# Radionuclides Activity and Effective Doses Referred to Geological Formations

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***Abstract*—Naturally occurring radioactive materials (NORM) are present in Earth's crust and they caused natural background radiation, variable in different regions. Liquid, gas and solid radionuclides emit three types of radiation – alpha, beta and gamma. Fluctuations of natural radioactivity in different geological formations in the world and in Poland were compared in relation to radiological hazard. Also drilling cuttings from boreholes in Pomerania were investigated by a dosimeter to estimate absorbed doses associated with unconventional oil and gas exploration. It provides the possibility to verify the hazard of exposure to ionizing radiation from rocks during oil and gas activities in this area.**

***Index Terms*—natural radioactivity, gamma radiation, radionuclides, geological formations, rocks**

## I. Introduction

Natural radioactivity is caused by radiation emitted from naturally occurring radioactive materials (NORM) which are present in environment in varying concentrations. Origin and concentration of radionuclides is variable, e.g. thorium and uranium are present in the earth's crust at concentrations of 4.2 and 12.5 ppm [1].

Radioactive elements can be divided into two groups. First are primodial radionuclides created during the formation of the earth or products of their decays. An essential part in the background gamma radiation is radioisotopes from decays of Th-232 and U-238, as well as the unstable isotope K-40 [2]. They are currently present beceasue their half-life is comparable to the age of the earth [3]. The second group are the elements created by the nuclear reactions of cosmic ray particles with atmosphere components such as H-3, Be-7, C-14, Na-22 [3] [4]. First radionuclides were created through nucleosyntheses occurred in stars.

The objective of this work is to compare background radiation and natural radioactivity of rocks in different locations and lithology, particularly in Poland and also to measure samples of rocks from boreholes being drilled in Pomerania to estimate radiological hazard.

## II. Radioactivity of Geological Formation

### A. Significance of Ionizing Radiation from Rocks

Measurement of NORM concentration in geological formation is important to estimate radiological hazard resulting from them and avoid elevated doses of ionizing radiation, especially when they are used as construction or ornamental material. In some kind of branches of industry external and internal risk of exposure to ionizing radiation is observed because of accumulating of TENORM (Technologically Enhanced NORM) [5]. This can be observed in mining and milling activities, ore processing, cement production [6] [7]. Natural gamma radiation measured during well logging or core testing gives information about lithological parameters and characteristics of rocks [8]. It is also an indicator in recognizing a type of geological formation and could be used for geological mapping [8] [9]. Elevated gamma radiation originates from igneous rocks [3]. Higher radioactivity regarding volcanic rocks and clays (shale, sandstone, granite), lower is mainly in sedimentary rocks. [3] [10] High ionizing radiation is an indicator of "shaliness" [8]. The concentration oncentration of radioactive elements increases also in bituminous rocks, pyrobituminous and gilsonite [3] [10].

### B. Radionuclides in Rocks

Activity of radioisotopes measured in different type of rocks in around the world is provided in Table I. Natural radioactivity is strongly associated with geological and geographical conditions [3] [9] and depend on variable activity concentrations of natural radioisotopes associated with the type of rock, petrology features, lithology and mineral composition [6] [11].

Results from Table I. confirm that concentrations of radioisotopes in different rocks are variable. Potassium K-40 dominates in all types of rocks, especially in igneous rocks like granite.

Global typical values present in Table II show that the range of radioactive variability is wide even for the same geological formation.

Table II provides results of NORM activity concentrations in Poland. As has been stated natural gamma radiation observed in the environment is associated with lithology and other geological and geographical conditions. Polish Geological Institute made a dose rate map of Poland (Fig. 1)–observed results correspond with the presence at the surface rocks with higher natural radioactivity such as granitoids (Giant

Manuscript received December 19, 2013; revised April 16, 2014.


doi: 10.12720/jiii.2.4.284-288

Mountains), shales (Intra-Sudetic Depression) and igneous rocks (Złote Góry and Śnieżnik massifs) [12]. Most of the results reported in the literature come from southern Poland. In northern Poland values are scarse because formations rich in radioisotopes are in deeper strata.

TABLE I. ACTIVITY OF RADIONUCLIDES IN DIFFERENT TYPE OF ROCKS [3] [11] [13] [14]

| Country | Type of rock | Radionuclide | Activity [Bq/kg] | Reference |
|---|---|---|---|---|
| Egypt | Gneiss | Ra-226 | 28,4±3,0 | 13 |
| | | Th-232 | 37,4±4,0 | |
| | | K-40 | 1167,6±42,0 | |
| Egypt | Granite | Ra-226 | 118±7,0 | 13 |
| | | Th-232 | 90,5±7,0 | |
| | | K-40 | 2208,0±91,0 | |
| Egypt | Basalt | Ra-226 | 59,5±4,0 | 13 |
| | | Th-232 | 67,7±6,0 | |
| | | K-40 | 718,5±42,0 | |
| Egypt | Sandstone | Ra-226 | 7,5±1,5 | 13 |
| | | Th-232 | 12,5±3,0 | |
| | | K-40 | 264,0±11,0 | |
| Cyprus | Plagiogranite | Th-232 | 2,8±0,1 | 3 |
| | | U-238 | 3,0±0,1 | |
| | | K-40 | 128,4±5,0 | |
| Cyprus | Limestone | Th-232 | 2,1±0,1 | 3 |
| | | U-238 | 8,3±0,3 | |
| | | K-40 | 20,0±1,0 | |
| Cyprus | Bentonitic Clay | Th-232 | 40,7±1,1 | 3 |
| | | U-238 | 18,3±0,6 | |
| | | K-40 | 278,9±10,8 | |
| Nigeria | Sandstone | Ra-226 | 38,3±10,9 | 11 |
| | | Th-232 | 88,1±26,1 | |
| | | K-40 | 114,0±21,0 | |
| Nigeria | Shale | Ra-226 | 44,8±24,4 | 11 |
| | | Th-232 | 79,8±24,9 | |
| | | K-40 | 470,0±331,0 | |
| Nigeria | Granite | Ra-226 | 129,0±38,0 | 11 |
| | | Th-232 | 131,0±43,0 | |
| | | K-40 | 882,0±298,0 | |
| Global | Granite | Ra-226 | 1,0,0-370 | 14 |
| | | Ra-228 | 0,4-103,0 | |
| Global | Basalt | Ra-226 | 0,4-41,0 | 14 |
| | | Ra-228 | 0,2-36,0 | |
| Global | Limestone | Ra-226 | 0,4-340 | 14 |
| | | Ra-228 | 0,1-540,0 | |
| Global | Clay/shale | Ra-226 | 1,0-990,0 | 14 |
| | | Ra-228 | 0,8-147,0 | |
| Global | Gneiss | Ra-226 | 1,0-1800,0 | 14 |
| | | Ra-228 | 0,4-420,0 | |

TABLE II. ACTIVITY OF RADIONUCLIDES IN DIFFERENT TYPE OF ROCKS IN POLAND [2] [15]

| Region | Type of rock | Radionuclide | Activity [Bq/kg] | Reference |
|---|---|---|---|---|
| Krzeszowice | Tuff | Ra-226 | 32,7±5,5 | 2 |
| | | K-40 | 3154,0±15,0 | |
| Krzeszowice | Porphyry | Ra-226 | 23,5±4,5 | 2 |
| | | K-40 | 1032,0±6,0 | |
| Krzeszowice | Carbonifero-us Limestone | Ra-226 | 35,7±2,4 | 2 |
| | | K-40 | 53,0±2,0 | |
| Krzeszowice | Devonian Limestone | Ra-226 | 43,2±6,8 | 2 |
| | | K-40 | 473,0±9,0 | |
| Świeradów-Zdrój | Quartz | Ra-226 | 4,6,8±6,6 | 15 |
| | | K-40 | 324,0±7,0 | |
| Świeradów-Zdrój | Granite-gneiss | Ra-226 | 49,8±6,9 | 15 |
| | | K-40 | 1177,0±13,0 | |
| Świeradów-Zdrój | Hornfelses | Ra-226 | 30,7±3,7 | 15 |
| | | K-40 | 494,0±6,0 | |

### C. *Gamma Dose Rate*

Total air absorbed dose rate [nGy/h] at 1m elevation above ground can be estimated by equation (1) [16]

$$D = 0{,}462ARa + 0{,}604ATh + 0{,}042Ak \quad (1)$$

Average gamma dose rate in Poland reported in Polish Geological Institute research is much lower: 34, 2 nGy/h with range from 23,3 nGy/h to 65,3 nGy/h [12]. Results from different countries are provided in Table III. The map with results obtain in Poland is on Fig. 1.

Global average absorbed dose rate according to UNSCEAR Reports is 58 nGy/h. Selected values from different countries are given in Table IV.

Annual average equivalent absorbed dose in Poland is 3, 3 mSv/a [17] – both from natural and artificial sources.

 

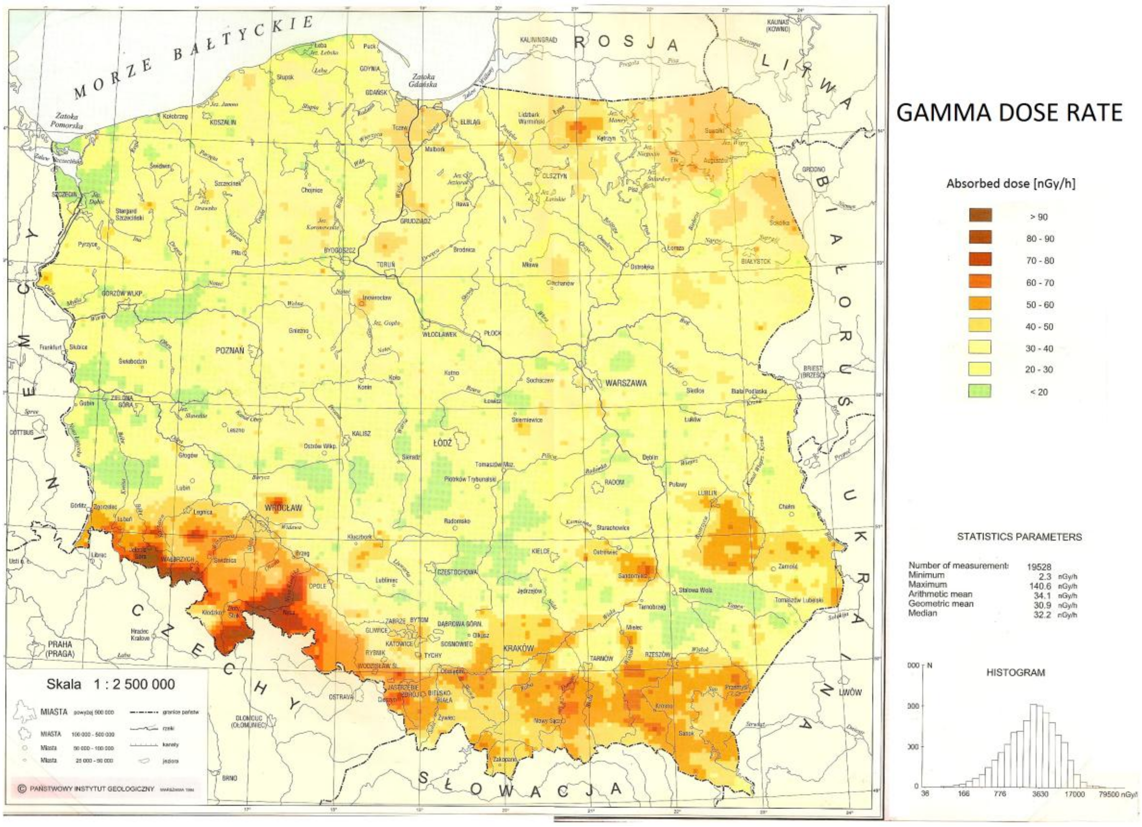


Figure 1. Map of gamma dose rate [12]

TABLE III. RANGE OF ABSORBED DOSE RATE OF GAMMA RADIATION IN AIR IN DIFFERENT COUNTRIES [18]

| Country | Absorbed dose rate [nGy/h] |
|---|---|
| Canada | 31-75 |
| Cuba | 38-196 |
| Indonesia | 45-102 |
| Turkey | 32-94 |
| Lithuania | 79-115 |
| Italy | 57-243 |
| Poland | 51-126 |

TABLE IV. RANGE OF EQUIVALENT ABSORBED DOSE RATE IN DIFFERENT COUNTRIES [19]-[24]

| Country | Equivalent dose [nSv/h] from natural sources | Total equivalent dose [nGy/h] | References |
|---|---|---|---|
| United Kingdom | 223 | 270 | 19 |
| Ireland | 340 | 395 | 20 |
| Australia | 150 | 230 | 21 |
| Canada | 180 | - | 22 |
| Poland | 244 | 330 | 23 |
| Global | 240 | 281 | 24 |

## III. EXPERIMENTAL

### A. Sample Procurement and Measurment

Samples of fractioned drilling cuttings (shown on Fig. 2.) from several Pomeranian boreholes were investigated. Shale rocks outcrop cannot be found in Pomeranian part of the Baltic Basin, however, exposure to ionizing radiation is associated with prospection of unconventional shale gas reservoirs and deep-seated geological structure. Location and characteristics of samples is classified due to the requirement made by the drilling companies.

Figure 2. Drilling cuttings from deep-seated geological structure (Paleozoic) in Pomerania (Poland)

 

GAMMA SCOUT dosimeter with Geiger–Müller counter was used for the measurement of equivalent absorbed dose rate during standard procedure. Every sample was measured 30 times and average values are given. Background radiation in Gdansk (in laboratory of Gdansk University of Technology) was measured 100 times.

### *B. Results and Discussion*

Average absorbed dose rate data from fractioned drilling cuttings is provided in Table V and also shown on histogram.

TABLE V. EFFECTIVE ABSORBED DOSE RATE FROM MEASUREMENT OF DRILLING CUTTINGS

| Sample | Absorbed dose rate [nSv/h] |
|---|---|
| Background | 181±40 |
| DC1 | 172±33 |
| DC2 | 203±40 |
| DC3 | 178±36 |
| DC4 | 190±42 |
| DC5 | 166±42 |
| DC6 | 171±38 |

We assumed that the background radiation consists of natural and artificial sources which give absorbed dose rate 181 nSv/h. This value is a reference one to the other results and they were considered in respect to the background in the area of the experiment. It is lower than the average dose in Poland which amounts 330 nSv/h [4]. The annual dose rate from terrestrial gamma radiation in Poland is lower than global one equal to 58 nGy/y but the annual average equivalent absorbed dose in Poland is 3,3 mSv/a which exceeds global 2, 81 mSv/h. Total equivalent dose from background radiation obtained in Gdansk University of Technology (1,56 mSv/h) is lower than the worldwide average. Considering Polish results that correspond with the data provided by the Polish Geological Institute one can deduce that Pomerania is an area with low gamma radiation (Fig. 1).

Fig. 3 shows the comparison of background radiation measured in Gdansk and other location listed in Table IV.

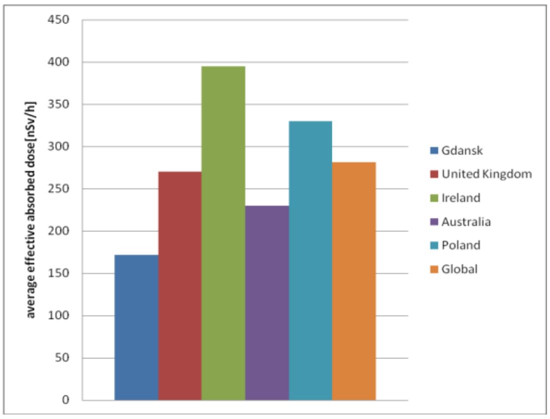


Figure 3. Comparison of effective absorbed dose rate from background in different countries

Pomerania samples do not exceed the range of background radiation therefore they do not represent any hazard of internal and external radiation to workers and inhabitants living nearby. The comparison of results from investigated samples is shown in Fig. 4.

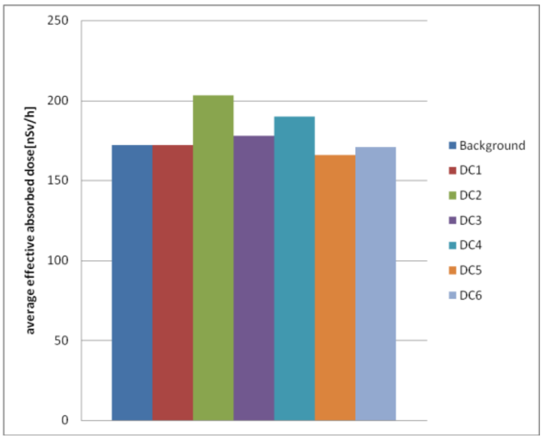


Figure 4. Effective absorbed dose rate from measured drilling cuttings

## IV. FINAL COMMENTS

Natural radioactivity depends on geological and geographical conditions and it is strongly correlated with lithology – different types of rocks have variable activity of radionuclides and variable ratio between potassium, uranium, thorium and radium. Elevated levels of NORM pertain to volcanic rocks and clays. In oil/gas well logging elevated gamma radiation is an indicate "shaliness".

Terrestrial gamma dose rate in Poland is lower than the global average dose and the region with the lowest radiation is northern Poland. Equivalent absorbed dose in Poland is higher than the average worldwide result.

Background radiation determined in Gdansk (GUT) is 181±40 nSv/h. The result is lower than the average value in Poland 330 nSv/h which corresponds to data shown in the map (Fig. 1) showing that absorbed doses in this area are lower than the total in Poland. The examined samples of rocks–drilling cuttings from northern Poland (Pomerania) boreholes do not present hazard of exposure to ionizing radiation because equivalent absorbed doses are comparable to background radiation in this area.

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