THE METHOD FOR RECALIBRATION OF THORON CONCENTRATION READING OF RAD7 AND OBTAINING THE THORON EXHALATION RATE FROM SOIL SURFACE

by

Yanliang TAN [1,2*] ***and Detao XIAO*** [2]

[1]Department of Physics and Electronics, Hengyang Normal University, Hengyang, China
[2]School of Nuclear Science & Technology, University of South China, Hengyang, China

Technical paper
DOI: 10.2298/NTRP1301092T

Thoron exhalation rate can be obtained through the combination of the "accumulation chamber" technique and RAD7. Thoron's rapid decay causes the intake path and the air flow rate to become important factors in calibration. In field conditions, since the flow rate of the internal pump in RAD7 will change as the voltage of the battery decreases, the big drying tube is more suitable for a long measurement than the small drying tube. We developed the method for recalibration of the thoron concentration reading of RAD7 based on the calibration factor for ^{222}Rn, and obtained the thoron exhalation rate from soil surface near by the Radon Laboratory of the University of South China. This method can be applied to develop and improve instruments for measuring the radon exhalation rate.

Key words: thoron exhalation rate, soil, RAD7

INTRODUCTION

^{220}Rn, also known as "thoron" is a natural decay product of thorium. It has a half-life of 55.6 seconds and emits alpha radiation. Indoor surveys in Europe and Asia revealed that the dose contribution due to the inhalation of ^{220}Rn and its progeny can equal or even exceed that of ^{222}Rn and its progeny [1]. Nowadays, the significance of ^{222}Rn has been recognized and the interest in the measurement of the indoor ^{220}Rn concentration has been increased [2-4]. Major part of ^{220}Rn comes from the top layer of the earth. Measuring the exhalation rates for thoron indicates significant presence of thoron in indoor environment which is also supported by indoor measurements of thoron and its progeny [5]. Thoron exhalation rate measurements may be performed by the "accumulation chamber" technique [6]. The experimental set-up for thoron exhalation rate measurement is conducted by a solid state nuclear track detector. However, this method needs a long time to obtain the results.

RAD7 is much less susceptible to radon-thoron interference due to its ability to distinguish the isotopes by their unique alpha particle energies. It separates radon and thoron signals and counts the two isotopes at the same time with a little interference from each other. Some researchers had used RAD7 in a laboratory to determinate the ^{222}Rn and ^{220}Rn exhalation rates from building materials, simultaneously [7]. As the manual of RAD7 indicates, the RAD7 calculates thoron concentration on the basis of the count rate of the 6.78 MeV alpha line of ^{216}Po. Thoron's rapid decay causes the intake path and the air flow rate to become important factors in calibration. The RAD7 factory calibration for thoron is based on a standard RAD7 inlet filter, a standard 3-foot long, 3/16 inch inner diameter vinyl hose, and a standard small (6 inch) drying tube. The thoron concentration in the internal cell of RAD7 is about 50% of the original sample; the thoron reading is intended to compensate, already, for the loss of the sample by decay. It means that the reading value of thoron concentration from RAD7 is the double of the real thoron concentration in the internal cell. Deviation from this arrangement can change the thoron results.

Generally, a small drying tube is suitable for measuring thoron concentration. In this case, the interspace volume of the small drying tube is so small that can be ignored. The manual of RAD7 also indicates that the big drying tube will last for days under continuous operation at high humidity in the NORMAL mode, before it needs regeneration. But the small drying tube containing 30 g of desiccant will last for only a few hours. The big drying tube is more suitable for long measurements than the small drying tube.

The manual of RAD7 indicates that RAD7 has enough battery capacity to go for two to three days without any external power source. So, RAD7 can be

* Corresponding author; e-mail: hytyl@163.com

used to perform the thoron exhalation rate measurements from soil surface in field conditions. However, the flow rate of the pump will change as the voltage of the battery decreases, and the big drying tube is more suitable for long time measurements than the small drying tube. In this paper, we will present the method for recalibration of thoron concentration reading in order to obtain the accurate thoron exhalation rate. All the users of RAD7 can use this method and the data to recalibrate the thoron concentration reading of RAD7 without a standard thoron source.

METHOD FOR MEASURING THORON EXHALATION RATE FROM SOIL SURFACE

The experimental set-up for thoron exhalation rate measurement conducted by RAD7 is presented in fig. 1. Because the linked pipeline is short, the thoron concentration in the accumulation chamber is determined by the following differential equation

$$\frac{\mathrm{d}C_V}{\mathrm{d}t} \quad \frac{JS}{V} \quad (\lambda \quad \lambda_{\mathrm{leak}} \quad \lambda_{\mathrm{b}})C_V \quad \frac{L}{V}C_V \quad \frac{L}{V}C_R\mathrm{e}^{\lambda\frac{V_0}{L}} \tag{1}$$

where C_V is the thoron concentration in the accumulation chamber, C_R – the thoron concentration in the internal cell of RAD7, J – the thoron exhalation rate, S – the area of the chamber bottom, V – the volume of the accumulation chamber, V_0 – the internal hose volume from the internal cell to the accumulation chamber, L – the flow rate of the pump, λ – the decay constant of thoron, λ_{leak} – the chamber leakage coefficient, and λ_{b} – the back-diffusion coefficient. JS/V presents the yield of the thoron exhalation, $(\lambda \quad \lambda_{\mathrm{leak}} \quad \lambda_{\mathrm{b}}\ C_V$ presents the yield of the thoron decay, leakage and back-diffusion, $(L/V)C_V$ presents the yield of thoron drawn to the internal cell of RAD7 by the internal pump, and $(L/V)C_R\mathrm{e}^{\lambda(V_0/L)}$ presents the yield of thoron sent back from the internal cell by the internal pump.

As far as thoron exhalation rates are regarded, the effects of leakage and back diffusion were not observed and evaluated because of the short half-life of thoron. The half-life is only 55.6 s and we confirm that

$$\lambda \gg \lambda_{\mathrm{leak}} + \lambda_{\mathrm{b}} \tag{2}$$

Since V_0 is small, eq. (1) can be predigested as

$$\frac{\mathrm{d}C_V}{\mathrm{d}t} \quad \frac{JS}{V} \quad \lambda C_V \quad \frac{L}{V}(C_V \quad C_R) \tag{3}$$

According to the smooth flow equation [8], the thoron concentration at the inlet of the RAD7, C_1, can be expressed as

$$C_1 \quad C_V\mathrm{e}^{\lambda\frac{V_1}{L}} \tag{4}$$

where V_1 is the interspace volume of the big drying tube and the pipe volume.

The sample decays slightly as it passes from the RAD7 inlet to the internal cell, and the air flow is also a smooth flow and the internal cell inlet concentration, C_2, can be calculated as

$$C_2 \quad C_1\mathrm{e}^{\lambda\frac{V_2}{L}} \tag{5}$$

where V_2 is the internal hose and dust filter volume, which is 29 ml.

Within the RAD7 internal cell, the air flow is turbulent. According to the turbulent flow equation [8], the equilibrium thoron concentration, C_R, will be determined by the formula

$$C_R \quad \frac{C_2}{1 \quad \dfrac{\lambda V_3}{L}} \quad C_V\frac{\mathrm{e}^{\lambda\frac{V_1 \quad V_2}{L}}}{1 \quad \dfrac{\lambda V_3}{L}} \tag{6}$$

where V_3 is the volume of the internal cell of RAD7. Equation (6) is just the same as the formula given in the manual of the RAD7.

When the thoron concentration in the accumulation chamber reaches the steady-state,

$$\frac{\mathrm{d}C_V}{\mathrm{d}t} \quad 0 \tag{7}$$

Thus, eq. (3) can be rewritten as

$$J \quad \frac{V}{S} \quad \lambda C_V \quad \frac{L}{V}(C_V \quad C_R) \tag{8}$$

Equation (6) can be rewritten as

$$C_V \quad C_R\frac{1 \quad \dfrac{\lambda V_3}{L}}{\mathrm{e}^{\lambda\frac{V_1 \quad V_2}{L}}} \tag{9}$$

By inserting eq. (9) into eq. (8) the following equation is obtained

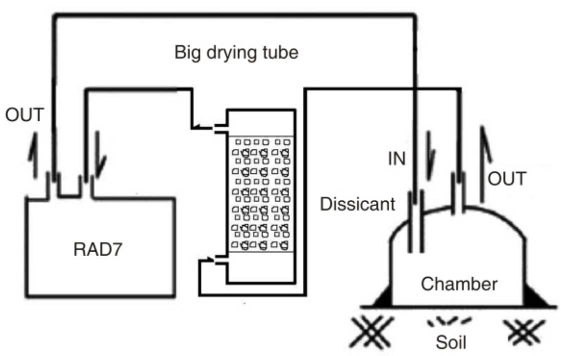

Figure 1. Thoron exhalation rate measurement scheme. (the volume of the accumulation chamber is 4 L, the interspace volume of the big drying tube and the pipe volume from the accumulation chamber to the inlet or RAD7 is 450 ml, the internal hose and dust filter volumes in the RAD7 is 29 ml, the volume of the internal cell of RAD7 is 0.723 L)

$$J = \frac{VC_R}{S}\left[\frac{1+\frac{\lambda V_3}{L}}{e^{\lambda\frac{V_1+V_2}{L}}}\left(\lambda+\frac{L}{V}\right)-\frac{L}{V}\frac{e^{-\lambda\frac{V_1+V_2}{L}}}{1+\frac{\lambda V_3}{L}}\right] \tag{10}$$

The equation can be used for estimation of the thoron exhalation rate from soil surface in the accumulation chamber.

THE METHOD FOR RECALIBRATION OF THE READING OF RAD7 AND ESTIMATION OF V_1

The reading of thoron concentration from RAD7 is double of the real thoron concentration in the internal cell. Some researchers proposed that the measurement sensitivity of the RAD7 for ^{220}Rn is about 30% less than its sensitivity to ^{222}Rn. The reports of Japanese Institute of Radiological Sciences (NIRS) indicate that the calibration factor of the RAD7 for ^{220}Rn is roughly 1.25-1.3 [9, 10]. The reports of the University of South China indicate that the calibration factor is 1.40 [11]. In this paper, we determined that the calibration factor of RAD7 for ^{220}Rn is 1.35 and it is the mean value of the reports of NIRS and University of South China.

Thus, eq. (10) can be written as

$$J = \frac{1.35VC_R}{2S}\left[\frac{1+\frac{\lambda V_3}{L}}{e^{\lambda\frac{V_1+V_2}{L}}}\left(\lambda+\frac{L}{V}\right)-\frac{L}{V}\frac{e^{-\lambda\frac{V_1+V_2}{L}}}{1+\frac{\lambda V_3}{L}}\right] \tag{11}$$

A kind of self-made thoron flow-through solid source was used as thoron standard, which is stable enough with a relative deviation of 2.5% over 5 year, with relative humidity range from 50% to 90%. The emanation percentage of this thoron source is 96.5 + 3.0%.

For the including the interspace volume of the big drying tube filled with desiccant, the accurate interspace volume of the desiccant is not known. Figure 2 shows the solid flow-through thoron source [8] was used to accurately measure the interspace volume of the big drying tube and the pipe volume. V_1 can be determined by eq. (12)

$$C_R = \frac{A}{L}\frac{e^{-\frac{V_1+V_2}{L}}}{1+\frac{\lambda V_3}{L}} \tag{12}$$

where is A is the thoron activity emanated from the solid flow-through thoron source.

$$V_1 = 450\,\text{mL} \tag{13}$$

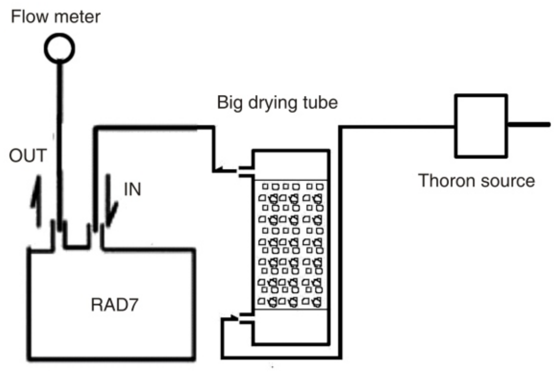

Figure 2. V_1 measurement scheme

EXPERIMENT AND RESULTS

RAD7 with calibration factor for ^{222}Rn of 1.12 is used to perform the thoron exhalation rate from soil surface measurement near by the Radon Laboratory of the University of South China. The area of the chamber's bottom is 430 cm^2, whereas the volume is 4 L; the volume of the internal cell of RAD7 is 0.723 liters (Provided by Dr. Derek Lane-Smith, the president of DURRIDGE Company, Inc.); the decay constant of thoron is 0.756 min^{-1}.

The settings of RAD7 are as follows: cycle, 30 min; mode, sniff; protocol, thoron. Because there is no external power source in field condition, this measurement was performed only by the battery in the RAD7. Since the flow rate of the pump changes with decreasing of the battery voltage, we recorded the voltage of the battery in each cycle, and obtained the flow rates of the internal pump for various battery voltages, in the laboratory.

Because sufficient time is needed for the thoron concentration in the chamber and the internal cell of the RAD7 to achieve equilibrium, the first datum is discarded. Table 1 lists the experiment data and the thoron exhalation rates obtained by eq. (11).

From tab. 1, we can find that the thoron exhalation rates from soil surface are relatively stable when the weather conditions are relatively stable. The average thoron exhalation rate in two hours is 2.85 ± 0.23 Bqs/m^2.

Some researchers indicated that thoron diffusion length in the air is very short (2.9 cm); therefore, in usual chambers with dimensions of 10 cm magnitude order, uniformity of thoron concentration is not feasible [6]. However, in tab. 1, a correlation between the flow rate and thoron exhalation rate do not exist. Maybe the internal pump of RAD7 forces the air mixing in the accumulation chamber.

Table 1. Experiment data and the thoron exhalation rates

Cycle	Measured value ×1.12 q m^3]	Air pressure [hPa]	Temperature [°C]	Relation humidity [%]	Battery voltage [V]	Flow rate [mlmin^{-1}]	Thoron exhalation rate [Bqs^{-1}m^{-2}]
2	580 186	1017	8.4	73.2	6.18	430	2.70 0.87
3	542 180	1017	6.7	78.7	6.12	415	2.65 0.88
4	556 182	1017	6.5	82.6	6.09	395	2.91 0.95
5	582 186	1017	5.9	83.1	6.06	385	3.15 1.01

CONCLUSIONS

The alpha detector, which is much less susceptible to radon-thoron interference due to its ability to distinguish the isotopes by their unique alpha particle energies, can be used to measure the thoron concentration in the "accumulation chamber" and the thoron exhalation rate can be obtained. In field conditions, the flow rate of the internal pump in RAD7 will change while the voltage of the battery decreases, the big drying tube is more suitable for long measurements than the small drying tube. These parameters are very important for measuring thoron concentration. Thus, the calibration factor for thoron is not suitable to calibrate the thoron concentration reading of RAD7. We developed the method for recalibrating the thoron concentration reading of RAD7 based on the calibration factor for ^{222}Rn.

ACKNOWLEDGEMENT

Project is supported by the National Natural Science Foundation of China (Grant No. 11075049), the Excellent Talents Program of Hengyang Normal University of China, the construct program of the key discipline in Hunan province and the Science Foundation of Hengyang Normal University of China (Grant No. 11B41). The authors would also like to thank Dr. Derek Lane-Smith for providing all the dimensions in the RAD7.

AUTHOR CONTRIBUTIONS

Theoretical analysis was carried out by Y. Tan and experiments were carried out by D. Xiao. The manuscript was written by Y. Tan and the figures were prepared by D. Xiao and Y. Tan.

REFERENCES

[1] Steinhäusler, F., Environmental ^{220}Rn: A Review, *Environment International, 22* (1996), 1, pp. 1111-1123

[2] Yamada, Y., *et al*., Radon-Thoron Discriminative Measurement in Gansu Province, China, and Their Implication for Dose Estimates, *Journal of Toxicology and Environmental Health, 69* (2006), 7, pp. 723-734

[3] Calamosca, M., Penzo, S., A New CR-39 Nuclear Track Passive Thoron Measuring Device, *Radiation Measurements, 44* (2009), 9-10, pp. 1013-1018

[4] Yonehara, H., *et al*., Thoron in the Living Environments of Japan, International Congress Series, Volume 1276, February 2005, pp. 58-61

[5] Sharma, N., Virk, H. S., Exhalation Rate Study of Radon/Thoron in Some Building Materials, *Radiation Measurements, 34* (2001), 1-6, pp. 467-469

[6] Ujić, P., *et al*., Standardization and Difficulties of the Thoron Exhalation Rate Measurements Using an Accumulation Chamber, *Radiation Measurements, 43* (2008), 8, pp. 1396-1401

[7] Tuccimei, P., Moroni, M., Norcia, D., Simultaneous Determination of ^{222}Rn and ^{220}Rn Exhalation Rates from Building Materials Used in Central Italy with Accumulation Chambers and a Continuous Solid State Alpha Detector: Influence of Particle Size, Humidity and Precursors Concentration, *Applied Radiation and Isotopes, 64* (2006), 2, pp. 254-263

[8] Qiu, S., Calibration of a ^{220}Rn Flow-through Source, *Radiation and Environmental Biophysics, 45* (2006), 3, pp. 215-220

[9] Kobayashi, Y., *et al*., Practicality of the Thoron Calibration Chamber System at NIRS, Japan, *Proceedings*, 6th International Conference on High Levels of Natural Radiation and Radon Area, Osaka, Japan, September 6-10, 2004, Int. Cong. Ser., 1276, 2005, pp. 281-282

[10] Sorimachi, A., *et al*., Performance of NIRS Thoron Chamber System, AIP Conf. Proc., August 7, 2008, Vol. 1034, pp. 206-209

[11] Qiu, S., Xiao, D., Liu, L., First Intercomparison of Tn–Rn Discriminative Measurements in China, *Radiation Protection Dosimetry, 28* (2008), 1, pp. 124-127

Received on September 17, 2012
Accepted on November 20, 2012

Јанлианг ТАН, Детао КСИАО

МЕТОДА РЕКАЛИБРАЦИЈЕ RAD7 ЗА ОЧИТАВАЊЕ КОНЦЕНТРАЦИЈЕ ТОРОНА И ОДРЕЂИВАЊЕ БРЗИНЕ ЕКСХАЛАЦИЈЕ ТОРОНА СА ПОВРШИНЕ ЗЕМЉИШТА

Брзина ексхалације торона може се одредити комбинацијом “акумулационе коморе” и RAD7. Торонов брз распад разлог је зашто су путања уноса и брзина протока ваздуха битни фактори за калибрацију. У теренским условима, брзина протока унутрашње пумпе у RAD7 мења се смањењем напона батерије, те је велика цев за сушење погоднија за дуготрајна мерења у односу на кратку цев. Развили смо методу за рекалибрацију очитавања концентрације торона засновану на калибрационом фактору за ^{222}Rn и одредили брзину ексхалације са површине земљишта у близини Радонске лабораторије Универзитета Јужне Кине. Ова метода може се применити за развијање и унапређење инструмената за одређивање брзине ексхалације радона.

Кључне речи: брзина ексхалације торона, земљиште, RAD7