

RADON MEASUREMENT IN CONSTRUCTION MATERIALS FROM THE NORTHEASTERN REGION OF THAILAND

Ritiron Samran, Phachirarat Sola*, Uthaiwan Injaroen, and Roppon Picha

Received: August 25, 2021; Revised: August 03, 2022; Accepted: November 18, 2022

Abstract

Indoor radon concentration plays a vital role in the total annual effective dose due to internal radiation exposure. This research investigated the radon gas found in concrete, which consists of rocks, sand, and cement. It can be found in most houses and buildings in Thailand to evaluate the possible residents' health hazards. Radon was measured using an ionization chamber detector (ATMOS 12 DPX), and the values of the radon concentration, radon exhalation rate, and annual effective dose were calculated. This study collected concrete samples from Loei, Khon Kaen, Nong Bua Lam Phu, Bueng Kan, Nakhon Phanom, Mukdahan, Ubon Ratchathani, and Nakhon Ratchasima provinces in the northeastern region of Thailand. The radon concentration in the concrete samples varied from 22.00 ± 4.00 to 110.00 ± 8.00 Bq·m⁻³, with an average of 56.77 ± 5.77 Bq·m⁻³. These values were below the guideline level of 148 Bq·m⁻³, recommended by the US Environmental Protection Agency (US EPA). The radon exhalation rate varies from 4.20 ± 0.84 to 55.07 ± 4.00 Bq·kg⁻¹·h⁻¹, with an average of 15.47 ± 1.68 mBq·kg⁻¹·h⁻¹. The annual effective dose ranges from 0.57 ± 0.10 to 2.89 ± 0.21 mSv·y⁻¹, with an average of 1.47 ± 0.15 mSv·y⁻¹. The International Commission recommends the dose limit of 1 mSv·y⁻¹ for public exposure on Radiological Protection (ICRP).

Keywords: Annual effective dose; Construction materials; Radon; Thailand provinces

Introduction

Construction materials such as rocks, soil, and sand contain naturally occurring radioactive materials (NORMs). One of the most prevalent radioactive substances is radon (Rn-222), which is a decay product of Ra-226 in the U-238 decay series. Rn-222 has a half-life of 3.82 days. It emits alpha particles of high energy (5.5 MeV). These alpha particles can damage DNA (deoxyribonucleic acid)

in humans. Therefore, radon entering the respiratory system can increase lung cancer risk. From a World Health Organization (WHO) report, radon is the second most important cause of lung cancer, next to cigarette smoking (Naomi *et al.*, 1984; Hajo and Ferid, 2009). Rn-222 is a gaseous radioisotope commonly found in the outdoor and indoor atmospheres. However, the radon concentration

Thailand Institute of Nuclear Technology (Public Organization). 9/9 Moo 7, Saimoon, Amphur Ongkarak, Nakhon Nayok, 26120, Thailand. E-mail: ritiron@tint.or.th; phachirarats@tint.or.th*; uthaiwan@tint.or.th; and aeroppon@tint.or.th

* Corresponding Author

DOI:

outdoors is lower than indoors because of better ventilation. Therefore, radon gas is accumulated inside houses and buildings (Konstantin, 2006). Radon can diffuse from the floor and cracks in homes and residential buildings and be contained inside such structures (Cothorn *et al.*, 1987). Different building materials such as brick, stone, soil, sand, iron, and cement all contain NORMs which can also be contaminated with metal particles (Po-218, Bi-214, Pb-210, and natural uranium) (Grace *et al.*, 2008). Construction materials from different geographical locations may have different elemental compositions; therefore, they can have different radioactivity levels (Aksoy *et al.*, 2002; Righi *et al.*, 2006; Joseph *et al.*, 2010).

This study aims to measure radon concentration in concrete, the main component of most residential buildings. The samples were collected from the northeastern region of Thailand, including Loei, Khon Kaen, Nong Bua Lamphu, Bueng Kan, Nakhon Phanom, Mukdahan, Ubon Ratchathani, and Nakhon Ratchasima provinces. The closed-chamber method measured the alpha radiation using an ionization chamber (ATMOS 12 DPX). The radon exhalation rate and annual effective dose were calculated to assess the health impact of the construction materials. The radiation safety level of 1 mSv·y⁻¹ set by the International Commission on Radiological Protection (Smith, 1991) was used as the reference.

Materials and Methods

The source of radon can be raw materials used in construction. Therefore, concrete may contain radon-emitting materials. However, in the northeastern provinces of Thailand, especially in the small cities, concrete products are mixtures of raw materials such as gravel, sand, cement, and water, etcetera, bought from the local market. In this study, 26 concrete samples were collected from random locations in the northeastern region of Thailand to analyze the radon level in each province's raw materials. The provinces are shown in Figure 1.

The samples were ground into powder, dried, weighed, and kept inside a closed stainless chamber (0.064m³). The samples were left inside the chamber for about three hours to check for chamber leakage. A pressure gauge was used to confirm that the tank did not leak. Air was fed into the tank through an activated charcoal cylinder. The samples were kept inside until an equilibrium was reached between Rn-222 and radon products (typically, it took 30 days). After that, the ionization chamber (ATMOS 12 DPX) was connected to the tank's gas flow system to measure the radon released from the construction

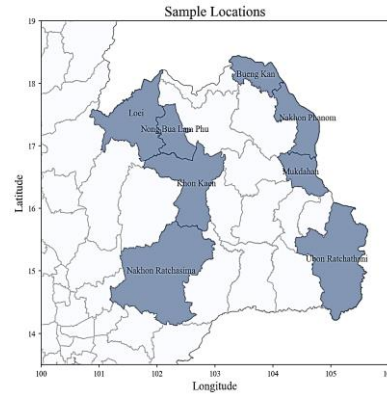


Figure 1. Sampling areas of the concrete samples in the northeastern region of Thailand. The unit of latitude and longitude shown is degrees (°)

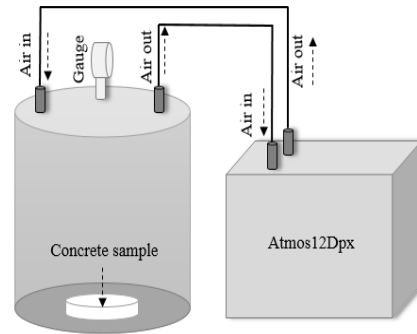


Figure 2. Diagram of radioactivity measurement using the ionization chamber (ATMOS 12 DPX)

materials in Figure 2. The measurement time for each sample was approximately two hours.

The mass radon exhalation was calculated from the radon concentration in the closed system and the radon exhalation:

$$C_{\infty} = \frac{C(t)}{(1 - e^{-\lambda t})} \quad (1)$$

$$E = \frac{C_{\infty} V \lambda}{S} \quad (2)$$

where C_{∞} is the maximum measured radon concentration in the equilibrium ($\text{Bq} \cdot \text{m}^{-3}$), $C(t)$ is the radon concentration measured ($\text{Bq} \cdot \text{m}^{-3}$) at time t (h), λ is the decay constant of Rn-222 ($7.6 \times 10^{-3} \text{ h}^{-1}$), E is the radon exhalation rate of the sample ($\text{Bq} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$), V is the volume of the stainless-steel tank used in sample measurement (m^3), S is the surface area of the sample (m^2).

In the case where a sample does not have a geometrical shape and is in powder form, the radon

exhalation rate can be replaced by the mass exhalation rate:

$$E_{Mass} = \frac{C_{\infty} V \lambda}{M} \quad (3)$$

where E_{Mass} is the mass radon exhalation rate of the sample ($\text{Bq} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$), and M is the sample weight (kg) (Kovler *et al.*, 2005). We calculated the annual effective dose from the equation:

$$H = C \times F \times T \times D \quad (4)$$

Where H is the annual effective dose ($\text{mSv} \cdot \text{y}^{-1}$), C is the radon concentration ($\text{Bq} \cdot \text{m}^{-3}$), F is the radon equilibrium factor (0.4), T is the indoor occupancy factor ($7000 \text{ h} \cdot \text{y}^{-1}$), and D is the dose conversion factor ($9.0 \times 10^{-6} \text{ mSv} \cdot \text{h}^{-1} \text{ per } \text{Bq} \cdot \text{m}^{-3}$) (United Nations, 2000).

Results and Discussion

The measured radon concentrations of the samples ranged from 22.00 ± 4.00 to $110.00 \pm 8.00 \text{ Bq} \cdot \text{m}^{-3}$, of which the lowest value was found at Nakhon Phanom and the highest value at Mukdahan. The summary statistics based on different locations are shown in Table 1. The calculated mass radon exhalation ranged from 4.20 ± 0.84 to $55.07 \pm 4.00 \text{ mBq} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$, the average radon exhalation rate ($17 \text{ mBq} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$) is lower than the previous values

of Hungary, Norway, and USA reported by UNSCEAR (1988) in Table 2. The annual effective dose was from 0.57 ± 0.10 to $2.89 \pm 0.21 \text{ mSv} \cdot \text{y}^{-1}$. Overall, the radon concentration was $56.77 \pm 5.77 \text{ Bq} \cdot \text{m}^{-3}$, the radon exhalation was $15.47 \pm 1.68 \text{ mBq} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$, and the annual effective dose was $1.47 \pm 0.15 \text{ mSv} \cdot \text{y}^{-1}$.

Conclusion

The radon concentrations of the concrete samples collected from the northeastern region of Thailand, measured in the closed system using an ionization chamber, ranged from 22.00 ± 4.00 to $110.00 \pm 8.00 \text{ Bq} \cdot \text{m}^{-3}$, with an average of $56.77 \pm 5.77 \text{ Bq} \cdot \text{m}^{-3}$. The calculated radon exhalation rate ranged from 4.20 ± 0.84 to $55.07 \pm 4.00 \text{ mBq} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$, with an average of $15.47 \pm 1.68 \text{ mBq} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ and the annual effective dose from 0.57 ± 0.10 to $2.89 \pm 0.21 \text{ mSv} \cdot \text{y}^{-1}$, and the average is $1.47 \pm 0.15 \text{ mSv} \cdot \text{y}^{-1}$. It can be seen that the radon concentrations in the region studied are lower than the average indoor radon concentration ($148 \text{ Bq} \cdot \text{m}^{-3}$) as reported by the United States Environmental Protection Agency (US EPA, 1992). The calculated annual effective doses in some areas were slightly higher than the standard $1 \text{ mSv} \cdot \text{y}^{-1}$ recommended by the International Commission on Radiological Protection (ICRP). However, the results were from the measurement in a closed system. Characteristically, due to natural ventilation, radon

Table 1. Radon concentration, mean mass radon exhalation, and annual effective dose of concrete samples by province

Location	Mean Radon Concentration ($\text{Bq} \cdot \text{m}^{-3}$)	Mean Mass Radon Exhalation ($\text{mBq} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$)	Mean Annual Effective Dose ($\text{mSv} \cdot \text{h}^{-1}$)
Loei	61.67 ± 5.67	10.60 ± 1.00	1.60 ± 0.13
Khon Kaen	54.00 ± 6.67	7.63 ± 0.90	1.40 ± 0.20
Nong Bua Lam Phu	86.00 ± 7.00	14.60 ± 1.20	2.20 ± 0.20
Nakhon Ratchasima	65.00 ± 6.00	11.70 ± 1.10	1.70 ± 0.20
Buang Kan	54.67 ± 5.60	15.95 ± 1.83	1.41 ± 0.14
Nakhon Phanom	22.00 ± 4.00	10.80 ± 2.00	0.57 ± 0.10
Mukdahan	110.00 ± 8.00	55.07 ± 4.00	2.89 ± 0.21
Ubon Ratchathani	26.00 ± 4.00	16.50 ± 2.50	0.70 ± 0.10
Average	59.92	17.86	1.56
SD	28.95	15.34	0.75

Table 2. Radon exhalation rates reported in previous research. (UNSCEAR, 1988)

Material	Country	Number of samplings	Rn-222 mass exhalation rate ($\text{mBq} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$)
Concrete	Hungary	100	28
Concrete	Denmark	4	17
Concrete	Norway	137	34 - 58
Concrete	USA	50	9 - 72

concentrations in enclosed spaces are higher than in open-air areas. Good airflow can effectively reduce the build-up of radon concentration.

Acknowledgment

The authors thank Ms. Koonlanat Warangkul and Ms. Areeya Kluakrathok from TINT for their assistance in sample preparation.

References

- Aksoy, A., Al-Jarallah, M.N., and Al-Haddad, M.N. (2002). Natural radioactivity in the scale of water well pipes. *Journal of Environmental Radioactivity*, 61(1):33-40. [https://doi.org/10.1016/S0265-931X\(01\)00112-6](https://doi.org/10.1016/S0265-931X(01)00112-6)
- Cothorn, C.R., and Smith, J.E. (1987). *Environmental Radon*. Springer. New York, 218p. <https://doi.org/10.1007/978-1-4899-0473-7>
- Grace, W.W., Gao-Tang, Y.H., Tam, C.M., and Gao, X.F. (2008). Anti-radon coating for mitigating indoor radon concentration. *Atmospheric Environment*, 42(37):8,634-8,639. <https://doi.org/10.1016/j.atmosenv.2008.08.009>
- Hajo, Z., and Ferid, S. (2009). WHO handbook on indoor radon- a public health perspective. WHO, France, 95p.
- Joseph, G.A., Taeko, M., Theodore A.M., James. H.S., John, F. M, and David, L.M. (2010). Assessing exposure to granite countertops part 2-Radon. *J. Expo Sci Environ Epidemiol*, 20(43):263-272. <https://doi.org/10.1038/jes.2009.43>
- Konstantin, K. (2006). Radon exhalation of hardening concrete: monitoring cement hydration and prediction of radon concentration in construction site. *Journal of Environmental Radioactivity*, 86(3):354-366. <https://doi.org/10.1016/j.jenvrad.2005.10.005>
- Kovler, K., Perevalov, A., Steiner, V., and Metzger, L.A. (2005). Radon exhalation of cementitious materials made with coal fly ash: Part 1 – scientific background and testing of the cement and fly ash emanation. *Journal of Environmental Radioactivity*, 82(3):321-334. <https://doi.org/10.1016/j.jenvrad.2005.02.004>
- Naomi, H., Harley, F.T., Cross, B.D., Stuart, V.E., Archer, D.A.M., and John, H.H. (1984). Evaluation of Occupational and Environmental Exposures to Radon and Radon Decay products in the United States. NRPC, USA, 203p.
- Righi, S., and Bruzzi, L. (2006). Natural radioactivity and radon exhalation in building materials used in Italian dwellings. *Journal of Environmental Radioactivity*, 88(2):158-170. <https://doi.org/10.1016/j.jenvrad.2006.01.009>
- Smith, H. (1991). Recommendation or the international commission on radiological protection. ICRP publication, New York, 422p.
- United Nations. (2000). United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly with Scientific Annexes. United Nations, New York, 659p.
- UNSCEARS. (1988). Effects and Risks of Ionizing Radiation- Annex B: Exposures from nuclear power production. United Nations, New York, 647p.
- US EPA. (1992). National emission standards for hazardous air pollutants, emission standards for radon emissions from phosphogypsum stacks (final rule) Federal Register (40CFR61). United States: U.S. Environmental Protection Agency. Available from: <https://www.ecfr.gov>. Accessed date: June 25, 2021