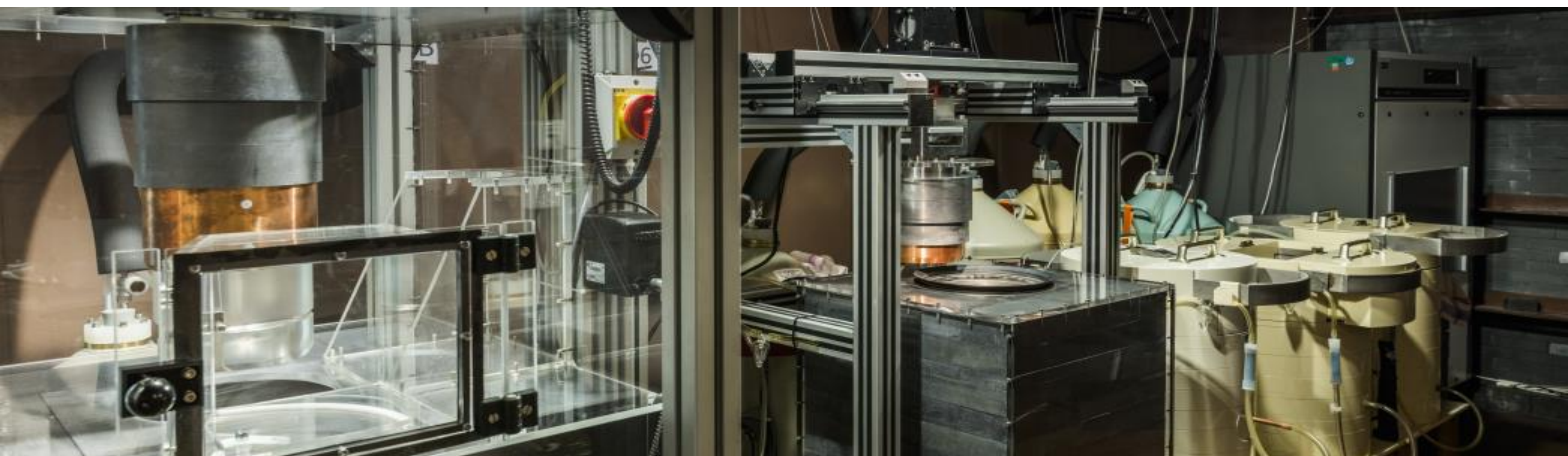
VKTA DRESDEN
STRAHLENSCHUTZ | ANALYTIK | ENTSORGUNG

Recent activities in the underground laboratory Felsenkeller

Detlev Degering, VKTA



CELLAR community meeting
28 – 30 November 2022, Dresden/Rossendorf

29.November 2022

INTRODUCTION

Location, Characterisation, Methods, Equipment

Location:

- Cellars of a former brewery used for storage of ice
- laboratory founded in 1982 (NAA)
- ≈ 140 m w.e. overburden (≈ 45 m of rock)
- Monzonite (low quartz content):
  ^{238}U 100 ... 230 Bq/kg
  ^{232}Th 100 ... 210 Bq/kg
  ^{40}K 400 ... 1300 Bq/kg
- Tunnel:
  ^{222}Rn 130 ... 500 Bq/m³ (↑ since 2018)
- Measuring chambers:
  MK1: old steel + serpentinite
  (1.3 Bq/kg ^{238}U, 0.3 Bq/kg ^{232}Th, 6 Bq/kg ^{40}K)
  MK2: 28 cm steel + 5 cm old steel
  + 3 cm "boliden" lead

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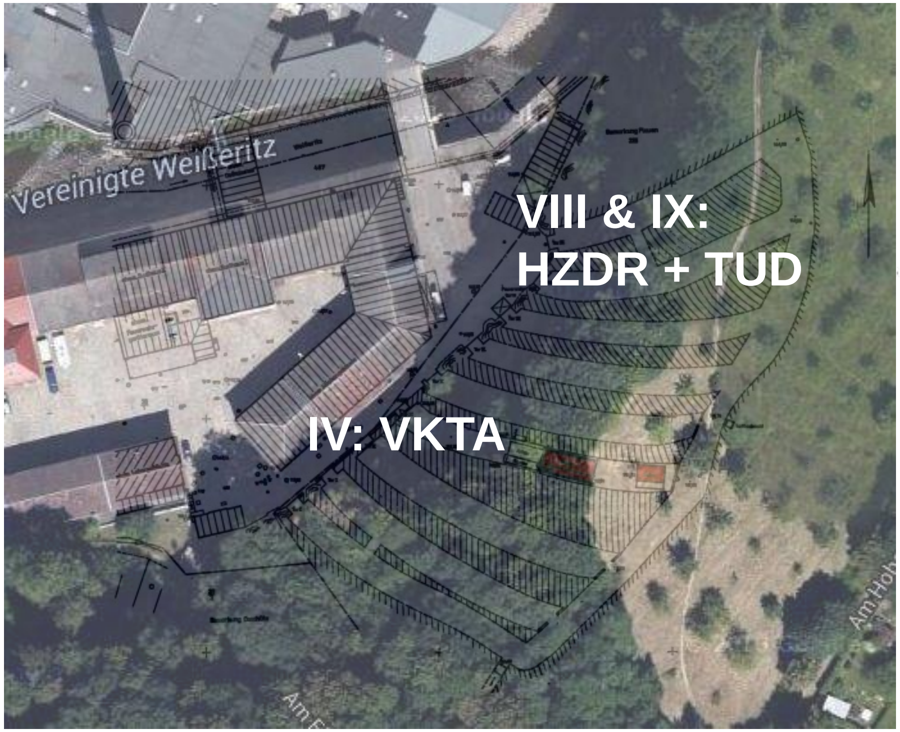

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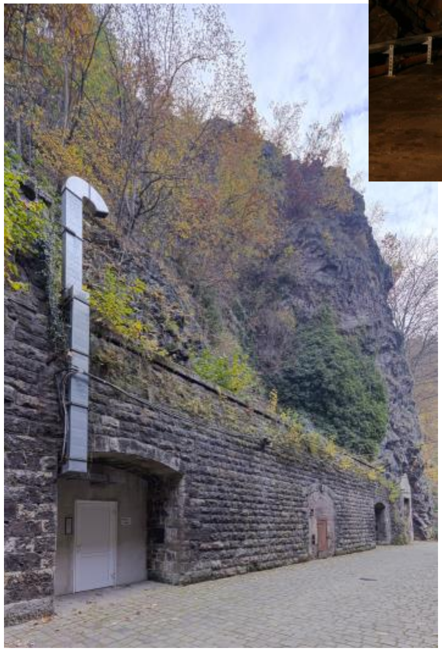
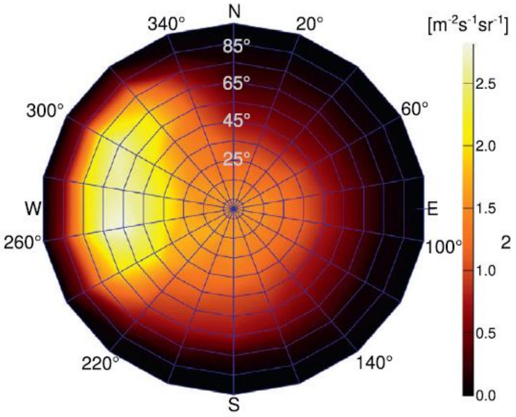


INTRODUCTION

Location, Characterisation, Methods, Equipment

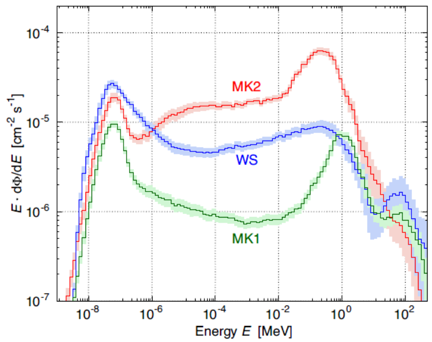
Characterisation :

- **Cosmic radiation, muon component:**
  - reduction of muon flux in vertical direction: ≈ factor 50
  - inhomogeneous spatial distribution
  - reduction of surface flux in total: ≈ factor 30 ... 40 (position dependent)



Ludwig, F. et al.: The muon intensity in the Felsenkeller shallow underground laboratory, Astroparticle Physics 112 (2019) 24 - 34

- **Neutron flux:**
  - (μ,n) reactions and (α,n) reactions from rock
  - energy range: thermal ... > 10 MeV
  - neutron flux at different locations: $0.65 \ldots 4.6 \cdot 10^{-4}$ cm^{-2} s^{-1}, depending of the surrounding shielding material



Grieger, M. et al.: Neutron flux and spectrum in the Dresden Felsenkeller underground facility studied by moderated ³He counters, Phys. Rev. D 101 (2020) 123027

INTRODUCTION
Location, Characterisation, Methods, Equipment

Methods:

- low-level gamma spectrometry (2000 samples per year)
- low level tritium analyses (300 ... 400 samples per year)

- analytical services for:
  - ✓ consumer protection (spring & tap water, medical ceramics, food, ...)
  - ✓ radiation protection & monitoring (abandoned uranium mining sites, deep geothermal energy ...)
  - ✓ science (luminescence dating in geology & archaeology, hydrogeology ...)
  - ✓ decommissioning of NPPs (determination of nuclide vectors ...)

Wagner, G.A. et al. (2010): Radiometric dating of the type-site for Homo heidelbergensis at Mauer, Germany; PNAS **107** 19726–19730

Degering, D., Köhler, M. (2009): Langfristige Betriebssicherheit geothermischer Anlagen, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Förderkennzeichen 0329937C, Abschlussbericht

ilac-MRA DAkkS Deutsche Akkreditierungsstelle D-PL-14498-01-00

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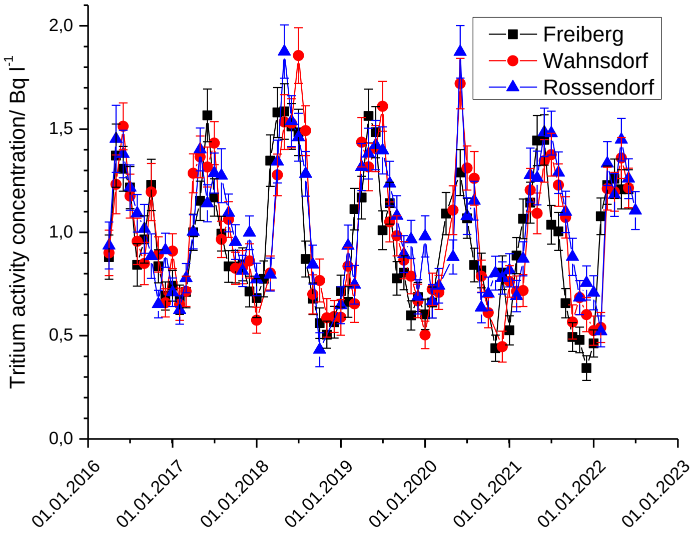

Annual variation of Tritium concentration in precipitation at different sites in Saxony, germany

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INTRODUCTION

Location, Characterisation, Methods, Equipment

Equipment:

- **gamma spectrometer:**
  - 6 x low background (20 ... 70 %)
    [n-type coaxial and p-type extended range]
  - 1 x ultra low background well type (30 %)
  - 1 x ultra low background 92 %
  - by contract: 1 x ultra low background 95 % (PTB)
    - minimum decision limit for 1 d measurements: ≈ 10^{-3} Bq

- **liquid scintillation counter:**
  - Quantulus 1220-002 (1994, Wallac Oy, Turku, Finland)
  - AccuFLEX LSC-LB7 (2019, Hitachi-Aloka)

- **installation for electrolytic enrichment of tritium**
  - decision limit 0.1 Bq l^{-1} with enrichment

RECENT THEMES

Water analysis, Meteorites

German Drinking Water Ordinance:

- implementation of obligatory analysis of radioactive parameters (10.03.2016)
- ≈ 15 000 wells, 4 samples in 4 different calendar quarters ⇨ ≈ 60 000 water samples (2016 – 2019)

- Parameters:
  - ^{222}Rn 100 Bq l^{-1}
  - **“total indicative dose”** 0.1 mSv a^{-1}
  - ^{3}H (if ordered by authorities) 100 Bq l^{-1}
  - Uranium (for chemical reasons!) 10 µg l^{-1}

- Determination of the total indicative dose:
  - screening total alpha + ^{228}Ra + ^{210}Pb
  - screening total alpha
  - single nuclides $^{238,234}U$, $^{226,228}Ra$, ^{210}Pb, ^{210}Po

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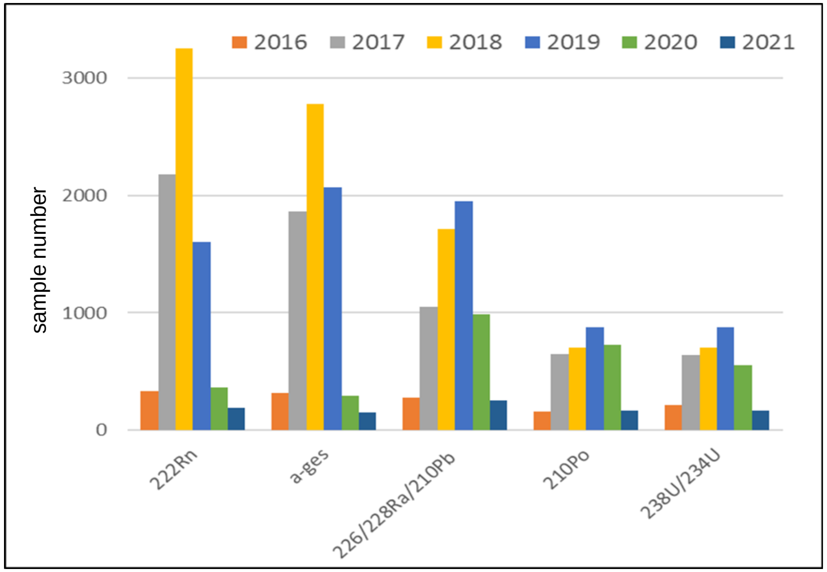
$BaSO_4$ precipitate for $^{226,228}Ra$ + ^{210}Pb analysis

	Detection limits		
	Reference	Required	Laboratory
^{226}Ra	0.5 Bq l^{-1}	0.04 Bq l^{-1}	0,003 Bq l^{-1}
^{228}Ra	0.2 Bq l^{-1}	0.02 Bq l^{-1}	0,002 Bq l^{-1}
^{210}Pb	0.2 Bq l^{-1}	0.02 Bq l^{-1}	0.005 Bq l^{-1}



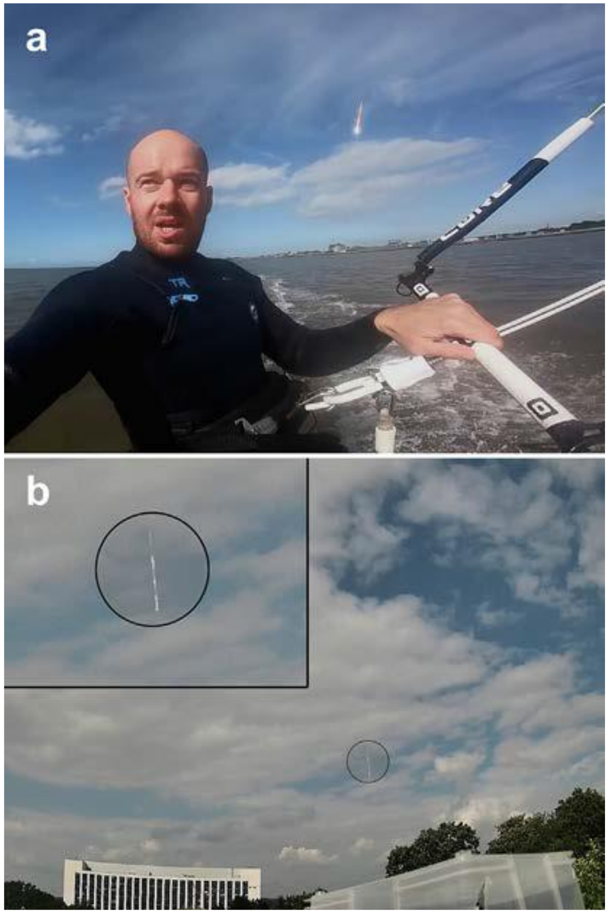
- Total number of samples 2016-2021: 14 105
  $^{226,228}Ra$ + ^{210}Pb: 6 435

RECENT THEMES

Water analysis, Meteorites

Meteorite „Flensburg“:

- 12 September 2019: a daylight fireball was observed by hundreds of observers from UK to Denmark
- Friday, 13 September 2019: small meteorite of 24.5 g mass was found by accident in a garden in Flensburg, Germany
- Immediate gamma spectrometry in the Felsenkeller laboratory was arranged by Dieter Heinlein (German Fireball Network) and Silke Merchel (HZDR)
- 17 d measurement (11 Oct 2019 – 28 Oct 2019) at 92 % ultra-low-level HPGe detector
- Short living radionuclides ($T_{1/2}$ < 100 d) verify recent fall
- Common „meteorite-nuclide“ ^{26}Al below detection limit of gamma spectrometry
  AMS (HZDR): 0.209 ±0.030 dpm kg^{-1}



Bischoff, A. et al., 2021:The old, unique C1 chondrite Flensburg – Insight into the first processes of aqueous alteration, brecciation, and the diversity of water-bearing parent bodies and lithologies, Geochim. Cosmochim. Acta 293, 142-186

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Radionuclide	Half-life	Massic activity (dpm kg^{-1})	σ (%)
^{7}Be	53.22 d	140	21
^{22}Na	2.6029 a	81	13
^{26}Al	7.17 10^{5} a	< 1.7	
^{46}Sc	83.787 d	15.5	19
^{48}V	15.9735 d	32	25
^{51}Cr	22.704 d	130	31
^{54}Mn	312.19 d	183	13
^{56}Co	77.236 d	9.0	25
^{57}Co	271.81 d	20	18
^{58}Co	70.85 d	20	19
^{60}Co	5.2711 a	123	12

RECENT THEMES

Water analysis, Meteorites

Meteorite „Flensburg“:

- extraordinary composition and mineralogy:
  - classified as very old and unique carbonaceous chondrite breccia (parent body was formed about 3 Ma after formation of first solid bodies in solar system [4565 Ma])
  - indication of aqueous alteration (carbonates, phyllosilicates) ⇨ indicates earliest existence of fluid water
- short exposure time of ~ 5000 years

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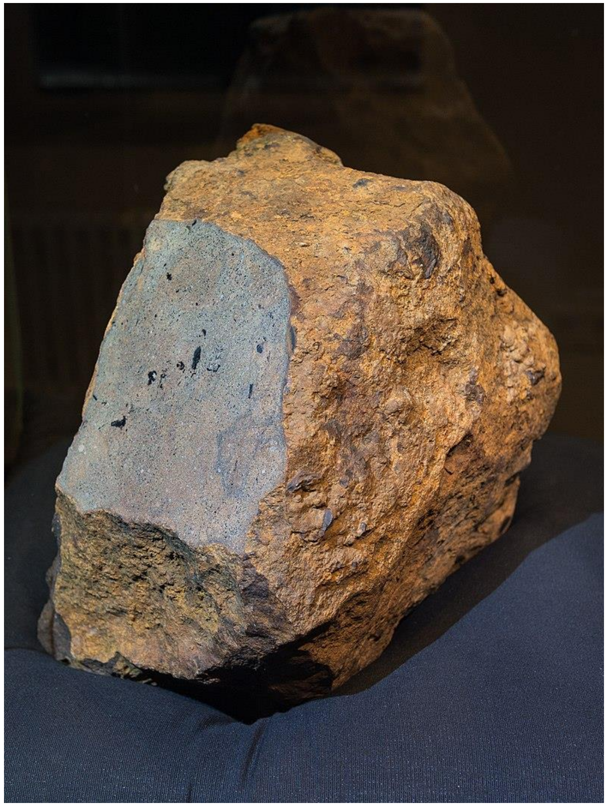
Meteorite „Blaubeuren":

- 1989 during digging a cable trench in 50-70 cm depth a large, magnetic and unusually heavy stone of about 30 kg mass was found in Blaubeuren (Southern Germany)
- placed in the garden as a decorative element
- 2015 almost discarded, but moved to the cellar
- 2020 idea – could be a meteorite???
- Dieter Heinlein (German Fireball Network) checked a sample

indeed an ordinary chondrite

- 2020 a second fragment of 410 g mass was found, probably broken off from the main piece
- laid on a well cover also as decorative element for 31 years

⇨ analysed in Felsenkeller by low-level gamma spectrometry



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Water analysis, Meteorites

Meteorite „Blaubeuren“:

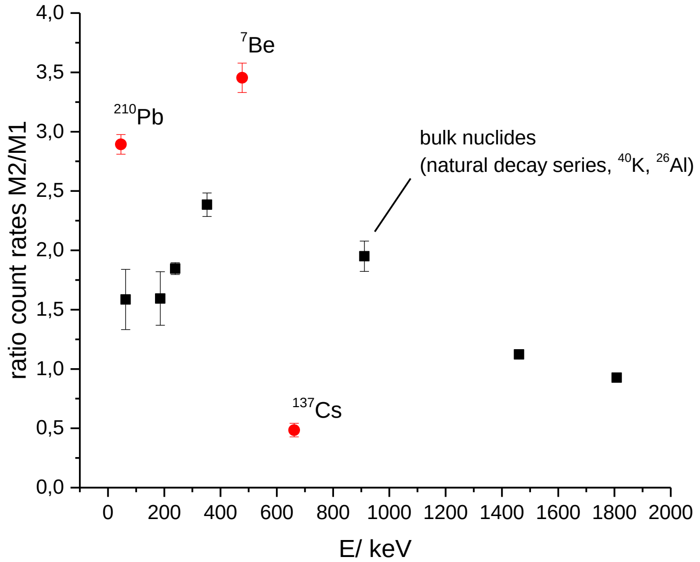
- only cosmogenic radionuclide: ^{26}Al 44 ± 3 dpm kg^{-1}
- much more interesting: the other detected nuclides

- turning the piece upside down: count rate ratio of ^{7}Be, ^{137}Cs and ^{210}Pb differs from the bulk nuclides
  ⇨ surface contaminations
- aerosol-bound ^{7}Be and ^{210}Pb deposited on top of the piece
- activities per (projected) area match perfectly to values found in topsoil layers nearby in the garden

⇨ piece was situated outside for a long time (^{210}Pb, 22 a) and also recently (^{7}Be, 53 d)

- ^{137}Cs activity per area only 1 % of topsoil value, contamination on the bottom of the stone

⇨ fragment was not exposed to Chernobyl fallout in 1986



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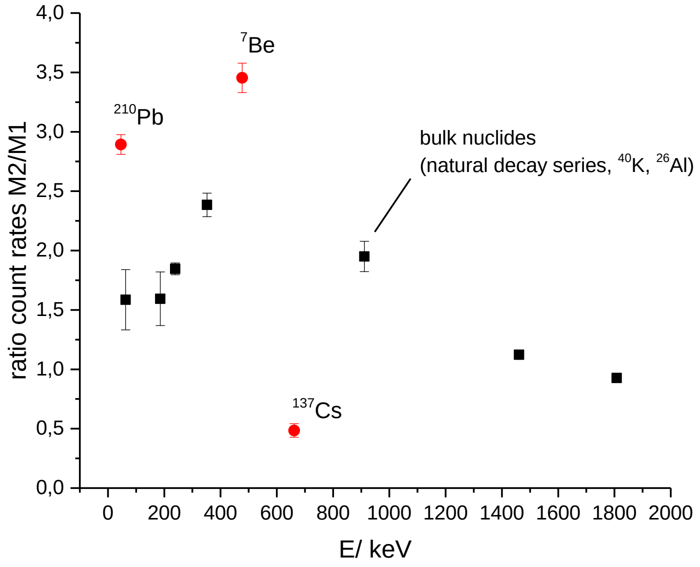
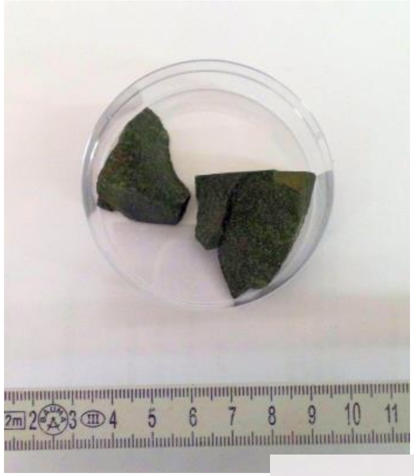


! Radionuclides do not contradict the finder‘s statements !

RECENT THEMES
Water analysis, Meteorites

„Meteorites“ are sometimes „METEOWRONGS“

- Lack of cosmogenic nuclides indicates an origin from earth instead of space
- Radionuclide analysis may serve as verification of meteoritic origin



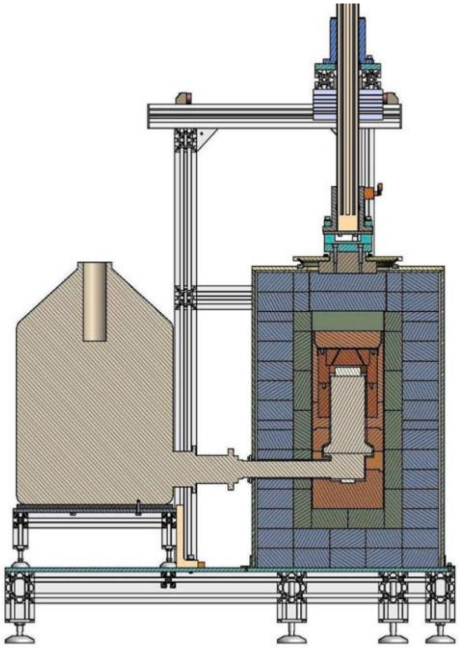
METHODICAL

Active Shielding

First steps towards an active shielding

- **Detector:**
  92 %, p-type extended range, selected materials,
  built 2007, Canberra Lingolsheim

- **Passive shielding:**
  5 cm "underground" OFRP copper (Aurubis)
  5 cm Pb (2.7 ± 0.6) Bq (^{210}Pb) kg^{-1} (Plombum)
  10 cm Pb (33 ± 4) Bq (^{210}Pb) kg^{-1} (van Gahlen)
  minimized air volume, flushed with N_2



Köhler, M. et al.: A new low-level γ-ray spectrometry system for environmental radioactivity at the underground laboratory Felsenkeller, Appl. Rad. Isot. 67 (2009) 736-740

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- **Additional active shielding:**
  large area plastic scintillators (EJ-200, Scionix)
  550 x 600 x 50 mm^3
  550 x 800 x 50 mm^3
  600 x 800 x 45 mm^3
  covering about 2π

Degering, D., Mauksch, B., Köhler, M.: Implementation of an active muon veto in an existing low-level g-ray spectrometer
at the underground laboratory Felsenkeller
poster on ICRM-LLRMT conference,
LNGS Assergi, May 02 – 06 2022

METHODICAL

Active Shielding

First steps towards an active shielding

- **Electronics:**
  analog NIM modules
- **Homogeneity tests of plastic scintillators with ^{90}Sr source:**

0.867	0.888	0.881	0.835
0.888	0.929	0.921	0.860
0.890	1.000	0.973	0.856
0.884	0.935	0.919	0.862
0.862	0.892	0.884	0.846

>>Signal

0.931	0.968	1.000	0.999	0.974	0.910
0.888	0.955	0.960	0.955	0.952	0.878
0.898	0.950	0.974	0.976	0.959	0.878
0.880	0.932	0.949	0.941	0.932	0.860
0.894	0.935	0.969	0.963	0.928	0.895

>>Signal

0.947	0.969	0.959	0.952	0.955	0.926
0.965	1.000	0.985	0.971	0.985	0.950
0.929	0.989	0.991	0.991	0.971	0.919
0.931	0.979	0.989	0.985	0.973	0.928
0.951	0.989	0.977	0.973	0.979	0.951
0.927	0.942	0.941	0.946	0.936	0.928

<<HV
>>Signal

- **Definition of coincidence window:**
  -1 µs ... +19 µs (contains 99.6 % of all events)

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METHODICAL

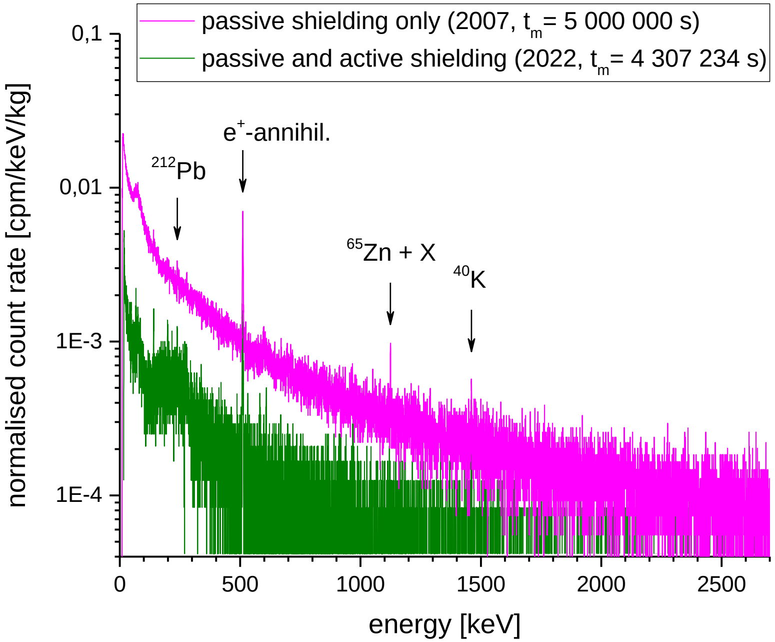
Active Shielding

First steps towards an active shielding

- **Comparison of background spectra:**
  distinct suppression of continuous background
  (40 ... 2700 keV)
  passive only: (2.057 ± 0.004) min^{-1} kg^{-1}
  active + passive: (0.2994 ± 0.0015) min^{-1} kg^{-1}

⇨ **Total suppression ratio (0.1455 ± 0.0008)**

- **But:**
  energy dependent suppression ratio
  structure at 200 ... 300 keV ?
  lower suppression for 511 keV line ?
  ? gate not sufficiently long ?
  late oscillations prevent easy use of digital spectrometer?



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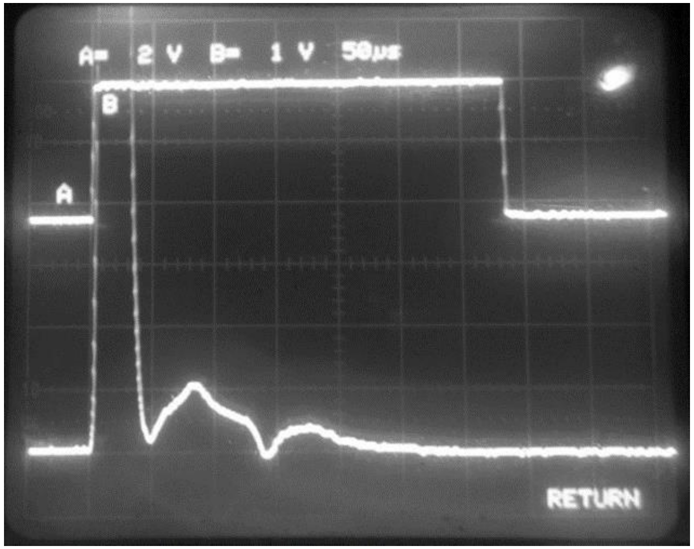

OUTLOOK

Plan for the future:

- **Construction of a low-level spectrometer best adapted to a medium deep underground lab**
- **Based on a SAGe well low-level detector (Mirion, Lingolsheim)**

- **Shallow underground:**

  direct and secondary muon events — double veto

  direct and muon induced neutron events — neutron moderators and absorbers

  Heusser, G. et al, 2015: GIOVE: a new detector setup for high sensitivity germanium spectroscopy at shallow depth; Eur. Phys. J. C 75 531.

- **Deep underground:**

  negligible muon events — -

  neutron events from ambient radioactivity — neutron absorbers

  internal radioactivity — selected materials

  Ackermann, N. et al., 2022: Monte Carlo simulation of background components in low level Germanium spectroscopy; talk on ICRM-LLRMT conference, LNGS Assergi, May 02 – 06 2022

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- **Medium deep underground:**

significantly reduced muon events	single veto (4π)
muon induced neutron events	neutron moderator(s)? and absorber(s)?
internal radioactivity	selected materials

- **Deep underground:**

negligible muon events	-
neutron events from ambient radioactivity	neutron absorbers
internal radioactivity	selected materials

Ackermann, N. et al., 2022: Monte Carlo simulation of background components in low level Germanium spectroscopy; talk on ICRM-LLRMT conference, LNGS Assergi, May 02 – 06 2022

THANK YOU
FOR YOUR ATTENTION!

VKTA – Strahlenschutz, Analytik &
Entsorgung Rossendorf e. V.
Bautzner Landstraße 400, 01328 Dresden

0351 – 260 3493
kontakt@vkta.de
www.vkta.de

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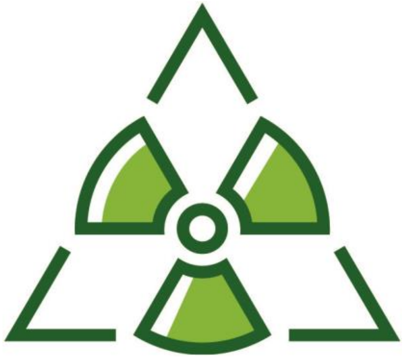
- Strahlungsmesstechnik, betrieblicher Strahlenschutz, Freigabe und Verwaltung radioaktiver Stoffe

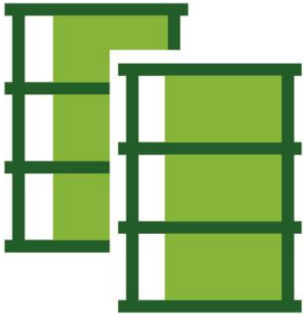


ANALYTIK

- Akkreditiertes Labor für Umwelt- und Radionuklidanalytik mit Niederniveaumesslabor
- Analytik von künstlichen/natürlichen Radionukliden sowie Umweltkontaminanten
- Ingenieurleistungen für Probennahmen, Bestimmung von Nuklidvektoren und Abfallcharakterisierung

ENTSORGUNG

- Vorkonditionierung und Lagerung von radioaktiven Abfällen/Betrieb der Landessammelstelle
- Behandlung und Freimessung von festen und flüssigen radioaktiven Reststoffen und Abfällen
- Beratung bei Bewertungsprojekten sowie Erstellung und Durchführung von Freimessprogrammen



VKTA

VKTA – Strahlenschutz, Analytik & Entsorgung Rossendorf e. V.
Bautzner Landstraße 400, 01328 Dresden

0351 – 260 3493
kontakt@vkta.de
www.vkta.de