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The Underground Tourist Route Kowary Drifts – An Example to Follow

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Abstract:

In recent decades, we have seen a rapid increase in the number of underground tourist routes. One of them, the underground tourist route "Kowary Drifts" placed in the tunnel No. 9 in the former uranium mine "Liczyrzepa", was launched in 2002. Thanks to the high awareness of the owners, since the very beginning the route has been fully controlled, including control of exposure to radon. For the measurement of radon concentration trace detectors and scintillation chambers were used. Long-term studies have shown that the average concentration in this tourist route is 500 Bqm^{-3}. Staff of the underground tourist route, and inhalation should be counted in the category of B radiation exposure.

Keywords: Radon; Underground tourist rout; Radiation protection

Introduction

The emergence and development of Kowary was associated primarily with iron ore mining and blacksmithing. According to oral tradition, in 1148, Lawrence Angelus, a Walloon miner, found iron ore on the slopes of Mount Rudnik. Ten years later, the Polish prince Boleslaw IV the Curly, the ruler of the territory, sent first miners to settle at the location. Kowary lies in the valley of the river Jedlica - in its upper reaches, between the Rudawy Janowickie and the Karkonosze mountains (http://www.polskieszlaki.pl202017).

Intensive development of the Kowary mining industry continued during the 19^{th} and 20^{th} centuries. The major materials mined included iron ore, fluorite, and the ores of zinc, lead, silver, copper and uranium (Gawor 2009).

Exploitation of uranium ore in Kowary started before World War II from the deposits of magnetite mine Freedom, and the total pre-war production from that mine was roughly 70 tons in terms of pure uranium. As a result of the success of the post-war geological explorations, operation of the Kowary Mines started in 1948. The next step was to launch the Industrial Plants R-1 group. The group was very large, it included all mines extracting uranium ore in other parts of Poland, e.g. in Rudki near Kielce. The management of the mines, laboratory, transportation and maintenance facilities were located in Kowary. The R-1 group, in the 1948-1972 period, employed about 25-26 thousand people. Throughout that period, all operations were top secret. It wasn't until 1956 that Polish experts were permitted to hold managerial positions.

Since 1952, due to the development of nuclear fusion technology, interest in the mining (for military applications) of uranium ore in which the content of the fissile isotope U-235 was about 0.7% (relative to the total of the isotopes) continued to abate. In the spring of 1958, the last Russians left the R-1 plants. After the exhaustion of exploitable deposits, 1962 saw the closing of the last mine in Kowary, named Freedom. Since then, the management of R-1 group continued closing mines in other regions, and in 1973, R-1 was formally dissolved.

Working in the mines was associated with hazards typical to mining, primarily dust generated ore and rocks were mined and transported, as well as ionizing radiation. Until 1957, there had been no official mention of the risks associated with the presence of ionizing radiation. In the mining of uranium, there are two kinds of risks from ionizing radiation: the elevated levels of gamma radiation and the high concentration of radon and its derivatives in the air. According to the data accessible to myself, e.g. in the third quarter of 1957 radon concentration (depending on the measuring location) ranged from 18.5 to 888 $kBqm^{-3}$ (Muras 2009). This means that during that period, the effective doses of radon to miners might exceed 1 Sv. As a result of discontinued operation of the mines, the mining and exploration drifts, heaps of mined material and other elements of the mines have become useless.

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Reassignment of post-mining excavations

The idea to use excavations for other purposes after the mines were no longer in use was put forward quite early (1968). There were plans to launch an underground radon inhalation facility in the former mine Podgórze that would replicate the inhalation facility in Bad Gastein, Austria. The first inhalation room (radon galleries) for treating patients was put into trial in 1974. Drift No. 19a was used for this purpose. In 1975, plans were developed for the reassignment of mine drift No. 9, known as the Liczyrzepa Drift. It had been scheduled to house the Mining Laboratory of the Institute of Mining, Technical University of Wroclaw. Drift 9 also housed an inhalation chamber for about 20 patients. At the turn of 90/91, political changes and economic circumstances caused the works in the Podgórze mine to be phased out, inhalation facilities closed, and in 1994, the mining laboratory was also shut down. The region of drift 9 and 19 for several years had been unused and neglected, and gradually deteriorated.

Steps taken by Marek Jankowski and Wojciech Jablonski, two businessmen from the Wielkopolska region, have saved the drift No. 9 and buildings that were erected there from total destruction. Their interest in the drift No. 9 resulted, on 29th April 2000, in starting the underground tourist route Kowary Drifts and in 2002, the radon inhalation facility was created. Since the beginning of the implementation of these plans, the owners of the drifts were aware of the presence of radon in the area, which can be harmful to the health of workers, but also - as shown by previous studies of Professor Bogumil Halawa of Wroclaw Medical University - at low concentrations it may be successfully used for treatment of many diseases (Halawa 1980).

The study had two objectives. Firstly, to examine the level of threat from radon to personnel before starting the route. Secondly, to continuously monitor the concentration of radon in the indoor tourist route after its launch.

Measuring methods

The following instruments and measurement methods were used for the determination of radon hazards.

1. Passive dosemeters with track detectors - to measure individual exposure to radon and/or periodic radon concentration changes in the air.
2. Scintillation chambers for the measurement of radon levels in the air in a short period of time.

Ad.1 passive dosimeter

The term "passive dosimeter" means that the recording of radiation takes place in a passive manner, without the use of assistive mechanical or electronic devices. A passive dosimeter consists of a dosimeter cartridge and a track detector. A closed type NRPB dosemeter was used for long-term measurements of radon concentrations in underground tourist routes.

A closed cartridge dosimeter type NRPB is made of plastic (Gilvin et al, 1988). It consists of two parts. The cartridge dimensions are: diameter 5.5 cm, thickness 2 cm. A track detector CR-39 is located inside the cartridge. An important design feature of the cartridge NRPB is that after it is closed, only the radon is able to diffuse through micro cavities to the inside. Thus, radon concentration inside the chamber reaches a value equal to that in the ambient air, regardless of the concentration of radon daughters. It is therefore a device for the determination of radon exposure. When precise measurement time is known, one can calculate the average concentration of radon prevailing in the air during that period. Dosemeter NRPB is presented in Figure 1.

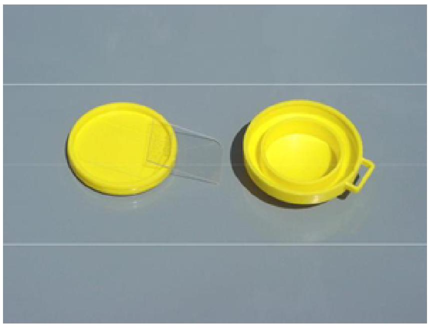

Figure 1: Disassembled dosemeter cartridge type NRPB with detector CR-39

Basic specifications
Lower detection limit: 20 kBqhm^{-3}
Upper detection limit: 1 MBqhm^{-3}
Measurement precision: 15%
Analyzed area: 192 mm^{2}

After the completion of the exposure, detectors CR-39 (or Tastrak) are subjected to a chemical treatment involving the etching in 20% solution of NaOH at 80°C for 18 hours.

Analysis of track detectors is performed using an image analysis system (IMAL Co.) at the Nofer Institute of Occupational Medicine. (Kluszczynski et al, 1996) The density of tracks (tr/mm2) obtained a result of the analysis is then converted to the value of the exposure received by the detector.

Ad 2. RDA 200 and scintillation chambers

An RDA-200 meter consisting of a scintillation chamber known as Lucas cell, and a recording system with a photomultiplier (EDA, Canada) is a device designed to measure the concentration of the radioactive gas radon ^{222}Rn found in ambient air. The measurement of the concentration of radon involves the determination of the alpha radioactivity of air sample aspired through a filter into the scintillation chamber by a manual or mechanical pump. The scintillation chamber capacity is 176 cm^{3}. About 2 dm^{3} of the air must be aspired through the filter to ensure full exchange of the air. The sampling time depends on the efficiency of the pump. In the scintillation chamber, radon and its daughters emit alpha particles that produce flashes of light in the scintillator material covering the chamber wall. Radiation-induced flashes of light are recorded by a photomultiplier placed under the transparent window at the bottom of the chamber and are then converted into electrical pulses. The number of pulses is proportional to the activity of the air sample.

Measuring the activity of the sample of air in the scintillation chamber should start after 3 hours of collection. This time, it is necessary to ensure that a full radioactive equilibrium between radon and its derivatives in the chamber has been reached. This period should not be longer than 5 hours, because otherwise measurement results require correction for the decay of radon. The measuring set (Pylon Canada) is shown in Figure 2.

Figure 2: RDA-200 Meter (Pylon, Canada) for grab sampling

Basic specifications;
Lower detection limit: 0.03 kBqm^{-3}
Upper detection limit: 3 MBqm^{-3}
Measurement precision: ±10%
Measuring time: automatically controlled: 1, 2, 5, 10, 30, 60 min, manually controlled: at will.

In order to read the radon concentration from Lucas cells, the mining radiometer type RGR-13 equipped with a head type FG-11 was used. (Scintillator set, 1985).

Measurement results

Determinations of radiological parameters of the environment of underground drifts 9 and 9a in Kowary-Podgórze were performed even befor e launching the route for tourists, as early as 1999. This is, of course, the future tourist route Kowary Drifts. The determinations included measurements of both temporary and long-term radon concentrations. (Chruścielewski et al, 2000)

The study showed that radiation in mine drifts 9 and 9a is mainly due to exhalation from the rocks of the radioactive gas radon, which can achieve instantaneous levels of activity as high as 1000 Bqm^{-3}, while the average long-term activity values are stable at approx. 400 Bqm^{-3}, as confirmed by two long-term tests.

Systematic measurements of exposure to radon in the underground tourist route have been started already in 2000, as a result of an agreement signed with the Nofer Institute of Occupational Medicine in Lodz. The first measurements were made, because of organizational considerations, at the turn of 2000 and 2001. The dosemeters were replaced every 3 months. Six employees (tour guides) were enlisted into the individual dosimetry schedule, while environmental dosemeters were deployed at 4 locations along the route. The average concentration of radon during the time worked by the employees included in the individual dosimetry schedule was 560 ± 50 Bqm^{-3}, while the average concentration of radon in that period measured by environmental dosemeters was 520 ± 140 Bqm^{-3}.

Periodic measurements of radon concentration were carried out at five locations along the tourist route on a quarterly basis. The results of measurements of the average annual radon concentration are shown in Figure 3.

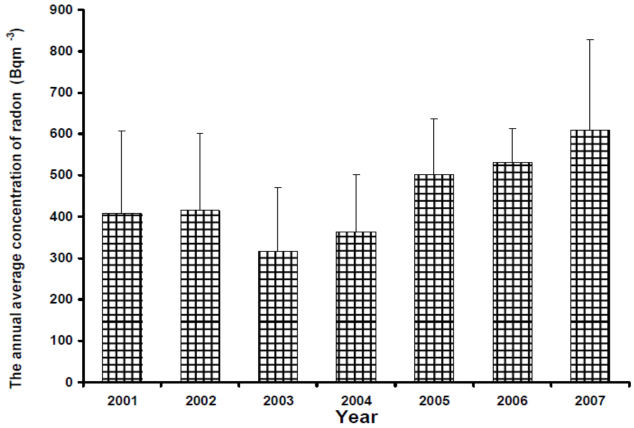

Figure 3: The results of measurements of the average annual radon concentration along the tourist route Kowary Drifts

The results of tests performed in 2001 - 2007 showed that the annual average radon concentration in drifts ranged from 300 to 600 Bqm^{-3}. Average five-year radon concentration was 450 ± 100 Bqm^{-3}.

In 2001 – 2007, a total of 17 people (guides and se rvice personnel) were subject to individual exposure monitoring.

It was assumed that dose conversion factor DCF ratio is 9 nSv/Bqm^{-3}·h, and equilibrium factor for rooms is 0.4 (SOURCES AND EFFECTS, UNSCEAR 2000).

Distribution of individual doses from radon in the measurement period is shown in Figure 4. The average estimated annual effective dose was 0.92 ± 0.37 mSv. The maximum annual dose of 1.73 mSv was recorded in 2002.

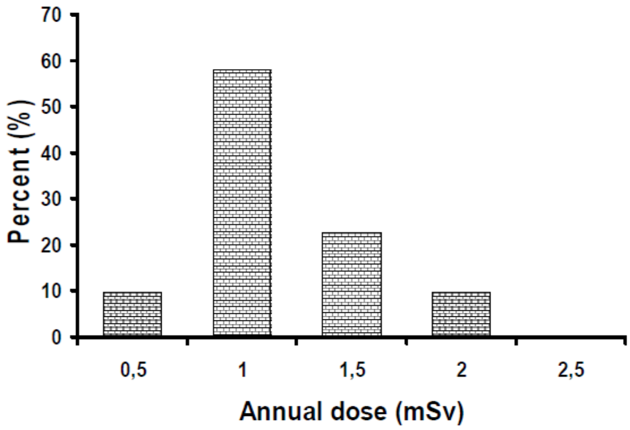

Figure 4: Distribution of individual doses from radon since 2001 – 2007

However, the value of DCF for radon exposure has been recently discussed. The new epidemiological and dosimetric data suggest increase of DCF value to 14 nSv•m^{3}Bq^{-1}h^{-1} or even 20 nSv•m^{3}Bq^{-1}h^{-1} (Muller at al, 2016). In such case, previously calculated effective dose values should be recalculated.

The combined measurements of exposure to radon were continued in the Kowary Drifts until 2008. Since January 2008, the number of measuring points spaced along the tourist route has been increased from 4 to 12, and individual dosimetry has been discontinued.

Figure 5 shows the results of measurements of the average annual radon concentrations for the tourist route and separately for the radon galleries since 2008 till 2016.

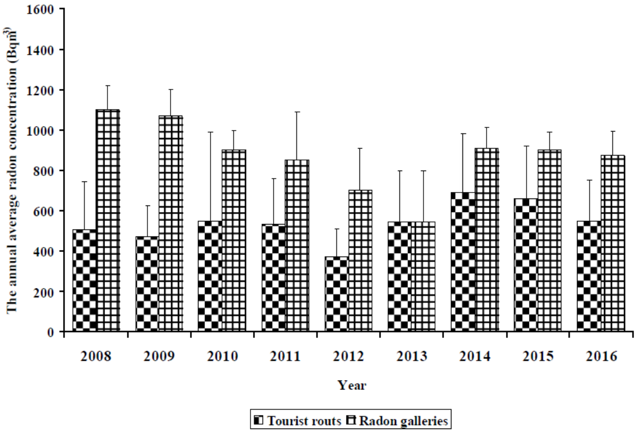

Figure 5: Average annual radon concentrations measured in the indoor tourist route and in the radon galleries

The average annual radon concentrations during the period 2008 - 2016 were 540 Bqm^{-3} in the tourist route and 870 Bqm-3 in the radon galleries. The highest annual average concentration in the indoor tourist route, 690 Bqm^{-3}, was recorded in 2014, and in the inhalation room (radon galleries) the highest concentration value, 1100 Bqm^{-3}, was noted in 2008.

The average annual radon concentrations during the period 2001 - 2016 were 500 Bqm^{-3} in the tourist route.

In 2010, another expert opinion on exposure to radon was released. The conclusions in the expert opinion are as follows:

1. Long-term measurements of radon in the tourist route Kowary Drifts have shown that radon concentrations exceeding 1000 Bqm-3 are not expected to occur in areas accessible to the visitors.
2. Service personnel (including guides) of the tourist route and the inhalation room should be classified as category B of exposure to ionizing radiation.
3. It is necessary to ensure a permanent monitoring of the long-term average radon concentrations at selected points along the route and in the radon galleries.
4. The exposure of the personnel should be evaluated from environmental measurements and records of time spent by the personnel within the drifts of the tourist route and in the radon galleries.

Complementary measurements

In addition to the studies described above, since 2001 measurements of instantaneous concentrations of radon were carried out at several points of the tourist route. Such studies were conducted in 2001 and 2004, and in 2010, 2011 and 2012.

Measurements of radon concentrations were performed using scintillation chambers. Instantaneous measurements of radon concentration were performed in September 2001, in six points of the tourist route. The concentration varied from 210 to 800 Bqm^{-3}, and the average was 380 ± 220 Bqm^{-3}.

Instantaneous measurements of radon concentration were made in June 2004, in five points of the tourist route. The concentration varied from 100 to 500 Bqm^{-3}, with the average of 230 ± 180 Bqm^{-3}

Instantaneous measurements of radon concentration were made also in July 2010, in fourteen points of the tourist route. The concentration varied from 100 to 890 Bqm^{-3}, and the average was 480 ± 240 Bqm^{-3}.

Measurements conducted in July 2011 showed that the instantaneous concentrations of radon measured in the drift ranged from 550 to 1300 Bqm^{-3}, with a mean of 790 ± 260 Bqm^{-3}.

Instantaneous measurements of radon concentration were made in August 2012 in nine points of the tourist route. The concentration varied from 100 to 620 Bqm^{-3}, and the average was 390 ± 170 Bqm^{-3}. Figure 6 shows the distribution of radon concentrations measured by scintillation chambers. The specified values represent grab sampling results.

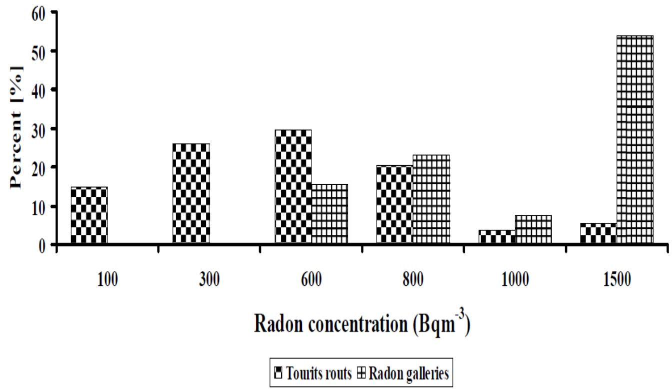

Figure 6: Distribution of radon concentrations measured in five series of grab sampling measurements in 2001-2012.

Just like the long-term measurements, instantaneous measurements have confirmed that:

1. It is necessary to ensure permanent monitoring of the long-term average radon concentration at selected points along the route and in the radon galleries.
2. The measurements have shown the correct selection of the measuring points for environmental dosimetry.
3. Concentrations of radon in the radon galleries are higher than those prevailing in the tourist route.

Measurements performed within the area in front of the entrance to the tourist route

As part of the monitoring, the concentrations of radon within the area in front of the drift were measured. These measurements were performed on a quarterly basis using closed-type dosemeters. During the period 2001 – 2016, as many as 28 measurements were performed. Average measured concentration was 110 Bqm^{-3}, with standard deviation of 70 Bqm^{-3}. The lowest concentration, 20 Bqm^{-3}, was noted at the turn of 2001/2002 and the highest, 310 Bqm^{-3}, was recorded in the third quarter of 2007. The differences in the concentrations were due to diversified terrain and climatic conditions.

Summary

The above-described activities associated with the presence of radon in the underground tourist route may serve as an example to follow for the management of other underground tourist routes, and those that are currently being developed in particular. It is also important because of the upcoming major change in approach to radon, resulting from the publication of COUNCIL DIRECTIVE 2013/59/Euratom on 5 December 2013. The directive specifies basic safety standards for the protection against the hazards arising from exposure to ionizing radiation and repeals Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. (COUNSIL DIRECTIVE 2013) The EU Member States must bring into force the laws, regulations and administrative provisions necessary to comply with this Directive not later than 6 February 2018.

The 73-page Directive consolidates and updates the legislation in the EU countries using the latest research and achievements in the field of radiological protection. The Directive applies to all planned, existing or emergency situations, involving risks arising from exposure to ionizing radiation that cannot be disregarded considering the necessity to ensure radiation protection of humans and the environment and ultimately safeguard long-term protection of human health. This is a new approach to radiation protection for virtually all situations in which a person is exposed to ionizing radiation.

The starting point for a new approach to exposure to radon and its daughters is that recent epidemiological findings from residential studies demonstrate a statistically significant increase of lung cancer risk from prolonged exposure to indoor radon at levels of the order of 100 Bqm^{-3}. (Preamble to the Directive, item 22.) Under item 23, it has been pointed out that the combination of smoking and high exposure to radon causes a significantly higher risk of lung cancer in a single person than each of these factors individually, and that smoking, on the level of a population, increases the risk of developing cancer as a result of exposure to radon. It has been also concluded that it is important that Member States take steps to reduce those two types of health risk.

The Directive recommends that Member States establish national reference levels for radon concentrations at indoor workplaces. The reference levels cannot exceed 300 Bqm^{-3} of the average annual concentration of radon in the air, unless it is considered acceptable because of the prevailing national conditions.

It is estimated that in Poland, there are currently about 200 underground tourist routes, possibly employing over 1.5 thousand people. Research conducted in 2012 in 66 underground routes has shown that in the overwhelming majority of the underground routes, measured concentrations significantly exceeded 300 Bqm^{-3} (the reference level proposed by the Council of Europe). (Olszewski et al, 2015) In 33% of the surveyed routes, the arithmetic mean of the measured concentrations exceeded 1000 Bqm^{-3}.

This shows how important it is for owners of tourist routes to appreciate the radon problem, as illustrated by the praiseworthy example of the underground tourist route Kowary Drifts.

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