Measurement of radon concentrations and effective dose assessment in groundwater from Kamphaeng-Saen district, Nakhon Pathom province and Ban-Pong district, Ratchaburi province

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Abstract: Radon monitoring has been increasingly conducted worldwide because it is considered as the hazardous effects on the human healthy, probably making an increased cancer risk when people received radon by inhalation of air and ingestion of water containing high concentrations over extended periods of time. Radon is natural occurring radionuclides found in the rock, soil and water, and can therefore enter in the water supplies used for drinking water. The objective in this study was to determine the radon level in groundwater in order to set up a policy on water management. The groundwater radon concentrations were measured by RAD7 device with RAD H₂O technique following a protocol proposed by the manufacturer from 26 groundwater samples randomized in Kamphaeng-Saen District, Nakhon Pathom Province and Ban-Pong District, Ratchaburi Province where the groundwater has been frequently used for public tap water. The results show that the radon concentrations range between 0.05 and 2.51 BqL⁻¹ with an average value of 0.95 BqL⁻¹. All measured radon concentrations are well below the allowed maximum contamination level (MCL) of radon concentration in water of 11 BqL⁻¹, proposed by US Environmental Protection Agency (USEPA). The annual effective doses of adults calculated for inhalation and ingestion are below 12.74 µSv y⁻¹, and also well lower than the safe limit (100 µSv y⁻¹) recommended by World Health Organization and EU Council. Thus radon in groundwater of this study do not pose any significant health risk to the public.

1. Introduction

The concerned attention of natural occurring radionuclides conducing to high background radiation and the largest risk to human health is pointed to radon [1–2]. Radon, ²²²Rn, is natural occurring radionuclides, colourless, odourless and tasteless noble gas, a half-life of 3.82 days produced by the decay of radium, ²²⁶Ra, in ²³⁸U decay chain which has existed since earth formation, so it is found anywhere in the rock, soil, air and water. Radon gas can easily transfer into the atmosphere, surface dwelling and groundwater through fragmented rocks and faults [1,3]. In USA, more than 50% of the effective dose received by the general public is from radon and its short-lived decay products [3]. When radon gas is inhaled, the highly-ionizing alpha particles emitted by deposited short-lived decay products of radon such as Polonium-218, ²¹⁸Po, and Polonium- ²¹⁴Po, can interact with the biological tissue in the lungs leading to DNA damage that is considered as an important step in the carcinogenesis process.
High concentration of this gas in water will also lead to gastric cancer [1]. In addition, dissolved radon in groundwater can increase indoor radon concentrations and may increase the incidence of stomach cancer in populations using groundwater as their source of drinking water [1–5]. The radon is considered as the hazardous effects on the human healthy, probably making an increased cancer risk when people receive radon by inhalation of air and ingestion of water containing high concentrations over extended periods of time.

Radon monitoring has therefore been increasingly conducted worldwide. In Thailand, radon concentrations in air, groundwater and hot-spring water were also frequently measured. In the Suan-Phueng hot spring of Suan-Phueng district, Ratchaburi province, the radon concentrations in air were in the range of 10 – 17 and 11 – 147 Bqm$^{-3}$ for outdoor and indoor, respectively, and in hot spring water range from 2 – 154 BqL$^{-1}$ [6]. In drinking water, the radon concentrations of bottled water collected from the market areas ranged 0 – 0.018 [7] and 0.14 – 0.92 BqL$^{-1}$ [8] at Meaung district, Yala province and at Meaung district, Khonkhaen Province, respectively. The radon concentrations in shallow-well water which rural people use for drinking, in Namom district, Songkhla province ranged from 0.1 to 483.0 BqL$^{-1}$ [9–10]. Some samples are higher than the allowed maximum contamination level (MCL) of radon concentration in water of 11 BqL$^{-1}$, proposed by US Environmental Protection Agency (USEPA) [11].

In this paper, radon concentrations of groundwater in Kamphaeng-Saen District, Nakhon Pathom Province and Ban-Pong District, Ratchaburi Province were measured and the annual effective doses of radon for adults from ingestion were also estimated and compared with the safe limit of health risks recommended by international agencies.

2. Methodology
A total of 26 groundwater samples were collected by sample random sampling method in Kamphaeng-Saen District, Nakhon Pathom Province and Ban-Pong District, Ratchaburi Province where the groundwater has been frequently used for public tap water as well as in animals and crop production. To ensure that the sample collected served as a representative sample, we stored the groundwater from bore wells after 10 min of pumping in plastic container of 1 L with no empty space, and sent to the radon measurement laboratory of Thailand Institute of Nuclear Technology (Public Organization) after day of collecting. After that the water samples were drained in special glass bottles (250 mL capacity). The RAD7 radon detector has been used with RAD H$_2$O technique following a protocol proposed by the manufacturer for the measurement of radon concentration in the water sample [12]. Radon concentrations at the moment of sampling were corrected by radioactive decay equation with storage time calculated by recording sampling time and reading time. Also the pH, total dissolved solids (TDS) and electrical conductivity (EC) of water samples were measured.

The annual effective doses for adults from ingestion of radon in water are determined using the documentation of United Nations Scientific Committee on the Effects of Atomic Radiations [13]. Annual effective dose for ingestion ($AED_{ing}$) was accounted by equation (1):

$$AED_{ing} = C_{Rn} \times A_i \times D_f$$

where $D_f$ is the ingesting dose conversion factor for radon (3.5 nSv Bq$^{-1}$ for adults [13]), $A_i$ is the annual water intake (730 Ly$^{-1}$ for adults [14]) and $C_{Rn}$ is the radon activity concentration (Bq L$^{-1}$)

The annual effective dose from inhalation of radon ($AED_{inh}$) which the radon in water release to the air is calculated using by equation (2) [13]:

$$AED_{inh} = C_{Rn} \times R_w \times F \times t \times D_f$$

where $C_{Rn}$ is the radon activity concentration in water (Bq L$^{-1}$), $R_w$ is the ratio of radon in air to the radon in water ($10^{-4}$), $F$ is the equilibrium factor between radon and its progenies (0.4), $t$ is the average indoor occupancy time per person (7,000 hr y$^{-1}$) and $D_f$ is the ingesting dose conversion factor for radon (9 µSv hr$^{-1}$ Bq$^{-1}$ L [13]).
3. Results and Discussion
The results show that the radon concentrations in the groundwater range between 0.05 and 2.51 Bq L\(^{-1}\), with an average value of 0.95 Bq L\(^{-1}\), as shown in table 1. They are well below the allowed maximum contamination level (MCL) of radon concentration in water of 11 Bq L\(^{-1}\), proposed by US Environmental Protection Agency (USEPA). The total annual effective doses of adults calculated for ingestion (0.13 – 6.41 µSv y\(^{-1}\)) and inhalation (0.13 – 6.33 µSv y\(^{-1}\)) vary 0.26 – 12.74 µSv y\(^{-1}\), and also well lower than the safe limit (100 µSv y\(^{-1}\)) recommended by World Health Organization and EU Council. Thus, the radon in groundwater of this study do not pose any significant health risk to the public. In addition to radon concentration, the physicochemical parameters of ground water such as pH, total dissolved solid (TDS) and electrical conductivity (EC) were measured, as shown in table 1. The pH values are very similar and the mean of 7.45, range between 7.02 and 7.79. It indicates that the groundwater in this area are slightly acidic. The TDS and EC range 177 – 756 mg L\(^{-1}\) and 355 – 1536 µS cm\(^{-1}\), respectively. These probably indicated that the groundwater contacts with the carbonate rocks such as limestone and dolomite.

Table 1. Radon concentration, pH, total dissolved soils (TDS), electrical conductivity (EC), annual effective dose of radon for adults from ingestion (AED\(_{\text{ing}}\)) and inhalation (AED\(_{\text{inh}}\)) of groundwater, and total annual effective dose (AED\(_{\text{T}}\)) of radon in groundwater.

| No. | Location (UTM 47N) | pH   | TDS (mg L\(^{-1}\)) | EC (µS cm\(^{-1}\)) | \(^{222}\)Rn (Bq L\(^{-1}\)) | AED\(_{\text{ing}}\) (µSv y\(^{-1}\)) | AED\(_{\text{inh}}\) (µSv y\(^{-1}\)) | AED\(_{\text{T}}\) (µSv y\(^{-1}\)) |
|-----|-------------------|------|---------------------|---------------------|----------------|-------------------------------|---------------------------------|---------------------------------|
| 1   | 597136            | 7.37 | 240                 | 529                 | 1.97±0.21 | 5.03                          | 4.96                            | 10.00                           |
| 2   | 598416            | 7.36 | 756                 | 1536                | 1.78±0.22 | 4.55                          | 4.49                            | 9.03                            |
| 3   | 598045            | 7.02 | 621                 | 1334                | 0.25±0.08 | 0.64                          | 0.63                            | 1.27                            |
| 4   | 598831            | 7.63 | 521                 | 1009                | 2.20±0.23 | 5.62                          | 5.54                            | 11.17                           |
| 5   | 601273            | 7.64 | 540                 | 1154                | 0.43±0.08 | 1.10                          | 1.08                            | 2.18                            |
| 6   | 602645            | 7.61 | 717                 | 1346                | 0.87±0.09 | 2.22                          | 2.19                            | 4.42                            |
| 7   | 601927            | 7.11 | 739                 | 1447                | 1.73±0.12 | 4.42                          | 4.36                            | 8.78                            |
| 8   | 603204            | 7.79 | 473                 | 1013                | 0.43±0.09 | 1.10                          | 1.08                            | 2.18                            |
| 9   | 592723            | 7.22 | 335                 | 656                 | 2.08±0.13 | 5.31                          | 5.24                            | 10.56                           |
| 10  | 593469            | 7.46 | 242                 | 436                 | 0.45±0.09 | 1.15                          | 1.13                            | 2.28                            |
| 11  | 593722            | 7.48 | 329                 | 652                 | 0.61±0.08 | 1.56                          | 1.54                            | 3.10                            |
| 12  | 595957            | 7.41 | 221                 | 425                 | 0.26±0.05 | 0.66                          | 0.66                            | 1.32                            |
| 13  | 597372            | 7.38 | 197                 | 421                 | 1.30±0.11 | 3.32                          | 3.28                            | 6.60                            |
| 14  | 595401            | 7.41 | 235                 | 459                 | 0.77±0.09 | 1.97                          | 1.94                            | 3.91                            |
| 15  | 596201            | 7.63 | 329                 | 684                 | 0.58±0.09 | 1.48                          | 1.46                            | 2.94                            |
| 16  | 594677            | 7.73 | 304                 | 613                 | 0.58±0.05 | 1.48                          | 1.46                            | 2.94                            |
| 17  | 590871            | 7.15 | 307                 | 612                 | 1.60±0.09 | 4.09                          | 4.03                            | 8.12                            |
| 18  | 590858            | 7.73 | 461                 | 918                 | 0.26±0.08 | 0.66                          | 0.66                            | 1.32                            |
| 19  | 588925            | 7.38 | 203                 | 405                 | 0.20±0.05 | 0.66                          | 0.66                            | 1.32                            |
| 20  | 591732            | 7.49 | 201                 | 402                 | 0.31±0.06 | 0.79                          | 0.78                            | 1.57                            |
| 21  | 591518            | 7.55 | 236                 | 471                 | 0.63±0.10 | 1.61                          | 1.59                            | 3.20                            |
| 22  | 592501            | 7.35 | 177                 | 355                 | 2.51±0.25 | 6.41                          | 6.33                            | 12.74                           |
| 23  | 590617            | 7.57 | 223                 | 445                 | 1.78±0.14 | 4.55                          | 4.49                            | 9.03                            |
| 24  | 590041            | 7.71 | 202                 | 406                 | 1.06±0.09 | 2.71                          | 2.67                            | 5.38                            |
| 25  | 588360            | 7.61 | 264                 | 532                 | 0.24±0.06 | 0.61                          | 0.60                            | 1.22                            |
| 26  | 586334            | 7.33 | 428                 | 855                 | 0.05±0.05 | 0.13                          | 0.13                            | 0.25                            |

4. Conclusion
This study showed that the groundwater radon concentrations from 26 groundwater samples in Kamphaeng-Saen District, Nakhon Pathom Province and Ban-Pong District, Ratchaburi Province where the groundwater has been frequently used for public tap water are well within the allowed maximum contamination level (MCL) of radon concentration in water of 11 Bq L\(^{-1}\), proposed by US Environmental
Protection Agency (USEPA). The annual effective doses of adults calculated for ingestion and inhalation are below 12.74 µSv\(^{-1}\), and also well lower than the safe limit (100 µSv \(y^{-1}\)) recommended by World Health Organization and EU Council. The measured radon concentrations will pose none significantly serious health risks, hence the study area is considered to be safe for the residents. These data must be regarded as preliminary and in the further extensive studies should be done on large scale and detailed completely investigation for others radionuclides and trace elements contamination to increase awareness and mitigate possible hazards.

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