Available online at www.sciencedirect.com
SCIENCE DIRECT®
Science of the Total Environment 367 (2006) 653 – 665
Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Humankind
www.elsevier.com/locate/scitotenv

Radon concentration in houses over a closed Hungarian uranium mine

János Somlai [a], Zorán Gorjánácz [c], András Várhegyi [b], Tibor Kovács [a,*]

[a] University of Veszprém Department of Radiochemistry, H-8200, Veszprém P.O.B.: 158, Hungary
[b] Mecsek-Öko Environmental Protection Co. H-7614, Pécs, P.O.B.: 121, Hungary
[c] Mecsek Ore Environmental Protection Co. H-7614, Pécs, P.O.B.: 121, Hungary

Received 28 April 2005; received in revised form 14 February 2006; accepted 22 February 2006
Available online 24 May 2006

Abstract

High radon concentration (average 410 kBq m^{-3}) has been measured in a tunnel of a uranium mine, located 15–55 m below the village of Kővágószőlős, Hungary. The mine was closed in 1997; the artificial ventilation of the tunnel was then terminated and recultivation works begun. In this paper, a study has been made as to whether the tunnel has an influence on the radon concentration of surface dwellings over the mining tunnel. At different distances from the surface projection of the mining tunnel, radon concentration, the gamma dose, radon exhalation and radon concentration of soil gas were measured. The average radon concentration in the dwellings was 483 Bq m^{-3}. Significantly higher radon concentrations (average 667 Bq m^{-3}) were measured in houses within ±150 m from the surface projection of the mining tunnel +50 m, compared with the houses further than the 300-m belt (average 291 Bq m^{-3}). The average radon concentration of the soil gas was 88.8 kBq m^{-3}, the average radon exhalation was 71.4 Bq m^{-2} s^{-1} and higher values were measured over the passage as well. Frequent fissures crossing the passage and running up to the surface and the high radon concentration generated in the passage (average 410 kBq m^{-3}) may influence the radon concentration of the houses over the mining tunnel.

Keywords: Radon; Soil gas; Radon exhalation; Uranium mine

1. Introduction

More than half of the radiation dose of natural origin of the population originates from radon (UNSCEAR, 2000). Most of our time is spent within buildings; therefore, the measurement and limitation of radon concentration of buildings are important (Risica, 1998; Hámori et al., 2004).

The major radon sources for homes in order of importance are: soil below the building, building material, outside air and water from private wells. Soil subjacent to the building is by far the most important source of indoor radon (Borisov and Yakovleva, 2005; The Radon Manual, 2001).

Radon (^{222}Rn) is one of the intermediate products of ^{238}U. Uranium is present to some extent in all rocks and soils. The population-weighted average concentration in soil is 33 Bq kg^{-1} (median 35 Bq kg^{-1}) (UNSCEAR, 2000).

^{222}Rn is the gaseous radioactive product of the decay of ^{226}Ra. Some of the atoms of this radon isotope are released from the solid matrix of the material by recoil when the ^{226}Ra decays. Radon atoms entering the pore space are then transported by different ways through the

* Corresponding author. Tel./fax: +36 88 427 681.
E-mail address: kt@almos.vein.hu (T. Kovács).

0048-9697/$ - see front matter
doi:10.1016/j.scitotenv.2006.02.043

space until they in turn decay or are released into the atmosphere (exhalation) (Tanner, 1980).

The gas movement in the subsurface can be induced by two types of forced fields: concentration gradients and pressure gradients. In the first case, a spreading out of gas molecules in a direction tending to equalize concentrations in all part of a rock system occurs: this is gas "diffusion". In the second case, the whole gaseous mass tends to move from a high pressure zone to a low pressure zone; this mass transportation is called "advection". Diffusion is important only in capillaries or small-pore rocks; advection may assume an exclusive role in larger pores or in fractured media. Diffusion (whose velocity is on average in the order of 10^{-4} to 10^{-2} m day^{-1}) does not allow radon to be transported for distances over about 1 m before the decay of the ^{222}Rn atoms has reduced the concentration to a level which is indistinguishable from the background, even if the radon source is strong.

^{222}Rn transport over long distances requires the presence of a relatively fast-moving advective fluid. Kristiansson and Malmquist (1982) considered that radon movement is linked to the existence of a naturally occurring microflux of gas (geogas). This gas flow is advective and is realized as microbubbles when the geogas crosses an aquifer. The bubbles seem to be able to pick up and transport trace elements upwards for long distances. This mechanism may be responsible for rapid and long-distance (10 to 10^3 m day^{-1}) radon transport (Etiope and Martinelli, 2002; Fleischer et al., 1980; Mogro-Campero and Fleischer, 1977; Popit and Vaupotič, 2002; Várhegyi et al., 1992).

Radon enters the atmosphere or into buildings (Wang and Ward, 2002). Generally, the radon concentration does not result in high value (Soor et al., 2001; Deka et al., 2003). However, where ^{226}Ra concentration in the soil (Quindós et al., 1995; Papp et al., 2002) or in the building material (Papp, 1998; Risica et al., 2001a) is high, a significant increase of radon concentration must be accounted for (Thomas et al., 2002; Font and Baixeras, 2003; Chauhan et al., 2003). In case of materials with high ^{226}Ra concentration in buildings, even the gamma dose capacity significantly exceeds the world average (Somlai et al., 1998; Alvarez et al., 2002; Risica et al., 2001b).

The radon concentration in the buildings is determined by the building construction and by geological conditions (Sundal et al., 2004), such as the radon exhalation and soil gas radon concentration. The level of exhalation is influenced by the ^{238}U and ^{226}Ra concentration of the soil (Singh et al., 1999, 2002; Sroor et al., 2001), the cleavage and permeability of the soil (Johner and Surbeck, 2001; Mäkeläinen et al., 2001) and meteorological conditions (seasons, temperature, pressure) (Cosma et al., 2001).

In a few countries, a geology-based classification was proposed to identify radon-affected areas. In Germany, both the gas permeability of the soil and soil gas radon concentrations have to be measured at 1 m depth (Kemski et al., 2001, 1996). This results in a classification with radon classes. Similar results were found in Luxemburg and the UK, where radon soil gas concentrations and permeability were found to be correlated with indoor radon concentrations. Assessment of the radon potential in the Czech Republic is also based on the determination of soil gas concentration (at 0.8 m depth) and a classification of permeability (Neznal et al., 1996). Based on these, it can be considered as being average over 30 kBq m^{-3} and, as a high risk category over 100 kBq m^{-3}, even with soils that have low permeability. With soils with high permeability, 30 kBq m^{-3} is considered to be in the high risk category.

When high rates of radon entry into buildings are found, advection is usually the main factor. This advection is driven by the pressure differential between the building shell and the ground around the foundation, produced by the higher temperatures within the shell (the stach effect), mechanical ventilation and, to some degree, also by wind blowing against the building. The effectiveness of this pressure differential in pulling in radon-laden soil gas through the foundation is critically dependent on the effective permeabilities of both the building foundation and the adjacent earth (Nazaroff et al., 1985; Riley et al., 1999).

Atmospheric pressure fluctuations can also represent an important mechanism of radon entry.

Generally, higher ^{226}Ra concentration can be found in the environs of uranium mines. This may lead to higher radon concentration in buildings in settlements located in their vicinity (Quindós et al., 2004).

Previously, uranium mining was performed near the village of Kővágószőlős in the Mecsek Mountain in Hungary (Fig. 1).

Fig. 1. The village of Kővágószőlős in the Mecsek Mountain in Hungary.