Characteristics of natural radiation background at the Research and Education mine Reiche Zeche (Germany) performed within the BSUIN project.

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GI5.7
Multidisciplinary underground laboratories and test sites – what makes them tick?

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BSUIN - BALTIC SEA UNDERGROUND INNOVATION NETWORK

The project aims to develop the capabilities of ULs in order to improve their service offering as a capacity for innovation, and to create a network of the Baltic Sea Region's ULs in order to provide the users an easy access and environment for business development and innovation.

Underground Laboratories

PARTNER LABORATORIES:

- Callio Lab, Pyhäsalmi (Finland),
- Äspö Hard Rock Laboratory, Oskarshamn (Sweden),
- TU-Freiberg's Research and Education Mine "Reiche Zeche" (Germany),
- Conceptual Lab development coordinated by KGHM Cuprum R&D center (Poland),
- Ruskeala, Karelia (Russia),
- Underground Laboratory of Khlopin Institute in St Petersburg (Russia).

ASSOCIATED ORGANIZATION LABORATORY

- Experimental mine Barbara, Poland
- Hagerbach Test Gallery, Switzerland

BSUIN - Partners

- University of Oulu, Kerttu Saalasti Institute, Oulu/Nivala, Finland
- Oulu University of Applied Sciences, Oulu, Finland
- University of Silesia, Poland
- Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden
- KGHM Cuprum Research & Development Centre Ltd., Poland
- TU Bergakademie Freiberg Technical University, Freiberg, Germany
- Helmholtz-Centre Potsdam, German Research Centre for Geosciences, Potsdam, Germany
- Vilnius University, Lithuania
- National Center for Nuclear Research, Poland
- Baltic Scientific instruments, Riga, Latvia
- Karelian Research Center of Russian Academy of Sciences, Petrozavodsk, Russia
- Joint stock company "Khlopin Radium Institute", St Petersburg, Russia
- Sotkamo Silver AB, Stockholm, Sweden
- Tallinn University of Technology, Tallinn, Estonia

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Education and Research Mine "Reiche Zeche" of the Technical University of Freiberg (Germany)

- "Reiche Zeche" mine is located on the edge of the Erzgebirge in the municipality of Freiberg in the orthogneiss rock, whereas the Freiberg is placed in the centre of Saxony between Dresden and Chemnitz.
- The mine has a drifts of 129 km, of which 19 km are safely accessible and frequently in use.
- The mine is accessible up to a level of 230 m, the water level of Rothschönberger Stolln (the level of up to 750 m is flooded).
- The access to the mine is possible by two shafts (Reiche Zeche and Alte Elisabeth).

Education and Research Mine "Reiche Zeche" of the Technical University of Freiberg (bsuin.eu)

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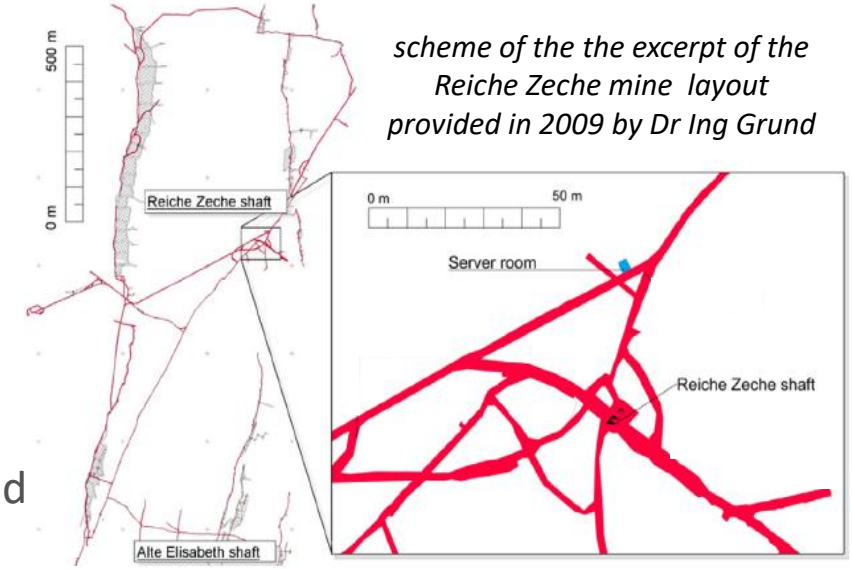
Measurements of Natural Background Radiation (NBR) in Reiche Zeche mine

NBR measurements were performed at 1st level at a depth of 150 m (410 m w.e.):

- In-situ γ spectrometry (by using portable HPGe semiconductor spectrometer),
- Radon concentration in air (by using RAD7 electronic radon detector).



scheme of the the excerpt of the Reiche Zeche mine layout provided in 2009 by Dr Ing Grund

The water samples from the mine water gullets and the rock samples from a newly blasted excavation were taken for laboratory analysis in the Institute of Physics, University of Silesia, Katowice (Poland). In the laboratory, the following measurements were performed:

- concentration of radioisotopes in water samples (by using a liquid scintillation counter (LSC) and α spectrometry technique),
- concentration of radioisotopes in rock samples (by using α and γ spectrometry techniques).

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In-situ γ ray measurements

The in-situ γ measurements were performed in the „server room" (dimensions 3 m x 3 m x 2.2 m).

Equipment used for measurements (Canberra Industries, Inc., USA):

- GR4020 portable spectrometer,
- HPGe coaxial detector (40% relative efficiency),
- InSpector™ 2000 multichannel analyser (for data collecting),
- Genie™ 2000 v.3.2.1 software package (for spectra analysing)

Before measurements two calibrations were made:

- the energy calibration: 7 radioactive sealed sources (^{133}Ba, ^{137}Cs, ^{54}Mn, ^{57}Co, ^{109}Cd, ^{22}Na, ^{60}Co),
- the efficiency calibration: the in Situ Object Counting System (ISOCS™)- a mathematical calibration software was used.

During the measurement, the HPGe detector was placed in the horizontal position 1 m in front of the nearest wall (as on the figure).

in-situ gamma ray measurement by using HPGe detector in server room

In-situ γ ray measurements

	Reiche Zeche server room*	Gran Sasso**	Modane***	Boulby ****
Counts per second [cps]	371.52±0.05	49±9	79±23	24±4
Energy range [keV]	[7-3150]	[7-2734]	[7-2734]	[7-2734]

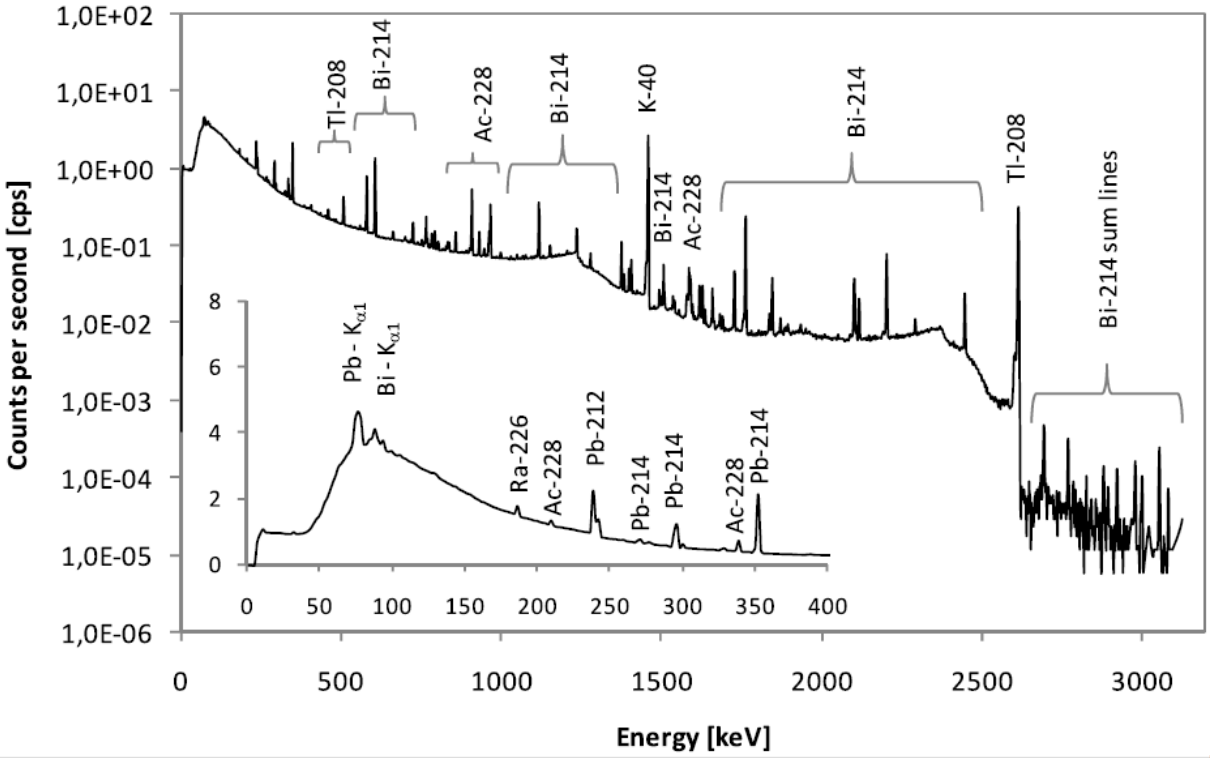
*K.Polaczek-Greliket al.,Nucl. Instrum. Methods Phys. Res. A 946 (2019) 162652,
**D.Malczewskiet al., J RadioanalNuclChem(2013) 295:749–754
*** D.Malczewskiet al., J RadioanalNuclChem(2012) 292:751–756,
**** D.Malczewskiet al., J RadioanalNuclChem(2013) 298:1483–1489

Gamma ray flux density:
2.8 ± 0.8 $cm^{-2}s^{-1}$

Effective dose rate:
0.036 ± 0.008 µSv/h.

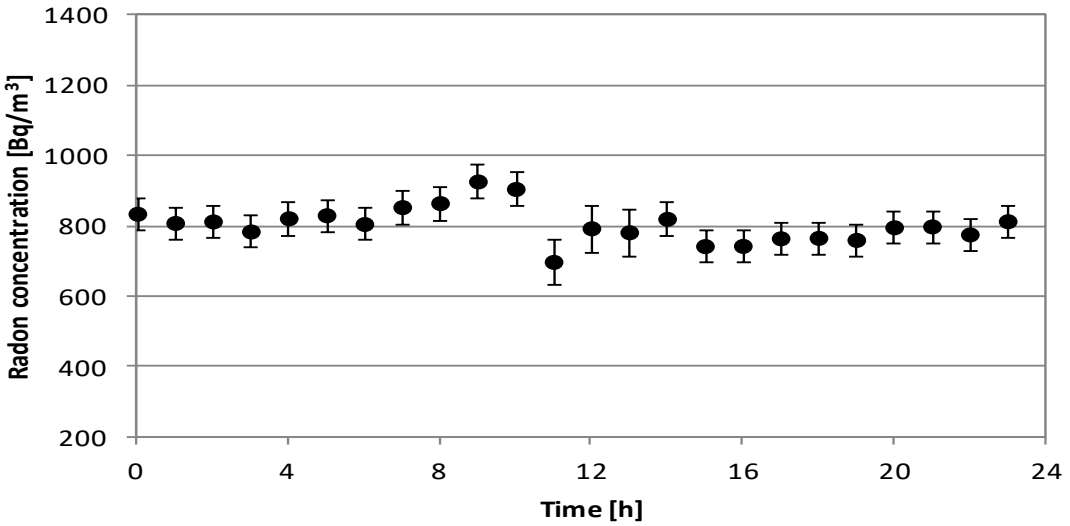
Radioisotopes that have the main contributions in effective dose:
^{40}K (39%) and ^{214}Bi (27%)

Measurement in server room with concrete-coated walls



Radon concentration in air

- The measurement was done in server room by using RAD7 electronic radon detector (Durridge Company, Inc.), which was located near the gamma ray spectrometer.
- Radon concentration was obtained from 24 measurements (1 h-long each).



measurements radon concentration in air by using RAD7 detector in server room

Isotope	Reiche Zeche server room*	Gran Sasso**	Modane**	Boulby**
^{222}Ra [Bq/m^3]	805.1±10.4	50-120	5-15	<3

*K.Polaczek-Grelik et al., Nucl. Instrum. Methods Phys. Res. A 946 (2019) 162652

** L. Pandola, arXiv:1102.0208v1 [hep-ex] 1 Feb 2011

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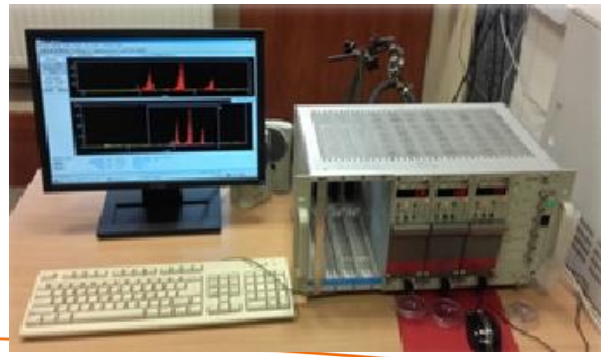
^{238,234}U concentration in water sample

- The measurements of ^{234,238}U isotopes concentration were performed with the use of α spectrometry technique (7401VR from Canberra (Packard)).
- Before measurements the radiochemical procedure was made.
  - Samples were acided with HNO_3.
  - The standard ^{232}U of known activity was added to each water sample.
  - The separation of uranium was done with the use of the anion exchange resin Dowex 1×8*.
  - A thin α-source was prepare d by coprecipitation with NdF_3 and filtration.
  - The Minimum Detectable Activity (MDA) was 0.5 mBq/l for uranium isotopes (^{234,238}U) and 0.5 l initial sample volume.

Isotope	Reiche Zeche ** [mBq/l]
^{238}U	150.4±5.2
^{234}U	142.4±4.9
^{234}U/^{238}U	0.95±0.5
U	12.2±0.4 µg/l



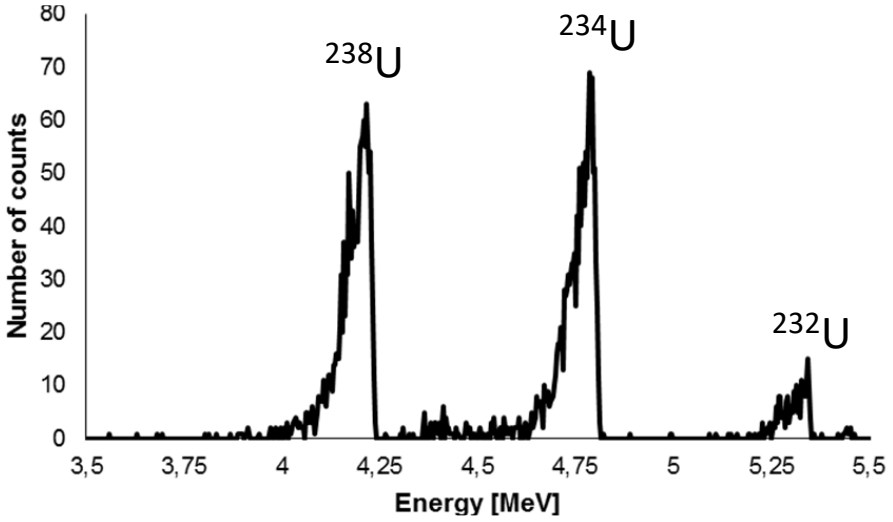
α- spectrometer 7401VR c

*J. Suomela, Method for Determination of U-Isotopes in Water," Swedish Radiation Institute, Stockholm, 1993
**K.Polaczek-Grelik et al., Nucl. Instrum. Methods Phys. Res. A 946 (2019) 162652

^{238,234}U concentration in rock sample

- The measurements of ^{234,238}U isotopes concentration were performed with the same technique as for water sample.
- Additionally, the wet-mineralization of rock samples with hot, concentrated acids were performed.
- Uranium was pre-concentrated with iron and co-precipitated at pH 9.
- The samples were separated from other radio-nuclides in the same way as for water samples.

typical alpha spectrum



Isotope	Reiche Zeche*	Gran Sasso**	Modane***	Boulby ****
^{238}U [Bq/kg]	32.4±2.3 rock	9.5±0.3 concrete 1.8±0.1 rock	22.8±0.7 concrete 11.8±0.6 rock	0.40±0.09 halite 7.1±0.2 mudstone
^{234}U [Bq/kg]	34.4±2.4 rock	-	-	-
^{234}U/^{238}U	1.06±0.11	-	-	-

*K.Polaczek-Grelik et al., Nucl. Instrum. Methods Phys. Res. A 946 (2019) 162652,
**D.Malczewski et al., J Radioanal Nucl Chem (2013) 295:749–754
*** D.Malczewski et al., J Radioanal Nucl Chem (2012) 292:751–756,
**** D.Malczewski et al., J Radioanal Nucl Chem (2013) 298:1483–1489

^{226,228}Ra concentration in water

- The measurements of ^{226,228}Ra activity concentrations were done by using LSC technique (WinSpectral 1414 liquid scintillation counter from Wallac).
- Before measurements the chemical procedure* was applied.
- The time of measurement sample was 1 h (once per day over a period of 25 days, until a secular equilibrium between ^{226}Ra and its daughters was reached).
- The activity concentrations of radium isotopes were below MDA (^{226}Ra: 0.015 Bq/l; ^{228}Ra: 0.04 Bq/l; 3600 s counting time; 1.5 l of water initial sample volume).

Isotope	Reiche Zeche [mBq/l]**
^{226}Ra	<15
^{228}Ra	<40

samples of water

1414 WinSpectral α/β LSC counter from Wallac

*Polish Norm PN-89/ZN-70072, Radium isotopes determination in water with LSC method. Wydawnictwa Normalizacyjne Alfa, 1989.
**K.Polaczek-Grelik et al., Nucl. Instrum. Methods Phys. Res. A 946 (2019) 162652

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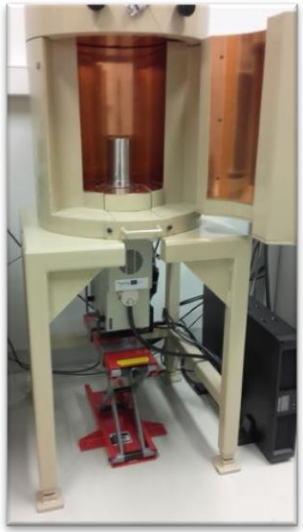
Measurements of radioisotopes in rock samples

- The measurements of radioisotopes concentration (^{40}K, ^{226}Ra, $^{228}Ra(^{232}Th)$) were performed using gamma spectrometry method.
- Before the measurements, rock samples were dried, crushed, ground and stored in Marinelli container (for the period of one month in order to achieve the secular equilibrium in thorium and uranium series).
- The gamma spectrometer was equipped with a lead-shielded HPGe detector (60.7 mm crystal diameter and a Cryo-Pulse 5 Plus, an electrically powered cryostat), with a relative efficiency of 20%.

sample of rock

crushed sample of rock

sample of rock placed in Marinelli container



measurement by using HPGe detector

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Measurements of radioisotopes in rock samples

- The radioactivity concentrations were calculated based on a standard prepared from certificated materials from the Central Laboratory for Radiological Protection in Poland.
- The activity of ^{226}Ra was calculated as the weighted mean of the values obtained from the ^{214}Pb (295.2; 351.9 keV) and ^{214}Bi (609.3; 1120.3 keV) isotopes, whereas the activity of ^{228}Ra was calculated from the gamma lines 338.3 keV and 911.1 keV originating from ^{228}Ac, while the activity of ^{40}K from the 1460.8 keV line.

Isotope	Reiche Zeche*	Gran Sasso**	Modane***	Boulby ****
^{226}Ra [Bq/kg]	43.4±1.6 rock	-	-	-
^{232}Th [Bq/kg]	31.5±0.6 rock	3.7±0.2 concrete 1.5±0.1 rock	6.7±0.2 concrete 10.2±0.5 rock	0.6±0.1 halit 3.9±0.1 mudstone
^{40}K [Bq/kg]	1049±17 rock	70±2 concrete 4.9-26 rock	91±13 concrete 182±30 rock	11±1 halit 120±2 mudstone

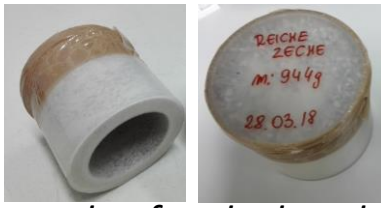
*K.Polaczek-Grelik et al., Nucl. Instrum. Methods Phys. Res. A 946 (2019) 162652,
**D.Malczewski et al., J Radioanal Nucl Chem (2013) 295:749–754
*** D.Malczewski et al., J Radioanal Nucl Chem (2012) 292:751–756,
**** D.Malczewski et al., J Radioanal Nucl Chem (2013) 298:1483–1489

Reiche Zeche

Gamma ray spectrum.
Measurement time: 2.8 days

sample of rock

crushed sample of rock



sample of rock placed in Marinelli container

measurement by using HPGe detector.

Counts

1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0

186.2 226Ra
238.6 212Pb (Th)
295.2 214Pb (Ra)
351.9 214Pb (Ra)
327.6; 338.3 228Ac (Th)
409 228Ac (Th)
463 228Ac (Th)
510.8 208Tl (Th)
583.1 208Tl (Th)
609.3 214Bi (Ra)
665.5 214Bi (Ra)
727.2 214Bi (Th)
764.8 214Bi (Ra)
785.9 214Pb (Ra)
806.2; 934.1 214Bi (Th)
794.7; 835.5 228Ac (Th)
860.4 208Tl (Th)
911.1 228Ac (Th)
934.1 214Bi (Ra)
964.6; 969.1 228Ac (Th)
1001 214Pa (U)
1120.3 214Bi (Ra)
1155.2 214Bi (Ra)
1238.1 214Bi (Ra)
1281 214Bi (Ra)
1377.7; 1385.3 214Bi (Ra)
1401.5; 1408 214Bi (Ra)
1460.8 40K
1495.8 228Ac (Th); 1509.3 214Bi (Ra)
1583.2 214Bi (Ra); 1588.0 228Ac (Th)
1592.7 208Tl Escape
1620.6 214Bi (Ra)
1630.4 228Ac (Th);
1661.3 214Bi (Ra)
1729.6 214Bi (Ra)
1764.5 214Bi (Ra)
1847.4 214Bi (Ra)
2103.7 208Tl Escape
2118.6 214Bi (Ra)
2204.2 214Bi (Ra)
2293.4 214Bi (Ra)
2247.9 214Bi (Ra)
2614.7 208Tl (Th)

0
500
1000
1500
2000
2500

Energy [keV]

Summary

- The results of the characterization of the NBR measured in the server room, Reiche Zeche mine, Germany were presented.
- The in-situ measurements and laboratory analyses were performed with the use of different techniques (α, γ spectrometry, LSC technique).
- The obtained results of radioisotopes concentration in rock samples and also radon concentration in air (in Reiche Zeche mine) are higher than those concentration of radioisotopes in three main European ULs such as: Gran Sasso, Modane and Boulby.
- The concentrations of radium in water samples were below MDA.
- The calculated gamma ray flux density and the effective dose rate (on the base of the γ-ray spectrum) were 2.8 ± 0.8 $cm^{-2}s^{-1}$ and 0.036 ± 0.008 μSv/h, respectively.

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