Low-background techniques in direct dark matter searches

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Outline

- Introduction
- Low Radioactivity Assay Techniques
- Selected results
- Summary

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Introduction

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- Detectors devoted to direct dark matter searches require ultra-low (zero) background
- Background sources: producing events, which can mimic the signal (e.g. radioactive decays, n, muons, detector-specific sources)
- Background reduction techniques:

✓ Graded shielding: traveling inward to the center, each component is more radio-pure and it is protected from external radiation by the preceding one

✓ Active (definition of FV, Čerenkov veto) and passive (buffer volume) suppression of external radiation

✓ Careful selection of construction materials and detector components with respect to content of radioactive isotopes, ^{222}Rn emanation and permeability

✓ Preventing surface contamination

✓ Application of appropriate purification (liquids, gases) and cleaning techniques

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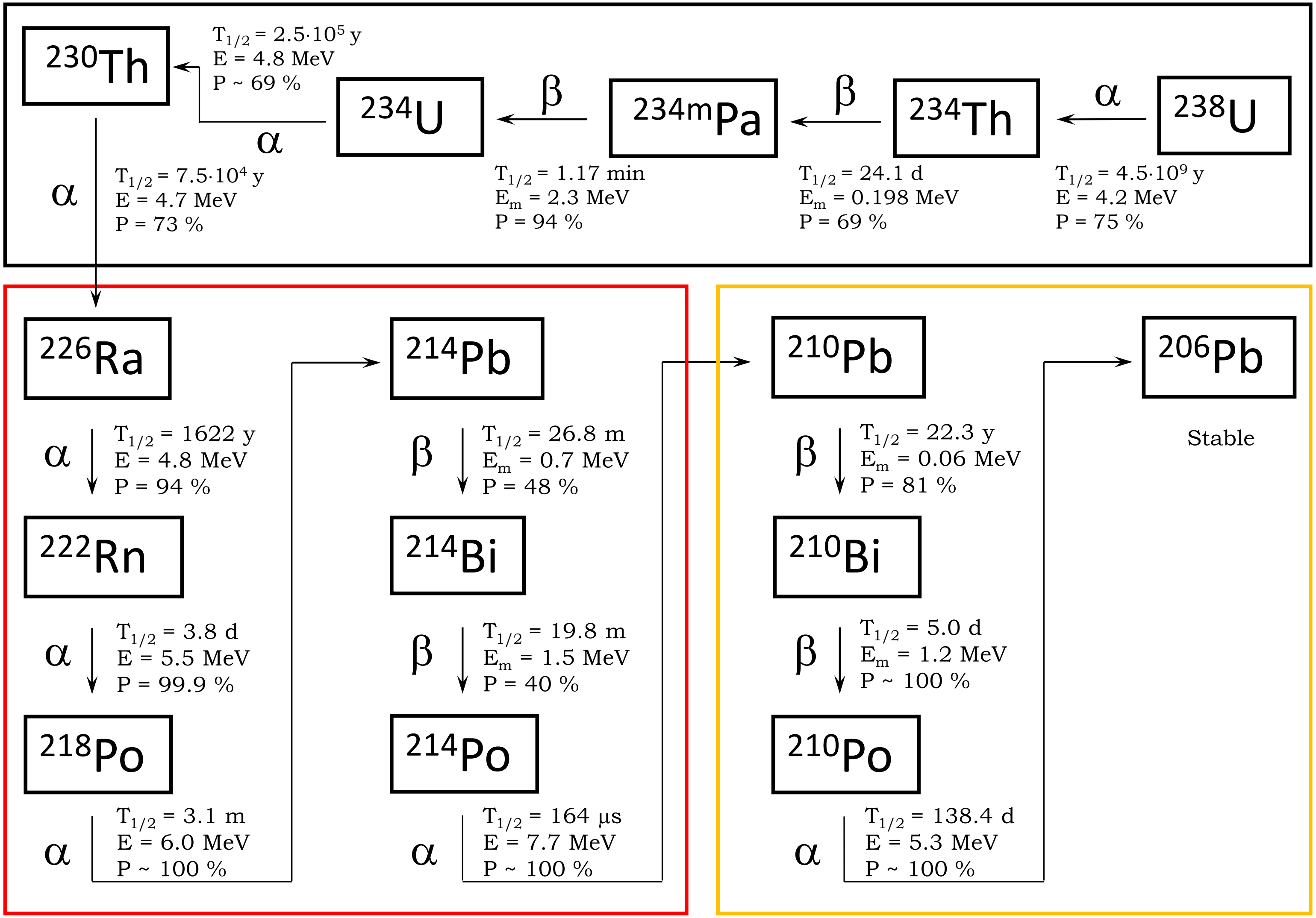
^{238}U decay chain



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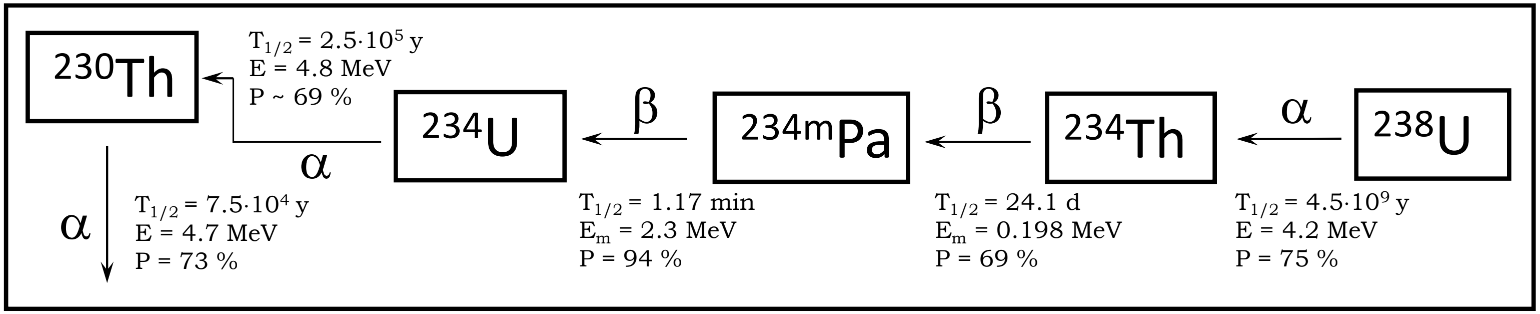
^{238}U decay chain



- Assay methods: ICP-MS / AMS / GDMS
- Inductively Coupled Plasma Mass Spectrometry supported by a proper sample preparation methodology allows for the analysis of various materials and specialty components important in ultralow background physics experiments
- Assay of materials, which can be put into liquid form (polymers, electronic components, wires/cables, metals, *etc.*)
- Extremely sensitive, fast (couple of days for a measurement), requires small amounts of sample (< 1 g)
- Commercially available instruments can reach < 0.01 ppt sensitivity for U/Th (< 0.1 μBq/kg)

NIM A 775 (2015) 93

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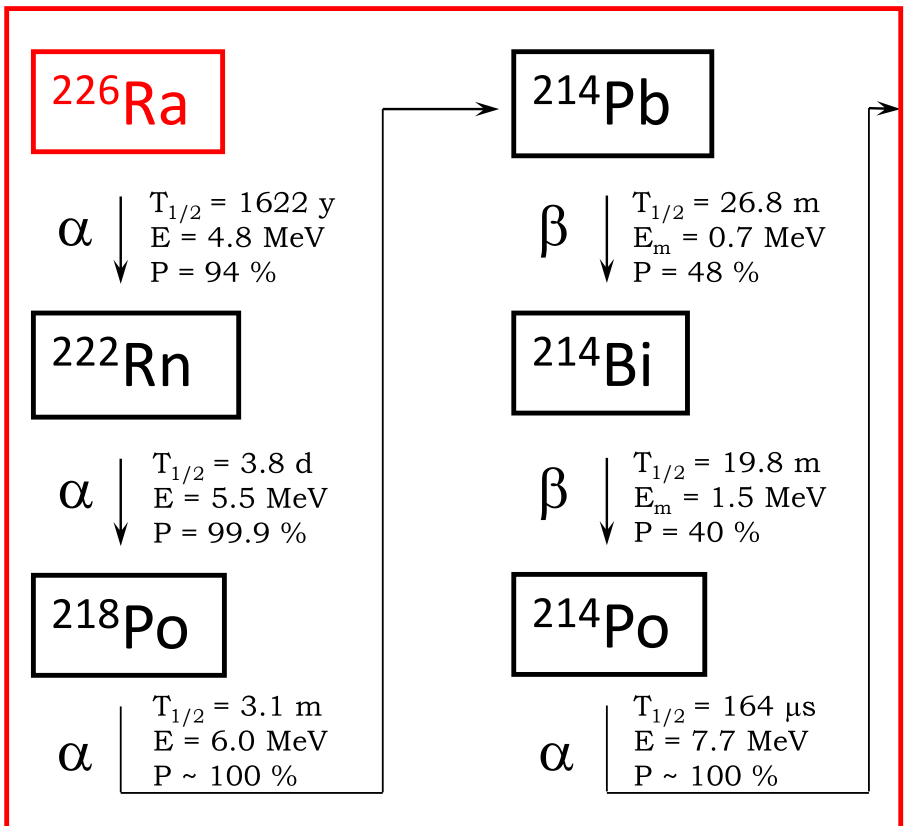
^{238}U decay chain

Gamma-ray spectroscopy: GeMPIs (MPIK-HD)

- Sensitivity: ~10 µBq/kg (~1 ppt U equiv.)

Appl. Rad. Isot. 53 (2000) 191
Astrop. Phys. 18 (2002) 1



High sensitivity Rn emanation

- Chambers coupled to the cryogenic Rn detector
- Integrated automatic pumping system
- Integrated automatic heating system (emanation tests up to 150 °C possible)
- Simultaneous real-time detection of emanated ^{220}Rn and ^{222}Rn
- Detection limit of ~10 µBq

Appl. Rad. Isot. 53 (2000) 371
IJMP A 32 (2017) 1743004

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^{238}U decay chain

Radio-chemical method

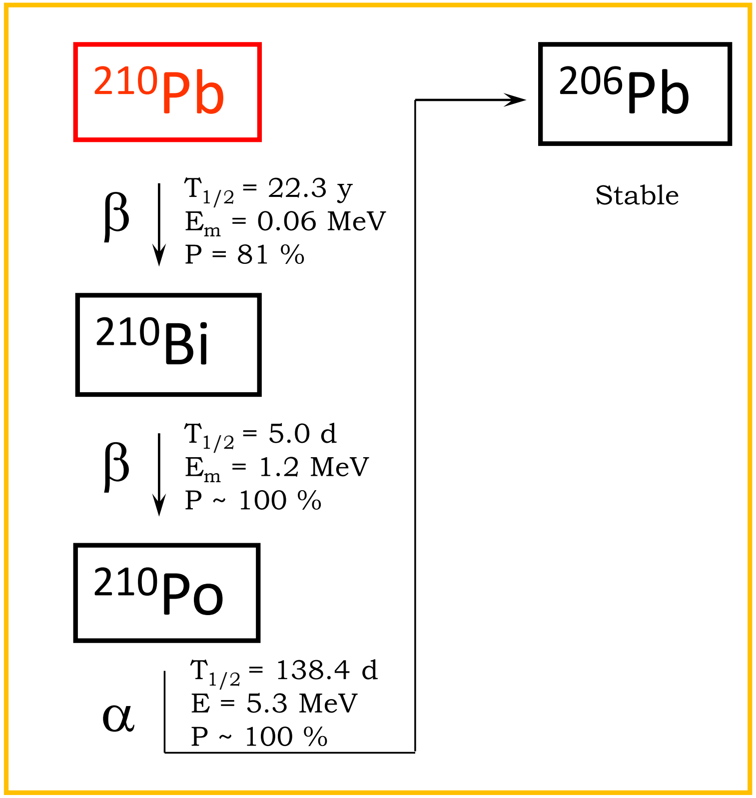
- Dissolution of a sample in acid
- Deposition of ^{210}Po on a (silver) disc
- Counting with an ultra-low background alpha spectrometer
- Sensitivity: ~1 mBq/kg (bulk + surface)

Direct counting of ^{210}Po

- Large surface low background alpha spectrometer
- Assay of bulk and surface contamination
- Sensitivity: ~50 mBq/kg (bulk)
  ~1 mBq/m^2 (surface)

A series of measurements of ^{210}Po in time for the same sample provides information about ^{210}Pb

Appl. Rad. Isot. 126 (2017) 165



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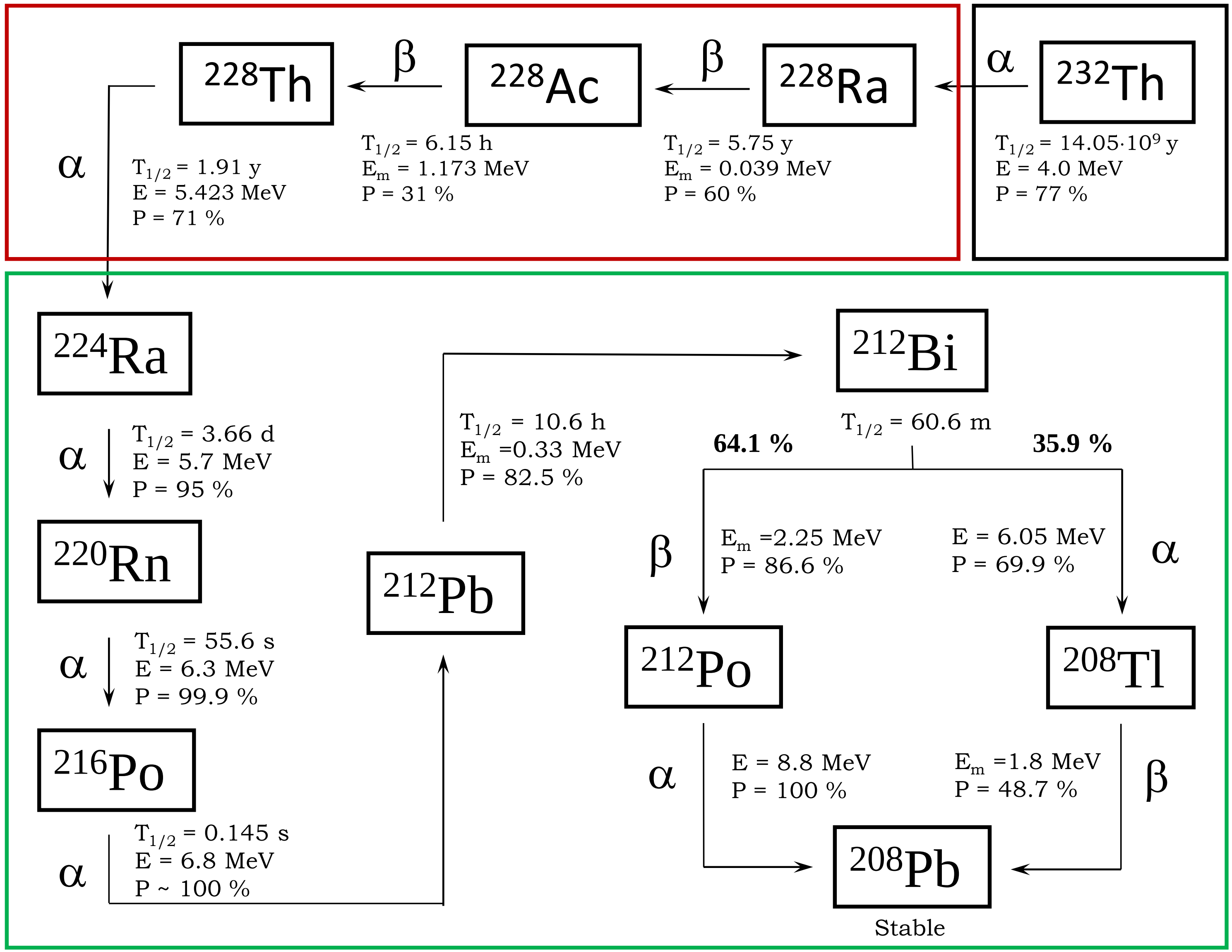
^{232}Th decay chain

Introduction
Assay methods
Selected results
Summary



Examples of dis-equilibrium

Introduction

Assay methods

Selected results

Summary

^{238}U chain: BX nylon / steel for the GD cryostat

Sample	^{226}Ra / ^{238}U equiv.	^{238}U
Capron B73ZP foil	220 μBq/kg / 18 ppt	~1 ppt
Sniamid foil	16 μBq/kg / 1.3 ppt	~10 ppt
Acroni/Slovenia, G5	(1.0 ± 0.6) mBq/kg	(54 ± 16) mBq/kg

NIM A 498 (2003) 240

NIM A 593 (2008) 448

^{232}Th chain: steel for the GD cryostat

Sample	^{228}Ra [mBq/kg]	^{228}Th [mBq/kg]
Acroni/Slovenia, G4	< 3	5.1 ± 0.5
Acroni/Slovenia, G7	1.9 ± 1.0	5.2 ± 0.5

Gamma-ray spectroscopy

NIM A 593 (2008) 448

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Rn emanation studies

Introduction

Assay methods

Selected results

Summary

Sample	^{222}Rn	^{220}Rn
PMT Cu window	< 90 µBq/piece	< 80 µBq/piece
TPB coated PMT Cu window	(140 ± 70) µBq/piece	< 80 µBq/piece
PMT R11410_10	< 80 µBq/piece	(330 ± 140) µBq/piece
Kapton-Cu cable	(37 ± 13) µBq/m	(38 ± 16) µBq/m
Feedthroughs	< 30 µBq/piece	< 40 µBq/piece
DS-50 cryostat	(140 ± 40) µBq	--
DS-50 TPC	(1350 ± 400) µBq	--
HP Ti sponge	< 0.15 mBq/kg	< 0.10 mBq/kg
SAES Getter pellets	(2.7 ± 0.7) mBq/kg	(3.2 ± 0.8) mBq/kg

All measurements performed at room temperature

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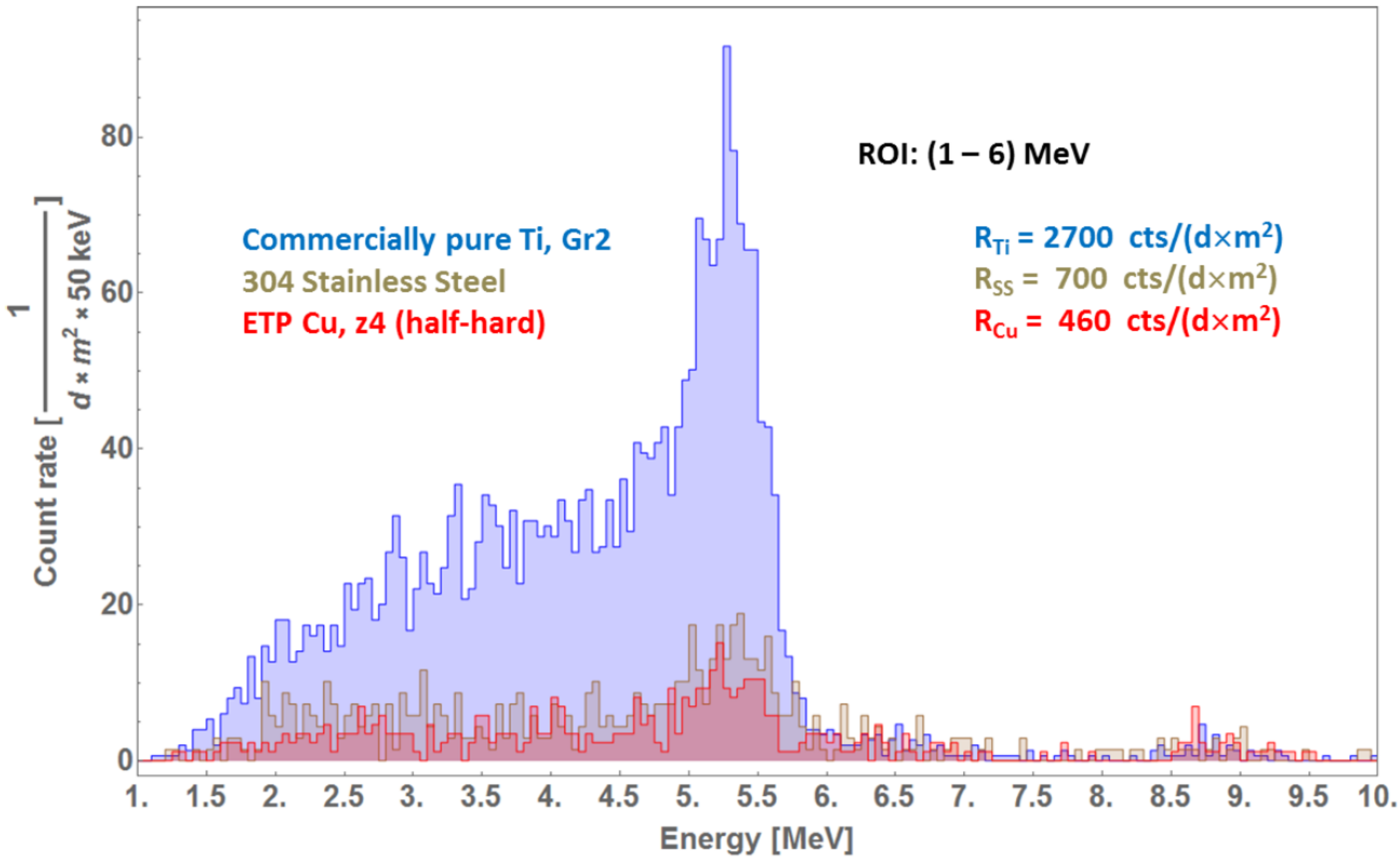
Assay of ^{210}Pb-^{210}Po sub-chain

- Only ^{210}Po studied
- Low background, large surface alpha spectrometer
- Sample size: 43×43 cm
- Possibility to determine bulk and surface contamination

Assay of ^{210}Pb-^{210}Po sub-chain



Assay of commercial Ti

Introduction

Assay methods

Selected results

Summary

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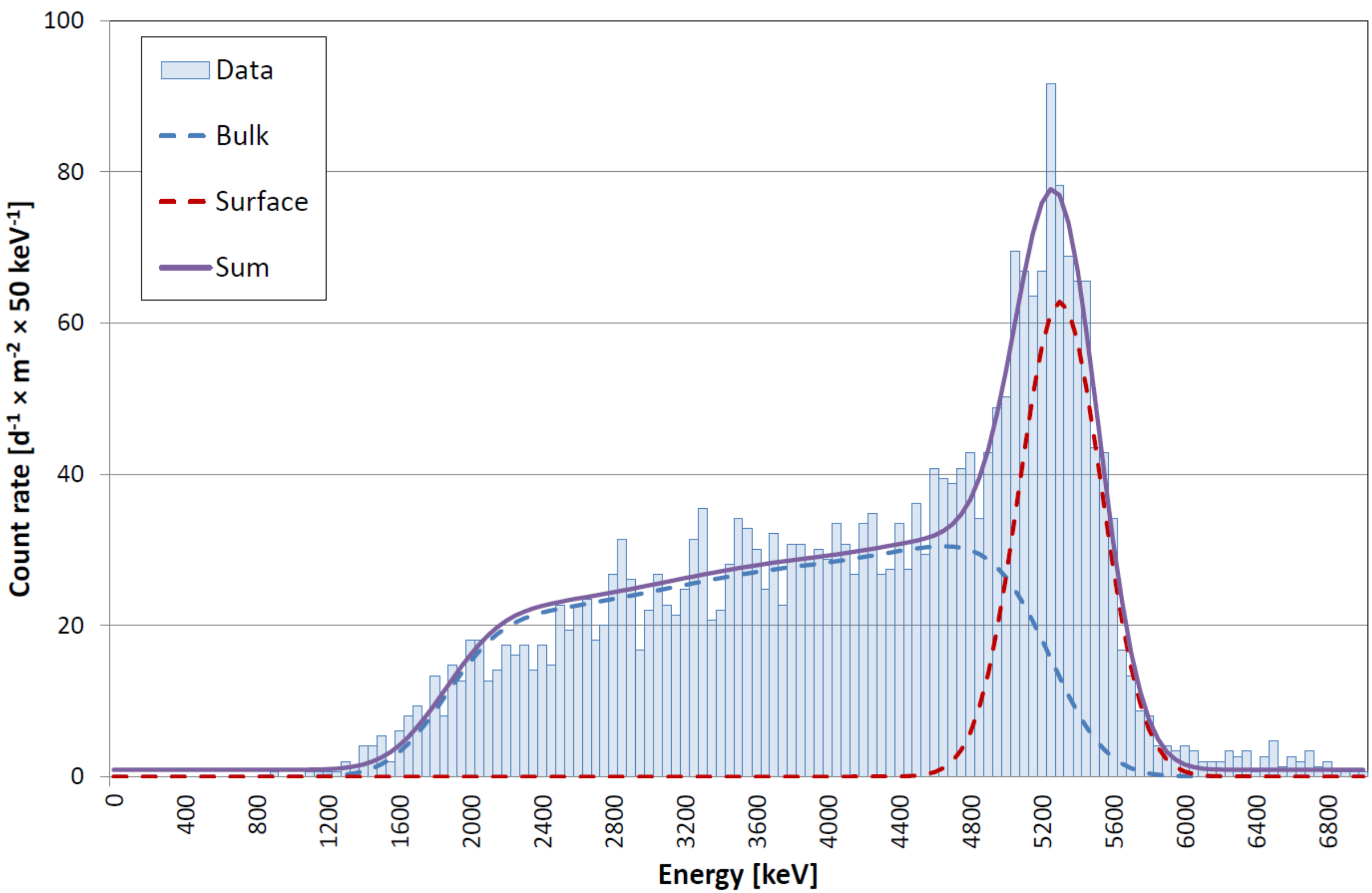
Spectrum of commercial high purity Ti (Gr2) sample



^{210}Po in various samples

Introduction

Assay methods

Selected results

Summary

Material	Bulk ^{210}Po [mBq/kg]	Surface ^{210}Po [mBq/kg]	Remarks
OF Copper	54	≤ 3	z4 (half hard)
ETP Copper	75	≤ 3	z4 (half hard)
„Old” ETP Copper	280	170	z4 (half hard)
Stainless Steel	80	≤ 3	Type 304
Titanium	1500	68	GR2
Teflon	$\leq$ 46	–	High purity, ATP

Appl. Rad. Isot. 126 (2017) 165

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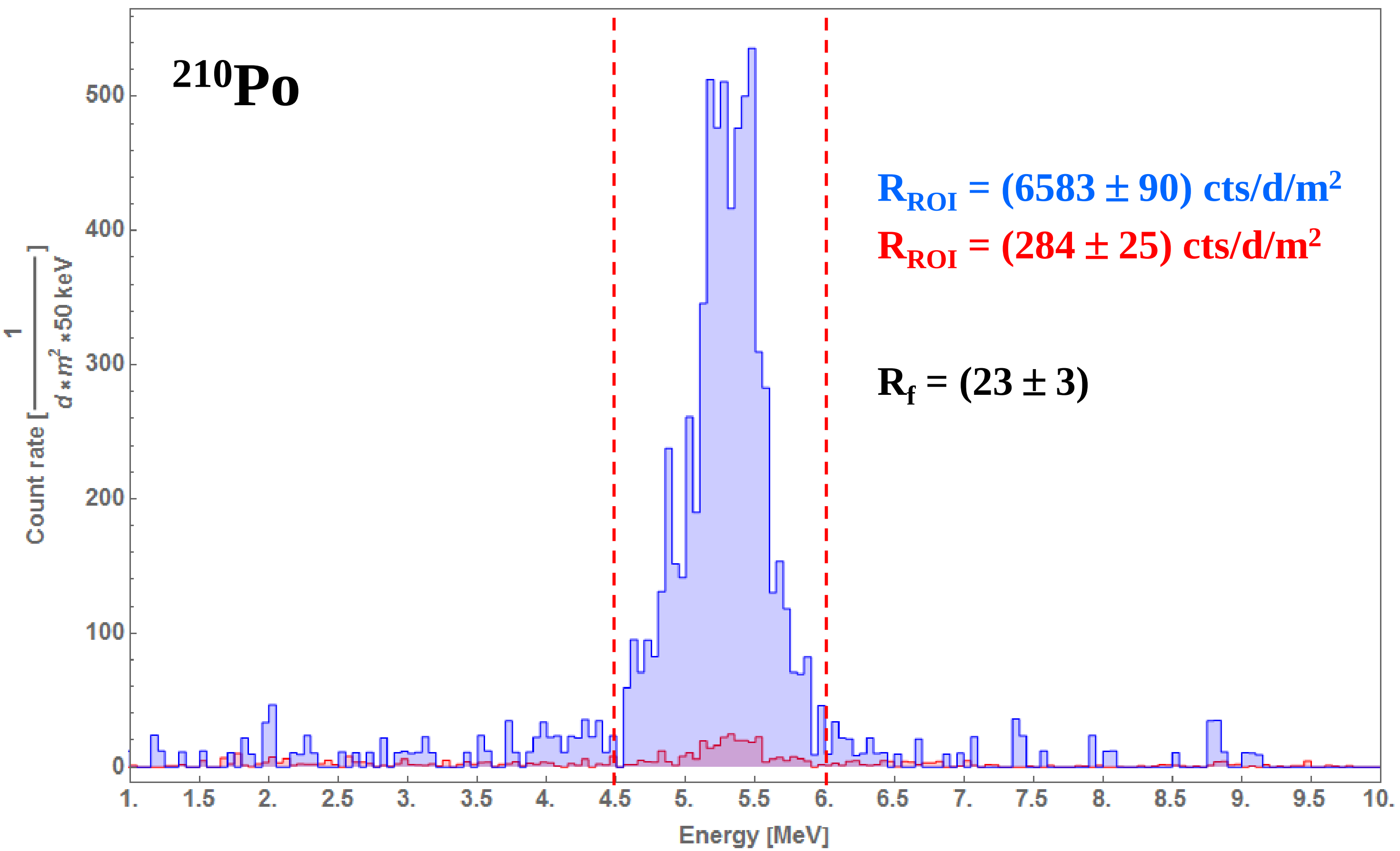
Electro-polishing of copper



- Polishing mixture: 95% H_3PO_4 + 1% 1-butanol
- Polishing conditions: 2.5 A/dm^2, 3 V, 20 min, distance between plates: 2 cm, room temperature

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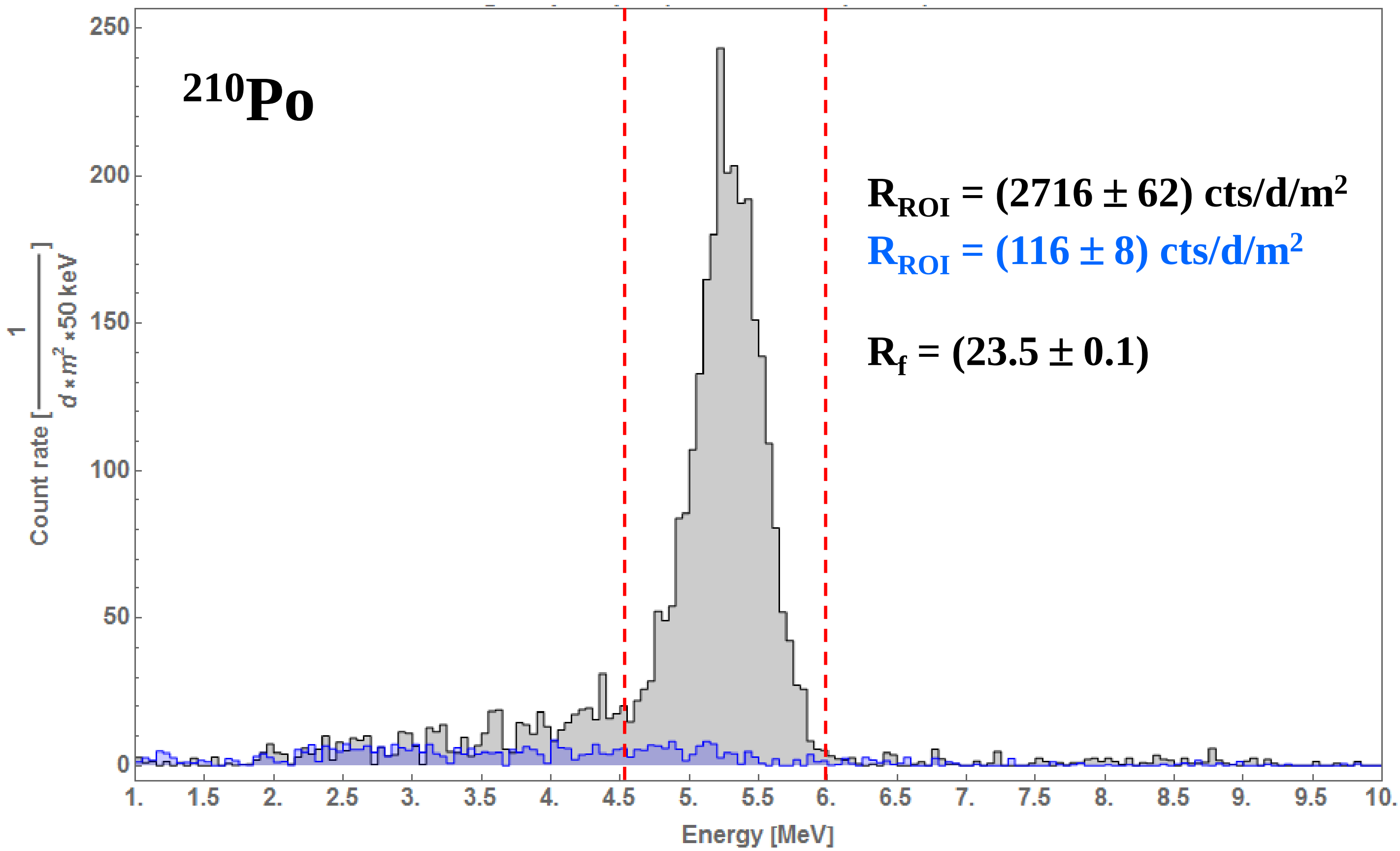
Electro-polishing of stainless steel

SS 1.4301 (304): sheet No. 2, 43 cm x 43 cm x 0.1 cm,



- Polishing mixture: 1:1 of 95% H_2SO_4 and 85% H_3PO_4
- Washing: 5 min in 15% HNO_3 and later in HP water
- Polishing conditions: 2.5 A/dm^2, 2 V, 25 min, distance between plates: 2 cm, T ~ 50 ^{o}C

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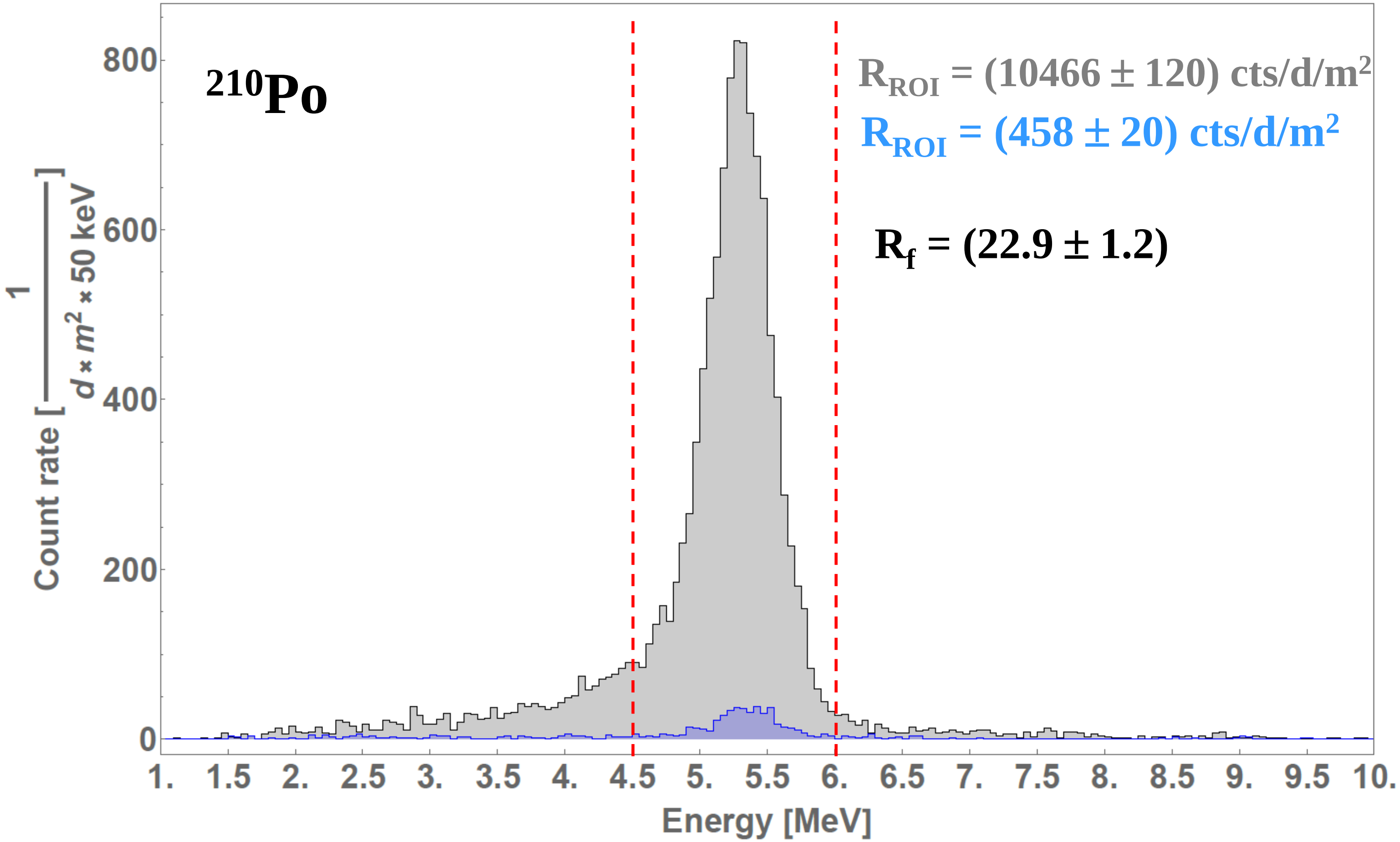
Etching of copper

„Dynamic" etching, 3 single runs



- Etching procedure: 3 x 1 min wash with a mixture of 1% H_2SO_4 + 3% H_2O_2
- Passivation with 1% citric acid at the end
- Washing in high-purity deionized water (18 MΩ×cm)

Etching of copper

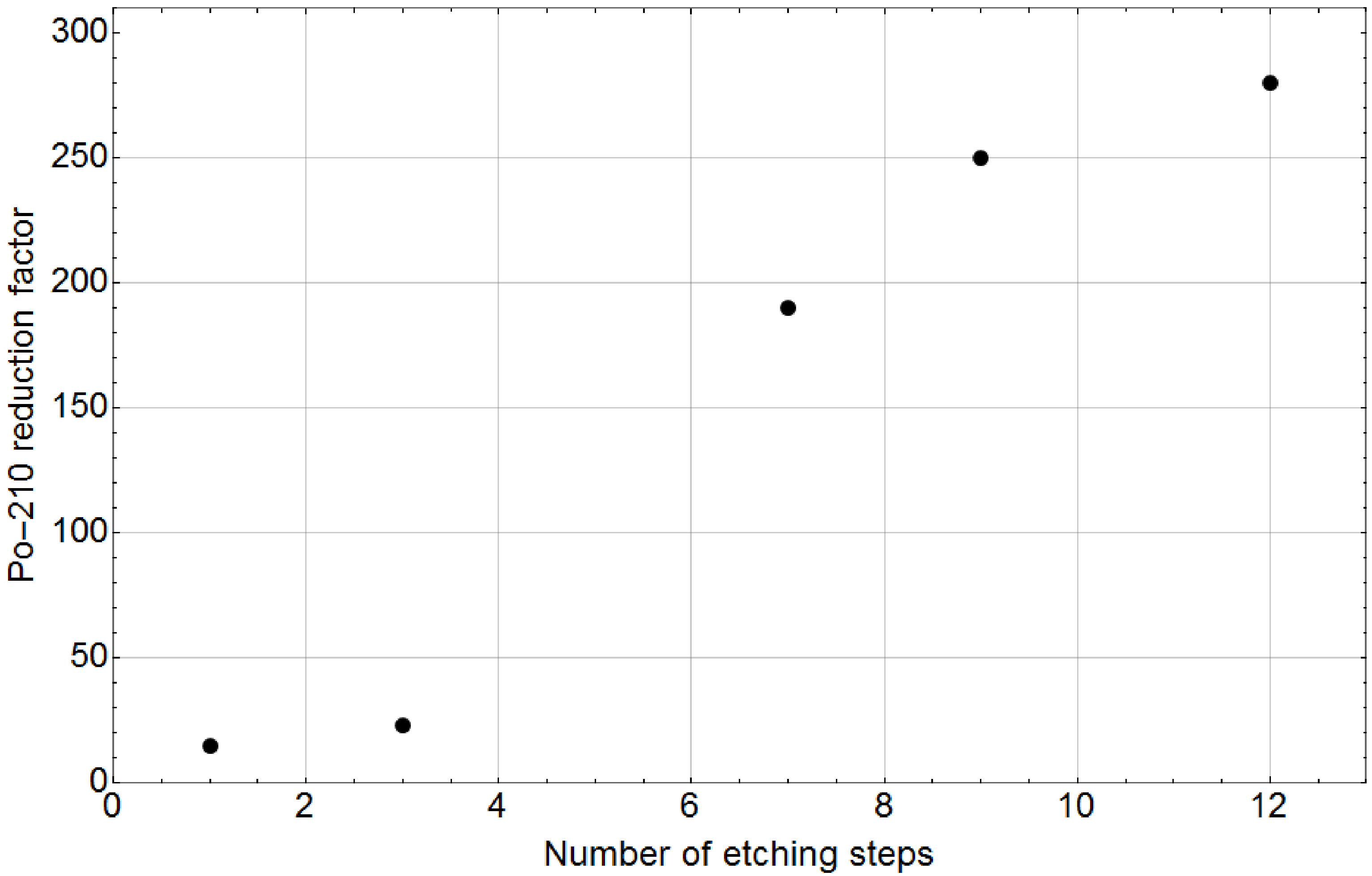
Introduction

Assay methods

Selected results

Summary

Multiple etching



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DarkSide ^{222}Rn-free clean rooms

Avoiding deposition of long-lived ^{222}Rn daughters

- Class 10 - 100
- Radon daughters plating out on surfaces of the detector may cause dangerous alpha-induced nuclear recoils
- Dedicated scrubbing system reducing ^{222}Rn concentration in the air down to ~1 mBq/m^3 has been implemented
- DarkSide clean rooms are supplied with the ^{222}Rn-free air
- ^{222}Rn content in the clean rooms is monitored online by a dedicated detector

Typical radon in hall C air ~50 Bq/m^3

Cleanroom radon levels 5 – 50 mBq/m^3

DARKSIDE ^{222}Rn-free clean rooms

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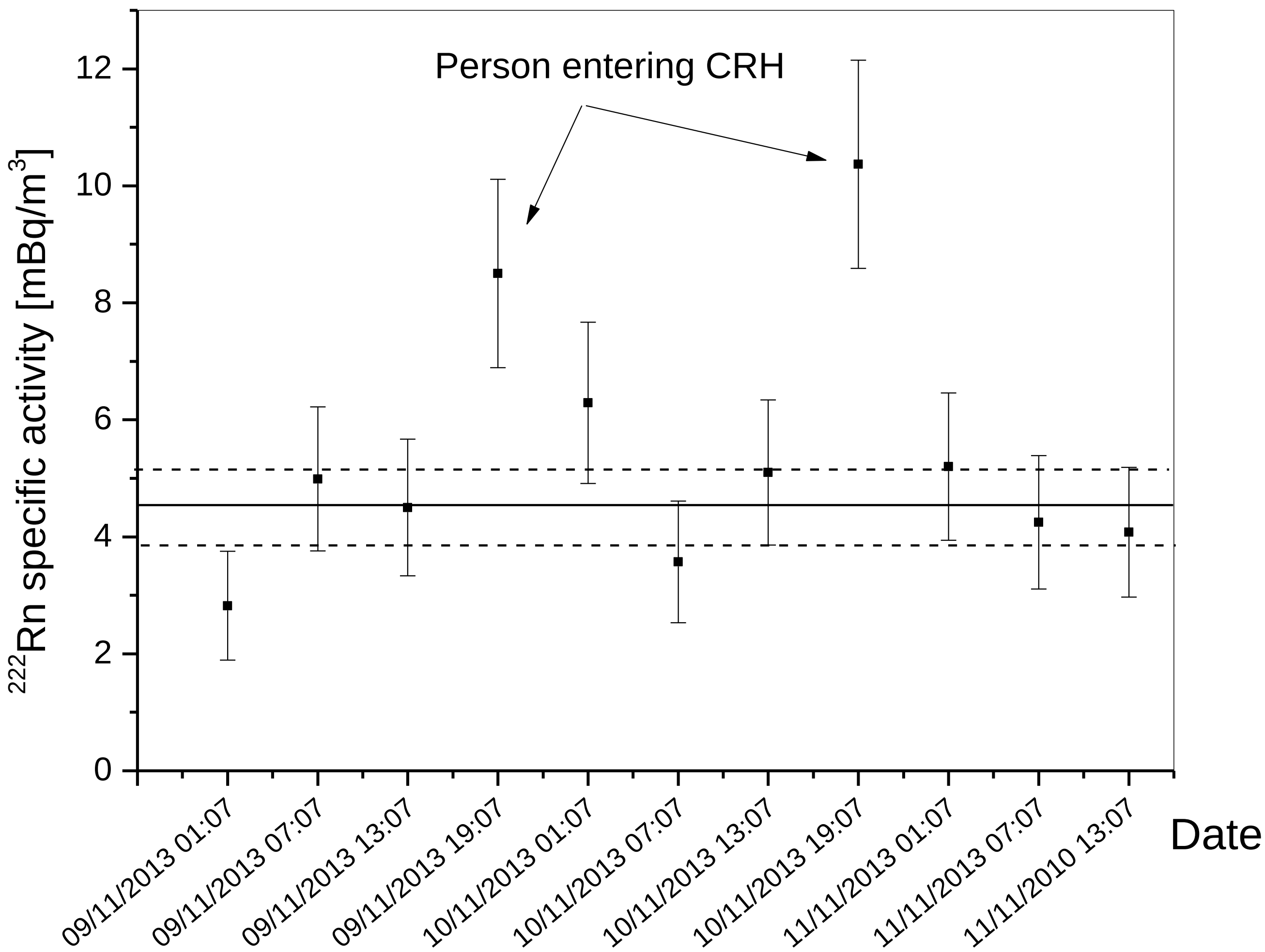

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- Ultra-low (ultimately zero) background is required in direct dark matter searches
- Proper estimation of background from various sources (e.g. n from α-n reactions) requires assay of all U/Th sub-chains
- MS techniques for the assay of the long-lived U/Th isotopes sensitive down to 0.01 ppt (0.1 μBq/kg)
- γ-ray spectrometers for determination of Ra isotopes sensitive down to 10 μBq/kg (10 ppt equiv.). Better sensitivity may be achieved in some cases by performing Rn emanation studies
- Presently, the bottom part of the ^{238}U chain is accessible only at some tens of mBq/kg (~1 ppb equiv.)
- Determination of Ra and ^{210}Pb at lower specific activities needed (e.g. ^{210}Pb in PTFE down to at least 1 mBq/kg) $\rightarrow$ new developments

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