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Inspection and radiation dose evaluation results for NORM-containing products in Taiwan

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Abstract

In 2018, "negative ion powder" mattress produced by a South Korean manufacturer producing a dose rate of > 1 mSv/year, was found to have monazite powder in it. In order to verify if other products advertised as containing "negative ion powder" were also hazardous, an investigation had been carried out by the Atomic Energy Council and Institute of Nuclear Energy Research in Taiwan. By the end of April 2019, 11 kinds and a total of 59 samples were inspected for radon content. The radiation doses for the samples were evaluated using Atomic Energy Council approval evaluation setup which was established according to the characteristics of the products. The highest concentration of ^{220}Rn among the inspected mattresses was over 10 kBq/m^3 and the evaluated annual dose was about 78.5 mSv. The linearity of the surface dose rate and the measured thoron gas concentration for the mattress samples was also discussed in this study.

Keywords ^{220}Rn · ^{222}Rn · NORM · Concentration · Internal dose · Surface dose

Introduction

Radon is a naturally occurring radioactive material formed by slow decay of uranium and thorium found in the earth's crust, and is the major source of human exposure caused by natural radiation. The danger posed by radon is primarily due to the alpha radiation emitted by its daughter nuclides that damages DNA in the lungs. Radon is stipulated as the second leading cause of lung cancer after smoking by the World Health Organization [1]. In general, the main research topics for radon measurement include indoor radon [2–4], mining [5] and geological survey [6]. There is not much research on radon content in commercial products.

In May 2018, a housewife in South Korea found abnormally high radon concentrations around her mattress while monitoring the air quality in her room by using a commercially available Rn detector. This mattress was produced by a South Korean manufacturer, and it was found to contain monazite powder (a naturally occurring radioactive material, NORM) in it. The thorium element contained in the monazite powder emits beta or gamma radiation during the decay process, thereby ionizing the air on the surface of the mattress and generating negative ions. Negative ions are believed beneficial to health by some people, but have never been scientifically proven. Radon gas (^{220}Rn) formed by the decay of thorium contained in the monazite powder causes the radiation exposure, and the Nuclear Safety and Security Commission (NSSC) in South Korea concluded that the annual radiation dose caused by the mattresses were above the dose limit of the public (1 mSv/year) [7].

The Atomic Energy Council (AEC), in collaboration with INER (Institute of Nuclear Energy Research) have conducted an audit on the radiation content of commercial products, which are advertised as containing "negative ion powder" and suspected to contain NORM, in August 2018, trying to find out whether there are similar products in Taiwan. As of April 2019, a total of 59 samples were inspected for radon content. The concentration of radon gas (including ^{220}Rn and ^{222}Rn) was determined, and the total radiation dose was also evaluated and compared to the dose limit (1 mSv/year) of the public in Taiwan.

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Experimental

The concentration of radon gas (including ^{220}Rn and ^{222}Rn) was measured with Durridge RAD7 radon monitors. All samples were measured in a closed laboratory (6 m × 3.5 m × 3 m), to minimize the effect on activity concentration of radon gas due to the ventilation conditions. The samples were placed 50 cm above the ground and 30 cm from the wall, to decrease the radon gas interference from the ground and walls [8]. The measurement was carried out in a continuous manner, and the activity concentration of radon gas would be recorded when it reached the equilibrium state for internal dose evaluation. The equilibrium time for each object under each convection condition before the next reading was about 3–4 h. In addition, the laboratory would be exhausted for 30 min before the next measurement, to reduce the interference of radon gas generated by the previous sample. A 2-min sampling test to confirm the background state. There were two air extractors in the radon measurement laboratory. The air turnover rate is 8 m^3/min for each, and it would circulate indoor air 8.5 times within 30 min ventilating time. The background thoron and radon activity concentrations in the room were about 11.1 ± 3.1 Bq/m^3 and 15.6 ± 2.0 Bq/m^3, respectively. Measurement uncertainty mainly comes from instrument calibration and measurement, the total evaluated uncertainty for ^{220}Rn and ^{222}Rn is about 27.3% and 18.5% ($k = 2$) in the study. The internal radiation dose resulting from the progeny of radon gas (including ^{220}Rn and ^{222}Rn) was evaluated by using the internal dose conversion factors (DCFs) reported in ICRP Publication 115 [9] shown as Eq. (1):

$$\text{Internal dose} = \text{Conc. of radon gas } (^{220}\text{Rn or } ^{222}\text{Rn}) \times \text{DCF} \times W \times F \times R \times T \tag{1}$$

Working level (WL) is any combination of short lived decay products in 1 litre of air which will ultimately emit 1.3×10^5 MeV of alpha energy. 1 WLM is the cumulative exposure from breathing an atmosphere at a concentration of 1 WL for a working month of 170 h. DCF is the effective dose resulted from 1 WLM, and the DCFs for ^{220}Rn and ^{222}Rn are 2.14×10^{-5} (WLM m^3 Bq^{-1} h^{-1}) and 1.57×10^{-6} (WLM m^3 Bq^{-1} h^{-1}) respectively [9]. The conversion factor (W) of radiation dose and working level month are 5.7 (mSv WLM^{-1}) for ^{220}Rn and 12.9 (mSv WLM^{-1}) for ^{222}Rn respectively [9]. The equilibrium factor (F) for ^{220}Rn and ^{222}Rn are 0.04 and 0.4 respectively [10, 11]. The respiratory rate (R) during sleep is 0.37 for the bedding products, while the daily respiratory rate is 1.0 for the non-bedding products [12]. The exposure time (T) depends on the types of the products. The evaluation setup for the products in this study is described in detail in the supplementary information.

The surface dose rates of the samples containing NORM were measured with ATOMTEX AT-1121, and the external doses were obtained by multiplying the measured surface dose rates of the products by the likely exposure time of the products, Eq. (2). The annual effective dose resulted from using the NORM-containing product can be obtained by summing up the internal dose and external dose.

$$\text{External dose} = \text{Surface dose rate } \times T \tag{2}$$

Results and discussion

From August 2018 to April 2019, AEC had inspected 11 kinds and a total of 59 samples. Distances from nose to the products were set as the measurement distances for the surface dose rates of radon gas, assuming that nose was the closest human organ in the measurement of surface dose rate. The remaining parameters used for dose assessment (e.g. respiratory rate and exposure time) are described in detail in the supplementary information. The range of concentration of ^{220}Rn and ^{222}Rn reported directly from the Rn monitor was shown in Table 1. After subtracting the background concentration of ^{220}Rn and ^{222}Rn from the measurement results, the internal doses can be calculated using Eq. (1). It can be seen that the highest concentration of ^{220}Rn was over 10 kBq/m^3 among 20 mattresses, and the evaluated annual dose was about 78.5 mSv, which exceeded the regulatory standard (1 mSv/year) in Taiwan.

Since internal exposure from the use of a NORM-containing product is mainly caused by radon gas, the convection in the room will affect the concentration of radon gas inhaled by human body. Among the 59 inspected samples, one mattress with the highest internal dose was further tested for the content of radon gas at different heights above the mattress, under different air conditioning environments. The concentration of radon gas at 2 cm above the surface of the mattress is assuming to have a user lying face down, while the concentration of radon gas at 10 cm above the surface of the mattress is assuming to have a user lying on their back (Fig. S1). The measured concentration and evaluated dose of ^{220}Rn and ^{222}Rn in different conditions are shown in Table 2.

The results show that ^{220}Rn and ^{222}Rn concentration were decreased by about 5.5 times with height when the window is closed; while the ^{220}Rn concentration measured at the same height as above was decreased by about 6–15 times and ^{222}Rn concentration was decreased to about background due to the dilution of air. However, the experiment was carried out under the condition of uncontrolled air flow, the degree of reduction in gas concentration is not directly related to the air conditions.

Except for the few specific mattresses that had monazite powder embedded in the inner layer of the mattress, so that the emission of beta/gamma rays would be shielded, the relationship between the concentration of ^{220}Rn and the surface radiation dose rates (include the background count rate which was about 16 cps) measured by the surface contamination monitor is linear, as shown in Fig. 1. The above finding is useful for rapid screening of the concentration of thoron gas from the mattresses.

Table 1 Inspected quantities and dose evaluation results for the 11 kinds of products

Product type	Number of inspection sample	Number of annual effective dose exceeding 1 mSv	^{220}Rn conc. (Bq/m^3)	^{222}Rn conc. (Bq/m^3)	Internal dose (mSv/year)	External dose (mSv/year)
Mattress	20	8	0–11,550	18–215	0–78	0–0.5
Quilt	14	3	4–986	7–60	0.01–7	0–1
Pillow	9	4	9–21,760	7–89	0.07–144	0–0.1
Mask	4	3	11–19,140	25–258	0.01–9	0–0.002
Eye mask	2	2	100–2860	34–122	11–20	0.03–0.04
Scarf	1	1	175	17	4	0.11
Carpet	1	1	93	11	2	0.5
Shawl	1	1	372	21	10	0.2
Protective gear	2	0	13–19	6–11	0.006–0.4	0–0.02
Water cup	4	0	10–27	3–16	0–0.4	0–0.04
Kettle	1	0	14	10	0.02	0

Table 2 Radon gas concentration versus different air condition

Air condition	Measurement distance (from the surface of the mattress) (cm)	^{220}Rn conc. (Bq/m^3)	^{222}Rn conc. (Bq/m^3)	Internal dose (mSv/year)
Closed window	2	11,550 ± 160	251 ± 17	78.4
	10	2077 ± 67	45 ± 5	13.8
Open window	2	750 ± 40	22 ± 4	4.83
	10	362 ± 28	34 ± 4	2.4

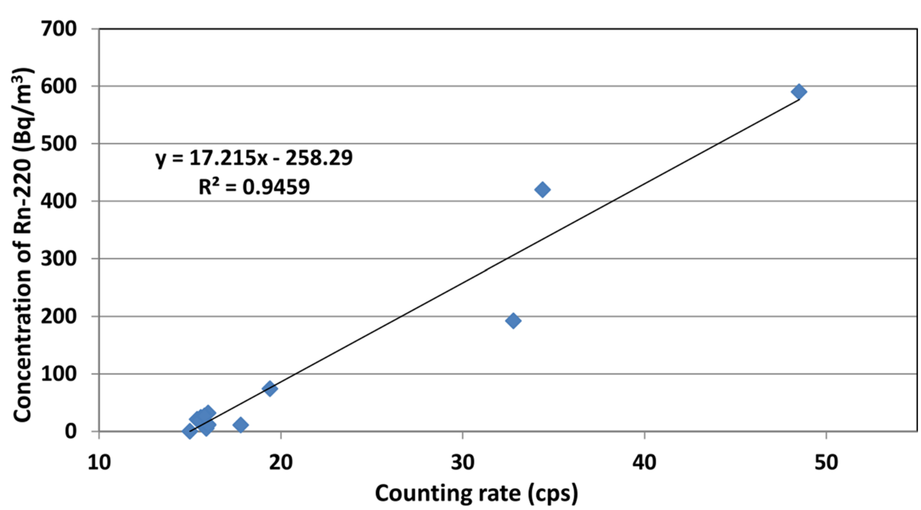

Fig. 1 Concentration of ^{220}Rn versus surface counting rate (large surface monazite powder sources like mattress)

Conclusions

From August 2018 to April 2019, INER had assisted AEC in completing 59 inspected samples for radon content analysis and radiation dose assessment. About 40% of the tested samples exceeded the regulatory standard (1 mSv/year) of Taiwan, and these items were removed from the shelves and processed as radioactive waste. The mattress with the highest internal dose evaluation result was further tested for the content of radon at different heights above the mattress, under different air conditioning environments. It was found that the concentration of radon (and thoron) decreased with increasing indoor convection. Moreover, the linearity between the surface dose rate and the measured thoron gas concentration for mattress samples has found to be useful for rapid screening of the concentration of thoron gas from the mattresses.

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Compliance with ethical standards

Conflict of interest The authors have no potential conflict of interest.

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