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Measurement of Indoor Radon Concentration in a Residential House of Surrey (BC) Canada using LR-115 type II Plastic Detector

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Abstract

Indoor radon concentration activity measurement has been considered as a useful parameter in evaluation of health hazards due to radon. The major health hazard is lung cancer attributable to radon in Canada which causes 16% of total lung cancer deaths. The purpose of this study is to determine indoor radon concentration (Bq/m^3) and effective annual dose (mSv/yr) in a residential building. Plastic detector LR-115 Type II has been used for recording alpha tracks emanated by Radon and its progenies. To determine track density, tracks were counted using optical microscope, after etching detector foils of 1.5 cm^2 with 2.5 N NaOH at 55°C for 120 minutes. Radon concentration was estimated using a calibration factor, 0.0344 $track.cm^{-2}.d^{-1}/Bq.m^{-3}$. The time interval for indoor radon recording was 45 days and 30 days, respectively. The highest value of radon activity (106.0±7.4 $Bq.m^{-3}$) was recorded in the basement of our house and the lowest (24.2±2.4 $Bq.m^{-3}$) on the first floor. The corresponding average annual doses are estimated to be 2.05±0.14 and 0.44±0.04 mSv/yr, respectively. These values are within the safe limit proposed by WHO.

Keywords: Indoor Radon, Plastic Detector, Alpha Tracks, Effective Dose, Lung Cancer

INTRODUCTION

World Health Organisation (WHO) [1] has published a comprehensive handbook on indoor radon which summarizes the health hazards of radon, its measurement indoors, its prevention and mitigation using cost effective strategies. Chapter 6 of this handbook refers to national radon surveys and national reference levels adopted for safety of public and remediation of health risk due to high levels of indoor radon. An important source of residential radon is the soil gas entry by infiltration. On the basis of epidemiological evidence, it has been concluded that indoor radon is responsible for a substantial number of lung cancers in the general population. Recent studies [2–7] on indoor radon and lung cancer in Europe, North America and Asia provide an estimate that from 3 to 20% lung cancers are attributable to indoor radon depending on the average radon concentration in the country concerned and the calculation methods. The distribution of indoor radon in most countries is best represented by a log normal distribution, with the majority of the radon concentrations occurring in the lower range. As a result, the vast majority of radon induced lung cancers are thought to occur following exposure to low and moderate radon concentrations. Even a single alpha particle emitted from radon can cause enough damage in DNA of the cell that it can induce the cancer in a cumulative process of mutations and proliferation of cell damages.

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Radon is a radioactive gas that is present almost everywhere where Uranium exists. It is a decay product of Uranium and emanates from rocks and soils containing Uranium in traces. It has three isotopes, namely, 222Rn (Radon), 220Rn (Thoron) and 219Rn (Actinon). All three are decay products (daughters) of 238U, 232Th and 235U series, respectively. Radon (222Rn) and its short-lived decay products (218Po, 214Pb, 214Bi and 214Po) contribute nearly 50% of the global mean effective dose to the public from the natural radioactivity. In the United States of America, exposure to radon is the second cause of lung cancer after smoking. Scientists estimate that about 20,000 lung cancer deaths per year are related to radon [8]. In fact, approximately 16% of lung cancer deaths in Canada are due to long-term exposure to radon gas indoors. Furthermore, radon gas is the primary cause of lung cancer in non-smokers and the second leading cause in smokers [9].

Indoor radon investigations have been carried out by several groups [10–18] throughout the world to evaluate the source of radon in the indoor environment, to estimate the volumetric radon concentration in living rooms of the residential buildings and workplaces, and to study health hazards due to high exposure to indoor radon. Author's group [19, 20] carried out indoor radon survey in the dwellings of Punjab and Himachal Pradesh (India) under a Department of Atomic Energy (DAE) sponsored national project.

Various countries around the world have adopted radon action levels varying from 150 to 1000 Bq/m^3, as summarized in Figure 1 [21]. Guidelines and rationale for radon concentration in dwellings has also been reported for some countries [22]. Some of the countries have multiple action levels, for example, one for existing homes and another for new houses. Some action levels are recommendations, such as that of Canada [23]; others are enforced. It can be seen that the current Canadian radon guideline is one of the highest in the world. Only Switzerland has a higher value for existing homes (1000 Bq/m^3) but this is an enforceable standard. The recommended Swiss value for new homes is 400 Bq/m^3.

More recently, efforts are being made to protect people exposed to lower levels of radon in homes below the action level. The recent publication of the combined analyses of residential radon studies in Europe [24] and North America [25] have shown that there is a measurable risk of lung cancer at radon levels as low as 100 Bq/m^3. This is significantly below the current Canadian radon guideline of 800 Bq/m^3 set in 1988. Most countries today have adopted guidelines in the range of 200 Bq/m^3 to 400 Bq/m^3. Canada has not changed its guidelines for new dwellings and kept it 800 Bq/m^3, which is highest in the world. This is despite the fact Canada reported 10% deaths due to lung cancer attributable to indoor radon alone in 1997 (Table 1).

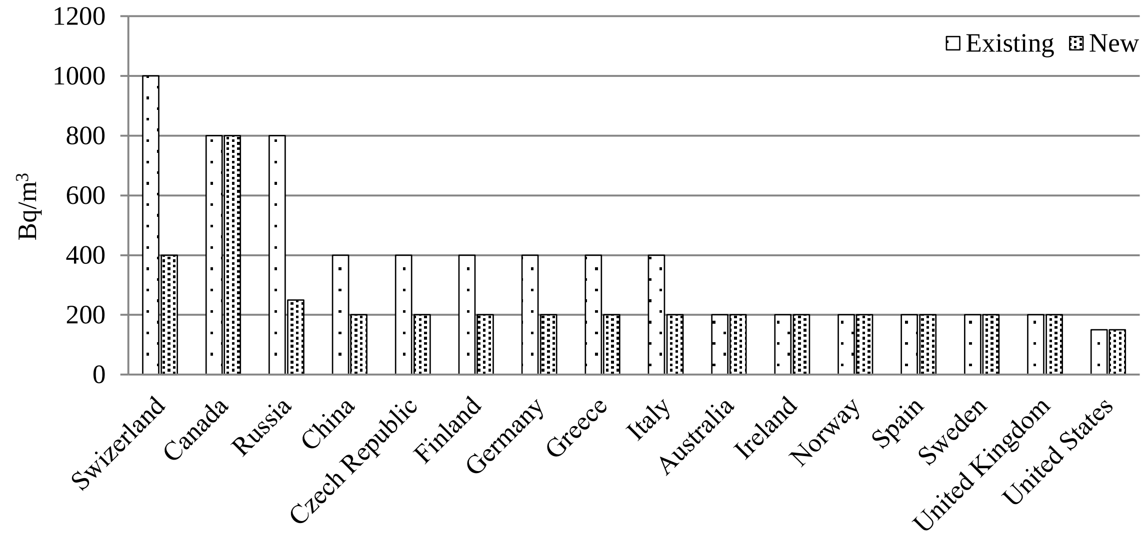


Figure 1. International country wise guidelines for radon in existing and new dwellings.

Table 1. Causes of death in canada–1997.

Causes of death	**No. death**
All Causes of Death	215669
Diseases of the circulatory system	79457
All malignant neoplasms including lung	58703
All lung cancers	15439
Suicides	3681
Motor vehicle accidents	3026
Accidental falls	2622
Infectious and parasitic diseases	2482
Estimated lung cancers attributable to radon	1589
Accidental poisonings	703
Homicides	440
Drownings	283
Fires	272
Air transport accidents	73
Adverse reactions to therapeutic drugs	64
Railway accidents	47
Electrocution	30
Lightening	06

OBJECTIVES OF THIS STUDY

Radon Working Group Canada [21] has issued “Radon Guideline for Canada” with the following recommendations:

- Remedial measures should be undertaken in a dwelling whenever the average annual radon concentration exceeds 200 Bq/m^3 in the normal occupancy area.
- The higher the radon concentration, the sooner remedial measures should be undertaken. At levels of 800 Bq/m^3 or above, these measures should be completed within one year.
- When remedial action is taken, the radon level should be reduced to a value as low as practicable.
- The construction of new dwellings should employ techniques that will minimize radon entry and will facilitate post-construction radon removal, should this subsequently prove necessary.

There are two main objectives of undertaking this study of indoor radon in a residential building. To the best of my knowledge, there is no published survey of indoor radon in the Surrey region of British Columbia (BC). In the recent past, we reported radon studies in water of Surrey region [26]. It was followed by our investigation in to radon occurrence and its activity concentration in Lakes of Kelowna area and Fraser River [27]. Simultaneously, we are engaged in radon emanation in the soil gas of our residential complex as well as in the ambient air of its environs. We hope this will generate a baseline data of radon for the Surrey region of BC, Canada.

The second objective is concerned with public health issues of immigrants, mostly students and workers, who are reaching the shores of Canada in millions. Since they have meager resources to fend for their education and livelihood, they have to live in poorly lit basements on sharing basis of crowded environments. All indoor radon studies have established that radon concentration is highest in cellars, basements and other unventilated dwellings in cold climates. This study may provide data base for public health officials and epidemiologists to investigate health hazard effects of living in basements.

EXPERIMENTAL TECHNIQUE

The basics features of Plastic detector technique are common in all types of media used for radon concentration measurements. However, small variations exist in the employment of detector foils when media changes. For example, in water media, radon detectors are used as reported in our previous studies [28–30]. In air media, detector foils of 1.0 cm^2 and 1.5 cm^2 were suspended inside rooms at a height of 60 cm from the floor level. To allow full space for use of inhabitants, we fixed the foils on the side walls of the room with a scotch tape keeping the sensitive layer exposed to air inside the room. Detector foils were used to record radon concentration in the basement of the house, store facility inside living room, and the guest house on the first floor. Office and bedrooms were also used in the first attempt made during 15 March to 30 April, 2022 which proved to be unsuccessful. Experiment was repeated for 30 days during month of May, 2022 due to reasons beyond our control.

Passive techniques are considered to be the most convenient method to determine radon concentrations over long periods of time under the changing effects of seasonal, weather, and environmental conditions. Use of LR 115 SSNTD, which is composed of a cellulose nitrate film coated on a 100 μm thick polyester base, was made for radon conc. measurement. The LR 115 detector consists of two categories: Type I films have a thickness of 6 μm and Type II films have a thickness of 12 μm. Furthermore, the cellulose nitrate film of the detector is sensitive to alpha particles and has a chemical composition of $C_6H_8O_6N_{12}$. Alpha particles with an energy range of 1.9–4.2 MeV are recorded by the LR 115 Type II film as it has been designed for a given window of energy range and it is less sensitive to other energies.

LR-115 Type II detector foils were collected from the rooms after the exposure time of 45 days. The track detector foils were removed from the scotch tape used for fixing the foils on the walls and etched in a constant temperature bath using 2.5N NaOH solution as etchant for two hours at 55°C. The temperature fluctuation of bath during etching was observed to be ±2°C. Track density (no. of tracks/cm^2) was then determined using an optical microscope with a magnification of 400 M. It was observed that some foils get dissolved during etching while some others are either over-etched or under-etched. In both the latter cases, track counting is not possible. In such cases, the experiment was repeated for an exposure of 30 days. The etching had to be done in steps intermittently using the same temperature and normality. The foils were examined after one hour etching. If no damage is detected, etching was repeated in two steps of 30 min. each. Photomicrographs of alpha tracks were recorded using cell phone camera with an attachment to the optical microscope. The circular tracks can be distinguished from the other features as shown in Figure 2. Over-etched and damaged detector foils are shown in Figure 3(a and b).

The track count was converted into a radon concentration level in Bq/m^3 using the formula: CRn=ρ(no. of tracks/cm^2)/kt(days), where k is the calibration factor of LR-15 Type II detector (0.0344±0.002) track.cm^{-2}.d^{-1}/Bq.m^{-3} [30, 31].

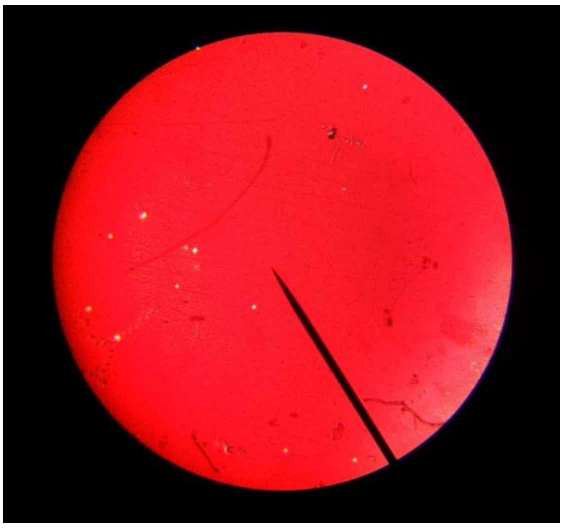


Figure 2. Photomicrograph of alpha tracks holes in LR-115 Type II detector foils.

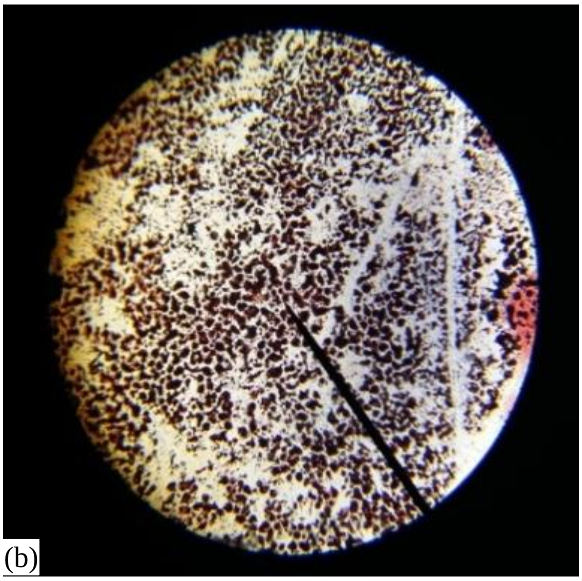

(a)

(b)

Figure 3. (a) Over-etched detector foil, and (b) Totally damaged detector foil with no tracks.

RESULTS AND DISCUSSION

It has been observed that the air pressure inside a home is lower than in the soil surrounding the foundation during major part of the year. This difference in pressure helps to push air and other gases in the soil, including radon, into the home through any openings where the house contacts the soil. Potential entry routes for soil gases and radon in homes with poured concrete foundations include: exposed soil or rock in crawlspaces; cracks or joints in floor slabs; hollow objects, such as support posts; utility penetrations; floor/wall joints; cracks or flaws in foundation walls; floor drains & sumps.

It clearly shows that indoor radon levels will be highest in the underground basement of a dwelling as explained above. We exposed our plastic detectors at different levels of the house. During our first exposure of 45 days (15 March to 30 April), most of our samples were either damaged or dissolved during etching process. This was a big setback. During second exposure of 30 days, we used step by step etching and examined the etched detector foils under the microscope. This way, we could select the undamaged foils for counting of tracks. Track counting was performed using M = 100 or 400 in 20 field of views or more depending upon track density. Area of field of view is estimated by calibration for each magnification. Radon concentration in air was estimated by using the formula [26]:

C_{Rn} (Bq/m^3) = (ρ/t.k)

Where;
k is the calibration constant (0.034 track.cm^{-2}.d^{-1}/Bq.m^{-3}),
ρ is track density (tracks/cm^2),
t is exposure period (days)

Table 2 summarizes the data for track density, statistical counting error, radon concentration in Bq/m^3 and annual effective dose in mSv/year, extrapolated from the monthly data.

Table 2. Indoor radon data for the residential house in surrey.

Floor level	Track density (tracks/cm^2)	Counting error (%)	Radon conc.(Bq/m^3)	Effective dose (mSv/year)
Basement (Underground)	109	7	106.0±7.4	2.05±0.14
Ground Floor (Store Room)	75	8	72.7±5.8	1.28±0.10
First Floor (Guest Room)	25	10	24.2±2.4	0.44±0.04

To determine the effective annual dose due to indoor radon, we took recourse to ICRP reports [32] as utilized by Choukri and Hakam for their study of Morocco dwellings and workplaces [15]. ICRP reports (Publications 65 and 66) were used for calculation of the effective dose per unit exposure to radon and radon progeny based on the criteria of a standard convention of Working Level Month (WLM). The values suggested for workers and general public are: 5 mSv per WLM and 4 mSv per WLM, respectively. The effective dose is calculated from the value estimated for radon concentration indoors by assuming that the residents of the dwelling stay inside the building for 7000 h/yr. The radon concentration of 1 Bq/m^3 during 1 year as per ICRP report = 4.4×10^{-3} WLM.

The highest value of radon concentration is estimated for underground basement of dwelling (106.0±7.4 Bq/m^3) and the corresponding effective dose turns out to be 2.05±0.14 mSv/year. As we move upwards, the radon concentration decreases rapidly. Its value for first floor is 24.2±2.4 Bq/m^3 and the corresponding effective dose 0.44±0.04 mSv/year. The store room on the ground floor shows intermediate values. As a matter of fact, the store is part of a living room which is unventilated; hence it shows abnormal radon concentration. Most of the bed rooms used for sleeping happen to be located on the first floor with very low effective dose; hence it is safe for living.

For sake of comparison, our indoor radon concentration and effective dose values are within the safe limits set by WHO [1]. In view of the latest scientific data, WHO proposes a reference level of 100 Bq/m^3 to minimize health hazards due to exposure to indoor radon in the dwellings. But in any case, the chosen reference level should not exceed 300 Bq/m^3 which represents approximately 10 mSv per year according to recent calculations by the International Commission on Radiation Protection. If we compare our estimated indoor radon values with global values listed in Table 3, we have some surprises.

A university of Calgary report [33] declares: "One in five Canadian houses exceeds 200 Bq/m^3". According to Health Canada, the inhalation of the radioactive (radon) gas is the leading cause of lung cancer in non-smokers, and about 3,200 Canadians die from exposure each year. The number of lung cancer deaths have more than doubled as compared with the data reported in 1997 (Table 2). A very useful document has been prepared by Health-Canada, a government of Canada organization, to create awareness about Radon entry into dwellings and its mitigation for public safety [34]. Canadian Nuclear Safety Commission [35] has summarized the sources and average effective dose from Natural Background Radiation in selected Canadian cities as given in Table 4. The total worldwide average

Table 3. Comparison of the mean indoor radon concentration in different countries of World

Country	Mean Indoor Concentration (pCi/l)
Malaysia	0.30–1.54
Finland	3.46 (128 Bq/m^3)
Norway	1.97 (73 Bq/m^3)
France	1.68 (62 Bq/m^3)
Denmark	1.43 (53 Bq/m^3)
UK	0.54 (20 Bq/m^3)
Canada	0.92 (34 Bq/m^3)
Hungary	1.14 (42 Bq/m^3)
USA	1.14 (42 Bq/m^3)
Jordan	1.41 (52 Bq/m^3)
Saudi Arabia (Riyadh)	0.49 (18 Bq/m^3)
Japan	0.43–5.14 (16–190 Bq/m^3)
Indoor Global Mean	1.08 (40 Bq/m^3)

Table 4. Sources and average effective dose from natural background radiation in selected Canadian cities.

Canadian City	Total (mSv/y)	Cosmic radiation (mSv/y)	Terrestrial background (mSv/y)	Annual inhalation dose (mSv/y)	Radionuclides in the body (mSv/y)
Vancouver	1.3	0.5	0.1	0.4	0.3
Toronto	1.6	0.4	0.2	0.8	0.3
Québec City	1.6	0.4	0.2	0.7	0.3
Montreal	1.6	0.4	0.3	0.7	0.3
St-John's	1.6	0.4	0.2	0.7	0.3
CANADA	1.8	0.3	0.2	0.9	0.3
Victoria	1.8	0.5	0.1	0.9	0.3
Ottawa	1.8	0.4	0.2	0.9	0.3
Fredericton	1.8	0.3	0.3	0.9	0.3
Charlottetown	1.8	0.3	0.2	0.9	0.3
Whitehorse	1.9	0.5	0.2	0.9	0.3
Iqualuit	1.9	0.5	0.2	0.9	0.3
Edmonton	2.4	0.5	0.3	1.3	0.3
Halifax	2.5	0.3	0.3	1.5	0.3
Yellowknife	3.1	0.4	1.4	0.9	0.3
Regina	3.5	0.4	0.3	2.4	0.3
Winnipeg	4.1	0.4	0.2	3.2	0.3

Sources: Gratsky et al., 2004, UNSCEAR 2008, Geological Survey of Canada

effective dose from natural radiation is approximately 2.4 mSv a year. Out of 15 Canadian cities listed in Table 4, only 4 exceed the world average. Our residence in Surrey is part of Greater Vancouver area which is within safe limits having 1.3 mSv annual effective dose from natural background radiation sources.

CONCLUSIONS

1. Indoor radon measurements are easy to perform in residential homes for making an assessment of health hazard effects of radon. But it is imperative to keep in view the standard national protocols to ensure accurate and consistent measurements.
2. The highest value of radon concentration (106.0±7.4 Bq/m^3) is recorded in the basement of our residence because the plinth level of basement is 2 m below the ground surface.
3. The annual effective dose (2.05±0.14 mSv/yr) is highest in the basement as compared to other levels in the residence.
4. Our limitation is short duration of indoor radon survey. Long-term integrated radon measurements should be preferred for assessing the annual average radon concentration and effective dose within a residential building.
5. Another limitation is high temporal variation of indoor radon which makes short-term measurements unreliable for most applications. We plan to undertake yearlong measurements of indoor radon after this preliminary survey.

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