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Estimation of radon risk exposure in selected underground workplaces in the Sudetes (southern Poland)

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ABSTRACT

The risk of exposure to increased ionizing radiation from radon was assessed for two groups of people who spend time, either for work (employees serving these visitors, mainly guides) or leisure (members of the public – visitors), in underground tourist facilities: Bear Cave in Kletno, the Gold Mine complex in Złoty Stok and the Underground Educational Tourist Route in the Old Uranium Mine in Kletno. These facilities had been chosen due to their location within the Sudetes, the most radon–prone area in Poland, and because of continuous radon activity concentration measurements conducted there since May 2008 to the end of January 2012. The selected facilities also meet the criteria for a radiation hazard workplace set by Polish law.

The annual limit of the effective ionizing radiation dose allowed for employees in Poland, which is 20 mSv/year, is exceeded for guides working in all the facilities. Also, according to Polish radiological protection regulations, their working conditions qualify them as exposed workers of category A or B. After a month's work, guides receive the annual effective radiation dose allowed for category B workers (>1 mSv/year) and after a few months – an annual effective radiation dose allowed for people employed in category A conditions (>6 mSv/year). Members of the public spending no longer than one hour inside each facility are at risk of receiving small effective radiation doses, ranging from 0.001 to 0.2 mSv/h.

1. Introduction

1.1. *Ionizing radiation exposure from radon in workplaces*

Due to its ability to emit natural alpha ionizing radiation, radon is a source of real hazard in every workplace. This hazard increases with the rise in the values of radon activity concentration recorded in these environments. There is a possibility of defining the level of such hazard to the human organism from this natural radionuclide in any workplace. Such assessment is based on the effective radioactive dose expressed in Sv (sieverts) estimated from ^{222}Rn activity concentration in the air of the studied space [$Bq \cdot m^{-3}$], the ratio of the number of conversion emitted per unit time (conversion

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coefficient), exposure time [h] and coefficient F [–] of radioactive equilibrium between ^{222}Rn and its short–lived progeny (UNSCEAR, 2000; Gillmore, Phillips, Denman, Sperrin, & Pearce, 2001; Kávási et al., 2009, 2010; Sainz, Quindós, Fuente, Nicolás, & Quindós, 2007; Papachristodoulou, Patiris, & Ioannides, 2010; Dueñas, Fernández, Cañete, Pérez, & Gordo, 2011).

Polish law defines the annual limit of effective radiation dose allowed for employees and members of the public and specifying the categories of exposure to which employees working in conditions do not correspond to regulations on radiological protection, safety and health at work should be allocated (Regulation, 2005; Ustawa, 2000). The allowable annual limit of effective radiation dose is different for each designated group – 1 mSv/year for members of the public (Regulation, 2005; art. 5, para. 1) and 20 mSv/year for employees (Regulation, 2005; art. 2, para. 1). Based on the level of effective radiation dose received in a year, employees are allocated to category A or B of occupational exposure. Category A represents the risk of receiving an effective radiation dose greater than 6 mSv/year, while category B – a dose greater than 1 mSv/year. The purpose of this classification is to enable employers to properly choose the principles of dosimetry measurements used for further assessment and of monitoring employee exposure levels (Ustawa, 2000; c. 3, art. 17, para. 3 & 4).

In Poland, unit heads are obliged by law to monitor and assess ionizing radiation exposure in workplaces whose work environments meet strict criteria (Ustawa, 2000). According to Atomic Law, professional activity carried out in mining companies, health resorts, caves and other underground spaces is such a criterion (Ustawa, 2000; c. 3, art. 23, para. 3.1). Despite the existence of appropriate guidelines, measures aimed at defining the level of increased ionizing radiation exposure are taken only in one type of workplace meeting the defined criteria, i.e. in underground mining (Kisiel, 2007; Kisiel et al., 2010; Komosa, Chibowski, Klimek, & Chałupnik, 2004; Olszewski, 2006; Olszewski, Chruścielewski, & Jankowski, 2005; Skubacz & Bywalec, 2003). Other companies, despite meeting the exposure conditions defined by the regulations, are not subject to regular inspection. This problem is particularly significant due to a growing interest in such spaces and these more and more frequent adaptation to new workplaces, referred to as underground spas and inhalatoriums or underground tourist routes, both in Poland (Olszewski et al., 2005; Olszewski, 2006; Przylibski, 1999, 2001, 2010; Przylibski et al., 2010; Przylibski & Fijałkowska–Lichwa, 2010; Fijałkowska–Lichwa & Przylibski, 2011; Fijałkowska–Lichwa, 2012, 2014) and in other countries (Calin & Calin, 2010; Cevik, Kara, Celik, Karabidak, & Celik, 2011; Dueñas, Fernández, & Cañete, 2005; Espinosa, Golzarri, Vega–Orihuela, & Morales–Malacara, 2013; Gillmore et al., 2001; Kávási et al., 2010; Somlai, Kávási, Szabó, Várhegyi, & Kovács, 2007, 2011;). By 2010, as many as 75 underground tourist routes had been catalogued in Poland, including 15 situated in the country's most radon–prone area (Fijałkowska–Lichwa & Przylibski, 2011; Fijałkowska–Lichwa, 2012, 2014; Przylibski & Fijałkowska–Lichwa, 2010).

1.2. *Study objects*

The selected underground facilities are located in two geological units of the Western Sudetes in Poland (Fig. 1A, B). There are mountain ranges of the crystalline Śnieżnik Massif, represented by the western and north–western slopes of the Stroma Massif and the northern part of the Golden Mountains (Fig. 1B).

Two of the subjects are the mining excavations and smelting operations carried out in Kletno and Złoty Stok (Fig. 1D; Gustaw, 2005; Ciężkowski & Krahl, 2001; Plantos, 1997; Mikoś, Salwach, Chmura, & Tichanowicz, 2009; Zagożdżon & Zagożdżon, 2010), while the second is a natural underground facility, which was discovered as a result of mining activity in the marble quarry Kletno III (Fig. 1C; Pulina, 1977; Ciężkowski, 1989, 1996; Kozłowski, 1989). The plan of the Underground Educational Tourist Route in the Old Uranium Mine in Kletno has been published by Fijałkowska–Lichwa (2014).

Bear Cave was opened as a tourist venue in 1983 and since then every year it is visited by about 70 000 tourists (Ciężkowski, 2006). The Gold Mine complex in Złoty Stok is known as underground tourist route since 1996 (Plantos, 1997; Przylibski, 2001). The Underground Educational Tourist Route in the Old Uranium Mine in Kletno was a part of the 'Kopaliny' mine. It was opened to visitors in 2002. In the 50's of the last century this mine extracted first uranium ores, and the second by fluorite's deposits (Ciężkowski & Gustaw, 2007; Ciężkowski & Krahl, 2001; Fijałkowska–Lichwa, 2014).

The description of selected facilities at these sites can be found in many published works by Przylibski (1999) (2001) (2010); Przylibski et al. (2010); Przylibski and Fijałkowska–Lichwa (2010); Fijałkowska–Lichwa and Przylibski (2011); Fijałkowska–Lichwa (2014).

2. Material and methods

The exposure assessment was based on estimated levels of the effective radiation dose that could be received by any member of the public and an employee staying inside the facility for a particular period of time. In order to identify the level of ionizing radiation exposure in the selected underground tourist facilities of the Sudetes each estimated dose of ionizing radiation, in a measuring points, for the time periods of radon activity concentrations measured, were compared (Tables 1–7). In order to calculate the annual effective doses of ionizing radiation to which guides and visitors were exposed on the selected underground tourist routes, it was used results of radon activity concentration measurements, recorded on a hourly basis for a measurement time periods.

2.1. *Measurement location*

The assessment of ionizing radiation exposure from radon and its decay products was conducted in three underground workplaces meeting the criteria of occupational exposure set by the regulations of the Polish Atomic Law (Ustawa, 2000; c. 3, art. 23, para. 3.1): Bear Cave in Kletno, the Gold Mine complex