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Factors affecting atmospheric radon concentration, human health

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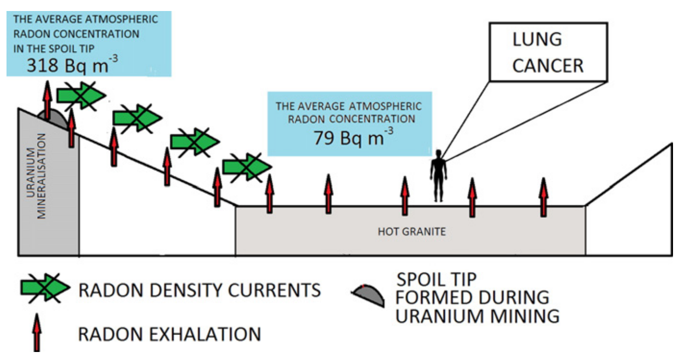
HIGHLIGHTS

- Seasonal and spatial variations of radon concentration in the atmosphere
- Increased radon concentration in the atmosphere induces lung cancer.
- Radon density currents were not observed.
- Terrain, geology and weather condition impact on radon concentration

GRAPHICAL ABSTRACT



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ABSTRACT

We studied the influence of terrain, geology and weather condition on radon concentration in the atmosphere and occurrence of radon density currents.

The survey was carried out in Kowary (SW Poland) and in the spoil tip formed during uranium mining. The measurements of radon concentration were performed using SSNTD LR-115. The measurements of uranium thorium and potassium content in soil were carried out using gamma ray spectrometer Exploranium RS-230.

We noticed that terrain and stability of weather condition had significant impact on atmospheric radon concentration. The seasonal variations of radon concentrations in Kowary differ from those usually registered in temperate climate. Based on our analyses, the increase of radon concentration in winter and spring was caused by inversion occurring in that area during these seasons.

The observed seasonal variations of radon concentrations in the spoil tip were consistent with those characteristic for temperate climate (the highest radon concentration registered in spring and summer and the lowest in winter and autumn). The spoil tip is located above 900 m a.s.l. and is not cover by grass or trees. These circumstances promoted radon exhalation. The air movement above the spoil tip area is intensive, even in winter time. The average atmospheric radon concentration in the spoil tip was 318 Bq m^{-3}.

The performed research did not reveal occurrence of radon density currents and flow of radon from the spoil tip to lower lying areas in Kowary.

We noticed interdependence of atmospheric radon concentration measured at the height of 1.5 above the ground and uranium content in soil and no correlation between thorium content and radon concentration.

The lung cancer in residents of Kowary which is more common than in Poland can be associated with increased concentrations of radon. The average radon concentration in the atmosphere in Kowary was 79 Bq m^{-3}.

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1. Introduction

Radon is a radioactive gas with symbol Rn and atomic number 86. The density of radon is 9.73 kg m^{-3}, whereas the density of the Earth's atmosphere at sea level is 1.217 kg m^3 (Wiliams, 2016).

Radon has 36 isotopes with atomic masses ranging from 193 to 228. None of these isotopes is stable. Four isotopes occur naturally: Rn-222, Rn-218, Rn-220, Rn-219. The most stable isotope Rn-222 has half-life 3.8 days and then Rn-220 with half-life 55.6 s. The half-life of Rn-219 is 3.96 s and the half-life of Rn-218 is 35 ms. Generally in nature, radon occurs mainly as Rn-222 and Rn-220 (Jönsson, 1995).

Rn-222 and Rn-218 are formed as intermediate steps in uranium series (U-238), Rn-219 in U-235 series, and Rn-220 in thorium series. Uranium and thorium are the two most common radioactive elements on the Earth.

Uranium in nature has three main isotopes: U-238, U-235 and U-234. The contributions of these isotopes are as follows: the largest content of U-238 which is 99.2739–99.2752%, then U-235 0.7198–0.7202%, and a very small amount of U-234 (0.0050–0.0059%). The half-life of U-238 is 4.47 billion years, U-235 is 704 million years and U-234 is 246 thousand years. The isotope U-238 exists in current form longer than the Earth (which was formed about 4.5 billion years ago) and even longer than the Universe (the generally accepted age of the Universe formation is about 13.8 billion years). Together with Th-232 they are primordial nuclides (Dalkham, 1993).

Thorium is most commonly considered to be mononuclidic (although has 6 naturally occurring isotopes). The main isotope is Th-232, with half-life 14.05 billion years. However, in deep seawaters the isotope Th-230 (with half-life 70.5 thousand years) became significant enough that IUPAC reclassified thorium as a binuclidic element in 2013.

Uranium and thorium occur naturally in low concentrations of a few parts per million in soil, rocks and water. The concentration of thorium in the Earth's crust is about three to four times higher than uranium (Durrance, 1986).

Thorium and uranium and their decay products (including radon) will therefore continue to occur for tens of millions of years at almost the same concentrations as they do now. Usually in nature, radioactive equilibrium exists in uranium and thorium radioactive series, which means that the rate of decay of each nuclide is equal to its rate of production. It follows that all rates of decay of the different nuclides within the sample are equal (IAEA, 2003).

Radon concentration in the atmosphere varies widely from place to place. The world average radon concentration in the atmosphere is 10 Bq m^{-3} (Jönsson, 1995).

Radon concentration in the atmosphere is depended on: contents of uranium and thorium within a few meters in soil or rock; parameters of ground such as: porosity, moisture, mineral content; type of soil cover (Pressanov et al., 1995; Nagaraja et al., 2003). The other factors influencing atmospheric radon concentration are: wind speed, atmospheric pressure and temperature, precipitations (Gudresen and Wanty, 1993; Porstendörfer, 1994).

We carried out the research of atmospheric radon concentration in Kowary in order to examine the influence of terrain and terrain-related parameters such as weather conditions on radon concentration. Moreover we wanted to answer the following questions: (i) can radon accumulate in depressions or lower-lying areas? (ii) does radon density currents exist? (iii) can radon flow from upper located places through slopes to depression? (iiii) can accumulation of radon outdoor be dangerous for people?

1.1. Location

We kept the following criterions choosing appropriate location to carry out research: (i) a region of diverse terrain – hills, mountains and depressions (ii) upper-lying areas with soils and bedrock of elevated uranium content, where increased radon concentrations in the atmosphere can be expected in order to be able to register radon density currents and flowing of radon through slopes.

Eventually, we carried out research in Kowary (SW Poland, SW Jelenia Góra Valley) (Fig. 1). Kowary is a town with an area 37.4 km^2 inhabited by over 11.5000 residents, located between Karkonosze Mts. and Rudawy Janowckie. This town is stretched in the direction NW-SE and characterised by varied terrain from 420 m a.s.l. (Lower Kowary) to 1280 m a.s.l. (Upper Kowary) (Woś, 1999).

Municipality Kowary is situated within the climate of mountain type, with features specific to temperate climatic zone. Mostly, moist air masses from the west flow on this region. Two local climatic zones are observed in the area of Kowary: moderately warm with the average annual temperature of 5–8 °C (lower-lying area – Lower Kowary) and moderately cool with the average annual temperature of 2–5 °C (higher altitudes a.s.l. - Upper Kowary). The temperature decreases with increase of altitude a.s.l. from 7.2 °C (420 m) to 2.8 °C (1.268 m), with the average of 0.51 °C per 100 m. In the Kowarski Ridge (Upper Kowary), usually, temperature is lower about 3–5 °C than in the city center (Lower Kowary). Sometimes, during cold seasons inversion occurs. Then the temperature in lower-lying areas is lower than in surroundings hills and mountains (Woś, 1999).

The 10-year seasonal average values of temperature, precipitation, atmospheric pressure and wind directions are reported in Table 1.

Kowary is situated in the area of the Karkonosze Granite intrusion and the Izera-Kowary Unit which are a part of the Karkonosze-Izera Massif - a major tectonic unit in the Western Sudetes. The Karkonosze intrusion comprises three lithological varieties: coarse-crystalline, porphyritic, "central" granite, fine-crystalline "ridge" granite and granophyric granite. The Karkonosze Granite reveals increased uranium contents in comparison with other granites in the Sudetes (Mochnacka and Banaś, 2000). According to Jeliński (1965) average uranium content in equigranular granite was to 18.3 ppm, in porphyritic granite to 10.6 ppm and in granophyric granite to 11.3 ppm

The Izera-Kowary Unit comprises gneisses and mica schists. The eastern and the southern parts of the Izera-Kowary Unit comprise the Kowary Gneises and Karkonosze Gneisses. The schists series are composed of muscovite-albite schists with amphibolite, quartzite and quartzofeldspathic rock intercalations and mica schist with quartzites, erlans, crystalline limestones, striped amphibolies, felsitic metavolcanics as well as chlorite and graphite schist interbeds (Mochnacka and Banaś, 2000). The Izera-Kowary Unit hosts a number of ore deposits and ore minerals occurrences and has been the site of ore mining operations since at least XII century. The mining activity had declined and rejuvenated many times during this time. The final closure of mining activity occurred in the 1960s. Relics of old mines: shafts, adits, spoil tips and tailings are still visible in this region.

In Kowary area, the following mines existed.

The Kowary magnetite-uranium–polymetallic mine, where first magnetite, then also uranium were exploited. It is complicated structure composed of two different types of spatially related orebodies: magnetite and uranium-polymetallic. The stratabound magnetite orebody is hosted in the metamorphic succession named Podgórze ore-bearing formation. Magnetite lenses are located at the contacts of marbles and amphibolites, within amphibolites, in the vicinity of skarn bodies and the contacts of skarns and marbles. Accompanying minerals are pyrrhotite and pyrite with other minor sulphides. The hydrothermal, uranium-polymetallic orebodies are generally related to local fault but ore accumulations rather follow the accompanying, small, secondary dislocations. Moreover, there appear minor, nest-like aggregates of uranium minerals accompanied by various sulphides hosted in quartz stockworks whereas close to the surface uranium minerals are enclosed in carbonate veins (Mochnacka, 1967). Uranium – polymetallic orebodies are located mainly in the segment of the metamorphic ore-bearing formation which plunges under the Karkonosze Granite (Mochnacka et al., 2015).