ENVIRONMENTAL RADON/THORON CONCENTRATIONS AND RADIATION LEVELS IN SARAWAK AND SABAH

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ABSTRACT

*The indoor and outdoor radon/thoron progenies concentrations and natural background radiation levels throughout Sarawak and Sabah were measured. The measurements were carried out at 234 locations in 40 towns in Sarawak and Sabah. The mean indoor and outdoor radon equilibrium equivalent concentrations (EEC) in Sarawak were found to be 1.2 Bqm^{-3} and 1.5 Bqm^{-3} respectively. In Sabah, the mean indoor and outdoor radon equilibrium equivalent concentrations were 1.7 Bqm^{-3}. The mean indoor and outdoor thoron equilibrium equivalent concentrations of 0.4 Bqm^{-3} and 0.3Bqm^{-3} respectively, were the same for Sarawak and Sabah. The mean indoor and outdoor radiation levels of 46 $nGyh^{-1}$ and 42 $nGyh^{-1}$ in Sarawak were slightly lower than the respective values in Sabah, **i.e**. 53 $nGyh^{-1}$ and 46 $nGy\ h^{-1}$.*

ABSTRAK

*Kepekatan anak-anak radon/toron, aras sinaran latarbelakang tabii di dalam dan luar rumah kediaman di seluruh Sarawak dan Sabah telah diukur. Pengukuran telah dilaksanakan di 234 lokasi di 40 buah bandar di Sarawak dan Sabah. Min kepekatan kesetaraan keseimbangan bagi radon di dalam dan di luar rumah di Sarawak masing-masing adalah 1.2 Bqm^{-3} and 1.5 Bqm^{-3}. Di Sabah pula, kedua-dua nilai tersebut adalah sama iaitu 1.7 $Bq\ m^{-3}$. Min kepekatan kesetaraan keseimbangan bagi toron di dalam dan luar rumah yang masing-masingnya 0.4 Bqm^{-3} dan 0.3 Bqm^{-3}adalah sama bagi Sarawak dan Sabah. Min aras sinaran di dalam dan di luar rumah di Sarawak iaitu 46 $nGyj^{-1}$ dan 42 $nGyj^{-1}$ **adalah** lebih rendah dari nilai di Sabah iaitu 53 $nGy\ j^{-1}$ dan 46 $nGyj^{-1}$.*

Keywords: Environmental, indoor, natural, outdoor, radiation, radon, thoron

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INTRODUCTION

The exposure to natural radiation has been the integral part of man's life. The natural radiation consist of cosmic ray from extraterrestrial and radiation from radionuclides present in earth's environment (terrestrial) which could be found in materials such as soil, rock, water and air. Terrestrial radiation level depends on the type and concentration of radionuclides in the environment. The main radionuclides from terrestrial sources are ^{238}U series, ^{232}Th series and ^{40}K that emit gamma radiation and could contribute to external exposure.

Radon (^{222}Rn of the ^{238}U series) and thoron (^{220}Rn of the ^{232}Th series) gases decay to short-lived particulate progenies (see decay series 1 and 2). Inhalation of these progenies could cause internal exposure. In air, some portions of particulate radon progenies are attached to aerosol plated-out onto surfaces. Thus, radon gas and its particulate progenies do not exist in a complete equilibrium in air.

Radon $^{222}Rn \rightarrow {}^{218}Po \rightarrow {}^{214}Pb \rightarrow {}^{214}Bi \rightarrow$ (1)

$t_{1/2}$ 3.82 d 3.05 min 26.8 min 19.7 min

Thoron $^{220}Rn \rightarrow {}^{216}Po \rightarrow {}^{212}Pb \rightarrow {}^{212}Bi \rightarrow$ (2)

$t_{1/2}$ 56 s 0.15 s 10.64 h 60.6 min

Radon/thoron progenies concentrations in air are necessary to be measured to estimate the dose received by the people. However, there are limited numbers of equipment available in the market that able to directly measure these progenies. As for environmental concentration in air, radon gas concentration is usually measured using the many commercially available monitors. In the literatures, radon concentrations are reported in various units either for the gas or its progenies. For comparison with values reported by other researchers or authorized limits issued by regulatory agencies, there is a need to convert progenies concentrations to radon gas concentrations and vice versa. Progenies concentrations can be converted to radon equilibrium equivalent concentration (EEC), i.e. the concentration of radon gas if it would be in equilibrium with its progenies using reported conversion factors (UNSCEAR, 2000). Using assumed (from established references) or known (from previous measurements) progenies-to-radon gas equilibrium factors, the concentration of radon gas can be estimated from progenies concentrations or otherwise.

As the half-life of radon gas is 3.8 days, it could move to a reasonable distance from its source. Thus, the short-lived radon daughters could be found away from radon source. As for thoron, although its half-life is only 56 s, but its longer-lived daughter, i.e. ^{212}Pb ($t_{1/2}$ = 10.6 h) could be transferred to a distance from its source by wind.

Based on the awareness on the exposure from natural radiation and radioactivity, there are a number of extensive studies been conducted all over the world (Abe *et al.,* 1984; Chu *et al.,* 1989; Cliff *et al.,* 1992; Deworm *et al.,* 1988; Green *et al.,* 1988; Guo *et al.,* 1992, 1995; Lai *et al.,* 1999; McAulay, 1980; Miller, 1992; Mjones, 1986; Mjones *et al.,* 1992; Rannou *et al.,* 1988; Stuardo, 1996; Stranden, 1980; Tu *et al.,* 1992; Tso, 1991; Wrixon *et al.,* 1988; Yamasaki, 1995; Zhuo, 1999). UNSCEAR (2000) has reported that radiation from terrestrial source is the main component from all natural sources of exposure to man.

Baseline data on soil radioactivity (Omar *et al*., 1991), radon/thoron progenies concentration in air (Sulaiman *et al*., 1994) and environmental background radiation level (Omar *et al*., 2000) for Peninsular Malaysia have previously been reported. In order to obtain a complete baseline data for Malaysia, a study has been carried out in the East Malaysia (Sarawak and Sabah). This paper describes the measurement results of natural environmental radiation and radon/thoron concentrations in indoor and outdoor air.

MATERIALS AND METHODS

Radon monitors (Alphadosimeter model 560, Alphanuclear, Canada) were used to measure radon and thoron progenies concentration in indoor and outdoor air. The equipment consists of a servo pump, a microprocessor, a RS-232 interface, a silicon surface barrier detector (for α detection), a filter holder just below the detector and a battery. The sampling of radon and thoron progenies was performed by pumping the air through the filter paper. The pumping duration was set using a provided program on a computer. The monitor was normally placed on a table or cupboard at least 30 cm from the wall. The sampling duration was chosen depending on situation, suitability of a place and safety of the equipment especially when measuring outdoor. As far as possible, the measurement was conducted for a period of about 24 hours in order to obtain a representative average radon and thoron progenies concentrations for one day. The analysis was conducted 3.5 hours after end of sampling to obtain the results in milliWorking Level (mWL). Radon and thoron progenies concentrations in mWL unit were then converted to Equilibrium Equivalent Concentration (EEC) in Bqm^{-3} of radon and thoron using the following conversion factors (UNSCEAR, 2000):

$$0.27 \text{ mWL} = 1 \text{ Bqm}^{-3} \text{ for } {}^{222}\text{Rn and}$$
$$3.64 \text{ mWL} = 1 \text{ Bqm}^{-3} \text{ for } {}^{220}\text{Rn.}$$

A portable spectrometer (model GR-130, Exploranium, Canada) was used to measure natural background radiation dose rate (in $nGyh^{-1}$) indoor and outdoor. The spectrometer uses a NaI(Tl) detector which show a good response to gamma radiation below 4 MeV. Indoor measurements were made at about 1m above the floor and more than 1m from the wall. Outdoor measurements were performed in open spaces around the house at about 1m above ground. The spectrometer was calibrated at the Secondary Standard Dosimetry Laboratory (SSDL) of the Malaysian Nuclear Agency.

The measurements of radon and thoron progenies and natural background radiation were conducted at 234 locations in 40 towns throughout Sarawak and Sabah (Figure 1). The indoor and outdoor measurements were carried out involving three types of houses, namely brick houses (concrete floors and brick walls), half- brick houses (concrete floors, partially brick and wooden walls) and wooden houses (wooden floors and walls). Measurements were also carried out at water village where the wooden houses were built on the water. These houses are accessed by wooden bridges.

RESULTS AND DISCUSSION

Concentrations of Radon and Thoron

The radon and thoron EEC in Sarawak and Sabah are shown in Tables 1 and 2. The mean indoor and outdoor radon EEC in Sarawak were 1.2 and 1.5 Bqm^{-3} respectively. In Sabah the respective values were equal i.e. 1.7 Bqm^{-3}. The mean indoor and outdoor thoron EEC of 0.4 and 0.3 Bqm^{-3} respectively were the same for Sarawak and Sabah. For comparison, the mean EEC of indoor radon and thoron in northern Greece are 22 Bqm^{-3} and 0.9 Bqm^{-3} respectively (Clouvas *et al*., 2008). Table

3 shows radon and thoron EEC based on different types of houses in the East Malaysia. Statistically, at 95% confidence level, it was found that there was no significant difference of radon (and thoron) EEC for different types of houses in both states.

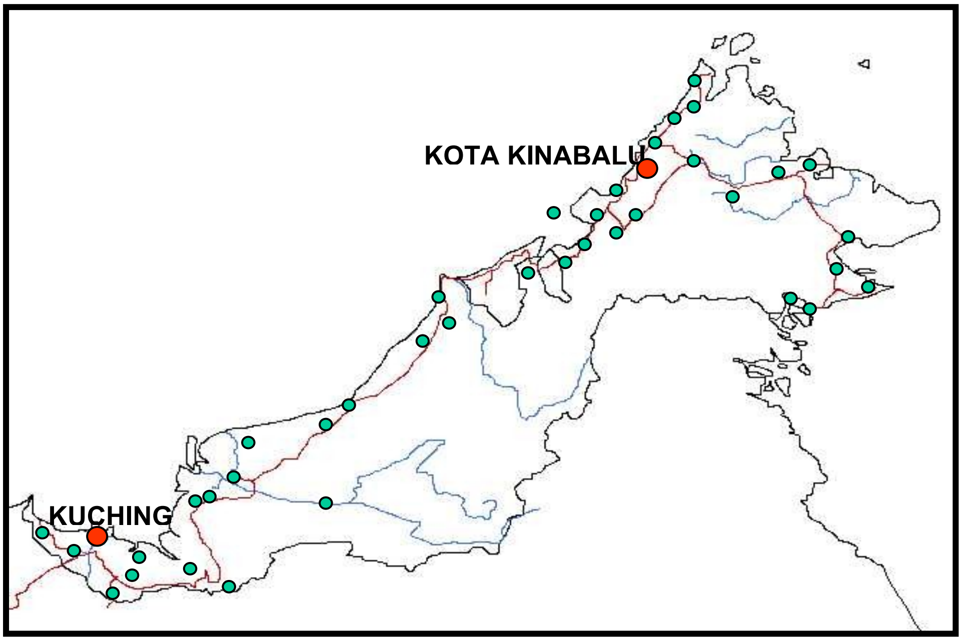

Figure 1: Locations of towns for radon/thoron and radiation measurements in Sarawak and Sabah

The distributions of radon and thoron concentrations are shown in Figures 2 and 3. The concentrations were generally low and more than 80% of the values were less than 2 Bqm^{-3}. There was no area or house which showed significantly high concentrations of radon and thoron in Sarawak and Sabah.

The mean indoor and outdoor radon EEC in the East Malaysia was lower than the Peninsular Malaysia. The mean indoor and outdoor radon EEC in Peninsular Malaysia were equal i.e. 5.6 Bqm^{-3} while the mean indoor and outdoor thoron EEC were 1.1 Bqm^{-3} and 0.5 Bqm^{-3} respectively (Sulaiman *et al*., 1994). Soil and building materials are the major sources of radon and thoron concentrations in air. The low radon and thoron EEC are probably due to the low radioactivity content of radium in soil (Omar *et al*., 1991; Sulaiman *et al*., 2007) and building materials. While other building materials might be imported from the same supply sources for Peninsular Malaysia, locally manufactured bricks might be used in the East Malaysia. Although studies on radium concentration of building materials in the East Malaysia have not been found, the local bricks (made of clay) are expected (based on local soil radioactivity) to contain lower radium concentration compared to bricks of Peninsular Malaysia (Omar, 2000).

The indoor-to-outdoor ratios of radon EEC in Sarawak and Sabah were 0.8 and 1.0 respectively while the ratios for thoron in both states were equal i.e. 1.3. Wind and ventilation play important role in influencing the radon/thoron and its daughters concentrations in air. The indoor and outdoor radon (and thoron) levels were almost similar, probably due to good indoor-outdoor air exchange. As houses in Malaysia are considered to have good ventilation with windows almost always open, it is expected that the concentration of indoor radon (and thoron) is, to some extent, influenced by the outdoor concentrations. This is obvious from the measurement made in several wooden houses at water village (radon source is not expected from the building materials) where radon (and thoron) concentrations were not much different from houses built on land (Table 3). In this case wind from the land may carry away the radon gas and thoron daughters (^{212}Pb) toward the water village and thus influencing the indoor radon/thoron EEC. Measurements also show that there is no significant difference between radon (and thoron) level at a highland town (Ranau), coastal and water village.

Table 1: Concentration of radon and thoron in Sarawak

Location	Radon EEC (Bqm^{-3})		Thoron EEC (Bqm^{-3})	
	Indoor	Outdoor	Indoor	Outdoor
Kuching	1.6	1.6	0.4	0.3
Tebedu	1.1	1.8	0.9	0.8
Serian	1.6	3.4	0.4	0.3
Bintulu	0.7	1.1	0.3	0.2
Tatau	0.7	1.0	0.3	0.5
Miri	0.7	0.9	0.4	0.1
Niah	1.9	4.6	1.0	0.6
Beluru	0.5	0.7	0.5	1.0
Limbang	0.6	0.4	0.3	0.2
Lawas	1.5	0.6	0.7	0.3
Kota Samarahan	0.7	0.4	0.3	0.4
Sri Aman	0.7	0.8	0.2	0.3
Lubuk Antu	0.6	2.3	0.6	0.2
Sibu	0.8	1.0	0.3	0.3
Dalat	0.7	0.5	0.2	0.2
Bintangor	1.2	1.1	0.2	0.1
Sarikei	1.8	1.3	0.4	0.3
Kapit	2.2	3.8	0.8	0.2
Bau	1.6	0.4	0.4	0.3
Lundu	1.8	1.3	0.2	0.4
Mean ± σ	1.2 ± 0.5	1.5 ± 1.2	0.4 ± 0.2	0.3 ± 0.2

Table 2: Concentration of radon and thoron in Sabah

Location	Radon EEC (Bqm^{-3})		Thoron EEC (Bqm^{-3})	
	Indoor	Outdoor	Indoor	Outdoor
K.Kinabalu	3.3	2.6	0.6	0.4
Papar	1.9	1.6	0.6	0.4
Keningau	3.1	3.3	0.6	0.6
Tenom	2.1	1.0	0.3	0.8
Beaufort	1.4	1.8	0.5	0.5
Sipitang	1.0	1.6	0.4	0.1
Ranau	0.6	1.0	0.6	0.2
Tawau	2.6	2.4	0.4	0.4
Merotai	1.8	2.9	0.6	0.6
Lahad Datu	1.1	1.3	0.8	0.3
Semporna	0.8	2.8	0.2	0.1
Kunak	0.6	1.1	0.4	0.1
Sandakan	1.2	1.0	0.3	0.3
Beluran	1.3	1.5	0.4	0.3
Kudat	1.5	1.4	0.5	0.2
Kota Marudu	2.4	1.9	0.3	0.3
Kota Belud	1.6	1.8	0.6	0.3
Tuaran	2.7	1.0	0.3	0.3
Telupid	1.5	0.4	0.2	0.4
Labuan (WP)	1.1	0.7	0.1	0.1
Mean ± σ	1.7 ± 0.8	1.7 ± 0.7	0.4 ± 0.2	0.3 ± 0.2

Table 3: Mean radon and thoron concentrations inside and outside houses made of different building materials

	Building Material	Radon EEC (Bqm^{-3})		Thoron EEC (Bqm^{-3})	
		Indoor	Outdoor	Indoor	Outdoor
Sarawak	Brick	1.1 ±1.2	1.4 ± 1.6	0.5 ± 0.6	0.3 ± 0.4
	Half-brick	1.4 ± 1.3	1.0 ±1.3	0.3 ± 0.6	0.5 ± 0.4
	Wooden	1.1 ± 0.9	2.1 ± 1.7	0.3 ± 0.4	0.2 ± 0.2
	All type	1.2 ± 1.2	1.5 ± 1.6	0.4 ± 0.5	0.3 ± 0.4
Sabah	Brick	2.0 ± 1.6	1.7 ± 1.6	0.4 ± 0.4	0.3 ± 0.3
	Half-brick	1.1 ± 1.3	1.5 ± 1.3	0.5 ± 0.4	0.3 ± 0.2
	Wooden	1.1 ± 1.0	1.9 ± 1.6	0.5 ± 0.4	0.4 ± 0.4
	All type	1.7 ± 1.5	1.7 ± 1.6	0.4 ± 0.4	0.3 ± 0.3

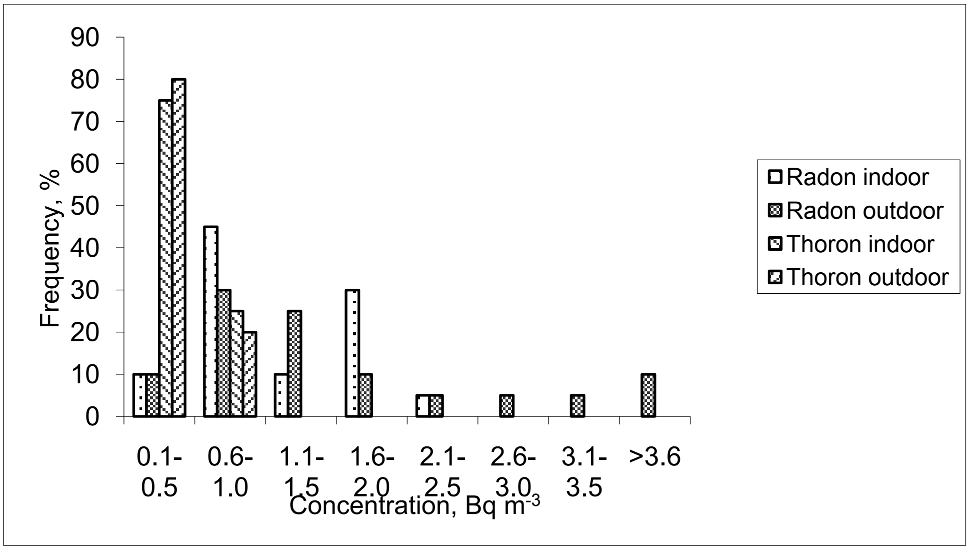

Figure 2: Distribution of radon/thoron concentration in Sarawak

Natural radiation level

The terrestrial radiation levels in Sarawak and Sabah are shown in Tables 4 and 5. There was no area or house showing significantly high level of natural radiation. The mean indoor and outdoor natural background radiation levels in Sarawak were 46 nGyh^{-1} and 42 nGyh^{-1} respectively. In Sabah the respective values were 53 nGyh^{-1} and 46 nGyh^{-1}. The values for Sarawak and Sabah are about half of the values measured in the Peninsular Malaysia (97 nGyh^{-1} and 94 nGyh^{-1} respectively - Omar *et al*, 2000). For comparison, the mean indoor radiation level in northern Greece is 47 nGyh^{-1} (Clouvas *et al*., 2008). The distributions of natural radiation levels in Sarawak and Sabah are shown in Figures 4 and 5.

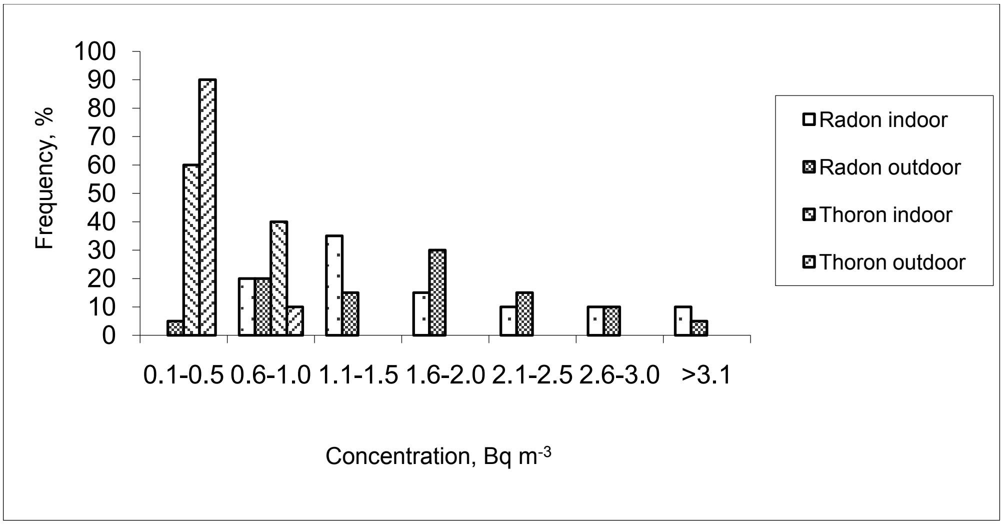

Figure 3: Distribution of radon/thoron concentration in Sabah

Table 4: Terrestrial Radiation Level in Sarawak

Location	Radiation level ($nGyh^{-1}$)	
	Indoor	Outdoor
Kuching	40	33
Tebedu	43	39
Serian	42	39
Bintulu	43	44
Tatau	48	44
Miri	43	43
Niah	43	43
Beluru	36	43
Limbang	39	39
Lawas	56	46
Kota Samarahan	33	39
Sri Aman	52	49
Lubuk Antu	49	49
Sibu	64	41
Dalat	45	30
Bintangor	53	39
Sarikei	52	54
Kapit	56	49
Bau	43	39
Lundu	43	38
Mean ± σ	46 ± 8	42 ± 6

Various building materials used in Malaysia contain significant concentration of natural radionuclides (Omar, 2000) and thus play important role in determining the indoor radiation levels. Radiation level was found to be highest in brick house followed by half-brick house and wooden house. This is because brick is known to contain significant amount of radionuclides from ^{238}U and ^{232}Th series (Omar, 2000). As radionuclides content in wood is expected to be negligible, the radiation level would be very low inside the wooden house. The wooden house above the seawater at water village showed the lowest radiation level (10 nGyh^{-1}) coming from merely cosmic radiation. There is insignificant radiation from sea sediment due to distance, besides, seawater could also act as a radiation shielding.

Table 6 shows mean natural radiation levels based on different types of houses. Statistically, there is no significant difference between natural radiation level of brick and half-brick house in Sarawak and Sabah. The same situation is observed for half-brick and wooden houses. However, at 95% confidence level there is a significant difference of natural radiation level between brick and wooden houses in both states.

Table 5: Terrestrial Radiation Level in Sabah

Location	Radiation level (nGyh^{-1})	
	Indoor	Outdoor
K.Kinabalu	69	57
Papar	68	56
Keningau	51	44
Tenom	48	39
Beaufort	43	43
Sipitang	26	29
Ranau	56	47
Tawau	55	49
Merotai	41	45
Lahad Datu	50	46
Semporna	57	49
Kunak	29	47
Sandakan	57	51
Beluran	31	41
Kudat	70	40
Kota Marudu	69	56
Kota Belud	65	49
Tuaran	74	57
Telupid	47	46
Labuan (WP)	49	38
Mean ± σ	53 ± 14	46 ± 7

Table 6: Mean terrestrial radiation levels inside and outside houses made of different building materials

State Name	Building Material	Radiation level ($nGyh^{-1}$)	
		Indoor	Outdoor
Sarawak	Brick	50 ± 13	44 ± 10
	Half-brick	41 ± 8	42 ± 8
	Wooden	31 ± 10	40 ± 13
	All type	45 ± 14	43 ± 11
Sabah	Brick	60 ± 14	48 ± 12
	Half-brick	54 ± 15	49 ± 11
	Wooden	28 ± 11	38 ± 14
	All type	53 ± 13	44 ± 10

The outdoor natural radiation level at a highland town (Ranau) was comparable with other places in Sabah. This is due to low radioactivity level of the soil (Omar *et al*., 1991) and probably the rock in this area as well. The radium concentration of granite in Peninsular Malaysia has been reported (Omar et al.,1999), but the levels for East Malaysia could not be found in the literature. Generally, the indoor radiation level is higher than the outdoor with the indoor-to-outdoor radiation level ratios in Sarawak and Sabah are 1.1 and 1.2 respectively.

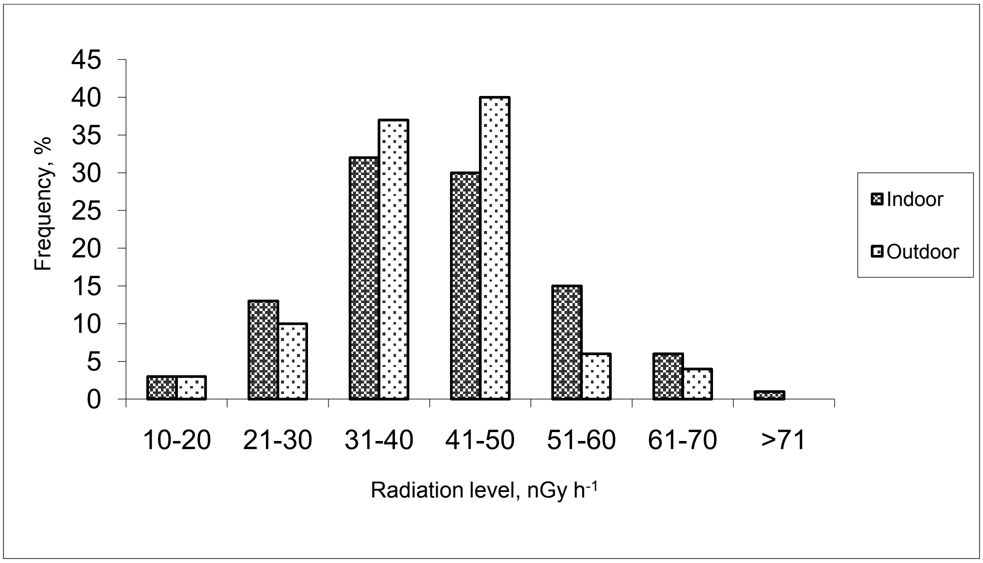

Figure 4: Distribution of terrestrial radiation level in Sarawak

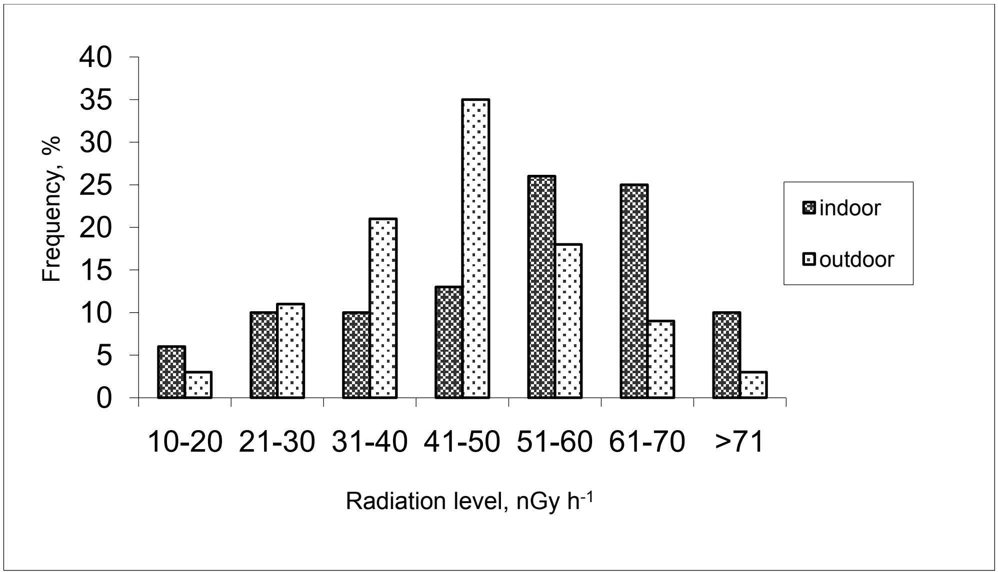

Figure 5: Distribution of terrestrial radiation level in Sabah

Effective Dose

In order to estimate the annual effective dose received by the public, it was assumed that people was exposed for 365 days a year and the UNSCEAR's conversion factors i.e. occupancy factor of 0.8 (indoor) and 0.2 (outdoor), dose conversion factor of 9 $nSvh^{-1}/Bqm^{-3}$ (radon progenies), 40 $nSvh^{-1}/Bqm^{-3}$ (thoron progenies) and 0.7 $SvGy^{-1}$ (terrestrial radiation) (UNSCEAR, 2000) were used. The estimated effective dose is shown in Table 7.

The annual effective doses from indoor radon and thoron progenies were almost similar for Sarawak and Sabah. It seems that contribution from thoron is as significant as the radon and should not simply be ignored. Generally, the indoor doses were higher than the outdoor, i.e. about four times the outdoor values. The annual effective dose from radon and thoron progenies in Sarawak and Sabah were found to be 0.21 mSv and 0.25 mSv respectively, i.e. about 1/3 of the value estimated for Peninsular Malaysia (0.69 mSv – Sulaiman *et al*., 1994).

The annual effective dose from terrestrial radiation in Sarawak and Sabah were 0.27 mSv and 0.32 mSv respectively, i.e. about half of the value estimated for Peninsular Malaysia (0.54 mSv – Sulaiman *et al*., 1994). For comparison, the mean annual effective doses due to indoor gamma radiation, radon progeny and thoron progeny in northern Greece are 0.29 mSv, 1.36 mSv and 0.2 mSv respectively (Clouvas *et al*., 2008).

Table 7: Estimated annual effective dose from radon/thoron progenies and terrestrial radiation in Sarawak and Sabah

State Name	Types of exposure	Sources of exposure	Dose, mSv		
			Indoor	Outdoor	Total
	Internal	Radon	0.08	0.02	0.10
Sarawak		Thoron	0.09	0.02	0.11
	Total internal		0.17	0.04	0.21
	External	Terrestrial radiation	0.22	0.05	0.27
	Total		0.39	0.09	0.48
	internal	Radon	0.11	0.03	0.14
Sabah		Thoron	0.09	0.02	0.11
	Total internal		0.20	0.05	0.25
	external	Terrestrial radiation	0.26	0.06	0.32
	Total		0.46	0.11	0.57

CONCLUSION

Generally, radon, thoron and natural radiation levels in Sarawak and Sabah are about half of the values in the Peninsular Malaysia. Thus, the population in Sarawak and Sabah are expected to receive a lower dose from natural background radiation sources compared to the population of Peninsular Malaysia.

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