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KRATKA NAVODILA
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Meleq Bahtijari

RADON IN KOSOVO

Doctoral Dissertation

RADON NA KOSOVU

Doktorska disertacija

Supervisor: Prof. Dr. Peter Stegnar

Co-Supervisor: Prof. Dr. Zahadin Shemsidini

June 2011

MEDNARODNA PODIPLOMSKA ŠOLA JOŽEFA STEFANA
JOŽEF STEFAN INTERNATIONAL POSTGRADUATE SCHOOL
Ljubljana, Slovenia

Index

Abstract

Radon and its progeny play an important role contributing to the dose of radiation which a person receives from all natural sources of ionizing radiation. This is one of the reasons why this problem has been of great interest, as a result of which an increased number of scientific works and monographs have been written on this issue. Such works have mainly been concerned about the concentration of radon and its progeny in the air. Certainly, the most interesting areas were those with high levels of radon concentration.

Accordingly, one of the purposes of this research study was to investigate further the causes of high concentrations of radon. So far, we have been able to understand properly some of the parameters affecting the radon concentration which increases in the air of the closed rooms. We know that radon comes primarily from the soil/ground; hence the floors and walls which meet the surface of the soil must be of high quality. Therefore, prior to building any structure, a feasibility study of the geological conditions of the ground should be studied. Attention must be paid, of course, to the choice of appropriate building materials. The concentration of radon in the air of a room is also affected by microclimatological parameters and the life style of the inhabitants.

Due to the large number of parameters that affect the concentration of radon and its progeny in the air, it is necessary to make appropriate calculations and to draw correct conclusions from the measurements by means of mathematical–physical models.

The final purpose of the study was to assess the doses received during the breathing process from radon and its progeny in several settlements and working facilities. From this dose one can further consider the likelihood of the appearance of lung cancer.

The primary aim of this doctoral thesis was the measurement of radon concentrations in schools, houses, mines and caves, which were spread in various locations, different geological, weather and soil conditions. Measurements were performed on different floors of buildings or in different places, in caves and different mine horizons. These results were published and presented in tabular form and graphics in scientific journals, which copies are attached to this doctoral dissertation.

The values of radon concentrations in Kosovo were compared with measurements made in different countries of the world.

In this study, we were interested in obtaining the most accurate possible data; hence, besides the current measurements of radon concentration by means of the alpha scintillation method, we also used solid state nuclear track detectors (SSNTD) for longer measurements in places where preliminary measurements were made. On comparing measurements obtained from both methods, no significant differences between the two methods were noticed.

It is worth pointing out that the places where measurements were carried out were selected not only because of their geological conditions, but also because they were bombed by NATO with depleted uranium – containing munitions.

Prior to bombing, the radon concentrations in these places were within the normal limits, but an increase of radon concentrations has been noticed in recent times. Consequently, the measurements were repeated at different time periods.

Taking into consideration the measurement results in general, and by comparing these measurements with those in different countries, it can be concluded that the concentrations of radon in Kosovo are relatively low. But this does not mean that such measurements should not be continued in the future, because in the course of time these buildings will age and cracks may appear, and thus radon could penetrate inside such houses. Therefore, in order to avoid this, it should be our task to find out the modes of penetration of radon into buildings in order to avoid or reduce this problem.

We consider that this doctoral thesis and the published articles are a solid basis for other researchers dealing with this issue, because it could make their research easier with respect to comparisons and references dealing with this topic.

The first measurements of radon concentration were made in 2003. Measurements were continued in the following years, and there were many to perform in order to include all the areas of Kosovo, so as to be able to create a map of radon concentration.

Indoor air radon (^{222}Rn) concentrations were measured in spring and winter in 30 classrooms of nine

elementary schools and in 19 classrooms of high schools in Prizren.

Indoor air radon (^{222}Rn) concentrations were measured in March, May, August and December in 15 classrooms of five elementary schools and in six classrooms of one high school in Sharr.

At eleven points along the guided tourist route in the Gadime Cave of Kosovo, air radon concentrations were measured in summer and winter, using alpha scintillation cells and solid state nuclear track detectors. At two points in summer, values higher than 1700 Bq m^{-3} were observed. They were otherwise in the 400–1000 Bq m^{-3} range. The values were lower in winter. The effective dose received by a person during a 90-minute visit is 3.7 μSv in summer and 2.5 μSv in winter. For a tourist guide, the annual effective dose does not exceed 3.5 mSv.

Indoor air radon concentrations were measured by exposing etched SSNTDs in the sleeping and living rooms of 18 houses in six villages of the Sharri community in Kosovo. Values ranged from 24 Bq m^{-3} to 209 Bq m^{-3} (only one exceeding 200 Bq m^{-3}), with a geometric mean and geometric standard deviation of 95.4 Bq m^{-3} and 1.6 Bq m^{-3}, respectively. Based on the assumption that the spring radon concentrations obtained in this survey represent the yearly average, annual effective doses of residents were calculated; they ranged from 0.89 to 4.7 mSv y^{-1}, with a geometric mean of 2.2 mSv y^{-1} and a geometric standard deviation of 1.5 Bq m^{-3}.

Research programme

Issues

Of the total dose of natural ionizing radiation which the human body receives, about half is due to radon and its progeny. The respiratory system tissues are very sensitive to alpha, beta and gamma radiation, which thus increase the risk of lung cancer. Considering the damage caused by radon and its descendants, measurements of radon concentration were taken in different locations throughout Kosovo. Therefore, the characteristics of radon and its descendants, as shown in Chapter 4, and the consequences of radon in the human body, as presented in Chapter 3, should not be overlooked.

Implementation of doctoral dissertation

The concentration of radon and its descendants can be calculated according to the measured and mean values of radon and the additional data for the equilibrium between radon and its short-lived daughters. This requires consideration of the time of human exposure, which depends on the living and working habits in the home, or residence of the population in public places (schools, mines and caves, in this study). Such calculations were extensively presented in my papers published in scientific journals, and which as such are attached to this dissertation. For the convenience of the reader, a summary has been included at the beginning of each publication.

Results

Measurement results of radon concentration can be seen in each paper separately, where they have been presented in tabular and graphic forms. 80% of the total work was performed by the author, such as taking samples in the field, measurements and calculation of results, writing of papers and their preparation for publication. It should be pointed out that prior to sending the papers for publication, consultations were conducted with associates from the “Jozef Stefan” Institute: Prof. Dr. Ivan Kobal, Asst. Prof. Dr. Janja Vaupotič, and Prof. Dr. Peter Stegnar.

Definitions and units

Activity:

The activity of a radioactive source is the number of its nuclei that decay per unit time.

The unit of activity is the Becquerel (Bq), equal to one nuclear transformation per second.

1 Curie (Ci) equals 3.7×10^{10} Bq

Absorbed dose:

The absorbed dose is the quantity of energy imparted to a unit mass of material by ionising radiation.

The unit of absorbed dose is the Gray (Gy) equal to one Joule per kilogram.

1 Gy equal 100 rads.

Dose equivalent:

The dose equivalent is the product of the absorbed dose and the quality factor for a specific type of radiation. The quality factor accounts for the ability of the radiation to cause biological damage. For beta particles, gamma rays and X rays, the quality factor is usually taken unity, but for alpha particles it is 20.

The unit of dose equivalent is the Sievert (Sv) equal to one Joule per kilogram.

1 Sv equals 100 rems [NOTE: Effective dose equivalent is also expressed in Sieverts].

Effective dose equivalent:

This is the sum of the products obtained by multiplying the dose equivalents to various organs and tissues by the appropriate risk weighting factor for each. This quantity is expressed in Sieverts.

Potential alpha energy:

In the context of this study the potential alpha energy of an atom in radon or thoron decay schemes is the total alpha energy emitted during the decay of this atom along the decay chain down to 210Pb or 208Pb, respectively. For example, in the case of ^{218}Po it is 13.7 MeV (i.e. 6.00 + 7.68). This is usually expressed in J or MeV.

Potential alpha energy concentration (PAEC)

The potential alpha energy concentration (PAEC) in air of any mixture of ^{222}Rn or ^{220}Rn (thoron) daughters is the sum of the potential alpha energy of all daughter atoms present per unit volume for air. This is usually expressed in J m^{-3}.

Working level (WL):

1 WL (radon) corresponds to the PAEC of short – lived radon daughters in equilibrium with a radon air activity concentration of 3700 Bq m^{-3} [100 pCi/l]. This represents a concentration of ^{222}Rn daughters which will deliver 2.08 x 10–5 J m^{-3} (or 1.3 x 105 MeV l^{-1}) of air in decaying through ^{214}Po (RaC).

1 WL (thoron) corresponds to the PAEC of short–lived thoron daughters in equilibrium with a thoron air activity concentration of 275 Bq m^{-3} [7.43 pCi/l]. This represents a concentration of ^{212}Po (ThB) and ^{212}Bi (ThC), which yields 1.3 x 105 MeV l^{-1} of air in decaying to ^{208}Pb (ThD).

Potential alpha energy exposure:

For an individual exposed to short–lived radon or thoron daughters this is the time–integral over the PAEC of the daughter mixture to which the individual is exposed during a definite period of time. Its basic unit is Jhm–3, which is often expressed in units of WLM (see definition below).

Working level month (WLM):

The WLM corresponds to an exposure of 1 WL (2.08 x 10–5 J m^{-3}) during a working period of one month (170 hours). 1WLM = 170 WLh = 3.5 x 10^{-3} J h m^{-3} = 22.1 x 106 Mev h l^{-1}.

Equilibrium equivalent radon concentration:

The equilibrium equivalent radon concentration (EER) is the concentration of radon (Bq m^{-3}) for which its daughters, if they were in equilibrium, would have the same potential alpha energy that the actual mixture of daughters have in the atmosphere of interest. In the literature a number of acronyms are to be found for the equilibrium equivalent radon concentration. These are EER, EEC, and ECRn.

.

Equilibrium factor F:

The equilibrium factor (F) with respect to potential alpha energy is defined as the ratio of the ERR to the actual activity concentration of radon in the air.

Unattached fraction of potential alpha energy f_p :

This is the fraction of airborne radon daughters that is not attached to aerosol particles, expressed in terms of the potential alpha energy of the mixture, and not in terms of the activity of any individual daughter nuclide.

1. Introduction

1.1. Natural radioactivity and the radon problem

The earliest life on our planet was exposed to different kinds of radioactivity. The origin of this activity is space and Earth [1]. The same conditions have been present during the evolution of life forms, and the effects of exposure to ionizing radioactivity still exist today [2].

Nowadays, people have an irrational fear of radioactivity that is focused on artificial radiation sources, especially nuclear facilities. Most people do not suspect that the greatest exposure of the population is caused by natural sources (see Figure 1). The body has always been exposed to natural radiation, and, to a great extent, this exposure has been unavoidable. Some groups of the population on Earth are exposed to radiation doses that are one to two orders of magnitude higher than the global mean value of radiation doses. In certain cases, the doses reach the specified maximum recommended limits of radiation. It is surprising that little attention has been paid since the 1980's to the highest exposures of the population caused by indoor radon.

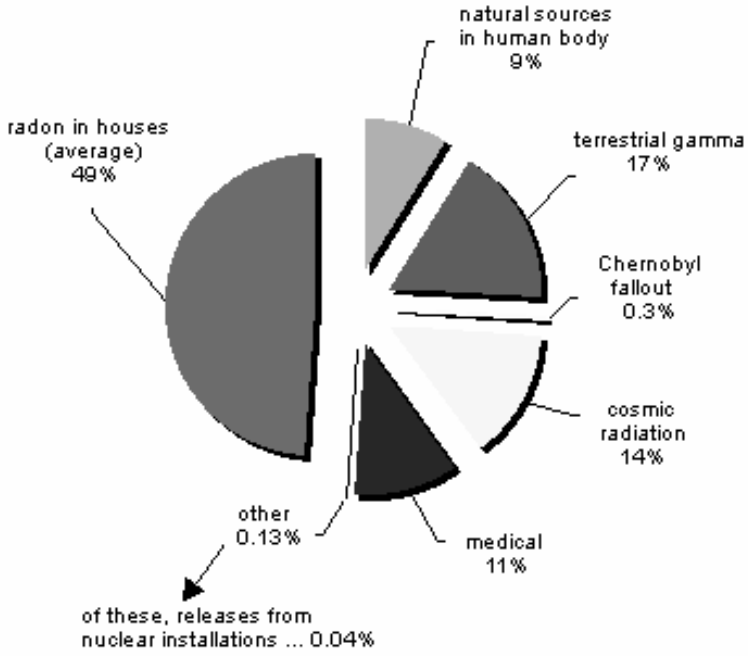

Figure 1: Population exposure to ionizing radiation

The basis according to which the exposure level of the population to radioactivity is determined is the annual average dose from natural sources of radiation. It has been estimated that this is 2.2 mSv per person in a year time [3].

It is estimated that the dose equivalent to radon and thoron is 1.3 mSv over a year [4].

Some natural radiation sources are affected by human activities, and it is reasonable to try to control them. Examples are as follows: remedial measures during the construction of new buildings or the reconstruction of existing buildings; remedial measures to reduce exposure of the population to underground water sources with higher concentrations of natural radionuclides; and control of natural radionuclides released into the environment during industrial activities.

Radon is one of the rare elements confirmed as a cause of lung cancer in human beings. As such, it was classified into the group of carcinogenic elements by the World Health Organization (WHO) in 1996 [5] [6].

The participation of radon in the annual doses of radioactivity which the population receives, is of special significance in abnormal areas, where the level of radon is increased [6].

When the quality of air present in closed environments is analysed, radon comes fourth, behind asbestos, tobacco smoke and fibreglass, as the most important element that is being controlled for legal purposes in EU countries [7].

Absorbed ionizing radiation causes chemical reactions that can cause dramatic biological changes. This means that the DNA molecule can be irreparably damaged, so in this case the result radioactivity is

destructive to the human body [7].

Each kind of biological organism has its own sensitivity to ionizing radiation, meaning that it has a characteristic radiosensitivity or a characteristic radioresistance [8].

Radiosensitivity can be understood as the result of constant reactions of the biological system to different kinds of radiation. Therefore, it is entirely reasonable to say that radio- sensitivity is characterised in terms of the response that can be found. However, many reactions to radiation are special, ranging from those in microorganisms to those in bio-systems consisting of special tissues. This can be illustrated by the behaviour of a cell to radiation that can usually be noticed most in actively growing tissue.

The latest knowledge on the effects and risks of radiation leads many people to take protective action against radioactivity, not only people who work professionally with ionizing radiation sources, but also people who are exposed to natural ionizing radiation.

The annual average dose that is received by the population is twice as large as previously thought because, according to new estimates, the doses from radon gas and thorium should be taken into consideration.

In most European countries the allowed concentration of radon in closed environments where people live is determined according to national regulations for radon. Thus, the recommended maximum concentration, i.e., the action level for new buildings, is 200 Bq m^{-3} of air, while the concentration for the old ones is 400 – 600 Bq m^{-3} [9] [10].

As radon is the main source of radioactivity in the environment in nomal circumstances, the measurement of radon in schools, houses, other buildings and working places (mines, caves, etc.) is important because the inhabitants and staff are exposed there and this, therefore, was the main topic of my dissertation.

1.2 Natural radioactivity and its distribution

Exposure to natural radiation is caused by two different sources:

A. Cosmic radiation that impacts the Earth, the intensity of which depends on the height above sea level and the geographical positions on Earth.

B. Natural radionuclides that are normally present in the environment. These nuclides can be divided into three groups according to their origin:

- Cosmogenic nuclides that are generated by nuclear reactions during the interaction between cosmic radiation and stable isotopes, especially in the atmosphere (for example, a well-known ^{14}C isotope is generated by the reaction ^{14}N (n, p) ^{14}C). The other radionuclides generated are as follows: ^{3}H, ^{7}Be, and ^{22}Na.

- The original primordial nuclides that originated in the early stages of the universe are still present on the Earth due to their long half-lives (>108 years) in significant quantity (e.g., ^{238}U, ^{235}U, ^{232}Th, ^{40}K, ^{87}Rb, etc.). Many other nuclides that were generated early have decayed due to their short half-lives, and in practical terms, these nuclides are not now detectable.

The original radionuclides disintegrate to secondary radionuclides and form the decay series. Of the four well-known decay series, i.e., the uranium-radium decay chain (starting from 238U), the thorium decay chain (starting from ^{232}Th), the actinium decay chain (starting from ^{235}U) and the neptunium decay chain (starting from ^{237}Np), we can only meet with the first three decay series in the open. The last two groups of natural radionuclides originate from the Earth, and these are called "terrestrial". From the point of view of human exposure, only certain natural radionuclides are important. External exposure is mainly caused by ^{226}Ra (or by uranium), ^{232}Th and ^{40}K, which can be found in rocks and soil of the earth's surface (the thickness of the layer is a few tens of centimetres). The dose rate that originates from terrestrial nuclides is about 0.057 μGy h^{-1} (this is the mean value on Earth), and the maximum values have been measured on monazite sand in Guarapari, Brazil (up to 50 μGy h^{-1}), in Kerala, India (about 2 μGy h^{-1}), and on rocks with a high radium concentration in Ramsar, Iran (from 1 to 10 μGy h^{-1}) [90].

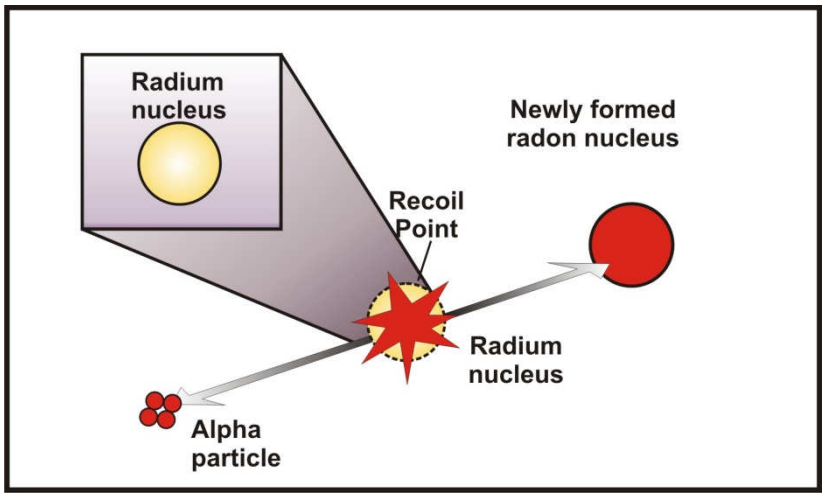

Figure 2: Decay of radium nucleus.

From the point of view of internal exposure, radon (^{222}Rn), thoron (^{220}Rn) and their decay products prevail, and potassium ^{40}K in the body is also a significant nuclide.

The potassium concentration in the human body is strictly based on the homeostatic principle, hence the concentration is mostly constant in all people at a level of about 55 Bq kg^{-1}, which corresponds to an annual effective dose of 0.17 mSv. Because of internal exposure, attention should be paid to the following nuclides: ^{226}Ra and ^{228}Ra, ^{238}U and ^{234}U, ^{210}Po and ^{210}Pb. Great differences may appear in nuclide uptake (and also in the corresponding doses) for individual persons or for groups of the population. With the exception of the inhalation of radon and its decay products, which contribute the highest doses to the population, the uptake by ingestion is, in general, much higher than that by inhalation. From the point of view of the exposure to the population, the contribution of the cosmogenic nuclides (not cosmic radiation) is negligible.

1.3 Physical and chemical properties of radon

^{222}Rn is generally regarded as a naturally occurring, inert radioactive gas, with a half-life of 3.8 days and is produced within the ^{238}U decay series (Figure 3) [12]. Radon is considered a health hazard because it decays into solid decay products with the emission of alpha particles. ^{222}Rn decays with a half-life of 3.8 days to ^{218}Po, which itself then decays (with a shorter half-life of 3 minutes) with emission of the alpha particles to ^{214}Pb.

Radon is a natural, radioactive gas that migrates from the ground into buildings. Prolonged exposure to high levels of this gas can cause lung cancer. Therefore, radon can be a serious health threat in workplaces, schools and especially homes.

At least some uranium is present in all terrestrial materials. On continental surfaces, the rocks, sediments and soils typically contain between 1 and 3 parts per million (abbreviated ppm) of this element. In other words, a million kilograms of rock (1000 tons) will have 1 to 3 kilograms of uranium distributed through it on average. Some terrestrial materials have uranium contents significantly above this amount and, consequently, may be the cause of locally high indoor radon levels. Such radon sources are found in some places throughout Kosovo, thus providing the motivation for the study in this thesis.

In fact, ^{222}Rn is only partly inert. ^{222}Rn may also be regarded as a metalloid [13].

The atomic number of radon (Rn) is 86. The natural isotopes of radon are: ^{222}Rn (radon), ^{218}Rn, ^{219}Rn (actinon) and ^{220}Rn (thoron). (Figure 3) [14, 15].

^{220}Rn also has a short half-life, and in comparison to ^{222}Rn, can travel only a small distance from its source. Therefore, information concerning the major distance for the source or processes on earth is dominated by ^{222}Rn.

Radon is a colourless and odourless gas, and therefore not detectable by human senses alone. At standard temperature and pressure, radon forms a monatomic gas with a density of 9.73 kg/m^3, about 8 times the surface density of the Earth's atmosphere, 1.217 kg/m^3. It is one of the heaviest gases at room temperature and the heaviest of the noble gases, excluding ununoctium. Although colourless at standard temperature and pressure, when cooled down below its freezing point of −71 °C, radon has a brilliant phosphorescence which turns yellow as the temperature is lowered, and becomes orange-red as the air liquefies at temperatures below −180.1 °C; Upon condensation, radon also glows because of the intense radiation it produces. Critical temperature is 104.4°C, while the critical pressure is 63.2 x 10^5 Pa [14, 15].

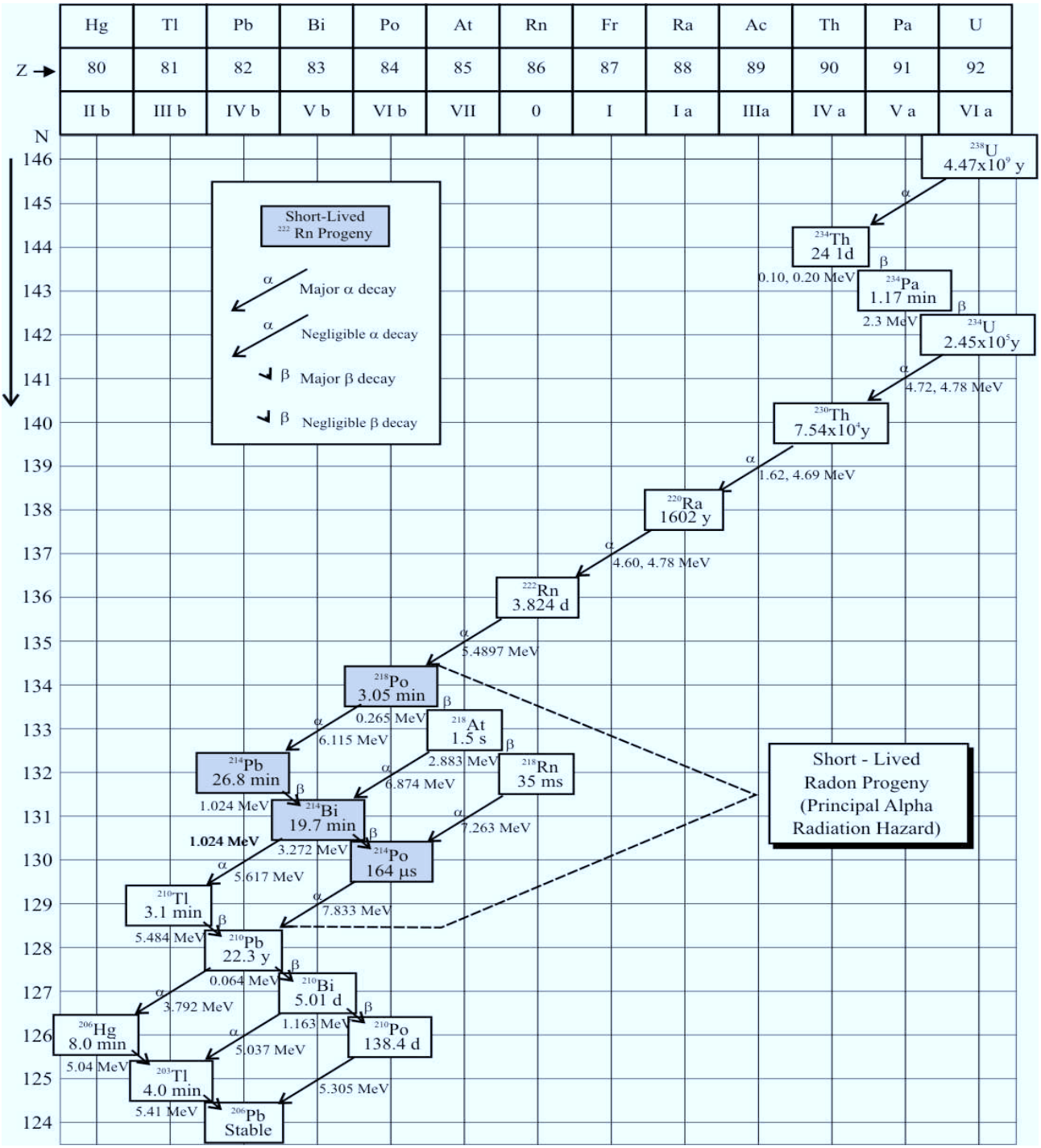

Figure 3: ^{238}U decay series taken from M.S. Field, where the horizontal scale Z is the number of protons in the nucleus, while the vertical scale, N, is the number of neutrons in the nucleus. Also, shown are the half – lives, types of decay (either by α - or β - particles), and the major radiation energies (in MeV) of ^{238}U and its progeny.

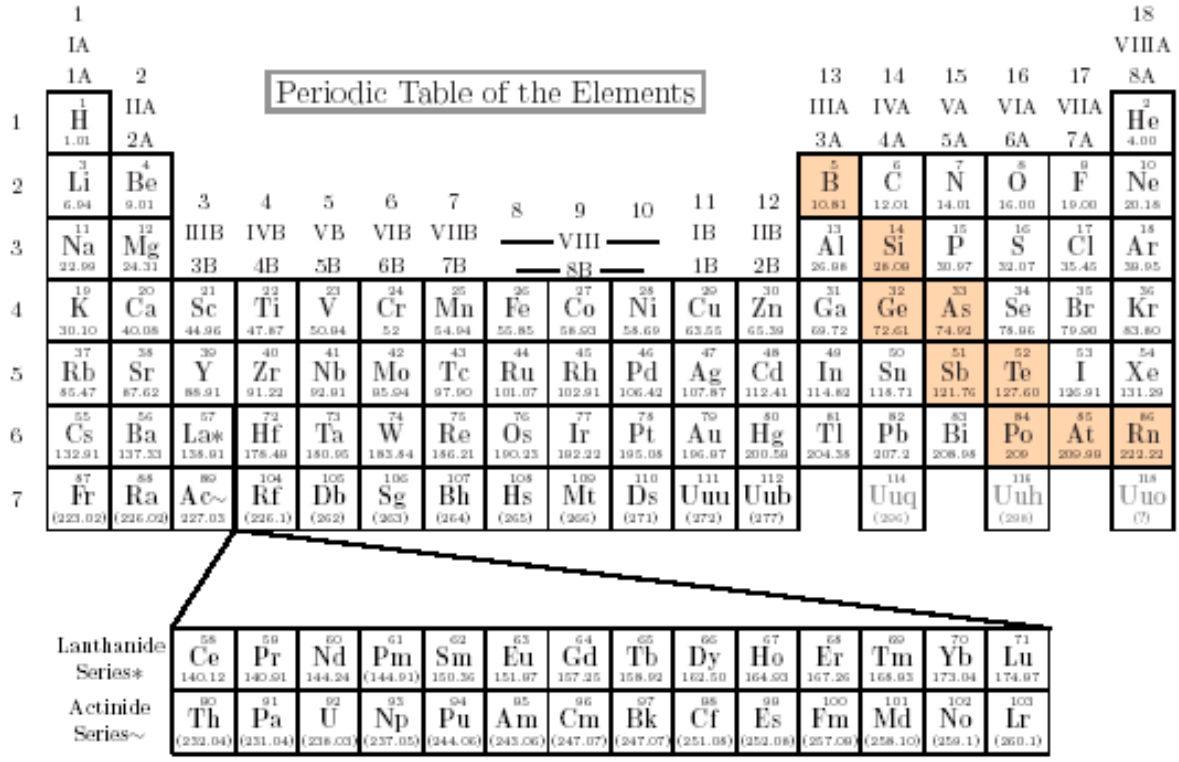

Figure 4: Arrangement of the metalloid elements (dark shading) in the periodic Table [13].

It has a similar capacity to dissolve in water as other noble gases: 0.25 ml in 1 ml water at 20°C and at a pressure of 760 mmHg. Radon solubility in water is inversely proportional to temperature: the higher the environmental temperature, the lower the amount of radon present as a solute in water. The following showes the amount of radon in water against radon in the air (atoms in volume units): 0.53 (0°C), 0.43 (6°C), 0.28 (15°C), 0.22 (26°C), 0.16 (40°C) and 0.11 (100°C).

Radon dissolves in carbon disulfide, sulphur, chloroform, xylene, toluene, etc. It also dissolves easily in the blood, as well as being efficiently absorbed in human fat tissues [14]. A total of 27 radioactive isotopes of radon have been created artificially, with mass numbers of 200-226 [17], but only three of them, ^{219}Rn, ^{220}Rn and ^{222}Rn, are found in nature. ^{222}Rn is the only naturally occurring isotope that could be used in geological, seismic and tectonic studies and has the potential of becoming a toxic gas. The half-lives for ^{219}Rn and ^{220}Rn are 3.96 s and 55.6 s, respectively.

Radon is colourless, odourless and the heaviest gas occurring in nature under standard temperature and pressure conditions. It has a closed–shell electronic structure and is inert. Its solubility in water is high and as stated above, decreases with increasing temperature (Kofler, 1908). Though the chemical properties of radon are relatively unknown, it is considered that it could react with oxygen and fluorine and form clathrates with water and organic chemicals. The atomic radius is estimated to be $2.35 \cdot 10^{-10} m$, based on the noble gas radius trend. This large radius implies that it could form clathrates with water or organic radicals and be carried by more abundant gases, i.e., CO_2 and CH_4, to near surface environments.

1.4 ^{222}Rn and its Progeny

^{222}Rn is the heaviest of the noble gases and because it is a relatively nonreactive gas, it tends to migrate to and concentrate in enclosed spaces (basements, caves, tunnels, etc.). However, ^{222}Rn is not a major health risk by itself.

High concentrations of ^{222}Rn progeny (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) are widely recognised as a source of lung cancer and possibly other cancers [19,20] through the emission of α and β particles with dense ionisation along their tracks, although it is the α particles that are most responsible for the resulting high–linear energy transfer (LET) because of their large +2 charge and relatively large mass ($\approx$8,000 times that of an electron). The emission of β particles (high energy electron) results in a low LET because of the ± 1 charge of the β particle and its much smaller mass compared with α particles. In either case, both low and high LET interactions can cause significant DNA damage [21], but it is the densely ionising radiation produced by α particle decay that causes the many double-strand DNA breaks that are the most difficult for the cell to repair and are most likely to give rise to cancer formation [22].

Based on several studies done in 1993 and 2006 [23], it has been proven that ^{222}Rn causes lung cancer in large numbers of the population.

However, lung cancer and other adverse health effects may be more a results of smoking than of inhaling ^{222}Rn gas [24].

Some authors [25, 26, 27, and 28] think that exposure to ^{222}Rn in closed buildings can cause leukaemia in adults, but this is not certain because detailed investigations have not yet been performed [26].

1.4.1 ^{222}Rn Progeny

Although it is true that ^{222}Rn represents a risk to cavers in terms of lung cancer, its relatively long half-life will more often result in the exhalation of ^{222}Rn prior to the emanation of an α particle that could penetrate the epithelium of the lung to cause a cancerous growth. So, even though the energy associated with the emission of an α particle from ^{222}Rn is relatively high (5.49 MeV), it is not likely that α emission will actually occur during the time that the ^{222}Rn gas stays in the lung. This situation is considerably different with the ^{222}Rn progeny.

The four ^{222}Rn progeny (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) are either metals (^{214}Pb and ^{214}Bi) or metalloids (^{218}Po and ^{214}Po) that are relatively short–lived and emit α particles with relatively low energy (Figure 3). It is these features, principally the α particles that represent the main risk posed by ^{222}Rn.

The risk of lung cancer occurrence is exacerbated by smoke and dust particles because these metals and metalloids readily react with and adsorb on the particles, which are then easily inhaled and penetrate the lungs.

1.4.2 ^{218}Po

^{218}Po has a half-life of 3.05 min and is the immediate progeny resulting from the decay of ^{222}Rn. When ^{218}Po decays, it emits an α particle with a relatively high energy of 6.12 MeV. With a half-life of 3.05 min, it is possible that ^{218}Po will emit an α particle during the time that it resides in the lung. However, its relatively short half-life tends to prevent it from being easily distributed throughout the body from the lungs.

1.4.3 ^{214}Pb and ^{214}Bi

^{214}Pb and ^{214}Bi are metals with half-lives of 26.8 min and 19.7 min, respectively. These two radioisotopes decay by low-energy β emission, but are still a threat to human health, although less than the other short–lived ^{222}Rn progeny that decay by α emission (Figure3). Their relatively longer half-lives and lower energies relegate ^{214}Pb and ^{214}Bi to a slightly lesser threat status. In addition, their half-lives are still too short to allow for substantial distribution throughout the body.

1.4.4 ^{214}Po

^{214}Po has a very short half-life (164 μs). It emits an α particle with a high energy of 7.69 MeV. With a half-life of just 164 μs , it is highly likely that ^{214}Po will emit an α particle during the time it resides in the lung. Its very short half-life and high energy makes ^{214}Po a significant threat to human health. Although the very short half-life of ^{214}Po prevents its distribution throughout the body, the relatively long half-life of its immediate progeny ^{210}Pb (22.3 y) can result in serious harm to parts of the body other than the lungs from the decay of ^{210}Pb.

Polonium radionuclides have many of the characteristics of rare-earth elements, are amphoteric and tend to form hydroxides and radiocolloids in vitro and in vivo. The latter tends to cause polonium to become phagocytised by cells of the reticuloendothelial system for eventual deposition in the spleen, lymph nodes, bone marrow, liver and kidneys after parenteral administration [29]. Fortunately, the half-lives of the polonium radionuclides in the immediate ^{222}Rn decay series are of too short duration (t1/2 = 164 μs) to be of concern.

1.4.5 ^{214}Pb

^{210}Po is an alpha emitter with a half–life of around 138 days. ^{210}Po is omnipresent in the environment in low concentrations (e.g., water, cigarette smoke, radon etc.). It is also used in industry, primarily in static elimination devices, where the alpha-particles create intense ionisation that can neutralise positive and negative static charges. Since it has a massive specific activity (166500 GBq g^{-1}), its alpha emission causes it to be hot even in gram quantities; this property has been used for power sources in satellites.

2. Radon in the Environment

Because of the extended half-life of uranium and its abundance in the earth's surface, radon is continually being formed in the soil and released in the air [59]. This normal emanation of radon from Rradium-226 in soils is the largest single source of radon in the global atmosphere [60]. Using average emanation rates from available measurements, estimated soil emanation of radon is in the order of 7.4 x 10^{19} Bq ^{222}Rn y^{-1}. This estimation is equivalent to 60 Bq cm^{-2} radon soil y^{-1}. Groundwater that is in contact with radium-containing rock and soil will be a receptor of radon emanating from the surroundings. When the groundwater reaches the surface by natural or man-made forces, this radon will be released in the air. Although most of the radon present in groundwater will decay before reaching the surface, groundwater is still considered to be the second largest source of environmental radon and is estimated to contribute $1.85x10^{9}$ Bq ^{222}Rn y^{-1} to the global atmosphere [60].

However, the major source of radon in single family dwellings is the soil directly under the building [60]. For these reasons, the radon levels, as measured in ambient conditions (i.e., soil gas) and under confined conditions (indoor radon) are used as indicators for measurement of the potential for emission from naturally occurring radioactive materials (NORM).

2.1. Entrance of Radon

The concentration of radon in the home depends on the amount of radon-producing uranium in underlying rocks and soils, the routes available for its passage into the home and the rate of exchange between indoor and outdoor air. Radon gas enters houses through openings such as cracks in concrete floor-wall junctions, gaps in the floor and small pores in hollow-block walls, as well as through sumps and drains. Consequently, radon levels are usually higher in basements, cellars or other structural areas in contact with the soil.

The exchange of indoor air with the exterior depends on the construction of the house, the ventilation habits of the inhabitants and the sealing of the windows. The radon concentration in houses, directly adjacent to each other, can be very different. Radon concentrations within a home can vary with the time of year, from day to day and from hour to hour. Because of these fluctuations, the estimation of the annual mean concentration of radon in the indoor air requires reliable measurements of mean radon concentrations for at least three months, preferably longer. Short-term radon measurements give only limited information.

The average radon level outdoors normally varies between 5 and 15 Bq m^{-3}, but both higher and lower values have been observed.

The concentration of radon from the basement towards the upper floors decreases, as shown below in Figure 5.

However, when the gas emerges from of the house, its concentration is 15 Bq m^{-3}, compared to 20000 Bq m^{-3} underground.

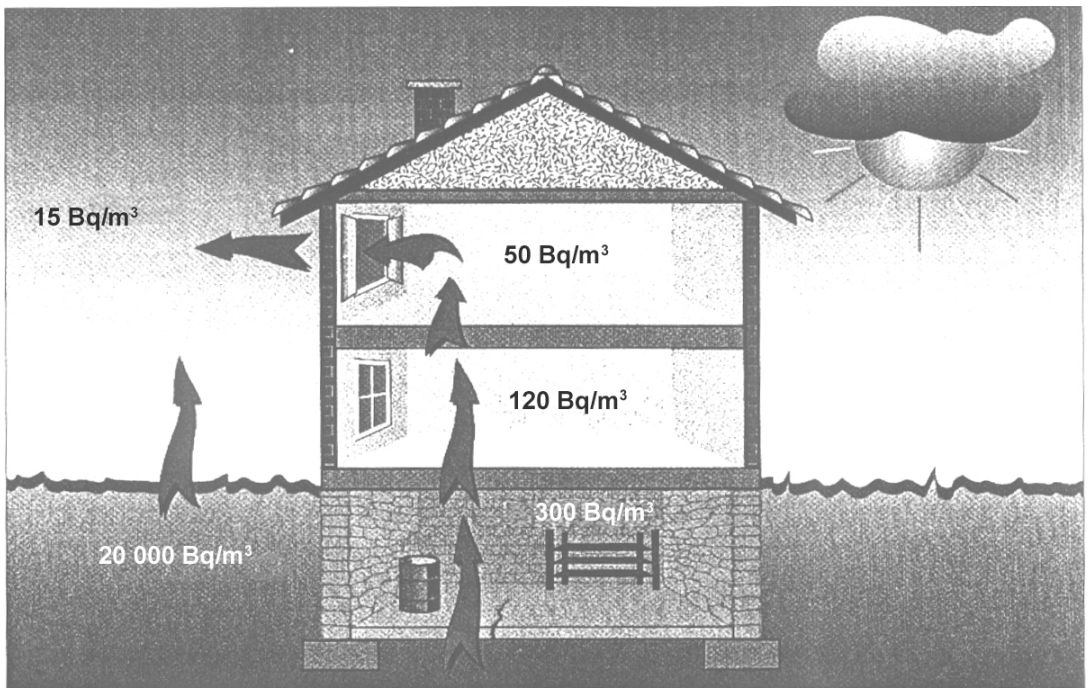

Figure 5: The concentration of radon from the basement towards the upper floors dcreases

The release of ^{222}Rn atoms from mineral grains to the soil pores can be the result of diffusion or by the recoil effect, in which the emerging ^{222}Rn atom receives the α decay energy of its precursor ^{226}Ra. The ^{222}Rn diffusion coefficient in mineral grains (10^{-10} – 10^{-24} m s^{-1}) is very small [60], therefore, recoil is the dominating process in soil grains. The recoil distance is in the range of 0.02 – 0.07 μm within mineral grains, so a fraction of the generated ^{222}Rn atoms is ejected into the pore space. The fraction of ^{222}Rn atoms that enters the pore space is called the emanation coefficient or emanation power [30 - 32].

To a first approximation, the most important influence on emanation is the ^{226}Ra concentrations in rocks and soils, which have an average value of 40 Bq kg^{-1} [33].

Of course, ^{222}Rn concentrations in the soil-gas are likely to rise at high ^{226}Ra concentrations of the soil. Indeed, slight differences of ^{226}Ra concentrations in soil in comparison with greatly varying ^{222}Rn concentrations show, on the whole, that a number of parameters must influence the emanation strongly. One of these parameters is the spatial distribution of ^{226}Ra within the solid phase of the soil.

In general, soil has higher Rn emanation rates than the rocks from which they have developed, and a fine-grained soil, with its large overall grain surface, usually has a larger emanation rate than a coarse-grained one.

Another important parameter influencing ^{222}Rn emanation is the amount of soil moisture. The investigations of Strong and Levins (1982) [34] [35] showed a positive correlation between the emanation coefficient and soil moisture content. The emanation rate can differ by up to a factor of 30 between dry and water saturated soils [34].

The term ^{222}Rn migration describes the movement of ^{222}Rn atoms within the litho-, pedo-, and hydrosphere's or atmosphere. Usually, this term is used for transport within the soil. There are two transport mechanisms in the movement of ^{222}Rn from its place of origin: diffusion and advection. A measure of ^{222}Rn diffusion is given by the ^{222}Rn diffusion coefficient (D). This indicates the number of atoms that diffuse through a surface in a given time interval. The diffusion coefficients are: 0.1 cm^2 s^{-1} in air, 10^{-5} cm^2 s^{-1} in water [36] and 0.04 to 0.004 cm^2 s^{-1} in soil [30]. Additionally an effective diffusion coefficient (De) is used; this describes the diffusion through a surface (or soil volume) in respect of pore space only. Therefore De is increased in comparison to D by the porosity (n): $D_e = \frac{D}{n}$ [31].

Table 1: Measurements of emanation coefficients of 222Rn in unconsolidated soils and other Materials

Material	Emanation Coefficient	Moisture Content	Reference
Unconsolidated soils	0.14 (0.06 – 0.18)	Unknown	Sisigina (1974)
Sand	0.21 (0.10 – 0.36)	Unknown	Sisigina (1974)
Sandy loam	0.24 (0.18 – 0.40)	Unknown	Sisigina (1974)
Silty loam	0.20 (0.17 – 0.23)	Unknown	Sisigina (1974)
(Heavy) loam	0.28 (0.18 – 0.40)	Unknown	Sisigina (1974)
Clay	0.22 (0.02 – 0.70)	0–70% dry wt	Damkjaer and Korsbech 1985
Various soils (Danish)	0.30 (0.03 – 0.55)	Unknown	Barreto (1974)
Soil	0.12 (0.09 – 0.15)	Oven-dried	Megumi and Mamuro (1974)
Soil	0.28 (0.06 – 0.55)	Moist, saturated	Thamer et al (1981)
Other materials	0.14 (0.02 – 0.36)	Vacuum-dried	Thamer et al (1981)
Uranium ore (crushed)	(0.29 – 0.31)	Saturated	Strong and Levins (1982)
Uranium mill tailings	(0.067 – 0.072)	Oven-dried	

The ^{222}Rn diffusion coefficient for soils lies in the range of 10^{-5} and 10^{-10} cm^2 s^{-1}, which are the diffusion coefficients for ^{222}Rn in the atmosphere and in water. Most soils have a coefficient of the order of $10^{-6} – 10^{-7}$ cm^2 s^{-1} [32]. For wet soils, the diffusion distance is only a few centimetres, whereas in dry soils it can reach about 1.5 m [37].

During advective transport, ^{222}Rn is moved passively with the flow of the medium, which can be seeping water or soil-gas, like CO_2 or CH_4. Soil contamination with organic liquids can generate a strong convective flow when liquids easily vaporise. Processes leading to convective transport are both endogenous as well as exogenous in nature. Endogenous processes are linked to geothermal exhalations and seismotectonics [38] [39] [40] [41] [42] [43]. Otherwise, the stronger influence of exogenous mechanisms on ^{222}Rn transport is limited to the uppermost few metres of the soil, except for the influence of seeping water, which can extend deeper [44]. Beside the temperature gradient between the soil-gas and the atmosphere, change of atmospheric pressure [45] is the driving force of ^{222}Rn convection.

2.2. Logarithmic distribution of radon in buildings

In the environment, radon comes from the earth with a flux density that depends on the geological composition of the earth, the altitude and the dispersion in the atmosphere. All of these are linked to weather conditions. A number of factors influence the concentration of radon and among these are:

- the radium content in the soil under the building,
- the soil permeability and
- the construction materials of the building.

In the basement, radon penetrates through cracks and holes, especially in the floor. Radon is also released from the construction material of the house. There are differences among buildings due to factors that influence the concentrations of radon. The radon distribution in buildings is logarithmic. The concentration of radon is subject to this logarithmic distribution, which is ascertained statistically.

When a parameter depends on several independent factors, it can be confirmed that the measured values of that parameter are subject to a"normal" distribution. In the case of radon in buildings, there are many independent factors. They are multiplicative rather than being additive. The radon concentration indoors can be represented by the equation:

$$Rn_{in} = Rn_{out} + A \cdot B \cdot C.... \qquad \text{Equation 1}$$

Rnin is the concentration of radon in the building, and Rnout is the concentration of radon outside the building. A, B, C ... are the factors such as the radium concentration in the ground, the permeability of the

ground, number and size of entry routes, under-pressure in the building, and the ventilation of the building. These factors determine how much of the radon from the source enters the building and how long it will remain there. The model assumes that these factors are largely independent and are multiplicative. The equation can be rewritten as:

$$\ell n\left(Rn_{in} - Rn_{out}\right) = \ell n\,(\mathrm{A}) + \ell n(B) + \ell n(C) + \ldots \qquad \text{Equation 2}$$

This equation conforms to the requirements that a normal distribution is a sum of independent terms: hence, if there is a sufficient number of independent terms and each is randomly distributed, then ℓn (Rnin - Rnout) should be normally distributed.

This distribution has been widely observed in practice in surveys of radon levels in buildings in many countries. To estimate the extension of distribution with the assistance of the average geometrical value and geometrical standard deviation for any place, the natural logarithms and estimation of the average standard deviation should be used. This distribution was widely used in research on radon concentrations in buildings, and it was found that the results of measurements match a logaritmic distribution, irrespective of the size of the site area being surveyed [46 - 48].

2.3. Radon distribution in building compartments

A source of radon can be higher in certain rooms or parts of a building. From there, radon can be carried into other parts of the building through air ventilation. Whether ventilation is continuous or whether intermittent, this will affect the transport of radon inside the building. Once radon has reached parts of the building where there is no ventilation, it remains there. By convection, air flows from lower parts of the building towards higher ones. Convection is important if the temperature in a building is equal to or higher than the temperature outside. In different rooms inside a building, basements have higher concentrations of radon because they are less ventilated and because they are in immediate contact with the soil, which is the biggest source of radon [49].

Based on the research carried out in Sweden encompassing 488 buildings, the average values of radon concentrations in the upper floors were lower as compared to lower floors and basements. This confirms the fact that the highest concentration of radon is in the lower parts of the building. Such a conclusion was also made from studies carried out in Germany. The results of those studies are shown in Table 2.

Table 2: Average levels of radon (Bq/m3) in different floors in Germany found in national research survey [50]

Floor	Basement	Ground floor	1st floor	2nd floor	Outside
Average level of radon [Bq/m^3]	52	43	38	33	14

If the source is under the soil surface on which the building was constructed, then the concentration of radon in the floors will rise, especially in those floors that lack ventilation.

Since radon is a gas, ventilation in the house is an important factor that influences its concentration. Weather conditions cause ventilation effects to vary. If the wind speed outside is low, ventilation in the buildings is practically non-existent. The effect of these conditions results in the growth the radon concentration [51].

The concentration of radon in buildings also depends on the habits of the inhabitants in it, i.e., how long they keep their doors and windows open, etc.

As the soil beneath the house, the building material and the potable water supply and cooking gas can be major sources of radon in houses, a brief description of various radon sources is given. Emanation from the soil is considered to be the dominant source for ground floor dwellings, whereas the dominant sources in high-rise dwellings are building materials and outdoor air. Figure 6 outlines typical radon sources and pathways into a dwelling.

(1: Cracks in solid floors, 2: Constructions joints, 3: Cracks in walls below ground level, 4: Gaps in suspended floors, 5: Cracks in walls, 6: Gaps around service pipes, 7: Cavities in walls)

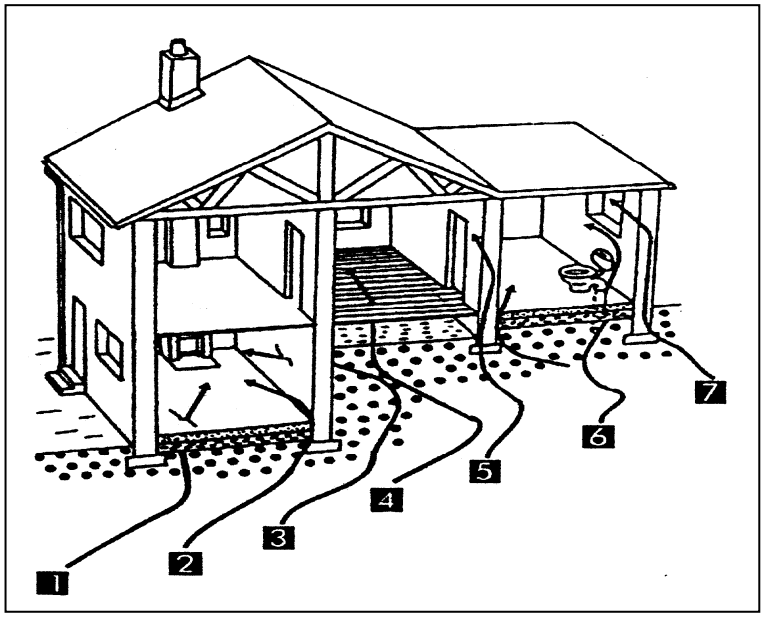

Figure 6: Radon penetration pathways into a building

2.4. Construction materials in buildings as radon sources

All materials contain uranium (^{238}U) and are consequently-– potential radon emitters. This is true both for natural and artificial materials. Typical uranium-bearing natural materials are certain granites, but it is always possible to find uranium-rich bedrocks of different types locally used as building material. Certain types of rock and soil used as construction materials contain larger amounts of uranium. A considerable contribution to the growth of radon concentrations in houses comes from powdered materials derived from rocks enriched with uranium. These materials are sometimes used as insulation for floors or walls. The radon exhalation from such grains depends on the size of the grains. It can be expected that:

$$E = C_{Rn} \cdot D^{-x} \qquad \text{Equation 3}$$

where E is the exhalation rate, CRn is the radon concentration and D is the mean diameter of the grain; x is between 0.5 and 1, depending on the grain density [52]. In theoretical calculations, D should be understood as the statistical distribution of the grain size.

Tables 3 and 4 show the specific activities of radium (^{226}Ra) and thorium (^{232}Th) of some building materials. These radionuclides are potential sources of the emission of radon and thoron from these building materials [53]. These radionuclides affect the possible emission of radon and thoron.

Table3: ^{226}Ra and ^{232}Th contents of some Swedish building materials [53]

Material	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
Brick	40 – 164	71 –180
Limestone	7 – 15	4 – 10
Concrete	31 – 63	46 –127
Lightweight concrete, sand based	3 – 132	2 – 157
Lightweight concrete, alumshale based	788 –2627	19 – 96
Gypsum, natural	2 – 9	0 – 12
Clinker of clay	89	161 – 184

Table 4: ^{226}Ra and ^{232}Th contents in some German building materials and wastes [54]

Material	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
Granite	30 – 500	71 – 180
Baked materials	10 – 200	12 – 200
Limestone	4 – 41	2 – 20
Gypsum	2 – 70	2 – 100
Concrete	7 – 92	4 – 71
Lightweight concrete	6 – 80	1 – 60
Old copper slag	861 – 2100	18 – 78
Tin slag	1000 – 1200	230 – 340
Brown coal ash	4 – 200	6 – 150

2.5. How does radon get inside buildings?

Because radon is a gas, it easily diffuses upward through the ground to the Earth's surface. How much of it reaches the surface depends on the uranium content of the underlying soil materials, together with their depth and permeability (that is, the presence of fractures and interconnected pore spaces that act as conduits for radon). Radon will enter the lowest level of a building using whatever pathways are available. For basement structures or slab-on-grade foundations, the entry points include: (1) cracks and pores in floor slabs, walls and floor/wall joints; and (2) openings around sump pumps, floor drains and pipes penetrating floors and walls. Structures with a crawl space between the ground and the lowest floor level may be less vulnerable to radon, which tends to escape to the outside air when appropriate vents are installed, but they can still admit some of the gas through cracks in the flooring.

The amount of radon entering a building depends not only on the existence of entry points but also on the mechanical and other design characteristics of the structure.

Probably most radon is drawn into buildings by the "stack effect." This effect is greatest during the colder parts of the year when buildings are closed.

The stack effect is enhanced by the use of exhaust fans in kitchens and bathrooms, air distribution blowers and clothes dryers. During the warm months when buildings are either open or well-ventilated through air conditioning, the indoor radon levels are largely determined by geological rather than mechanical factors.

It has been observed in numerous studies that radon levels in the living areas of a house are about 1.6 times higher in winter than in summer, and they are in between the winter and summer values during the autumn and spring. For the same houses, the annual average radon level in basements is up to 2.5 times higher than it is on the first floor.

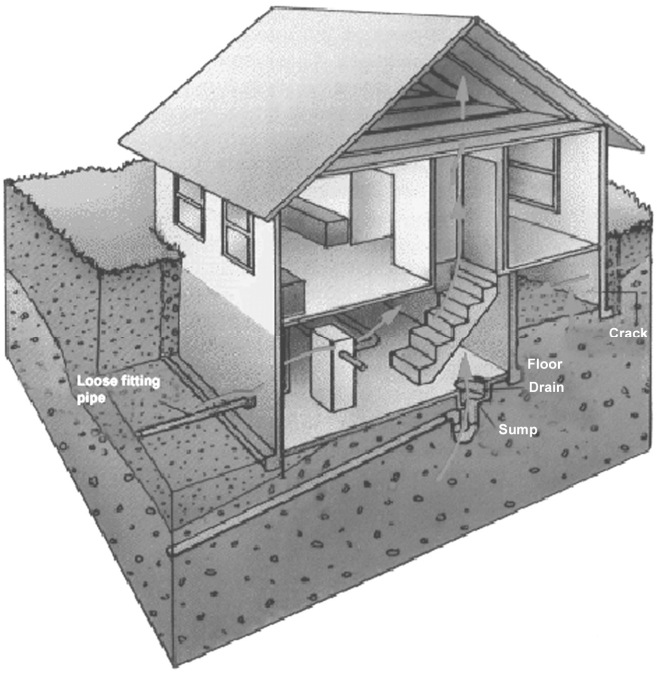

Figure 7: Radon can enter a house through many paths

It was also found that well-weather proofed (tight) houses have average radon levels about 1.4 times higher than poorly-weather proofed houses. The reasons for these differences are easy to understand. There should be more radon in basements because that is where it enters a house, and radon levels should be higher during the cold months when the stack effect is greater and the

indoor/outdoor exchange is very low (especially in tight houses).

In nearly all cases, indoor radon is derived only from the soil materials underlying a building. However, it can also come from construction materials, if uranium-enriched rock is used for fireplaces, fieldstone walls or concrete aggregate or from private well-water, if it is drawn from an uraniferous aquifer. In rare instances, radon can also be released from natural gas burned in furnaces and household appliances.

Regarding health effects, a Recommended Action Level for homes is suggested by various agencies. The recommended level is derived mainly from extrapolation of exposure data from a number of credible studies on miners. The recommended level is not an indicator of the boundary between safe and unsafe, but rather a level at which a reduction of radon level can usually be justified. Assuming occupants spend 70% of their time indoors, the risk of exposure to radon at the recommended level throughout one's lifetime is considered acceptable. Depending on the geological composition and socio-economic considerations, the recommended indoor action levels vary from country to country. The recommended action level in Canada is 800 Bq m^{-3}, whereas in the United States, remediation is recommended when indoor radon levels exceed 150 Bq m^{-3} (Table 5).

Table 5: Recommended Action Level of Rn in the home

Country	Canada	Finland	Germany	Hong Kong	Ireland	Luxe-mburg	Switz-erland	United Kingdom	USA
A.level (Bq m^{-3})	800	400	250	200	200	200	400	200	150

2.6. Exhalation

The term ^{222}Rn exhalation or flux refers to the passage of ^{222}Rn from the soil to the atmosphere. The measure of exhalation is given by the exhalation rate, which is the number of atoms leaving the soil per surface unit and time interval. Even more than for migration, exogenous parameters control exhalation. It is appropriate to distinguish between meteorological conditions influencing soil-physical parameters and conditions that change the ^{222}Rn concentration directly. Among the first, the frequency and amount of precipitation are important, as they influence soil moisture content and gas permeability. The second group includes parameters like atmospheric pressure, temperature, wind force and again precipitation. Rainfall or snow cover can lead to a temporal sealing of the soil surface, whereby ^{222}Rn is accumulated beneath the sealing and the exhalation rate is minimised. A change of atmospheric pressure can influence the exhalation rate, which usually correlated negatively with the atmospheric pressure gradient [61 - 64]. With increasing pressure, atmospheric air with low ^{222}Rn concentrations is pushed into the soil, whereby exhalation is decreased. Vice versa, a falling pressure induces an effusion of ^{222}Rn rich soil-gas from the soil, resulting in high exhalation and subsequent delivery of ^{222}Rn from deeper soil horizons. Wind force is an unknown exogenous parameter acting on exhalation [65, 66].

While the processes of emanation are largely known and are consistently described in the literature, at least qualitatively, the processes of migration and especially of exhalation are still discussed as being controversial. This may be explained mainly by soil-physical parameters (such as ^{226}Ra concentration, grain size), whereas migration and exhalation are influenced much more through exogenous processes (precipitation, temperature, air pressure, wind), which change quickly and distinctively. This leads to fluctuations in the intensity of influences on migration, especially on exhalation.

2.7. Guidelines for concentrations of radon in air

Most countries have adopted a radon concentration of 200–400 Bq m^{-3} for indoor air as an Action or Reference Level above which mitigation measures should be taken to reduce the level in homes. Other countries have chosen higher or lower Action Levels. The choice of Action Levels generally has been based on the concept of acceptable risk, i.e., these levels which are thought to represent population health risks similar to other everyday risks.

Another seldom-used measure is expressed in "working level" units (WL). Instead of representing the radon concentration directly, working levels reflect the amount of decay by-product atoms and, hence, are an indirect measure of radon concentration. Radon decay by-products are more dangerous than radon itself.

There is no exact equivalence between the two concentration measures, but for a typical house, the level of radon corresponds to about 0.02 WL of decay by-product atoms.

The impact of the Indoor Air Quality Objectives recently established by the Indoor Air Quality Management Group, HKSAR, has been substantial in different parts of society. Levels of air pollutants that exist in the indoor environment have now been given more attention than ever before. With the increase of awareness regarding health effects associated with air pollutants, it seems to be no coincidence that requests for Indoor Air Quality (IAQ) monitoring on campuses are on the rise. Under the IAQ certification scheme, monitoring of a prescribed list of air pollutants is required. Among these pollutants, radon seems to raise more interest than others. This could be partly due to the fact that radon is found to be ubiquitous in indoor environments and that perhaps, more importantly, radon is the only radioactive air pollutant on the monitoring list.

2.8. Radon in caves and mines

2.8.1. Radon in caves

Caves are commonly considered to be static environment, where there is not only perpetual darkness but also the temperature and high relative humidity are stable. In most cases, this belief is not justified because air currents can cause measurable changes in the physical parameters. Caves occur everywhere on Earth, although mainly in karst areas, as they are formed mostly in limestone environments. It is obvious that the noble gas radon, which moves freely through pores of permeable rocks, will easily penetrate into subsurface cavities and even into huge caves.

The sources of radon in caves are the bedrock and deposits. Radon levels in caves are influenced primarily by the uranium content of the rock. Limestone and other sedimentary rocks are found to contain about 16 – 31 Bq kg^{-1} ^{238}U on average.

The relatively high values of radon found in caves are due to these low quantities of parent substances that occur naturally, as well as within the interior surfaces of caves. Increased ^{238}U concentrations can be associated either with fluorite mineralization or hydrocarbons present in the surrounding limestone.

It has been known for a long time that elevated radon concentrations may be found in the air of karst caves [72 - 78]; the values depend on the radon exhalation rate of surfaces in the cave, the volume and shape of the cave, the inflow of outside air and the intensity of its mixing with the cave air. The influence of meteorological conditions on radon levels and their temporal variations depends mostly on the shape of the cave and the number as well as directions of cracks and fissures connecting the cave chambers with the outdoor atmosphere. In horizontal caves, the driving force for air movement within the cave, and thus the inflow of fresh air and the release of cave air into the atmosphere, is the temperature difference between the cave air and outdoor air, while in vertical caves, it is the difference between the barometric pressure at the bottom and the top of the cave [79]. If the cave corridors run mostly horizontally and the cave air temperature, being practically constant all year round, is higher than the outdoor air temperature, as it occurs in winter, the cave behaves as a large chimney and due to the air drought, the radon-rich cave air is released to the atmosphere, allowing an inflow of fresh air with low radon levels. Therefore, in such caves, the maxima in radon concentrations are observed in the summer, while the minimal occur in winter [72] [78] [80] [81 - 84], whereas the situation is reversed in caves with several horizontal levels [85].

The exposure of tourists to radon and short-lived radon decay products [86] during their short visits to caves is insignificant, while annual effective doses to tourist guides and maintenance workers, who spend the majority of their working time in the cave, may reach or even exceed 20 mSv [7] [81] [87 - 92]. Their working time in the cave should be limited based on the results of permanent radon monitoring [93].

Radon poses a substantial threat to human health when a build–up occurs in confined spaces such as homes, mines and caves [55] and when the exposure time is sufficiently long. The average annual radiation dose from exposure to ^{222}Rn in caves is estimated to be 1 mSv, although cavers and cave workers are expected to receive much higher doses [21]. Tourist caves are a recognised hazard in terms of ^{222}Rn exposure to cave workers (tour guides, maintenance personnel, employees working in shops built over cave entrances, etc.) [94], but because of the sensitive nature of cave environments, high ^{222}Rn gas concentrations cannot easily be lowered [94]. Forced air ventilation in caves is regarded as unthinkable because of the likely deleterious effects on the microclimates and biota [95].

The existence of elevated concentrations of ^{222}Rn in caves is well established in the literature (Table 6). Table 6 gives a selection of the literature containing extensive ^{222}Rn concentration values, but it does not list all of the basic literature on caves and ^{222}Rn (see, for example, [98] [99]). However, the risks to cavers and cave workers from exposure to the relatively high ^{222}Rn concentrations in caves are poorly understood

and rarely reported in the literature [76] [77] [93][100].

The measurements in karst caves depend on examining natural ventilation regimes. Since interrelations between surface and cave environments are affected by flowing air masses, the exploration of transport processes is a precondition when gathering knowledge about the development and the changes of the cave microclimate, and the propagation mechanism of external effects.

The radon values found should be compared to environmental parameters, e.g., microclimate, temperature, humidity, ventilation rates, etc. The spin-off would be to understand emanation control in these environments, and as a result, this would help to control the radiation risks.

Table 6: Summary of cave 222Rn measurement in the literature (modified from Hyland and Gunn, 1994).

Country	Mean ^{222}Rn Concen. (Bq m^{-3})	Number of ^{222}Rn Measure-ments	Max. ^{222}Rn Concen. (Bq m^{-3})	Min. ^{222}Rn Concen. (Bq m^{-3})	Reference
Australia	**610**	**274**	**4.045**	**9**	**Solomon *et al.* (1996)**
China[a]	**141**	**32**	**278**	**38**	**Wiegand *et al.* (1995)**
Czech Repub.	**1,235**	**60**	**21,000**	**200**	**Burian and Stelcl (1990)**
Great Britain	**2,907**	**820**	**46,080**	**10**	**Hyland and Gunn (1994)**
Great Britain	**…..**	**2,000**	**155,000**	**100**	**Hyland and Gunn (1994)**
Great Britain	**35,890**	**34**	**155,000**	**7,400**	**Gunn *et al.* (1991)**
Great Britain	**9,306**	**13**	**12,552**	**68**	**Gillmore *et al.* (2000)**
Great Britain	**365**	**42**	**3.187**	**26**	**Gillmore *et al.* (2002)**
Great Britain	**315**	**28**	**3.047**	**34**	**Gillmore *et al.* (2002)**
Greece	**25,179**	**6**	**88,060**	**185**	**Papastefanou *et al.* (1986)**
Hungary	**3,300**	**25**	**14,000**	**500**	**Somogyi *et al.* (1989)**
Hungary	**2,468**	**8**	**13,200**	**200**	**Lenart *et al.* (1990)**
Ireland	**4,127**	**26**	**7,940**	**200**	**Duffy *et al.* (1996)**
Japan	**11**	**5**	**20**	**< 1**	**Miki and Iauthora (1980)**
Malaysia	**596**	**39**	**1.978**	**100**	**Gillmore *et al.* (2005)**
Poland	**1,166**	**279**	**4,180**	**60**	**Przylibski (1999)**
Russia	**2,390**	**14**	**8,550**	**373**	**Gunn (1991)**
Slovenia	**1.412**	**101**	**7.220**	**15**	**Kobal *et al.* (1986)**
Slovenia	**965**	**66**	**5,920**	**60**	**Kobal *et al.* (1987)**
Spain	**108**	**301**	**488**	**5**	**Dueñas *et al.* (1998)**
Spain	**3,564**	**8,587**	**7,120**	**186**	**Lario *et al.* (2005)**
South Africa	**267**	**63**	**2.319**	**3**	**Gamble (1981)**
Switzerland	**25,000**	**6**	**40,000**	**2,000**	**Surbeck (1990)**
United States	**1,927**	**60**	**9,350**	**37**	**Yarborough (1976)**
United States	**2,589**	**11**	**9,460**	**370**	**Eheman *et al.* (1991)**
United States	**1,475**	**…**	**2,350**	**744**	**Ahlstrand (1980)**
United States	**……..**	**860**	**1,850**	**333**	**Ahlstrand and Fry (1976)**
United States	**11,678**	**37**	**82,177**	**11**	**Bashor (undated)**

Note that many of the references include 222Rn measurements from several sources

a Data quality control is likely to vary for each study conducted in each country, a fact which makes comparison of results problematic

2.8.2. Radon in mines

The presence of uranium or thorium in the surrounding rocks, as well as the confinement of the atmosphere underground, may lead to an increased concentration of radon isotopes and of their decay products in the mine atmosphere.

The atmosphere of underground mines contains, in gaseous form or in the form of aerosols, all natural radionuclides of the decay chains of uranium and thorium.

The source of the radionuclides present in the atmosphere of a mine, in most cases, is derived from:

1. for radon,
   - mineralised working faces,
   - all the walls of tunnels and workings.
2. for the decay products of radon
   - the radon having diffused into the atmosphere of the mine,
   - the radon originating from the above-mentioned sources.

The atmosphere of a mine may be characterised mainly by the following physical parameters: temperature, relative humidity, particle size distribution of aerosols, volume concentration of radon, age of the ventilation air and volume concentration of radon decay products.

The temperature of the atmosphere of a mine may vary between -50C and +300C; it has generally no great influence on the functioning of the devices used to quantify Rn, either by the phenomenon of frost formation for the lowest temperatures, or for the highest temperatures, by the phenomenon of erasure of latent tracks on the detectors used.

Relative humidity is a characteristic of great importance; in fact, it modifies the conditions of the attachment of the free fraction of aerosols by changing the total number of condensation nuclei; a high level of humidity (often close to 100% in underground mines) consequently reduces the proportion of the free fraction.

Knowledge of the particle size distribution of aerosols is vital for the assessment of exposure to deposited alpha energy. It has, actually, an effect on the conversion factor that allows us to calculate the dose from the exposure.

The volume concentration of radon depends principally on two variables:

- The magnitude of the radon source (surfaces of walls, cracks and fissures in contact with the air; pressure gradient; water saturation),

- The rate of ventilation, which also defines the dwelling time of the atmosphere in contact with the source.

The time of air ventilation also allows the ventilation quality of a mine to be classified as one of the conditions influencing the radon concentration. This is directly linked to operating costs (size of the ventilation system) and age of the mine.

3. Estimates of Health Effect from Exposures to ^{222}Rn and its Progeny

3.1. Health Effects

Inhalation exposure to significant levels of ^{222}Rn and its progeny (assumed to be in equilibrium) has been shown to cause acute and chronic effects in laboratory animals and humans. However, the processes linking the inhalation of ^{222}Rn and its progeny to increased lung cancer risk are complex [55] (e.g., smoking). For this reason, many of the epidemiological studies made on miners and animals have been inadequate, and hence research on health effects has continued.

The ^{222}Rn concentrations used in studies cited by [56] ranged from a low of 56 Bq m^{-3} (human studies) to a high of 8.14 x 10^9 Bq m^{-3} (animal studies). In human studies, a cancer effect level in lungs was identified (actual exposure frequency/ duration was from > 2 – 30 y). In animal studies, mouse mortality and the development of haematological (anaemia) symptoms occurred after a 30 d Median Lethal Dose (LD50) study (actual exposure frequency duration was from 5 – 40 h).

Studies with mice obviously involved much higher doses of ^{222}Rn than would typically be experienced by a caver, but the exposure time was comparable. The human study and other similar studies cited by [56] include ^{222}Rn concentrations that a typical caver might be exposed to, but the exposure times examined were generally longer than would be typical for a caver (an exception can be made for tour guides, maintenance workers, etc.).

The animal studies resulted in fawn lung cancers (21% in dogs, zero in mice and 1.3% in Syrian hamsters), even though the ^{222}Rn doses to which the animals were exposed were extremely high [57]. Syrian hamsters did not develop any tumours at exposures below 3.89 x 10^5 J s m^{-3}, whereas rats showed a high incidence of respiratory–tract tumours after exposure to ^{222}Rn. However, according to [57], the mechanistic bases of these interspecies differences are such that species–to–species extrapolation of animal data to humans cannot be used to predict absolute risk.

Epidemiological studies on the effects of ^{222}Rn gas and its progeny on human health consist primarily of studies of phosphate miners (^{238}U is associated with phosphate deposits). The human studies, except for one study [58], mostly tend to cluster in the cancer region for ^{222}Rn concentrations around 1.000 to 10.000 Bq m^{-3}. These epidemiological studies of cohorts of miners confirm that long–term exposure to high levels of ^{222}Rn gas and its progeny represents a very serious threat to human health.

One human study [58], while suggesting a clear link between ^{222}Rn and small cell carcinoma in the lung, it also noted that cancers were less prevalent in the rural cohort over the urban cohort, where ambient air pollution was a positive confounder. This discrepancy is regarded by the authors as a serious flaw in the study. Additionally, according to [104], no conclusions regarding dose and effect below 50 mSv may be drawn because of large uncertainties and statistical errors. This suggests that the risks to cavers and cave workers from exposure to ^{222}Rn in caves may not be overly significant.

3.2. Health impact on the population

The general population is exposed to radon by inhalation, both outdoors and indoors. Outdoor levels, also referred to as ambient or background levels, are the results of radon emanating from soil. These levels vary widely with geographical location, depending on factors such as the radium content of soil, soil porosity and moisture content. However, a reasonable average for the near ground level is suggested by [67] to be of the order of 5.55 Bq m^{-3} in air. Because of the gaseous nature of radon, radon levels decrease with increase of height from the soil surface. Studies of this vertical gradient indicate that a child who is 0.5 m tall would be exposed to 16% more radon than an adult who is 1.5 m tall [68].

In contrast to the average ambient levels of radon, which are usually quite low, indoor levels are found to be due to the movement of radon from underlying soil and rock through the foundation of the building, the release of radon from water and utility use, radon emanation from radium-containing structural

materials and the rate of ventilation [60]. The contribution of each of these to the overall indoor radon level is difficult to assess, except qualitatively. It has been determined that elevated indoor radon levels are primarily due to radon emanation from the underlying soil [67].

The actual indoor levels are greatly affected by other parameters such as the composition of the foundation materials and the ventilation rate of the enclosed area. Two of the largest indoor monitoring efforts in the United States report arithmetic mean levels ranging at 55 to 157 Bq m^{-3} [69] [70].

Although the primary source of indoor radon is emanation from soil, the release of radon from the water supply may contribute to indoor levels [71]. An analysis had been performed that combined information on water use, the efficiency of radon release from water, house volumes and ventilation rates to determine the impact on indoor radon levels. Their analysis estimated that the use of groundwater contributes an average of 2% to the main indoor radon concentration in houses. As with levels in other media, levels of radon in groundwater vary greatly. Radon ingestion from drinking water has been of less concern in comparison to the dose received from inhalation. Due to the short residence time in the stomach, ingested radon contributes only a small dose to the stomach when compared to the one delivered to lungs by inhalation of radon released from water. Since the dose to the stomach is small, statistically it is not significant [67].

The contribution of building materials to indoor radon is estimated to be low in comparison with the amounts that emanate directly from soil and rock. In general, among common building materials, concrete releases more radon than other materials. The potential of radon release from building materials is expressed by the radium content and the radon emanation rate, which is a function of pressure, temperature, porosity and radon concentration.

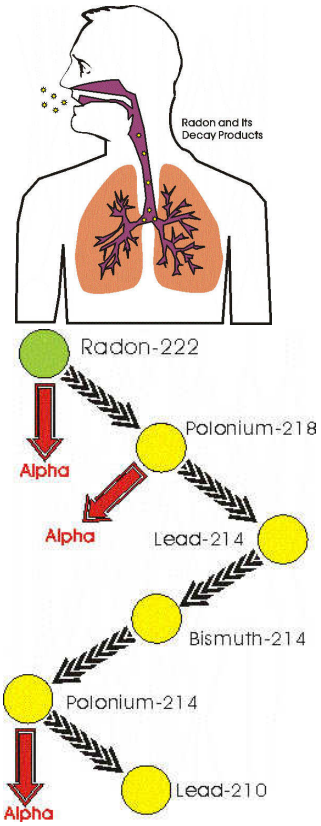

Figure 8: Radon and its Decay products in lung

Radon-induced lung cancer cases were first noticed in miners. Excessive lung cancer deaths were observed among uranium miners in the USA, France, Canada, China and Czechoslovakia. Among other contributing factors, radon was identified as the culprit for some of the excessive lung cancer cases reported. Numerous studies have been carried out to try to establish suitable health standards and guidelines for radon exposure. Radon is a known human carcinogen with genotoxic action at high doses. The most prominent risk model, currently accepted world-wide, assumes a linear, no-threshold approach, implying that the probability of a health effect is in direct proportion to the exposure dose. Consequently, higher risks of biological effects are expected with increase of exposure doses. Under the linear, no-threshold concept, no safe level for exposure to radon can be assumed. Unless exposure to radon is completely eliminated, which is impracticable, the risk of exposure to radon is not preventable but can only be minimised.

The Environmental Protection Agency of the States (USEPA) has estimated that the lifetime risk of lung cancer death from exposure to 150 Bq m^{-3} radon at home throughout a lifetime is around 2.3% for the general public and around 0.7% for non smokers. The U.K. National Radiation Protection Board has also estimated the risk of lung cancer death for the general public to be around 3% at 200 Bq m^{-3}, shown in Table 7, which is comparable to the EPA estimates [23].

Table 7: Lifetime Risk of Lung Cancer Death from Lifelong Exposure to Radon at Home

Agency	Radon level* (Bq m^{-3})	Lifetime risk of lung cancer death from lifelong exposure to radon at home	
		Non smokers	General population
USEPA#	148	0.7 %	2.3 %
	296	1.5 %	4.5 %
NRPB+	200	1.0 %	3.0 %

* Average radon level at home
\# U.S. Environmental Protection Agency
+ National Radiation Protection Board, U.K.

4. Estimates of Health Effect from Exposures to ^{222}Rn and its Progeny

To determine the correct dose from radon and its progeny, which is received by people during the breathing process, one should know their concentration in any volume of inhaled air. The condition would be best met if one could make continuous measurements, though taking a large number of such samples sometimes would present difficulties. This is the reason why measurements are performed with the simplest and cheapest techniques possible. These techniques provide us with partial information, but they are intended for general use. For this purpose measuring techniques are applied in worldwide for measuring the concentration of radon, which as such can serve as a good basis for the assessment of doses in houses, where people spend more than 60% of their time.

In this study efforts were made to determine average values of radon concentration in appropriate environments, in order to assess the corresponding dose. In some schools and other workplaces, additional measurements were made over a longer period of time (3-5 months), in order to monitor the radon concentration to which students and workers are exposed at work. In addition, several criteria were considered for measuring radon in apartments and homes, for example the age of such buildings, heating and ventilation conditions and the floor level where measurements were made. From all the measurements and calculations made, information was gathered regarding the annual effective dose received by students, residents and workers in houses and workplaces.

On the basis of the data gathered in schools and in the selected houses, a general methodology was developed for assessing the doses in these places. Comparisons were made between the instantaneous measurements and those taken over a longer period of time. The results obtained were compared among themselves, because besides being repeated they were also conducted by two methods, alpha scintillation cells and track detectors. Comparisons of the results by these methods showed them to be very similar. It is worth pointing out that different results appeared in different seasons, for summer and winter (in schools and apartments). These results obtained in different seasons and in different locations are presented in this doctoral dissertation, in the form of six scientific papers.

These studies were on a small scale compared to others made in countries outside Kosovo. However, bearing in mind the conditions under which the research has been conducted (self - financing and with equipment borrowed from the "Jožef Stefan" Institute), this study could serve as an initial or baseline reference point for researchers who in the future might deal with radon in Kosovo.

4.1. Measurement Techniques

Techniques for measuring radon and its short-lived successors have been primarily based of alpha and gamma radiation measurement. They differ at only with respect to the model and the time for which the measurement was made. A distinction is made between active and passive models, which are further classified into momentary, continuous and average methods. [70]

All the above-mentioned techniques can be used for measuring the concentration of radon and its progeny in the living environment. The most widespread method for measuring the concentration of radon in the living environment is integrated measurement of the average concentration of radon during a longer period of time, up to even several months. Cases of increased concentration must be further followed.

Nowadays there are various instruments for measuring and monitoring the concentration of radon and its progeny. These instruments have not only been perfected for measuring the concentration of radon and its progeny, but they can be used simultaneously for measuring temperature, humidity and air pressure. Below are presented some measuring instruments used in the attached scientific papers, which as such constitute the main part of this doctoral dissertation.

Radon measurement techniques are generally based on the following principles. Radon diffuses into the detector through a filter that retains its progeny. In the detector radon decays into its short-lived descendants. Normally, alpha particles are detected from the decay of radon and its progeny to new short-lived decay products.

The following techniques are available for detecting the alpha particles:

- alpha scintillation cells
- ionisation cells
- etched tracks detectors
- electrets method

For measuring radon in this thesis, the following techniques were used:

• alpha scintillation cells
• Solid State Nuclear Track Detectors (SSNTD)s

4.1.1. Alpha scintillation cells

The alpha scintillation cell, known as the Lucas cell [101][102], has been used for measuring radon for fifty years. This method is based on the measurement of the alpha decay of ^{222}Rn and from its short-lived progeny ^{218}Po and ^{214}Po. The cells can consist of different materials and be of different shapes. Their inner walls are coated with scintillation material (crystal), which also plays a role in the optical contact with the photomultiplier. Different crystals can be used as scintillations: inorganic crystals such as; ZnS (Ag), NaI (Tl) etc.

For measurement, scintillation cells have been used with walls coated with ZnS activated with silver (Ag) [103]. When an alpha particle is released by decay of radon or one of its decay products, it collides with zinc sulphide. Light is released with a wavelength of about 600 nm. The photomultiplier tube transforms light signals into electric impulses which can be counted. This method provides us with momentary/instantaneous radon concentrations in the air.

The Instruments used (PRM-145) are made of two parts, stored in a carrying case. The first, cylindrical part serves as the impulse detector and contains the photomultiplier, its power supply, an impulse amplifier and container for the scintillation cell.

The second part contains the microcontroller, battery, power supply and impulse selector. It has a keyboard, a control light for the container cover, the power switches and a 2 line alphanumeric liquid crystal display.

The PRM 145 can store data from a maximum of 100 scintillation cells. Every cell has a serial number between 1 and 65535, constant k_1 (cell efficiency, decimal number, in [$s^{-1}Bq^{-1}m^3$]), k_2 (cell volume in m^3) and the last measured background. The Instrument calculates the scintillation sensitivity of the cell (b [$s^{-1}Bq^{-1}m^3$]) by dividing k_1 with k_2. The Scintillation sensitivity is later used to calculate the measurement value (Equation 4).

$$C_{Rn} = \frac{\frac{n_s}{t_s} - \frac{n_b}{t_b}}{60 \cdot b \cdot e^{-0{,}693\frac{t}{\tau}}} \qquad \text{Equation 4}$$

C_{Rn} - radon concentration in air [Bq m^{-3}]

n_s - pulse count

t_s – duration of measurement [s]

n_b – background pulse count

t_b – duration of background measurement [s]

b – cell constant, calculated from k1 and k2 [$s^{-1}Bq^{-1}m^3$]

k_1 – cell constant 1 [$s^{-1}Bq^{-1}m^3$]

k_2 – cell constant 2

t – time between sampling and start of measurement, minus 3 h [s]

τ – half-life of Rn (13752 s)

4.1.2. Solid State Nuclear Track Detectors (SSNTD) (Z.S.Žunić, Ph.D. thesis, 2010)

The most commonly used detectors for the passive detection of radon are known as Solid State Nuclear Track Detectors (SSNTD) or as track-etch detectors. The most suitable and most common for indoor measurements is CR-39, a polymer derived from the monomer oxydi-2, 1-ethanediyl di-2-propenyl diester of carbonic acid.

CR stands for "Colombia Resin" and its physical appearance is similar to Perspex. It was shown that it was a particularly sensitive etched track detector. The optical quality and the response to incident radiation of the CR-39 depends on the initiator and the additives during the manufacturing process. A small quantity of a plasticizer D.O.P (di-iso-octyl-pthalte) or D.N.P. (di–nonyl-phthalte) is added during manufacture and this improves the quality of the post-etch surface and, more importantly, alters the response of the bulk plastic material to alpha particles. Addition of D.O.P improves the optical clarity and reduces the number of surface defects, while D.N.P. improves the homogenity of the CR-39 but decreases the etch rate. CR-39 is sensitive to alpha particles from energies of 0.1 MeV up to 60 MeV proposed that track formation is dependent on the total energy deposited per unit path length by the incident ion. When an alpha particle strikes and penetrates CR -39, it slows down to rest by depositing its energy in a series of interactions with the surrounding material. The energy loss per unit distance travelled (dE/dx) is referred to as the stopping power. Tracks are formed when the Linear Energy Transfer (LET) expressed as dE/dx, the energy loss per unit distance travelled, exceeds some critical value. This can be calculated using a form of the Bethe-Bloch equation. Alpha particles penetrating the material cause damage to the chemical bonds. After chemical etching, the damaged regions become visible when magnified and are seen as conical tracks or holes in the plastic.

It consists of a two part polypropylene conducting holder and a CR-39 detecting element (13 mm x 37 mm). The detector shell is impregnated with carbon fiber and therefore is conducting to avoid any electrostatic effects that might affect the behavior of the charged radon progeny inside the chamber. The upper part of the detector is hemi-spherical and has a circular retaining strut that holds the CR-39 element in place in a recess in the base. Radon gas enters the detector chamber by diffusion with a half-time of about 25 minutes, which is short in comparison to the half-life of radon of 3.82 days. It has been shown that the long term average radon concentrations inside the holders is essentially the same as the long term average concentration outside, though there may be short-term variations in the outside concentrations.

A protocol for the preparation of CR-39 detectors was developed, which included the anti-static precaution of dipping the plastic in a 1:500 solution of detergent and water which has been shown to reduce the static charge on the plastic. The holder acts as a simple radon diffusion chamber, excluding radon decay products and dust, limiting access of moisture but allowing the entry of radon gas.

Another SSNTD used frequently is LR 115, a cellulose – nitrate film produced by Kodak Pathe. This film consists of a thin (13 micrometers), red alpha particle sensitive layer and a supporting transparent film. LR 115 has a much narrower energy "window" than CR-39. This energy window is highly sensitive to etching conditions, and for etching conditions of a 70 minutes etching in 2.25 N NaOH at 60 degree Celsius, the energy window is approximately 1.2-2.4 MeV. This detector is easily charged which may disturb the radon progeny behavior near the detector. Thus great care must be taken to reduce or eliminate the static charge, by dipping the LR 115 in a dilute (1:500) solution of detergent and then by allowing it to dry before use. The LR 115 film is also very susceptible to damage while handling, as the sensitive layer is so thin (13 micrometers) it is easily removed. Gloves were worn at all times when handling the film as even grease from handling can affect the etching. LR 115 is also sensitive to damage by ultra-violet radiation, such as sunlight. After exposure to UV light the sensitive layer disintegrates during etching and accurate counting is impossible. When counting the tracks in LR 115 using a microscope a light filter is used which creates a quasi – monochromatic light source at a wavelength of 546 nm, since both optical lenses and the human eye respond best to green light.

5. Doze and exposure to ^{222}Rn

5.1. Cumulative Exposure

The decay of ^{222}Rn to its progeny results in a state of secular equilibrium, provided that none of the progeny plate out (i.e., adsorb on to the walls). Cumulative exposure CE has historically been calculated in terms of working levels (WL) with 170 h for a working level month (WLM) and is calculated using the equation [57]:

$$C_E = \sum_{i=1}^{n} (\overline{C}_{Rn})_i \frac{t_i}{170} \qquad \text{Equation 5}$$

When $(\overline{C}_{Rn})$ is the average concentration of ^{222}Rn and of its decay products during an exposure interval expressed in J m^{-3}, where t_i represents the number hours exposed.

Of significance to cavers is the time of exposure. According to [57], the cumulative exposure for individuals who continuously occupy a residence (commonly known as ,,shut–ins'') at a given decay product concentration is greater than four times that for an occupational exposure (8,766 h compared to 2,000 h worked on an annual basis). This means that cave tour guides, who work no more than 170 hours per month, are exposed to one quarter of what individuals are exposed to when they do not leave their dwellings. For recreational caving, exposure will generally be considerably smaller.

The net result is that individuals living in above-ground dwellings, which are not necessarily shut–Tins, are annually exposed to 4.8 mSv of ^{222}Rn, as compared to coal and metal miners who are annually exposed to just 0.7 and 2.7 mSv of ^{222}Rn, respectively [125]. For cavers and cave workers, radiation doses are likely to be much less because, although ^{222}Rn concentrations in caves are likely to be similar to that of coal mines, they will be lower than in ^{238}U mines, while exposure times are typically much less than of an occupant of a [s^{-1}Bq^{-1}m^3]

5.2. Effective doses

The effective dose for a person following a guided path in a cave was calculated according to the ICRP-65 methodology [55]. For that purpose, the path was divided into steps of ''equal'' radon concentrations, as shown in Fig. 2 for ''summer'' and ''winter''. The value of radon concentration measured at a point was assumed to be valid from the middle of the previous point to the middle of the next point. The ffective dose gained in a step (Ei) was calculated applying the general formula [86] [93]:

$$Ei = (C_{Rn} \times F) / 3700 \times (t/ (60 \times 170)) \times DCF. \qquad \text{Equation 6}$$

Here, C_{Rn} is the radon concentration (in Bq m^{-3}) fixed for the selected step and t is the time (in minutes) needed to pass this step. F is the equilibrium factor between radon and radon short-lived products, while DCF is the dose conversion factor, which is the ratio between the weighted equivalent dose to lung (assuming a radiation weighting factor for α particles, wα = 20, and a tissue weighting factor for lung,

wlung = 0.12) expressed in mSv, and the exposure to radon short-lived decay products expressed either in WLM or Bq m^{-3} h^{-1}. The old but still widely used unit, 1 WLM (working-level-month) is the exposure resulting from 170 hours breathing in air with an activity concentration of short-lived radon decay products of 1 WL (working-level), originally defined as the activity concentration of ^{218}Po, ^{214}Bi and ^{214}Pb (^{214}Po) which are in radioactive equilibrium (F = 1) with 100 pCi L–1 (3700 Bq m^{-3}) of ^{222}Rn, resulting in an alpha energy concentration of 1.3×105 MeV L–1 [86]. In our calculations, F was set at 0.4 and DCF at 5 mSv WLM−1, in accordance with the ICRP-65 recommendations [55]. When Ei is summed up as a result of following the tourist path, the cumulative effective dose E is obtained as shown in Fig. 2 [144]. During a visit, as seen from Fig. 2 [144], a tourist receives an effective dose of 3.7 μSv in summer and 2.5 μSv in winter. This value is insignificant in comparison to the annual effective dose of 1.25 mSv a member of the general public receives annually from radon and radon short-lived decay products as a worldwide average, or 2.5 mSv received from all natural radioactive sources [126]. The situation is different for a tourist guide in the cave: if she/he worked a maximum of 1300 hours (866 visits of 1.5 h) under summer conditions, she/he would receive an annual effective dose of 3.2 mSv, whereas if she/he spent the entire time in the cave in winter the dose would be 2,2 mSv. Given that only two guides work in winter, they do not spend more than 200–300 hours in the cave during this season. To be on the safe side, we may say that average annual effective doses for guides do not exceed the higher value, 3.2 mSv. Even under this assumption, annual effective doses of guides are low. For this reason, we consider that there is no need to reduce their exposure to radon, or accordingly limit their time spent in the cave.

6. Measurements and results of measurements Doze and exposure to ^{222}Rn

The first measurements of radon concentration in Kosovo were started in March 2003, while working on my master's thesis, in which several school buildings from Prizren, Sharr, Suhareka and Malisheva municipalities were included. Based on the results obtained, it was noticed that radon concentrations in some school classrooms were of a high level, while in other localities they were of a low level. Measurements were mostly carried out in different seasons, where a change in radon concentration was noticed.

Measurements in some classrooms were repeated in different months, but the results were approximately the same, with only small differences, which we considered insignificant.

Work was continued in measuring radon concentrations in some houses of the Sharr municipality. In these measurements, track detectors were used whereas those made in schools used the alpha scintillation method. Measurements were made in the mines of Trepça and the Gadime cave. In the mines of Trepça, measurements were made by the alpha scintillation method, whereas in the Gadime cave, apart from the alpha scintillation method, track-etch detectors were also used.

6.1. Geology of Kosovo

Kosovo has a varied geology that dates from the Neo-Proterozoic to the Holocene period. The geology is characterised by substantial structural features on a regional scale, including normal faulting and thrusting. A general simplification of the stratigraphic sequence is as follows. The oldest rocks form the Neo-Proterozoic basement, which is composed of crystalline schists and granites, representing the products of regional high-grade metamorphism. These rocks mainly outcrop in the north-east of Kosovo. Laid down on top of this continental basement is an extensive sequence of shallow water marine sediments (clastic and chemical) of Late Permian to Early Triassic age that were invaded by acid magmas as the continental crust thinned, resulting in anatexis of the pre-existing rocks. Continuation of stretching and thinning led to a physical separation of the continental crust, resulting in the extrusion of basalt, hosting highly irregularly shaped pods of high-grade chromite.

This separation was extensive enough to lead to the formation of the Paratethys Ocean which ran across the Balkans, including Kosovo. The Paratethys was a branch of the main Tethys Ocean that ran across southern Europe, the Mediterranean and North Africa. A reversal of tectonic plate movement led to the eventual closure of the Mesozoic-age Tethys Ocean, including a segment called the Vardar Ocean (Paratethys) across Kosovo. By late Jurassic times, the presence of a remnant of the Vardar Ocean as a shallow sea led to the chemical deposition of thick and extensive carbonate platforms. By Cretaceous times, the eventual retreat of this sea, and the stability provided as a passive continental margin, led to the deposition of clastic sediments that range from marine to terrestrial in origin. Collision between the landmasses that had flanked the Vardar Ocean forced the westward abduction of remnants of the oceanic crust upon the continental crust. The result is the remnants of the oceanic crust found throughout the Balkans, forming linear ophiolitic sequences aligned along the regional NNW-SSE structural trend. These abduction events are polyphase and would appear to represent crustal accretion, resulting in the development of several linear belts of ophiolites, ranging in age of abduction from Jurassic to Cretaceous. The rocks that were overthrust during the emplacement of ophiolites are called the 'sole' rocks and their form units are called mélange. Such ophiolitic mélanges are characteristically composed of chert, serpentinite, mafic volcanics and carbonates, all of which may be in the form of fragments within chaotically sorted olistostrome units. In Late Cretaceous times, extensive continental collision during the

Alpine Orogeny led to the formation of the Alps and associated mountain ranges throughout central and southern Europe. The rapid erosion of these contorted rocks of both marine and continental origin resulted in the deposition of the flysch cover sequence, composed of mainly limestone and clastics. As the Alpine Orogeny waned, so the young mountain ranges were eroded to produce the continental molasses cover sequences that were predominantly formed in intermountain basins throughout the Alpine Zone. Some of the continental clastic sediments preserved in Kosovo probably represent molasse deposits. Basin depressions within Kosovo were sites of luxuriant vegetation growth that finally became overwhelmed by sedimentation and led to the formation of substantial stratiform lignite deposits that are mined by KEK. The Pleistocene glaciations that affected Europe removed much of the soil cover from Kosovo's ring of surrounding mountains, leading to the formation of substantial talus deposits along the steep mountain flanks.

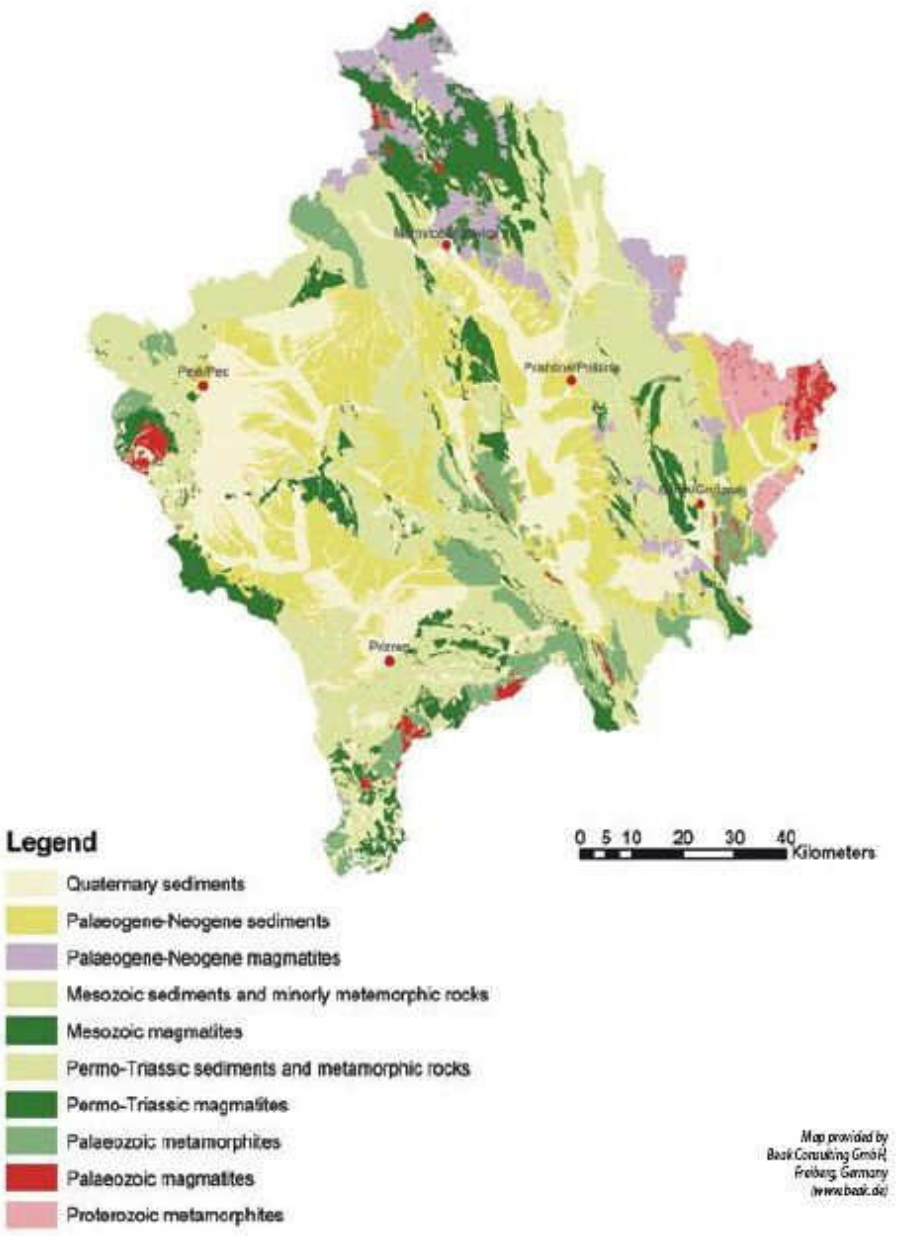

Figure 9: Geology Map of Kosovo.

6.2. Tectonic structure of Kosovo

Structurally, Kosovo is geologically divided into two roughly equal-sized halves (the Vardar Zone to the east, and the Drina–Ivanjica/Korabi–Pelagonian Zone to the west) by the NNW-SSE trending suture between the Serbo-Macedonian Geological Belt in Kosovo and the Dinaric Geological Belt of Albania. The Mesozoic transform fault zone, the so-called Shkoder-Peja lineament, divides Drina and Korabi into two separate contiguous zones. The Vardar Zone is economically important as it hosts the Trepca lead-zinc-silver deposits. These deposits vary from carbonate-hosted skarns and karst fillings to vein deposits. The Mesozoic limestone platforms have been fractured by several generations of faults oriented in different directions. The limestones are reactive rocks capable of absorbing mineral-rich heated brines, and the metals were created by solution in these favourable horizons. The Vardar Zone may have originated either in the Early Palaeozoic, as part of the Palaeo-Tethys that separated Gondwanaland to the south from Eurasia in the north, or in the Triassic, similar to the present-day Red Sea oceanic basin. The final closure of the Vardar Ocean is unclear and may have occurred in either the Cretaceous or Early Tertiary. The formation of ophiolites via ocean closure and thrusting is important in that the ultra-basic units host chromium. Moreover, these serpentine rocks were broken down under tropical to sub-tropical weather in the course of time to produce accumulations of bauxite and lateritic nickel. The bauxite deposits in central west of Kosovo are hosted in karst limestones and represent the remnants of these weathered ultrabasics.

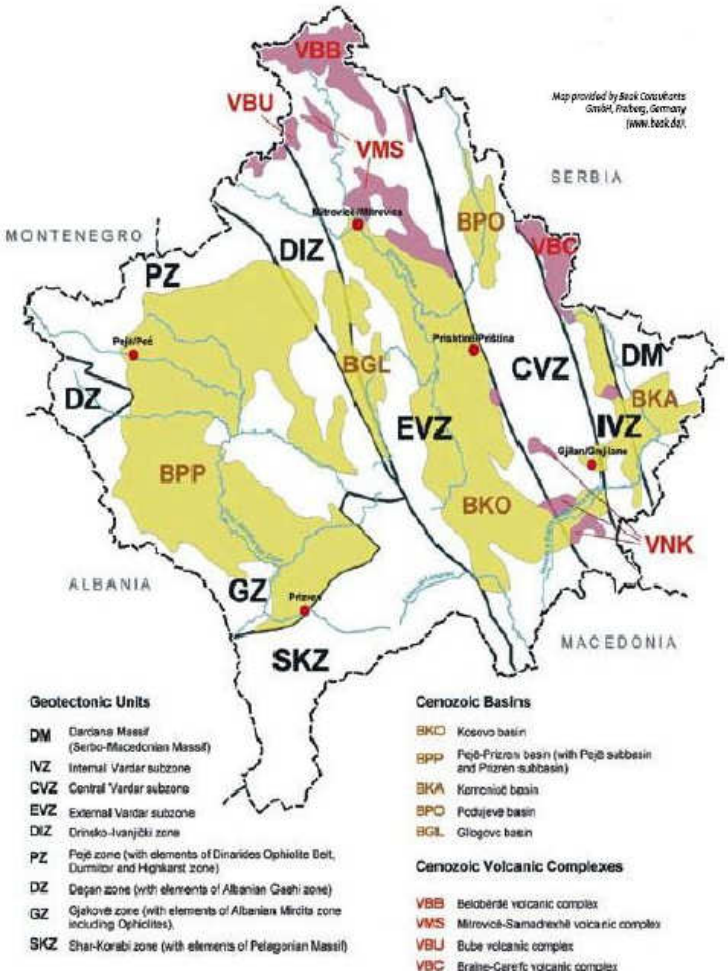

Figure 10: Structural Map of Kosovo.

6.2.1. Trepça and Mitrovica Mine

The municipality of Mitrovica lies approximately 40 kilometres north of Prishtina, covering an area of 350 square kilometres. It consists of one town and 49 villages. The town itself and two of the villages are ethnically mixed, while the remainder are ethnically Albanian.

Mitrovica had the largest metallurgic and mining combine (Trepça) in Europe, which recommenced its activities in 1993 with extraction of lead, cadmium and zinc. Many industrial plants existed in this complex, such as a lead smelter, a fertiliser production plant, a refinery, a battery factory, a zinc electrolysis facility and a sulphuric acid plant. A significant amount of heavy metal pollutants were released in the surrounding area, including populated residential areas, resulting in a threat for the health of the population.

The attractive geology of the mine has not yet been fully assessed; except for the excellent studies of the Selection Trust made by the geologist Forgan (supplemented by Schumacher in 1950), no comprehensive, detailed and well-illustrated study of this giant deposit has been published. In the meantime, however, the known extent of the mine along the dip has doubled. All publications issued are either an interpretation of the synthesis of ore deposits and of the whole mineralised belt (Jankoviç), or short accounts and guide-books for congress participants and visitors, without any detailed illustrations, or publications devoted to a particular topic, such as the stratigraphic datings by Kandic and Coll. (1973), which were also soundly interpreted by Strucl (1981).

The mine is located within the Dinarides alpine belt in the Vardar zone, a nappe of folded and over-ridden units comprising a Palaeozoic basement, a Jurassic sedimentary cover and overthrusted cretaceous ophiolites, intruded during the Tertiary by post-tectonic magmas (granodiorite and intrusive dacitic-andesitic lavas). The ore deposit is interlayered as a manto and as skarns within a sedimentary pile (the Stari Trg Series), below a thick layer of volcanic tuffs (ignimbrite) of tertiary age. More precisely, within the Stari Trg Series, the ore bodies are intercalated between (at the bottom) thick marmorised lime stones and (at the top) thick schists, a stratigraphic contact that is from place to place occupied by an intercalated layer of quartzite. This contact is folded in an anticlinal hinge, the NW-SE axis, which has a pitch of 40° towards the NW. The whole structure looks a little more complicated when becoming aware that a volcanic chimney (an explosion breccia of an oval 100 x 200 m section with a core made of a pipe of trachyte or dacite) was intruded all along the crest of this anticlinal hinge, precisely within the interface between the schists and the limestones. It is this pipe that (fundamentally) controls the presence of the mineralisation. The ore has wormed its way into or nearly into the interface of the schist/limestone on one side of the volcanic pipe or on the other. It reaches from 30 up to 60 m thick on average. There are a few discordant ore shoots as well. There are also other smaller prospects of the same type as Stari Trg in the neighbourhood of the mine.

6.2.2. Prizren

The town of Prizren, with about 168,000 inhabitants, is located in the southern part of Kosovo. Altogether, 9 elementary and 6 high schools, of which the former with 16,735 pupils and the latter with 5545 students, were included in the study. They are mostly one–storey buildings, made of stone and brick. Those built more recently are made of prefabricated elements. The weather in the region is typically continental, with severe winters and hot summers. In some buildings, rooms are heated individually by burning wood or coal, but in the majority, central heating is used, based on oil or coal, less frequently on gas. There is no air–conditioning and the rooms are ventilated simply by opening windows and doors.

6.2.3. Sharr

The town of Sharr (Dragaš) with 12,300 inhabitants is located in the southern part of Kosovo. Altogether, there are five elementary schools and one high school, of which 3631 pupils and 786 students, respectively, were included in this study. They are mostly single – storey buildings, some with a basement, some without. All were built after 1974, of stone and brick, and recently of prefabricated elements. The climate in the region is typically continental, with severe winters and hot summers. In some buildings rooms are heated individually by burning wood or coal, but in the majority, central heating is used, based on oil or coal, less frequently on gas. There is no air – conditioning and rooms are ventilated simply by

opening windows and doors.

Villages for radon survey were selected for the following reasons: the village of Sharr because it is the municipality of Kuk, Bellobrad and Glloboçicë villages which they were hit by depleted uranium projectiles during the NATO bombing in 1999; the village of Brrut because it is located above a karstic terrain with abundant caves; and the village of Bresanë because it is located over a copper deposit. In each village, 2–4 houses were selected in which radon was measured in 2–3 rooms, intended mostly for living and sleeping. All houses were made of concrete and brick between 1982 and 1997. The climate in the region is typically continental, with hot summers and severe winters. There is no air-conditioning; in winter; rooms are stove heated by burning wood, which is also used for cooking. The sizes of the households vary, ranging from 4 to 22 persons. A number of inhabitants are employed by state or private companies, some attend schools, others stay at home carrying out farm work, or taking care of animals, and their homes.

6.2.4. The Gadime Cave

The Gadime Cave [127] is located about 20 km from Prishtina, the capital city of the country. 5350 m of underground galleries and halls have been discovered to-date, of which 1350 m are open as show caves. The difference between the lowest and highest point along the guided tour is 50 m. Visits are possible from 9 a. m. to 6 p. m. in winter, and from 7 a. m. to 7 p. m. in summer. There are about one hundred visitors a month in winter and two to three hundred a day in summer, totalling at about 20 000 visitors a year. A guided walking tour lasts 60–90 minutes. For that purpose, 8 tourist guides are employed during the summer season (from May to September) and 2 during the winter season (the rest of the year), each spending 110 hours in the cave in a summer month, adding up to about 1300 hours annually.

6.2.5. Malisheva and Suhareka

The Municipality of Malisheva has a surface of 306.3 km2. It borders on the Municipality of Klina and Drenas in the south and with Lipjan and Suhareka in the east, in the south with Suhareka and Rahovec and with Rahovec and Klina in the west.

The Municipality of Malisheva, as an administrative and territorial unit, is made up of 39 cadastral units with 44 residencies, including here the very centre. The Municipality of Malisheva lies in the western part of Kosovo. Since it is approximately of the same distance from other regional centres, it can be said to lie in the centre of Kosovo. On this basis its citizens call their city the Heart of Kosovo. The regional centre of Malisheva is Prizren at a distance of 44 km. The distance from the capital Prishtina is 49 km; being positioned in the centre of Kosovo and having a favourable terrain enables Malisheva to have good communications with the whole country. The territory of the municipality is mainly mountainous. It is penetrated by the river Mirusha, with flat fertile lands on both its banks. The Municipality is circled by the mountains of Drenica, with the highest peak of Kozmaq (1,057 m) and the Mt. Koznik (1,006 m high). A Mediterranean climate also dominates the territory of Malisheva, characterized by cold winters and warm summers.

Maximal temperatures during the summer are 24.6°C, whereas minimal ones in January are about 10°C. Rainfall averages 511-1108 mm per year.

Due to lack of recent data about the size of the population, statistical data from before 1999 are presented below, as well as internal calculations of the Municipality made after 1999 (Directorate of Public Services). According to these data, the Municipality has over 65,000 inhabitants. From 1971 registration until today, it is estimated that the population of Malisheva has grown from 31,320 inhabitants, i.e. 1,010 inhabitants per year. The total number of families is 8,450, with an average number of 7.7 for each family. The gender structure of the population is 55% males and 45 % females.

The Municipality of Suhareka lies in the southern part of Kosovo. It has a territory of 361 km² and is made up of 43 villages. It borders with Prizren, Rahovec, Malisheva, Lipjan, Shtime, Ferizaj and Shtërpcë. It lies in the geographical north at 42o 15', and within it lies (in the south) National Park, of Sharri 42o 30', and the Berisha Mountains and Javor (in the north). The southern geographical length is 20o 45', and it borders with the Municipality of Rahovec (in the west) 21o 00, and with Mountains of Jezerc and the Stone of Delloc (in the south). The Municipality of Suhareka is encircled with high mountains; in the north-west

by the Pagarusha and Temeqina Mountains with a height of 796-828 m, in the north by Carraleva, 922 - 1.048 m high, in the south by the Mountains of Jezerc, 1.677 m (the Head of Ahishta), and in the south east by the Sharr Mountains, 2.092 m high (Pasha's Door), while in the west with the valley of Prizren. The average height is 455 m above sea level. The town of Suhareka lies at the height of 400 m., and the territory of the Municipality itself is 361 km², thus covering 3.3 % of the overall territory of Kosovo. Out of the whole territory of the municipality (36,099 ha, or 361 km²), 15,074 ha or 41.7 % are covered with forests, while 19,373 ha or 53.7 % is agricultural land. Through this municipality there pass many important roads that connect it with the capital Prishtina, the regional al centre of Prizren and further with Albania.

According to some data, the municipality has around 80,000 inhabitants. A specific feature of these inhabitants is their young average age, a very important factor for its future economic and social development. The gender structure of the population is almost equal by 50% (F) and 50% (M).

The data in Chapter 6 were collected from the municipalities where the measurements were made.

6.3. Paper resumes and published papers

6.3.1. Paper resume

Paper I – Resume

Paper II – Resume

Paper III – Resume

Paper IV – Resume

Paper V – Resume

Paper VI – Resume

6.3.1.1. Paper I resume

Radon concentration in different levels of Trepça mine

Universiteti i Shkodrës"Luigj Gurakuqi"Bul. Shk.,Ser.Shk. Nat. 2005. Nr.55: 13-20

M. Bahtijari, Z. Shemsidini, H. Ajazaj.

In this study, radon concentrations rates were systematically measured in eleven (11) levels of the Trepça mine in Kosovo. Alpha scintillation was the main method used for measuring the radon concentration.

Measurements have shown that radon concentration is higher in upper levels, because radon does not spring up from the depth of land.

Measurements have been obtained from 11 levels of the Trepça mine. Samples of air have been pumped inside the cells, and for each of them notes related to time and location were kept. Measurement procedure starts three hours after sampling and every measurement is repeated twice and for each case is found the mean value and error of measurement.

At the time of measurements the mine has just started to operate after a very long pause because of the war in Kosovo.

We have chosen Trepça mine to measure radon concentration because: i) It is supposed that radon concentration there is high. This is related to its big size and with what it produces (the mine has 11 floors where the last one is in the depth of about 700 m from the entrance level and there are produced lead and zinc), ii) the number of people working there is high. In the case of high radon concentration, long time of exposure would put their life in serious risk.

6.3.1.2. Paper II resume

INDOOR AIR RADON CONCENTRATION IN SCHOOLS IN PRIZREN, KOSOVO

Radiat. Prot. Dosim 121, 469-473 (2006)

Bahtijari, M., Stegnar, P., Shemsidini, Z., Kobal, I. and Vaupotič, J.

Indoor air radon (^{222}Rn) concentrations were measured in spring and winter in 30 rooms of 9 elementary schools and 19 rooms of 6 high schools in Prizren, Kosovo, using alpha scintillation cells. Only in three rooms of elementary schools and four rooms of high schools did winter concentrations exceed 400 Bq m^{-3}.

The town of Prizren with 168,000 inhabitants is located in the southern part of Kosovo. Altogether, there are 9 elementary and 6 high schools, of which 9 with 16,735 pupils and 6 with 5545 students, respectively, have been included in our study. They are mostly one-storey buildings, made of stone and brick, and recently of prefabricated elements. Weather in the region is typically continental, with severe winters and hot summers. In some buildings rooms are heated individually by burning wood and coal, but in the majority, central water heating is used, based on oil and coal, less frequently on gas. There is no air-conditioning and rooms are ventilated by simply opening windows and doors.

Radon concentration in air was measured with 0.7 dm^3 alpha scintillation cells manufactured at the Jožef Stefan Institute and calibrated according to the Rushing procedure using the NIST (National Institute of Standards and Technology, Washington DC, USA) standard $^{226}RaCl_2$ solution 4953 D. Cell efficiency is in the range from 0.0019 to 0.0022 $s^{-1}Bq^{-1}m^3$ and background in the range from 0.5 to 1.5 $\min^{-1}$, which gives a lower limit of detection of 10–30 Bq m^{-3} at 30–60 min counting time in an PRM-145 counter (AMES, Slovenia).

A day before air sampling, we visited a school to select three to six rooms for our survey, and asked the manager to keep these rooms closed overnight.

Then, we came early next morning, before anybody has entered the rooms, and sampled the air directly into scintillation cells. Cells were transported to the laboratory where alpha activity was measured after 3 h, by which time radioactive equilibrium between radon and its short-lived decay products has been established. The results thus obtained are reported as instantaneous radon concentrations under closed conditions.

Instantaneous indoor air radon concentrations (C_{Rn}) in elementary and high schools in Prizren obtained in May and December 2003 are shown in Tables 1 and 2, and their statistics in Tables 3 and 4, respectively. In the majority (74%) of rooms in the elementary schools, both the May and December values are <100 Bq m^{-3}; in three rooms, they are >200 Bq m^{-3} and exceed 400 Bq m^{-3} only in one classroom of the ES-PR-01 school (Table 3). Radon levels were also low in the high schools, although their distribution was shifted towards higher concentrations (Table 4): in December, values <100 Bq m^{-3} were found in <50% of rooms. Nevertheless, only in the gym hall of the HS-PR-02 school was the December value >400 Bq m^{-3}. Figure 1a and b shows, as expected, that radon concentrations obtained in December were higher in all rooms than those obtained in May (with only one exception in the ES-PR-07 elementary school, where it was, at both times, practically at the lower limit of detection). The average ratio C_{Rn} in May versus C_{Rn} in December was 0.90 for elementary and 0.73 for high schools.

Radon levels in the schools surveyed in Prizren are as low as in some other countries, for instance in Osijek, Croatia with a geometric mean of 70.6 Bq m^{-3}, ranging from 15 to 300 Bq m^{-3}, in Parma, Italy where they ranged between 10 and 108 Bq m^{-3}, in Austria with a mean concentration of 52 Bq m^{-3}, in Amman where they were <100 Bq m^{-3} in 30–50% cases, and in New York state where 150 Bq Bq m^{-3} was exceeded only in 47% buildings. On the other hand, our results are low compared with levels obtained in Slovenia, where in 8% of schools radon concentration was >400 Bq m^{-3} and in 3%, even >1000 Bq m^{-3}, in Austrian pottery schools with a mean value of 617 Bq m^{-3}, in Connecticut, USA where, at least in one room of 217 schools, radon concentration was >148 Bq m^{-3}.

6.3.1.3. Paper III resume

Indoor radon concentration of Malisheva and Suhareka Muncipality schools
AJNTS (1-2) XI (19-20), 346-349 (2006)

Bahtijari, M., Halimi, Y., Ylli, F. and Dollani, K.

During the year 2003 in experimental way were determined the concentration of radon in some schools in Malisheva and Suhareka. The measurements included a secondary school and primary schools, altogether 19 classrooms with the dissipation in the different premises. The measurements were carried out with portable apparatus PRM – 145, based in alpha scintillation method.
The radon indoor sampling was performed in the schools of Malisheva and Suhareka Muncipality, and was planned to include different teaching premises like classrooms, saloons, cabinets, etc. All premises were closed 12 hours before sampling for the equalization of the ventilation conditions. After the specimen was taken by the cell pump, the sampling time and location was recorded. All records were kept on a special table, especially prepared for the measurements, aiming the identification of locations with high radon concentration. After three hours since the moment that the specimen was taken, the process of measurement started. For each sampling, two measurements were performed and the average value was calculated.

The measurement time is depended from the value of radon concentration. For samples with relatively great concentration, it takes a short time and for samples where the concentration was smaller it takes a long time.
In the following tables are represented the radon concentration for every school separately.

There are two different values of radon concentration in Table 1 and 2, which belong to the measurements carried out in May and December. At the basements the obtained values are bigger than in the ground, and in December the values are bigger than in May, when the temperature is higher and premises faucets are also bigger.

Therefore, the results for indoor radon do not represent any danger for the health of the teaching staff and pupils.
In two classrooms of the school “Jeta e Re”, which are in the basements, the radon concentration is bigger in comparison to other classrooms. The radon concentration values differ from 340 Bq m^{-3} and 202 Bq m^{-3} in May, to 410 Bq m^{-3} and 208 Bq m^{-3} in December.
In one classroom of the primary school „7 Marsi” the radon concentration is also higher. The premise of the mentioned school is old, therefore the obtained results is in accordance to ICRP data for the old building indoor radon concentration (400 Bq m^{-3}).

6.3.1.4. Paper IV resume

Seasonal variation of indoor air radon concentration in schools in Kosovo

Radiat. Meas. 42, 286-289 (2007)

Bahtijari, M., Stegnar, P., Shemsidini, Z., Ajazaj, H., Halimi, Y., Vaupotič, J. and Kobal, I.

Indoor air radon (^{222}Rn) concentrations were measured in March, May, August and December in 15 rooms of five elementary and in six rooms of one high school in Sharr, Kosovo, using alpha scintillation cells. Only in one room did the value exceed 200 Bq m^{-3}.

The town of Sharr with 12,300 inhabitants is located in the southern part of Kosovo. Altogether, there are five elementary and high schools, of which six with 3631 pupils and one with 786 students, respectively, were included in this study. They are mostly single-storey buildings, some with a basement, some without. All were built after 1974, of stone and brick, and recently of prefabricated elements. Climate in the region is typically continental, with severe winters and hot summers.

In some buildings rooms are heated individually by burning wood and coal, but in the majority, central water heating is used, based on oil and coal, less frequently on gas. There is no air-conditioning and rooms are ventilated by simply opening windows and doors.

In all rooms, indoor air radon concentration (C_{Rn}) was low at all four surveys, as seen from Table 1. It exceeded 200 Bq m^{-3} only in classroom 2 of the HS-SH-01 high school. Such low concentrations have been found also in schools in other countries, for instance in Osijek, Croatia with a geometric mean of 70.6 Bq m^{-3}, ranging from 15 to 300 Bq m^{-3}, in Parma, Italy where they ranged between 10 and 108 Bq m^{-3}, in Austria with a mean value of 52 Bq m^{-3}, in Amman where they were below 100 Bq m^{-3} in 30–50% of cases (Kullab, and in New York state where 150 Bq m^{-3} was exceeded in 47%. In contrast, higher values were reported for Slovenia where in 8% of schools radon concentration was higher than 400 Bq m^{-3} and in 3%, even higher than 1000 Bq m^{-3}. Other cases of high levels were Austrian pottery schools with a mean value of 617 Bq m^{-3}, and Connecticut, USA where in at least in one room of 217 schools, radon concentration was above 148 Bq m^{-3}. This comparison is not justified because of different climates in the countries sited, and is simply aimed at ranking the radon levels.

If we generalise the above r values and assume them to be valid for other schools in the region, since they are subject to practically the same climate conditions and working regime, the measurements in our future study on radon exposure in schools may be optimised. In order to obtain the annual average radon concentration needed for dose assessment. Nonetheless, by using r values, we may expose detectors only during one season (e.g., winter), and then estimate radon concentration for other seasons (e.g., spring and autumn). In this way, either the number of detectors could be reduced or, with the same number of detectors, a larger number of buildings could be included into the study.

Fig. 2 shows a general trend of decreasing radon concentration from basement toward first floor. Therefore, our future radon measurements will be carried out only on ground floors when there is no basement underneath, or in basement rooms if they are used either for classes or as workshops.

6.3.1.5. Paper V resume

Exposure to radon in Dwellings in the Sharri Comunity, Kosovo
Radiation Protection Dosimetry (2008), Vol. 130, No. 2, pp. 244–248
M. Bahtijari, J. Vaupotič, A. Gregorčič, P. Stegnar, and I Kobal,.

Indoor air radon concentration was measured by exposing etched track detectors in the sleeping and living rooms of 18 houses in 6 villages of the Sharri community in Kosovo. Values ranged from 24 to 209 Bq m^{-3}, with only one exceeding 200 Bq m^{-3}, with a geometric mean and geometric standard deviation of 95.4 Bq m^{-3} and 1.6, respectively. On the basis of the assumption that the spring radon concentrations obtained in this survey represent the yearly average, annual effective doses of residents were calculated; they range from 0.89 to 4.7 $mSvy^{-1}$, with the geometric mean and geometric standard deviation of 1.5 and 2.2 $mSvy^{-1}$, respectively. No mitigation measures are planned to be undertaken.

The Sharri community is located in the south of Kosovo. Villages for radon survey were selected for the following reasons: the village of Sharri because it is the municipal centre; the villages of Kuk, Bellobrad and Gllobocice¨ because they were hit by depleted uranium projectiles during the NATO bombing in 1999 (just in order to diminish the widespread concern of the residents, although no impact of depleted uranium on radon levels was expected(8)); the village of Brrut because it is located above a karstic terrain with abundant caves; and the village of Bresane¨ because it is located over a copper deposit.

Detailed geology was not taken into account for this limited survey. In each village, 2–4 houses were selected, in which radon was measured in 2–3 rooms, mostly for living and sleeping, either on the ground or first floor. All houses were made of concrete and brick between 1982 and 1997. The climate in the region is typically continental, with hot summers and severe winters. There is no air-conditioning; in winter, rooms are heated by stoves burning wood that is also used for cooking. The size of a household varies, ranging from 4 to 22 persons. Some are employed by state or private companies, or attend school; the others stay at home taking care of field works, animals and house.

Radon concentrations are presented in Table 1, together with details of each village or town included in the survey. The distribution of radon concentrations in rooms is shown as a log-probit plot in Figure 1. The radon concentrations fit well (exceptions are the lowest two points) the lognormal distribution (Figure 2). As described above, site characteristics of the villages selected were different and so were possibly different radon sources, and, hence, a broken line in the log-probit plot is expected. Therefore, the prevailing radon source at each village was probably similar. Nonetheless, radon levels at Bresanë, lying over a copper deposit, are consistently higher than those at Kuk, hit by depleted uranium. On the other hand, at Brrut in the karst region both high and low values, and, at Gllobocice, the lowest and the highest values were observed. As the houses were built over a very narrow period of time and of practically the same material, the quality of construction appears to play a more important role than the geology of the ground.

Table 2 shows the ratio of radon concentrations in the sleeping and living room. The ratio was expected to be less than 1 where the living room was situated on a lower floor than the sleeping room, e.g. House- 1 in Sharri or House-3 in Brrut, but this ratio was also found in cases where both sleeping and living room were on the same floor, e.g. House-2 in Sharri or House-2 in Brrut. This may indicate that residents take care to ventilate their sleeping rooms well, by keeping windows open. In the majority of houses with both sleeping and living room on the same floor, the ratio was either close to 1 or above it.

Provided that almost the half of radon concentration values fall in the range 50–100 Bq m^{-3} and only one value was above 200 Bq m^{-3} (Table 1), the Sharri community may be considered as a low-radon level region(1). They are also well below the ICRP range of 200–600 Bq m^{-3}, allowed for homes. On the basis of the experience gained in schools in Kosovo, the radon concentrations in Table 1, obtained in spring, may be assumed to represent an approximate yearly average because autumn values would be similar, while summer and winter values would be 15–25% lower and higher, respectively.

Eeff values thus calculated are collected in the last column of Table 1. They actually do not represent personal annual effective doses but rather an annual effective dose a person would receive spending 80% of the time in the selected house. These are then the upper limits of doses, because a number of residents are employed and attending schools and their occupancy times are much lower, and consequently their actual doses received at home are probably lower. As seen from the distribution in Figure 3, Eeff values are grouped in two samples of almost equal size, one around 1.5 mSvy−1 (close to the world average(1)) and another, around 2.8 $mSvy^{-1}$. As radon concentrations and the resulting effective doses in all the houses surveyed so far in this region are acceptably low, no radon mitigation is necessary.

6.3.1.6. Paper VI resume

Exposure to Radon in the Gadime Cave, Kosovo
Journal of Environmental Radioactivity 99 (2008) 343 – 348.
Bahtijari, M., Vaupotič, J., Gregorčič, A., Stegnar, P. and Kobal, I.

Air radon concentration was measured in summer and winter at eleven points along the tourist guided route in the Gadime Cave in Kosovo using alpha scintillation cells and etched track detectors. At two points in summer, values higher than 1700 Bq m^{-3} were observed; they otherwise were in the range 400–1000 Bq m^{-3}. Values were lower in winter. The effective dose received by a person during a 90-minute visit is 3.7 μSv in summer and 2.5 μSv in winter. For a tourist guide the annual effective dose is less than 3.5 mSv.

There are several karst caves in Kosovo, of which the Gadime Cave is by far the most popular. Although we were aware of possibly elevated radon levels in the cave, in the first radon survey carried out in Kosovo a decade ago several mines and selected dwellings were included but no caves. In order to remedy this omission, in 2004 and 2005 we focused our attention to the Gadime Cave and measured radon activity concentration in the cave air by using alpha scintillation cells and etched track detectors. This paper reports the results obtained and comments on the effective doses estimated for the tourist guides.

The Gadime Cave is located about 20 km from Prishtina, the capital city of the country. 5350 m of underground galleries and halls have been discovered to date, of which 1350 m are open as show caves (Fig. 1). The difference between the lowest and highest point along the guided tour is 50 m. Visits are possible from 9 a. m. to 6 p. m. in winter, and from 7 a. m. to 7 p. m. in summer. There are about one hundred visitors a month in winter and two to three hundreds a day in summer, totalling about 20 000 visitors a year. A guided walking tour lasts 60–90 minutes. For that purpose, 8 tourist guides are employed in the summer working regime (from May to September) and 2 in winter the working regime (the rest of the year), each spending 110 hours in the cave in a summer month, adding up to about 1300 hours annually.

Instantaneous radon concentrations, measured with scintillation cells under the summer working regime (on 16 July 2004) along the guided tourist tour (Fig. 1), are listed in Table 1. Except for the Garden of Love and Concert Hall, where they exceeded 1700 Bqm^{-3}, they ranged from 400 to 1000 Bqm^{-3} and rank this cave among the low-radon-level caves (Field, 2007). Concentrations were lower in the periods from 24 September to 21 October 2004 and from 24 September 2004 to 10 January 2005 (winter working regime), as measured with etched track detectors (Table 2). Because the cave lies practically horizontal and the temperature of the cave air is constant all the year round, the temperature of the outdoor air was expected to have the predominant influence on radon levels in the cave air (Hakl et al., 1996). In winter, temperature in the cave is higher than outdoors and the cave system works as a huge fire-place with a chimney: the temperature difference forces radon-rich air to flow from the cave space through vertical shafts and cracks, into the outdoor atmosphere. Air draught outweighs radon exhalation from walls, thus preventing its accumulation in the cave air. The last column in Table 2 shows the ratio between radon concentrations measured in summer (data from Table 1) and in winter (data from column (2) in Table 2). The chimney effect appears to be at work in the majority of the cave space, except at Square to the Cake, Eagle and Skenderbeg's Head, where this ratio is even lower than 1. This part of the cave appears to be isolated from the outdoor atmosphere. Radon concentration in summer is reduced, probably by air movement through narrow corridors caused by the larger number of visitors.

6.3.2. Published papers

2005

Paper I

M. Bahtijari, Z. Shemsidini, H. Ajazaj.*Radon concentration in different levels of Trepça mine.* Universiteti i Shkodrës ”Luigj Gurakuqi” Bul. Shk., Ser. Shk. Nat., 2005. Nr. 55: 13 - 20

2006

Paper II

Bahtijari, M., Stegnar, P., Shemsidini, Z., Kobal, I. and Vaupotič, J. *Indoor air radon concentration in schools in Prizren, Kosovo*. Radiat. Prot. Dosim 121, 469-473 (2006)

2006

Paper III

Bahtijari, M., Halimi, Y., Ylli, F. and Koço, D. *Indoor radon concentration of Malisheva and Suhareka Muncipality schools.* AJNTS (1-2) XI (19-20), 346-349 (2006)

2007

Paper IV

Bahtijari, M., Stegnar, P., Shemsidini, Z., Ajazaj, H., Halimi, Y., Vaupotič, J. and Kobal, I. *Seasonal variation of indoor air radon concentration in schools in Kosovo*. Radiat. Meas. 42, 286-289 (2007)

2008

Paper V

M. Bahtijari, J. Vaupotič, A. Gregorčič, P. Stegnar, and I Kobal,. *Exposure to radon in dwellings in the Sharri Community, Kosovo.* Radiation Protection Dosimetry (2008), Vol. 130, No. 2, pp. 244–248

2008

Paper VI

Bahtijari, M., Vaupotič, J., Gregorčič, A., Stegnar, P. and Kobal, I. *Exposure to radon in the Gadime Cave, Kosovo*. Journal of Environmental Radioactivity 99 (2008) 343 – 348.

6.3.2.1. Scientific paper I:

”Radon concentration in different levels of Trepça mine"

Universiteti i Shkodrës „ Luigj Gurakuqi”
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Radon concentration in different levels of Trepça mine

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Abstract

In this work, radon concentrations rates were systematically measured in the 11 levels of Trepça mine in Kosovo. Alpha scintillation was the main method used to measure radon concentration.

Measurements have shown that radon concentration is higher in the upper levels, because radon does not spring up from the depth of land. Values of concentration found are within the values recommended by ICRP.

Introduction

Radon is a radioactive, noble gas, occurring naturally as the decay product of radium. It is one of the densest substances that remain a gas under normal conditions. For that it is found in air. Radon gas can be discovered and measured easily because of its radioactivity. Radon is absorbed by coal dust and this property is used to measure it. The density of radon in 0^0C is 0.00973 g/cm^3, melting point: -71.0 °C, boiling point: -61.8 °C, critical temperature 104.4 °C and critical pressure 63.2xl0^5 Pa (LUKAS, 1957). Its spectrum is analog with spectra of other noble gases. Radon is sparingly soluble in water, but more soluble than lighter noble gases: 0.25 ml of radon dissolves in 1 ml of water at the temperature 20 °C and pressure 760 mmHg. It's solubility in water is inversely proportional to temperature. The most stable isotope of radon is ^{222}Rn, which is a decay product of ^{226}Ra. So number of ^{222}Rn atoms depends on ^{226}Ra concentration.

The official reference level of radon in dwellings is defined in 1999: care range from 200Bq/m³ air for new dwellings and 400 Bq/m³ air for old buildings, and risk level of 1000 Bq/m³ air.

Since radon is a gas, its concentration indoor depends on the ventilation. On the other hand ventilation depends on the weather conditions. If the wind velocity outside the buildings is low, the air currents inside the buildings are low. It increases radon concentration indoors (VAUPOTIC, ANCIK & KOBAL, 1992). There exists several methods of measurements, depending on whether we would like to measure only radon, its progeny or both. We have measured radon concentration using alpha scintillation method.

Eksperiment

Alpha scintillation cell, known as Lukas cell (VAUPOTIC & KOBAL, 1973; KOBAL, VAUPOTIC & BURGER 1998), has been used for more than 30 years to measure radon concentration. This method is based on measuring total activity of alfa particles of ^{222}Rn and its short-lived progeny ^{218}Po and ^{214}Po. Cells are of different shapes and sizes and made of different materials.

The inside wall of the cells are coated with scintillating materials that serve for the optical contact with photomultiplier. As a scintillating material are used inorganic crystals like ZnS (Ag), NaJ (Ti) etc, and organic crystals like Anthracene, Stilbene, liquid or plastic scintillators.

The inside wall of the cell we have used (see figure 1 (ANNONYMUS 1993)) is coated with silver-activated zinc sulfide (ZnS:Ag).

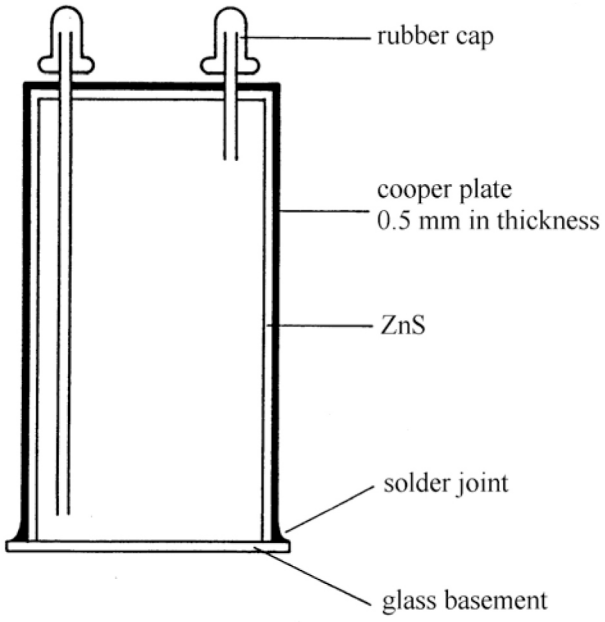

Figure 1. Schematic of scintillation cell.

Radon decays, emitting alpha particles. When these particles strike the scintillator (ZnS) film, they use a part of their energy to excite the atoms of the scintillator, which come to normal state after a relatively short time emitting photons with a wavelength of 600 nm ($6x10^{-7}$ m). Some of these photons hit the multiplier, more precisely photocathode which as a result emits electrons (the photoelectric effect). These electrons fall into diodes D_1, D_2,…, D_n which are aligned according to increased positive voltage generating as a output an electrical pulse which is further amplified through an electronic circuit. At the end we have a signal easily measured and further analyzed.

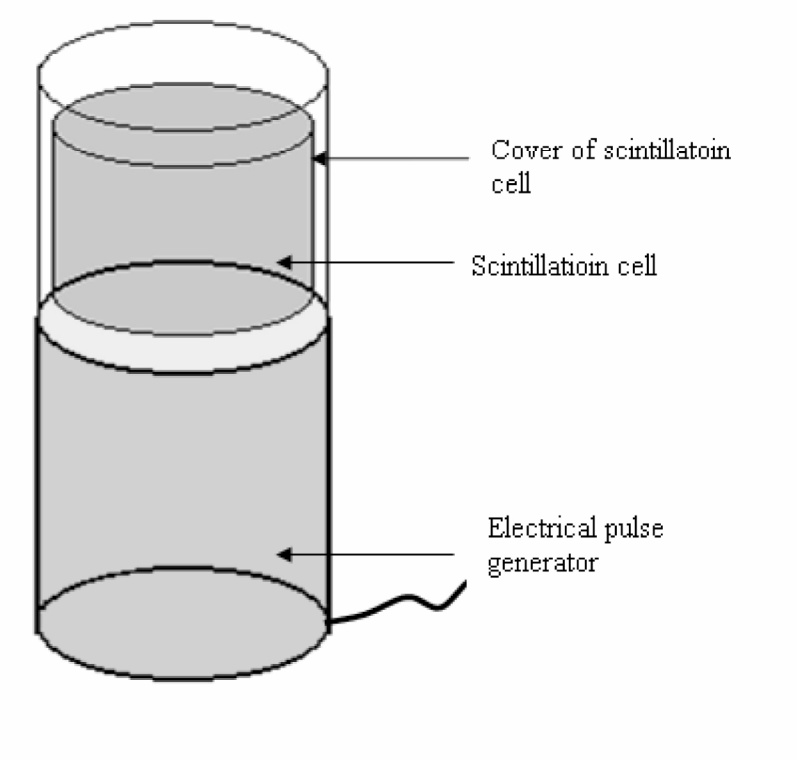

Figure 2. View of scintillation cell container

Background of measurement

With background will understand the main activity of radioactiv nucleus originating from cosmic rays and other sources. This activity will affect the radioactivity we would like to measure by increasing it. In order to measure background, scintillation cell must be cleaned with nitrogen (N_2). In the absence of N_2 the cell can be cleaned with outdoor air pumped inside the cell. The clean cell is placed in the container of cell and after that starts the measurement of pulses or radon concentration which lasts for 20-30 min.If we

start to measure immediately background the number of pulses counted would be about 100 more. For that it recommended to wait for about 30 min before measuring it. After that we write the number of the cell and the measuring time. During the measurement the apparatus shows the remaining time, total measuring time and the number of pulses counted.

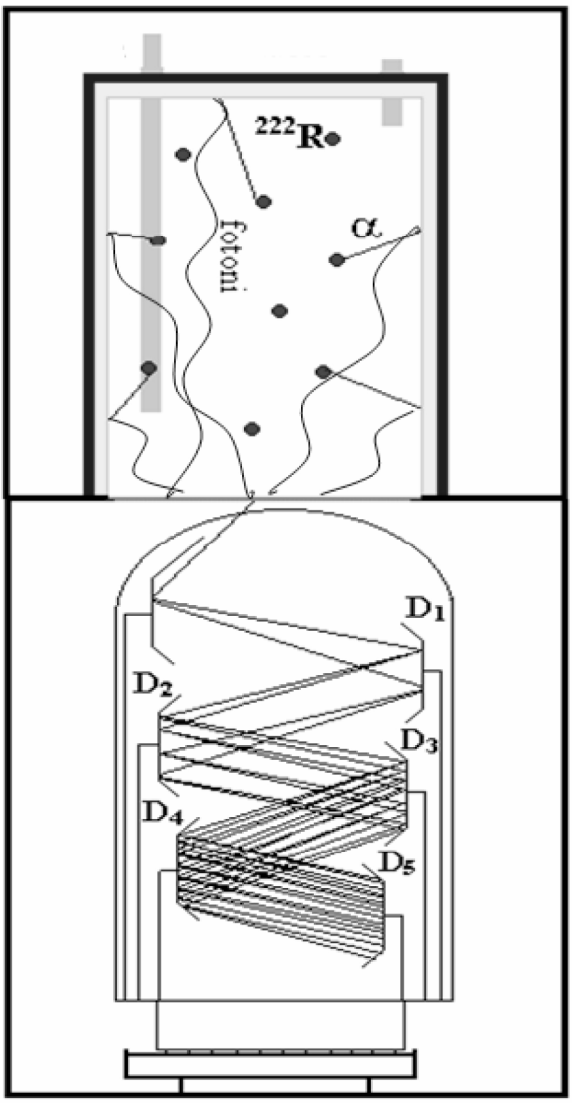

Figure 3. Photomultiplier

Sampling

Sample is the volume of air (expressed in m^3 or l) taken in the area where we are interested in measuring radon concentration. This area must be closed for at least 12 hours before measurements. Sample from the breathing height (1 - 1.5 m) is pumped into the scintillating cell. Radon continuously decays in its short-lived daughters, polonium isotopes (^{218}Po and ^{214}Po), emitting α particles, which are measured by our counter.

Measurements

Measurements are obtained in 11 levels of Trepça mine. Samples of air are pumped inside the cell and for each of them are kept notes related to time and location. Measurement procedure starts three hours after sampling and every measurement is repeated twice and for each case is found the mean value and error of measurement.

The duration of measurement depends on radon concentration. For places where radon concentration is high the duration is lower and vice-versa. In cases where measurements are taken after more then three hours (e.g. 12 hours) the measured values will be lower

then the true ones because of the half life of ^{222}Rn. At the time of measurements the mine has just started to operate after a very long pause because of the war in Kosovo.

We have chosen Trepça mine to measure radon concentration because: i) It is supposed that radon concentration there is high. This is related to its big size and with what it produces (the mine has 11 floors where the last one is in the depth of about 700 m from the entrance level and there are produced lead and zinc), ii) the number of people working there is high. In the case of high radon concentration, long time of exposure would put their life in serious risk.

Results and discussion

In table 1 are shown the results of measurements obtained in 11 levels of Trepça mine. In some areas the measurements have been repeated. At the end of our measurements we come with the conclusion that Radon concentration is within normal values and is not dangereous for the workers. These values are related to a very good ventilation in the time of measurements, in each floor of the mine and to the high temperature inside the mine, where in some areas it has reached about 40°C. The results are shown grafically in figure 4. It can be easily seen that the highest concentration is measured in the fourth floor. From the first to the fourth floor concentration keeps increasing and has very low values in other floors.

Table 1. Radon concentration in Trepça mine

Level	No. of cell	Sampling time	Time of beggining measurement	Sample Imp min^{-4}	Fon imp min^{-1}	^{222}Rn Bq/m^3
I	805	10:00	13:30	198/15 196/15	97/15	112±17
II	805	10:20	14:05	239/10 252/10	83/10	238±11
III	805	10:30	14:30	283/10 266/10	68/10	288±24
IV	805	10:35	15:05	420/10 450/10	74/10	485±13
V	805	11:45	15:30	152/10 192/10	68/10	101±25
VI	805	11:00	15:30	172/10 161/10	46/10	152±16
VII	805	11:10	15:55	158/10 144/ 10	76/10	102±18
VIII	805	11:20	16:20	125/10 114/10	64/10	78±22
IX	805	11:30	16:45	85/10 92/10	88/10	43±12
X	805	10:35	17:10	108/10 74/10	71/10	28±13
XI	805	11:45	17:35	93/10 85/10	74/10	11±6

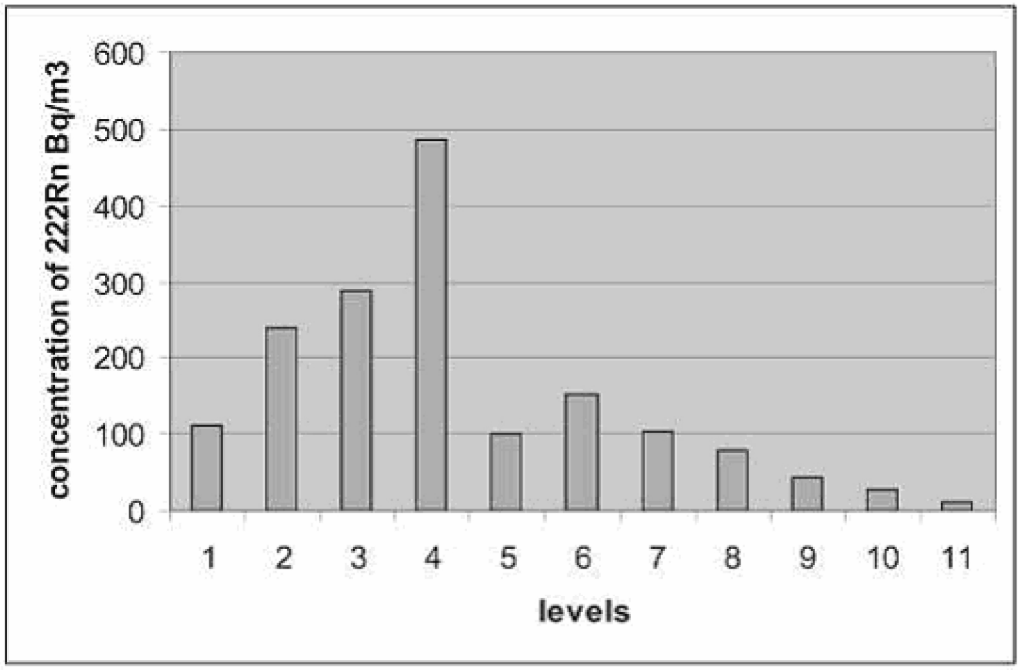

Figure 4. Radon concentrations in different levels of Trepça mine"

Conclusions

Measurements have shown that radon concentration measured in 11 levels of Trepça mine were different from level to level. High values where registered in the high levels and the highest value was registered in the fourth level. All the values are within the values recommended by ICRP.

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6.3.2.2. Scientific paper II:

“Indoor air radon concentration in Schools in Prizren, Kosovo”

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TECHNICAL NOTES

INDOOR AIR RADON CONCENTRATION IN SCHOOLS IN PRIZREN, KOSOVO

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Indoor air radon (^{222}Rn) concentrations were measured in spring and winter in 30 rooms of 9 elementary schools and 19 rooms of 6 high schools in Prizren, Kosovo, using alpha scintillation cells. Only in three rooms of elementary schools and four rooms of high schools did winter concentrations exceed 400 Bq m^{-3}.

INTRODUCTION

It is well known that, on average, radon (220 and 222 isotopes) and its short-lived decay products[1] contribute more than a half to the annual effective dose a member of the general public worldwide receives from all natural radioactive sources[2]. It is therefore not surprising that in the majority of developed countries comprehensive indoor air radon (^{222}Rn) surveys have been carried out over the last two decades, and buildings with too high exposures mitigated. In Slovenia and neighbouring countries systematic radon surveys were carried out a decade ago, and at least preliminary information on indoor levels in kindergartens in Ljubljana[3,4], Osijek[3,5,6], Belgrade[3] and Sarajevo[3] became available. In Kosovo, only a preliminary radon survey in mines and selected dwellings was performed at that time[7]. In order to obtain the data needed to assess the exposure of the population to radon, a decision was made in 2002 to perform indoor radon measurements in the entire region of Kosovo. Following the policy of the US Environmental Protection Agency and some other countries[8], and because radon is on the list of eight most hazardous environmental toxins for children[9], we first targeted the most sensitive young population[2] and have therefore started with schools.

In this paper, the first results of indoor radon concentrations obtained in winter and spring in nine elementary and six high schools in Kosovo are reported.

MATERIALS AND METHODS

Measuring sites

The town of Prizren with 168,000 inhabitants is located in the southern part of Kosovo. Altogether, there are 9 elementary and 6 high schools, of which 9 with 16,735 pupils and 6 with 5545 students, respectively, have been included in our study. They are mostly one-storey buildings, made of stone and brick, and recently of prefabricated elements. Weather in the region is typically continental, with severe winters and hot summers. In some buildings rooms are heated individually by burning wood and coal, but in the majority, central water heating is used, based on oil and coal, less frequently on gas. There is no air-conditioning and rooms are ventilated by simply opening windows and doors.

Measuring techniques

Radon concentration in air was measured with 0.7 dm^3 alpha scintillation cells manufactured at the Jožef Stefan Institute[3] and calibrated according to the Rushing procedure[10,11] using the NIST (National Institute of Standards and Technology, Washington DC, USA) standard $^{226}RaCl_2$ solution 4953 D. Cell efficiency is in the range from 0.0019 to 0.0022 s^{-1} Bq^{-1} m^3 and background in the range from 0.5 to 1.5 min^{-1}, which gives a lower limit of detection of 10–30 Bq m^{-3} at 30–60 min counting time in an PRM-145 counter (AMES, Slovenia).

A day before air sampling, we visited a school to select three to six rooms for our survey, and asked the manager to keep these rooms closed overnight. Then, we came early next morning, before anybody has entered the rooms, and sampled the air directly into scintillation cells. Cells were transported to the laboratory where alpha activity was measured after 3 h, by which time radioactive equilibrium between radon and its short-lived decay products has been established. The results thus obtained are reported as instantaneous radon concentrations under closed conditions.

In order to comply with the QA/QC requirements, our measuring devices have been regularly checked at the inter-comparison experiments organised annually by the Nuclear Safety Administration at the

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Slovene Ministry of the Environment and Spatial Planning[12]. In addition, alpha scintillation cells are calibrated monthly with $^{226}RaCl_2$ solution (see above).

Two surveys were performed, one in May and another in December 2003.

RESULTS AND DISCUSSION

Instantaneous indoor air radon concentrations (C_{Rn}) in elementary and high schools in Prizren obtained in May and December 2003 are shown in Tables 1 and 2, and their statistics in Tables 3 and 4, respectively. In the majority (74%) of rooms in the elementary schools, both the May and December values are <100 Bq m^{-3}; in three rooms, they are >200 Bq m^{-3} and exceed 400 Bq m^{-3} only in one classroom of the ES-PR-01 school (Table 3). Radon levels were also low in the high schools, although their distribution was shifted towards higher concentrations (Table 4): in December, values <100 Bq m^{-3} were found in <50% of rooms. Nevertheless, only in the gym hall of the HS-PR-02 school was the December value >400 Bq m^{-3}.

Figure 1a and b shows, as expected,[14] that radon concentrations obtained in December were higher in all rooms than those obtained in May (with only one exception in the ES-PR-07 elementary school, where it was, at both times, practically at the lower limit of detection). The average ratio C_{Rn} in May versus C_{Rn} in December was 0.90 for elementary and 0.73 for high schools.

Radon levels in the schools surveyed in Prizren are as low as in some other countries, for instance in Osijek, Croatia[15] with a geometric mean of 70.6 Bq m^{-3}, ranging from 15 to 300 Bq m^{-3}, in Parma, Italy[16,17] where they ranged between 10 and 108 Bq m^{-3}, in Austria[18] with a mean concentration of 52 Bq m^{-3}, in Amman where they were <100 Bq m^{-3} in 30–50% cases,[19] and in New York[20] state where 150 Bq m^{-3} was exceeded only in 47% buildings. On the other hand, our results are

Table 1. Radon concentrations and their standard deviations[13] (C_{Rn}) obtained in May and December 2003 in elementary schools in Prizren.

No	Elementary school code	Room	C_{Rn} (Bq m^{-3}) May	C_{Rn} (Bq m^{-3}) December
1	ES-PR-01	Library (basement)	238 ± 11	253 ± 21
2		Classroom-1	485 ± 13	492 ± 26
3		Classroom-5	111 ± 47	122 ± 18
4	ES-PR-02	Teachers's room	112 ± 26	132 ± 33
5		Secretary's office	91 ± 10	99 ± 16
6	ES-PR-03	Classroom-IXa	32 ± 12	38 ± 10
7		Classroom-IXb	46 ± 23	49 ± 23
8	ES-PR-04	Classroom-3a	127 ± 34	132 ± 21
9		Classroom-3b	335 ± 61	340 ± 12
10		Classroom-3c	86 ± 34	96 ± 7
11		Classroom-5	89 ± 34	92 ± 20
12	ES-PR-05	Classroom-VII-2	46 ± 13	52 ± 23
13		Classroom-IX-1	24 ± 18	32 ± 12
14	ES-PR-06	Classroom-1	59 ± 38	62 ± 29
15		Classroom-2	55 ± 32	66 ± 23
16		Classroom-5	33 ± 24	41 ± 16
17		Classroom-11	14 ± 27	12 ± 22
18		Classroom-12	13 ± 40	18 ± 33
19		Classroom-17	25 ± 15	32 ± 12
20		Classroom-20	34 ± 26	46 ± 23
21	ES-PR-07	Classroom-1	17 ± 09	54 ± 09
22		Classroom-5	11 ± 06	46 ± 23
23		Classroom-8	57 ± 18	54 ± 09
24	ES-PR-08	Classroom-1	106 ± 24	112 ± 34
25		Classroom-5	24 ± 16	38 ± 24
26		Teachers' room	36 ± 17	39 ± 21
27	ES-PR-09	Classroom-III-4	14 ± 13	22 ± 12
28		Classroom-IV-3	70 ± 26	84 ± 16
29		Classroom-VII-2	117 ± 35	136 ± 18
30		Classroom-VIII-5	28 ± 13	33 ± 20

School names are coded. All rooms are on the ground floor, except the library of ES-PR-01 in the basement.

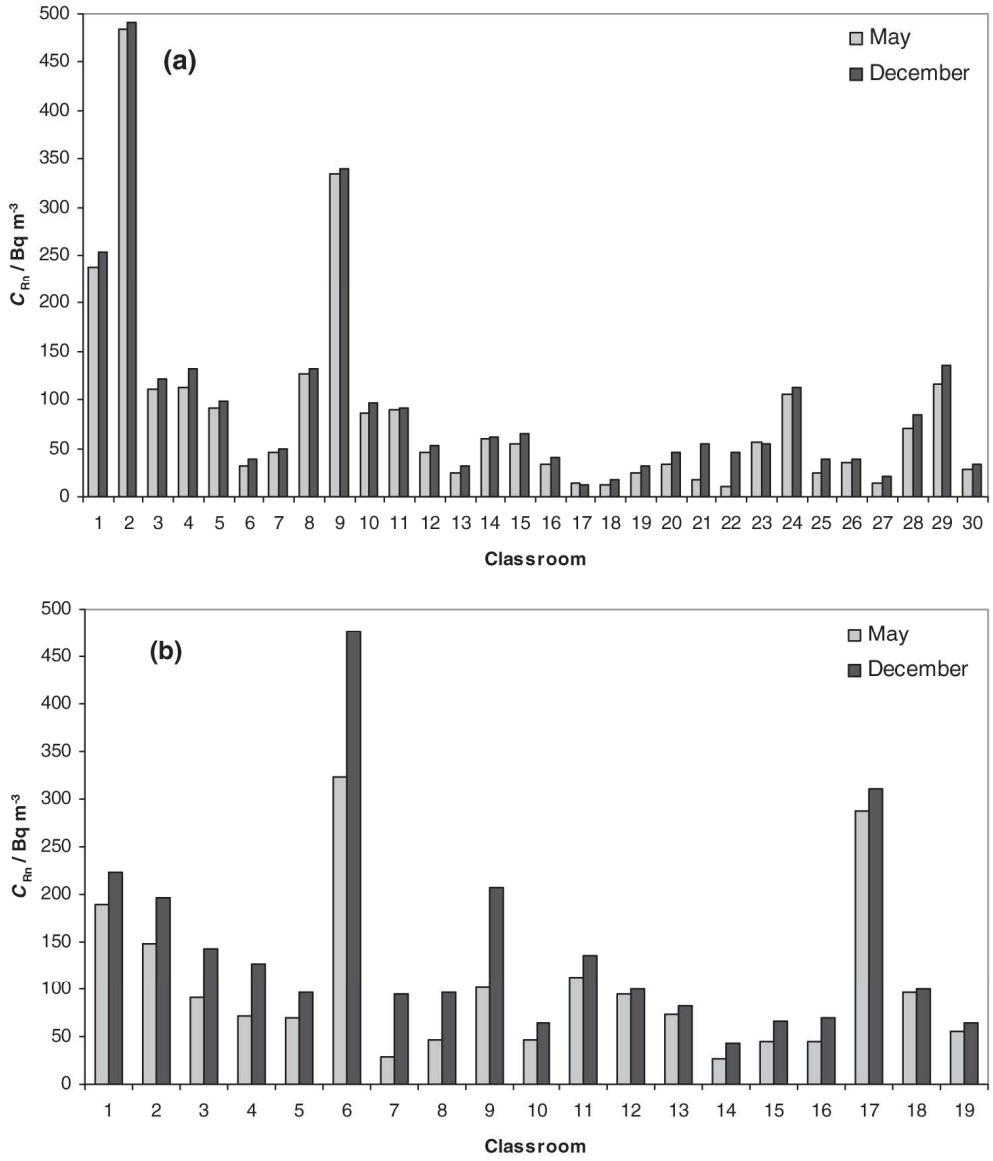

Figure 1. Comparison of radon concentrations measured in December and May in Prizren: (**a**) for elementary schools and (**b**) for high schools.

low compared with levels obtained in Slovenia,[21] where in 8% of schools radon concentration was >400 Bq m^{-3} and in 3%, even >1000 Bq m^{-3}, in Austrian pottery schools[18] with a mean value of 617 Bq m^{-3}, in Connecticut, USA[22] where, at least in one room of 217 schools, radon concentration was >148 Bq m^{-3}.

CONCLUSIONS

Indoor air radon (^{222}Rn) concentrations obtained in spring and winter in 30 rooms of 9 elementary schools and in 19 rooms of 6 high schools, using alpha scintillation cells, were relatively low. In elementary schools, in 74% of rooms the winter value was <100 Bq m^{-3} and in 3 rooms it exceeded 400 Bq m^{-3}, while in high schools, in 48% it was <100 Bq m^{-3} and in 4 rooms it exceeded 400 Bq m^{-3}. This initial screening has given a preliminary picture of the radon distribution which will be useful for an advanced survey by long-term measurements in schools in Kosovo aimed at evaluating effective doses of children and personnel.

Table 2. Radon concentrations and their standard deviations[13] (C_{Rn}) obtained in May and December 2003 in high schools in Prizren.

No	High school code	Room	C_{Rn} (Bq m^{-3}) May	C_{Rn} (Bq m^{-3}) December
1	HS-PR-01	Classroom-II-3	190 ± 13	224 ± 13
2		Classroom-III-3	148 ± 13	196 ± 26
3		Classroom-IV-9	91 ± 23	142 ± 17
4	HS-PR-02	Classroom-IV-9 (I)	71 ± 15	127 ± 24
5		Classroom-IV-3 (II)	70 ± 18	96 ± 18
6		Gym hall	324 ± 56	476 ± 29
7	HS-PR-03	Classroom-II-6	29 ± 12	95 ± 30
8		Classroom-IV-9	46 ± 14	96 ± 18
9		Classroom-IX-11	102 ± 18	208 ± 32
10		Director's office	46 ± 10	65 ± 12
11	HS-PR-04	Library	112 ± 15	136 ± 14
12		Classroom-IV-9a	95 ± 30	100 ± 18
13		Classroom-IV-9b	74 ± 28	82 ± 24
14	HS-PR-05	Classroom-1	27 ± 10	42 ± 15
15		Classroom-2	45 ± 14	66 ± 12
16		Classroom-3	44 ± 17	70 ± 14
17	HS-PR-06	Classroom-III-M-7	288 ± 23	310 ± 18
18		Classroom-IX-7	96 ± 36	100 ± 12
19		Classroom-II-6 (I)	56 ± 14	64 ± 20

School names are coded. All rooms are on the ground floor, except three for which description (I) and (II) means first and second floor.

Table 3. Distribution of indoor air radon concentartions (C_{Rn}) in the elementary schools in Prizren, in May and December.

C_{Rn} range (Bq m^{-3})	Number of rooms (%)	
	May	December
<100	22 (74)	22 (74)
100–200	5 (17)	5 (17)
200–300	1 (3)	1 (3)
300–400	1 (3)	1 (3)
>400	1 (3)	1 (3)

Table 4. Distribution of indoor air radon concentrations (C_{Rn}) in the high schools in Prizren, in May and December.

C_{Rn} range (Bq m^{-3})	Number of rooms (%)	
	May	December
<100	13 (69)	9 (48)
100–200	4 (21)	6 (32)
200–300	1 (5)	2 (10)
300–400	1 (5)	1 (5)
>400	0 (0)	1 (5)

ACKNOWLEDGEMENTS

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6.3.2.3. Scientific paper III:

“Indoor radon concentration of Malisheva and Suhareka Muncipality schools”

INDOOR RADON CONCENTRATION OF MALISHEVA AND SUHAREKAMUNCIPALITY SCHOOLS

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ABSTRACT

During the year 2003 in experimental way were determined the concentration of radon in some schools in Malisheva and Suhareka. The measurements included a secondary school and primary schools, altogether 19 classrooms with the dissipation in the different premises. The measurements were carried out with portable apparatus PRM-145, based in alpha scintillation method.
A large volume (1500 cm^3) alpha scintillation cell to measure indoor radon is described. Air was sampled directly into the cell and gross alpha activity was measured. All of the air samples were taken under the same conditions, which excluded ventilation of the interior 12 h prior to sampling.

INTRODUCTION

Radon (^{222}Rn) is the only radioactive element of uranium family, which is in the gaseous form and it is emanated by the radium decay. Radon is considered as a noble gas, with half life 3,8 days, and its density is nine time higher than air. Radon and its short-lived daughters are the most important radioactive sources in air and they bring about half of the effective dose equivalent of natural ionizing radiations (Steinhausler et al., 1983). Radon after emanation in soil and building materials through diffusion enters into air. The radon concentration in air is a few times higher indoors than outdoors, on average, depending on the rates of radon entry and air exchange in the dwellings.

The problem of indoor radon has attracted a great deal of attention worldwide (Doll 1992), as result of its high concentrations in dwellings and social buildings (kinder garden, class rooms etc.). Alpha, beta and gamma radiation energy absorbed by **the**

lung tissue, resulting from the radioactive decay of radon and its progeny, damages this tissue, increasing the risk of lung cancer (UNSCEAR 1993).

The measurements of the air radon concentration started in May 2003, inside the premises of Malisheva and Suhareka Municipality schools. The measurements were performed by alpha scintillation method in three secondary school and five primary schools (M. Bahtijari master's work) where the first results of the measurements were taken.

2. EXPERIMENTALSTUDY

Since their introduction 35 years ago [1,2], alpha scintillation cells of various sizes and shapes have found numerous applications in the determination of ^{222}Rn and ^{226}Rn in various environmental samples. Using a portable apparatus PRM-145 with Lucas-type 190 cm^3 cell manufactured at the "J. Stefan" Institute [3]. the measurement of indoor radon was performed by taking samples in 1200 cm^3 glass vessels followed by freezing out radon [4] and transferring it to the scintillation cell for counting. In order to minimize this time-consuming laboratory procedure, larger (1500 cm^3) scintillation cells were manufactured. The air sampling was entered directly into cell, and the measurement of alpha activity samples were carried out after a three hours period.

For each cell a suspension of 10 g of Lumilux Flu Blau scintilator (ZnS/Ag) (Riedel-de-Haen Ab, Seeltze-Hanover, Germany) in 20 cm^3 of dietilenchloride and a few drops of UHU (vertrieb GmbH, 7580 Buhl, Baden) universal glue was prepared in a beaker and then poured into the open cell. As the mixture is swirled, the solvent evaporates and the scintillator layer is attached and fixed to the cell walls. A skilled technician is able to make a uniform 14 - mg/cm^2 scintillator layer. After drying in air at room temperature for 24 hours and then at 80°C for another 24 hours, the window is fixed to the cell by a two-component glue. The outer wall of the glass cells was covered with two layers of paint in order to protect the scintillator from light, while the copper cells were electrolytically cleaned before the attachment of the scintillator.

RESULTS AND DISCUSSION

The radon indoor sampling was performed in the schools of Malisheva and Suhareka Municipality, and was planned to include different teaching premises like classrooms, saloons, cabinets, etc. All premises were closed 12 hours before sampling for the equalisation of the ventilation conditions. After the specimen was taken by the cell pump, the sampling time and location was recorded. All records were kept on a special table, especially prepared for the measurements, aiming the identification of locations with high radon concentration. After three hours since the moment that the specimen was taken, the process of measurement started. For each sampling, two measurements were performed and the average value was calculated.

The measurement time is depended from the value of radon concentration. For samples with relatively great concentration, it takes a short time and for samples where the concentration was smaller it takes a longer time.

In the following tables are represented the radon concentration for every school separately.

Table 1. Results of the radon concentration in the Malisheva schools

School	Venue of taking the sample	May ^{222}Rn [Bq/m^3]	December ^{222}Rn [Bq/m^3]
"Ibrahim Mazreku"	Class IV-2 ground	126±15	164±12
	Class HI-3 ground	79±14	120±10
"Abdyl Frasheri"	Class IX-2 ground	161±16	176±24
	Class VI-2 ground	144±12	184±16
"Ram Bllaca"	Class HI-3 ground	127±34	I38±13
	Class VII-2 ground	148±15	164±19
	Teacher's Hall	82±37	96±12

Table 2. Results of the radon concentration in the Suhareka schools

School	Venue of taking the sample	May ^{222}Rn [Bq/m^3]	December ^{222}Rn [Bq/m^3]
„Skender Luarasi"	Class 1-10 ground	67±12	83±17
	Class 1-1 ground	36±10	64±16
„Jeta e Re"	Class II-3 basement	73±14	92±15
	Class 1 1-5 basement	340±26	410±23
	Class II-8 basement	202±21	208±12
„ Shkendija"	Class VI-2 ground	82±25	93±24
	Class IX-9 ground	117±27	134±13
„ 7 Marsi "	Class V-l ground	243±20	276±10
	Class V-3 ground	302±22	383±12
	Class IV-2 ground	30±18	46±13

There are two different values of radon concentration in the Table 1 and 2, which belong to the measurements carried out in May and December. At the basements the obtained values are bigger than in the ground, and in December the values are bigger than in May, when the temperature is higher and the premises faucets are also bigger. However, those values are under the action levels for indoor radon concentration. All the schools where the measurement was done are designed and constructed in 1974 and later, having good isolation and faucet. Therefore, the results for indoor radon do not represent any danger for the health of the teaching staff and the pupils.

In two classrooms of the secondary school "Jeta e Re", which are in the basements, the radon concentration is bigger in comparison with other classrooms. The radon concentration values differ from 340 Bq/m^3 and 202 Bq/m^3 in May, to 410 Bq/m-' and 208 Bq/m^3 in December. The measurements were repeated in these classrooms and the results have approximately the same values. These values are above action levels for new buildings indoor radon concentration (200 Bq/m^3) and some investigations **are** necessary to perform aiming the clarification of the causes and the ways of the preventing of the radon penetration into the classes environment.

In one classroom of the primary school "7 Marsi" the radon concentration is also higher. The premise of the mentioned school is old, therefore the obtained result is in accordance to ICRP recommendation for the old building indoor radon concentration (400Bq/m^3).

CONCLUSIONS

1. The obtained results for indoor radon concentration are less than action levels for respective premises. The results are obtained for the two seasons: one during the summer (May) and the other during the winter (December).
2. The results obtained for the indoor radon concentration, indicate that these concentrations are under action levels for indoor radon of the new buildings (200 Bq/ m^3) and for old buildings (400 Bq/m').
3. The results for the indoor radon concentration are in good accordance with geological structure of respective area, which represents soil layers (argils) with low contents of uranium and other natural radioactive elements and with low penetration properties. Such structures do not create the conditions for the emanation of the great quantities of radon as well for its penetration from the soil into the air. The high values of radon indoor obtained in some causes need detailed investigations in the respective classes for localization of the holes, cracks and other building defects which permit entering of radon from the soil into basement and other environments.

SUMMARY

In this work are describes the methodology and the results obtained for indoor radon concentration in primary and secondary schools of the Malisheva and Suhareka Municipality. The measurements were carried out with portable apparatus PRM-145 for two seasons: winter and summer. The indoor radon concentration are under the action levels, except some values in the basement of two schools „Jeta e Re" and „7 Marsi", which are equal or less than the levels recommended for radon indoor concentrations.

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6.3.2.4. Scientific paper IV:

”Seasonal variation of indoor radon concentration in schools in Kosovo”

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Seasonal variation of indoor air radon concentration in schools in Kosovo

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Abstract

Indoor air radon (^{222}Rn) concentrations were measured in March, May, August and December in 15 rooms of five elementary and in six rooms of one high school in Sharr, Kosovo, using alpha scintillation cells. Only in one room did the value exceed 200 Bq m^{-3}. Values decreased from December to August, and from basement to first floor.

Keywords: Radon; Scintillation cells; Indoor air; Schools; Concentrations; Seasonal variation

1. Introduction

More than half the annual effective dose received by a member of the general public from all natural radioactive sources originates from the radioactive noble gas radon and its short-lived decay products. For this reason, the problem of indoor radon has attracted great attention worldwide, and many countries have carried out nation-wide radon surveys (UNSCEAR, 2000). Although the first radon measurements in Kosovo were made in the course of prospecting for uranium in the period 1983–1989 (Jakupi et al., 1989), it was ten years later when monitoring of indoor radon in dwellings was started (Jakupi et al., 1997). Radon concentrations obtained by exposing track etched detectors (Šutej et al., 1988) in 83 buildings varied in the range of 20–100 Bq m^{-3} (with an average value of 50 Bq m^{-3}) in the cities of Prishtina and Brezovica, while in houses in the suburbs of Prishtina, lying over a lignite layer, the values were in the range of 150–450 Bq m^{-3}. Values of more than 1000 Bq m^{-3} were found in several houses built of stone in Gornja Stubla town, where elevated radon levels in soil gas had been found during uranium prospecting. In order to make the radon map more complete, a decision was made in 2002 to carry out an indoor radon survey in the entire territory of Kosovo. The survey will be carried out in steps, lasting several years, following the experience gained in Slovenia (Vaupotič et al., 2000). Starting with public buildings, such as kindergartens and schools, monitoring will be continued in other environments potentially exposed to radon, such as karst caves, water works and other underground workplaces. In this survey, scintillation cells will be used for fast screening purposes, while etched track detectors will be exposed to obtain average radon concentration.

In this paper, we report on indoor radon concentrations in elementary and high schools in Sharr, Kosovo, with the emphasis on their seasonal variations.

2. Experimental

2.1. Measuring sites

The town of Sharr with 12,300 inhabitants is located in the southern part of Kosovo. Altogether, there are five elementary and high schools, of which six with 3631 pupils and one with 786 students, respectively, were included in this study. They are mostly single-storey buildings, some with a basement, some without. All were built after 1974, of stone and brick, and recently of prefabricated elements. Climate in the region is typically continental, with severe winters and hot summers. In some buildings rooms are heated individually by burning

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wood and coal, but in the majority, central water heating is used, based on oil and coal, less frequently on gas. There is no air-conditioning and rooms are ventilated by simply opening windows and doors.

2.2. Measuring techniques

Radon concentration in air was measured with 0.7 dm^3 alpha scintillation cells manufactured at the Jožef Stefan Institute (Vaupotič et al., 1992) and calibrated according to the Rushing procedure (Rushing et al., 1964; Kristan and Kobal, 1973) using a NIST (National Institute of Standards and Technology, Washington, DC, USA) standard $^{226}RaCl_2$ solution 4953 D. Cell efficiency is in the range from 0.0019 to 0.0022 s^{-1} Bq^{-1} m^3 and background in the range from 0.5–1.5 min^{-1}, which gives a lower limit of detection of 10–30 Bq m^{-3} at 30–60 min counting time in an PRM-145 counter (AMES, Slovenia).

A day before air sampling, we visited a school to select 2–6 rooms for our survey, and asked the manager to keep these rooms closed overnight. We came early next morning, before anybody had entered the room, and sampled the air directly into scintillation cells. Cells were transported to the laboratory where alpha activity was measured after 3 h, when radioactive equilibrium between radon and its short-lived decay products had been established.

In order to comply with the quality assurance/quality control requirements, our measuring devices have been regularly checked at the inter-comparison experiments organized annually by the Nuclear Safety Administration at the Slovene Ministry of the Environment, Spatial Planning and Energy (Križman, 2001). In addition, alpha scintillation cells are calibrated monthly with $^{226}RaCl_2$ solution (see above).

Four surveys have been carried out, in March, May, August and December 2003.

3. Results and discussion

In all rooms, indoor air radon concentration (C_{Rn}) was low at all four surveys, as seen from Table 1. It exceeded 200 Bq m^{-3} only in classroom 2 of the HS-SH-01 high school. Such low concentrations have been found also in schools in other countries, for instance in Osijek, Croatia with a geometric mean of 70.6 Bq m^{-3}, ranging from 15 to 300 Bq m^{-3} (Planinić et al., 1995), in Parma, Italy where they ranged between 10 and 108 Bq m^{-3} (Malanca et al., 1997a,b), in Austria with a mean value of 52 Bq m^{-3} (Ennemoser et al., 1992), in Amman where they were below 100 Bq m^{-3} in 30–50% of cases (Kullab et al., 1997), and in New York state where 150 Bq m^{-3} was exceeded in 47% (Kunz et al., 1996). In contrast, higher values were reported for Slovenia where in 8% of schools radon concentration was higher than 400 Bq m^{-3} and in 3%, even higher than 1000 Bq m^{-3} (Vaupotič et al., 1994, 2000; Vaupotič, 2001). Other cases of high levels were Austrian pottery schools with a mean value of 617 Bq m^{-3} (Ennemoser et al., 1992), and Connecticut, USA where in at least in one room of 217 schools, radon concentration was above 148 Bq m^{-3} (Siniscalchi et al., 1996). This comparison is not justified because of different climates in the countries sited, and is simply aimed at ranking the radon levels.

Table 1
Radon concentrations (C_{Rn}) obtained in March, May, August and December 2003 in five elementary schools (codes with initials ES-) and one high school (code with initials HS-) in Sharr, Kosovo

School code	Classroom	Floor	C_{Rn}/Bq m^{-3} March	C_{Rn}/Bq m^{-3} May	C_{Rn}/Bq m^{-3} August	C_{Rn}/Bq m^{-3} December
ES-SH-01	V-1	g	126 ± 10	134 ± 15	98 ± 20	147 ± 10
	VII	g	144 ± 15	122 ± 20	110 ± 15	161 ± 10
	VII-1	I	90 ± 18	86 ± 15	78 ± 14	102 ± 12
	VIII-2	I	104 ± 15	94 ± 13	76 ± 09	120 ± 10
ES-SH-02	VI-2	g	79 ± 10	98 ± 14	58 ± 14	102 ± 16
	VII-1	g	68 ± 16	56 ± 25	34 ± 12	86 ± 24
ES-SH-03	V-a	I	174 ± 26	152 ± 28	122 ± 20	194 ± 16
	V-b	I	136 ± 17	101 ± 38	87 ± 10	179 ± 15
	VI-a	I	136 ± 19	124 ± 41	101 ± 15	166 ± 24
ES-SH-04	1	g	98 ± 19	92 ± 13	66 ± 25	106 ± 24
	2	I	74 ± 14	66 ± 17	46 ± 15	104 ± 14
	3	g	129 ± 12	100 ± 41	77 ± 18	160 ± 11
ES-SH-05	III	b	66 ± 17	43 ± 12	30 ± 14	54 ± 16
	V-1	b	39 ± 14	26 ± 10	20 ± 15	55 ± 12
	VIII	b	49 ± 15	26 ± 34	28 ± 13	46 ± 21
HS-SH-01	1	b	140 ± 20	128 ± 12	96 ± 15	196 ± 15
	2	b	200 ± 15	212 ± 25	168 ± 26	236 ± 11
	3	g	110 ± 14	104 ± 10	86 ± 14	123 ± 20
	4	g	110 ± 12	96 ± 14	91 ± 10	139 ± 18
	5	I	58 ± 10	46 ± 17	29 ± 17	63 ± 12
	6	I	38 ± 16	32 ± 12	20 ± 10	48 ± 15

The floor is indicated as b—basement, g—ground floor, I—first floor.

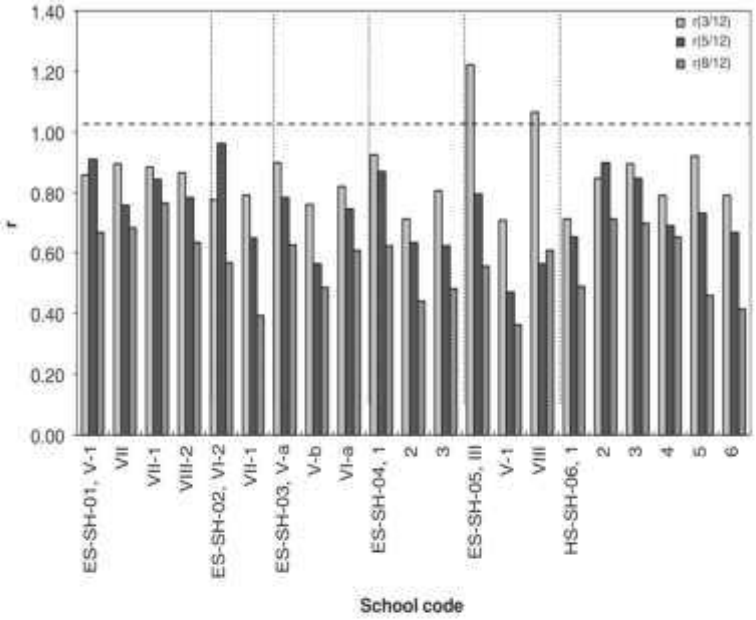

Fig. 1. Ratios: $r(3/12) = C_{Rn}(\text{March})/C_{Rn}(\text{December})$, $r(5/12) = C_{Rn}(\text{May})/C_{Rn}(\text{December})$ and $r(8/12) = C_{Rn}(\text{August})/C_{Rn}(\text{December})$ for elementary (ES) and high schools (HS), according to the notation in Table 1.

As expected (Vaupotič et al., 1998), radon concentrations in all rooms were higher in winter than in summer. Ratios: $r(3/12) = C_{Rn}(\text{March})/C_{Rn}(\text{December})$, $r(5/12) = C_{Rn}(\text{May})/C_{Rn}(\text{December})$ and $r(8/12) = C_{Rn}(\text{August})/C_{Rn}(\text{December})$ are plotted in Fig. 1. In two rooms of the ES-SH-05 school, was $r(3/12)$ higher than 1, but all other r values were below 1. In the majority of rooms, radon concentration decreases in the order: December > March > May > August; exceptions were classrooms V-1 in ES-SH-01, VI-6 in ES-SH-02, VIII in ES-SH-05 and 2 in HS-SH-01. We believe these exceptions are not real, but most probably some kind of irregularity. We suspect the manager did not keep the room closed overnight as promised. Including all rooms of all the schools, the following average values were obtained: $r(3/12) = 0.85$, $r(5/12) = 0.74$ and $r(8/12) = 0.57$.

If we generalise the above r values and assume them to be valid for other schools in the region, since they are subject to practically the same climate conditions and working regime, the measurements in our future study on radon exposure in schools may be optimised. In order to obtain the annual average radon concentration needed for dose assessment, we have planned to expose etched track detectors in selected rooms all the year round. Nonetheless, by using r values, we may expose detectors only during one season (e.g., winter), and then estimate radon concentration for other seasons (e.g., spring and autumn). In this way, either the number of detectors could be reduced or, with the same number of detectors, a larger number of buildings could be included into the study.

Fig. 2 shows a general trend (Korhonen et al., 2000; Mnich et al., 2004) of decreasing radon concentration from basement toward first floor. Therefore, our future radon measurements

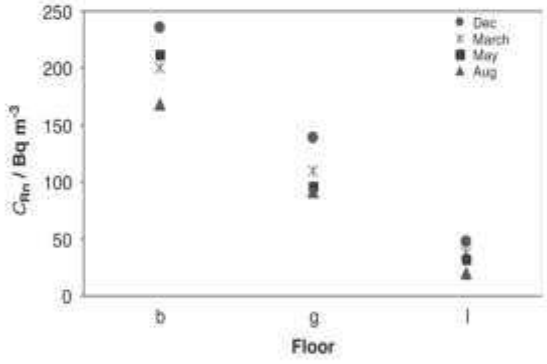

Fig. 2. Decrease of radon concentration from basement to the first floor. The floors are indicated as b—basement, g—ground floor, I—first floor.

will be carried out only on ground floors when there is no basement underneath, or in basement rooms if they are used either for classes or as workshops.

In a school selected for the future survey based on high radon level, radon will be first measured in all rooms with alpha scintillation cells, and then etched track detectors will be exposed in several rooms with the highest radon concentrations and highest occupation times, in order to obtain average radon concentrations needed for dose estimates. In addition to environmental conditions, such as barometric pressure, air temperature and relative humidity, also ventilation rate and working regime will be recorded. Based on the effective doses obtained, further actions will be planned, either towards undertaking more comprehensive measurements or mitigation measures.

4. Conclusions

Indoor air radon (^{222}Rn) concentrations obtained in March, May, August and December in 15 rooms of five elementary schools and in six rooms of one high school using alpha scintillation cells were relatively low: only in one room did the value exceed 200 $Bq\,m^{-3}$. Except in two rooms, winter concentrations were higher than summer ones, and the following average values were obtained for ratios: $C_{Rn}(March)/C_{Rn}(December) = 0.85$, $C_{Rn}(May)/C_{Rn}(December) = 0.74$ and $C_{Rn}(August)/C_{Rn}(December) = 0.57$. Concentrations in rooms on the ground and first floors were 3–5 times lower than in the basement.

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6.3.2.5. Scientific paper V:

“Exposure to radon in the Sharri Comunity, Kosovo”

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SCIENTIFIC NOTE

EXPOSURE TO RADON IN DWELLINGS IN THE SHARRI COMMUNITY, KOSOVO

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Indoor air radon concentration was measured by exposing etched track detectors in the sleeping and living rooms of 18 houses in 6 villages of the Sharri community in Kosovo. Values ranged from 24 to 209 Bq m^{-3}, with only one exceeding 200 Bq m^{-3}, with a geometric mean and geometric standard deviation of 95.4 Bq m^{-3} and 1.6, respectively. On the basis of the assumption that the spring radon concentrations obtained in this survey represent the yearly average, annual effective doses of residents were calculated; they range from 0.89 to 4.7 mSv y^{-1}, with the geometric mean and geometric standard deviation of 1.5 mSv y^{-1} and 2.2, respectively. No mitigation measures are planned to be undertaken.

INTRODUCTION

On average worldwide, more than half the annual effective dose received by a member of the general public from all natural radioactive sources is due to breathing air contaminated with the radioactive noble gases radon (^{222}Rn) and thoron (^{220}Rn) and their decay products[1]. Radon has been confirmed as a major cause of lung cancer, second only to cigarette smoking[2]. For this reason, indoor radon levels have attracted considerable attention and many countries have conducted nation-wide radon surveys. In Kosovo, the first radon measurements were carried out in the course of prospecting for uranium between 1983 and 1989[3]. Ten years later, indoor radon was surveyed in 83 selected dwellings. Radon concentrations in the range of 20–450 Bq m^{-3} were found, with exception of several houses built of stone in the uranium ore deposit area where values exceeded 1000 Bq m^{-3} [4]. Recently, a systematic radon monitoring programme was initiated in order to make the radon map of Kosovo more complete. Radon has been already measured in elementary and high schools in several towns[5,6] and in a karst cave[7]. In continuation, it is planned to survey the majority of kindergartens and schools, together with a representative number of dwellings in the country and, eventually, underground workplaces as well.

In this paper, radon monitoring in dwellings in six villages of the Sharri community in the south part of the country, carried out by exposing etched track detectors, is described and radon concentrations reported. Annual effective doses of the residents are estimated and commented.

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EXPERIMENTAL

Selection of measurement sites

The Sharri community is located in the south of Kosovo. Villages for radon survey were selected for the following reasons: the village of Sharri because it is the municipal centre; the villages of Kuk, Bellobrad and Gllobočicë because they were hit by depleted uranium projectiles during the NATO bombing in 1999 (just in order to diminish the widespread concern of the residents, although no impact of depleted uranium on radon levels was expected[8]); the village of Brrut because it is located above a karstic terrain with abundant caves; and the village of Bresanë because it is located over a copper deposit. Detailed geology was not taken into account for this limited survey. In each village, 2–4 houses were selected, in which radon was measured in 2–3 rooms, mostly for living and sleeping, either on the ground or first floor. All houses were made of concrete and brick between 1982 and 1997. The climate in the region is typically continental, with hot summers and severe winters. There is no air-conditioning; in winter, rooms are heated by stoves burning wood that is also used for cooking. The size of a household varies, ranging from 4 to 22 persons. Some are employed by state or private companies, or attend school, the others stay at home taking care of field works, animals and house.

Measuring techniques

Radon concentration was measured with the etched track detectors purchased from the Karlsruhe Forschungszentrum[9], which are based on the

Makrofol E foil. After exposure, detectors were sent back to Karlsruhe for development and evaluation. As the result of their reading, the average radon concentration for the period of exposure together with standard deviations has been received. All detectors were exposed by the personnel in the same period from 2 March to 2 May 2004. Detectors were placed on a cupboard or shelf 100–150 cm above the floor and 30–50 cm away from the wall.

In order to comply with the quality assurance—quality control protocols, the etched track detectors were calibrated in Karlsruhe and have been regularly checked at the inter-comparison experiments organised annually by the Slovene Nuclear Safety Administration[10]. In addition, at 10% of points, etched track detectors were exposed in duplicate.

RESULTS AND DISCUSSION

Radon levels

Radon concentrations are presented in Table 1, together with details of each village or town included in the survey. The distribution of radon concentrations in rooms is shown in Figure 1. The radon concentrations fit well (exceptions are the lowest two points) the lognormal distribution (Figure 2). As described above, site characteristics of the villages selected were different and so were possibly different radon sources, and, hence, a broken line in the log-probit plot is expected. Therefore, the prevailing radon source at each village was probably similar. Nonetheless, radon levels at Bresanë, lying over a copper deposit, are consistently higher than those at Kuk, hit by depleted uranium. On the other

Table 1. Radon concentrations (C_{Rn}) and estimated annual effective doses of residents in dwellings in villages in the Sharri Community obtained with etched track detectors exposed in the period from March 2 to May 2, 2004.

Village/Town	Place	Room	Floor	C_{Rn}(Bq m^{-3})	E_{eff}(mSv)
Sharri (4200/620)[a]	House-1 (18)[b]	Sleeping room	g	96 ± 18	2.5
		Living room	b	172 ± 27	
	House-2 (12)	Sleeping room	g	124 ± 39	2.68
		Living room	g	170 ± 20	
	House-3 (4)	Kitchen	I	155 ± 44	2.76
Brrut (1586/169)	House-1 (15)	Sleeping room	I	120 ± 14	3.09
		Living room	g	127 ± 9	
		Kitchen	g	85 ± 12	
	House-2 (6)	Sleeping room	g	34 ± 8	0.89
		Living room	g	62 ± 12	
	House-3 (10)	Sleeping room	II	96 ± 20	1.98
		Living room	b	122 ± 18	
Bellobrad (1320/148)	House-1 (10)	Sleeping room	g	112 ± 10	1.4
		Cellar, store	b	55 ± 10	
	House-2 (6)	Sleeping room	g	85 ± 12	1.53
		Living room	g	87 ± 17	
	House-3 (22)	Sleeping room	g	93 ± 19	2.88
		Sleeping room	g	69 ± 15	
	House-4 (4)	Sleeping room	I	82 ± 17	1.46
Kuk (2136/224)	House-1 (12)	Sleeping room	g	65 ± 8	1.07
		Living room	g	57 ± 12	
	House-2 (8)	Sleeping room	g	124 ± 27	1.89
		Living room	g	93 ± 20	
	House-3 (18)	Sleeping room	g	87 ± 12	1.63
		Kitchen	g	58 ± 11	
	House-4 (4)	Living room	g	63 ± 9	1.33
		Living room	g	66 ± 14	
Bresanë (3867/340)	House-1 (16)	Sleeping room	I	154 ± 23	3.31
		Living room	g	209 ± 30	
	House-2 (9)	Sleeping room	g	159 ± 12	2.86
		Living room	g	162 ± 18	
Gllobočicë (1484/223)	House-1 (6)	Living room	I	117 ± 23	4.65
		Kitchen	g	193 ± 37	
	House-2 (5)	Sleeping room	II	24 ± 6	2.98
		Living room	I	116 ± 21	

[a]number of inhabitants/houses in the village, [b]number of persons in the household, and floor: b, basement; g, ground floor; I, first floor; II, second floor.

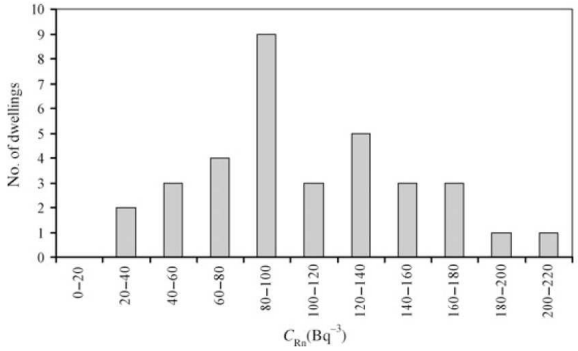

Figure 1. Distribution of indoor radon concentrations in dwellings in the Sharri community.

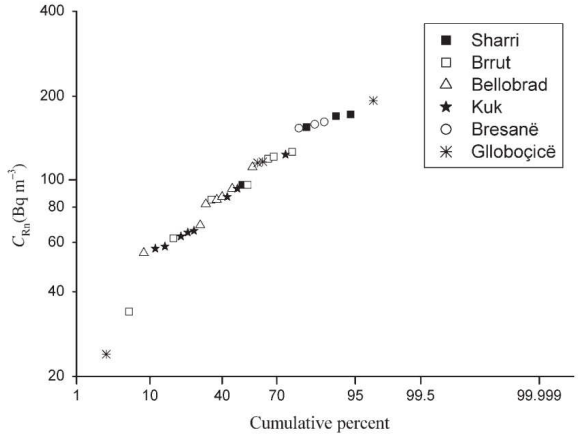

Figure 2. Log-probit plot indicating that the indoor concentrations of radon in dwellings in the Sharri community are lognormally distributed.

hand, at Brrut in the karst region both high and low values, and, at Gllobojçicë, the lowest and the highest values were observed. As the houses were built over a very narrow period of time and of practically the same material, the quality of construction appears to play a more important role than the geology of the ground[11,12].

Table 2 shows the ratio of radon concentrations in the sleeping and living room. The ratio was expected to be less than 1 where the living room was situated on a lower floor than the sleeping room, e.g. House-1 in Sharri or House-3 in Brrut, but this ratio was also found in cases where both sleeping and living room were on the same floor, e.g. House-2 in Sharri or House-2 in Brrut. This may indicate that residents take care to ventilate their sleeping rooms well, by keeping windows open. In the majority of houses with both sleeping and living room on the same floor, the ratio was either close to 1 or above it.

Table 2. Ratio of radon concentrations in the sleeping and living room (also given are the floors of sleeping/living rooms: b, basement; g, ground floor; I, first floor; II, second floor).

Village/Town	Place	Sleeping/Living
Sharri	House-1	0.558 (g/b)
	House-2	0.729 (g/g)
Brrut	House-1	0.945 (I/b)
	House-2	0.548 (g/g)
	House-3	0.787 (II/b)
Bellobrad	House-2	0.977 (g/g)
Kuk	House-1	1.140 (g/g)
	House-2	1.333 (g/g)
	House-3	1.500 (g/g)
Bresanë	House-1	0.737 (I/g)
	House-2	0.981 (g/g)
Gllobojçicë	House-2	0.207 (II/I)

Provided that almost the half of radon concentration values fall in the range 50–100 Bq m^{-3} and only one value was above 200 Bq m^{-3} (Table 1), the Sharri community may be considered as a low-radon level region[1]. They are also well below the ICRP range of 200–600 Bq m^{-3}, allowed for homes[13]. On the basis of the experience gained in schools in Kosovo, the radon concentrations in Table 1, obtained in spring, may be assumed to represent an approximate yearly average because autumn values would be similar, while summer and winter values would be 15–25% lower and higher, respectively[6].

Dose estimates

To calculate annual effective doses of residents (E_{eff}) the following general formula was used[14,15]:

$$E_{\text{eff}} = \frac{C_{\text{Rn}} \times F}{3700} \times \frac{t}{170} \times \text{DCF}. \quad (1)$$

Here, C_{Rn} is the yearly average indoor air radon concentration and t, the time (in hours) spent by a person in the room considered. According to the ICRP Publication 65 recommendations[13], 0.40 was taken for the equilibrium factor F between radon and its short-lived decay products (^{218}Po, ^{214}Bi, ^{214}Pb, ^{214}Po[14]), and 5 mSv WLM^{-1} for the dose conversion factor DCF. Denominators 3700 and 170 are necessary to convert the measured exposure to radon into exposure in WLM, the old, though practical and still widely used, unit. Exposure of 1 WLM is gained by 170-h breathing air in which the concentration of potential alpha energy due to decay of radon short-lived decay products is 1.3×10^5 MeV L^{-1}, equivalent to 3700 Bq m^{-3} (100 pCi L^{-1}) of radon in radioactive equilibrium ($F = 1$) with its decay products.

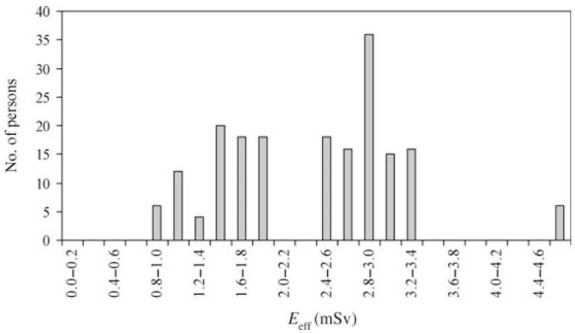

Figure 3. Distribution of estimated annual effective doses of residents of the dwellings in the Sharri community.

As no statistical data were available on the living habits of residents, an occupancy factor of 0.80 was taken in the calculations, as proposed by the National Radiological Protection Board[16], although other values[2,17,18] might better represent the actual situation. Thus, of the total of 8760 h in a year, 7008 were taken as spent indoors. Of these, 2920 h (8 h day^{-1}) were assumed to be spent in the sleeping room and the rest (4088 h) somewhere else indoors. In cases when radon was not measured in the sleeping room but in several other rooms of a house, the total time indoors was partitioned equally to all rooms. For a room, radon concentration from Table 1 was taken as the yearly average value, based on the discussion in the previous section. E_{eff} values thus calculated are collected in the last column of Table 1. They actually do not represent personal annual effective doses but rather an annual effective dose a person would receive spending 80% of the time in the selected house. These are then the upper limits of doses, because a number of residents are employed and attending schools, and their occupancy times are much lower, and consequently their actual doses received at home are probably lower. As seen from the distribution in Figure 3, E_{eff} values are grouped in two samples of almost equal size, one around 1.5 mSv y^{-1} (close to the world average[1]) and another, around 2.8 mSv y^{-1}. As radon concentrations and the resulting effective doses in all the houses surveyed so far in this region are acceptably low, no radon mitigation is necessary.

CONCLUSIONS

By exposing etched track detectors in the spring period, indoor air radon concentrations were obtained in dwellings of six villages of the Sharri community in Kosovo. Values ranged from 24 to 209 Bq m^{-3}, with the geometric mean and geometric standard deviation of 95.4 Bq m^{-3} and 1.6, respectively. On the basis of the assumption that spring radon concentrations may well represent the yearly average, annual effective doses of residents (the upper level) were estimated to range from 0.89 to 4.7 mSv y^{-1}, with the geometric mean and geometric standard deviation of 1.5 mSv y^{-1} and 2.2, respectively. In this community, no mitigation measures will be undertaken.

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6.3.2.6. Scientific paper VI:

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Exposure to radon in the Gadime Cave, Kosovo

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Abstract

Air radon concentration was measured in summer and winter at 11 points along the tourist guided route in the Gadime Cave in Kosovo using alpha scintillation cells and etched track detectors. At two points in summer, values higher than 1700 Bq m^{-3} were observed; they otherwise were in the range 400–1000 Bq m^{-3}. Values were lower in winter. The effective dose received by a person during a 90 min visit is 3.7 μSv in summer and 2.5 μSv in winter. For a tourist guide the annual effective dose is less than 3.5 mSv.

Keywords: ^{222}Rn; Air; Karst cave; Effective doses; Gadime

1. Introduction

It has been known for a long time that elevated radon (α-radioactive ^{222}Rn isotope, half-life, $t_{1/2} = 3.82$ days) activity concentrations may be found in the air of karst caves (Wilkening and Watkins, 1976; Yarborough, 1980; Fernández et al., 1984; Papastefanou et al., 1986; Kobal et al., 1986, 1987; Quindós et al., 1987). The values depend on the radon exhalation rate from the surfaces in the cave, the volume and shape of the cave, the inflow of outside air and the degree of its mixing with the cave air. The influence of meteorological conditions on the radon levels and their temporal variations depends mostly on the shape of the cave, and the number and directions of cracks and fissures connecting the cave rooms with the outdoor atmosphere. In horizontal caves, the driving force for air movement within the cave, and thus the inflow of fresh air and release of the cave air to the atmosphere, is the temperature difference between the cave air and outdoor air, while in vertical caves, it is the difference between the barometric pressures at the bottom and the top of the cave (Hakl et al., 1996). If the cave corridors run mostly horizontally and the cave air temperature, being practically constant all the year round, is higher than the outdoor air temperature, as it appears in winter, the cave behaves as a large chimney and, due to air draught, the radon-rich cave air is released to the atmosphere, allowing inflow of fresh air with low-radon-levels. In such caves, therefore, maxima in radon concentration is observed in summer and minima in winter (Wilkening and Watkins, 1976; Quindós et al., 1987; Kobal et al., 1988; Dueñas et al., 1999; Papastefanou et al., 2003; Quindós Poncela et al., 2004; Dueñas et al., 2005), although the situation is reversed in caves with several horizontal levels (Kies and Massen, 1997).

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The exposure of tourists to radon and radon short-lived decay products (i.e., ^{218}Po, α decay, $t_{1/2} = 3.10$ min; ^{214}Pb, β/γ decay, $t_{1/2} = 26.8$ min; ^{214}Bi, β/γ decay, $t_{1/2} = 19.9$ min; and ^{214}Po, α decay, $t_{1/2} = 164$ μs, Nero, 1988) during their short visits to show caves is insignificant, while the annual effective doses of tourist guides and maintenance workers, who spend the majority of their working time in the cave, may reach or even exceed 20 mSv (Papastefanou et al., 1986; Jovanovič, 1996; Dueñas et al., 1999; Pinza-Molina et al., 1999; Sperrin et al., 2000; Kávási et al., 2003; Gillmore et al., 2005; Field, in press), and their working time in the cave should be limited, based on the results of permanent radon monitoring (Vaupotič et al., 2001). It was therefore logical to include also the caves into the European (CEU, 1996) and international (IAEA, 2003) guidelines dealing with radiation exposure at workplaces other than uranium mines.

There are several karst caves in Kosovo, of which the Gadime Cave is by far the most popular. Although we were aware of possibly elevated radon levels in the cave, in the first radon survey carried out in Kosovo a decade ago (Jakupi et al., 1997) several mines and selected dwellings were included but no caves. In order to remedy this omission, in 2004 and 2005 we focused our attention to the Gadime Cave and measured radon activity concentration in the cave air by using alpha scintillation cells and etched track detectors. This paper reports the results obtained and comments on the effective doses estimated for the tourist guides.

2. Experimental

2.1. Cave description

The Gadime Cave (Pllana, 1981) is located about 20 km from Prishtina, the capital city of the country. Underground galleries and halls (5350 m) have been discovered to date, of which 1350 m are open as show caves (Fig. 1). The difference between the lowest and the highest point along the guided tour is 50 m. Visits are possible from 9 a.m. to 6 p.m. in winter, and from 7 a.m. to 7 p.m. in summer. There are about 100 visitors a month in winter and 200–300 visitors a day in summer, totalling about 20,000 visitors a year. A guided walking tour lasts 60–90 min. For that purpose, eight tourist guides are employed in the summer working regime (from May to September) and two in the winter working regime (the rest of the year), each spending 110 h in the cave in a summer month, adding up to about 1300 h annually.

2.2. Measuring techniques

Instantaneous radon concentrations in air were measured using 0.7 dm^3 alpha scintillation cells manufactured at the Jožef Stefan Institute (Vaupotič et al., 1992) and calibrated with a standard $^{226}RaCl_2$ solution (National Bureau of Standards and Technology, Standard Reference Material 4953D), according to the Rushing procedure (Rushing et al., 1964; Kristan and Kobal, 1973). Cell efficiency is about 1.4×0^{-3} s^{-1} Bq^{-1} m^3, providing a lower limit of detection of 10–20 Bq m^{-3} at 30–60 min counting time and 1–2 min^{-1} background. At a selected point, air was sampled directly into a cell, the cell transported to the laboratory, and gross alpha radiation counted after 3 h, when radioactive equilibrium between radon and its short-lived decay products had been reached.

Average radon concentrations were measured with etched track detectors purchased from the Karlsruhe Forschungszentrum (Urban and Schmitz, 1993), which are based on the Makrofol E foil. After exposure, detectors were sent back to Karlsruhe for development and evaluation.

In order to comply with the quality assurance – quality control protocols, both the cells and etched track detectors have been checked regularly at the inter-comparison experiments organised annually by the Nuclear Safety Administration at the Slovene Ministry of Environment and Spatial Planning (Križman, 2001). In addition, alpha scintillation cells are calibrated monthly with $^{226}RaCl_2$ solution, as described above and, at 10% of the measurement points, etched track detectors were exposed in duplicate.

3. Results and discussion

3.1. Radon levels

Instantaneous radon concentrations, measured with scintillation cells under the summer working regime (on 16 July 2004) along the guided tourist tour (Fig. 1), are listed in Table 1. Except for the Garden of Love and Concert Hall, where they exceeded 1700 Bq m^{-3}, they ranged from 400 to 1000 Bq m^{-3} and rank this cave among the low-radon-level caves (Field, in press). Concentrations were lower in the periods from 24 September to 21 October

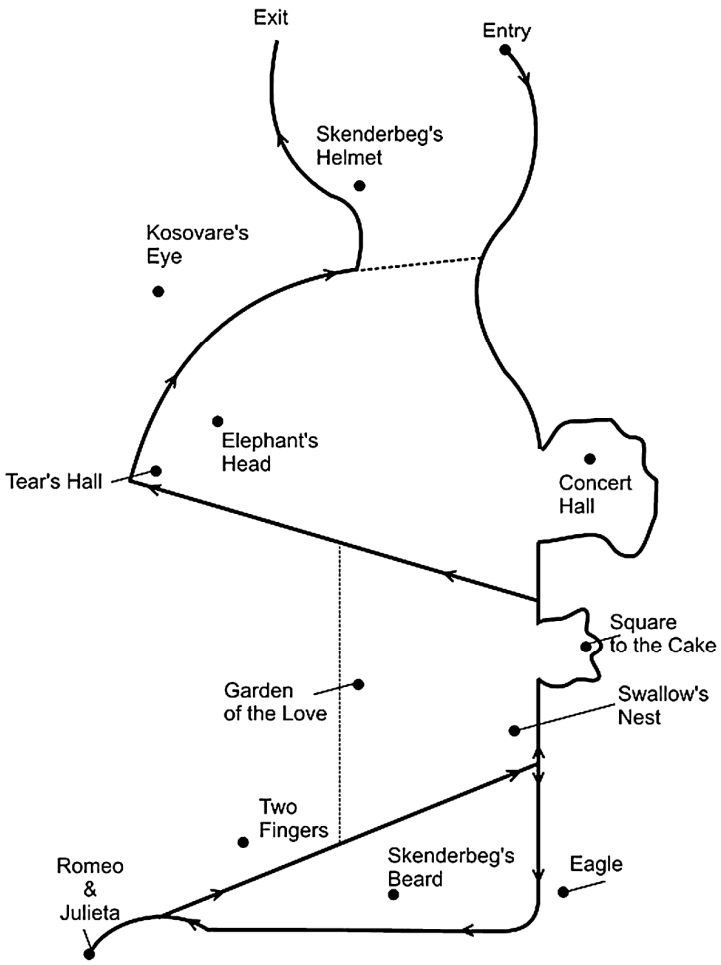

Fig. 1. Schematic map of the Gadime Cave.

2004 and from 24 September 2004 to 10 January 2005 (winter working regime), as measured with etched track detectors (Table 2). Because the cave lies practically horizontal and the temperature of the cave air is constant all the year round, the temperature of the outdoor air was expected to have the predominant influence on radon levels in the cave air (Hakl et al., 1996). In winter, temperature in the cave is higher than outdoors and the cave system works as a huge

Table 1
Radon concentrations in the air (C_{Rn}) of the Gadime Cave obtained by alpha scintillation cells on 16 July 2004

No.	Place	Time	T/°C	RH/%	C_{Rn}/Bq m^{-3}
1	Concert Hall	11.40	12	60	1721 ± 40
2	Square to the Cake	11.45	11	85	971 ± 36
3	Swallow's Nest	11.50	14	90	618 ± 29
4	Eagle	11.55	14	80	559 ± 28
5	Skenderbeg's Beard	12.00	14	85	425 ± 26
6	Two Fingers	12.10	11	70	922 ± 33
7	Garden of Love	12.20	12	90	1783 ± 40
8	Tears' Hall	12.30	13	87	461 ± 27
9	Elephant's Head	12.35	13	83	625 ± 28
10	Kosovare's Eye	12.45	13	65	585 ± 27
11	Skenderbeg's Helmet	12.55	14	65	551 ± 28

Table 2
Radon concentrations in the air (C_{Rn}) of the Gadime Cave measured by exposing etched track detectors in the periods: (1) from 24 September 2004 to 21 October 2004, and (2) from 24 September 2004 to 10 January 2005; July/winter C_{Rn} ratio is the ratio between C_{Rn} measured on 16 July 2004 and in the period 24 September 2004–10 January 2005

No.	Place	C_{Rn}/Bq m^{-3} (1)	C_{Rn}/Bq m^{-3} (2)	July/winter C_{Rn} ratio
1	Concert Hall	385 ± 19	217 ± 13	7.9
2	Square to the Cake	784 ± 26	812 ± 20	1.2
3	Swallow's Nest	759 ± 36	768 ± 12	0.80
4	Eagle	877 ± 25	780 ± 18	0.72
5	Skenderbeg's Beard	510 ± 26	790 ± 32	0.54
6	Two Fingers	570 ± 25	680 ± 28	1.4
7	Garden of Love	1200 ± 60	739 ± 30	2.4
8	Tears' Hall	372 ± 19	299 ± 15	1.5
9	Elephant's Head	520 ± 26	680 ± 14	0.92
10	Kosovare's Eye	410 ± 15	390 ± 20	1.5
11	Skenderbeg's Helmet	326 ± 35	410 ± 17	1.3

fire-place with a chimney: the temperature difference forces radon-rich air to flow from the cave space through vertical shafts and cracks into the outdoor atmosphere. Air draught outweighs radon exhalation from walls, thus preventing its accumulation in the cave air. The last column in Table 2 shows the ratio between radon concentrations measured in summer (data from Table 1) and in winter (data from column (2) in Table 2). The chimney effect appears to be at work in the majority of the cave space, except at Swallow's Nest, Eagle and Skenderbeg's Beard, where this ratio is significantly lower than 1. This part of the cave appears to be isolated from the outdoor atmosphere. Radon concentration in summer is reduced, probably by air movement through narrow corridors caused by the larger number of visitors.

3.2. Effective doses

The effective dose for a person walking along the guided path in the cave was calculated according to ICRP-65 methodology (ICRP, 1994). The path was divided into steps of 'equal' radon concentration, as shown in Fig. 2 for 'summer' and 'winter'. The value of radon concentration measured at a point was assumed to apply from half way to the previous point to half way to the next point. The outdoor concentration was 25 Bq m^{-3}. Ten minutes were needed to walk from the entrance to the Concert Hall, and from the Skenderbeg's Helmet to the exit. The effective dose received in a step (E_i) was calculated, applying the general formula (Nero, 1988; Vaupotič et al., 2001):

$$E_i = (C_{Rn} \times F)/3700 \times (t/(60 \times 170)) \times \mathrm{DCF}.$$

Here, C_{Rn} is the radon concentration (in Bq m^{-3}) fixed for the selected step and t is the time (in min) needed to traverese this step (cf. Fig. 2). F is the equilibrium factor between radon and radon short-lived products and DCF is the dose conversion factor, i.e., the ratio between the weighted equivalent dose to lung (assuming a radiation weighting factor for α particles, $w_\alpha = 20$, and a tissue weighting factor for lung, $w_{lung} = 0.12$) expressed in mSv, and the exposure to radon short-lived decay products expressed either in WLM or Bq m^{-3} h. The old but still widely used unit, 1 WLM (working-level-month) is the exposure resulting from 170 h breathing in air with an activity concentration of short-lived radon decay products of 1 WL (working-level), originally defined as the activity concentrations of ^{218}Po, ^{214}Bi and ^{214}Pb (^{214}Po) which are in radioactive equilibrium ($F = 1$) with 100 pCi L^{-1} (3700 Bq m^{-3}) of ^{222}Rn, resulting in an alpha energy concentration of 1.3×10^5 MeV L^{-1} (Nero, 1988). In our calculations, F was set at 0.4 and DCF at 5 mSv WLM^{-1}, in accordance with the ICRP-65 recommendations (ICRP, 1994). When E_i are summed for walking along the path, the cumulative effective dose E is obtained as shown in Fig. 2.

As seen from Fig. 2, during a visit a tourist receives an effective dose of 3.7 μSv in summer and 2.5 μSv in winter. This value is insignificant in comparison with 1.25 mSv, the annual effective dose a member of the general public receives from radon and radon short-lived decay products on a worldwide average, or 2.5 mSv received from all natural radioactive sources (UNSCEAR, 2000). The situation is different for a tourist guide in the cave: working the maximum of 1300 h (866 visits of 1.5 h) under summer conditions would lead to an annual effective dose of 3.2 mSv and, for the entire time spent in winter the dose would be 2.2 mSv. Because only two guides work per shift in winter and they do not spend more than 200–300 h in the cave, to be on the safe side from the radiation protection

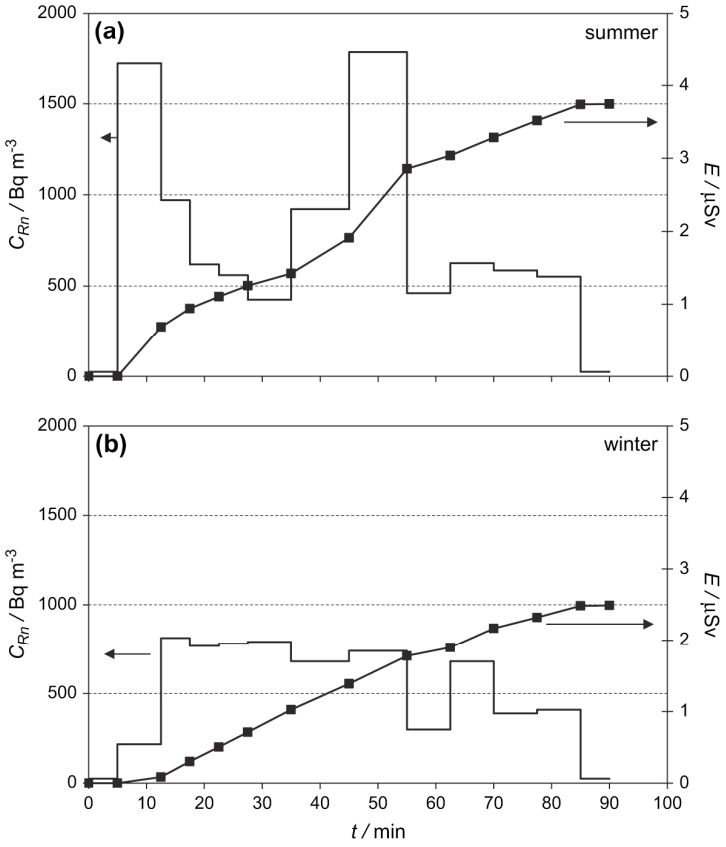

Fig. 2. Radon concentration values (C_{Rn}) along the guided path and the cumulative effective dose (E) gaining by a person during a 90 min visit to the cave in: (a) summer (July), and (b) winter (September 2004–January 2005).

point of view, the average annual effective dose for guides is not expected to exceed the higher value, 3.2 mSv. Even under this assumption the annual effective doses of guides are low and we believe that no concern is needed to reduce their exposure to radon, and consequently to limit their time spent in the cave.

4. Conclusions

A radon survey in the Gadime Cave has resulted in the following conclusions:

- radon levels are relatively low, in the range 400–1000 Bq m^{-3}, with exceptions at two locations with about 1700 Bq m^{-3},
- at the majority of places in the cave, radon concentration is lower in winter than in summer,
- the annual effective dose received by a tourist guide from radon and radon short-lived decay products by breathing in the cave air does not exceed 3.5 mSv,
- no mitigation measures (e.g., limiting the time spent by the guides in the cave) are considered to be necessary.

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7. Conclusions

The first measurements of radon concentration were started in March 2003 while working on my master's thesis, where some school buildings of Prizren, Sharr, Suhareka and Malisheva Municipality were included in the study. Based on the results obtained it was ascertained that radon concentration in some school classrooms had a high level, whereas some had a low level. Measurements were mainly made in different seasons, where a change in radon concentration was noticed. Measurements in some classrooms were repeated in different months; however the results were approximately the same, except for trivial differences which was not worth noting down in the Table.

Measurements of radon concentrations were also carried out in some houses of Sharr Municipality. In these measurements track detectors were used, whereas in schools alpha scintillation methods were used. Measurements were made in the mines of Trepça and Gadime Cave. In Trepça mines measurements were made by the alpha scintillation method, whereas in the Gadime cave, apart from alpha scintillation method, track detectors were also used. In this work, radon concentrations were systematically measured in eleven (11) levels of the Trepça mine in Kosovo. Alpha scintillation was the main method used for measuring radon concentration.

The measurements showed that the radon concentration is higher on the upper levels, because radon does not increase with depth. Values of concentration found are within the values recommended by ICRP.

Indoor air radon (^{222}Rn) concentrations obtained during the spring and winter season from 30 classrooms of 9 elementary schools and 19 rooms of 6 high schools, using alpha scintillation cells, were relatively low. In 74% of the classrooms of elementary schools the winter value was $<100\ Bq\,m^{-3}$, while in 3 rooms it exceeded $400\ Bq\,m^{-3}$, whereas in 48% of high school classrooms it was $<100\ Bq\,m^{-3}$, and in 4 rooms it exceeded $400\ Bq\,m^{-3}$. This initial screening gave a preliminary picture of radon distribution, which could be useful for an advanced survey by long-term measurements in schools in Kosovo, aimed at evaluating the effective doses to children and personnel.

Indoor air radon (^{222}Rn) concentrations obtained in March, May, August and December in 15 classrooms of five elementary schools and in six classrooms of one high school using alpha scintillation cells were relatively low: only in one room did the value exceed 200 $Bq\,m^{-3}$. Except in two rooms, winter concentrations were higher than summer ones, and the following average values were obtained for ratios:

CRn(March)/CRn(December) = 0.85,
CRn(May)/CRn(December) = 0.74 and
CRn(August)/CRn(December) = 0.57.

Concentrations in rooms on the ground and first floors were 3–5 times lower than in the basement.

A radon survey in the Gadime Cave has resulted in the following conclusions:

- Radon levels are relatively low, in the range of 400–1000 $Bq\,m^{-3}$, except for two locations with about 1700 $Bq\,m^{-3}$;
- In the majority of places in the cave, the radon concentration is lower in winter than in

summer,

- The annual effective dose received by a tourist guide from radon and radon short-lived decay products breathing air in the cave, does not exceed 3.5 mSv; hence
- No mitigation measures (e.g., limiting the time spent by the guides in the cave) are considered to be necessary.

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[143] **Bahtijari, M., Stegnar, P., Shemsidini, Z., Ajazaj, H., Halimi, Y., Vaupotič, J. and Kobal, I.** ***Seasonal variation of indoor air radon concentration in schools in Kosovo*****, Radiat. Meas. 42, 286-289 (2007)**

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Appendix

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I, Meleq BAHTIJARI, was born in 19.01.1968; my father's name is Bajram and my mother's name is Shefije, from Brrut village in the Dragash municipality. I finished Primary School in the "Sezai Surroi" Primary School in Bellobrad village. I finished Secondary School in the "Emin Duraku" Gymnasium in Dragash with the title of Laboratory Technician in Biology. I graduated in 1986, and my diploma's theme was "Dragash's Flora." In 1987-1988, I was enrolled in the Natural Mathematical Faculty in Prishtina in the Physics Department. While attending in the academic year 1988-1989, I was elected student-pro-dean in the Natural Mathematical Faculty in a biennial mandate.

In 20.09.1982, I finished my studies in Prishtina University with a diploma theme of "Infiltration of Alpha, Beta and Gamma Rays Through the Solid Troops."

In the 1993-1994 academic year, I was employed in the secondary school of medicine "Luciano Motroni" in Prizren as a teacher, where I am presently still working.

In the academic year 1988-1989, I was registered in post-graduate studies in the Natural Sciences Faculty in Tirana with the option of physics in the Bio-physics department, which I had to stop because of the war in Kosovo.

I continued my studies in Tirana in 2000-2001, and on 24.02.2004, I finished my post-graduate studies with the master's thesis topic of "Radon in Some Schools in Kosovo and the After-effects in People."

The experiments for this study were conducted while I worked in the "Jožef Stefan" Institute in Ljublana with Doc. Dr. Janja Vaupotiq as my mentor.

In 2002-2003, I worked on the concentration measurement of Radon in the houses in the Dragash and Hasi regions in the Prizren municipality, while in the meantime in 2003 I followed the concentration investigation of Thoron and Radon in the Trepça Mines.

In 2003, I started the measurement of Radon in the Gadime cave, where I elaborated and edited the results of this project which I am still investigating.

As a continuation of this study, I made concentration measurements of Radon in the schools, hospitals and children's schools in Kosovo. In May 2004, I applied in the International post-graduate school in the "Jožef Stefan" Institute in Ljublana for my doctoral studies, where I was accepted and am continuing to work on my dissertation on "Radon in Kosovo."

Engagements in the University of Prishtina

In the 2004-2005 academic year, I lectured in the Education Faculty for these subjects:

1. Basics of natural sciences – Basics of natural sciences with methodology
2. The experimental practice for physics' basis
3. Teaching methodology and practice work in technology and informatics.

In the academic year 2005-2006, I was selected again as a teacher in the Faculty of Education in Prishtina for these subjects:

1. The experimental practice for physics' basis
2. The classical mechanics.

In May 2006, I was a coauthor of a physics workbook for years VI, VII, and VII for the publishing house of "Dukagjini" in Peja in May 2006.

I have been the author of authorized mimeographed notes for the following subjects (because there wasn't any adequate literature)

1. Basics of Natural Science-Basics of Natural Science with methodology.
2. Teaching methodology and practice work in technology and informatics.

In the academic year of 2006-2007, I was a teacher in the Education Faculty in this subject:

The experimental practice for Physics' basis.

In the academic year of 2006-2007, I was employed in the "Rezonanca" Medical Science University in Prishtina to teach the experimental exercises in these subjects:

1. Subject Physics-The Pharmacy Faculty
2. Physics with electronic-subject-The Physiotherapy Faculty

In the academic year of 2006-2007, I was employed in the "Rezonanca" Medical Science University in Prishtina to teach the experimental exercises in these subjects:

1. Physics-The Pharmacy Faculty
2. Physics with electronics-The Physiotherapy Faculty

In the academic years of 2007-2008, 2008-2009, 2009-2010, I was a teacher in the Faculty of Education in Prizren for these subjects:

1. The General Methodology of Teaching
2. The Methodology and Working from Physics

Participation in Workshops

1. M.Bahtjari, Z.Shemsidini, H.Ajazaj
   The Education Faculty, Prishtine
   Concentration of Radon according to horizons in Trepca mine.
   Shkodra University "Luigj Gurakuqi" Bul, Shk, Ser, Shk, Nat, 2005.Nr. 55:13-20

2. Meleq Bahtijari1, Peter Stegnar2, Zahadin Shemsidini1, Ivan Kobal2 and Janja Vaupotič2
   Indoor air radon concentration in schools in Prizren, Kosovo
   Radiation Protection Dosimetry (2006), Vol.121, No.4, pp. 469 – 473

3. M. Bahtijari, P. Stegnar, Z. Shemsidini, H. Ajazaj, Y. Halimi , J. Vaupotič , I. Kobal
   Seasonal variation of indoor air radon concentration in schools in Kosovo
   ELSEVIER Radiation Measurements 42 (2007) 286 – 289

4. Meleq Bahtijari, Ymer Halimi. Fatos Ylli, Koço Dollani
   Indoor radon concentration of Malisheve and Suhareka muncipality Schools
   AJNTS 2006 (1 – 2) XI (19 – 20) 346 – 349, Tirana – Albania.

5. M. Bahtijari, J. Vaupotič, A. Gregorčič P. Stegnar and I. Kobal
   Exposure to radon in Dwellings in the Sharri Community, Kosovo
   Radiation Protection Dosimetry, 130 (2) (2008), pp. 244-248.

6. M. Bahtijari, J. Vaupotič, A. Gregorčič P. Stegnar and I. Kobal
   Exposure to radon in the Gadime Cave, Kosovo
   Journal of Environmental Radioactivity, 99 (2) (2008) 343-348.

7. M. Fetah Murtez Halili, Ismet Dervish Bajraktari, Agim Maliq Gashi, Meleq Bahtijari, Naser Troni and Kemajl Bislimi
RADON AND HEMOGRAM OF THE TWO SECONDARY SCHOOLS STUDENTS IN SUHAREKA – KOSOVA
739.12 The Federation of American Societies for Experimental Biology (FASEB)

Participation in Scientific Conferences

The conference "On Natural Science Studies and Their Didactics "in Shkodra, 14 December 2004.

1. Meleq Bahtijari, Zahadin Shemsidini, Hamdi Ajazaj
"Definition of Radon's concentration with alpha method (shintiluse) in the Trepca Mine"

2. Change of Radon's concentration according to floors of the Science Faculty Natural-Mathematical in Prishtina – poster

ALB-Science Prishtina Kosovo 28-29.08.2008. M. Bahtijari, Y Halimi, N Troni, R Berisha.
"Concentration of Radon in Planeja and Gorozhup (Has) villages Prizren.

ALB-Science Tetove- Macedonia 30-31.12.2008 and 1-2.01.2009.
M Bahtijari, Y Halimi, N Troni, R Berisha
"The Workers' risks in caves which dispose of Radon's radiation - 222

ALB-Science Tirana Albania 02-05.09.2010. M. Bahtijari, Y Halimi,
"Two method's for measurement on radon Concentration".