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Original Article

INDOOR RADON SURVEY IN NEPAL USING PASSIVE TECHNIQUE SOLID STATE NUCLEAR TRACK DETECTOR

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ABSTRACT

Context: It has been proved from many epidemiological studies that the inhalation of the radioactive, inert gas radon (^{222}Rn) is the main cause of lungs cancer after smoking. **Objective**: The survey was conducted to estimate the indoor radon concentration, the annual effective dose rate and the annual dose equivalent rate to the lung. **Material and Methods**: Altogether 50 dwellings were chosen randomly at 5 different districts of Nepal. The dosimetric measurements were carried out over a period of 3 months using time-integrated passive radon detectors, CR-39 based on type II Solid State Nuclear Track Detector (SSNTD) technique. The type of houses was concrete with plastered walls and mud house. **Results**: The minimum concentration of radon in the study areas was found to be $<20 Bq.m^{-3}$ and the maximum concentration was $110 \pm 20 Bq.m^{-3}$. Also the corresponding values of annual effective dose and annual equivalent dose to the lung respectively varied from <0.60 to $3.30 mSv.y^{-1}$ and $0.16x10^{-7}$ to $0.88x10^{-7} Sv.y^{-1}$. The uncertainty was measured at 95% confidence level. **Conclusion**: The indoor radon concentration varies considerably with the ventilation condition, lifestyle of the people, construction of the dwellings and climate of the areas. The measurements show that the radon concentrations were found to be well below the reference levels of ICRP.

KEYWORDS: Indoor Radon, Annual Effective Dose, CR-39, Ventilation Condition, Dwelling.

INTRODUCTION

The continuous exposure to radiation causes significant health hazards such as genetic disorder, cancer, sterility etc[1]. The radioisotope radon (^{222}Rn) and its short-lived progenies in the dwellings represent the major source of exposure to ionizing radiation, contributing more than 50% of the global effective dose to the public[2]. The study of cellular mutation, experimental research in animals and many epidemiological studies have proved that radon is a human lung carcinogen[3-6]. Naturally occurring noble gas ^{222}Rn is characterized by a half-life of 3.8 days and is produced through alpha disintegration of radium-226 in the uranium-238 decay chain[7,8]. The inhalation of such alpha particles and associated ionizing decay products are known to cause potential DNA damages such as incorrectly repaired DNA damages that indicates the positive risk coefficient for lung cancer[9].

Since the parent element, uranium is ubiquitously present in the geological terrain; radon emanates from rocks and soils and leaks out in the atmosphere through long distances. Then it tends to diffuse into enclosed spaces like underground mines or get trapped in poorly ventilated dwellings thereby enhancing the elevated level of indoor radon concentration[6,10]. The typical values of exhalation rate, amount of activity released per unit area of the surface per unit time, for ^{222}Rn in soil and building materials[11] are respectively 0.02 and $5.0 \times 10^{-4} Bqm^{-2}s^{-1}$. It has been estimated that an increase in radon concentration of 100 $Bq.m^{-3}$ is associated with approximately a 16% increased chance of developing lung cancer[12]. The temporal and regional distribution of radon in the dwellings depends upon the meteorological and geophysical conditions, lifestyle of the people, water sources, construction materials, condition of ventilation, heating and cooling system inside the room, etc[13,14]. However some studies conclude that there is pronounced influences on indoor radon concentration due to building design than the habits and preferences of the occupants[15].

For the monitoring of radon, both the active and passive techniques have been developed. Active methods which require a power source are used for short-term measurements of radon and for detailed investigations of the sites under investigation. Passive methods which do not require a power source are suitable for the assessment of radon exposure over long time and can be used for large-scale surveys at moderate price[16,17]. Solid State Nuclear Track Detectors (SSNTDs), a class of passive detectors developed in the early 1960s have been recognized as very potential and effective tools in detecting radiation in the form of nuclear tracks[18].

OBJECTIVE OF THE STUDY

The main objective of this survey was to assess the indoor radon concentration, the annual effective dose rate and the annual dose equivalent rate to the lung.

MATERIALS AND METHODS

Detector

Poly-allyl-diglycol-carbonate (PADC), generally known by its commercial name as Columbia Resin (CR) -39, based on Solid State Nuclear Track Detector (SSNTD) was employed in this study for the measurement of indoor radon activity. SSNTDs are passive and time integrated method which are insulating solids both naturally occurring and man-made[19]. The monomer composition of CR-39 is $C_{12}H_{18}O_7$. CR-39 is mechanically rigid but very transparent and sensitive to ionizing radiation due to alpha particles. Thus it is an excellent nuclear track recorder. It can detect protons of energy up to10 MeV and has wide range from 0.1MeV to several tens of MeV for alpha particles[20].

Estimation of annual effective dose

In order to estimate the annual effective dose for the dwellers, one has to take into account the conversion coefficient from absorbed dose in air to effective dose and the indoor occupancy factor. In UNSCEAR report, a value of 9.0 x 10^{-6}mSvh^{-1}/Bqm^{-3} was used for the conversion factor, 0.4 for the equilibrium factor of ^{222}Rn for indoor exposure and 0.8 for the indoor occupancy factor[21]. To calculate the annual effective dose to the occupants, the equation below is used[22]. In this research an indoor occupancy factor of 0.4 will be used for our calculations.

Figure 1. CR- 39 hanged on the wall.

At a certain radon concentration C_{Rn} in Bq.m^{-3}, the annual absorbed dose due to radon, D_{Rn} is usually expressed in the unit of mSv.y^{-1} from the following relation:

D_{Rn} (mSv.y^{-1}) = C_{Rn}. D.H.F.T ……………..………… (1)

Where,

D_{Rn} = Annual Absorbed dose

C_{Rn} = measured ^{222}Rn concentration in Bqm^{-3}

D = 9.0x10^{-6} mSvh^{-1}/Bqm^{-3}, dose conversion factor

H= 0.4, indoor occupancy factor

F= 0.4, ^{222}Rn equilibrium factor for indoor exposure

T= 24 h x365 = 8760 h.y^{-1}, indoor occupancy time

To calculate the annual equivalent dose and effective dose, it is to apply a tissue and radiation weighting factors[23]. The equivalent dose is the radiation-weighted absorbed dose. The radiation weighting factor (W_R), for alpha particles is 20 as recommended by ICRP, 1991. With the effective dose, a tissue weighting factor (W_T), is applied. According to ICRP, the tissue weighting factor for lung is 0.12. The annual effective dose (E) is then calculated according to the equation below:

$E\ (mSv/y) = D_{Rn}.W_R.W_T$ …………………………….. (2)

Where,

$W_R = 20$, Radiation Weighting Factor for Alpha Particles

$W_T = 0.12$, Tissue Weighting Factor for the Lung

However, it is apparent that the time spent by individuals in the home varies widely. The occupancy factor of 0.8 overestimates the excess lung cancer risk in the tropical regions but may be valid for the occupants of the cold climate zone [22]. In the tropical regions, people spend most of their time in outdoor air and only go indoors to sleep at night. In this study, the occupancy factor that was used for the annual absorbed dose calculation will be 40% (0.4). The indoor occupancy factor used was calculated, based on the fact that dwellers spend only about 9 hours indoors out of the 24 hours in a day. In case of the annual equivalent dose to the lungs, the radon content of the lung air has to be taken into account, which results in the equation below according to UNSCEAR:

$H_{lungs}\ (Sv/y) = 8 \times 10^{-10}\ C_{Rn}$ …………………..(3)

STATISTICAL ANALYSIS

For each value of radon concentration, an uncertainty (2σ)Bq/m^3 is given which reflects the uncertainty of the measurement. The uncertainty is given at 95% confidence level (e.g. a value of 100±20Bq/m^3 means that the radon concentration most probably is between 80–120Bq/m^3 with 100Bq/m^3 as the most probable value).

RESULTS

Radon monitoring was carried out in 50 houses at five different districts of Nepal. Among which the number of dwellings selected in Bhaktapur, Kathmandu and Lalitpur districts of Kathmandu Valley was 3, 4 and 17 respectively and that in Kaski and Siraha districts was 16 and 10 respectively. The minimum concentration of radon (^{222}Rn) was found to be <20Bq.m^{-3} and the maximum concentration was 110±20Bq.m^{-3} in the study areas. Also the corresponding values of annual effective dose and annual equivalent dose to the lung respectively varied from <0.60 to 3.30mSv.y^{-1} and 0.16x10^{-7} to 0.88x10^{-7} Sv.y^{-1}.

The measured radon concentration (C_{Rn}), annual effective dose (E) and annual equivalent dose to the lung (H_{lung}) in the study areas are shown in Table 1, 2 and 3 respectively.

Table 1. Measured radon concentration, annual effective dose and annual equivalent dose to the lung in dwellings of Kathmandu Valley:

SN	Detector No.	($C_{Rn} \pm 2\sigma$) Bq.m^{-3}	(E) mSv.y^{-1}	(H_{lungs}) Sv.y^{-1}
1	908108-4	29±6	0.87	0.23×10^{-7}
2	908701-6	48±8	1.44	0.38×10^{-7}
3	921896-7	35±6	1.05	0.28×10^{-7}
4	966177-8	20±4	0.60	0.16×10^{-7}
5	963341-3	41±6	1.23	0.32×10^{-7}
6	911326-7	110±20	3.30	0.88×10^{-7}
7	910090-0	47±8	1.41	0.38×10^{-7}
8	902412-6	24±6	0.72	0.19×10^{-7}
9	325451-3	34±6	1.02	0.27×10^{-7}
10	917769-2	32±6	0.96	0.26×10^{-7}
11	910293-0	27±4	0.81	0.22×10^{-7}
12	907108-5	28±6	0.28	0.22×10^{-7}
13	926936-6	< 20	<0.60	<0.16×10^{-7}
14	913620-1	< 20	<0.60	<0.16×10^{-7}
15	699336-4	21±4	0.63	0.16×10^{-7}
16	927230-3	32±6	0.96	0.26×10^{-7}
17	699529-4	21±4	0.63	0.16×10^{-7}
18	908615-8	39±10	1.17	0.31×10^{-7}
19	966232-1	44±6	1.32	0.35×10^{-7}
20	699638-3	< 20	<0.60	<0.16×10^{-7}
21	957372-6	26±4	0.78	0.20×10^{-7}
22	927897-9	25±6	0.75	0.20×10^{-7}
23	966588-6	78±14	2.34	0.62×10^{-7}
24	699620-1	49±12	1.47	0.39×10^{-7}

Table 2. Measured radon concentration, annual effective dose and annual equivalent dose to the lung in dwellings of Kaski district

SN	Detector No.	($C_{Rn} \pm 2\sigma$) $Bq.m^{-3}$	(E) $mSv.y^{-1}$	(H_{lungs}) $Sv.y^{-1}$
1	902872-1	40±6	1.20	0.32×10^{-7}
2	964038-4	< 20	<0.60	$<0.16\times10^{-7}$
3	946204-5	39±6	1.17	0.31×10^{-7}
4	911859-7	22±4	0.66	0.18×10^{-7}
5	903925-6	< 20	<0.60	$<0.16\times10^{-7}$
6	699456-0	43±6	1.29	0.34×10^{-7}
7	926911-9	45±8	1.35	0.36×10^{-7}
8	955368-6	24±4	0.72	0.19×10^{-7}
9	936932-3	55±8	1.10	0.44×10^{-7}
10	910939-8	22±4	0.66	0.18×10^{-7}
11	949316-4	33±6	0.99	0.26×10^{-7}
12	908598-6	28±6	0.84	0.22×10^{-7}
13	699415-6	< 20	<0.60	$<0.16\times10^{-7}$
14	926542-2	21±4	0.63	0.16×10^{-7}
15	936340-9	21±4	0.63	0.16×10^{-7}
16	903951-2	33±6	0.99	0.26×10^{-7}

Table 3. Measured radon concentration, annual effective dose and annual equivalent dose to the lung in dwellings of Siraha district

SN	Detector No.	($C_{Rn} \pm 2\sigma$) $Bq.m^{-3}$	(E) $mSv.y^{-1}$	(H_{lungs}) $Sv.y^{-1}$
1	928283-1	< 20	<0.60	$<0.16\times10^{-7}$
2	946049-4	< 20	<0.60	$<0.16\times10^{-7}$
3	927000-0	< 20	<0.60	$<0.16\times10^{-7}$
4	926326-0	< 20	<0.60	$<0.16\times10^{-7}$
5	966163-8	< 20	<0.60	$<0.16\times10^{-7}$
6	946044-5	< 20	<0.60	$<0.16\times10^{-7}$
7	699670-6	< 20	<0.60	$<0.16\times10^{-7}$
8	699323-2	< 20	<0.60	$<0.16\times10^{-7}$
9	913896-7	< 20	<0.60	$<0.16\times10^{-7}$
10	949195-2	< 20	<0.60	$<0.16\times10^{-7}$

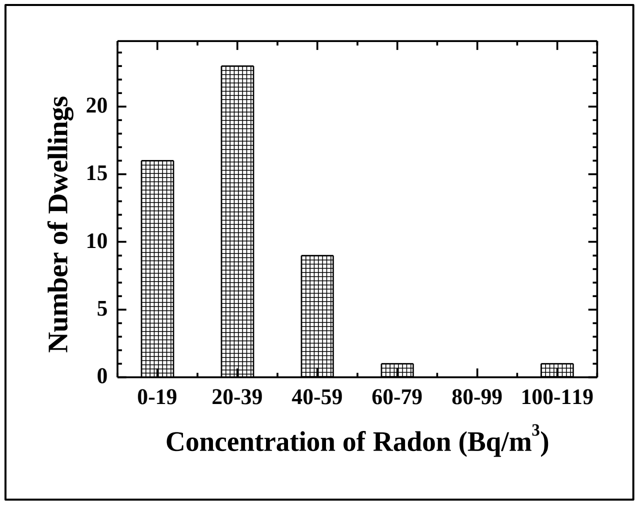

Figure 2. Number of dwellings with respect to different radon concentration

DISCUSSION

The survey was conducted with the collaborative effort of International Atomic Energy Agency (IAEA), Vienna, Austria; Ministry of Science, Technology and Environment (MoSTE), Nepal and Nepal Academy of Science and Technology (NAST) to accentuate the assessment of ^{222}Rn concentration in the dwellings of Nepal with the aim to create public interest and augment general awareness about the radiological effect of radon in the community. Nepal, in common with other developing countries, has not yet formulated national directives to enforce radon limits in dwellings and workplaces. There is no general awareness or factual knowledge about radon and its health hazards among the public[24].

IAEA provided altogether 50 CR-39, each having unique detector number, to monitor radon in the dwellings. In this context, our group was actively involved in carrying out measurements of indoor radon levels. The different types of houses were selected within 5 different districts of Nepal for the measurement of radon. The major study areas were Bhaktapur, Lalitpur and Kathmandu districts of Kathmandu Valley, Pokhara of Kaski district and Lahan of Siraha district. Altogether 24 houses were selected randomly in Kathmandu Valley, 16 houses in Pokhara, Kaski and 10 houses in Lahan, Siraha. The majority of the houses were concrete with plastered walls and proper ventilation system and the few were mud houses with poor ventilation and less number of windows. The detectors were exposed to the open environment of the living room or bed room by hanging them on the wall for a period of 3 months from March 2014 to May 2014 as shown in figure 1. Since the radon atoms are homogeneously distributed in the room[25], the position for radon detector in the room was so chosen that it lies at the height of 2m from the floor[26-28] and far away from the effect of heating sources[29].

Before installing dosimeters in the dwellings, a questionnaire was set up and filled in by our group for every house surveyed. Besides occupant's name and address the questionnaire included general information about types of dwellings (mud, concrete or wooden), year in which the house was built, floor level and type, wall material type, condition of ventilation, water management system, number of members in the family, health history of the members including cases of cancer, number of smokers and non-smokers, etc. The exposed detectors were retrieved after 3 months and sent to the laboratory LANDAUER NORDIC AB, Uppsala, Sweden for track reading.

The detectors were received by the laboratory on 2014-07-08 and measured on 2014-07-10. LANDAUER NORDIC AB is accredited (no. 1489) by SWEDAC to do measurements of the radon-gas concentrations using the measurement method Closed alpha- track detector. The measurement was performed following the standard ISO 11665-4, Measurement of radioactivity in the environment–Air: radon-222, Part 4: Integrated measurement method for determining average activity concentration using passive sampling and delayed analysis. The detector container is manufactured from electrically conducting plastic. Through a small slit (filter), radon gas enters the detector. The track-detecting material (film) inside the detector is hit by alpha particles generated by the radon entering the container and the decay products formed from it. On the film, the alpha particles make small tracks which are enlarged with chemical etching and later counted in a microscope in order to determine the radon exposure. The analysis equipment was checked daily and the detectors were regularly calibrated[30].

The high radon concentration level was found in mud house which are made up of mud brick, wood and tile roofing. It is due to the poor ventilation, lifestyle and the accumulation of dust in the room. The lowest value was found in concrete houses which are made up of Reinforced Cement Concrete (RCC) with plastered walls and adequate ventilation. The radon concentration in Kathmandu Valley varied from <20 to 110±20Bq/m^3. The concentration in Kathmandu Valley was higher among the study areas although this value is lower than that of the previous study performed by Dinesh Thapa and Buddha Ram Shah[8] in the year 2013 in which the overall radon concentration using LR115 varied from 8±2 to 787±134Bq/m^3 with the average value of 80±15Bq/m^3. Similarly, the minimum concentration of radon, less than 20Bq/m^3 was found in 32% of the dwellings and 46% of the dwellings had concentration ranging from 40-59Bq/m^3. Also the number of dwellings with respect to different radon concentration is given by graphical representation in fig. 2 in which there is greater number of dwellings for radon concentration ranging from 20-39Bq/m^3.

However, at present there is no nationwide action level recommended for indoor radon concentration in Nepal. Action level is defined as the level of dose rate or activity concentration above which remedial actions should be followed**.** It has been recommended that it is most exigent to focus attention in the radon-prone areas[22,23,31]. A ^{222}Rn prone area is defined as the one in which about 1% of the buildings has concentrations of ^{222}Rn above 200Bqm^{-3}. Such building has the recommended action level of 200Bqm^{-3} which corresponds to an annual effective dose of 5mSv/y. None of the study areas was regarded as radon prone area as all the dwellings have radon concentration below 200Bqm^{-3}.

The survey covered only 50 dwellings of 5 districts of Nepal due to the limited number of dosimeters. Also we don't have well equipped laboratory to carry out track analysis and to determine calibration factor for the radon dosimeter. These are the limitations of the study.

CONCLUSION

There is significant variation of radon concentration in the study areas. Although 18% of the dwellings have concentration greater than the world average radon concentration[21] of

40Bq/m^3, the overall concentration of radon in the study areas is well below the reference level (200-600Bq/m^3) set by International Commission of Radiation Protection (ICRP)[32] and the level (148Bq/m^3) set by USEPA for the USA[33]. But one of the dwellings has maximum radon concentration of 110Bq/m^3 which is higher than the new reference level (100Bq/m^3) set by WHO, 2009. There is no significant radiological health hazard to the population living in the study areas. Hence, it is to address that most of the dwellings in Nepal do not warrant any action level with respect to indoor ^{222}Rn levels. It can also be concluded that the poor ventilation, the season and the lifestyle of the occupants are responsible for the accumulation of radon gas to a risky level for the public. However, the study stresses the need for a more extended survey on radon risk all over the country.

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CONFLICT OF INTEREST

Nil.

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