Radon Exhalation Rates of Soil Samples from Khon Kaen Province, Thailand

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Date received: April 30, 2021
Revision accepted: November 27, 2021

Abstract

Radon, which can be also detected in water, forms naturally from the decay of uranium and radium found in different amounts in soil and rock. Radon from soil gases is the main cause of health hazards. Radon exhalation escapes from the ground into the air, where radon and radon progeny decays and produces radioactive particles. When inhaled, they can damage the deoxyribonucleic acid and potentially cause lung cancer. Hence, this study measured the radon exhalation rates in soil samples from 26 districts of Khon Kaen Province, Thailand by the active detector method. The closed-loop measurement system in the active detector was made up of the electronic radon detector and a bulk chamber in a 2.8-L volume. The measurement time for each sample was 24 h. Results showed that the radon concentration in soil samples varied from 5.60 to 67.10 Bq m^{-3} (average: 21.94±4.55 Bq m^{-3}). The radon mass exhalation rates ranged from 7.34 to 17.51 mBq kg^{-1} h^{-1} (average: 11.39±3.38 mBq kg^{-1} h^{-1}) while the radon surface exhalation rates were in the range of 0.29 to 1.31 mBq m^{-2} h^{-1} (average: 0.81±0.90 mBq m^{-2} h^{-1}). The radon surface exhalation rate of the soil samples was below the average worldwide value of 57,600 mBq m^{-2} h^{-1} as set by the United Nations Scientific Committee on the Effects of Atomic Radiation. It was concluded that the soil from the province does not pose any radiological health hazard to the general public.

Keywords: Khon Kaen, radon exhalation rate, RAD7, soil sample, Thailand

1. Introduction

Radon is a naturally occurring radioactive inert gas with a half-life of 3.825 days resulting from the radioactive decay of uranium, thorium and the actinium series (Aswood *et al*., 2017; Maier *et al*., 2021). Today, radon and its progeny constitute the most important natural radiation exposure (Parajuli *et al*., 2015). Since radon is a colorless, odorless and tasteless gas, its effect cannot be realized until it manifests some biological disorders in organisms. Radon decay products are extremely small solid particles that can be easily inhaled and can produce highly ionized alpha, beta, or gamma radiation, which damages the deoxyribonucleic acid (DNA) and potentially leads to cancer (World Health Organization [WHO], 2009; Hassan and Ibrahim, 2018).

Soil is recognized as an important source of indoor radon – an air pollutant that is associated with roughly half of the effective dose equivalent to the general public from natural radiation (Grzywa-Celinska *et al*., 2020; Thumvijit *et al*., 2020). The main entry of radon into the atmosphere is by molecular diffusion. Radon generates the main natural radiation exposure for human beings and has been recognized as a carcinogenic gas (Duggal *et al*., 2015). Das (2021) underscored that that radon exposure is associated with the risk of leukemia, melanoma and kidney and prostate cancer. The soil-gas radon concentration and its exhalation rate depend on the geology of the area, soil porosity and structures (shears, faults and thrusts), and is associated with uranium mineralization (Kumar *et al*., 2017). Although these elements occur in virtually all types of rocks and soils, their concentrations vary depending on the specific sites and the geological formation of materials.

Thailand has been a subject of study on radon and the risk of radon exposure. In Phu Wiang District, Khon Kaen Province; Saraphi District, Chiang Mai Province; and Na Mhom District, Songkhla Province, the indoor radon levels were at 21±70, 21±6 and 52±17 Bq m^{-3}, respectively; measurements on dissolved radon in 75 natural hot spring samples collected from 22 provinces yielded radon levels of 0.80 to 7,219.70 Bq L^{-1} (Wanabongse *et al*., 2005). Thumvijit *et al.* (2020) quantified the indoor radon concentrations and their associated risk in Chiang Mai Province, Thailand. The radon levels and total indoor annual effective doses were in the range of 29 to 101 Bq m^{-3} and 0.90 to 3.80 mSv y^{-1}, respectively. The investigation of radon in drinking water at Mueang District, Khon Khaen Province revealed that the radon concentrations were at 0.14 to 0.92 Bq L^{-1} with a mean of 0.47 Bq L^{-1}, while the annual effective dose for drinking water ranged from 0.010 to 0.066 mSv y^{-1} (mean: 0.033 mSv y^{-1}) (Atyotha and Sola, 2015). Sola *et al.* (2013) found that the radon concentrations in indoor and outdoor air, hot spring water and bottled water produced in a hot spring area in Suan Phueng District, Ratchaburi Province varied from 10 to 17 (indoor) and 11 to 147 Bq m^{-3} (outdoor); 2 to 154 Bq L^{-1}; and 17 to 22 Bq L^{-1} (seven days of storage) and 0.2 to 0.3 Bq L^{-1}

(90 days of storage), respectively. Furthermore, the radon concentration and radon exhalation rate and the effective dose from rock used for building materials with 27 samples had an average of 49.24±8.43 Bq m^{-3}, 16.56±3.00 mBq kg^{-1} h^{-1} and 1.24±0.21 mSv y^{-1}, respectively. (Kaewtubtim *et al*., 2019).

Based on the mentioned reports on radon in Thailand, there are no data or research studies on radon in soil, specifically its radon exhalation rate – the rate at which radon escapes or emanates from the soil into the surrounding air. This may be measured by either per unit mass or per unit surface area of the soil. Measuring the radon exhalation rate of soils and rocks is highly significant in studying radon health hazards, and understanding and minimizing the risk of radon exposure to humans (Thabayneh, 2018; Negm *et al*., 2019). Thus, this study aimed to determine the radon concentration and radon mass and surface exhalation rates of soil samples from the different districts of Khon Kaen Province, Thailand by using a bulk chamber and a RAD7 radon detector (Abbas *et al*., 2020; Mohammed *et al*., 2020).

2. Methodology

2.1 Study Area

The study was carried out in 26 districts of the Khon Kaen Province, Thailand (Figure 1). Khon Kaen Province is on the Khorat Plateau with an elevation of 187 m. It is the center of the mid-northeastern provincial group of Thailand. Having an area of 10,886 km^2, the province is located between the latitude of 15 to 17 N and the longitude of 101 to 103 E. The Khon Kaen Province's terrain is sloping from west to the east and south. The high area on the west side has a limestone rocky area interspersed with slightly undulating waves. Khon Kaen has a large area of highlands, where the soil looks like deep soil that is deeper than 101.6 cm and continues until rocks or another strongly contrasting materials are found. The topsoil is sandy or loamy with brown-gray or brown color. The lower soil is also sandy and loamy with a pink and very pale brown hue. With a pinkish-gray color, the clay layers are found at a depth of less than 100 cm from the surface. Pale brown and sandy loam soil with brown spots is seen at the bottom ground and red-yellow in the ground below. The soil condition is medium acidic to acidic (pH: 5 to 6) making it unsuitable for crops cultivation (Ministry of Natural Resources and Environment, 2009).

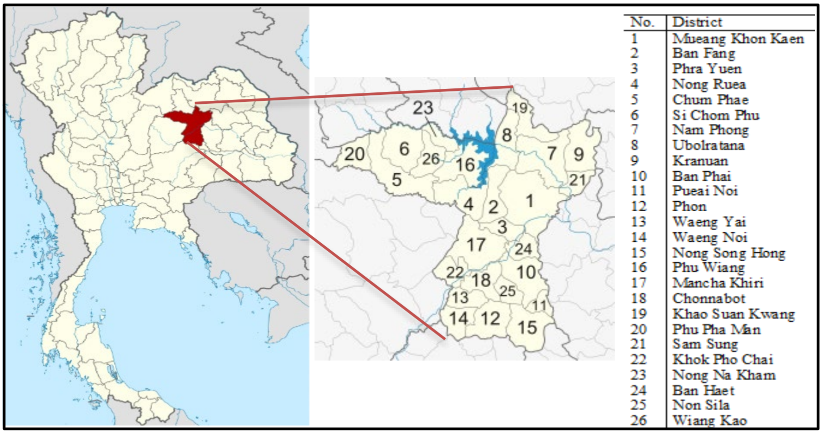

Figure 1. Map of Khon Kaen Province, Thailand showing the 26 districts where the soil samples were collected

2.2 Sampling Method

The radon mass and radon surface exhalation rates were measured in the 94 soil samples of the selected 26 districts of the study area. The soil samples were collected at the depth of 15 to 30 cm from the soil profile to obtain undisturbed and pure soil samples. About 1 kg of soil samples was collected from each location. The soil samples were not collected from the surface because radium nuclides might have been flushed away by wind or water. While collecting the soil samples, it was ensured that soil samples were free from gravel and pebbles. After removing the stones and organic materials, samples were crushed into fine powder by using mortar and pestle. The fine quality of the sample was obtained using a scientific sieve of 100 mesh size. The samples were then oven-dried at ~110 °C for 24 h to remove the moisture content. The fine powder (0.25 kg) of samples from each district was placed in a container and sealed for a month to attain equilibrium. After a month, the radon mass and radon surface exhalation rates of soil samples were measured using the active detector method. Figure 2 shows the soil sample collection in Khon Kaen Province, Thailand (study areas).

2.3 Electronic Radon Detector

A calibrated electronic radon detector (RAD7, Durridge, United States) was used for the measurement of radon in air, soil gas and water. It was also utilized to quantify the emission of radon from surfaces, objects and bulk materials. The equipment is a highly versatile instrument for radon detection through which the radon concentration can be obtained in real time. It is also equipped with the semiconductor α-detector and works on the principle of converting energy of α-particles directly into electrical signals. The RAD7 is a sniffer that detects the 3-min alpha decay of a radon daughter (^{218}Po) without interference from other radiations. With a capacity to recover from high radon exposures in minutes, the instrument can sniff for entry points and radon gushers. The measuring range is between 4 and 750,000 Bq m^{-3}. The internal acquisition provides storage for up to 1,000 radon measurements. At the end of each run, the detector can print out a complete report.

Figure 2. The soil sample collection in study areas

2.4 Active Detector Method

A diagram of the experimental setup is given in Figure 3. The active detector method measured the radon mass and radon surface exhalation rates. The closed-loop measurement system was made up of the RAD7 and a bulk emission chamber, which is made of metals with a volume capacity of 2.8±0.05 L. Radon concentrations in the measurement system were observed as a function of time with data collection of 24 replication cycles at 1 h/cycle. The measurement time of 24 h was allocated for each sample. All measurements were conducted at room temperature and normal pressure while the relative humidity in the RAD7's internal sample cell was kept below 10%. The linear and exponential fittings were used to obtain radon mass and radon surface exhalation rates from observed data. For every measurement, before placing the soil sample inside the bulk emission chamber, the RAD7 was purged with fresh outdoor air for 20 min by the pump-air circulation to remove pre-existing radon gas in the chamber.

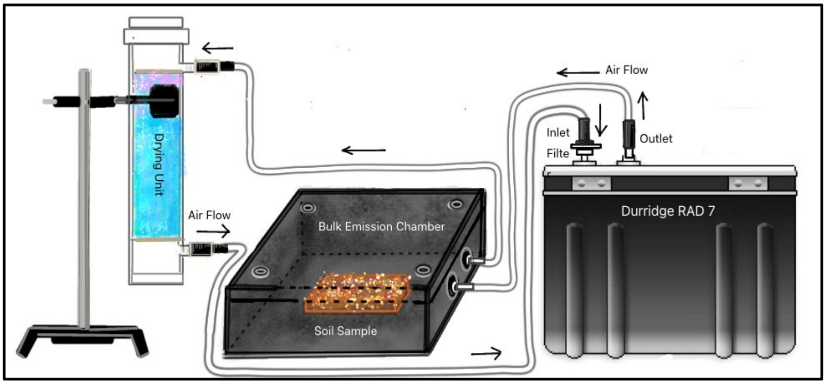

Figure 3. The experimental setup diagram of the active detector method

2.5 Calculation of Radon Surface and Mass Exhalation Rates

The radon surface and mass exhalation rates were calculated using Equations 1 and 2, respectively (Kaliprasad and Narayana, 2018; As-Subaihi *et al*., 2019).

$$E_A = \frac{CV\lambda}{A\left[T + 1/\lambda\left(e^{-\lambda T} - 1\right)\right]} \qquad (1)$$

$$E_M = \frac{CV\lambda}{M\left[T + 1/\lambda\left(e^{-\lambda T} - 1\right)\right]} \qquad (2)$$

where E_A is the radon surface exhalation rate (mBq m^{-2} h^{-1}), E_M is the radon mass exhalation rate (mBq kg^{-1} h^{-1}), C is the radon concentration as measured by RAD7 (Bq m^{-3}), V is the effective volume of the container (m^3), T is the exposure time (h), λ is the decay constant for radon (h^{-1}), A is the area of the cross-section of soil sample (m^2) and M is the mass of soil sample (kg).

3. Results and Discussion

3.1 Soil Radon Concentration

The radon concentrations in 94 soil samples from 26 Districts of Khon Kaen Province, Thailand were found to vary from 5.60 to 67.10 Bq m^{-3} with an average of 21.94±4.55 Bq m^{-3}. The soil samples from site 17 (Mancha Khiri District) obtained the highest radon concentration of 67.10 Bq/m^{-3} as shown in Table 1 and Figure 4. This was probably due to the presence of monazite, which is, from the geological data of the said district, mixed in a large amount of gravel, sand and silt (Ministry of Natural Resources and Environment, 2009). Monazite is a radioactive mineral that is a potential source of radon (Ault *et al*., 2015; Alnour *et al*., 2017). The results from Table 1 (radon concentration and GPS coordinates of sampling) were used to create a contour map for the distribution of radon concentration in 26 Districts of Khon Kaen Province as shown in Figure 4. This contour map provides the radon distribution projection in areas that have not yet been measured.

Table 1. Radon concentration in soil samples from Khon Kaen Province

Site	No.	Coordinates	C_{Rn} (Bq m^{-3})			Site	No.	Coordinates	C_{Rn} (Bq m^{-3})		
			Max	Min	Ave				Max	Min	Ave
1	7	16° 26’ 18” N, 102° 50’ 20” E	41.90	13.40	23.99	14	3	15° 48’ 13” N, 102° 24’ 57” E	24.40	5.60	11.87
2	3	16° 27’ 12” N, 102° 38’ 18” E	30.70	11.20	23.30	15	4	15° 44’ 1” N, 102 °47’ 44” E	33.00	9.30	21.33
3	3	16° 19’ 26” N, 102° 38’ 55” E	25.10	15.90	21.93	16	5	16° 39’ 16” N, 102° 22’ 37” E	36.30	14.00	27.38
4	4	16°29’ 36” N, 102° 26’ 0” E	28.40	18.20	21.45	17	3	16° 7’ 36” N, 102° 32’ 32” E	67.10	6.70	28.47
5	4	16° 32’ 39” N, 102° 5’ 59” E	33.50	14.00	23.78	18	4	16° 5’18” N, 102 °37’ 18” E	39.70	19.40	26.13
6	4	16° 48’ 1” N, 102° 11’ 16” E	25.20	5.60	15.40	19	3	16° 51’ 31” N, 102° 51’ 42” E	39.10	19.60	30.87
7	5	16° 42’ 10” N, 102° 51’ 17” E	39.10	5.60	20.12	20	3	16° 38’ 42” N, 101° 54’ 14” E	26.40	19.60	23.73
8	4	16° 45’ 10” N, 102° 37’ 58” E	27.90	11.20	18.80	21	3	16° 32’ 35” N, 103° 4’ 47” E	30.70	8.90	22.53
9	4	16° 42 ‘22” N, 103° 4’ 44” E	27.90	5.60	13.98	22	3	16° 5’ 1” N 102° 23’ 56” E	25.60	5.60	18.77
10	3	16° 3’ 36” N, 102° 43’ 51” E	22.40	11.50	15.97	23	3	16° 48’ 3” N, 102° 20’ 28” E	33.50	19.60	27.93
11	3	15° 52’ 17” N, 102° 54’ 20” E	23.20	14.00	18.00	24	3	16° 12’ 9” N, 102° 45’ 3” E	36.30	11.20	23.27
12	4	15° 48’ 57” N, 102° 35’ 55” E	33.50	17.80	27.48	25	3	15° 58’ 26” N, 102° 40’ 9” E	28.00	8.40	17.87
13	3	15° 57’ 34” N, 102° 32’ 52” E	36.40	12.20	23.03	26	2	16° 42’ 5” N, 102° 17’ 3” E	25.40	13.50	19.45

C_{Rn} – radon concentration; max: 67.10±8.19 Bq m^{-3}; min: 5.60±2.37 Bq m^{-3}; ave: 21.94±4.68 Bq m^{-3}

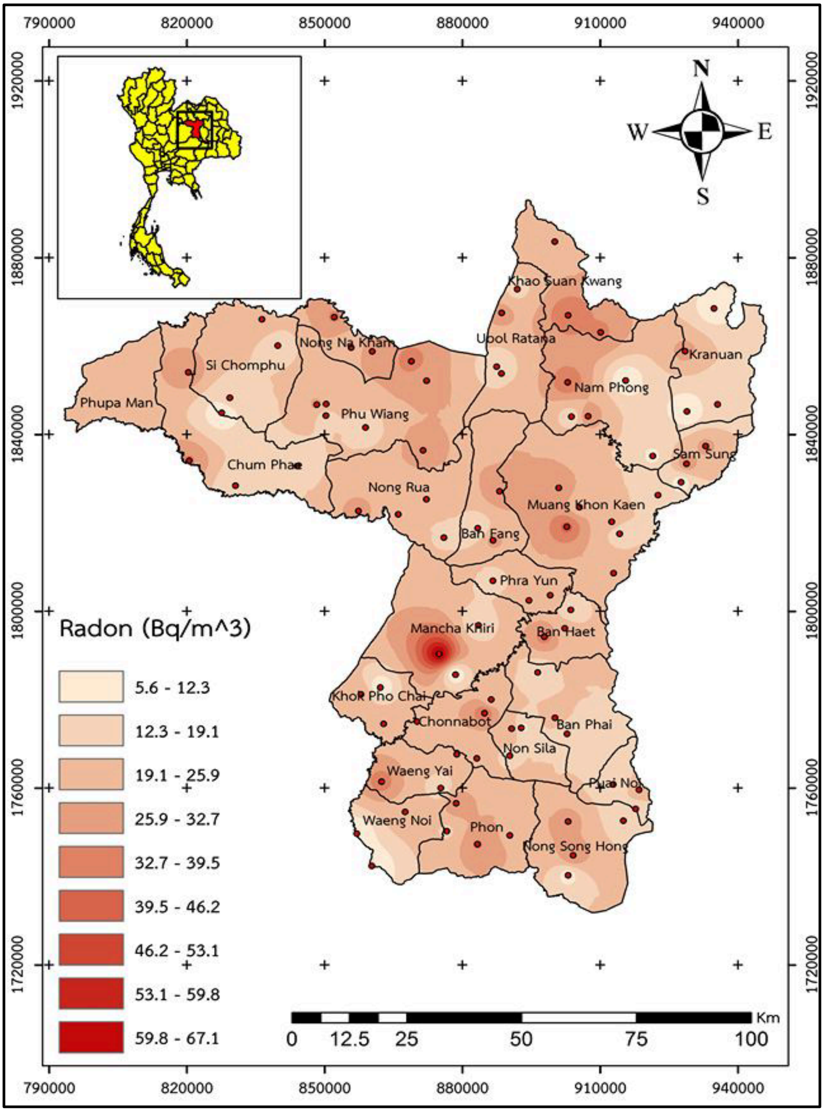

Figure 4. The contour map for distribution of soil radon concentration in Khon Kaen Province

The soil samples from site 14 (Waeng Noi District) had the lowest radon concentration (24.40 Bq m^{-3}). This can be linked to the presence of rock salt and potash distributed in the mentioned area (Ministry of Natural Resources and Environment, 2009). In Waeng Noi District, the geological condition is not the source of radon radiation; thus, the radon concentration in the soil was lesser.

3.2 Soil Radon Mass and Surface Exhalation Rates

Table 2 shows the results of calculated radon mass and radon surface exhalation rates from radon concentration in Table 1. The radon mass exhalation rates from the soil samples varied from 7.34 to 17.51 mBq kg^{-1} h^{-1} with an average of 11.39±3.38 mBq kg^{-1} h^{-1}, while the radon surface exhalation rates ranged from 0.29 to 1.31 mBq m^{-2} h^{-1} with an average of 0.81±0.90 mBq m^{-2} h^{-1}. Radon concentration levels of the soil samples collected from different sites in Khon Kaen Province, measured through the bulk emission chamber with RAD7, were found to be lesser than the range of 200 to 600 Bq m^{-3} as recommended by the International Commission on Radiological Protection (1993). Correspondingly, the said radon concentration levels were also lesser than the new reference level of 100 Bq m^{-3} set by the WHO (2009).

Table 2. The radon mass and surface exhalation rates soil samples from Khon Kaen Province

District	E_M (mBq kg^{-1} h^{-1})	E_A (mBq m^{-2} h^{-1})	District	E_M (mBq kg^{-1} h^{-1})	E_A (mBq m^{-2} h^{-1})
1. Mueang	11.17	0.69	14. Waeng Noi	7.34	0.74
2. Ban Fang	11.16	0.87	15. Nong Song Hong	10.08	0.90
3. Phra Yuen	9.73	1.26	16. Phu Wiang	14.76	0.74
4. Nong Ruea	12.41	1.14	17. Mancha Kiri	17.51	0.62
5. Chum Phae	12.41	0.89	18. Chonnabot	13.14	0.55
6. Si Chomphu	9.00	1.31	19. Khao Suan Kwang	15.39	1.29
7. Nam Phong	8.79	0.78	20. Phu Pha Man	13.99	0.78
8. Ubolratana	9.41	0.96	21. Sam Sung	8.70	0.79
9. Kranuan	7.34	0.47	22. Khok Pho Chai	11.83	0.77
10. Ban Phai	9.01	0.48	23. Nong Na Kham	14.66	0.95
11. Pueai Noi	8.78	0.91	24. Ban Haet	9.48	0.29
12. Phon	13.52	0.31	25. Non Sila	9.37	1.01
13. Waeng Yai	16.56	0.36	26. Wiang Kao	10.63	1.31
Total radon mass exhalation rates: max = 17.51±4.18; min = 7.34±2.71; ave = 11.39±3.37 mBq kg^{-1} h^{-1}					
Total radon surface exhalation rates: max = 1.31±1.14; min = 0.29±0.54; ave = 0.81±0.90 mBq m^{-2} h^{-1}					

E_M – radon mass exhalation rates; E_A – radon surface exhalation rates

The results of radon mass and radon surface exhalation rates (Table 2) were compared with the worldwide results (Table 3). It can be observed that the rates in the province were below than those previously reported in other countries. Hence, the said rates can be considered safe for people with reference to the international standards.

Table 3. Radon mass and surface exhalation rates of other countries and the present study

Country	E_M (mBq kg^{-1} h^{-1})			E_A (mBq m^{-2} h^{-1})			Reference
	Max	Min	Ave	Max	Min	Ave	
Saudi Arabia	251	135	-	8,400	4,580	-	Farid (2016)
India	1,052.66	29.99	247.21	1,890.39	80.92	521.08	Kaliprasad and Narayana (2018)
Palestine	7.84	0.26	1.97	207.20	6.90	52.20	Thabayneh (2018)
Yemen	53.02	25.99	36.28	938.47	460.08	642.12	As-Subaihi *et al.* (2019)
Iraq	0.64	0.16	0.37	27.56	6.89	15.13	Mohammed (2020)
Ireland	-	-	-	1,840	150	-	Aghdam *et al.* (2021)
Malaysia	0.72	0.11	-	2.00	0.31	-	Saipuddin *et al.* (2021)
South Korea	85	40	-	3,029	1,421	-	Lee and Kang (2021)
Thailand	17.51	7.34	11.39	1.31	0.29	0.81	Present study

It can be seen that the radon mass exhalation rates from this study were lower than that of the average values in Saudi Arabia, India, Yemen and South Korea. However, the present rates were higher than the average values found in Palestine, Iraq and Malaysia. On the other hand, the radon surface exhalation rates from this study were lower than that of the average values in all countries. The same with the case of the present study's radon concentration, the radon surface exhalation rates were well below the world average values of 57,600 mBq m^{-2} h^{-1} as laid down by the United Nations Scientific Committee on the Effects of Atomic Radiation (2000).

4. Conclusion

The radon concentration in the soil sample from 26 districts of Khon Kaen Province, Thailand were found at 5.60 to 67.10 Bq m^{-3}, which were below the acceptable range set by the international health organizations. In the same way, the observed values of radon mass (average: 11.39±3.38 mBq kg^{-1} h^{-1})

and radon surface exhalation (average: 0.81±0.90 mBq m^{-2} h^{-1}) rates in soil samples were lesser than the worldwide average. It can be concluded that the soil of the province has radon levels that are safe for the general public.

5. Acknowledgement

The authors would like to acknowledge and thank Rajamangala University of Technology Isan for funding and supporting this research.

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