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Experimental study of 2β decay of ^{150}Nd to the first 0^+ excited level of ^{150}Sm

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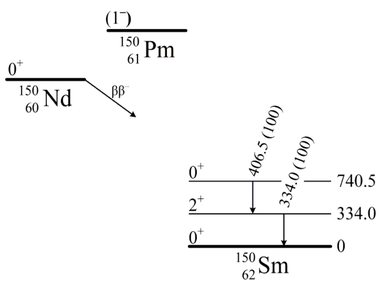
Introduction

The nuclide ^{150}Nd :

- High energy release $Q_{2\beta}$ = 3371.4(2) keV
- isotopic abundance δ = 5.64(3)%



Simplified decay scheme of ^{150}Nd

Summary of the recent experiments to search for the 2ν2β decay of ^{150}Nd to the 0_1^+ 740.5-keV excited level of ^{150}Sm. The statistical and systematic uncertainties, given in the original papers, are added in squares.

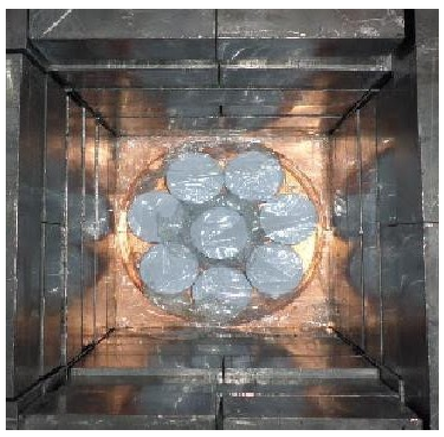
Short description	$T_{1/2}$, × 10^{19} y	Year [Ref.]
Modane UL (4800 m w.e.), HPGe 400 cm^3, 3046 g of Nd_2O_3 (δ = 5.638%), 11321 h, 1-d spectrum (preliminary result)	14^{+5}_{-4}	2004 [1]
Re-estimation of the result [4]	$13.3^{+4.5}_{-2.6}$	2009 [2]
Modane UL, NEMO-3 detector, foil with 57.2 g of $^{150}Nd_2O_3$ (δ = 91.0%), 40774 h, energies of e^- and γ, tracks for e^- (preliminary result)	7.1 ± 1.6	2013 [3]
Kimballton UL (1450 m w.e.), 2 HPGe (~304 cm^3 each one), 50 g $^{150}Nd_2O_3$ (δ = 93.6%), 15427 h, coincidence spectrum	$10.7^{+4.6}_{-2.6}$	2014 [4]
Gran Sasso UL (3600 m w.e.), 4 HPGe (~225 cm^3 each one), 2381 g of Nd_2O_3 (δ = 5.638%), 25947 h, 1-d spectra, coincidence spectrum	$6.9^{+4.2}_{-2.2}$	This work

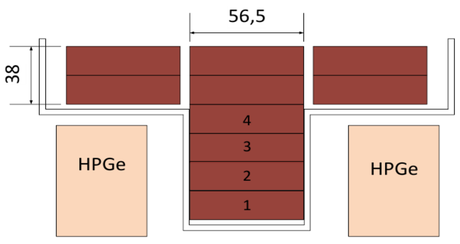
The Nd_2O_3 purification

The Nd_2O_3 was produced in the 1970-s and was used for the first positive observation of the decay [1, 2]. The material was additionally purified before using in the current measurements.

The radioactive contaminations of the samples [5, 6] before the purification were measured in the STELLA facility by using the ultra-low-background HPGe detector GePaolo (518 cm^3).

Experiment





Nd_2O_3 samples in the GeMulti setup:
(a) The samples of Nd_2O_3 placed on the HPGe detectors cryostat
(b) Schematical view of the Nd_2O_3 samples in the setup

- Gran Sasso Underground Laboratory (~3600 m w.e.)
- 2.381-kg Nd_2O_3 samples
- 4 HPGe detectors (225.2 cm^3, 225.0 cm^3, 225.0 cm^3, and 220.7 cm^3).
- The detectors are shielded by radiopure copper (10 cm) and lead (20 cm).
- The whole setup is enclosed in a Plexiglas box flushed with high-purity nitrogen gas to remove radon.
- The measurements are carried out also in the coincidence mode.

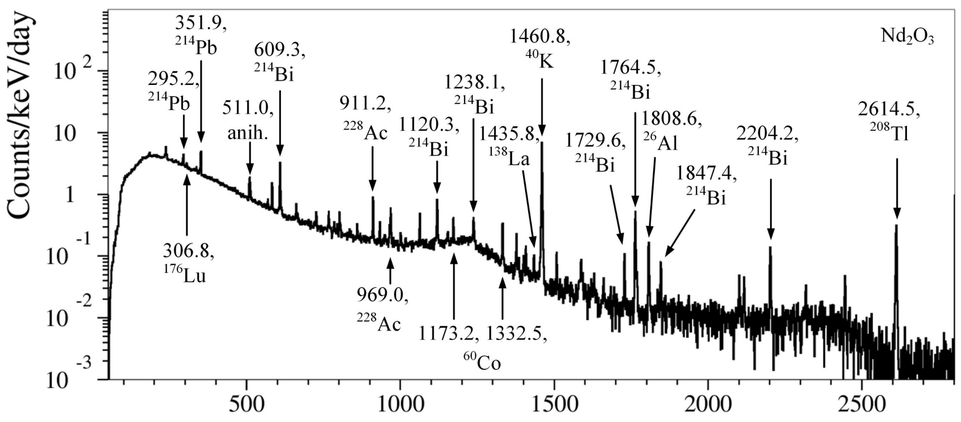
The energy resolution of the HPGe detectors measured with a ^{60}Co γ source.

Detector No.	FWHM, keV (1333-keV peak of ^{60}Co)
1	2.36(2)
2	2.01(2)
3	2.06(2)
4	4.01(4)

Results and discussion

The calibration of the setup was carried out in the beginning of the experiment with ^{22}Na, ^{60}Co, ^{133}Ba, ^{137}Cs and ^{228}Th γ-sources. Then the individual spectra of each detector (accumulated over 3000 – 5000 h each one) were transformed to the same energy scale by using most intensive background gamma peaks. The final energy resolution in the cumulative spectrum gathered with the Nd_2O_3 sample over 25947 hours can be described by the following function:

$$FWHM = \sqrt{2.7(5) + 0.0025(5) \times E_\gamma}\ .$$



The energy spectrum measured with the 2.381-kg Nd_2O_3 samples (top panel) and the background spectrum collected for 7862 h (bottom panel)

The half-life of ^{150}Nd relatively to the decay ^{150}Nd → ^{150}Sm (0^+, 740.5 keV) can be estimated as:

$$T_{1/2} = \frac{\ln 2 \cdot \varepsilon \cdot N \cdot t}{(1+\alpha) \cdot S},$$

where ε is the full absorption peak detection efficiency of the 4 HPGe detectors to the γ quanta, t is the time of measurements, N is the number of ^{150}Nd nuclei in the samples (4.8×10^{23}), α is the internal conversion coefficient, S is the number of events of the effect.

The γ-peaks, searched for in the experiment, were not observed in the 1-dimentional spectrum, while the effect was measured in coincidence mode:

$S = 6.1 \pm 2.2$

Therefore, the half-life value of ^{150}Nd → ^{150}Sm (0^+, 740.5 keV) process can be estimated as:

$$T_{1/2} = [6.9^{+4.0}_{-1.9}\ (\text{stat}) \pm 1.1(\text{syst})] \times 10^{19}$$

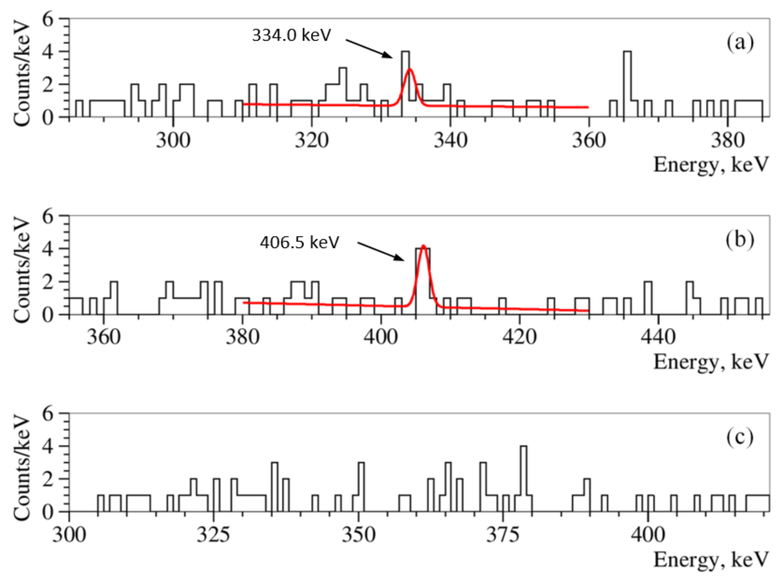
here $\varepsilon = 4.3 \times 10^{-4}$ (Monte-Carlo simulated with the EGSnrc package [7], values of internal conversion coefficients were included in simulation).

The systematic error (preliminary):

- Detection efficiency calculation (15 %),
- Interval of the fit (6 %).

Other sources of systematic will be checked after the experiment completion:

- Chemical formula of the sample (possible presence of (oxy)chlorides) → error of number of ^{150}Nd nuclei in the samples;
- Error of Monte Carlo simulation of the detection efficiency in coincidence mode (will be checked with γ sources).



The coincidence spectra accumulated with the Nd_2O_3 samples, when the energy in one detector is fixed to the energy interval where γ quanta from the decay measured in the experiment are expected: (a) 406.5 keV ± 3σ, (b) 334.0 keV ± 3σ, (c) 375 keV ± 3σ (a random coincidence background in the energy near the energy of interest).

Radioactive contamination of the Nd_2O_3 before and after purification [5,6]. Upper limits are given at 90% C.L. (obtained by Feldman-Cousins procedure [8]), the measured activities are given at 68% C.L.

Chain	Nuclei	Activity, mBq/kg		
		Previous experiment [1,2]	Before purification [5,6]	This work
	^{40}K	46	16 ± 8	≤ 1.8
	^{137}Cs	0.09	≤ 0.8	≤ 0.04
	^{138}La	0.07	–	0.057 ± 0.009
	^{176}Lu	0.5	1.1 ± 0.4	0.29 ± 0.04
^{232}Th	^{228}Ra	0.9	≤ 2.1	≤ 0.3
	^{228}Th	–	≤ 1.3	≤ 0.4
^{235}U	^{235}U	–	≤ 1.7	≤ 1.3
^{238}U	^{234}Th	–	≤ 28	≤ 5.4
	^{226}Ra	1.2	15 ± 0.8	≤ 1.9

Conclusions

Investigations of the double beta decay of ^{150}Nd to the first 0^+ (740.5 keV) excited level of ^{150}Sm are in progress at the Gran Sasso underground laboratory (Italy). The experiment utilizes a 4-crystals ultra-low-background HPGe spectrometer to detect γ quanta emitted in the cascade following the decay of ^{150}Nd in a 2.381-kg sample of highly purified Nd_2O_3. Both γ quanta with energies 334.0 keV and 406.5 keV are observed in coincidences between two detectors in the data collected over 25947 h. The obtained half-life $[6.9^{+4.0}_{-1.9}(\text{stat}) \pm 1.1(\text{syst})] \times 10^{19}$ y is in agreement with the results of previous experiments. Further improvement of the half-life accuracy will be achieved by the higher statistics.

References

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