

LOW BACKGROUND HPGE SPECTROMETER IN INVESTIGATIONS OF 2β DECAY



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Abstract:

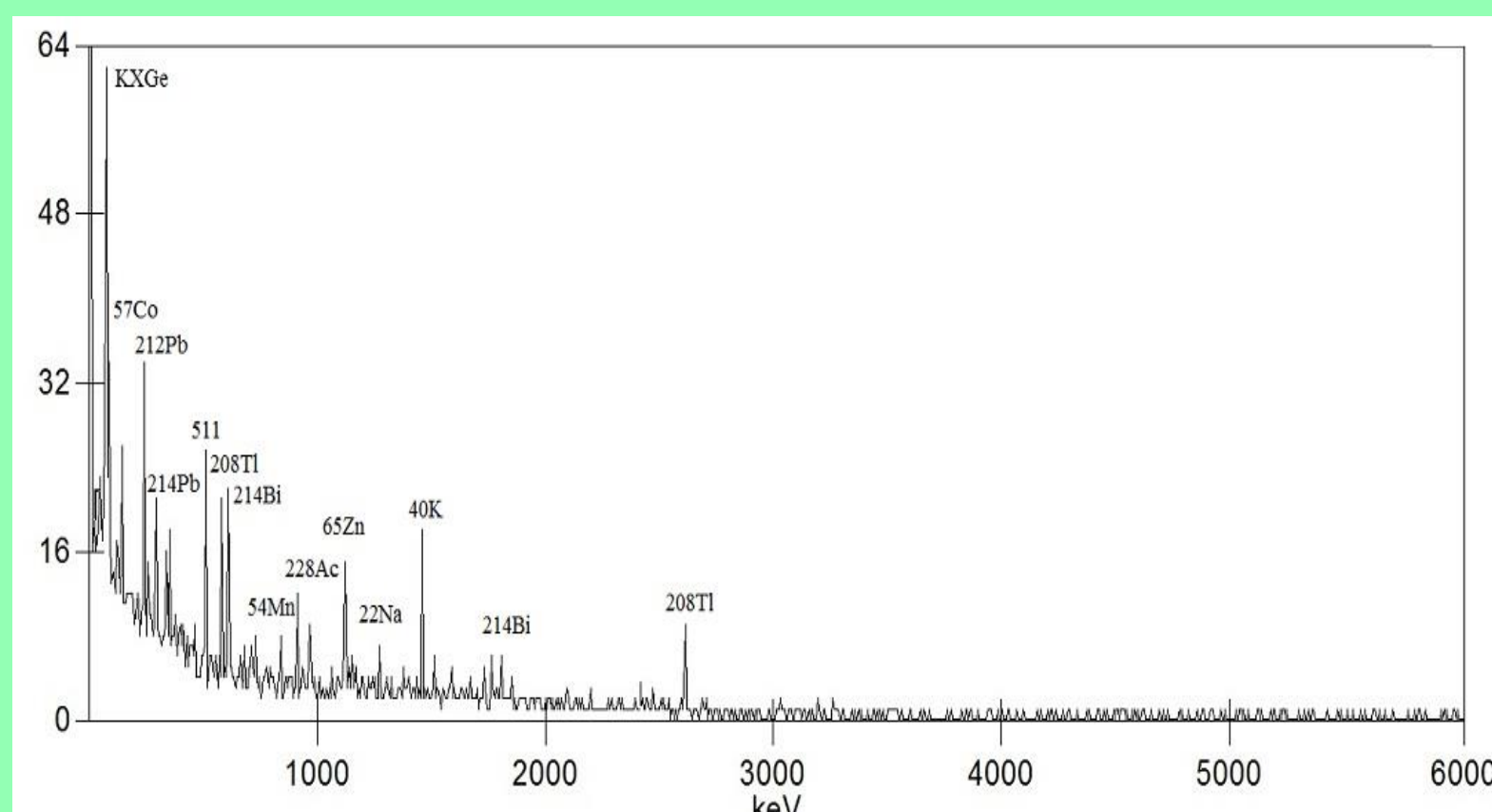
A low background HPGe spectrometer Obelix with sensitive volume of 600 cm³ was installed at the Modane Underground Laboratory (LSM, France, 4800 m w.e.), as a common activity of JINR Dubna, IEAP CTU in Prague and LSM. The detector was built as a multipurpose device, to search for double beta decay processes (0νEC/EC decay of ¹⁰⁶Cd in the frame of TGV experiment and 2ν2β⁻ decay of ¹⁰⁰Mo to the excited states of ¹⁰⁰Ru for NEMO-3 experiment), to measure contamination of enriched isotopes studied by the NEMO-3 experiment and radio-impurities in construction materials. Results of background measurement, efficiency of detector and contaminations in ¹⁰⁰Mo and ¹⁵⁰Nd samples are given. The preliminary results of 2ν2β⁻ decay of ¹⁰⁰Mo to the 0⁺ (1130 keV) and 2⁺ (540 keV) states are presented.

I. Experimental setup and background measurement



Sensitive volume: 600 cm³
Efficiency: 160%
Peak/Compton: 83
Energy resolution: ~1.2 keV at 122 keV (⁵⁷Co),
~2.0 keV at 1332 keV (⁶⁰Co)
Passive shielding: ~12 cm arch. Pb
~20 cm low active Pb
Distance from HPGe crystal to the end cap: 4mm
Entrance window: Al, 1.6 mm
Radon free air

General view of HPGe detector in lead shielding



Background spectrum for 40 days

| E (keV) | (Counts/h) |
|---------|-------------|
| 186 | 0.007±0.012 |
| 238 | 0.119±0.023 |
| 295 | 0.017±0.011 |
| 352 | 0.038±0.012 |
| 583 | 0.050±0.011 |
| 609 | 0.039±0.012 |
| 840 | 0.055±0.010 |
| 911 | 0.060±0.012 |
| 969 | 0.018±0.009 |
| 1124 | 0.157±0.018 |
| 1274 | 0.034±0.010 |
| 1460 | 0.050±0.012 |
| 1764 | 0.022±0.007 |
| 1809 | 0.018±0.007 |
| 2614 | 0.028±0.006 |

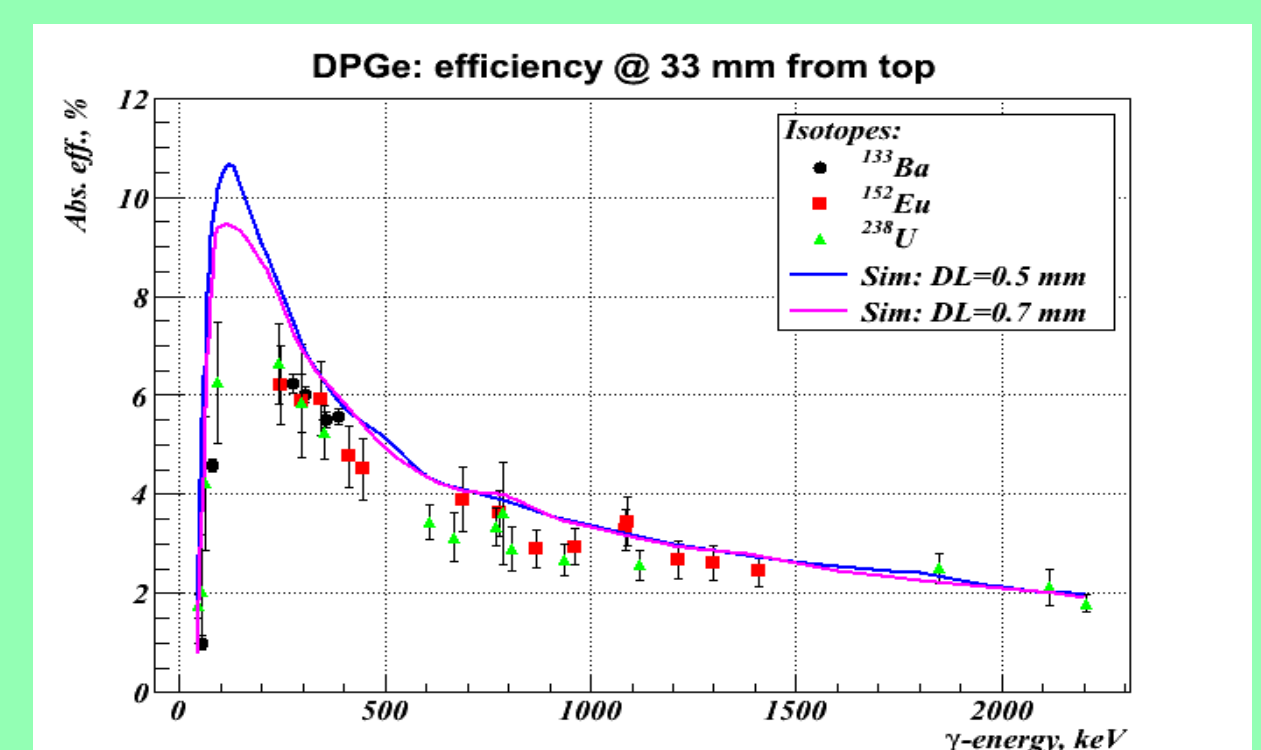
γ-lines identified in background

Detector Obelix is P-type coaxial HPGe detector produced by Canberra in U-type ultra low background cryostat located at LSM, France (4800 m w.e.). The background spectrum was measured for 40 days and important γ-lines are summarized in the table.

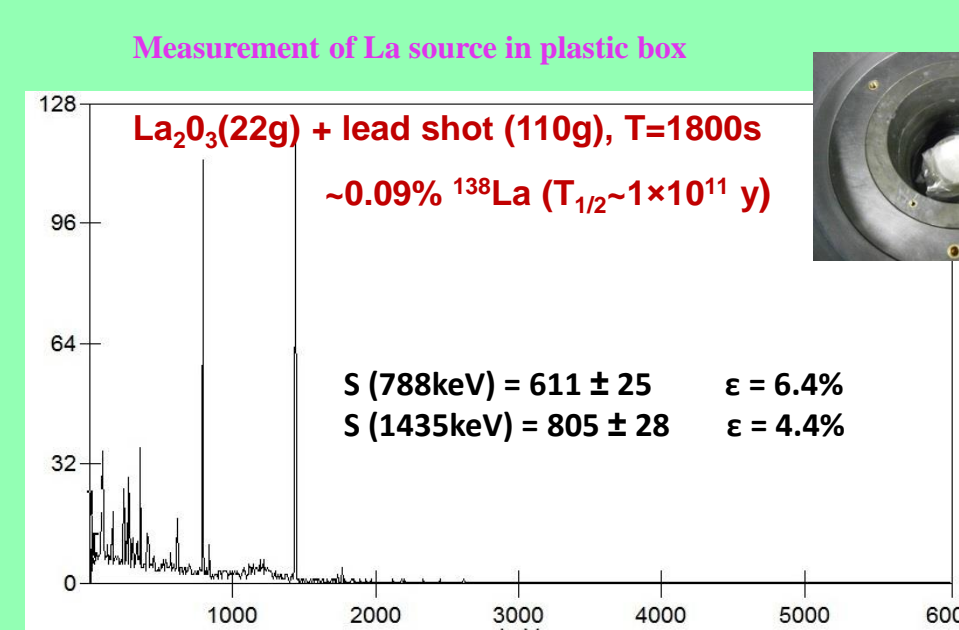
II. Efficiency of the detector



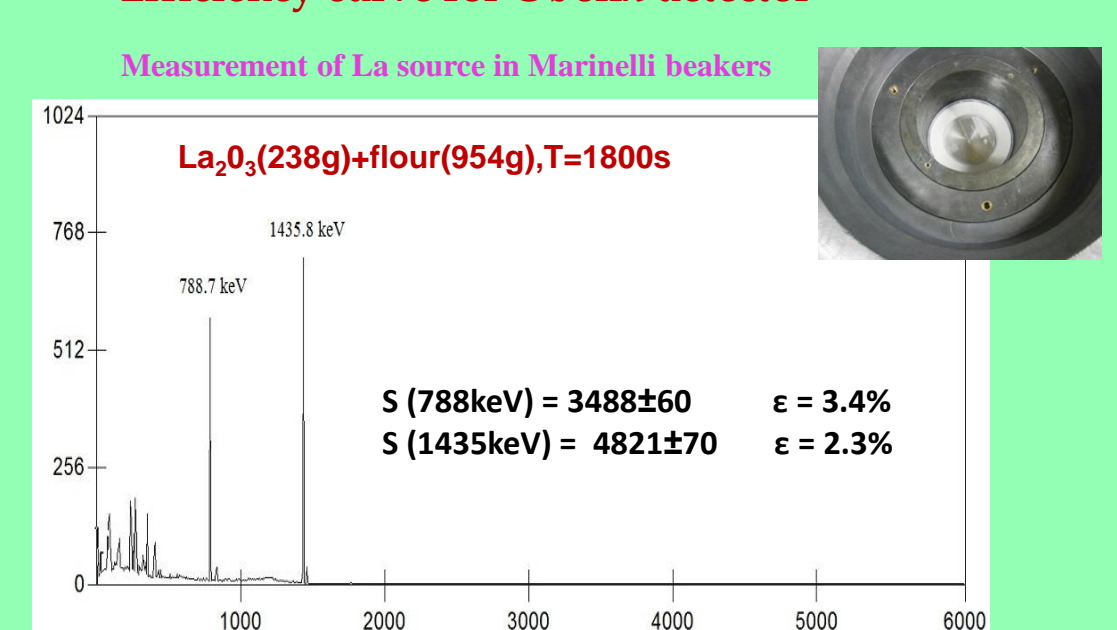
Experimental setup used for efficiency measurement



Efficiency curve for Obelix detector



Energy spectrum measured with La₂O₃ source (top arrangement)



Energy spectrum measured with La₂O₃ source (side arrangement)

To obtain the detector efficiency an original method using special low-active samples with known mass and activity was developed. The samples were produced from La₂O₃ mixed with different additives (e.g. flour, lead shot). The natural La contains ~0.09% of ¹³⁸La (T_{1/2}=1.02×10¹¹ years), which is characterized by emission of γ-rays with energies of 788.7 keV and 1435.8 keV. The samples in different geometries (mainly top and side arrangements) were investigated. Based on the results of measurements with La₂O₃ and standard sources of ¹⁵²Eu and ¹³³Ba, the total efficiency curve was obtained.

III. Radio-impurities in NEMO-3 samples

| Isotope | Energy (keV) | ¹⁰⁰ Mo | | ¹⁵⁰ Nd | |
|-------------------|--------------|-------------------|-------------------|-------------------|-------------------|
| | | Counts/h | Activity (mBq/kg) | Counts | Activity (mBq/kg) |
| ²¹⁴ Pb | 295 | 0.11 ± 0.03 | 4.15 ± 1.43 | ----- | ----- |
| ²¹⁴ Pb | 352 | 0.25 ± 0.0 | 3.2 ± 0.5 | 190 ± 36 | 71.8 ± 5.1 |
| ²⁰⁷ Bi | 570 | ----- | ----- | 395 ± 25 | 136 ± 9 |
| ²¹⁴ Bi | 609 | 0.235 ± 0.022 | 1.43 ± 0.15 | 112 ± 15 | 81 ± 18 |
| ²¹⁴ Bi | 1765 | 0.065 ± 0.02 | 1.1 ± 0.3 | ----- | ----- |
| ¹³⁷ Cs | 662 | 0.048 ± 0.015 | 0.16 ± 0.05 | 62 ± 12 | 18.8 ± 3.0 |
| ²²⁸ Ac | 911 | ----- | ----- | 48 ± 16 | 55.8 ± 17.2 |
| ²³⁴ Pa | 1001 | 0.041 ± 0.016 | 14.6 ± 4.7 | ----- | ----- |
| ²⁰⁷ Bi | 1064 | ----- | ----- | 207 ± 11 | 132 ± 14 |
| ¹⁵⁴ Eu | 1274 | ----- | ----- | 22 ± 5 | 21 ± 8 |
| ¹⁵² Eu | 1408 | ----- | ----- | 28 ± 7 | 54.4 ± 14.3 |
| ⁴⁰ K | 1461 | 0.6 ± 0.04 | 19.1 ± 1.3 | 123 ± 8 | 347 ± 62 |
| ²⁰⁸ Tl | 2615 | 0.05 ± 0.01 | 0.132 ± 0.041 | 20 ± 6 | 71.8 ± 9.7 |

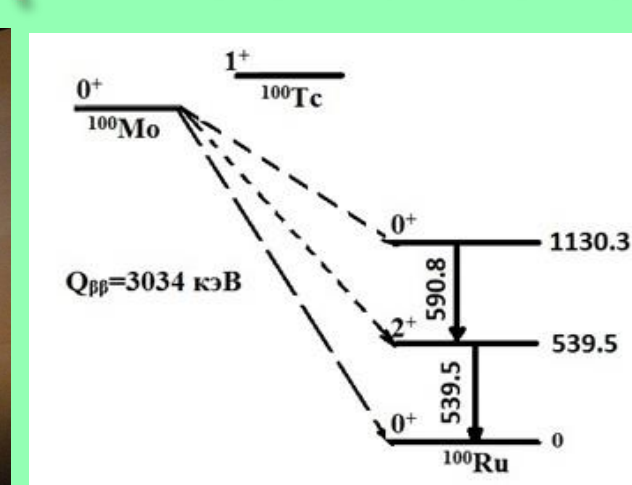
Contaminations in NEMO-3 samples (¹⁰⁰Mo and ¹⁵⁰Nd)

Experiment NEMO-3 was already stopped and all measured data are under final processing. The collaboration measured all the 2β decay isotopes before the beginning of experiment and during period of 2011-2012 (after the experiment was finished), Obelix detector was used to remeasure them. The results for foils made of ¹⁰⁰Mo and ¹⁵⁰Nd are presented. Total masses of ¹⁰⁰Mo and ¹⁵⁰Nd samples were 2517 g and 57.17 g, respectively.

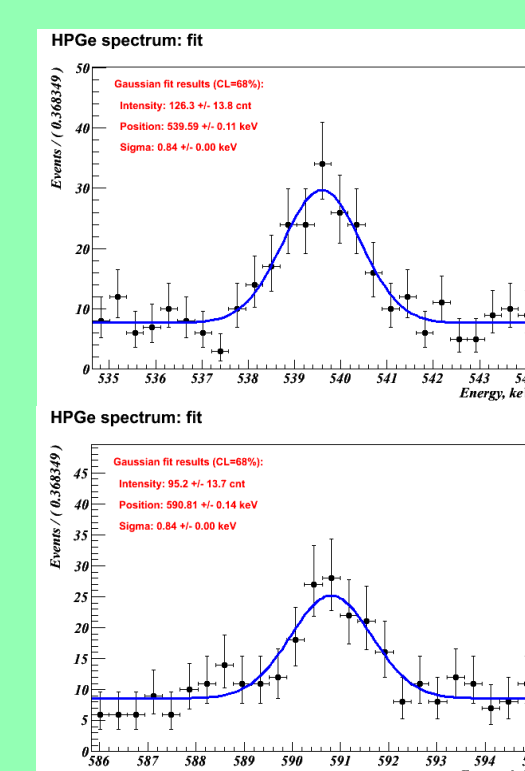
IV. Measurement of 2ν2β⁻ decay of ¹⁰⁰Mo (in collaboration with ITEP)



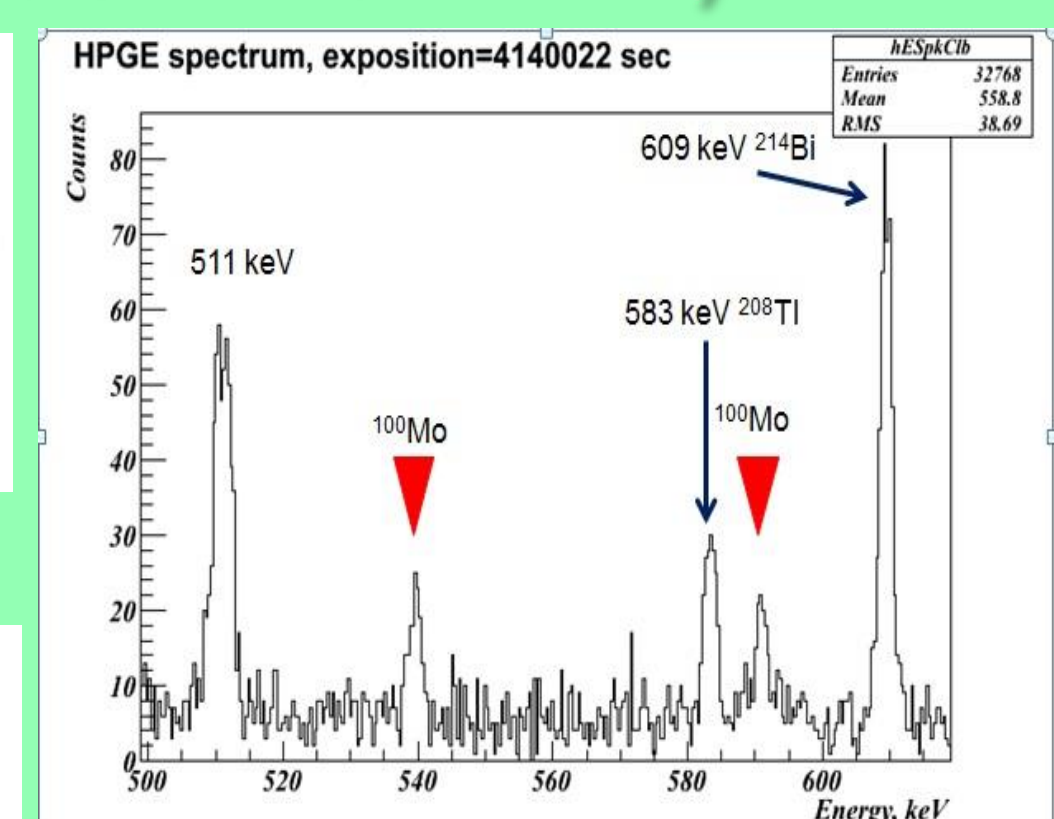
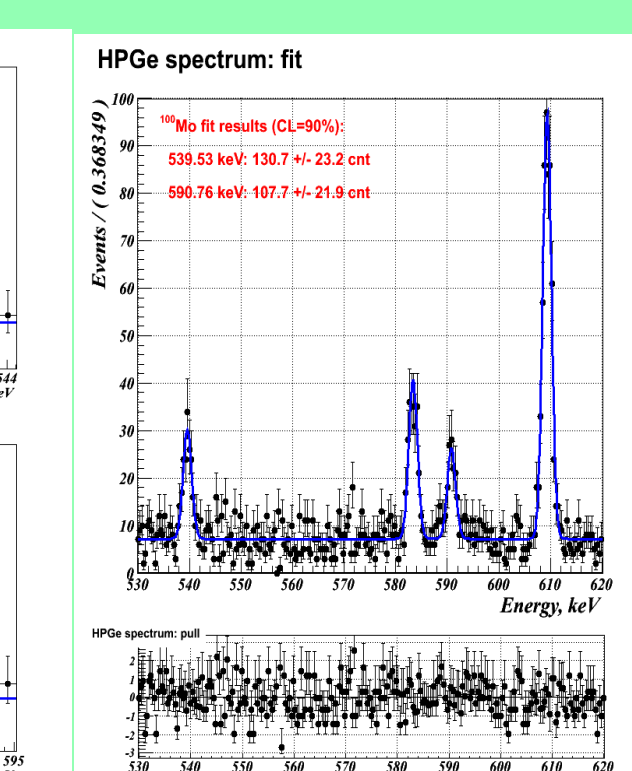
Geometry of ¹⁰⁰Mo sample foil



Decay scheme of ¹⁰⁰Mo



Fits of measured γ-lines (540 keV and 590 keV)



Measured spectrum with enriched ¹⁰⁰Mo

| Process | T _{1/2} [years] |
|--|--------------------------|
| 2ν2β ⁻ decay to 0 ₁ ⁺ (1130keV) | 7,5 × 10 ²⁰ |
| 2ν2β ⁻ decay to 2 ₁ ⁺ (540 keV) | >3 × 10 ²¹ |

Preliminary results of T_{1/2} for 2ν2β⁻ processes ¹⁰⁰Mo to the 0⁺ and 2⁺ excited states of ¹⁰⁰Ru.

Metallic foil of enriched ¹⁰⁰Mo with a mass of 2517 g was measured with the Obelix spectrometer for 2288 hours. From this measurement and using calibration curve presented above the half-lives of 2ν2β⁻ decay of ¹⁰⁰Mo to the 0⁺ and 2⁺ excited states of ¹⁰⁰Ru were obtained. The preliminary results are presented in the table.

Conclusion and future plans:

Obelix detector is very sensitive setup suitable for low background measurement. Using different calibration tests the efficiency curve for Obelix spectrometer was determined. The measurements with enriched samples of ¹⁰⁰Mo and ¹⁵⁰Nd were performed to define the internal radio impurities of the foils. Preliminary results for half-lives of 2ν2β⁻ decay of ¹⁰⁰Mo to the 0⁺(1130 keV) and 2⁺ (540 keV) excited states of ¹⁰⁰Ru were obtained as T_{1/2} = 7,5 × 10²⁰ years and T_{1/2} > 3 × 10²¹ years, respectively. The investigation of ββ decay using Obelix detector will continue with ¹⁰⁶Cd (0νEC/EC decay) and ¹⁵⁰Nd (longer time of measurement).