Investigation of radon level in air and tap water of workplaces at Thailand Institute of Nuclear Technology, Thailand

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Abstract. Thailand Institute of Nuclear Technology (TINT) has continuously monitored radiation exposure and radionuclide in workplaces specifically radon gas to estimate effective dose for workers. Radon exposure is the second leading cause of lung cancer in the world. In this study, radon in air and tap water at building no. 3, 7, 8, 9 and 18 on Ongkharak site of TINT have been measured for 5 years from 2012 to 2016. Radon level in air and tap water were investigated on 83 stations (workplaces) and 54 samples, respectively. Radon concentrations in air and tap water were measured by using the pulsed ionization chamber (ATMOS 12 DPX). Indoor radon concentrations in air were in the range of 12-138 Bq.m⁻³ with an average value of 30.13±17.05 Bq.m⁻³. Radon concentrations in tap water were in the range of 0.10 to 2.89 Bq.l⁻¹ with an average value of 0.51±0.55 Bq.l⁻¹. The results of radon concentrations at TINT were below the US Environmental Protection Agency (US EPA) safety limit of 148 Bq.m⁻³ and 150 Bq.l⁻¹, for, air and tap water, respectively. The average effective dose for TINT’s workers due to indoor radon exposure was approximately 0.20±0.11 mSv.y⁻¹. The value is 100 times less than the annual dose limit for limit occupational radiation worker defined by the International Commission on Radiological Protection (ICRP). As a result, the TINT’s workplaces are radiologically safe from radon content in air and tap water.

1. Introduction
Radon (Rn-222) is a colorless, odorless gas, a naturally occurring radioactive gas formed in the ground by the radioactive decay of uranium that presents in all rocks, soils and groundwater. Radon is the most important radio isotope from the environment in the viewpoint of human radiation exposure. People who inhale high level of radon and its progeny increase risk of developing lung cancer. Radon gas can enter a building and can be trapped indoors, thus the hazardous level for people can be elevated.

TINT has continuously monitored radiation exposure and radionuclide in workplaces specifically radon gas to estimate effective dose for workers. Radon concentration in workplaces (77 stations) at TINT was previously surveyed in 2012-2015 for determining level of the average radon concentrations and the annual effective dose in workplaces [1]. The average radon concentration and the annual effective dose for workers in workplaces at TINT were estimated to be 30.50 Bq.m⁻³ and 0.19 mSv.y⁻¹ respectively [1]. In this study, the radon measurement in 2016 was analyzed and combined with the previous radon data in 2012 to 2015 for obtaining higher accuracy and reliability. Besides, additional radon concentrations in 54 workplaces tap water were determined. The aim of this study is to investigate the radon exposure level for worker at TINT’s workplaces via radiation measurement of air and tap water.
2. Experiments

The radon concentration in air and tap water were investigated at building no. 3, 7, 8, 9 and 18 on Ongkharak site of TINT. The measurement has performed continually for 5 years between 2012 to 2016. The stations for measurements were selected by considering the workplaces where people always work such as laboratory, office, meeting room and basements, etc. The water samples were collected directly from hydrant at particular workplaces. Radon level in air was investigated on 83 stations (workplaces) and 54 tap water samples. Radon concentrations in both air and tap water was measured by the pulsed ionization chamber (ATMOS 12 DPX), showed in Figure 1. The measurement time for each air and tap water samples was 2 hours.

![Figure 1. The equipment set up for the measurement of radon concentrations in (a) air and (b) tap water][2].

The values of indoor radon from ATMOS 12 DPX were compared with the safety limit (148 Bq.m$^{-3}$) recommended by the US Environmental Protection Agency (US EPA, 1992) [3]. The indoor radon concentration (Bq.m$^{-3}$) from the detector were used to calculate of an annual effective dose ($H$) by using equation (1) which was introduced by United Nation Scientific Committee on the effects of atomic radiation (UNSCEAR, 2000) [4] as follows:

$$H = C \times E \times F \times T \times D$$  \hspace{1cm} (1)

Where $H$ is the annual effective dose (mSv.y$^{-1}$), $C$ is radon concentration (Bq.m$^{-3}$), $E$ is equilibrium factor ($=0.4$) [5], $F$ is the occupancy factor (5.85 h/day or 1500 h/year excluding primary industry, so, $1500/8760=0.17$ [6], $T$ is hours in a year (8760 h y$^{-1}$), and $D$ is the dose conversion factor ($9.0 \times 10^{-6}$ mSv (Bq.m$^{-3}$.h$^{-1}$)).

The annual effective dose (mSv.y$^{-1}$) was used for the total effective dose ($H_{total}$) calculation of TINT worker by the following equation [6]:

$$H_{total} = H_{dwelling} + H_{outdoor} + H_{workplace}$$  \hspace{1cm} (2)

Where $H_{workplace}$ is the effective dose calculated from the radon concentration at indoor workplace (mSv.y$^{-1}$), $H_{dwelling}$ is the effective dose calculated from the indoor radon concentrations in dwellings...
in Thailand which is equal to 20 Bq m$^{-3}$ or 0.40 mSv y$^{-1}$ [7-8]. $H_{\text{outdoor}}$ is an effective dose calculated from the radon concentration at outdoor environment which is between 5-10 Bq m$^{-3}$ or about 0.058 mSv y$^{-1}$[6]. The annual effective dose for workers were compared with the safety limit of 20 mSv.y$^{-1}$ for the occupational worker, regulated by International Commission on Radiological Protection (ICRP, 1991) [9].

The quantity of each water sample collected from particular workplaces was about 350 ml. The water sample was then introduced into degassing cylinder for 2 hours measurement per sample. The radon concentration ($C_a$, Bq.m$^{-3}$) from the detector was used for determining the radon concentration in tap water ($C_w$, Bq.l$^{-1}$) by using the following equation:

$$C_a = \frac{\alpha_1}{\alpha_1 + \alpha_2} \frac{V_a}{V_w} C_w \left[ e^{-\lambda t} - e^{-(\alpha_1 + \alpha_2) t} \right]$$

(3)

Where $\lambda$ is the radon decay constant (min$^{-1}$), $t$ is measurement time (min), $V_w$ is the water volumes (l) and $V_a$ is the air volumes (m$^3$). The transfer factors $\alpha_1$ and $\alpha_2$ are parameters of the transferred radon gas from the water to air, and air to water, respectively. The evaluations of the transfer factors, $\alpha_1$ and $\alpha_2$ were 0.0845 min$^{-1}$ and 0.00813 min$^{-1}$[10], respectively. Radon concentrations in tap water were finally compared with the safety limit of 150 Bq.l$^{-1}$, recommended by the US Environmental Protection Agency (US EPA, 1991) [11].

3. Results and Discussion
The levels of indoor radon concentration from each workplace are showed in Figure 2.

**Figure 2.** Level of indoor radon concentration at TINT compared with the safety limit (upper line, 148 Bq.m$^{-2}$) and indoor radon of dwelling in Thailand (lower line, 20 Bq.m$^{-2}$), ( ), ( ), ( ), ( ), and ( ) refered to radon measurement at building no. 3, 7, 8, 9, and 18, respectively.
The levels of indoor radon concentration from each workplace found in the range of 12 to 138 Bq.m\(^{-3}\), with an average of 30.13±0.13 Bq.m\(^{-3}\), which were within the safety level of 148 Bq.m\(^{-3}\), recommended by the US EPA (1992), however, many workplaces found radon concentration in higher amount than indoor radon of dwelling in Thailand (20 Bq.m\(^{-3}\)) [7-8]. Sample no. 71 and 79 collected at the basement laboratories of building no. 9 showed extremely high radon concentration.

The annual average and total effective dose of TINT’s workers at particular building were summarized in Table1. Besides, the radiation safety limits were added the table for data comparison.

**Table1. The calculation results of average radon concentration, average annual effective dose and total effective dose from exposing radon at workplaces of TINT, including the radiation safety limits.**

| No. of building | Average Rn concentration (Bq.m\(^{-3}\)) | Average annual effective dose (mSv. y\(^{-1}\)) | Total effective dose of workers (mSv.y\(^{-1}\)) |
|-----------------|----------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 3               | 27.00±7.90                             | 0.17±0.05                                    | 0.63±0.05                                    |
| 7               | 28.08±11.21                            | 0.18±0.07                                    | 0.64±0.07                                    |
| 8               | 26.07±7.30                             | 0.16±0.46                                    | 0.62±0.46                                    |
| 9               | 34.70±8.23*                            | 0.31±0.09*                                   | 0.71±0.10*                                   |
| 18              | 30.00±4.00**                           | 0.19±0.03**                                  | 0.65±0.48**                                  |
| Average         | 31.17±17.05                           | 0.20±0.06                                    | 0.66±0.04                                    |
| Safety limit    | 148 (US EPA, 1992)                     | 1 for public, 20 for the occupation worker    |                                              |

* data obtained by excluding sample no. 71 and 79
** refers to random error obtained by one station measurement

An annual effective dose in workplaces were in the range of 0.08 to 0.83 mSv.y\(^{-1}\), which the maximum value found in building no. 9, because the building has two basements with limit of ventilation. The average annual effective dose from exposing radon and total effective dose of workers at TINT’s workplaces were 0.20±0.06 and 0.66±0.04 mSv.y\(^{-1}\), respectively. All workplaces showed lower radon concentration than the safety limits of 20 mSv.y\(^{-1}\) for occupational worker. However, it is a recommendation for every workplace that the regular ventilation is needed for avoiding of unnecessary radon up taking.

The levels of radon concentrations in tap water at TINT workplaces and the safety limit of 150 Bq.l\(^{-1}\), recommended by the US EPA (1991) are showed in Figure 3.
Figure 3. Radon concentration in tap water at TINT compared with the safety limit (upper line, 150 Bq. l\(^{-1}\)) and an average of radon concentration in tap water (lower line, 0.51±0.55 Bq. l\(^{-1}\)). Numbers 3, 7, 8, 9, and 18 refer to radon measurement at building no. 3, 7, 8, 9, and 18, respectively.

The levels of radon concentrations in tap water were in the range of 0.10 to 2.89 Bq.l\(^{-1}\), with an average of 0.51±0.55 Bq.l\(^{-1}\). The radon concentration in tap water collected from building no. 9 showed significantly high concentration than samples from other buildings (no. 3, 7, 8 and 18). However, radon concentrations in all tap water samples are below the safety limit of 150 Bq.l\(^{-1}\). General recommendation to routinely used groundwater workplaces is that the clarifier system may be needed for reducing the radon concentration in groundwater.

4. Conclusions

Thailand Institute of Nuclear Technology (TINT) has been continuously monitored radiation exposure and radionuclides in workplaces include radon gas to estimate effective dose for workers. In this study, the results of radon concentration investigation in air and tap water at building no. 3, 7, 8, 9 and 18 on Ongkharak site during 2012 to 2016 were reported. Radon levels in air and tap water were investigated on 83 stations (workplaces) and 54 samples, respectively. Radon concentrations in air and tap water were measured by the pulsed ionization chamber (ATMOS 12 DPX). The indoor radon concentrations at TINT workplaces were in the range of 12-138 Bq.m\(^{-3}\), with an average of 30.13±17.05 Bq.m\(^{-3}\) (exclude building no.9). All indoor radon concentrations remain within the safety level (148 Bq.m\(^{-3}\)), recommended by the US EPA. However, it was noteworthy that some workplaces showed significantly high radon concentration than value of the indoor radon concentration of dwelling in Thailand (20 Bq.m\(^{-3}\)). Indoor radon at workplaces no. 71 and 79 (building no. 9) were extremely higher than other workplaces because they are basement laboratories with limit of ventilation. The average annual effective dose and total effective dose of TINT’s workers were about 0.20±0.06 and 0.66±0.04 mSv.y\(^{-1}\), respectively. As a result, the TINT workplaces have indoor radon concentration about 100 times lower than the safety limits (20 mSv.y\(^{-1}\)) for the occupational worker. Radon concentrations in tap water from all buildings were found in the range of 0.08 to 0.83 Bq. l\(^{-1}\) and an average was 0.51±0.55 Bq.l\(^{-1}\). The building no. 9 showed relatively high radon concentration in tap water. However, all tap water samples contain very low radon concentration when compared with the safety limit (150 Bq.l\(^{-1}\)). In addition, if any workplaces regularly use groundwater, the clarifier may be necessary to reduce radon concentration.
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