Chiang Mai J. Sci. 2016; 43(3) : 494-502
http://epg.science.cmu.ac.th/ejournal/
Contributed Paper

# Measurements of Indoor Radon Concentrations in the Phanom and Ko Pha-ngan Districts of Surat Thani Province, Thailand

**Kanokkan Titipornpun*[a], Somporn Sriarpanon [a], Apinun Titipornpun [b], Jan Gimsa [c], Tripob Bhongsuwan [d], Noodchanath Kongchouy [e]**

[a] Department of Physics, Faculty of Science and Technology, Suratthani Rajabhat University, Surat Thani 84100, Thailand.
[b] Suratpittaya School, Muang district, Surat Thani 84000, Thailand.
[c] Chair of Biophysics, Gertrudenstr. 11A, D-18057 Rostock, Germany.
[d] Department of Physics, Faculty of Science, Prince of Songkhla University, Songkla 90112, Thailand.
[e] Department of Mathematics and Statistics, Faculty of Science, Prince of Songkhla University, Songkla 90112, Thailand.
*Author for correspondence; e-mail: kmaswiwat@hotmail.com

Received: 18 November 2014
Accepted: 22 January 2016

## ABSTRACT

The Phanom and Ko Pha-ngan districts of Surat Thani province are known for their high atmospheric radon concentrations from different sources. While Phanom district is located in an active fault zone, the main radon source in Ko Pha-ngan district is the high amounts of equivalent uranium in the ground surface. Survey measurements of the indoor radon concentrations have been carried out in 105 dwellings and 93 workplaces, using CR-39 detectors that were exposed to indoor radon for forty days. Alpha tracks were made visible by chemical etching and counted manually under an optical microscope. The indoor radon concentrations in the two districts were found to vary between 9 and 63 Bq m$^{-3}$ (Phanom) and 12 and 645 Bq m$^{-3}$ (Ko Pha-ngan). The geometric mean radon concentration in Ko Pha-ngan district (51±2 Bq m$^{-3}$) was significantly higher than in the Phanom district (26±1 Bq m$^{-3}$) at a significance level of $p<0.05$ (t-test for independent samples). Nevertheless, only in two dwellings (1%), located in Ko Pha-ngan district, radon concentrations (177 and 645 Bq m$^{-3}$) were found to exceed the limit recommended by the US EPA of 148 Bq m$^{-3}$. The two houses are probably located near to radon sources which, in combination with low air convection, led to increased indoor levels of radon. Our study also shows that the geometric mean radon concentration was higher in workplaces than in dwellings (0.05 significance level) in both districts.

**Keywords:** indoor radon, CR-39 detector, active fault zone, equivalent uranium

## 1. INTRODUCTION

Radon-222 ($^{222}$Rn) is a natural radioactive, colourless, odourless and tasteless noble gas. It is formed by the decay of Radium-226 ($^{226}$Ra), which originates from the decay of Uranium-238 ($^{238}$U) which is found in all soils, rock and water. Generally, most of the exposure of the population to radon occurs domestically. Radon contributes more than one half to the effective dose received from all natural radiation sources [1]. Radon has a half-life of 3.82 days. During decay, it emits an alpha particle and transforms into a series of solid, shorted-lived fission products, of which polonium-218 ($^{218}$Po) and polonium-214 ($^{214}$Po) are of special medical importance. These daughter products decay rapidly, emitting high energy alpha particles (6-7.7 MeV). When the decay process occurs after inhalation, inside the lung, the emitted alpha particles may damage lung tissue, which can cause lung cancer in humans [2-5]. In the USA, radon isestimated to cause about 21,000 lung cancer deaths per year, which is the highest compared to other death causes such as drunken driving, domestic accidents, drowning, and home fires. The chances of a person getting lung cancer from radon depend on the indoor radon concentration, the amount of time spent indoors and whether the person had ever smoked or still is a smoker [6]. In many countries, radon is the second leading cause of lung cancer after smoking. Persons who smoke, or who have smoked in the past, are much more likely to get lung cancer than non-smokers. Especially, persons who smoke in homes with high radon levels, are at a high risk of lung cancer.The risk of health effects from radon exposure is about nine times higher among smokers than in non-smokers. However, there is no known threshold concentration below which no risk exists [7-8]. The indoor radon concentration of 4 pCi L$^{-1}$ (148 Bq m$^{-3}$) has been established as an "action level" by the Environmental Protection Agency (US EPA), above which measures are required to reduce the radon exposure in buildings [7]. At contrast, the World Health Organization (WHO) recommended an action level of 100 Bq m$^{-3}$and 300 Bq m$^{-3}$ in exceptional cases in order to minimize the health risksfrom radon exposure [8]. Radon typically moves through the ground up into the air and into homes through cracks in solid floors, construction joints, cracks in walls, gaps in suspended floors, gaps around service pipes, cavities inside walls and the water supply [9]. House construction materials, e.g., cement, bricks, sand, marble and concrete have been identified as the sources of indoor radon [10-13]. Some reports have correlated the indoor radon concentration with certain room types [14-16], the age of dwelling [14, 17], seasonal variations [17-21], and floor levels [15-18]. Moreover, the geogenic indoor radon values can be predicted using airborne equivalent uranium [22]. Because of the many factors influencing the indoor radon levels, the best way to estimate the actual indoor radon risk for a certain situation is to measure the indoor radon concentrations.

In this work, solid-state nuclear track detectors (SSNTDs) were used to measure the indoor radon concentrationsin workplaces and dwellings in the Phanom and Ko Pha-ngan districts of Surat Thani province, southern Thailand.

## 2. MATERIALS AND METHODS

### 2.1 The Study Area

Phanom and Ko Pha-ngan districts of Surat Thani province were selected as survey locations based on their high ground-surface concentrations of uranium according to airborne radiometric surveys that were carried out by the Department of Mineral Resources of Thailand. Below, the uranium concentration is given in parts per million of equivalent uranium (ppm eU). “Equivalent uranium” is referenced to the isotope equilibrium of the uranium-238 series.

Phanom district is located in the Klong Marui active fault zone where high levels of equivalent uranium are found in the ground-surface of some sub-districts, i.e., Plu Tuean, Khlong Cha Un, Phanom, Pang Karn, and Ton Yuan (Figure 1). The concentrations of radon in soil gas tend to increase in the vicinity to main fault planes [23-25], so dwellings that are located near the fault zone are at high risk for radon gas accumulation in buildings.

In the Ko Pha-ngan district, the ground surface-equivalent uranium levels are even higher than in Phanom district, exceeding 7 ppm eU in most areas (Figure 2). It must be assumed that these areas are at high risk of adverse indoor radon concentrations because areas with concentrations higher than 3 ppm eU have been identified as being at high risk for excessive indoor radon concentrations [26].

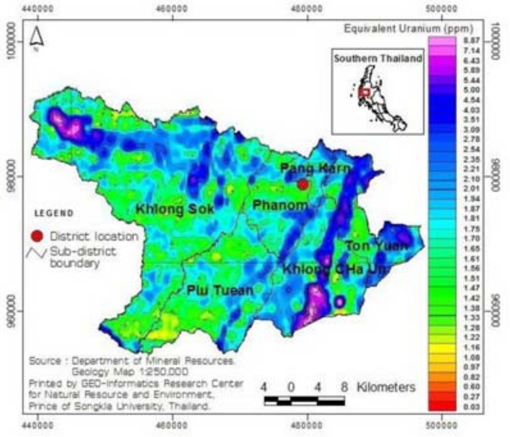

**Figure 1.** Map of equivalent-uranium concentrations in the ground surface of the Phanom district, Surat Thani province, Thailand.

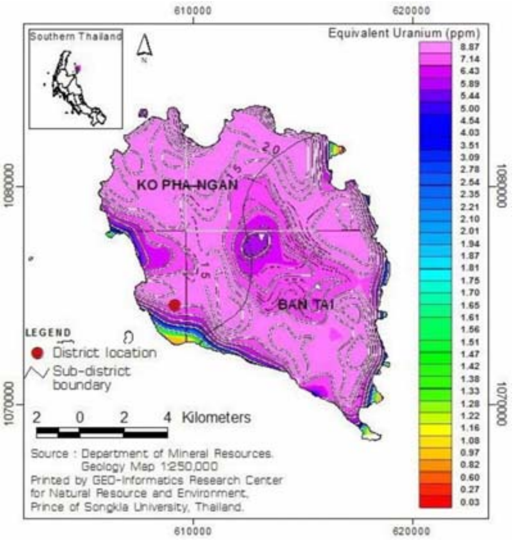

**Figure 2.** Map of equivalent-uranium concentrations in the ground surface of the Ko Pha-ngan district, Surat Thani province, Thailand.

### 2.2 Description of the Buildings

This study includes 198 buildings from two districts, which were selected for the survey. Totals of 115 and 83 buildings were selected from six sub-districts of Phanom district and two sub-districts of Ko Pha-ngan district. The sum of 198 buildings consists of 105 dwellings and 93 workplaces. As many as 84% of the buildings are single-storeyed, 15% have a second storey, while only 1% of the buildings have three storeys. The foundation of most buildings (94%) is flush with the ground, while some buildings (6%) had a crawlspace. Most of the buildings (78%) had been built generally using cement with bricks, sand, marble and concrete, while some buildings (19%) were built with cement and mainly wooden walls. Only a few old houses (3%) were made completely of wood. The natural ventilation of most buildings (82%) relies on open windows and doors throughout the day. In particular, rooms with air conditioning systems (18%) were poorly ventilated.

### 2.3 Indoor Radon Measurements

Radon measurements were carried out using CR-39 nuclear track detectors, commercially known as "TASTRAK" (Track Analysis Systems Ltd, UK). Large rectangular sheets (29 cm × 32 cm) of 1 mm thick CR-39 was cut into small rectangular pieces of 1.5 cm × 1.5 cm. These CR-39 chips were numbered at one corner for identification. For measurements, each CR-39 chip was fixed by a small piece of adhesive tape to the bottom center of 300 ml round plastic cups. The cups had an 8.5 cm diameter orifice, a 5 cm diameter base and a depth of 9.5 cm. The orifice of each cup was closed with cling film to allow only $^{222}$Rn gas to pass through the filter and to exclude the nongaseous radon daughters from entering the dosimeter [10, 27].

For the survey, a total of 198 detectors was used. They were mainly placed in the first floor of the buildings, either in the living or bedroom of dwellings, and in the workrooms of the places of work, at a height of approx. 1.5 m above the floor as the representative breathing height. Inside the rooms, the detectors were located away from the windows and doors. The detectors remained in the houses for an exposure time of 40 days. After this period, all detectors were removed and chemically etched in 6.25 M NaOH solution at 85°C for 100 minutes [28]. Each detector was thoroughly rinsed with distilled water and then dried. The alpha track density of each detector was counted manually under an optical microscope. The observed track densities were converted into radon concentration using a calibration factor (Figure 3).

## 3. RESULTS AND DISCUSSION

### 3.1 Calibration of Radon Concentrations

Calibration experiments were carried out to evaluate the relationship between the alpha track density and the actual radon concentration by the Thailand Institute of Nuclear Technology (Public organization), Nakhon Nayok province, Thailand, following the method of Sola, Wanabongse and Chankaw [29].

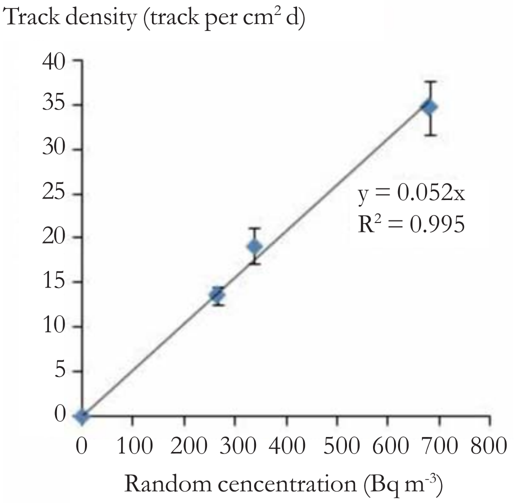

**Figure 3.** Plot of track densities over radon concentrations used to calibrate the CR-39 plastic cup detectors. The slope of the regression line of 0.052 tracks per cm$^2$d per Bqm$^{-3}$ represents the calibration factor k (Eq.(1)).

Figure 3 shows the relation of the detected track density and radon concentration. It allowed us to convert the observed track densities into radon concentrations using the Eq. (1):

$$C_{Rn} = \frac{D}{kt} \quad (1)$$

where $C_{Rn}$ is the radon activity concentration (in Bq m$^{-3}$), D is the track density in tracks per cm$^2$ corrected for background, t is the exposure time (40 d), and k is the calibration factor (0.052 tracks per cm$^2$ d per Bq m$^{-3}$).

### 3.2 Distribution of the Indoor Radon Concentrations

Figure 4 shows histograms of the number of samples as a function of indoor radon concentrations in the buildings in the Phanom and Ko Pha-ngan districts. The histogram of the Phanom district collected from 115 buildings of six sub-districts (Figure 4a) represents a slightly skewed distribution. Most number of samples had indoor radon concentrations in the range of 16 to 35 Bq $m^{-3}$ with 76 % (87 samples). The histogram for the Ko Pha-ngan district collected from 83 buildings in two sub-districts (Figure 4b) appears to be strongly skewed to the right. With 82 % of the data (68 samples) showed indoor radon concentrations between 21 to 80 Bq $m^{-3}$, the average radon concentration was clearly larger than in Phanom district.

Because the histograms in Figures 4a and 4b were found to be skewed to the right (Kolmogorov-Smirnov normality test, $p<0.05$), the data were transformed by applying the natural logarithm (Figures 4c and 4d). These figures indicated that the distribution frequency could be well fitted by the log-normal function (Kolmogorov-Smirnov normality test, $p>0.05$). Therefore, the geometric mean (GM) and geometric standard deviation (GSD) were used for further statistical description and hypothesis testing.

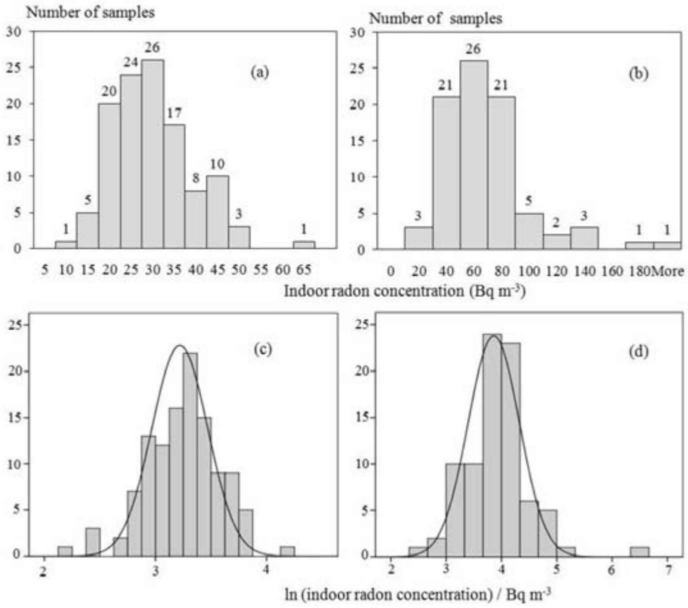

**Figure 4.** Histograms of the number of samples as a function of the indoor radon concentrations under normal plot and natural logarithm in the Phanom (a, c) and Ko Pha-ngan (b, d) districts.

### 3.3 Indoor Radon Concentrations in the Investigated Areas

Table 1 summarizes the statistical analysis of the indoor radon concentration measurements in the Phanom and Ko Pha-ngan districts. In the Phanom district, the indoor radon concentrations varied in the range from 9 to 63 Bq $m^{-3}$. The minimum indoor radon concentration was found in a well ventilated living room in the Ton Yuan sub-district,while the maximum concentration was found in a poorly ventilated living room in the Phanom sub-district. Comparison of the geometric mean indoor radon concentrations (GMIRC) between sub-districts showed statistically significant differences (One-way ANOVA, p = 0.008). The lowest GMIRC (22±1 Bq m$^{-3}$) was found in the Pang Karn sub-district, while the highest value (30±1 Bq m$^{-3}$) was found in the Ton Yuan sub-district, which were significantly different (Tukey's HSD, p = 0.018). The GMIRC for the entire investigated area of Phanom district was 26±1 Bq m$^{-3}$. In Ko Pha-ngan district, indoor radon concentrations varied from a minimum of 12 Bq m$^{-3}$ to a maximum of 645 Bq m$^{-3}$, which was an extreme value (Figures 5 and 6) found in a dwelling located in the Ko Pha-ngan sub-district. The difference of GMIRC between the Ko Pha-ngan sub-district (49±2 Bq m$^{-3}$) and Ban Tai sub-district (54±2 Bq m$^{-3}$) was not statistically significant (Independent samples t-test, two tailed, p = 0.115). The GMIRC of all samples in Ko Pha-ngan district was found to be 51±2 Bq m$^{-3}$.

**Table 1.** Variation of the indoor radon concentration in the Phanom and Ko Pha-ngan districts.

| District/ sub-district | Number of buildings | Indoor radon concentration (Bq m$^{-3}$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Min | Max | GM | GSD | >100 | >148 |
| Phanom district | 115 | 9 | 63 | 26 | 1 | - | - |
| 1. Phanom | 31 | 14 | 63 | 25 | 1 | - | - |
| 2. KhlongChaun | 17 | 11 | 42 | 23 | 1 | - | - |
| 3. KhlongSok | 19 | 19 | 41 | 27 | 1 | - | - |
| 4. Ton Yuan | 25 | 9 | 48 | 30 | 1 | - | - |
| 5. PluTuean | 7 | 17 | 42 | 25 | 1 | - | - |
| 6. Pang Karn | 16 | 12 | 31 | 22 | 1 | - | - |
| KoPha-ngan district | 83 | 12 | 645 | 51 | 2 | 8% | 2% |
| 7. KoPha-ngan | 51 | 12 | 645 | 49 | 2 | 8% | 2% |
| 8. Ban Tai | 32 | 19 | 177 | 54 | 2 | 9% | 3% |
| **Sum** | **198** | **9** | **645** | **34** | **2** | **4%** | **1%** |

GM = geometric mean, GSD = geometric standard deviation, >100 = indoor concentration level more than 100 Bq m$^{-3}$, >148 = indoor concentration level more than 148 Bq m$^{-3}$.

The GMIRC in the Ko Pha-ngan district was significantly higher than in the Phanom district (Independent samples t-test, two tailed, $p<0.05$). We suppose that the reason for this is that most of the buildings in Phanom district (95%) were well ventilated because their windows and doors were left open throughout the day. This relation has already been described for the radon levels in rooms with good or poorly ventilated rooms in India [30]. Furthermore, the levels of equivalent uranium in the ground surface are lower in Phanom district than in Ko Pha-ngan district (Figures 1 and 2).

Comparing indoor radon concentrations with the WHO and US EPA action levels, the results showed that 8% of the 83 buildings in Ko Pha-ngan exceeded the 100 Bq m$^{-3}$ action level recommended by the WHO [8] while only 2% exceeded the 148 Bq m$^{-3}$ action level recommended by the US EPA [7]. In the Ko Pha-ngan sub-district, the indoor radon concentration was found to exceed 100 Bq m$^{-3}$ in 8% of 51 buildings while 148 Bq m$^{-3}$

were exceeded only in 2% of the buildings. In the Ban Tai sub-district, 100 Bq m$^{-3}$ were exceeded in 9% of 32 buildings while 148 Bq m$^{-3}$ were exceeded in 3% of the buildings.

The GMIRC for our entire data was 34±2 Bqm$^{-3}$. At 52±17 Bq m$^{-3}$, the averaged indoor radon concentrations in Na Mom district of Songkla province, southern Thailand were higher than the mean, while they were lower in the Phu Wiang district of Khon Kaen province, North-East Thailand (21±7 Bqm$^{-3}$) and the Saraphi district of Chiang Mai province, northern Thailand (21±6 Bqm$^{-3}$) [31]. With respect to the action levels, the indoor radon concentrations were found to exceed 100 Bq m$^{-3}$ in 4% of all buildings while they exceeded 148 Bq m$^{-3}$ in only 1%.

### 3.4 Variation of the Indoor Radon Concentration for Different Types of Buildings

All 105 dwellings and 93 workplaces of the survey were compared, in order to consider the influence of the types of building on the indoor radon concentrations. Table 2 shows the minimum, maximum, geometric mean, standard deviation and the percentage of indoor radon concentrations exceeding 100 Bq m$^{-3}$ and 148 Bq m$^{-3}$, respectively. The minimum (9 Bq m$^{-3}$) and maximum (645 Bq m$^{-3}$) values were respectively found in dwellings with good and poor ventilations.

The GMIRC in workplaces (41±2 Bqm$^{-3}$) was found to be higher than in dwellings (29±2 Bqm$^{-3}$) at a 0.05 significance level (Independent samples t-test, two tailed, $p< 0.05$). While only 3% of the rooms in dwellings have air conditioning, this applies to 13% of the rooms in workplaces, resulting in poorer ventilation. Accordingly, the GMIRC in workplaces was higher than in dwellings. This finding is in agreement with radon concentration measurements in workplaces and dwellings in North-Western Greece [32] and Italy [33]. Out of 105 dwellings 1% and 2% exhibited concentrations exceeding 100 Bq m$^{-3}$ and 148 Bq m$^{-3}$, respectively, while 4% out of 93 rooms in workplaces exceeded 100 Bq m$^{-3}$. Nevertheless, indoor radon concentrations did not exceed 148 Bq m$^{-3}$ in any of the workplace rooms.

It is important to note that surveys to measure indoor radon concentrations in this work didn't include the spas and hotels in Ko Pha-ngan district. Therefore, the actual average indoor radon concentration of this district may be different from our result. This indicates that surveys to measure indoor radon concentrations in the buildings should be investigated in all types of buildings. Moreover, the results of this study were obtained from the short-term measurements which did not provide an accurate estimation of the annual average indoor radon concentration. The long-term measurements remain in the buildings for more than 90 days should be better for the annual average radon level [9]. In addition, the variation of indoor radon concentrations depends on many factors, e.g. building materials, building age and floor level. Therefore, a direct comparison with each factor should be a subject of a future study.

## 4. CONCLUSIONS

Indoor radon concentrations have been measured in the districts of Phanom (six different sub-districts, 115 buildings) and Ko Pha-ngan (two different sub-districts, 83 buildings). Both districts are located in the Surat Thani province, Thailand. Only in 1% of 198 buildings were radon concentrations (177 and 645 Bqm$^{-3}$) found that exceeded the action level recommended by the US EPA (148 Bqm$^{-3}$). Both of them were located in

Ko Pha-ngan district. By far most of the indoor radon concentrations were in the 16-to-35 Bq m$^{-3}$ ranges (geometric mean: 26±1 Bq m$^{-3}$) and 21-80 Bq m$^{-3}$ (geometric mean: 51±2 Bq m$^{-3}$) in the Phanom and Ko Pha-ngan districts, respectively. The difference from the geometric mean in the two districts was significant ($p<0.05$).

Our results suggest that radon concentrations are especially higher in houses with low ventilation located in areas with high levels of equivalent uranium in the ground surface. In most of the surveyed buildings (91%), the indoor radon concentration levels could be reduced by simply improving their ventilation. In houses with excessive radon concentrations in particular, the residents were able to take action to significantly reduce the concentration in a number of simple and inexpensive ways, e.g. by using a vent pipe system and fan, by sealing foundation cracks and other openings in the soil, by opening windows to provide passive ventilation, etc. [7]. We believe that our results should be confirmed by long-term measurements in order to take a closer look at seasonal variability or the influence of factors such as the age of houses, different construction material, etc.

## ACKNOWLEDGEMENTS

The authors wish to thank all the inhabitants of the buildings we investigated for their cooperation. We are grateful to the Department of Mineral Resources of Thailand for providing a map of the equivalent uranium distribution in the ground as well as the Geographic Informatics Research Center for Natural Resource and Environment, Prince of Songkla University, Thailand for designing a map of the uranium-equivalent distribution. We would also like to thank the Thailand Institute of Nuclear Technology (Public organization), Nakhon Nayok province, Thailand for help in calibrating our system. Last but not least, we gratefully acknowledge Suratthani Rajabhat University for granting our research. The authors wish to thank R. Sleigh for his help with the language.

## REFERENCES

[1] UNCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), Sources and effects of ionizing radiation, *Report to the general assembly, with scientific annexes*, United Nations, New York, 2000; vol. 1.

[2] NAS (National Academyof Science), Health risks of radon and other internationally deposited alpha-emitters, *BEIR IV Report*, National Academy Press, Washington, D.C., 1988.

[3] IARC (International Agency for Research on Cancer), Man-made mineral fibres and radon, *IARC Monographs on the evaluation of carcinogenic risks to humans*, 1988; ISBN 92-832-1243-6.

[4] ICRP (International Commission on Radiological Protection), Lung cancer risk from exposures to radon daughters, *ICRP Publication*, 1987; vol. 50: Ann. ICRP 17(1).

[5] NCRP (National Council on Radiation Protection and Measurements), Exposure from the uranium series with emphasis on radon and its daughters, *Report 77*, Bethesda, Maryland, 1984.

[6] US EPA(United States Environmental Protection Agency),Aphysician's guide: The health threat with asimple solution,*Air and radiation*, 1993; EPA 402-K-93-008.

[7] US EPA, Technical support document for the 1992 citizen's guide to radon, Air and radiation, 1992; EPA 400-R-92-011.

[8] WHO (World Health Organization), WHO Handbook on Indoor Radon: A Public Health Perspective, WHO press,

Geneva, 2009.

[9] US EPA, A citizen's guide to radon: the guide to protecting yourself and your family from radon, *Air and radiation*, 2012; EPA 402/K-12/002.

[10] Abu-Jarad F., Fremlin J.H. and Bull R.A., *Phys. Med. Biol.*, 1982; **25**: 683-694.

[11] Savidou A., Rapits C. and Kritidis P., *J. Environ. Radioact.*, 1996; **31**: 21-28.

[12] Rizzo S., Brai M., Basile S., Bellia S. and Hauser S., *Appl. Radiat. Isot.*, 2001; **55**: 259-265.

[13] Faheem M. and Matiullah, *Radiat. Meas.*, 2008; **43**: 1458-1462.

[14] Cucos (Dinu) A., Cosma C., Dicu T., Begy R., Moldovan M., Papp B., Nita D., Burghele B. and Sainz C., *Sci. Total Environ.*, 2012; **431**: 78-83.

[15] Rahman S.U. and Matiullan J.A., *Radiat. Meas.*, 2008; **43**: S401-S404.

[16] Al-Khateeb H.M., Al-Qudah A.A., Alzoubi F.Y., Alqadi M.K. and Aljarrah K.M., *Appl. Radiat. Isot.*, 2012; **70**: 1579-1582.

[17] Manousakas M., Fouskas A., Papaefthymiou H., Koukouliou V., Siavalas G. and Kritidis P., *Radiat. Meas.*,2010; **45**: 1060-1067.

[18] Bochicchio F., Campos-Venuti G., Piermattei S., Nuccetelli C., Risica S., Tommasino L., Torri G., Magnoni M., Agnesod G., Sgorbati G., Bonomi M., Minach L., Trotti F., Malisan M.R., Maggiolo S., Gaidolfi L., Giannardi C., Rongoni A., Lombardi M., Cherubini G., D'Ostilio S., Cristofaro C., Pugliese M., Martucci V., Crispino A., Cuzzocrea P., Santamaria A.S. and Cappai M., *Radiat. Meas.*, 2005; **40**: 686-694.

[19] Hadad K., Doulatdar R. and Mehdizadeh S., *J. Environ. Radioact.*, 2007; **95**: 39-52.

[20] Rahman S., *Radiat. Meas.*, 2010; **45**: 247-252.

[21] Burke O. and Murphy P., *Radiat. Meas.*, 2011; **46**: 1168-1172.

[22] Wattananikorn K., Emharruthai S. and Wanaphongse P., *Radiat. Meas.*, 2008; **43**: 85-90.

[23] Giammanco S., Imme G., Mangano G., Morelli D. and Neri M., *Appl. Radiat. Isot.*, 2009; **67**: 178-185.

[24] Burton M., Neri M. and Condorelli D., *Geophys. Res. Lett.*, 2004; **31(7)**: L07678.

[25] Bhongsuwan T., Pisapak P. and Dürrast H., *Songklanakarin J. Sci. Technol.*, 2011; **33(5)**: 609-616.

[26] Duval J.S., *Trans. Am. Geophys. Union*, 1988; **70**: 496-502.

[27] Abel-Ghany H.A., *Iran. J. Radiat. Res.*, 2008; **6(3)**: 113-120.

[28] Sirijarukul S., *The Investigation of Radon Gas in Ground Water Around Songkhla Lake Basin using Nuclear Track Etching Technique*, MSc Thesis, Prince of Songkla University, Thailand, 1999.

[29] Sola B., Wanabongse P. and Chankaw N., *Siam Physics Congress 2009*, Ch-am, Phetchaburi, Thailand, 19-21 March 2009; 1-7.

[30] Khan A.J., *Radiat. Meas.*, 2000; **32**: 87-92.

[31] Wanabongse P., Tokonami S. and Bovornkitti S., *International Congress Series*, 2005; **1276**: 208-209.

[32] Loannides K., Patiris D. and Papachristodoulou C., *Radioprotection*, 2009; **44**: 165-169.

[33] Bucci S., Pratesi G., Viti M.L., Pantani M., Bochicchio F. and Venoso G., *Radiat. Prot. Dosim.*, 2011; **145**: 202-205.