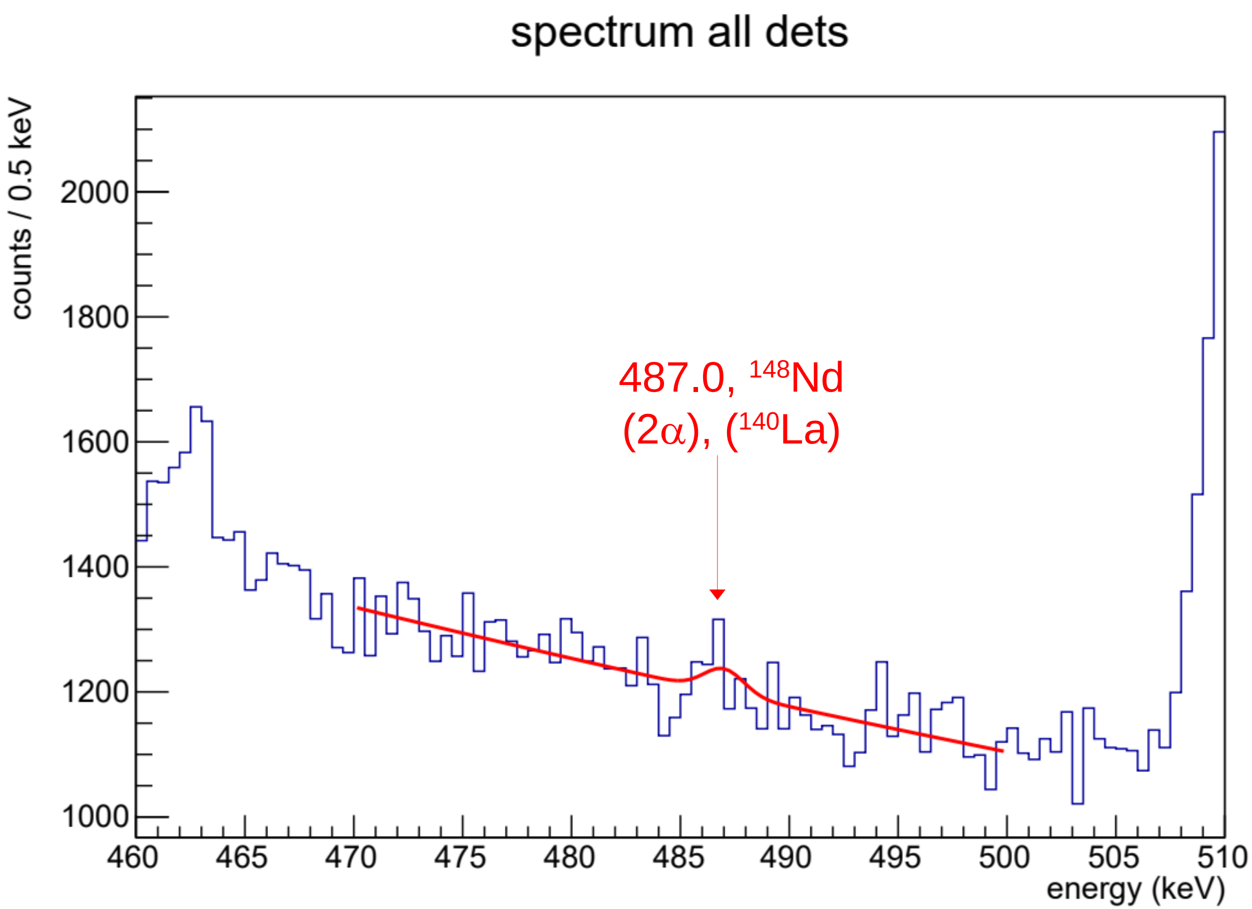
2) The obtained $T_{1/2}$ limits were improved by 2-3 orders of magnitude compared to current best limits.

3) For the first time $T_{1/2}$ limits were set for ^{148}Nd α and 2α decays.

4) The data analysis is in progress.

Back-up slides

Search for 2α decay of ^{148}Nd



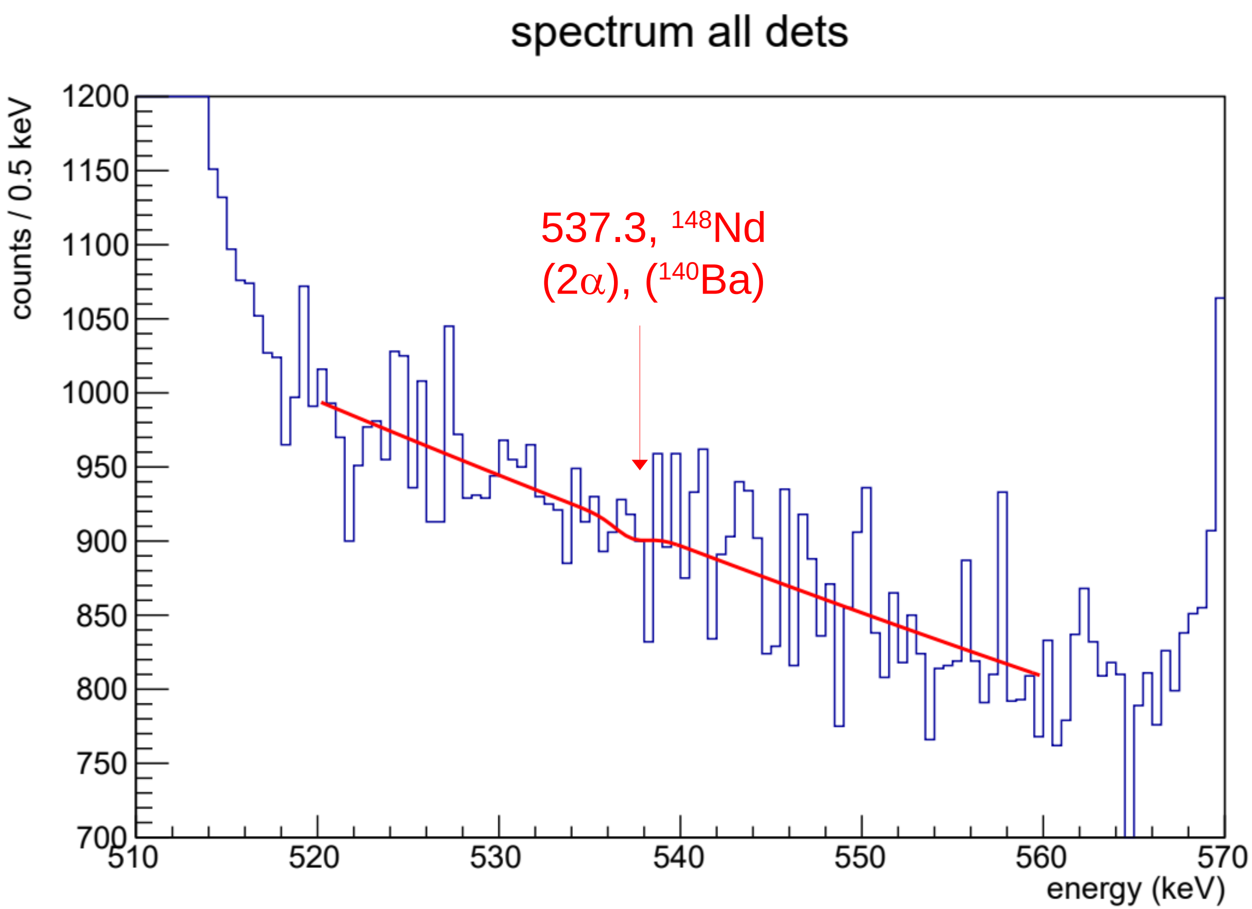
μ (keV)	σ (keV)	S
487.0	0.92	87.76 ± 47.62

$\chi^2/ndf = 93.92/57 = 1.65$

Sum energy spectrum measured by 4 detectors over 51237 h

nuclide, decay channel	energy (keV)	lim S	$T_{1/2}$ (y)
^{148}Nd, 2α	487.0	166	> 1.6×10^{20}

Search for 2α decay of ^{148}Nd

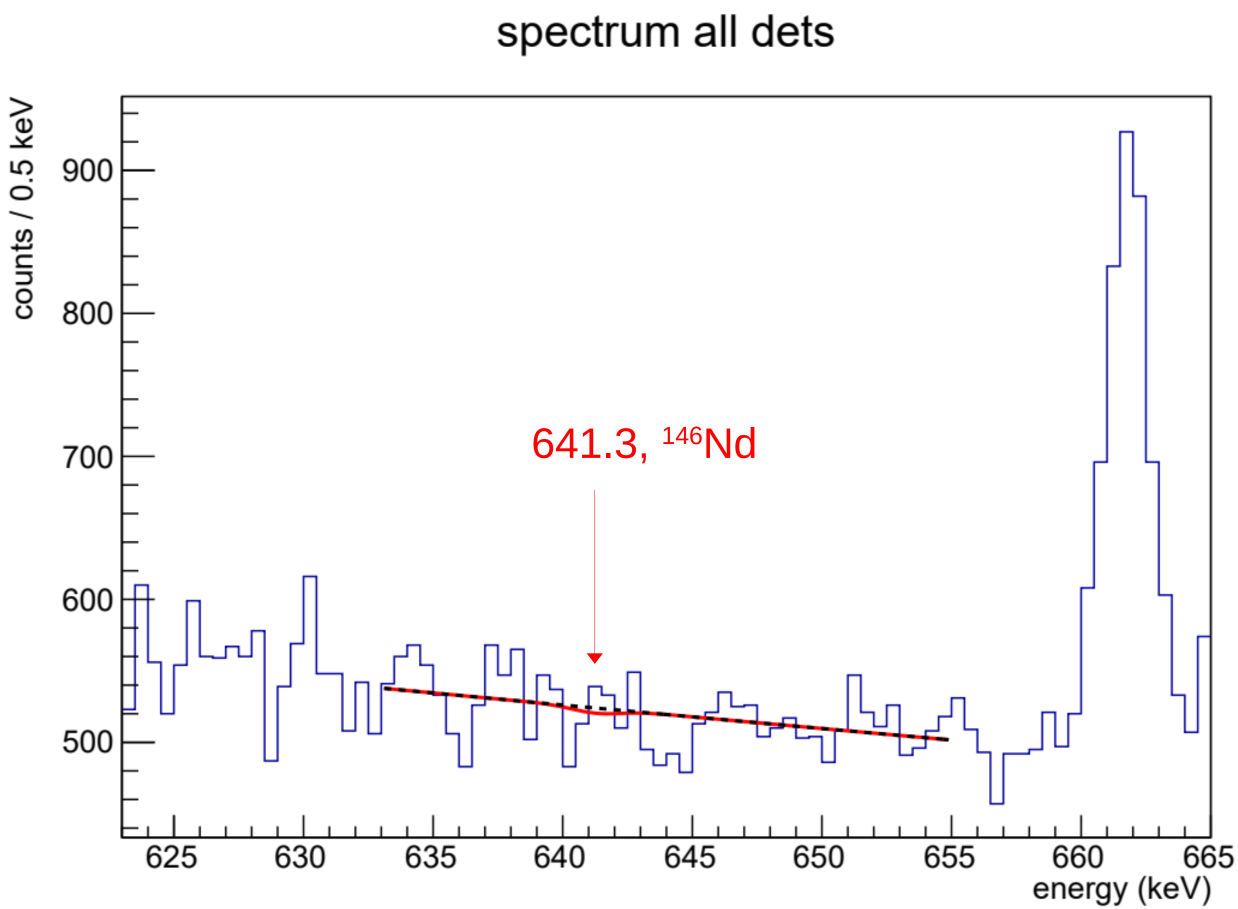


μ (keV)	σ (keV)	S
537.3	0.92	-18 ± 40

$$\chi^2/ndf = 142.84/77 = 1.86$$

nuclide, decay channel	energy (keV)	lim S	$T_{1/2}$ (y)
^{148}Nd, 2α	537.3	50	> 2.7×10^{20}

Search for alpha decay of ^{146}Nd

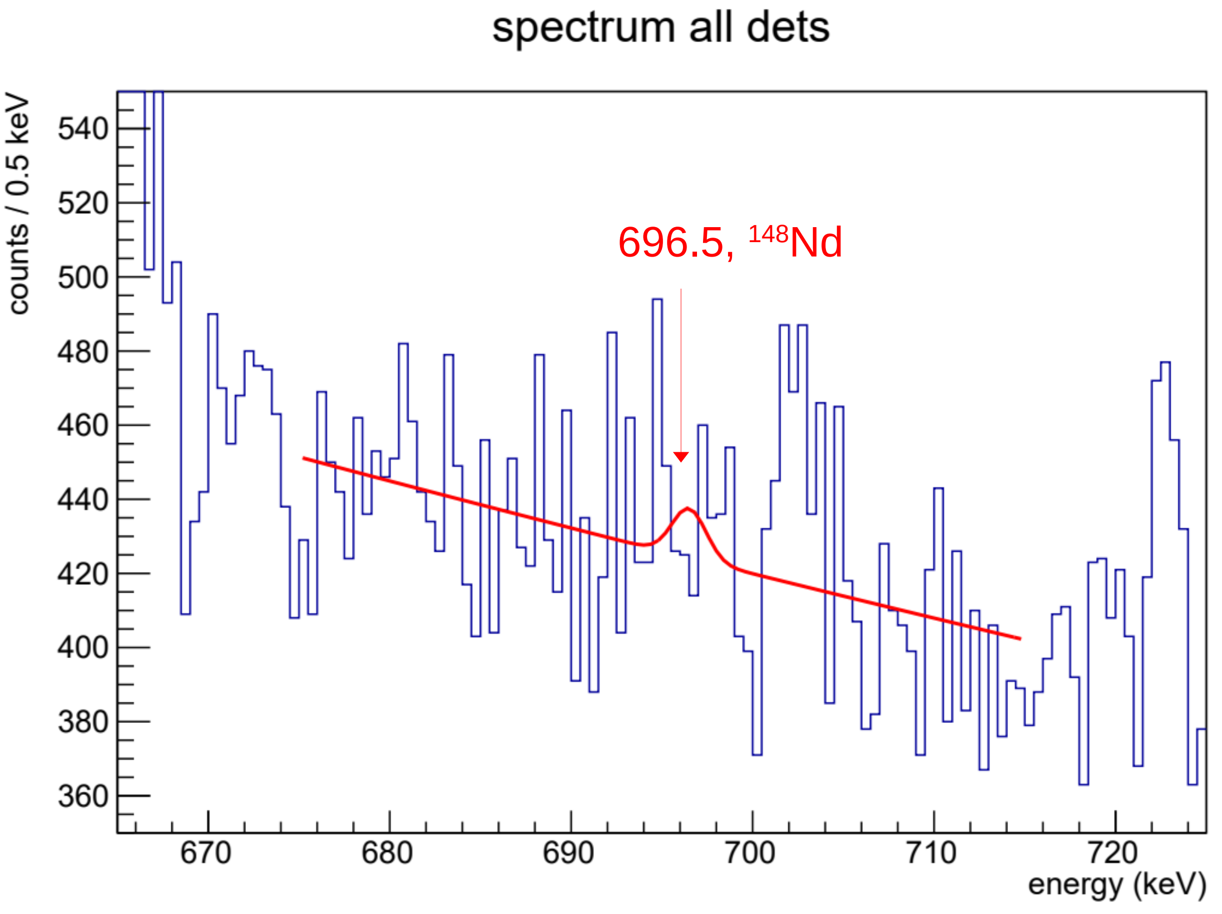


μ (keV)	σ (keV)	S
641.3	0.93	-8 ± 33

$$\chi^2/ndf = 40.43/41 = 0.99$$

nuclide, decay channel	energy (keV)	lim S	$T_{1/2}$ (y)
^{146}Nd, α	641.3	45	> 3.5×10^{21}

Search for alpha decay of ^{148}Nd



μ (keV)	σ (keV)	S
696.5	0.94	31 ± 28

$$\chi^2/ndf = 142.20/77 = 1.85$$

nuclide, decay channel	energy (keV)	lim S	$T_{1/2}$ (y)
^{148}Nd, α	696.5	77	> 9.0×10^{18}

Other limits

nuclide, decay channel	energy (keV)	lim S	$T_{1/2}$ (y)
^{148}Nd, 2α	487.0	166	$> 1.6\times10^{20}$
^{148}Nd, 2α	537.3	50	$> 2.7\times10^{20}$
^{146}Nd, α	641.3	45	$> 3.5\times10^{21}$
^{148}Nd, α	696.5	77	$> 9.0\times10^{18}$

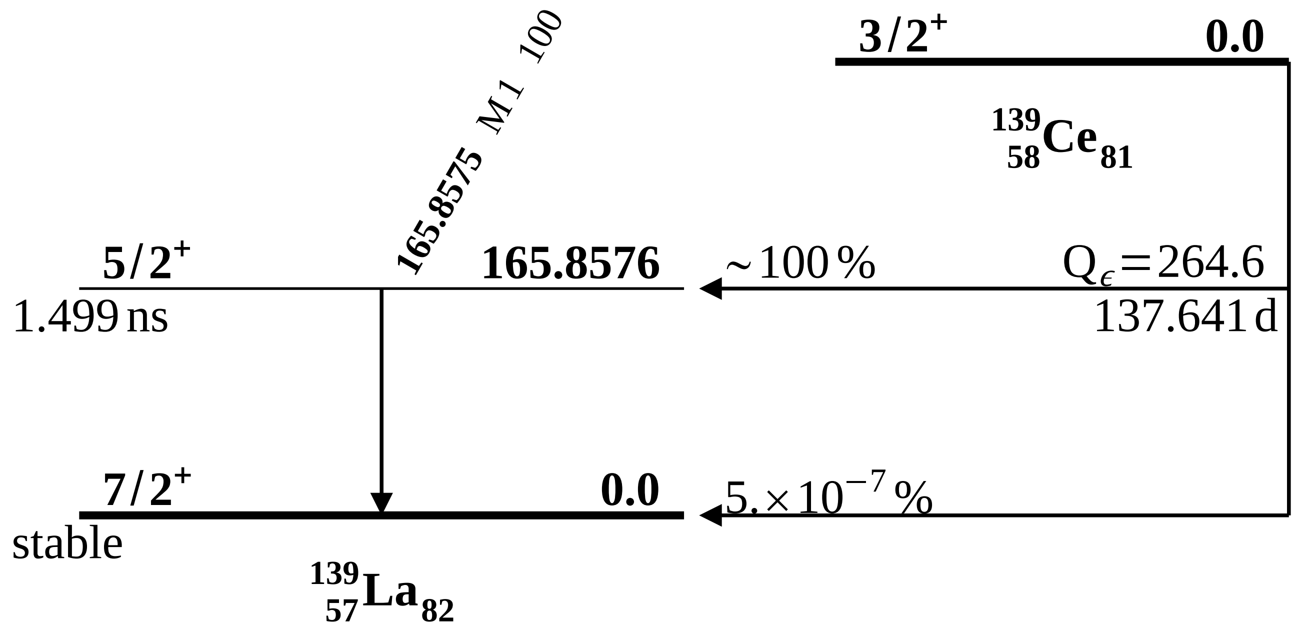
Decay scheme: ^{143}Nd

$^{143}Nd \rightarrow {}^{139}Ce \rightarrow {}^{139}La$

165.9 keV:

α = 0.2516

I_γ = 79.90

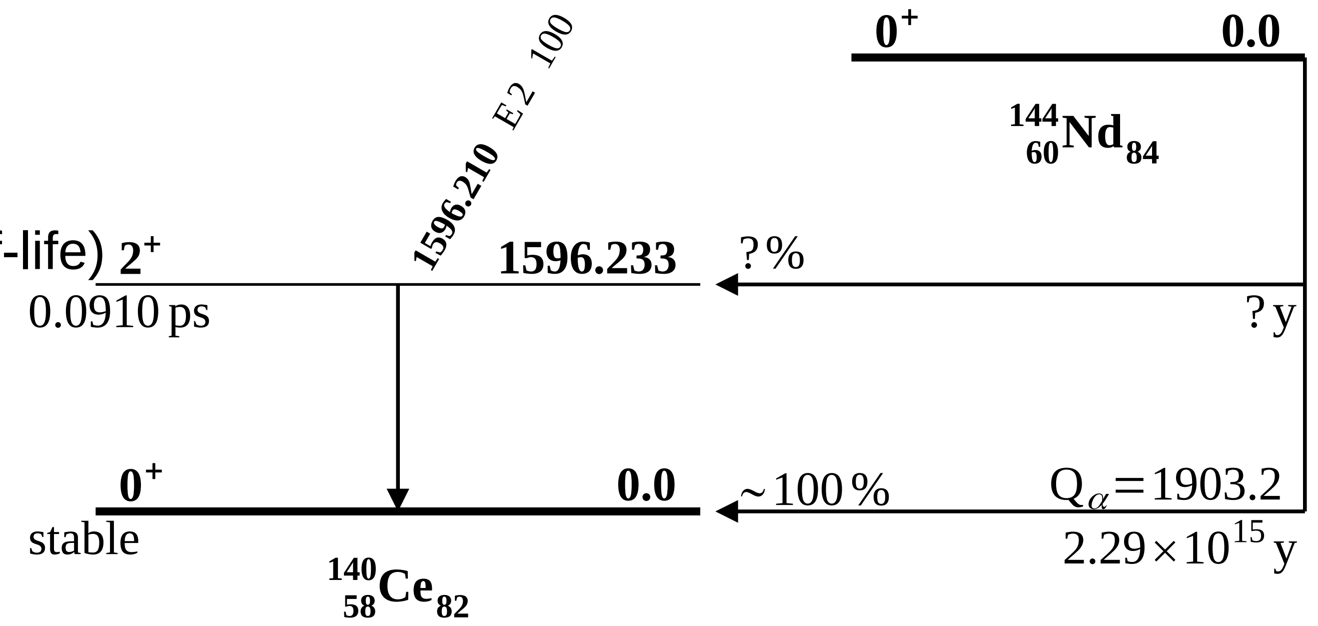


Decay scheme: ^{144}Nd

^{144}Nd → ^{140}Ce

1596.2 keV:

- α = 8.98×10^{-4} (bricc)
- $I_{\gamma+ce}$ = 100 (for partial half-life)
- I_{γ} = 0.9991



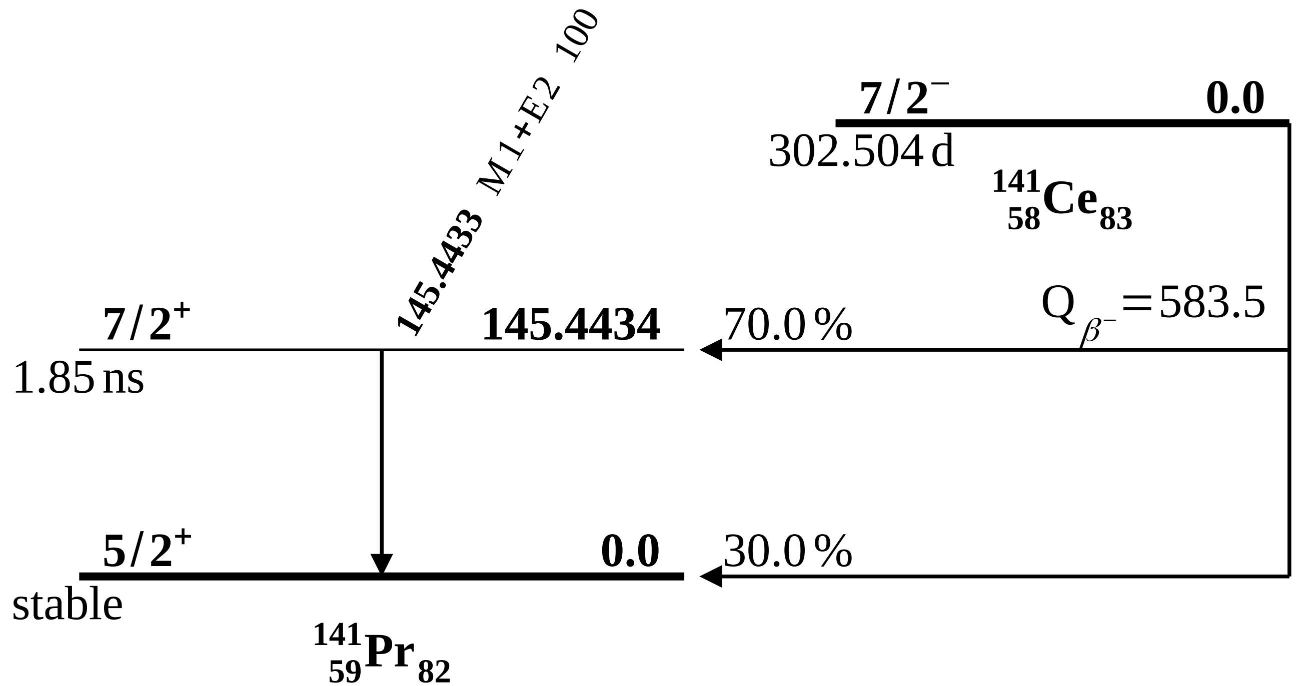
Decay scheme: ^{145}Nd

$^{145}Nd \rightarrow {}^{141}Ce \rightarrow {}^{141}Pr$

145.4 keV:

α = 0.448 (bricc)

I_γ = 48.3



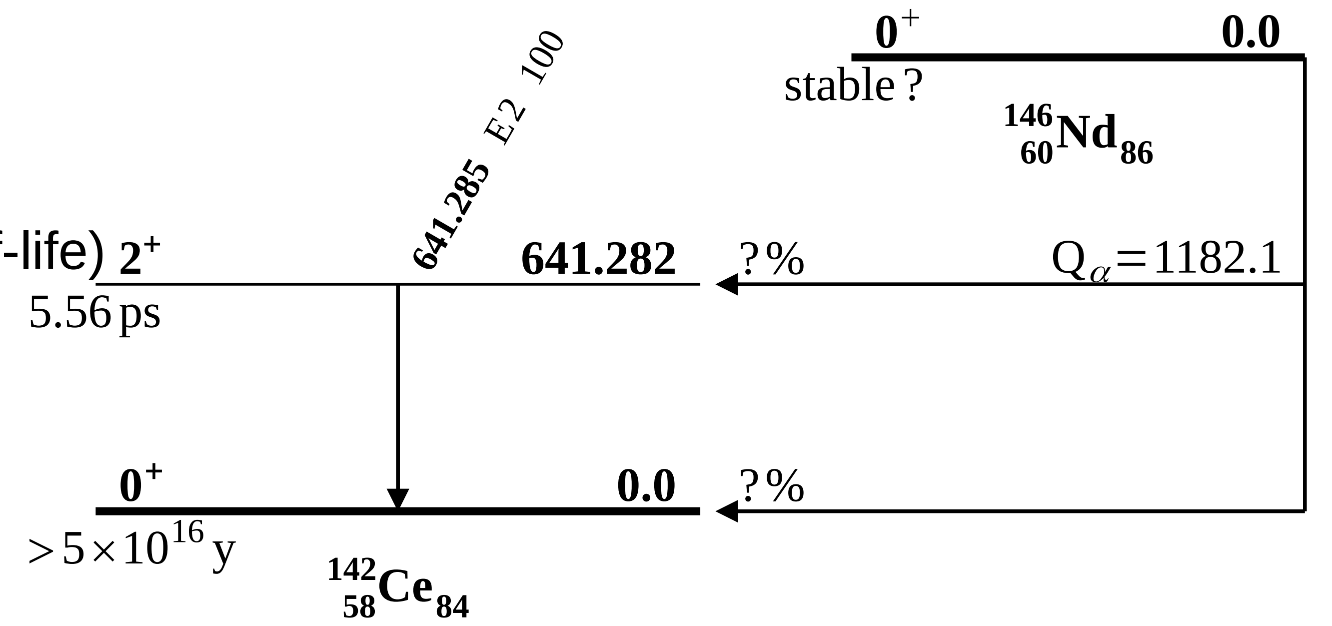
Decay scheme: ^{146}Nd

$^{146}Nd \rightarrow {}^{142}Ce$

641.3 keV:

- $\alpha = 5.63\times10^{-3}$ (bricc)
- $I_{\gamma+ce} = 100$ (for partial half-life)
- $I_\gamma = 0.9944$

α decay of ^{146}Nd wasn't observed



Decay scheme: ^{148}Nd

$^{148}Nd \rightarrow {}^{144}Ce \rightarrow {}^{144}Pr \rightarrow {}^{144}Nd$

133.5 keV:

- $\alpha = 0.579$ (bricc)
- $I_{\gamma+ce} = 17.5$
- $I_{\gamma} = 11.08$

696.5 keV:

- $\alpha = 5.11\times10^{-3}$ (bricc)
- $I_{\gamma+ce} = 1.349$
- $I_{\gamma} = 1.342$

2185.7 keV:

- $\alpha = 9.95\times10^{-4}$ (bricc)
- $I_{\gamma+ce} = 0.695$
- $I_{\gamma} = 0.694$