SOME REMARKS ON DIURNAL RADON CONCENTRATION AT VARIOUS LOCATIONS IN PENINSULAR MALAYSIA

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ABSTRACT

A study was carried out to determine short term diurnal radon concentration at five locations in Malaysia. Two locations (KG & AP) are former tin mining areas that has been converted to housing area and training centre respectively, one a relatively new city (SA), that was formerly a rubber and oil palm plantation area, one older cities (KB) and one housing complex by the sea (LP). The study was carried out in 2005, 2006 and 2007 using a diffused-junction photodiode sensor continuous radon monitor. The monitor is recognized by the USEPA. In each location, measurements were carried out on at least ten sites. Former tin mining areas of KG and AP shows up to seven times higher indoor average than the average in the other three locations. However the indoor average in all locations is still below the action level of 4 pCiL^{-1}. For outdoor, the former tin mining areas average concentration was higher than the global average of 0.4 pCiL^{-1}. For the twenty four hours temporal variation the trend indicated that former tin mining areas concentration are always higher, and at time up to six fold higher. The hourly variation of all locations follows an identical trend of high concentration during early to late morning and drop in the afternoon till evening. The outdoor twenty four hour temporal average of former tin mining areas is consistently higher than the outdoor global average of 0.4 pCiL^{-1}. The strong correlation between indoor and outdoor concentration at AP, indicates that indoor radon might originates from outdoor environment. The study was also extended to estimate the effective dose (mSvyr^{-1}) of Rn-222 to the public.

ABSTRAK

Satu kajian telah dijalankan bagi menentukan kepekatan diurnal radon melalui pengukuran jangka pendek bagi lima lokasi di Malaysia. Dua lokasi (KG & AP) merupakan bekas kawasan lombong bijih timah yang masing-masing telah ditebusguna menjadi kawasan kediaman dan pusat latihan, satu bandaraya baru (SA) yang sebelum ini ialah kawasan ladang getah dan kelapa sawit, satu bandaraya lama (KB) dan yang terakhir sebuah kawasan kompleks kediaman di tepi pantai (LP). Kajian dijalankan dalam tahun 2005, 2006 dan 2007 menggunakan pengesan radon berterusan (dengan sesor fotodiod simpang-teresap). Alat pengesan ini diiktiraf oleh USEPA. Bagi setiap lokasi, pengukuran sekurang-kurangnya dilakukan di sepuluh tempat. Hasil kajian di lokasi bekas tanah lombong (KG & AP) menunjukkan purata kepekatan radon dalam bangunan mencapai sehingga tujuh kali lebih tinggi berbanding lokasi-lokasi lain. Walau bagaimanapun kepekatan radon dalam bangunan tersebut masih lebih rendah daripada aras bertindak 4 pCiL^{-1}. bagi kawasan luar, kepekatan purata radon adalah lebih tinggi daripada kepekatan purata global iaitu 0.4 pCiL^{-1}. Bagi variasi kepakatan untuk tempoh 24 jam trend menunjukkan kepekatan di lokasi *bekas tanah lombong sentiasa lebih tinggi. Bagii semua lokasi, trend variasi setiap jam menunjukkan pola seiras di mana kepekatan radon adalah tinggi sewaktu dinihari dan menurun menjelang tengahari dan petang. Untuk kawasan luar bangunan di lokasi bekas lombong, variasi setiap jam bagi tempoh 24 jam sentiasa lebih tinggi daripada 0.4 pCiL^{-1}. Bagi lokasi AP terdapat korelasi yang kuat anatara kepekatan dalam bangunan dan luar bangunan, yang menunjukkanradon dalam bangunan berkemungkinan berpunca dari luar bangunan. Hasil kajian juga membolehkan pengiraan dos efektif (mSvth^{-1}) bagi Rn-222 kepada orang awam.*

Keywords: Radon, effective dose.

INTRODUCTION

Radon (Rn-222) is a colorless, odorless radioactive gas, produced from the decay of radium (Ra-226), originating from uranium (U-238) that present naturally in soil, rocks, and fossil fuels. Radon is an alpha emitter, and it decays into a number of daughter radionuclides that are alpha emitters as well. Being gas, radon is inhaled when we breathed, and these high energy alpha particles posed health risk to the lung. It has been estimated that radon is the second leading cause of lung cancer in human, after smoking (Pearce & Boyle, 2005). Being naturally originating, radon exposure to human is a universal phenomenon however its health effect is dependent on the radon concentration in the area. The concentration of radon in any location is very much influenced by the geological formation and amount of radon dissolved in water in that location. Indoor radon is effectively the results of outdoor radon finding it way into the house and accumulated in the house (Frumkin & Samet, 2001).

In the present study the short term, twenty-four hours variation (diurnal) of radon concentrations in five locations in Peninsular Malaysia were determined. Presently, Malaysia does not have any specific law or regulation on radon concentration. Therefore the indirect aim of the present study was to gather data on radon in Malaysia that may be useful to the relevant authority in formulating the regulation in future.

METHODOLOGY

Study Site

For the present study five locations of interest were chosen, representing different types of settlement that are found in Malaysia; the city, housing complexes, traditional residential area. The locations are summarized in Table while Figure 1 shows the five study locations (AP, KB, LP, SA and KG). In the table, a brief historical and soil description of each location is also included, together with the period of study for the respective locations. For each location ten to fifteen dwellings were chosen for indoor and outdoor radon measurement. As far as possible, an outdoor measurement was paired to the respective indoor measurement of the dwelling. The exact location of each dwelling (measurement point) was determined using a GPS instrument.

The Dwellings

Majority of the houses studied in AP, KG and KB are single storey having four to five rooms, while in LP they are three-room apartments. For SA all houses studied are double storey linked houses, having four rooms. All houses studied used cements and bricks, either sand or clay bricks, as the major construction materials. Walls are covered with plaster of sand, soil and cement mixture, and painted. Majority of the floors are made of concrete covered with tiles or marble. These building materials are expected to a certain extent contribute to the indoor radon concentration in the dwellings. Indoor radon monitoring were carried out in the living rooms of the houses. Majority of the living rooms size ranged between 4 x 4 x 3 m^3 to 4 x 5 x 3 m^3, having at least one window and an entrance from outside. The window and door are normally closed at night. All rooms are fitted with ceiling fan, usually in operation when the living rooms are in use.

Table 1: Study locations, description and the corresponding study period.

Locations	Period of Study	Information of the Locations
Ampang, Selangor (AP)	Jan – June 2005	Former tin mining area. Converted to residential area since 1980's. Sandy soils.
Kampung Gajah, Perak (KG)	Aug. – Nov. 2005	Former tin mining area, ceased operational since 40 years ago. Converted to training centre by retaining the original houses. Sandy soils.
Lumut, Perak (LP)	May – July 2006	Close to the Straits of Malacca. Converted to Malaysian Naval Base complex, inclusive of staff dwellings. Alluvium and sandy soils.
Shah Alam, Selangor (SA)	Oct. – Nov. 2006	Former oil palm plantation area, converted to residential and industrial city since 30 years ago. Mixed sandy clay soils.
Kota Bharu, Kelantan (KB)	May – July 2007	Older residential city, by the estuary of Kelantan River. Mixture of sand, alluvium and clay soils.

Radon Monitoring

The measurement used in the study is based on continuous radon monitor using diffused-junction photodiode sensor, manufactured by SunNuclear, USA. The monitor that able to produce hourly interval radon concentration, as well as the respective measurement average was manufacturer-calibrated and recognized by the USEPA. In the indoor study, the monitor was set and placed in the living room on a stool at about one meter above the floor and about one meter from the wall, at a point of less occupants' disturbance. For outdoor measurement, the monitor was placed on a special stand enclosed with wire-maze with top cover to avoid unauthorized disturbance and rain. The position of the monitor was about one meter above the ground. The measurement was stopped twenty-four hours later, and the recorded hourly interval radon concentration, and average concentration for the duration of measurement (24 hours), was printed out.

Analysis

The hourly concentrations of all dwellings at a location were averaged to produce the respective average concentration for that hour. Thus, the indoor hourly average concentration for twenty-four hour period of the location can be obtained. The corresponding outdoor values were obtained by the same manner. From this analysis, the twenty-four hour temporal variation of indoor and outdoor radon concentration can be obtained. The average radon concentration for all dwellings and all outdoor measurements in a location were averaged to obtain the mean indoor and mean outdoor radon concentration for the respective locations respectively. The annual effective dose of radon to public in the study locations was estimated using the formula by UNSCEAR as reported by Al-Saleh (2007):

$$E = C \times F \times H \times T \times D \tag{1}$$

In the equation C is the ^{222}Rn concentration in Bq m^{-3}, F is an equilibrium factor taking a value of 0.4, H the occupancy factor (0.8), T is the number of hours in a year (about 8760 h yr^{-1}, and D is the effective dose received by adults per unit ^{222}Rn activity per unit air volume known as dose conversion factor (9.0 x 10^{-6} mSv Bq m^{-3} h^{-1}).

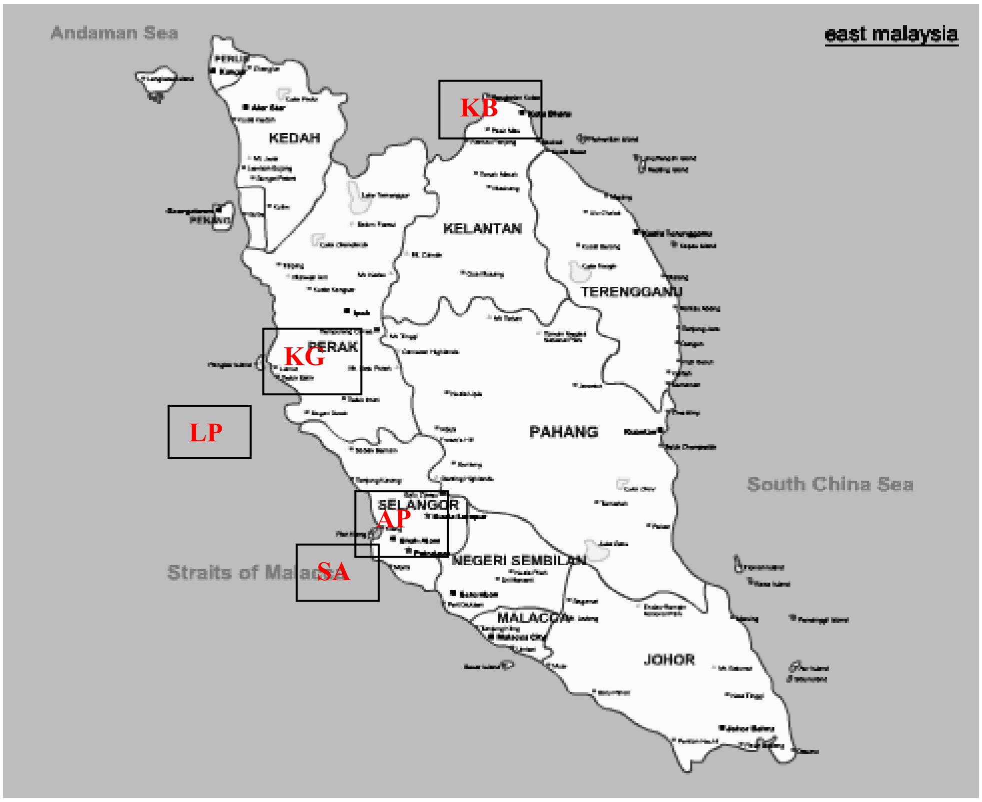
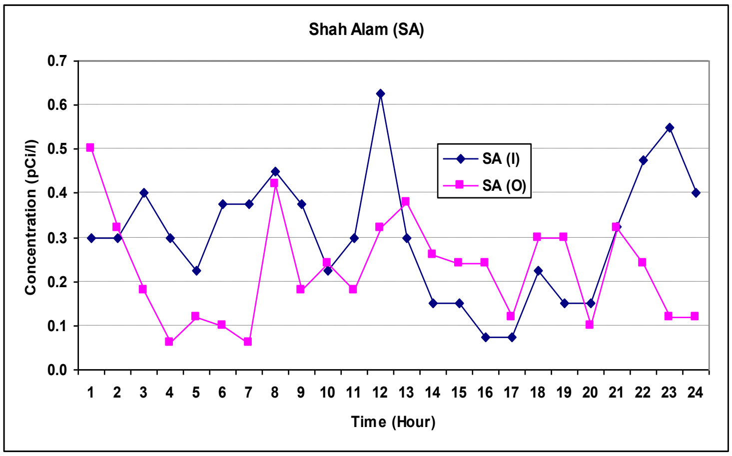


Figure 1: Map of Peninsular Malaysia showing the five study locations.

RESULTS AND DISCUSSION

One point that worth mentioning here is that although the study was short-term and the period for each location was different (Table 1), the effect of variation in weather on the results of the study is expected to be minimal. Malaysian weather is almost uniform, with rainfall throughout the year. This is evidenced by the average humidity of around 80%, almost constant outdoor pressure that averaged around 100.8 kPa, and temperature ranging between 25 ^{o}C to 30 ^{o}C, in the studied locations.

Figure 2 shows the temporal variation of radon concentration for twenty-four hours duration at the study locations. In the figure, for each location the indoor and outdoor variation was plotted on the same graph for comparison purpose. Generally, the results showed that in every location the indoor concentrations are higher than the corresponding outdoor. The indoor concentration especially in AP, KG, LP and KB followed a general trend of relatively higher concentration from the early hour in the morning till about 11 am as can be seen in Figure 2 (b, c, d and e). Much earlier study by another group on other location in Malaysia (Mahat *et al*., 1998) also showed the same trend of variation. The trend can be attributed to two reasons. The living style of the dwellers when they close the doors and windows and switched-off the living room fans at night might contribute to the observed trend. These will reduce ventilation in the living room, allowing the accumulation of radon gas in the room. The good correlation between indoor and outdoor concentration in these four locations indicated the possible outdoor origin of the indoor radon. The Pearson correlation coefficients between indoor and outdoor concentration are 0.754, 0.310, 0.580 and 0.342 for AP, KG, LP and KB respectively. This trend is also consistent with results of other study on the effect of ambient temperature to radon concentration. Being hotter in the afternoon, radon and its progeny concentration tends to be relatively lower (Sing *et al*., 2005). However the trend is not observable in SA as can be seen in Figure 2 (a). The Pearson correlation coefficient for SA is 0.052. The relatively low indoor and outdoor radon concentration in SA as compared to the four other locations might eclipse the expected trend pattern.



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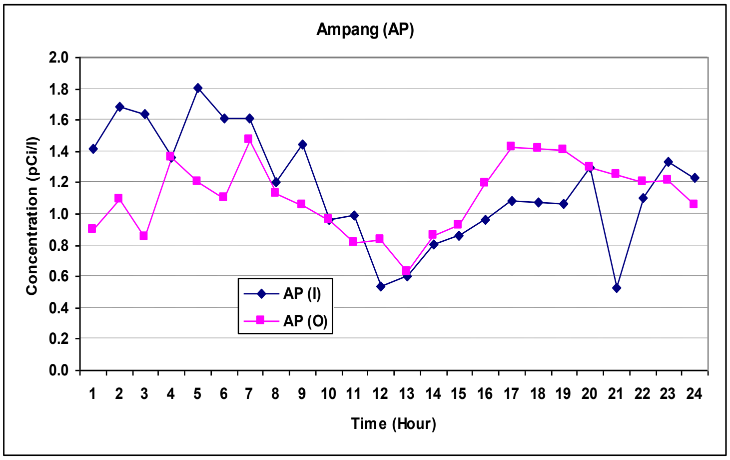

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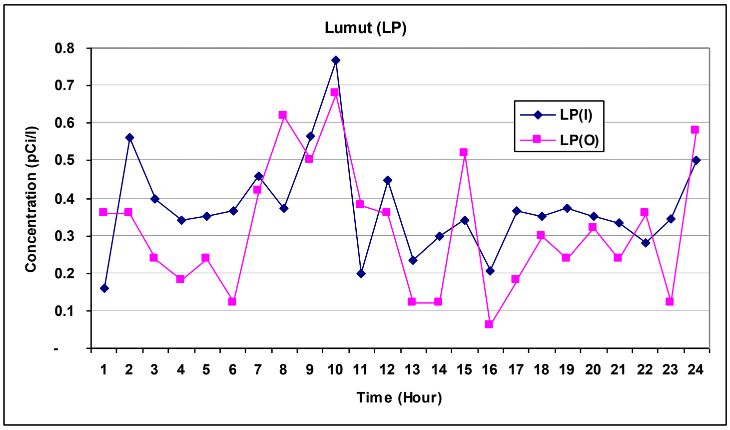

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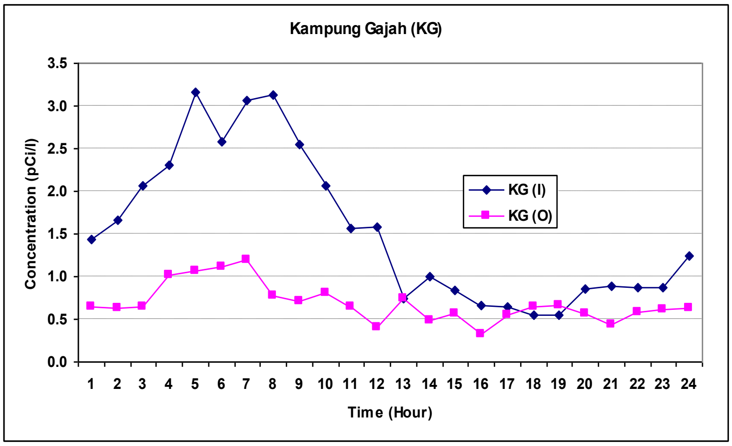

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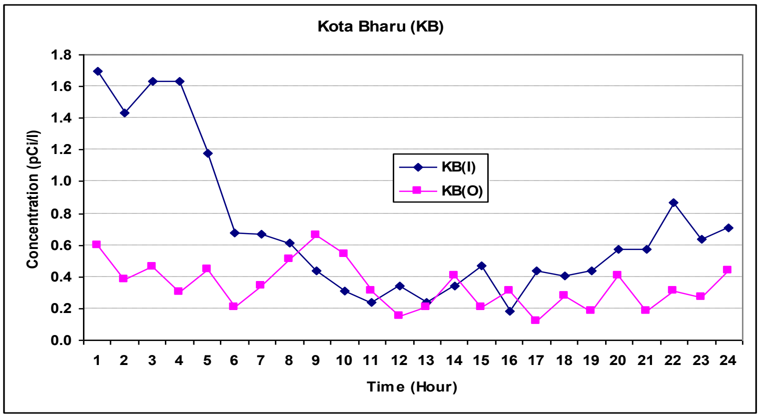

2(e)

Figure 2: Indoor and outdoor radon twenty-four hour temporal variation in (a) Shah Alam, SA (Oct – Nov. 2006), (b) Kampung Gajah, KG (Aug. – Nov. 2005), (c) Ampang, AP (Jan. – Jun. 2005), (d) Lumut, LP (May – July 2006), and.(e) Kota Bharu, KB, (May – July 2007).

Table 2: Indoor and outdoor mean radon concentration and the respective indoor annual effective dose at the study locations.

Locations	Number of Points	Mean ($pCiL^{-1}$)	Maximum ($pCiL^{-1}$)	Minimum ($pCiL^{-1}$)	Annual Effective Dose ($mSvyr^{-1}$)
SA (I)	15	0.30 ± 0.14	0.63	0.08	0.28 ± 0.13
SA (O)	15	0.23 ± 0.12	0.50	0.06	
KG (I)	15	1.54 ± 0.87	3.16	0.55	1.42 ± 0.81
KG (O)	15	0.69 ± 0.22	1.20	0.32	
AP (I)	15	1.18 ± 0.36	1.81	0.53	1.09 ± 0.33
AP (O)	15	1.11 ± 0.23	1.47	0.63	
LP (I)	15	0.37 ± 0.13	0.77	0.16	0.35 ± 0.12
LP (O)	10	0.32 ± 0.17	0.68	0.06	
KB (I)	10	0.70 ± 0.47	1.70	0.18	0.64 ± 0.43
KB (O)	10	0.34 ± 0.15	0.66	0.12	

Results of the studies on radon are normally presented in form of mean value and range. In Table 2 the mean values based on the 24 hours measurement of all motoring points at the respective locations, together with the corresponding maximum and minimum value of one hour interval are shown. Assuming minimal effect of weather variation as mentioned earlier, the results showed that both the indoor and outdoor means of KG and AP are up to five times higher than those of the other three locations. The concentrations reached maximum values at times between 5 am to 8 am. Being former tin mining areas, anthropogenic activities have disturbed the soil formation and contents in the areas, whereby uranium contained minerals such as ilmenite and monazite have been deposited on the top soil. Uranium (U-238) is the natural source of radon.

An Interesting observation is that the mean indoor concentration for KB, which is nearly twice higher than of SA and LP, though KB is not a former tin mine. This observation might be attribute to the fact that KB is situated on the delta of an estuary of a main river that originated in the mountain range on the backbone of Malaysia Peninsular. Sands and sediment, the results of weathering of igneous rock in the mountain range were carried by the river and deposited on the delta. Igneous rock naturally contained higher amount of uranium (Kadir *et al*., 2005). However, further study on uranium contents of soil in the vicinity need to be carried out to verify this.

The mean indoor radon concentration in all studied locations varies between 0.30 $pCiL^{-1}$ and 1.54 $pCiL^{-1}$. Presently Malaysia has no regulation on indoor radon concentration, these values, however are much lower than the indoor Action Level limit prescribed by either the USEPA (4 $pCiL^{-1}$) or NCRP (8 $pCiL^{-1}$) (Frumkin & Samet, 2001). The ruling for new buildings in Sweden is more stringent, whereby the maximum annual average is proposed not to exceed 70 Bqm^{-3} (about 2 $pCiL^{-1}$) (Crameri & Burkart, 1989). The global outdoor average radon concentration is 0.4 $pCiL^{-1}$ (UNSCEAR, 2000). The present study results found that the mean outdoor radon concentration in KG and AP are about four times higher than the global average. Again, assuming outdoor radon originates from soil, this showed that former tin mining soil emitted more radon gas than other soil in the study locations.

The mean indoor radon concentration ranging between 0.30 $pCiL^{-1}$ to 1.54 $pCiL^{-1}$ found in the present study is considerably lower than the mean in many European countries (Enflo, 2002) as shown in Table 3, and comparable to the mean in UK, Canada, USA, Hungary, Jordan and Saudi Arabia (Riyah). For Japan the corresponding mean concentration ranged between 0.43 $pCiL^{-1}$ and 5.14 $pCiL^{-1}$. Unlike Malaysia, indoor radon concentrations in majority of these temperate countries are affected by the season, where generally the concentrations are higher during colder seasons when doors, windows and openings are closed, hence little indoor and outdoor exchange of air taking place, thus trapping radon gas indoor.

Table 3: Comparison of the mean indoor radon concentration of the present study to the corresponding values of other countries.

Country	Mean Indoor Concentration ($pCiL^{-1}$)	Reference
Malaysia	0.30 – 1.54	Present Study
Finland	3.46 (128 Bqm^{-3})	Enflo, 2002
Norway	1.97 (73 Bqm^{-3})	Enflo, 2002
France	1.68 (62 Bqm^{-3})	Enflo, 2002
Denmark	1.43 (53 Bqm^{-3})	Enflo, 2002
UK	0.54 (20 Bqm^{-3})	Enflo, 2002
Canada	0.92 (34 Bqm^{-3})	Enflo, 2002
Hungary	1.14 (42 Bqm^{-3})	Hamori, *et al.*, 2006
USA	1.14 (42 Bqm^{-3})	Enflo, 2002
Jordan	1.41 (52 Bqm^{-3})	Kullab, 2005
Saudi Arabia (Riyadh)	0.49 (18 Bqm^{-3})	Al-Saleh, 2007
Japan	0.43 – 5.14 (16 -190 Bqm^{-3})	Enflo, 2002
Indoor Global Mean	1.08 (40 Bqm^{-3})	UNSCEAR, 2000

Finally, the study was extended to the estimation radon indoor annual effective dose to the dwellers by using Eq (1). The results for the five locations studied are shown in the last column of Table 2. The dose level ranged between 0.28 $mSvyr^{-1}$ in SA and 1.42 $mSvyr^{-1}$ in KG. Recent report of ICRP recommended the indoor action level of within the range of 3 $mSvyr^{-1}$ – 10 $mSvyr^{-1}$ (Al-saleh, 2007). On the basis of this recommendation the indoor dwelling effective dose found in the present study is lower than the action level.

ACKNOWLEDGMENTS

The authors would like to thank Universiti Teknologi MARA Malaysia for providing grant to carry out the study and to Hidayah, Norashikin, Norafiza and Azahari Ahmad (from Pusat Latihan UiTM) for their participation in the radon monitoring.

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