Original Paper

Indoor+Built
Environment

Indoor Built Environ 1996;5:241–244

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Contribution of Radon to Overall Exposure to Radiation in a Ten-Storey Block Building

Key Words
Radioactivity
Building materials
Gamma doses
Equivalent doses

Abstract

Radon is an inert radioactive gas released into the atmosphere from certain minerals and man-made products in which it is produced. It can accumulate in confined spaces. Radon emanation into a building can come from: the underlying soil, the building materials, tap water and natural gas. The principal isotope, ^{222}Rn, decays to products which if inhaled can result in exposure of the respiratory tract to alpha radiation. The decay products, radon daughters, are significant because of their potential to cause health effects. In this study we present measurements of radon concentration, and the internal and external gamma dose to which the inhabitants of a housing block with ten floors are exposed. Solid State Nuclear Track Detectors (CR-39) were used for the determination of radon concentration in the air. LiF (TLD-100) dosimeters were used for measuring the external gamma dose. Of the total equivalent dose to which people are exposed, it appears that from inside the building makes the greatest contribution.

Introduction

The main contributors to the natural background radiation are the members of the ^{238}U (^{226}Ra) and ^{232}Th decay series and ^{40}K. These radionuclides are present in soils, rocks, and waters in varying concentrations depending on their origin, on geological history and geochemical characteristics [1]. While components of traditional building materials rely on many natural materials from soil and rocks, we have today several new ones which originate from industrial processes. These, as a consequence of the refining or concentration which occurs during their production, contain these radionuclides in much higher amounts. Really they are industrial wastes for which useful roles have been found. They include materials such as fly-ash used in cement manufacture, phospho-gypsum used for plaster boards and similar products and refinery slag to make insulating wool [2–4].

The radiological implications of living or working in buildings made in part from these materials are increased external exposure of the body to gamma-emitting radionuclides and internal exposure to radiation, primarily of the respiratory tract, by inhaling ^{222}Rn and its daughters. Taking into account both the short range and the high rel-

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1420–326X/96/0054–0241$10.00/0

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Accepted:
July 14, 1996

ative biological effectiveness (RBE)[1] of alpha particles, the irradiation risk for the lung presented by inhaled ^{222}Rn and its daughters is higher than that presented by gamma rays due to external radiation.

The inert gas ^{222}Rn is the immediate decay product of ^{226}Ra which is found in trace quantities in many rocks. ^{222}Rn can escape more or less easily from the medium where it is produced into the air. Porous rocks such as sandstone provide little hindrance to its egress but it is released less readily from hard rock such as granite. The concentration of radon is low in the atmosphere, but it may be greater by accumulation in enclosed spaces [5, 6] such as mines and buildings. Underlying soils and groundwater as well as building materials are sources of the radon in indoor air.

Radiation exposure of the population has been increased in recent decades not only by the use of certain industrial wastes as building materials but also by changes in lifestyle as people spend much more of their time in buildings. Furthermore, in temperate countries, particularly those with cold winters, where thermal insulation of houses is necessary to conserve energy, there is a tendency to reduce ventilation which leads to higher levels of irradiation.

In this study we present the levels of radon measured in a building with ten floors, and the external and internal exposure to radiation of the people living in it.

Materials and Methods

The study was performed in a ten storey block building built in 1965 in the industrial city of Cluj, Romania, situated in an area with a 'normal' radiation background. The type of construction used for the building is fairly common in Cluj and the building is similar in character to those found in other industrial cities. The walls of the selected house where measurements were made are of red brick and the foundation is of concrete. The rooms in the block measured 5 × 4 × 2.5 m and had central heating. Natural gas was used for cooking.

The gamma dose and concentrations of radon and its daughters were determined in bedrooms at each floor level. The measurements were made in the spring (April 3 to June 3) and summer (June 6 to August 6) of 1993, under normal living conditions. LiF thermoluminescence dosimeters (TLD-100) were used for measuring gamma radiation. Groups of two LiF dosimeters introduced in polyethylene capsules were fixed on the walls of the rooms (1 m above the floor) for 2-month periods. These dosimeters were evaluated after exposure using a YAM-30 type reader (Vakutronik, from the erstwhile German Democratic Republic). Solid state nuclear track detectors (CR-39) were used simultaneously in the same locations, for determining the concentrations of ^{222}Rn. Two detectors were placed in every room. After an exposure time of 60 days, the detectors were chemically etched and counted under the optical microscope. The SSNTD radon monitors were given by the Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen, Hungary, and, also, evaluation of the track detectors was done in this Institute. Through the use of the track detectors, daily variations and dependence of ^{222}Rn concentrations on the ventilation conditions were averaged out by the long-term measurements.

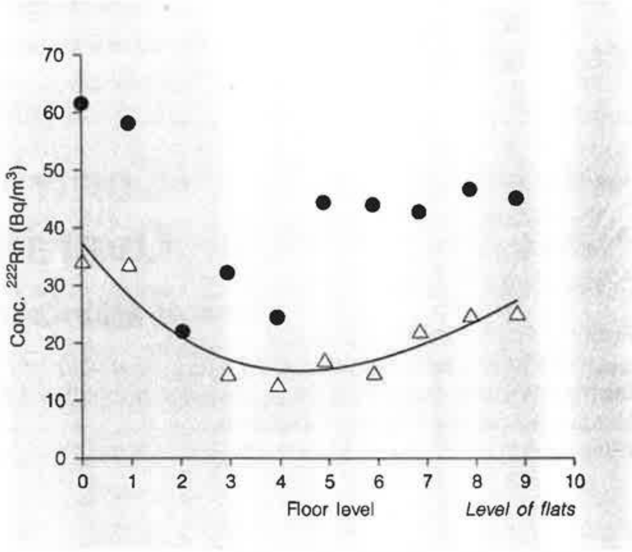

Fig. 1. Changes in the concentrations of ^{222}Rn between floors of the block in spring (●) and summer (△). The distribution of the values approximates to a 3rd-order polynomial.

In order to establish the daily variations in concentrations of ^{222}Rn and its daughters, other determinations were done in the two study periods: April to June and June to August, 1993. The ^{222}Rn concentration was determined by measuring the alpha activity of the air by means of scintillation cells. Air samples were collected from the middle of the living rooms of the ground floor, first, seventh and tenth floors. Air aspirated at a rate of 3 litre/min by a pump mounted inside the instrument passed directly through a set of filters into 1.83-litre scintillation cells, lined with ZnS(Ag). The concentrations of the radon decay products were determined in air samples aspirated at a rate of 56 litres/min through membrane filters (Synpor and Sartorius) for a period of 5 min. Alpha activity was measured over 3 time intervals from 2 to 5, 6 to 20 and 21 to 30 min after the end of sampling. Algorithms from Tshivoglu were used to obtain the concentration of the radon daughters. The characteristics of the filters and calibration of the measuring equipment were checked using a radium reference source and a scintillation alpha counter. Every measurement made inside the building was complemented by measurement of ^{222}Rn and its decay products in the open air.

The dose absorbed by the respiratory system cannot be measured directly, so it was calculated by taking into account such factors as

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[1] Relative Biological Effectiveness (RBE): to express the different amounts of potential harm to a person caused by unit dose of different types of radiation. For radiation protection purposes, a quality factor is defined for each class of radiation, based on RBEs for various relevant biological endpoints. Alpha particles have the highest quality factor usually taken as 20.

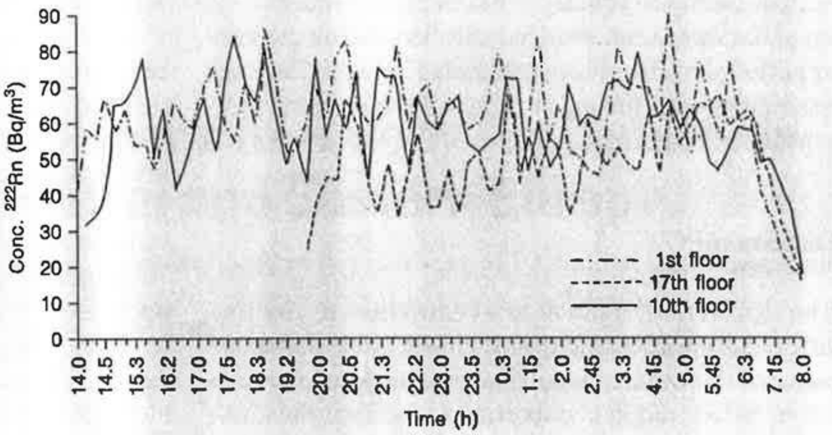

Fig. 2. Accumulation of ^{222}Rn in living rooms at different floor levels.

respiratory anatomy, radon daughter concentration, particle size, respiratory deposition, breathing characteristics and occupancy factor. The equilibrium factors were determined to be between 0.3 and 0.7. We used a value of 0.5, which is a representative mean value for the disequilibrium between ^{222}Rn and its short-lived daughters in human dwellings. The factor for converting exposure to radon daughters to absorbed dose is 7 mGy/WLM[2] (0.7 rad/WLM) [7, 8]. Assuming that people spend about 80% of their time indoors, we used an occupancy factor of 0.8. The International Commission on Radiological Protection gave a range of values of approximately 0.05–0.15 Sv/WLM, depending on the attached fraction and on the breathing rate. This would equate to 2.5–7.5 mGy/WLM, assuming the QF = 20 [9].

We estimated the equivalent dose (ED)[3] to the people by considering the external dose absorbed from the air and originating from building materials and also the internal dose absorbed in the respiratory tract from the decay of ^{222}Rn.

Results

The distribution of ^{222}Rn concentrations in the different levels of the block measured during the spring and summer periods showed that the maximum values obtained in the ground and first floor rooms might be due to the contribution of ^{222}Rn emanation from the soil, entering into the living areas through the floor. The block house substructure is made from concrete and there is a cellar under the ground floor. Overall, concentrations of radon decrease from the basement to the upper floors.

Figure 1 shows the characteristic shape of the distribution of ^{222}Rn concentrations over both seasons, which suggest the form of a third-degree polynomial. Slightly increasing radon concentrations found at the upper levels were probably due to reduced ventilation on these floors.

From measurements performed in rooms which were initially ventilated, over 24 h, it can be seen that in the first 3 h after closing the windows and the doors, the speed of ^{222}Rn accumulation is 12 Bq/m^3/h, followed by a slower accumulation of 2–3 Bq/m^3/h over the subsequent 9 h period (fig. 2).

The mean indoor ^{222}Rn concentration during the spring period was 41.5 ± 15.3 Bq/m^3 which is about twice the concentration in the summer period (22.1 ± 8.6 Bq/m^3). The annual average of indoor ^{222}Rn concentrations was 52.8 Bq/m^3 which is about 4 times higher than the corresponding value in the open air (12.3 ± 4.1 Bq/m^3). Variations of ^{222}Rn concentration day by day were averaged out by using long-term measurements. The above annual average value is higher than that measured in either the spring or summer periods and takes into consideration the fact that the autumn and winter results are higher than in the spring and summer presumably because of decreased ventilation in the colder months. Overall the values in the block are 3–10 times smaller than those measured in a detached house in same city. The difference between the mean ^{222}Rn concentrations determined for the short term and long term samples was 12%. Statistical

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[2] 1 WL (working level) = any mixture of short-lived alpha decay products of ^{222}Rn per litre which releases $1.3 \cdot 10^5$ MeV of alpha energy during complete decay; 1 WLM (working level month) is defined as exposure for 170 h to a concentration of 1 WL. The public exposure occurs for a period of 730 h each month.

[3] Equivalent dose (ED) is absorbed dose corrected for type of radiation and sensitivity of the irradiated tissue. It is a normalised index of potential harm from ionising radiation (International Commission on Radiological Protection recommendation, 1995).

errors in the track counting method were 20%. Comparisons made between monthly ^{222}Rn measurements and the mean of the short-term samples collected during the sampling period show there is a good match between the track measurements and the mean values of the seasonal measurements.

Discussion

The significance of radon as a contributor to environmental radiation and consequently its probable impact on human health is well known. Therefore, making measurements of indoor radon is important to monitor the levels to which people are exposed so that if they are high they may be reduced in order to reduce any possible health impact. Overly high levels of radon indoors may be readily and cheaply reduced even if the source of the radon is the building itself.

Based on our results, we estimated the ED attributable to the inhalation of ^{222}Rn and its daughters for the population we investigated. The dose rate they experienced ranged between 0.12 and 0.38 mSv/year. The results of our gamma dose measurements with TLD were between 0.02 and 0.4 mGy. This represents the mean values obtained from monthly integrated dose. We noticed that the doses found are about the same for people on every floor. The ED rates people receive in these flats from building materials (external exposure) is estimated to be between 0.01 and 0.20 mSv/year.

Although absolute values would be expected to vary between studies made in buildings of different construction and in different countries, we compared our values of ^{222}Rn concentration with those found by another group of investigators to see whether the overall pattern was in any way similar. The annual average of ^{222}Rn concentrations which were obtained by Dudney and Hawthorne [10] in 70 houses in USA were between 27 and 400 Bq/m^3 at upper levels and between 38–580 Bq/m^3 at lower levels. A result showing trends qualitatively in agreement with our figures. Higher concentrations in the lower floors of a block probably represent the additional contribution of ground emanations while the values for the higher floors are solely due to release from the building itself. This is supported by measurements of the external dose rate obtained from building materials which is the same at every floor level and depends only on the content of radioactive elements in the building materials. The internal dose from the red brick walls would seem to be the more important contributor to ED in this ten-floor block building.

Acknowledgement

We acknowledge and thank the inhabitants in whose flats these measurements were made.

References

1 Sources and Effects of Ionizing Radiation, UNSCEAR 1993, Report to the General Assembly, United Nations, New York, 1993;III:33–91.
2 Stranden E: Some aspects on radioactivity of building materials. Physica Norveg 1976;8: 167–173.
3 Mocsy I, Fulea C: Natural radioactivity of some building materials. Radiat Protect Dosim 1984;6:277–278.
4 Beretka I, Mathew PJ: Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys 1985;48:85–87.
5 Keller G, Folkerts KH, Muth H: Activity concentrations of Rn-222, Rn-220 and their decay products in German dwellings: Dose calculations and estimate of risk. Radiat Environ Biophys 1982;20:263–274.
6 Quindos LS, Newton GI, Wilkening MH: On the dose rate indoors from building materials. Radiat Protect Dosim 1987;19:125–128.
7 George AC: Measurement of Sources and Air Concentrations of Radon and Radon Daughters in Residential Buildings. ASHRAE Trans 1985; 91.
8 Keller G, Folkerts KH, Muth H: Special aspects of the Rn-222 daughters product concentrations in dwellings and in the open air. Radiat Protect Dosim 1985;7:151–154.
9 Lung Cancer Risk from Indoor Exposures to Radon Daughters. ICRP 1987;17(1).
10 Dudney CS, Hawthorne AR: Radon-222, Rn-222 progeny and Rn-220 progeny levels in 70 houses. Health Phys 1990;58:297–311.