Measurement of Indoor Radon-Thoron Concentration in Dwellings of Bali Island, Indonesia

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Abstract. *The indoor radon, thoron and their decay products are the main contributors of total inhalation dose in the living environment. Measurement of their levels in dwellings is an important aspect to assess the inhalation dose rate to humans. The exposure of population to radon and thoron gases has become an important issue in terms of radiological protection. The data on the radon and thoron gases in dwellings of Bali island, Indonesia is not available. The main objective of this study is to assess the health hazard due to the indoor radon-thoron in dwellings belonging to residential areas of Bali island. The measurements of radon and thoron concentrations in dwellings of Bali island were carried out using passive dosimeters with the CR-39 alpha track detector. The dosimeters were installed in living room and bedroom of each house. The radon and thoron concentrations in the dwellings varied from 9 to 48 Bq/m^3 and not detected to 66 Bq/m^3 respectively. The total annual effective dose due to the exposure of indoor radon, and thoron in study area have been found to vary from 0.38 mSv/y to 2.4 mSv/y with an mean value of 1.08 mSv/y. The mean annual estimated effective dose received by the residents of the studied area was found to be less than the action level recommended. The annual effective dose due to the exposure to radon and thoron concentrations in the dwellings of Bali island are within the permissible limits.*

Keywords: Passive radon-thoron detector, indoor concentration, annual effective dose, health hazard

Introduction

Radon (^{222}Rn) and thoron (^{220}Rn) are radioactive gases produced by the decay of ^{226}Ra and ^{224}Ra, which are themselves decay products of ^{238}U and ^{232}Th series in the ground, respectively. ^{222}Rn and ^{220}Rn gases enters into the house from various gaps in wall and open window or door. They decay producing isotopes of polonium (^{218}Po, ^{216}Po, ^{214}Po, ^{212}Po), lead (^{214}Pb, ^{212}Pb, ^{210}Pb), and bismuth (^{214}Bi, ^{212}Bi, ^{210}Bi) which are heavy metals chemically very active, which may exist briefly as ions and/or free atoms before forming molecules in condensed phase or attached to airborne dust particles, forming radioactive aerosols. This fraction may be inhaled and deposited in the respiratory tract, in which they release all their α-emissions. The indoor radon–thoron levels depend upon various factors like geological setting of area, nature of soil, meteorological conditions, living style of the dwellers and type of building material used for the house construction (Kumar et al., 2014; Mehra et al., 2011; Singh et al., 2011, Syarbaini et al. 2015). ^{222}Rn has a half-life of 3.825 days and is an alpha emitter; ^{220}Rn has a half-life of 55.6 s and is also an alpha emitter. The radon–thoron and their solid decay products contribute 55% of the total inhalation doses to human population (UNSCEAR, 1998).

The radon and thoron gases are inhaled in the human body through the nose or mouth, while the decay products of radon and thoron are solid phase that get attached to dust and form aerosol particles. These aerosols are inhaled, get deposited on the respiratory tracts and impart alpha energy to the lung (Kumar, A., 2014). Mostly natural radiation comes from radon, thoron and their solid short-lived daughter products. The decay products of radon and thoron are more dangerous as compared to their parents. Thus exposure to ^{222}Rn and/or ^{220}Rn and its progeny in indoor atmosphere can cause a significant inhalation risk to population particularly to those living in homes with much higher levels of radon. The main characteristic of ^{222}Rn and ^{220}Rn among other natural radioactive elements is the fact that their behaviour is chemically inert (noble gases), not affected by chemical processes. The ^{222}Rn and ^{220}Rn are free to move through soil pores and rock fractures; then to escape into the atmosphere. ^{222}Rn and/or ^{220}Rn exhaled from the earth's surface into the free atmosphere is rapidly dispersed and diluted by natural convection and turbulence (Hassan, et al. 2011). The radon is the second leading cause of lung cancer after smoking even for those people who never smoked (UNSCEAR, 2009; WHO, 2009) and for the people living in the high background radon area. Therefore it is important to study the indoor radon–thoron levels in dwellings.

Several reports have appeared in literature demonstrating the ever increasing interest in monitoring the radon-thoron in the dwellings all over the world and part of the studies show that some countries have high radon concentrations in many of their dwelling (Huda et al. 2012, Abd El-Zaher, M., 2013, Sarma, J., 2014) and even in certain cases doses from this source for some people living in these areas may exceed those received by occupational workers. The data on the radon and thoron gases in dwellings of Bali island, Indonesia is not available in the literature. The objective of the present work is to carry out the measurement of indoor radon and thoron concentrations in dwellings of Bali island. The result of this study will provide baseline data of radon-thoron in dwellings of Bali that may be useful for some guiding information in regards to the possibility of health hazardous problem.

Materials and Methods

Description of the study area

Bali island is a part of Indonesia which is the provinces located between Java island to the west and Lombok island to the east. This island is favorite tourist destination, known for its natural attractions, perfect climate and relaxed atmosphere. Bali is located 8°3'40" to 8°50'48" South Latitude and between 114°25'53" to 115°42'40" East Longitude. Bali is dominantly covered by volcanic rocks, overlying the Tertiary carbonate rocks that outcrop in the southern and western part of the island (Hadiwidjojo et al., 1998). The total area of Bali is 5.634,40 ha and coastline is 529 km.

Figure 1. Map of Bali Island study area

Measurement of indoor radon–thoron concentration

The measurement of indoor radon–thoron concentration in the study area was carried out by pasive dosimeter developed at the Center for Technology of Radiation Safety and Metrology, National Nuclear Energy Agency, using CR-39 polycarbonate as detector material, based on the solid state nuclear track detectors (SSNTDs) technique. The passive dosimeter is made up of a twin cup hemispherical system as shown in Figure 2. The dosimeter consisted of two hemispherical chambers having a diameter of 50 mm and connected by a pipe with a length of 15 mm and diameter of 20 mm.

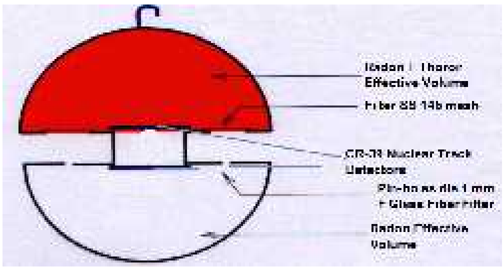

Figure 2. Schematic diagram of passive dosimeter used in the study

After an exposure time of three months, detectors films were removed from passive dosimeter and etched in 2.5 N NaOH solution at 60^0C for period of 80 minutes in a constant temperature bath. For uniform etching, we have used a magnetic stirrer. Then, these detectors were washed and dried. The Optical Microscope was used to see and count the tracks in nuclear detectors under magnification of 400x. The exposed area of the each film was scanned thoroughly and sufficiently, a large number of fields were counted to get an average track density to minimize the uncertainty due to counting errors. The track density is converted to radon concentration in dwelling using a calibration factor. The radon and thoron concentrations are determined by using the following relations :

$$C_{Rn} = \frac{N_1}{t.K_{Rn}} \qquad (1)$$

$$C_{Tn} = \frac{(N_2 - N_1)}{t.K_{Tn}} \qquad (2)$$

Where, C_{Rn} = radon concentration in Bq/m^3; C_{Tn} = thoron concentration in Bq/m^3; N_1 and N_2 = track density; t = exposure time; K_{Rn} = the calibration factor for radon and K_{Tn} = the calibration factor for thoron.

The dosimeters were distributed in 57 houses in several districts in Bali island. The names of the house owner in the survey area, their addresses, types of houses, ventilation conditions, and numbers of dosimeters were tabulated. The detectors were installed in living rooms and bedrooms at head height above the ground level about 3 m.. The passive dosimeters were installed in the dwellings for 3 months exposed to radon and thoron.

Dose calculations and risk estimate

Dose calculation have been formulated to assess the inhalation dose rates to the population due to ^{222}Rn, ^{220}Rn and their progeny (UNSCEAR, 2000). Absorbed dose rates to the critical cells of the respiratory tract due to ^{222}Rn, ^{220}Rn and their progeny can be estimated on the basis of aerosol characteristics, its size distribution, unattached fraction, breathing fraction, and fractional deposition in the airways, mucous clearance rate and location of the target cells in the airways. The estimated dose conversion factors varied drastically based on the breathing rate as well as the target tissue mass. In the present study, the dose conversion factors reported by UNSCEAR (2000) were used to estimate the indoor effective dose rates D ($mSvh^{-1}$) due to ^{222}Rn, and ^{220}Rn. The annual effective dose due to exposure to radon and thoron in the houses of study area were calculated by the relation :

Annual effective dose (mSv/y) = C_R (Bq m^{-3}) × 0.4 × 7000 h × 9 nSv/Bq.h m^{-3} x 10^{-6} (3)

Annual effective dose (mSv/y) = C_T (Bq m^{-3}) × 0.1× 7000 h × 40 nSv/Bq.h m^{-3} x 10^{-6} (4)

Where C_R and C_T are the radon and thoron concentrations in Bq/m^3, respectively. The value of 0.4 and 0.1 were used as the equilibrium factor for radon and thoron indoors, respectively. 9 and 40 are the dose conversion factor for radon and thoron progeny in nSv units, respectively. The multiplication factor 10^{-6} is used to convert the nSv units into mSv units. Indoor occupancy time is assumed 80 %, that is 7,000 h $year^{-1}$. The total effective dose is the sum of the effective doses due to exposures to indoor radon and thoron.

Results and Discussion

Table 1 presents the concentrations of radon and thoron in the some houses of Bali island. Radon concentrations was found to vary from 9 Bq m^{-3} to 48 Bq m^{-3} with an average value of 24.49 Bq m^{-3}. Thoron concentrations was found to vary from not detected to 66 Bq m^{-3} with an average value of 18.35 Bq m^{-3}. Figure 2 and 3 show the distibution of indoor radon and thoron concentrations in the some houses of Bali island. As can be seen in Figure 2 and 3, that wide variation was found in these concentrations. This wide variation in the concentration of both radon and thoron may be attributed to the variation in primordial radioactivity in the soil and to source extent ventilation condition. This may be due to the difference in the concentration of radioactive elements,viz. uranium and radium in the soil and building material of the studied area. The major part of indoor radon–thoron comes from the soil and building materials, because the uranium and radium are uniformly distributed in these materials from the time of origination of earth (Kumar et al., 2014; Patra et al., 2013).

The variation of indoor radon and thoron levels of the concentrations in the dwellings of Bali, may be also due to the building materials and style of architecture as well as the building characteristics. Materials commonly used in the traditional homes style and buildings include thatch roofing, coconut wood, bamboo poles, teak wood, stone, and bricks. Stones and red bricks are usually used as foundation and walls, while sandstone and andesite stone are usually carved as ornamentation. The dwellings under study are the traditional building style and combined with modern elements. With the island becoming more and more popular as a top tourist destination in the world, more dwellings are designed as luxury styles to compliment an exciting Balinese style. The building materials are expected to contribute significantly to sources of indoor radon and thoron. The sizes of houses and their rooms are different from area to area, and also within the location, the rooms chosen for the study were ventilated normally. Due to aging and fading effects during the sampling and measurement period, some detectors were rejected during the evaluation periods.

The values of concentrations are lower than the average values reported for the dwellings worldwide (UNSCEAR 2000). The average value are also less than the lower limit of the range of the action level recommended by the ICRP (1993).

Table.1 Levels of radon and thoron in the some houses of Bali island

Sample No.	Dwelling code	Indoor concentration (Bq m^{-3})	
		Radon (^{222}Rn)	Thoron (^{220}Rn)
1	INA-361	36 ± 3	n.d
2	INA-362	39 ± 3	20 ± 1
3	INA-363	24 ± 2	16 ± 1
4	INA-364	24 ± 2	42 ± 3
5	INA-365	30 ± 2	7 ± 0
6	INA-366	42 ± 3	16 ± 1
7	INA-367	21 ± 1	49 ± 3
8	INA-368	36 ± 3	n.d
9	INA-369	33 ± 2	29 ± 2
10	INA-370	30 ± 2	20 ± 1
11	INA-371	24 ± 2	13 ± 1
12	INA-372	33 ± 2	62 ± 4
13	INA-373	30 ± 2	33 ± 2

14	INA-374	42 ± 3	13 ± 1
15	INA.375	30 ± 2	7 ± 0
16	INA.376	36 ± 3	n.d
17	INA.377	48 ± 3	n.d
18	INA-378	45 ± 3	10 ± 1
19	INA-379	45 ± 3	7 ± 0
20	INA-380	30 ± 2	16 ± 1
21	INA-381	15 ± 1	13 ± 1
22	INA-382	15 ± 1	33 ± 2
23	INA-383	21 ± 1	16 ± 1
24	INA-385	15 ± 1	33 ± 2
25	INA-386	30 ± 2	n.d
26	INA-387	15 ± 1	16 ± 1
27	INA-388	18 ± 1	3 ± 0
28	INA-389	24 ± 2	13 ± 1
29	INA-390	12 ± 1	26 ± 2
30	INA-391	18 ± 1	10 ± 1
31	INA-392	12 ± 1	26 ± 2
32	INA-393	30 ± 2	n.d
33	INA-394	18 ± 1	7 ± 0
34	INA-395	12 ± 1	23 ± 2
35	INA-398	30 ± 2	7 ± 0
36	INA-399	27 ± 2	20 ± 1
37	INA-400	24 ± 2	7 ± 0
38	INA-401	9 ± 1	23 ± 2
39	INA-402	30 ± 2	16 ± 1
40	INA-403	9 ± 1	10 ± 1
41	INA-404	15 ± 1	52 ± 4
42	INA-420	21 ± 2	23 ± 2
43	INA-418	12 ± 1	16 ± 1
44	INA-419	43 ± 3	n.d
45	INA-405	9 ± 1	20 ± 1
46	INA-406	18 ± 1	20 ± 1
47	INA-407	21 ± 2	13 ± 1
48	INA-408	21 ± 2	13 ± 1
49	INA-410	15 ± 1	43 ± 3
50	INA-411	12 ± 1	66 ± 5
51	INA-412	18 ± 1	49 ± 3
52	INA-413	15 ± 1	n.d
53	INA-414	9 ± 1	36 ± 3
54	INA-415	27 ± 2	n.d
55	INA-416	24 ± 2	10 ± 1
56	INA-417	27 ± 2	13 ± 1
57	INA-421	27 ± 2	10 ± 1
Range		**9 - 48**	**n.d - 66**
Average		**24.49**	**18.35**

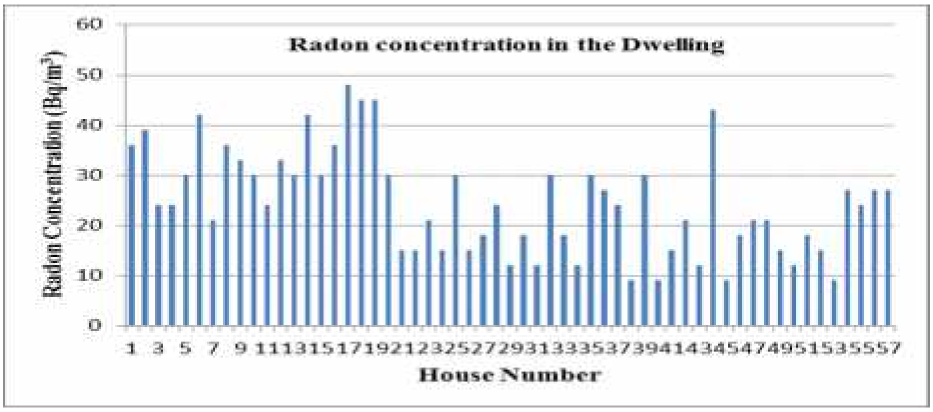

Figure 2. Variation of indoor radon concnetration

Annual effective dose of radon and thoron in the some houses of Bali island were presented in Table 2. As can be seen in Table 2 that the annual effective dose due to the exposure of radon in the study area has been found to vary from 0.23 mSv/h to 1.22 mSv/h with an average of 0.62 mSv/h. The annual effective dose from the exposure to thoron in the study area has been found to vary from not detected to 1.65 mSv/h with an average of 0.46 mSv/h. The total annual effective dose due to the exposure of indoor radon, and thoron in study area have been found to vary from 0.38 mSv/y to 2.4 mSv/y with an mean value of 1.08 mSv/y. The estimated values of radiation doses have shown no significant health risk due to exposure of radon, and thoron in the dwelling of Bali island. The annual effective dose due to the exposure to radon and thoron concentrations in the house of Bali island are within the permissible limits.

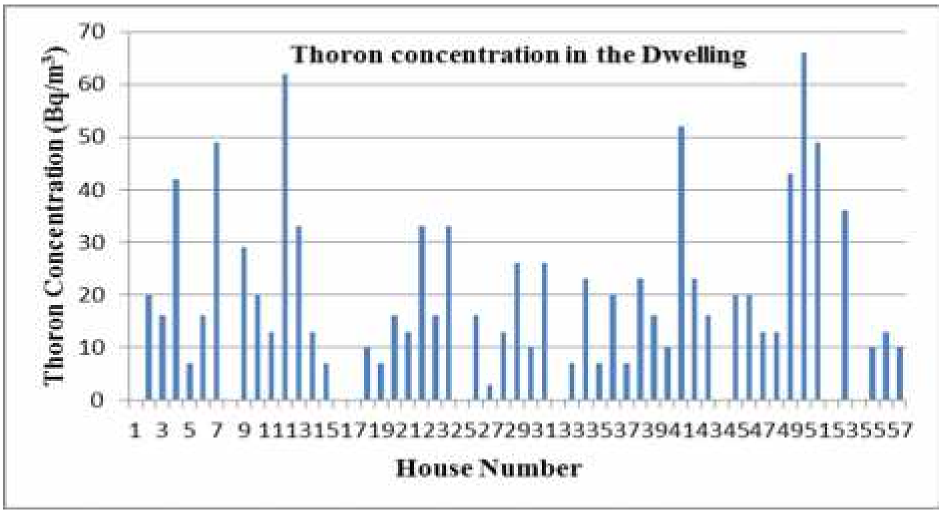

Figure 3. Variation of indoor thoron concnetration

Table 2. Annual effective dose of radon, thoron in the some houses of Bali island

Sample No.	Dwelling code	Annual effective dose (mSv)		
		Radon (^{222}Rn)	Thoron (^{220}Rn)	Total dose
1	INA-361	0.91	n.d	0.91
2	INA-362	0.99	0.49	1.48
3	INA-363	0.61	0.41	1.02
4	INA-364	0.61	1.07	1.68
5	INA-365	0.76	0.16	0.92
6	INA-366	1.07	0.41	1.48
7	INA-367	0.53	1.23	1.76
8	INA-368	0.91	n.d	0.91
9	INA-369	0.84	0.74	1.58
10	INA-370	0.76	0.49	1.25
11	INA-371	0.61	0.33	0.94
12	INA-372	0.84	1.56	2.39
13	INA-373	0.76	0.82	1.58
14	INA-374	1.07	0.33	1.39
15	INA.375	0.76	0.16	0.93
16	INA.376	0.91	n.d	0.91
17	INA.377	1.22	n.d	1.22
18	INA-378	1.14	0.25	1.39
19	INA-379	1.14	0.16	1.31
20	INA-380	0.76	0.41	1.17
21	INA-381	0.38	0.33	0.71
22	INA-382	0.38	0.82	1.20
23	INA-383	0.53	0.41	0.94
24	INA-385	0.38	0.82	1.20
25	INA-386	0.76	n.d	0.76
26	INA-387	0.38	0.41	0.79

27	INA-388	0.46	0.08	0.54
28	INA-389	0.61	0.33	0.94
29	INA-390	0.30	0.66	0.96
30	INA-391	0.46	0.25	0.71
31	INA-392	0.30	0.66	0.96
32	INA-393	0.76	n.d	0.76
33	INA-394	0.46	0.16	0.62
34	INA-395	0.30	0.57	0.87
35	INA-398	0.77	0.17	0.94
36	INA-399	0.69	0.50	1.19
37	INA-400	0.61	0.17	0.78
38	INA-401	0.23	0.58	0.81
39	INA-402	0.77	0.41	1.18
40	INA-403	0.23	0.25	0.48
41	INA-404	0.38	1.32	1.71
42	INA-420	0.54	0.58	1.12
43	INA-419	0.31	0.41	0.72
44	INA-419	1.08	n.d	1.08
45	INA-405	0.23	0.50	0.73
46	INA-406	0.46	0.50	0.96
47	INA-407	0.54	0.33	0.87
48	INA-408	0.54	0.33	0.87
49	INA-410	0.38	1.07	1.45
50	INA-411	0.31	1.65	1.96
51	INA-412	0.46	1.24	1.70
52	INA-413	0.38	n.d	0.38
53	INA-414	0.23	0.91	1.14
54	INA-415	0.69	n.d	0.69
55	INA-416	0.61	0.25	0.86
56	INA-417	0.69	0.33	1.02
57	INA-421	0.69	0.25	0.94
Range		**0.23 – 1.22**	**n.d – 1.65**	**0.38 – 2.4**
Average		**0.62**	**0.46**	**1.08**

Conclusions

The measurement of indoor radon and thoron concentrations in dwellings of Bali island was carried out for estimating annual effective dose received by the population. The concentrations of radon, and thoron have been found to be in wide variation depend on different of location and the building materials and style of architecture. The average values of radon and thoron concentrations in the study area were found to be lower than the global average values. The measured values of concentra-tions of radon, thoron in 57 houses of Bali were used for estimating the radiation dose received by the population of the study area. The total annual effective dose due to the exposure of indoor radon, and thoron in study area have been found to be lower limit of the recommended action level. The estimated values of radiation doses have shown no significant health risk due to exposure of radon, and thoron in the dwelling of Bali island. The annual effective dose due to the exposure to radon and thoron concentrations in the house of Bali island are within the permissible limits. Consequently, the health hazards related to radiation are expected to be negligible. Bali island, as a place to live in and/or to visit, is considered as safe area related to natural radiation.

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