



## CHARACTERISTICS OF NATURAL BACKGROUND RADIATION AT BSUIN AND EUL UNDERGROUND LABORATORIES

Katarzyna Szkliniarz\*

August Chelkowski Institute of Physics, University of Silesia in Katowice, Chorzów, Poland

**Abstract.** *Characterization of underground laboratories in terms of their natural radioactivity is necessary to determine the conditions that prevail there and plan using these sites for scientific research and other activities. The article compares natural background radiation in three underground laboratories located in the Baltic Sea region. The comparison includes measurements made in underground laboratories (in-situ) and detailed laboratory analyses of water and rock samples taken from these locations. Measurements were made by gamma, alpha spectroscopy, and LSC technique.*

**Keywords:** *Natural radiation, radioisotope concentration, underground laboratories*

### 1. INTRODUCTION

Natural radioactivity surrounds us everywhere, and its intensity varies depending on where we are currently staying. There are also places where the level of natural radioactivity is very low. Such places can be underground laboratories (ULs), where, among other things, large physical experiments are carried out, which need a unique environment to study extremely rare events such as neutrinoless double beta decay or searching for dark matter [1]. Increasingly, underground locations are also used for other purposes such as biology research, plant breeding, tourism, tunnel construction, and many more. The task of the BSUIN (Baltic Sea Underground Innovation Network) [2] and EUL (Empowering Underground Laboratories Network Usage) [3] projects is to strengthen underground laboratories located in the Baltic Sea region to make them more accessible to their users.

Physics experiments searching for rare events are performed deep underground to get rid of the disturbing background reactions caused by secondary cosmic radiation (SCR). At the shallow depths of the Reiche Zeche mine in Germany the shielding against SCR is already a factor of about 500 while it is even 6 orders of magnitude for the deepest of the three installations, the Callio Lab in Finland. The shielding against SCR at the Polkowice-Sieroszowice mine in Poland is about 5 orders of magnitude. In order to be able to take full advantage of ULs the determination of its shielding against SCR and the level of natural radioactivity should be examined.

The paper compares natural radioactivity in three ULs of the BSUIN and EUL projects (Callio Lab (Finland), Reiche Zeche mine (Germany), and in the Polkowice-Sieroszowice mine belonging to the Conceptual Lab development co-ordinated by KGHM Cuprum R&D centre (Poland)). The results include in-situ measurements in underground locations (gamma-ray measurements and radon concentration in the air) and laboratory analysis of rock and water samples from underground laboratories taken.

### 2. MATERIALS AND METHODS

#### 2.1. In-situ measurements

In-situ measurements were made in three underground locations. In the Reiche Zeche mine, Germany, at a depth of 150 m (410 m w.e.) in the server room (in the orthogneiss rock layer) [4]; at Callio Lab, Finland, at a depth of 1436 m (4100 m w.e.) in Lab 2 (at sulphide deposit in felsic volcanic bedrock) [5]; in the Polkowice-Sieroszowice mine, Poland, at a depth of 1014 m (2942 m w.e.) in excavation No. 3 near SW1 shaft (in the anhydrite layer) [6].

In-situ measurements included gamma-ray measurements and radon concentration in the air.

All in-situ gamma measurements at three underground laboratories were performed using the same method with the same equipment. The gamma-ray measurements were performed with the use of portable gamma-ray spectroscopy (GR4020, Canberra Ind., USA), HPGe detector (high purity germanium) with 40% relative detection efficiency, multi-channel

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\* [katarzyna.szkliniarz@us.edu.pl](mailto:katarzyna.szkliniarz@us.edu.pl)



The effective dose (to which people staying in UL are exposed) and gamma-ray flux at Callio Lab (Lab2) are four times higher than in the Reiche Zeche mine (server room) and 20 times higher than in the Polkowice-Sierszowice mine (excavation No.3). At the same time, the counts' rates at Callio Lab (Lab2) are three times higher than at the Polkowice-Sierszowice mine (excavation No. 3).

Based on the collected in-situ gamma-ray spectra, it can be concluded that among the three compared locations, Callio Lab has the highest level of natural radioactivity. The recorded spectra show summation lines in the energy area 2650-3150 keV and characteristic X-rays for the bismuth and lead isotopes, proving the increased content of bismuth  $^{214}\text{Bi}$  from the uranium isotope  $^{238}\text{U}$  (the uranium series precursor) in the surrounding walls of the studied underground locations.

The lowest radon concentration in the air was measured in excavation No. 3 (Polkowice-Sierszowice mine) and it is 120 times lower than in the server room (Reiche Zeche mine).

### 3.2. Results of laboratory analysis of water and rock samples

The comparison of the concentrations of radioisotopes of uranium ( $^{234,238}\text{U}$ ) and radium ( $^{226,228}\text{Ra}$ ) in water samples in two underground laboratories (Reiche Zeche mine and Callio Lab) is presented in Table 2. The table does not include the results of water samples from the Polkowice-Sierszowice mine because the mine does not have any water sources.

Table 2. Comparison of the radioisotopes concentration ( $^{234,238}\text{U}$ ,  $^{226,228}\text{Ra}$ ) in water samples from Reiche Zeche mine and Callio Lab.

Radioisotopes concentration [mBq/l]	Reiche Zeche mine [4]	Callio Lab [5]
$^{234}\text{U}$	142.4(4.9)	0.8(2)-11.1(9)
$^{238}\text{U}$	150.4(5.2)	<0.5-6.5(7)
$^{226}\text{Ra}$	<15	15.1(4)-116.6(2.7)
$^{228}\text{Ra}$	<40	6.1(9)-36.9(2.1)

On the other hand, Table 3 compares the concentrations of uranium ( $^{234,238}\text{U}$ ), radium ( $^{226,228}\text{Ra}$ ), and potassium ( $^{40}\text{K}$ ) in rock samples in the three underground laboratories tested.

Table 3. Comparison of the radioisotopes concentration ( $^{234,238}\text{U}$ ,  $^{226,228}\text{Ra}$ ,  $^{40}\text{K}$ ) in rock samples from Reiche Zeche mine, Callio Lab and Polkowice-Sierszowice mine.

Radioisotope concentration [Bq/kg]	Reiche Zeche mine [4]	Callio Lab [5]	Polkowice-Sierszowice mine [6]
$^{234}\text{U}$	34.4(2.4)	1.6(2)-10.3(1.3)	8.7(3)
$^{238}\text{U}$	32.4(2.3)	1.4(2)-11.4(1.4)	8.8(3)
$^{226}\text{Ra}$	43.8(4)	8.1(4)-58.0(2.3)	7.2(3)
$^{228}\text{Ra}$	31.5(6)	2.6(3)-46.6(2.4)	0.30(5)
$^{40}\text{K}$	1049(17)	104(10)-272(24)	9.4(3)

The highest concentrations of uranium radioisotopes were recorded in water samples from the Reiche Zeche mine. They were about 10 times higher for  $^{234}\text{U}$  and about 20 times higher for  $^{238}\text{U}$  than

samples from Callio Lab. On the other hand, the concentrations of radium ( $^{226,228}\text{Ra}$ ) radioisotopes in the water samples from the Reiche Zeche mine were below the detection limit.

Concentrations of uranium radioisotopes ( $^{234,238}\text{U}$ ) in rock samples in all ULs were at a similar level, which proving that a radioactive equilibrium between  $^{234}\text{U}$  and  $^{238}\text{U}$  was achieved (ratio  $^{234}\text{U}/^{238}\text{U}$  about 1.0). The highest concentration of  $^{234}\text{U}$  and  $^{238}\text{U}$  was recorded in the samples from the Reiche Zeche mine and the lowest for the rock samples from Callio Lab. In turn, the lowest concentrations of radium ( $^{226,228}\text{Ra}$ ) and potassium ( $^{40}\text{K}$ ) radioisotopes were tested in anhydrite samples from the Polkowice-Sierszowice mine. In the tested rock samples, a disequilibrium radioactive between the isotopes of uranium  $^{238}\text{U}$  and radium  $^{226}\text{Ra}$  from the uranium series can be noticed. The  $^{238}\text{U}/^{226}\text{Ra}$  ratio below one was determined for the rock samples from the Reiche Zeche mine (0.7) and Callio Lab (from 0.07 to 0.7). In the samples taken from the Polkowice-Sierszowice mine, this ratio was above one and was 1.2. This disequilibrium radioactive can be due to the difference in geochemical properties between radium ( $^{226}\text{Ra}$ ) and uranium ( $^{238}\text{U}$ ) and the greater mobility of radium in the environment.

In-situ gamma-ray measurements at Callio Lab and Reiche Zeche mine were made in rooms where the surrounding walls, floor, and ceiling were covered with concrete or bricks to stabilize the structure of the rooms [4,5]. Additionally, concrete samples were collected for Callio Lab for laboratory analysis (similar to rock samples). The uranium, radium, and potassium activities in concrete samples showed more significant activity (from 1 to 9 times) than for rock samples [5]. The increased concentration of the analyzed uranium series radioisotopes in the taken samples of concrete and rocks from Callio Lab and Reiche Zeche mine was confirmed by a higher level of gamma-ray in in-situ spectra.

## 5. CONCLUSION

Based on the presented comparison of three underground laboratories of the EUL and BSUIN projects (Callio Lab, Reiche Zeche mine, and Polkowice-Sierszowice mine), it can be concluded that the lowest level of natural radioactivity was estimated in the anhydrite layer of the Polkowice-Sierszowice mine. In combination with its very good shielding against SCR, although slightly worse than that of the Callio Lab, the Polkowice-Sierszowice mine is very well suited for rare event experiments, like the search for neutrino-less double beta decay or other fundamental physics experiments.

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