Characterization and application of the XIA UltraLo-1800 for ultra-low alpha measurements

Milena Czubak

JAGIELLONIAN UNIVERSITY IN CRACOW

Doctoral School of Exact and Natural Sciences
Jagiellonian University

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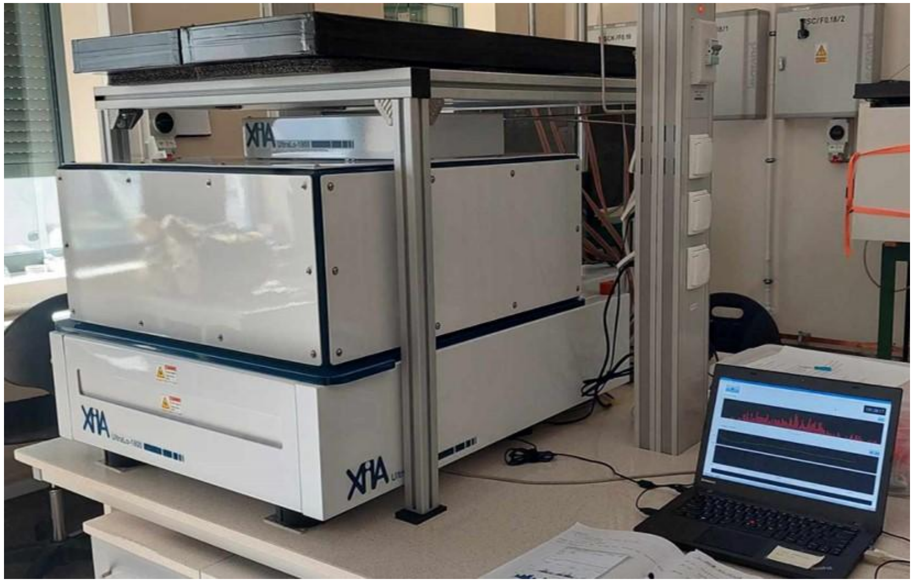
Overview of the XIA UltraLo-1800

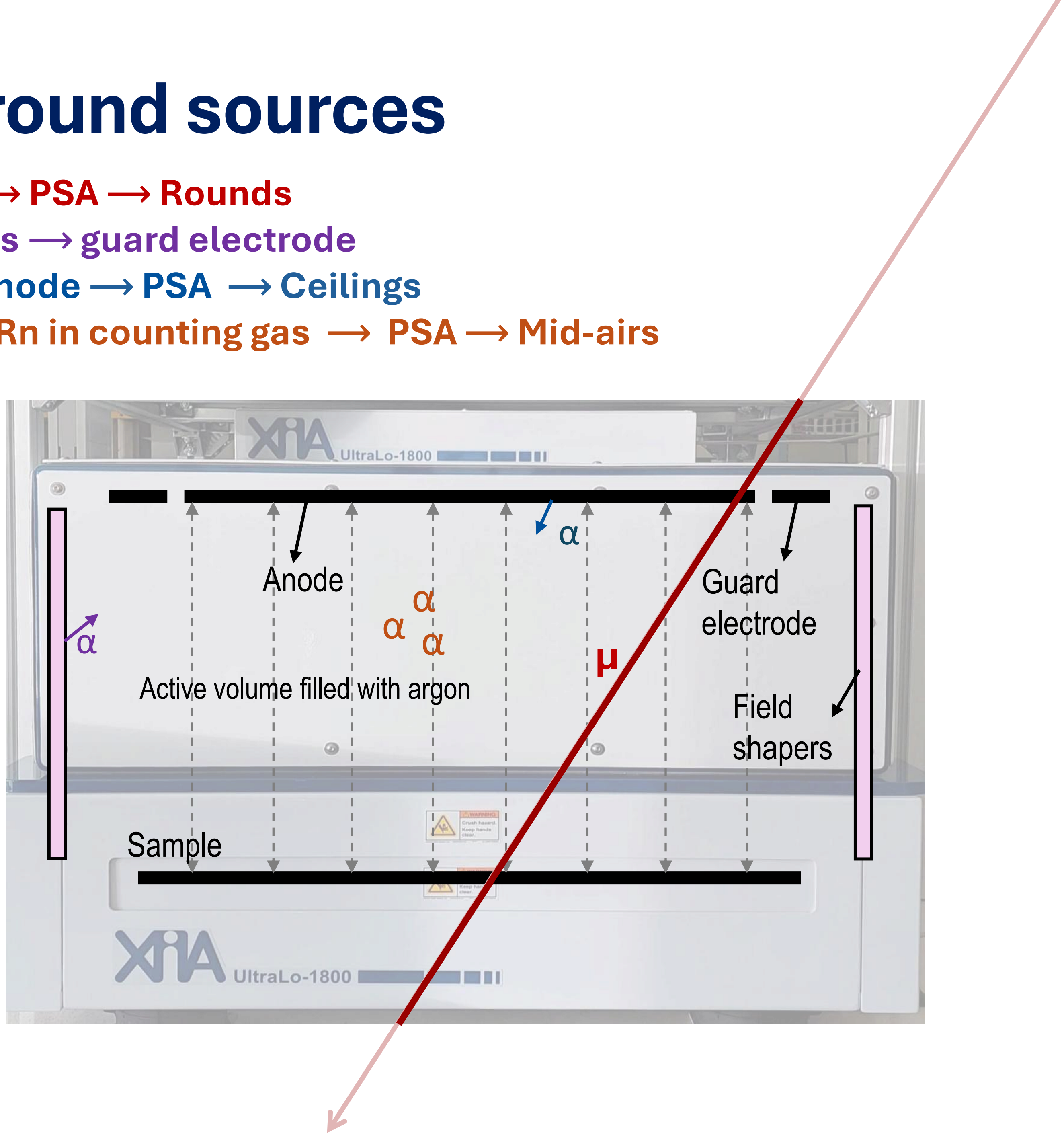
- **Alpha spectrometer**
- **Large-area**: accepts **43 × 43 cm²** and up to **4 mm thick** samples
- **Low background**: radio-pure materials, Pulse Shape Analysis (PSA) and guard electrode applied
- **Ionization** chamber, boil-off argon as counting gas
- **2 geometries**: „Full" (43 × 43 cm²) and „Wafer" (Ø 30 cm)
- **Muon veto** installation is ongoing



XIA UltraLo-1800 alpha spectrometer in the laboratory at Jagiellonian University

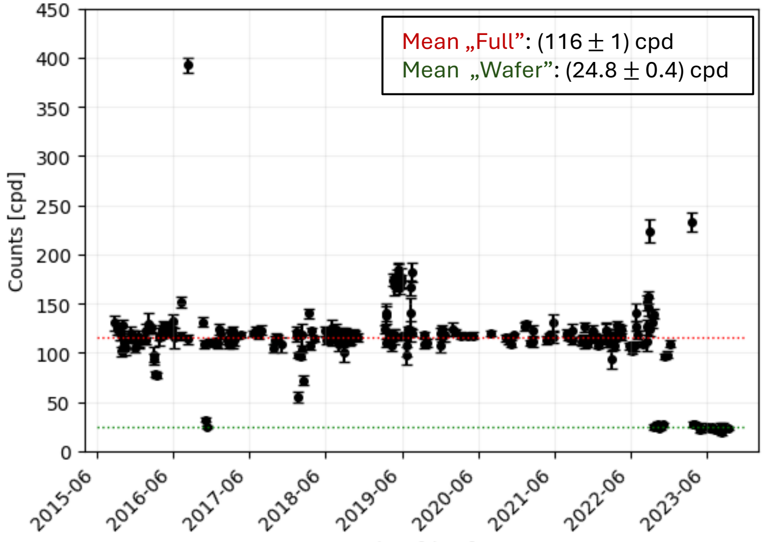
Background sources

- Muons ⟶ PSA ⟶ Rounds
- Sidewalls ⟶ guard electrode
- α from anode ⟶ PSA ⟶ Ceilings
- $^{222}Rn/^{220}Rn$ in counting gas ⟶ PSA ⟶ Mid-airs

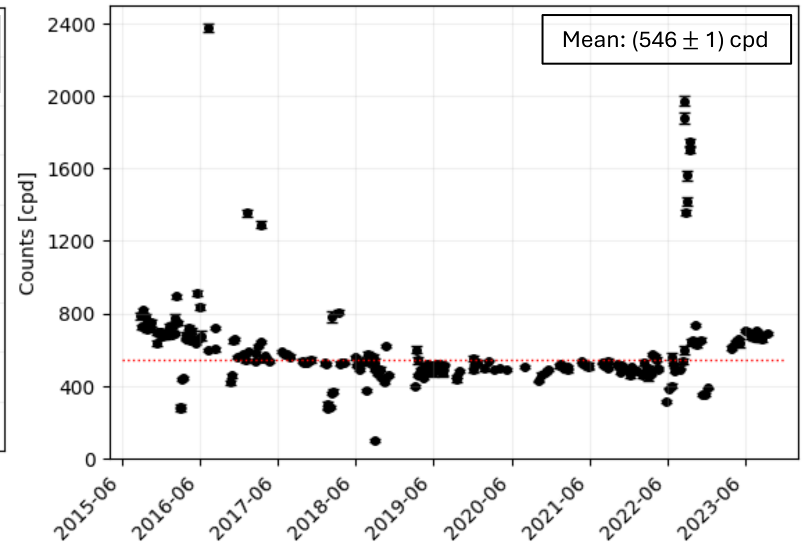


Background sources – rates over 8 years

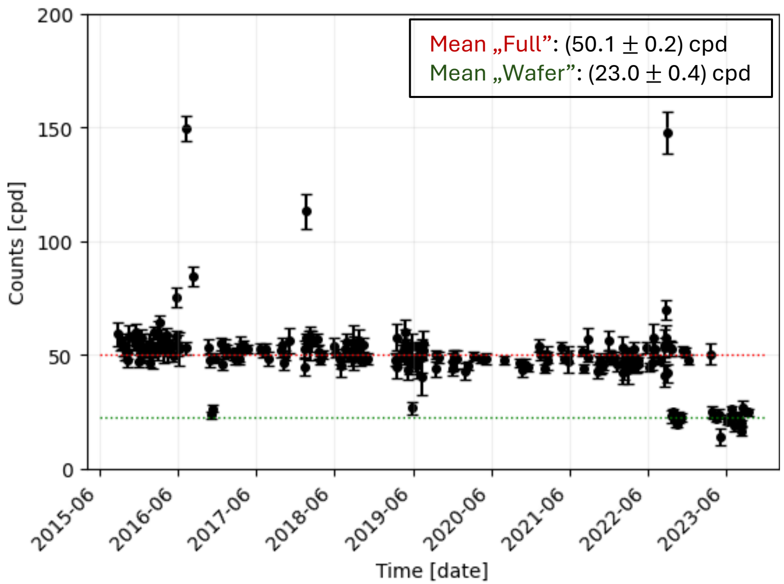
Rounds



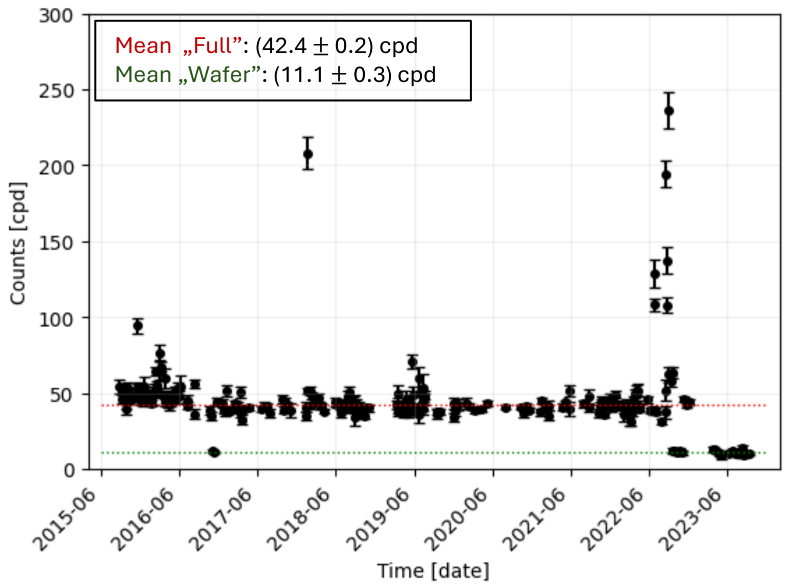
Sidewalls



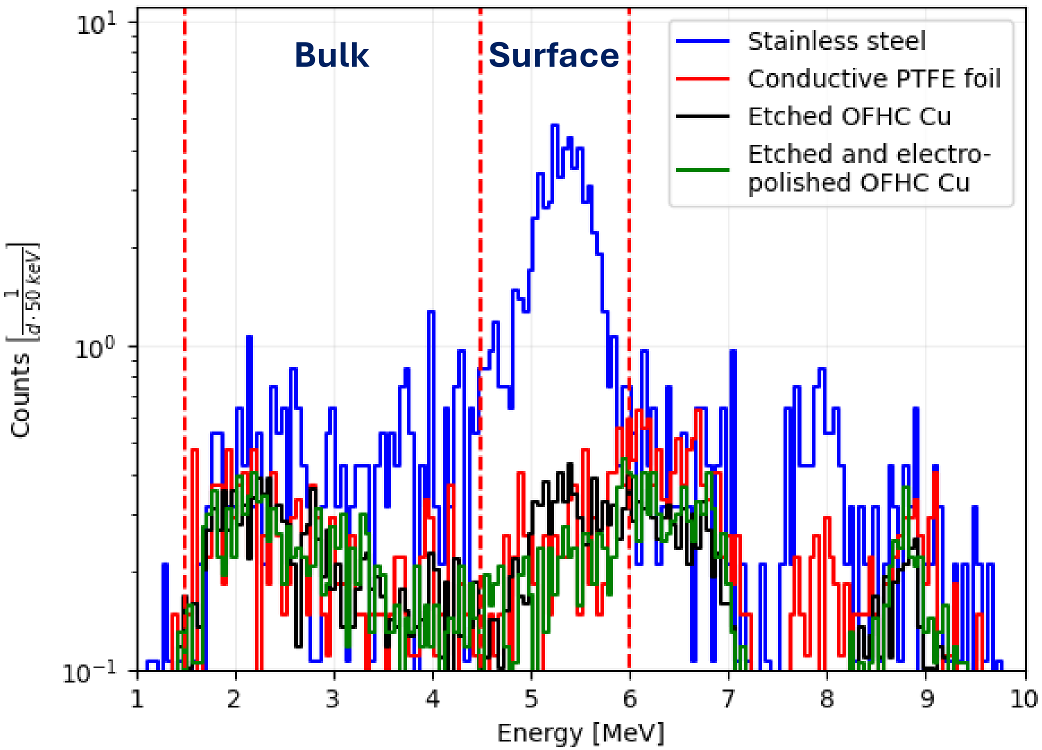
Ceilings



Mid-airs



Background spectrum

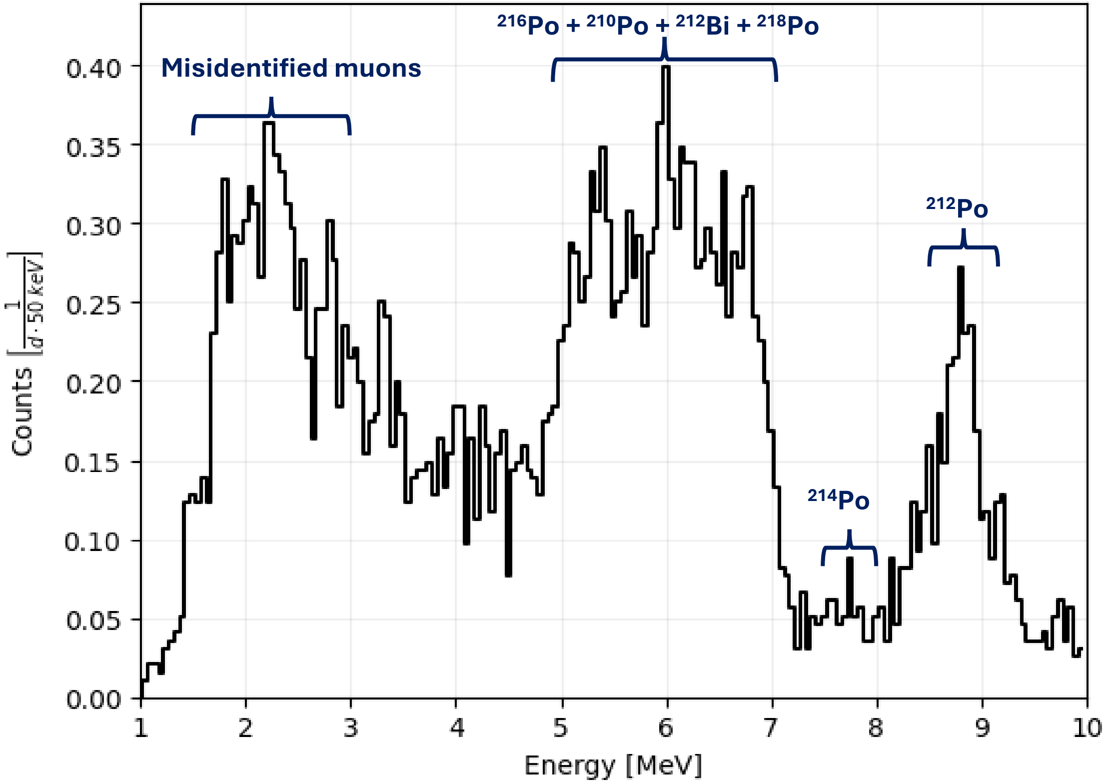


- **Several materials** tested as a „zero sample"

- **Bulk region:** 1.5 – 4.5 MeV
- **Surface region:** 4.5 – 6 MeV

Sample	Count rate in energy range [cts/d]		
	1.5 – 4.5 MeV	**4.5 – 6 MeV**	**1.5 – 10 MeV**
Stainless steel	26.4 ± 1.7	61.1 ± 2.6	111.8 ± 3.5
Conductive PTFE foil	13.2 ± 0.7	7.7 ± 0.5	37.5 ± 1.2
Etched OFHC Cu	13.0 ± 0.3	8.1 ± 0.3	31.3 ± 0.5
Etched and electropolished OFHC Cu	12.6 ± 0.4	6.4 ± 0.3	30.5 ± 0.6

Background spectrum



Etched + electropolished OFHC Cu

Measurement time: 195 days

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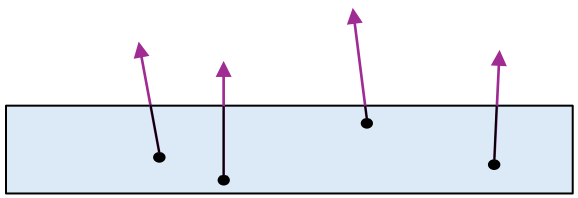
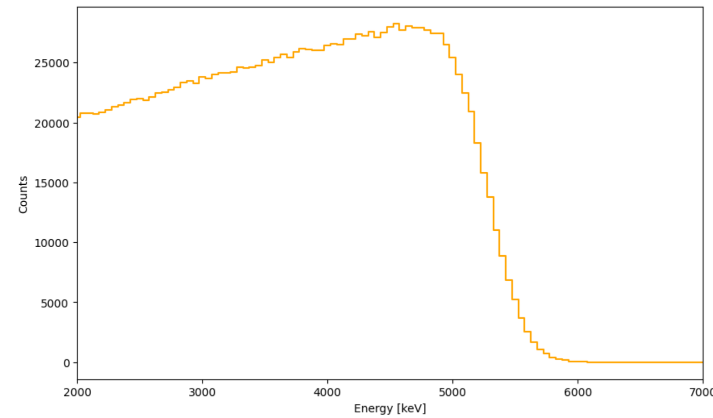
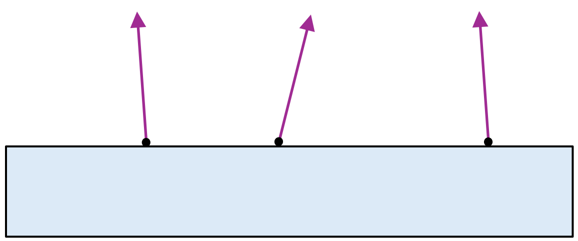
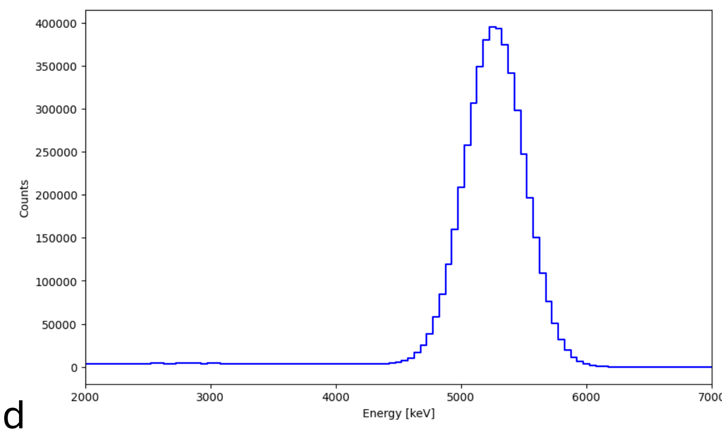
Determination of ^{210}Po activity

- Recording of alpha spectrum
- Implementing geometry of detector/sample and physical processes in Geant 4
- Monte Carlo simulation of spectrum components coming from
  - bulk activity
  - surface activity



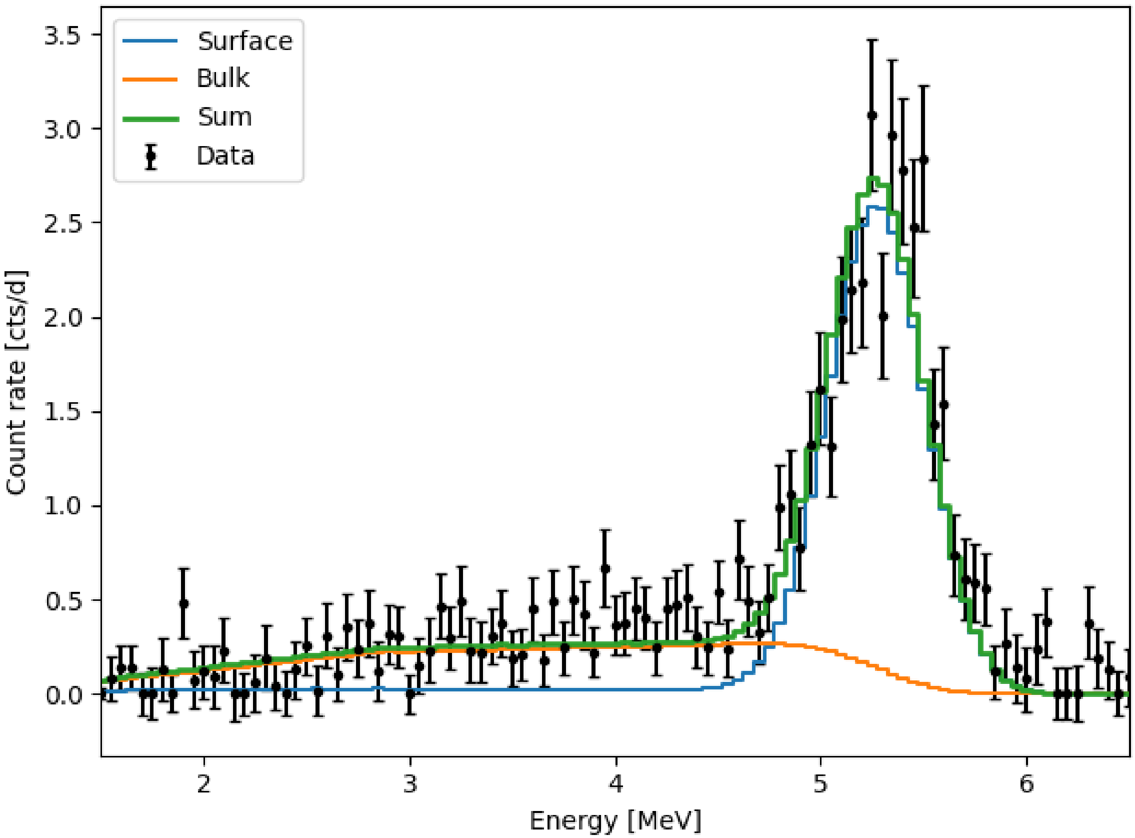


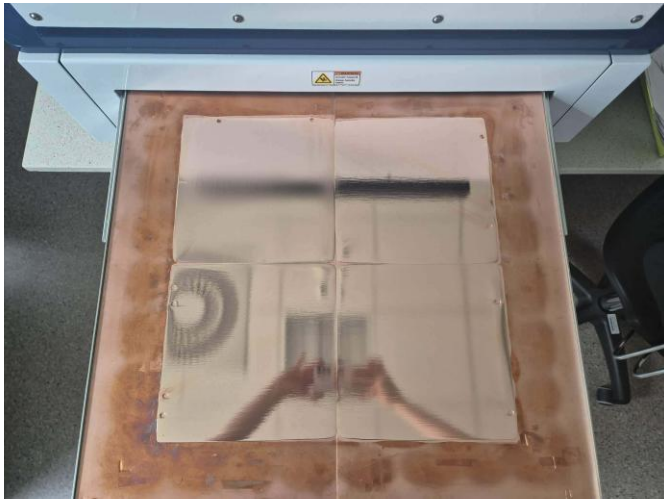




- Fitting combined spectrum to data using χ^2 method
- Deconvolution of surface and bulk activity

High-purity Copper from KGHM





Specific activity 225 days after copper production

C_{sf}= (4.7 ± 0.2) mBq/m²

C_{bl} = (68.9 ± 6.3) mBq/kg

Simplified analysis

- Specific activity

$$\boxed{C_{surface} = \frac{R(4.5-6\ \mathrm{MeV})}{CF_{sf}}} \quad \boxed{C_{bulk} = \frac{R(1.5-4.5\ \mathrm{MeV})}{CF_{bl}}}$$

Conversion factor: count rate $R_{sf/bl} \longrightarrow$ specific activity $C_{sf/bl}$

$$\boxed{CF_{sf/bl} = 86.4 \cdot \varepsilon_{sf/bl} \cdot X_{sf/bl}}$$

$X_{sf/bl}$ – area [m^2] / effective mass [kg]
$86.4 = 24 \cdot 3600 \cdot 10^{-3}$

- 5.3 MeV α-particle simulations to determine bulk and surface detection efficiencies $\varepsilon_{sf/bl}$
- Example materials

- Example efficiencies for Cu
  ε_{bl} = 13.7% („Full" / „Wafer" geometry)
  ε_{sf} = 44.8% („Full" geometry) and ε_{sf} = 42.9% („Wafer" geometry)

Conversion factors for different materials

$$CF_{sf/bl} = 86.4 \cdot \varepsilon_{sf/bl} \cdot X_{sf/bl}$$

Material	Bulk CF (Full) $\left[\frac{\text{cts/d}}{\text{mBq/kg}}\right]$	Surface CF (Full) $\left[\frac{\text{cts/d}}{\text{mBq/m}^2}\right]$	Bulk CF (Wafer) $\left[\frac{\text{cts/d}}{\text{mBq/kg}}\right]$	Surface CF (Wafer) $\left[\frac{\text{cts/d}}{\text{mBq/m}^2}\right]$
Cu	0.22 ± 0.01	7.2 ± 0.1	0.08 ± 0.01	2.6 ± 0.1
Steel	0.19 ± 0.01		0.07 ± 0.01	
Ti	0.17 ± 0.01		0.07 ± 0.01	
Al	0.14 ± 0.01		0.06 ± 0.01	
Si	0.14 ± 0.01		0.05 ± 0.01	
Pb	0.38 ± 0.01		0.15 ± 0.01	
Ge	0.23 ± 0.01		0.09 ± 0.01	
Teflon	0.13 ± 0.01		0.05 ± 0.01	

Minimum Measurable Specific Activity (MMSA)

MMSA: minimum specific activity measurable with a predefined relative uncertainty δ

$$\delta = \frac{\Delta C}{C}$$

For example: δ = 30% ⟶ minimum specific activity measurable with 30% relative uncertainty

$$\boxed{C_{sf/bl} = \frac{1 + \sqrt{1 + 4 \cdot (\delta^2 - \delta_e^2) \cdot \left(t^2 \cdot \sigma^2_{B\ sf/bl} + t \cdot B_{sf/bl}\right)}}{2 \cdot \varepsilon_{sf/bl} \cdot X_{sf/bl} \cdot t \cdot (\delta^2 - \delta_e^2)}}$$

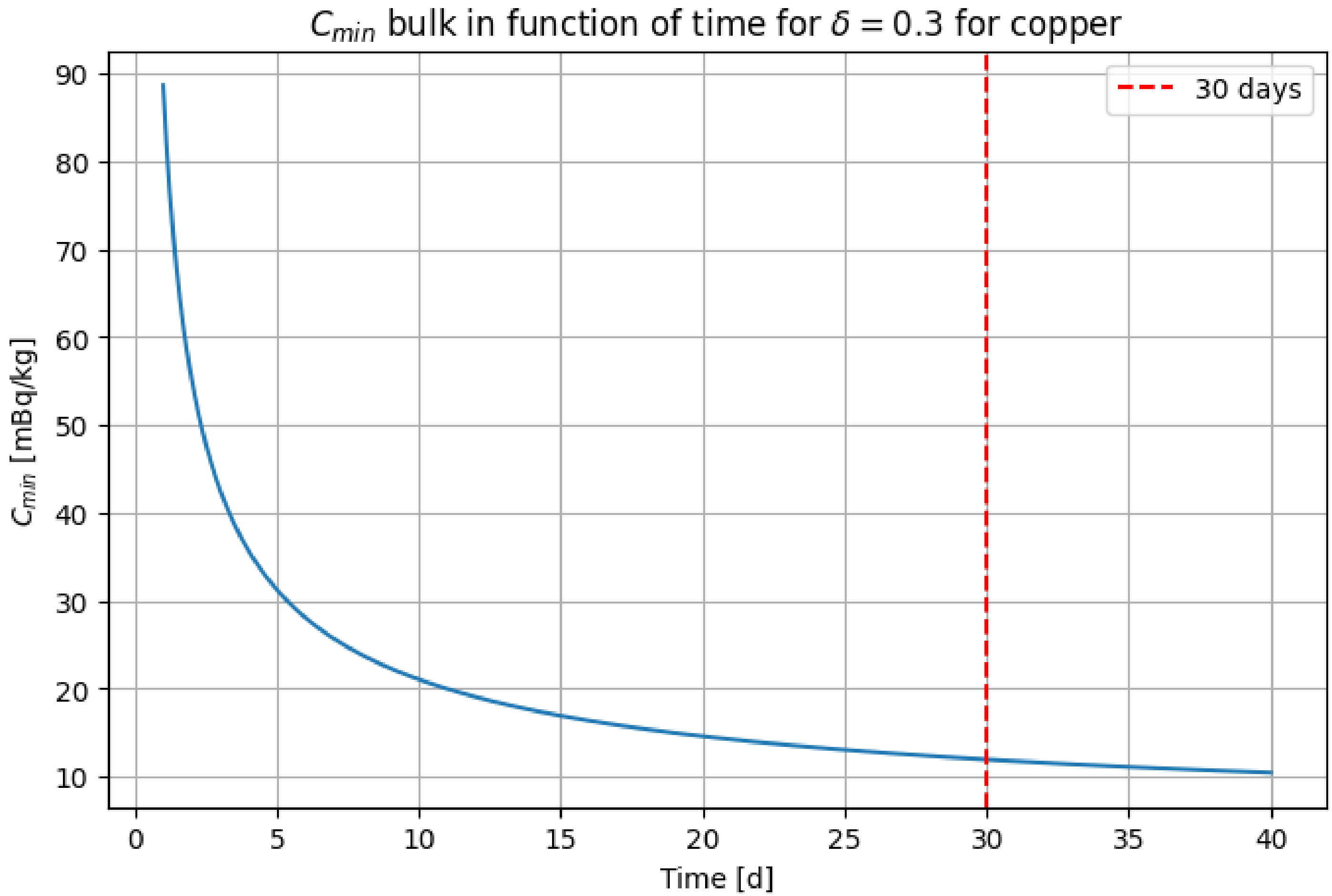
$B_{sf/bl}$ – background count rate

t – assumed measurement time

$\delta_e = \frac{\sigma_\varepsilon}{\varepsilon}$ - relative uncertainty of the detection efficiency

Pelczar, K., Zuzel, G., Wójcik, M. *et al.* An online radon monitor for low-background detector assembly facilities. *Eur. Phys. J. C* **81**, 86 (2021)

MMSA for Copper



MMSA for Copper

t = 30 days

δ [%]	Geometry „Full”		Geometry „Wafer”	
	$C_{min\_Surface}$ [mBq/m^2]	C_{min_Bulk} [mBq/kg]	$C_{min\_Surface}$ [mBq/m^2]	C_{min_Bulk} [mBq/kg]
10	1.0	47.8	2.0	93
20	0.44	19.0	0.78	34.3
30	**0.28**	**11.9**	**0.48**	**21.1**
40	0.20	8.7	0.35	15.3
50	0.16	6.9	0.27	12.0
60	0.13	5.7	0.22	9.8

Detection limit

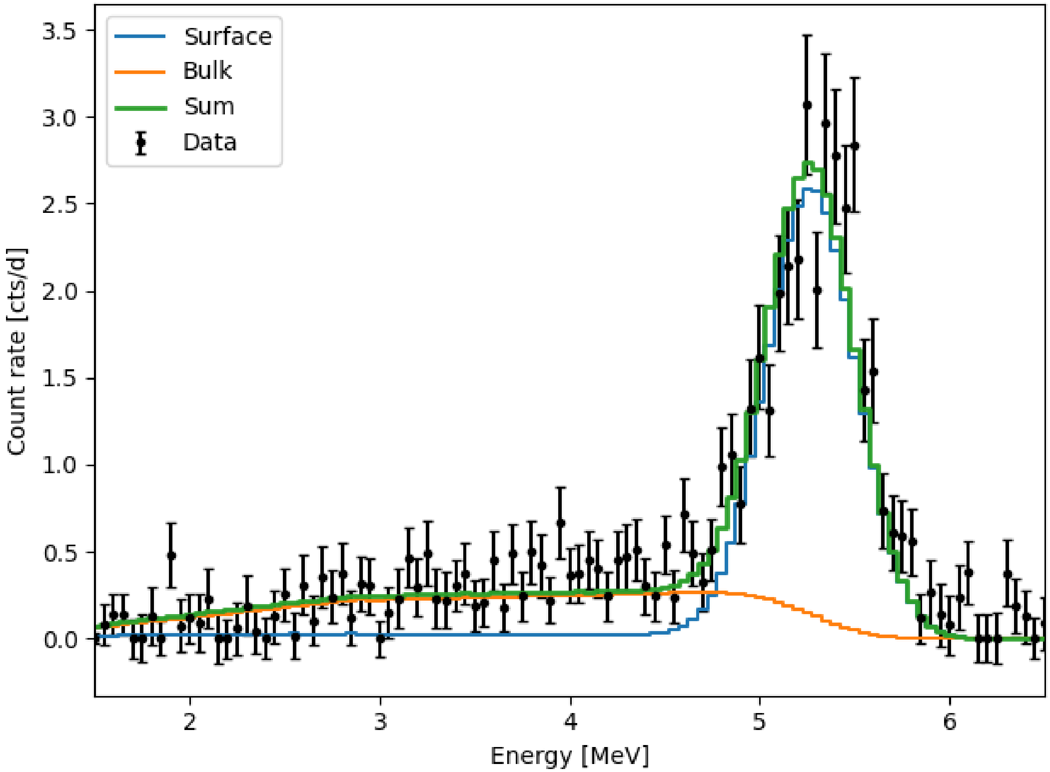
Limit of detection: minimum signal distinguishable from background

$$L_{sf/bl} = \frac{5 \cdot \sigma_{B(sf/bl)}}{CF_{sf/bl}}$$

$\sigma_{B(sf/bl)}$ – uncertainty of the background count rate

Material	Geometry „Full”		Geometry „Wafer”	
	L_{bl} [mBq/kg]	L_{sf} [mBq/m²]	L_{bl} [mBq/kg]	L_{sf}[mBq/m²]
Cu	6.0	0.14	16.8	0.37
Steel	7.0		19.6	
Ti	7.5		21.0	
Al	8.9		25.0	
Si	9.2		25.9	
Pb	3.3		9.4	
Ge	5.7		16.0	
Teflon	10.1		28.6	

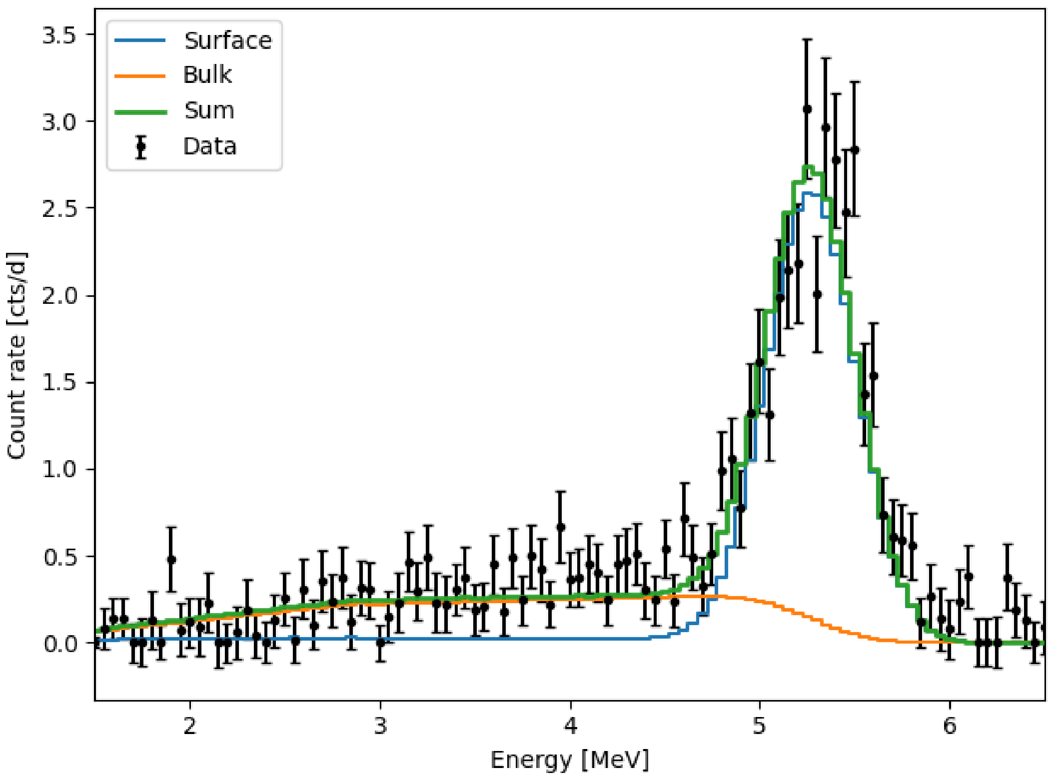
Full vs simplified analysis



Copper produced by the KGHM Company for shielding of HPGe spectrometer.
Production date: 30th July 2025

C_{sf}= (4.7 $\pm$ 0.2) mBq/m^2
C_{bl} = (68.9 $\pm$ 6.3) mBq/kg

Full vs simplified analysis



Copper produced by the KGHM Company for shielding of HPGe spectrometer.
Production date: 30th July 2025

C_{sf} = (4.7 ± 0.2) mBq/m²
C_{bl} = (68.9 ± 6.3) mBq/kg

Simplified analysis

R_{sf} = (38.3 ± 1.5) cts/d
R_{bl} = (13.7 ± 1.2) cts/d
CF_{sf} = (6.53 ± 0.03) $\frac{\text{cts/d}}{\text{mBq/m}^2}$
CF_{bl} = (0.190 ± 0.001) $\frac{\text{cts/d}}{\text{mBq/kg}}$

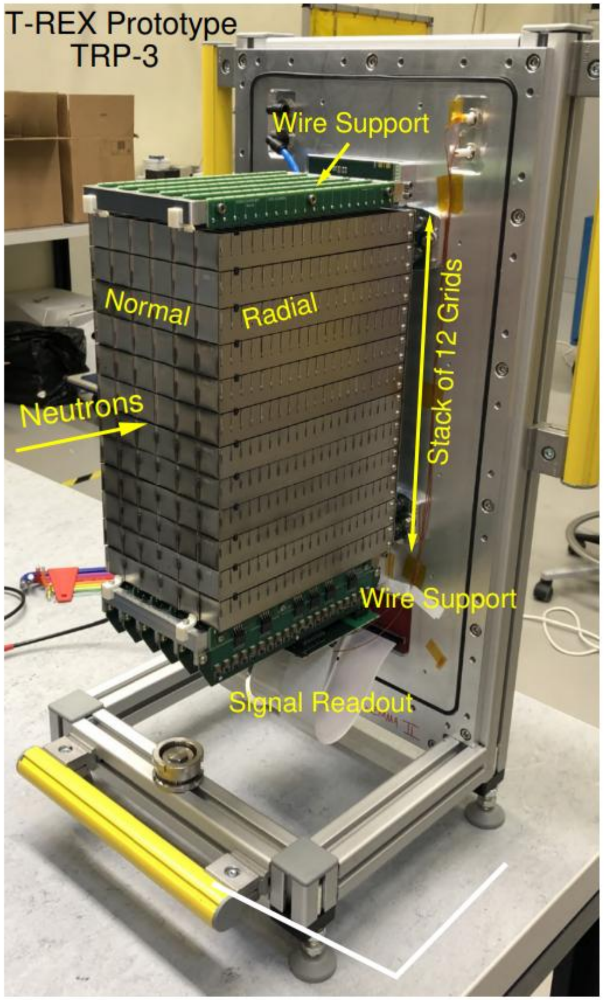
$$\longrightarrow \quad C_{sf/bl} = \frac{R_{sf/bl}}{CF_{sf/bl}} \quad \longrightarrow$$

C_{sf} = (5.9 ± 0.2) mBq/m²
C_{bl} = (71.7 ± 6.3) mBq/kg

Aluminium samples - ESS

- Analysis of the surface alpha rate in aluminium samples for the neutron detector

Sample	Size	Time	Surface alpha rate
	(cm)	(days)	$(\alpha/\text{day}/\text{m}^2)$
Al-1	$40 \times 40 \times 0.05$	12	320 ± 20
Al-1A	$40 \times 40 \times 0.05$	11	280 ± 20
Al-2	$40 \times 40 \times 0.05$	13	310 ± 20
BA	$30 \times 25 \times 0.10$	0.3	79440 ± 2300
NiP-BA	$30 \times 25 \times 0.15$	21	68 ± 19



A. Backis, C.-C. Lai, J.R.M. Annand, K.G. Fissum, G. Zuzel, M. Czubak and K. Livingston. Alpha background in multi-grid neutron detectors. JINST 21 P07032 (2026)

Summary

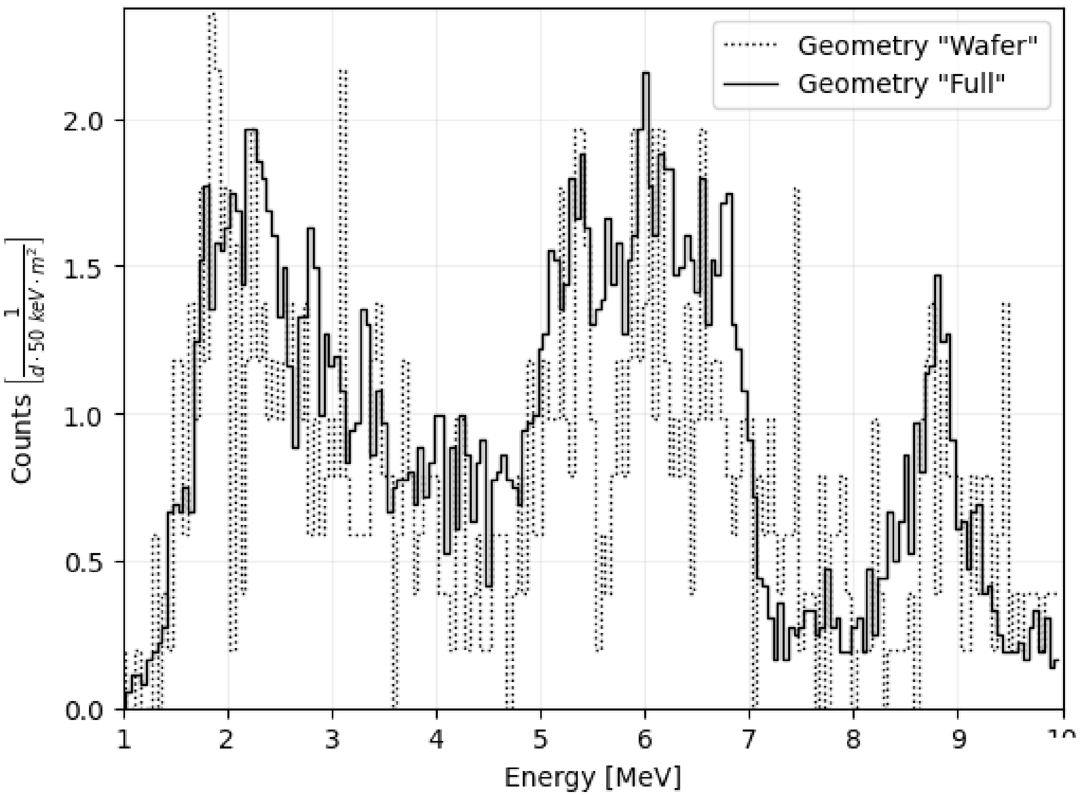
- Several materials were tested to minimize the background contribution from the XIA drawer. **The etched + electropolished OFHC copper was selected** as it provides the lowest background
- Count rates from different background sources over an 8-years period were analyzed, confirming **the long-term stability** of the detector
- **Conversion Factors, Minimum Measurable Specific Activities and Detection Limits** were determined for Cu, Steel, Ti, Al, Si, Pb, Ge and Teflon for surface and bulk contamination in two geometries – „Full" and „Wafer"
- **Monte Carlo-based method** for determining specific activities was developed
- **Simplified analysis provides results consistent with the full analysis based on MC and spectra deconvolution**
- Aluminium samples for the neutron detector were tested in the XIA alpha spectrometer in order to determine material with the lowest surface emissivity

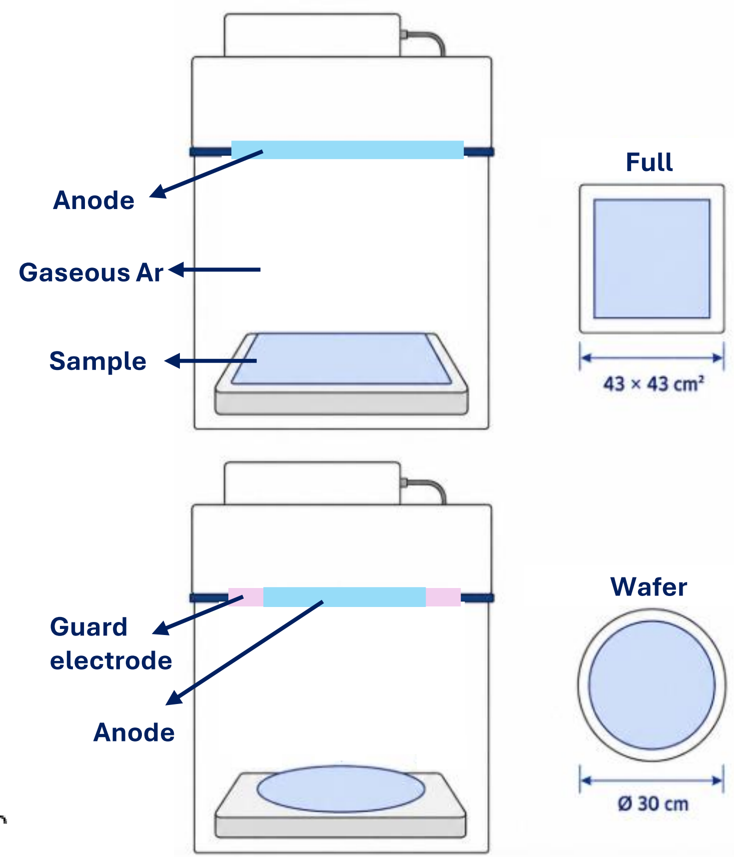
This work was supported by the Doctoral School of Exact and Natural Sciences of the Jagiellonian University under the Visibility and Mobility Module of the Strategic Programme Excellence Initiative at Jagiellonian University.

This work was performed in the framework of the NCN grant (Grant No. UMO-2023/51/B/ST2/02099)).

Backup

Geometries „Wafer” and „Full”





MMSA for different materials

Geometry Full (Wafer)

$t = 30$ days

δ [%]	C_{min_Bulk} [mBq/kg]						
	Steel	**Ti**	**Al**	**Si**	**Pb**	**Ge**	**Teflon**
5	464.9 (1120.1)	344.8 (807.5)	314.6 (719.6)	356.4 (822.5)	-	446.6 (1088)	333.7 (758.4)
10	55.5 (107.9)	58.5 (113.3)	68.2 (132.2)	71.2 (138.1)	36.5 (73.2)	45.6 (88.7)	77.2 (149.6)
20	22.1 (39.9)	23.6 (42.6)	28.0 (50.6)	29.0 (52.5)	11.1 (20.1)	18.1 (32.6)	31.8 (57.6)
30	13.9 (24.6)	14.9 (26.3)	17.7 (31.3)	18.4 (32.5)	6.8 (12.0)	11.4 (20.1)	20.2 (35.7)
40	10.2 (17.8)	10.9 (19.1)	13.0 (22.7)	13.4 (23.5)	4.9 (8.6)	8.3 (14.5)	14.8 (25.9)
50	8.0 (13.9)	8.6 (14.9)	10.2 (17.8)	10.6 (18.4)	3.9 (6.7)	6.6 (11.4)	11.7 (20.3)
60	6.6 (11.4)	7.1 (12.3)	8.5 (14.6)	8.8 (15.2)	3.2 (5.5)	5.4 (9.4)	9.6 (16.7)