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Hands on STELLA: study on the ^{182}Ta radioactivity

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This experience at the Gran Sasso Summer Institute took place in the field of the ultra-low background radioactivity measurements. In particular, the activity was centered on the analysis of some γ-spectra of a Ta sample acquired in the STELLA (*SubTErranean Low Level Assay*) facility at Laboratori Nazionali del Gran Sasso (LNGS).
Thanks to the high resolution of the Germanium detector, these spectra allowed the identification of the main γ-lines of the ^{182}Ta decay scheme. Starting from their decay rate, it was then possible to estimate the isotope half-life.

This preliminary work takes place in the framework of a wide scientific programme to study long lived radionuclides interesting for astrophysical processes. In particular, the final aim will be trying to detect the (not yet observed) radioactivity of a rare metastable state: $^{180\mathrm{m}}$Ta.

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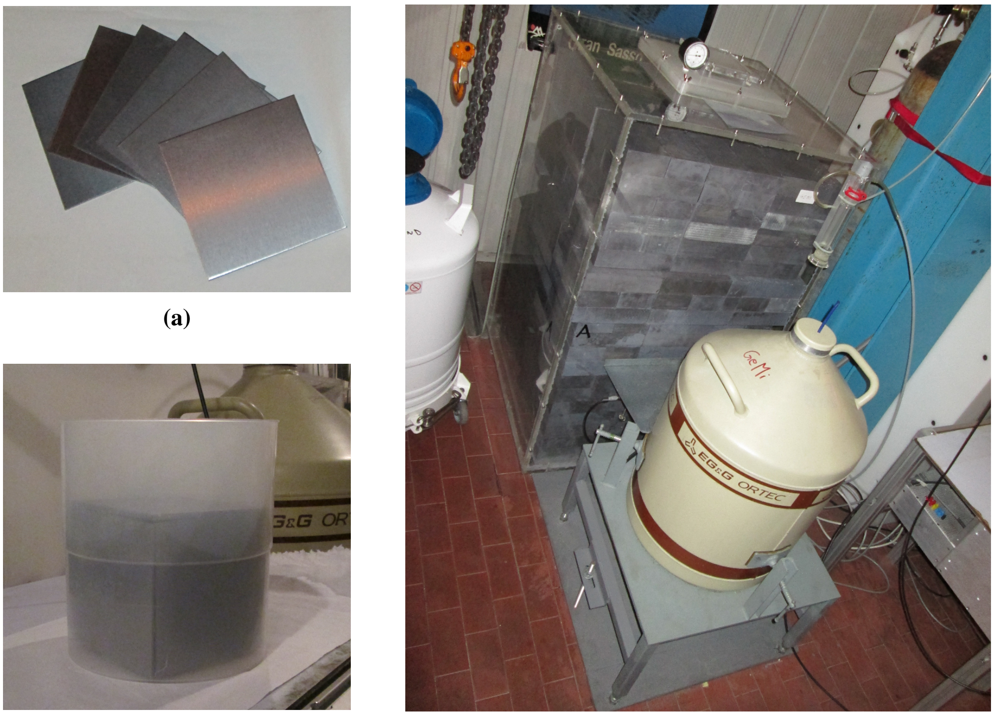

(a)

(b)

(c)

Figure 1: The analyzed Ta sample **(a)**, the Marinelli beaker **(b)** and the HPGe detector **(c)** used in the measurement in the STELLA facility.

1. Introduction

Tantalum (Ta) was discovered in 1802. However, it was only in 1954 that it was shown that this element was not monoisotopic, but, instead, it consisted of two isotopes: ^{181}Ta (99.98799(8)%, [2]) and ^{180}Ta (0.01201(8)%). Therefore, ^{180}Ta is the the rarest isotope of one among nature's rarest elements.

^{180}Ta presents a peculiarity: the ground state has a short half-life of only ~ 8.1 h but its metastable state is the known most long-lived metastable state. At present, the existing lower bound on the half-life of $^{180\mathrm{m}}$Ta is $2.0 \cdot 10^{16}$ yr [3]. Its decay has not been observed, yet.

Any new attempt to detect it requires the low background enviroment that can only be found in an underground laboratory, and an ultra-low background detector. This makes the STELLA facility [4, 5] at LNGS one of the most suitable places to succeed in this challenge, as both conditions are satisfied.

2. First measurement of a Ta sample in the STELLA facility

In 2009, a sample of Ta was brought underground in the STELLA facility. It consisted of 6 $(10 \times 10)\,\mathrm{cm}^2$ slabs, each of 1 mm thickness (Fig. 1). The total mass is of almost exactly 2 kg, corresponding to ~ 240 mg of $^{180\mathrm{m}}$Ta.

Due to the activation by the neutronic component of the cosmic radiation, a fraction of ^{181}Ta is always transmuted into ^{182}Ta. Therefore, an *intrinsic* background was added to the sample, making

Measurement	Start date	Live time [d]
Run I	2009-01-26	4.9
Run II	2009-04-03	41.5
Run III	2009-06-15	20.7

Table 1: Measurement campaign performed on the Ta sample in 2009.

it more difficult the observation of the characteristic peaks from the metastable state decay. At that time, a first measurement campaign to study the ^{182}Ta peaks was preformed. It consisted of three periods of data taking, the longest of which had an active live time of more than one month. The individual live times of the runs are listed in Tab. 1. A High Purity Germanium (HPGe) was used to detect the γ-lines from ^{182}Ta (Fig. 1).

The analysis of the acquired spectra, following an initial study of the literature about Ta and its physics, constituted the main activity of this Gran Sasso Summer Institute activity.

3. Analysis of experimental data

All spectra were calibrated in energy using as reference the γ-lines listed in Tab. 2.

The values of the γ-lines analysed in Run II are shown as an example; a linear fit was used, provided the almost linear response of the detector.

3.1 The study of ^{182}Ta half-life

In Fig. 2 an experimental spectrum is shown, with the main γ-lines of the ^{182}Ta decay (the reference energies of the peaks can be found in [6]).

The centroid energy of the peaks was obtained by taking the mean of the Gaussian distribution used for the interpolation of the number of counts. The deviation of our values from the ones found in the literature was always less than 0.5 keV. This corresponds to a difference between the two energies of $< 4‰$ for the peaks around $\sim$ 100 keV and of $< .4‰$ for the peaks above 1 MeV.

The number of net counts under each peak is estimated by subtracting the background contribution from the total area under the peak itself. To evaluate this, a linear interpolation of the count numbers around the peak was used. The daily rate can then simply be calculated dividing the net area by the measurement live time. The relative uncertainty is obtained through error propagation.

	^{234}Th	^{214}Bi	^{40}K	^{208}Tl
E [keV] (literature, [6])	92.38	609.32	1460.82	2614.51
E [keV] (Run II)	93.10	609.37	1460.82	2614.58

Table 2: Energy peaks selected for the spectrum calibration. The energies obtained for Run II after the calibration are compared to the ones reported in the literature.

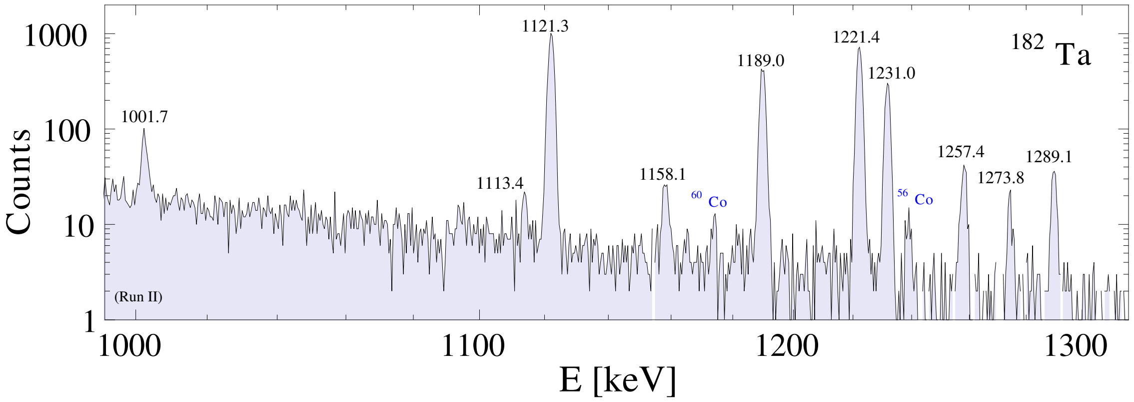

Figure 2: Zoomed region of the energy spectrum obtained during Run II. Many peaks from the ^{182}Ta radioactivity are evident [6].

The rate is expected to decrease according to an exponential decay, namely $\propto e^{t/t_{1/2}}$, where $t_{1/2}$ is the half-life time. Therefore, it was possible to estimate the value for this parameter by interpolating the data. The obtained results for the considered peaks and the relative uncertainties are shown in Tab. 3. From these, we obtained as the weighted mean for the half-life time:

$$t_{1/2} = (110.3 \pm 3.5)\,\mathrm{d}.$$

The present reference value that can be found in the literature is: (114.74 ± 0.12) d [7].

It can be seen that the two values are consistent within there uncertainties, despite the fact that a very simple analysis was performed.

4. Outlook and perspectives

The study, briefly performed during the GSSI 2014 period, can be seen as an initial step of a wider study on the search for the radioactive decay of $^{180\mathrm{m}}$Ta. First of all, the analysis on ^{182}Ta needs to be improved, e. g. better fits are to be performed and the γ-efficiencies have to be considered. Indeed, more than 15 ^{182}Ta half-lives have passed since the Ta sample was stored underground. The background contribution from this isotope is therefore negligible today. From the analysis of the new data, a further lower limit on the $^{180\mathrm{m}}$Ta half-life might be placed.

Acknowledgments

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References

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	Run I	Run II	Run III
1121.3 keV			
net counts	761 ± 43	4397 ± 102	1359 ± 57
rate [d^{-1}]	156.5 ± 8.8	106.0 ± 2.5	65.7 ± 2.8
half-life time [d]		110.3 ± 8.3	
1189.0 keV			
net counts	337 ± 28	1961 ± 69	618 ± 38
rate [d^{-1}]	69.3 ± 5.8	47.3 ± 1.7	29.9 ± 1.8
half-life time [d]		114 ± 13	
1221.4 keV			
net counts	582 ± 33	3252 ± 87	1007 ± 48
rate [d^{-1}]	119.7 ± 6.8	78.4 ± 2.1	48.7 ± 2.3
half-life time [d]		107.6 ± 8.6	
1231.0 keV			
net counts	211 ± 17	1321 ± 56	395 ± 30
rate [d^{-1}]	43.4 ± 3.5	31.8 ± 1.4	19.1 ± 1.5
half-life time [d]		117 ± 14	

Table 3: Number of counts and daily rates for the considered ^{182}Ta peaks in the different measurements. The isotope half-life is estimated for the individual cases.

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