Measurements of indoor radon concentrations in Chaiya and Tha Chana districts, Surat Thani province, Thailand

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Abstract. Chaiya and Tha Chana districts of Surat Thani province are located in the areas with high levels of equivalent uranium at the ground surface, which have been identified as sources of radon. A survey measurement of indoor radon concentrations was carried out in 248 houses, using CR-39 detectors in closed cups. The geometric mean of indoor radon concentrations in Chaiya and Tha Chana districts were $62 \pm 6 \text{ Bq} \cdot \text{m}^{-3}$ and $03 \pm 6 \text{ Bq} \cdot \text{m}^{-3}$, respectively. Although the minimum radon concentration was 4 Bq•m⁻³ in both locations, the maximum radon concentration was found to be 159 Bq•m⁻³ in Tha Chana district, while it was 88 Bq•m⁻³ in Chaiya district. The level of radon concentrations above the action level (148 Bq•m⁻³) recommended by the United States Environmental Protection Agency was only found in two houses, which accounted for 1% of the total buildings surveyed in this present study. The majority of houses, which accounted for 94% of the total buildings surveyed, showed the radon concentration below the action level. As these houses had access to air flow during the daytime through open doors and windows, it is likely that such ventilation was sufficient to keep radon at a low concentration.

1. Introduction
Radon gas ($^{222}\text{Rn}$) is well known to pose public health risk as it has been reported that indoor radon is the second leading cause of lung cancer after tobacco smoking [1]. In addition, radon is also an important source of the natural radiation. The effective dose of radon gas from inhalation is more than half of all natural radiation sources [2]. Because radon is an inert gas, it can easily enter into houses through cracks in walls and solid floors, gaps in suspended floors and around service pipes, construction joints, cavities inside walls and water supply [3]. The United States Environmental Protection Agency (U.S. EPA) has recommended the “action level” of 148 Bq•m⁻³ to reduce lung cancer risk due to radon exposure in homes [4]. While the World Health Organization (WHO) proposed a reference level of indoor radon concentrations at 100 Bq•m⁻³ for minimization of health
hazards [5]. Therefore, the measurement of the indoor radon concentration is important and has been investigated around the world. The worldwide arithmetic mean of the indoor radon levels has been estimated at 39 Bq m$^{-3}$ [5]. In Thailand, some measurements of indoor radon concentrations have been studied. The indoor radon concentrations were measured at Phu Wiang district of Khon Kaen province, Saraphi district of Chiang Mai province and Na Mom district of Songkhla province which are located in the northeastern, northern and southern regions of Thailand, respectively. In these areas, no excess level of radon above the action level of EPA was found [6]. A feasibility of geogenic indoor radon mapping from airborne radiometric survey had been studied on three basins of northern Thailand. The estimated indoor radon zone map showed that there was no alluvial and terrace basins of northern Thailand found in the risk zone [7]. In southern Thailand, the indoor radon concentrations were measured in Songkhla province. The result showed that the highest average radon concentration above the action level of EPA [8] was found in Na Mom district. However, the risk zone due to indoor radon concentration cannot be identified without measurement.

The main objective of this study was to measure the indoor radon concentrations in Chaiya and Tha Chana districts of Surat Thani province, southern Thailand. In addition, variation in indoor radon concentrations due to building materials was investigated.

2. Survey location
Chaiya and Tha Chana districts, which are located in the northern part of Surat Thani province in the south of Thailand, were selected as the survey locations to collect data on radon concentration (figure 1). Chaiya and Tha Chana districts were subdivided into 9 subdistricts (54 villages) and 6 subdistricts (81 villages), respectively. In addition to our data collection, radiometric surveys of airborne particles were performed by the Department of Mineral Resources of Thailand. The unit of uranium concentration at the isotope equilibrium for uranium-238 series is shown in part per million, equivalent uranium (ppm eU). The equivalent uranium at the ground surface in more than half of the investigated locations were higher than 3 ppm eU, the level that has been identified as the high level of indoor radon [9]. A total of 248 buildings were randomly selected for radon measurement. These included 131 buildings from 9 subdistricts in Chaiya district and 117 buildings from 6 subdistricts in Tha Chana district. All buildings were separated to be dwellings (7%), retail shops (79%), private offices (8%), and public offices (6%). Most buildings (97%) included in the survey area had one story, while the rest (3%) had two stories. The foundations of buildings were made from slab-on-ground (98%) and crawl space (2%), respectively.
3. Materials and Methods

A total number of 248 buildings were surveyed for measurements of indoor radon concentrations using CR-39 nuclear track detectors. The large rectangular sheets of CR-39 (29 cm x 32 cm, 1 mm thickness) were supplied by the Track Analysis Systems Ltd, UK. The sheets were then cut into 1.5 cm x 1.5 cm chips and each was numbered on the right corner for identification purpose. Control chips were stored in sealed bags at -15°C to minimize aging and gas leakage. For indoor radon measurement, each CR-39 chip was fixed by a small piece of the adhesive tape to the bottom centre of the plastic cup. Each cup has 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, 11]. In each building, a detector was mainly placed in the living room for dwellings, and in the working room for retail shops, private and public offices. The height of each detector was placed about 1.5 m above the floor as representative of breath height inside the rooms and away from the windows and doors. All detectors were installed on the first floor for 40 days, the time period that was within the range of established protocol that allowed for the quick and reliable assessment of radon measurement [3, 4]. After exposure to radon in air, all measured detectors including background chips were chemically etched in 6.25 M of NaOH solution at 85°C for 100 minutes [12]. After chemical etching, each detector was washed with distilled water and then dried out. The alpha track density caused by radon occurred in each detector was counted manually under an optical microscope. To relate track density with indoor radon concentration, the dosimeters were evaluated at Thailand Institute of Nuclear Technology (Public organization), Nakhon Nayok province, Thailand, following the method of Sola et al. [13].
densities were converted into radon concentrations using the calibration factor of 0.052 track·cm⁻²·d⁻¹ per Bq·m⁻³.

4. Results and discussion

4.1. Variation in indoor radon concentrations.

Figure 2 shows the frequency distribution histograms of the number of rooms as a function of indoor radon concentrations in the buildings in Chaiya and Tha Chana districts. The histogram of Chaiya district collected from 131 buildings (figure 2a) appeared to be slightly skewed to the right, whereas the histogram for Tha Chana district collected from 117 buildings (figure 2b) appeared to be strongly skewed. The majority of rooms had indoor radon concentrations in the range of 21 to 40 Bq·m⁻³ at both locations. Because of the skew in the data distribution of Chaiya and Tha Chana districts, the data were transformed by applying the natural logarithm shown in figure 2c (Chaiya district) and figure 2d (Tha Chana district). The frequency distributions of the indoor radon concentrations at both locations were well described by the log-normal model. Therefore, the geometric mean (GM) and geometric standard deviation (GSD) as well as minimum (Min) and maximum (Max) values were used to describe the results and for statistical comparisons.

![Figure 2](image.png)

Figure 2. Frequency distributions of the indoor radon concentrations under normal plot and logarithmic transformation in Chaiya (a, c) and Tha Chana (b, d) districts.
Table 1 summarizes the statistics of indoor radon concentrations in Chaiya and Tha Chana districts. In Chaiya district, the indoor radon concentrations were found to vary from 4 - 88 Bq m\(^{-3}\), whereas the indoor radon concentrations in Tha Chana district varied from 4-159 Bq m\(^{-3}\). The minimum indoor radon concentration was 4 Bq m\(^{-3}\) in both Phum Rieng and Wang subdistricts located in Chaiya and Tha Chana districts, respectively. The maximum radon concentration was 88 Bq m\(^{-3}\) in Pak Mark subdistrict of Chaiya district, whereas it was 159 Bq m\(^{-3}\) in Khlong Pha subdistrict of Tha Chana district. The minimum value was found in the coastal areas, whereas the maximum values were found in the mountainous areas.

| District/ subdistrict | Number of buildings | Indoor radon concentration (Bq m\(^{-3}\)) | % (No.) | % (No.) |
|-----------------------|---------------------|-------------------------------------------|---------|---------|
|                       |                     | Min | Max | GM\(^a\) | GSD\(^b\) | >100 Bq m\(^{-3}\) | >148 Bq m\(^{-3}\) |
| Chaiya district       |                     |     |     |         |         |                 |                   |
| 1. Talad Chaiya       | 12                  | 4   | 88  | 26      | 2        | -                | -                 |
| 2. Ta Krop            | 14                  | 11  | 49  | 24      | 2        | -                | -                 |
| 3. Thung              | 15                  | 16  | 39  | 24      | 1        | -                | -                 |
| 4. Pak Mark           | 20                  | 19  | 88  | 39      | 2        | -                | -                 |
| 5. Pa Way             | 18                  | 9   | 71  | 30      | 2        | -                | -                 |
| 6. Phum Rieng         | 14                  | 4   | 51  | 19      | 2        | -                | -                 |
| 7. Mo Tai             | 9                   | 16  | 58  | 33      | 2        | 8% (1)          | 8% (1)            |
| 8. La Med             | 17                  | 11  | 57  | 24      | 2        | -                | -                 |
| 9. Wieng              | 12                  | 8   | 47  | 20      | 2        | -                | -                 |
| Total                 | 131                 | 4   | 88  | 26      | 2        | 9% (11)         | 2% (2)            |
| Tha Chana district    | 117                 |     |     |         |         |                 |                   |
| 1. Khlong Pha         | 12                  | 7   | 159 | 36      | 2        | 8% (1)          | 8% (1)            |
| 2. Khan Thu Lee       | 21                  | 12  | 151 | 48      | 2        | 29% (6)         | 5% (1)            |
| 3. Tha Chana          | 23                  | 13  | 136 | 30      | 2        | 13% (3)         | -                 |
| 4. Phra Song          | 20                  | 7   | 72  | 27      | 2        | -                | -                 |
| 5. Wang               | 21                  | 4   | 48  | 20      | 2        | -                | -                 |
| 6. Samor Thong        | 20                  | 16  | 130 | 30      | 2        | 5% (1)          | -                 |
| Total                 | 117                 | 4   | 159 | 30      | 2        | 9% (11)         | 2% (2)            |

\(^a\)GM = geometric mean  
\(^b\)GSD = geometric standard deviation.

Comparison of the geometric mean indoor radon concentrations among the subdistricts showed statistically significant differences (\(p < 0.05\), one-way ANOVA) in both districts. In Chaiya district, the lowest geometric mean of radon concentration of 19 ± 2 Bq m\(^{-3}\) was found in Phum Rieng subdistrict, whereas the highest geometric mean of 39 ± 2 Bq m\(^{-3}\) was found in Pak Mark subdistrict (\(p < 0.05\), Tukey’s HSD). In Tha Chana district, the lowest geometric mean of indoor radon concentration (20 ± 2 Bq m\(^{-3}\)) was found in Wang subdistrict, while the highest value (48 ± 2 Bq m\(^{-3}\)) was found in Khan Thu Lee subdistrict, which were significantly different (\(p < 0.05\), Tukey’s HSD). These results showed that the lowest and the highest geometric means of indoor radon concentrations were found in the areas located in low and high equivalent uranium at the ground surface, respectively (see figure 1).

The geometric mean indoor radon concentration for the entirely investigated areas of Chaiya and Tha Chana districts were 26 ± 2 Bq m\(^{-3}\) and 30 ± 2 Bq m\(^{-3}\), respectively. The geometric mean of radon concentrations in Tha Chana district was significantly higher than in Chaiya district (\(p < 0.05\), independent sample t-test). However, the geometric mean of radon concentration for the entire data (28 ± 2 Bq m\(^{-3}\)) was lower than the worldwide average (39 Bq m\(^{-3}\)) of indoor radon levels [5].
Comparing indoor radon concentrations with the WHO and U.S. EPA action levels, the results showed that 9% of 117 buildings in Tha Chana district exceeded the 100 Bq•m$^{-3}$ action level recommended by WHO [5] while only 2% exceeded the 148 Bq•m$^{-3}$ action level recommended by U.S. EPA [4]. In Chaiya district, no excess level of radon concentration above the action levels was found. With respect to the action levels, the indoor radon concentrations were found to exceed 100 Bq•m$^{-3}$ in 4% of the buildings in the two districts together, while they exceeded 148 Bq•m$^{-3}$ in only 1% of the buildings. We supposed that the reason for this was that most of the buildings in both districts (94%) were well ventilated because their windows and doors were left open throughout the day.

4.2. Variation in indoor radon concentrations due to building materials.

All of the building materials surveyed in this study were categorized into two different groups; wood-brick-mortar and brick-mortar. The wood-brick-mortar combination was accounted for 42% of total buildings, while the other 58% of total buildings were built from a combination of brick and mortar. The minimum and maximum indoor radon values measured from the buildings made of wood, brick and mortar were 7 Bq•m$^{-3}$ and 130 Bq•m$^{-3}$, respectively, while the minimum and maximum values measured from the buildings made of brick and mortar were 4 Bq•m$^{-3}$ and 159 Bq•m$^{-3}$, respectively (table 2). The geometric mean of indoor radon concentrations for the brick-mortar buildings was significantly higher than the wood-brick-mortar buildings ($p < 0.05$). This result may be due to the fact that wood is not a source of radon, while radon exhalation in bricks has been reported [14, 15, 16]. Most buildings in southern Thailand are nowadays made of brick and mortar, therefore the risk of indoor radon concentration due to building materials should be emphasized.

| Types of building materials | Number of Buildings | % of buildings | Indoor radon concentration (Bq•m$^{-3}$) | GM$^a$ | GSD$^b$ |
|-----------------------------|---------------------|---------------|----------------------------------------|------|-------|
| Wood, brick and mortar      | 104                 | 42            | 7                                      | 130  | 24    |
| Brick and mortar            | 144                 | 58            | 4                                      | 159  | 31    |

$^a$GM = geometric mean  
$^b$GSD = geometric standard deviation.

5. Conclusion

The geometric mean indoor radon concentrations in Chaiya and Tha Chana districts were 26 ± 2 and 30 ± 2 Bq•m$^{-3}$, respectively. The geometric mean indoor concentration for entire surveyed areas was 28 ± 2 Bq•m$^{-3}$. Only 1% of 248 buildings surveyed were found to have radon concentration level that exceeded the action level recommended by the U.S. EPA. Moreover, the geometric mean indoor radon concentration of the buildings made of brick and mortar was higher than the buildings made of wood, brick and mortar.

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