Cleaning tests of the ESR foil

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Motivation

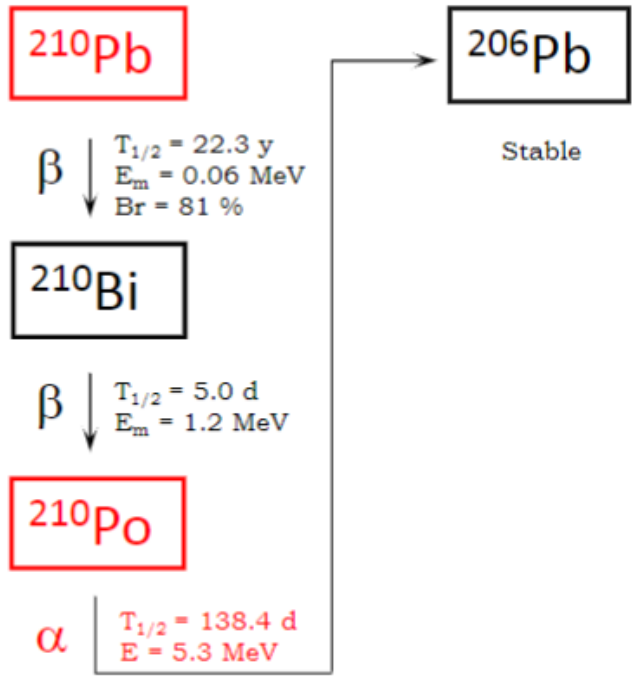
- DarkSide-20k requirements for the surface gross alpha emissivity of the ESR foil:

2.5 α/d/m² ⟶ **0.03 mBq/m²**

- Measured activity by the alpha spectrometer:

$$C_{sf} \leq 0.4 \text{ mBq/m}^2$$

- Cleaning method which allows to reduce the surface activity by a factor **10** is needed



- By applying a method which reduces the surface activity by a factor of **10** to a clean ESR foil the DS-20k requirement will be met

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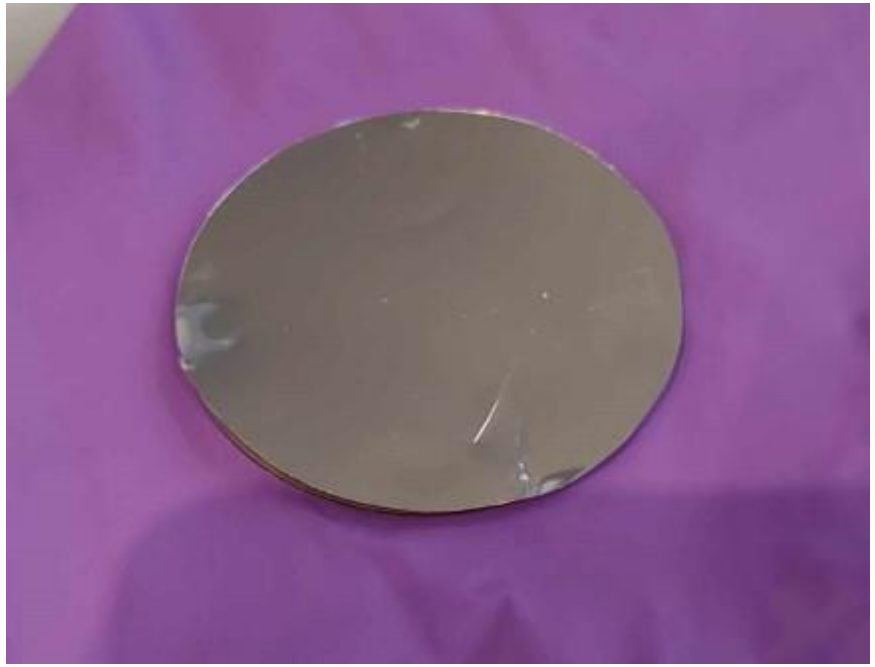
Cleaning tests of the ESR

- Six 50-mm diameter foil samples attached to copper/steel plates (for easier measurements in spectrometers)
- Samples kept for ~ 6 months in the strong (~30 kBq) ^{222}Rn source to increase the sensitivity to tested cleaning methods
- Tests of chemical and plasma cleaning methods
- Direct ^{210}Pb and ^{210}Po activity measurements of the artificially contaminated ESR foils by the gamma and alpha spectrometers, respectively
- 46.5 keV and 5.3 MeV peaks analyzed before and after cleaning



(Small) 50-mm diameter ESR foil

Results

- **Chemical cleaning** turned out to be ineffective in order to ^{210}Pb and ^{210}Po reduction:
  - reduction factors ~1 for ^{210}Pb and ^{210}Po
- **Atmospheric plasma** cleaning also is ineffective:
  - reduction factors ~1 for ^{210}Pb and ^{210}Po
- **Vacuum plasma** cleaning reduction factors:
  - **~5** for ^{210}Pb
  - **~10** for ^{210}Po
- Vacuum plasma cleaning is a promising method. Further tests are in progress.

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- More information #157:

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The DarkSide experiment has been designed to search for direct interactions of the cold dark matter particles with argon nuclei. Currently, the DarkSide-20k (DS-20k) detector is under construction in the Laboratori Nazionali del Gran Sasso in Italy. One of the material which is going to be used inside of the DS-20k time projection chamber (TPC) is the ESR foil. Due to its large surface applied (few hundred square meters) and close proximity to the active volume its surface must be extremely radiopure, mainly with respect to ^{210}Pb. The DS-20k requirements for the ^{210}Pb surface specific activity for the ESR foil is: C = 0.03 mBq/m^2 (2.5 α/d/m^2). The concentration measured by the most sensitive alpha spectrometer is ≤ 0.4 mBq/m^2. Due to this fact, a cleaning technique which reduces the ^{210}Pb activity by a factor of 10 is needed. By applying this method to the clean ESR foil, the DS-20k requirement will be met. To test different cleaning methods (cleaning by chemical solutions, plasma cleaning), the ESR samples were contaminated with ^{210}Pb/^{210}Po in a strong ^{222}Rn sources.

ESR foil

The ESR foil is a light highly reflecting material. This foil, covered with the wavelength shifter (TPB), will be used inside of the DS-20k time projection chamber in order to maximize the light detection.

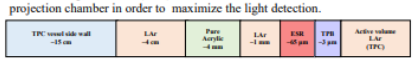

Fig. 1. Cross section of the TPC and inner veto including the ESR foil.

Fig. 2. The 43 × 43 cm^2 ESR foil measured by the alpha spectrometer.

The 43 × 43 cm^2 (big) ESR foil (see fig. 2) was investigated by the large-surface, low-background alpha spectrometer XIA UltraLo-1800 in order to establish its surface specific activity. Due to its thinness, the foil was attached to copper plate against curling up. The obtained ^{210}Po surface concentration is **≤ 0.4 mBq/m^2**. Taking into account the ^{210}Po half-life and manufacturing date of the foil, equilibrium between ^{210}Po and ^{210}Pb can be assumed. The established ^{210}Po surface concentration also applies to ^{210}Pb.

^{210}Pb (^{210}Po) measurements

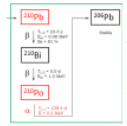

Fig. 4. Bottom part of the uranium decay chain.

The long-lived (22.3 y) ^{210}Pb decays, through the ^{210}Bi, to the alpha-emitter ^{210}Po (138.4 d). Alpha particles may produce neutrons in the (α, n) reactions. Interactions of neutrons with argon nuclei are indistinguishable from those originating from dark matter.

If the equilibrium between ^{210}Po and ^{210}Pb can't be assumed, the surface specific activity of the ^{210}Pb can be established by series of ^{210}Po measurements. The activity of ^{210}Po can **increase** ($A_{Pb} > A_{Po}$), **decrease** ($A_{Pb} < A_{Po}$) or remain **constant** ($A_{Po} = A_{Pb}$) and based on this analysis determination of ^{210}Pb concentration is possible (see fig. 5).

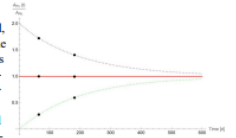

Fig. 5. Example of three scenarios of ^{210}Po activity change over time. Black dots symbolize measurements.

Cleaning procedures

In order to increase sensitivity to tested cleaning methods, big ESR foil sample was kept ~1 month in the strong ^{222}Rn source (~10 kBq/m^3) and then cleaning by different chemical solutions were tested. Alpha peak (5.3 MeV) was analyzed before and after cleaning.

Fig. 3. One of the investigated 50-mm diameter ESR foil attached to a copper plate.

Six 50-mm diameter ESR foil samples were attached to steel/copper plates and kept for ~6 months in the strong ^{222}Rn source (~30 kBq). After this, samples were measured by the semiconductor (Si) alpha- and coaxial (Ge) gamma- spectrometer in order to ^{210}Pb and ^{210}Po decay rates determination. Then tests of different cleaning methods (chemical and plasma cleanings) were performed.

Cleaning tests

Chemical cleaning

The following **chemical solutions** were tested with respect to ^{210}Po/^{210}Pb removal on the ESR foil samples (big and small):

- Isopropanol
- EDTA + 2% H_2O_2
- HCl (and HCl + isopropanol)
- HNO_3
- Citric acid (5%)
- EDTA (and EDTA + isopropanol)
- Acetic acid (20%)
- MeOH

For the big and small samples results for ^{210}Po removal are consistent (reduction factors < 2.0). The best reduction factors for the big ESR foil were obtain for the **HCl + isopropanol** (1.7 ± 0.1 for ^{210}Po) and for the small samples: **EDTA + 2% H_2O_2** (1.3 ± 0.1 and 1.2 ± 0.1 for ^{210}Po; 1.5 ± 0.2 and 1.4 ± 0.2 for ^{210}Pb). Further tests with EDTA + 2% H_2O_2 were performed for one more small sample, but results didn't meet DS-20k requirements. Sample was cleaned three times by this solution and total reduction factors were equal to 1.3 ± 0.1 for ^{210}Po and 1.8 ± 0.1 for ^{210}Pb.

Plasma cleaning

Small samples were processed applying **plasma cleaning** (under vacuum and argon/argon + helium atmosphere) at the INFN Legnaro (O. Azzolini). Even if the time between the determination of the activity and the cleaning is long, the half-life of ^{210}Pb makes it possible to compare the ^{210}Pb count rates directly. For ^{210}Po the situation is different and requires analysis of the potential ^{210}Po activity change. Expected activity prior cleaning has to be calculated taking into account Po decay and Po produced by Pb.

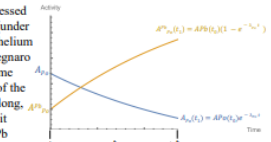

Fig. 6. ^{210}Po isotopes in t_0 decay (blue curve) and are pro-duced by the Pb (yellow curve). If t is comparable with $T^{Po}_{1/2}$ the Po activity in t_1 has to be predicted taking into account these two contributions.

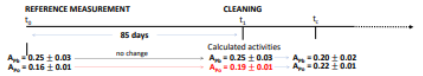

Fig. 7. Example of activity change for the small ESR foil sample before and after atmospheric plasma cleaning.

Tab. I. Results of plasma cleaning of the small ESR foils.

Sample	Cleaning method	Reduction factor ^{210}Po	Reduction factor ^{210}Pb
ESR 3	Vacuum plasma	7.8 ± 0.6	**4.8 ± 0.8**
ESR 6	Vacuum plasma	20.9 ± 1.9	**6.2 ± 0.8**
ESR 4	Atmospheric plasma (horizontal*)	0.9 ± 0.1	1.2 ± 0.2
ESR 4	Atmospheric plasma (vertical*)	1.0 ± 0.1	0.9 ± 0.2
ESR 4	Atmoshperic plasma (argon + helium**)	0.9 ± 0.1	1.1 ± 0.2

*sample configuration **process gas

Conclusions

Chemical cleaning and atmoshperic plasma cleaning turned out to be ineffective in ^{210}Pb removal (reduction factors are ~1 for ^{210}Pb and ^{210}Po). Vacuum plasma cleaning reduction factor is **~5** for ^{210}Pb and **~10** for ^{210}Po.

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Thank you