EXPERIMENTAL STUDY ON THE CHARACTERISTICS OF RADON COVER IN WASTE LANDFILLS

N. Nassiri-Mofakham
Nuclear Science and Technology Research Institute
Tehran, Iran
Email: nnasiri@aeoi.org.ir

M. Kakaei
Nuclear Science and Technology Research Institute
Tehran, Iran

Abstract

Waste from resource extraction industries contain uranium and thorium decay chain radionuclides. One important radiological impact of these wastes is the release of radon into the atmosphere. Therefore, prediction/evaluation of radon flux and effectiveness of different covers are the major elements in radiation protection, long-term safety aspects, and to model radon release to the environment for final assessment of radiological impacts and required remediation actions. The authors designed a measurement system by short-time accumulation technique based on transient-diffusion method and the validity of the laboratory model to quickly estimate the radon release from soils, diffusion coefficient, and the effect of covers was investigated. It was observed that after 0.5 m and 1 m clay cover layer with diffusion coefficient $(1.78\pm0.24)\times10^{-6}$ m^2 s^{-1}, the measured radon flux density from bare waste, 1.05±0.23 Bq m^{-3}, decreases by a factor of 1.7 and 2.8, respectively, to 0.61±0.12 Bq m^{-3} and 0.37±0.06 Bq m^{-3}. Concerning to the measured radon diffusion length, the radon flux reduction factor increases to 10 for 1.6 m clay cover layer. The results show that the effectiveness of the studied cover layer is 3, which is similar to theoretical and experimental results in uranium tailings pond.

1. INTRODUCTION

The countries with oil and gas industries, uranium ores extraction and other resource extraction industries produce enormous amounts of residues containing radionuclides of the uranium or thorium chain and natural occurring radioactive materials (NORM). One important pathway for radiological impact arising from radioactive waste and NORM residues is the release of radon isotopes into the atmosphere. The principal isotopes of radon, ^{222}Rn and ^{220}Rn, are generated from the radioactive decay of ^{226}Ra and ^{224}Ra, respectively, which are the decay daughters in ^{238}U and ^{232}Th decay series. The half-live of ^{220}Rn is 55 *s*, which is not included in the safety considerations due to its very short half-life. The half-life of ^{222}Rn is 3.8 *days* that allows it to move long distances before decay. Furthermore, the generation rate of ^{222}Rn continues for many thousands of years due to the long half-life of ^{226}Ra which is present in the tailings.

Atmospheric radon (^{222}Rn) and its decay products have potential radiological impacts on public health. Therefore, prediction/evaluation of radon flux and effectiveness of different covers are the major elements in radiation protection, long-term safety aspects, and to model radon release to the environment for final assessment of radiological impacts and required remediation actions [1,2]. The effectiveness of a cover material in attenuation of radon release depends on the material thickness and ability to control the diffusion of radon and trapped its solid daughters before it exhaled from the cover. Thus, radon attenuation, including the effect of various covers is an important element in rehabilitation planning. As a result, the radon cover design is one of the basic issues in waste management to reduce radon releases to the atmosphere and soil erosion in repositories. The key parameter that characterizes the degree of radon flux reduction is the diffusion coefficient.

The aim of the paper is to evaluate experimentally radon exhalation from soil samples and effectiveness of the cover layer for optimal design of the radon cover. A measurement system was designed to measure the radon diffusion coefficients and soil radon flux density by short-time accumulation technique based on the transient-diffusion method [3]. The validity of the theoretical equations governing radon release from the soil and of the laboratory model to quickly estimate the radon release from soils, diffusion coefficient, and the effect of covers was investigated [4]. Comparison of theoretical and experimental results show that both theoretical model and the presented method to measure radon flux have sufficient accuracy and the results of the radon cover designed in this device can be generalized to real conditions.

2. RADON EXHALATION FROM POROUS MATERIAL

The measurement techniques for radon flux are based on the techniques that measure radon concentration. Radon flux monitors measure radon concentration emanated through the soil layer accounting the soil surface from which the radon exhaled. Real-time radon flux monitors make use of accumulators in conjunction with a specialized ionization chamber such as AlphaGUARD [5] to measure radon concentration. A detection system of the AlphaGUARD with an accumulator can measure the radon flux along with the radon diffusion properties of the material under study.

In the study, a simple and reliable accumulator method with a system of continuous radon detector (consisted of the AlphaGUARD™ PQ2000 radon monitor, the AlphaPUMP with 1 $l\ min^{-1}$ flow rate, the dehumidifier, and the filter for absorbing radon daughters) was used to measure radon exhalation rate from bare and covered tailings (FIG. 1.).

Soil samples with different thicknesses were analyzed for radon exhalation rate. A plexiglass transparent chamber (28 cm diameter and 120 cm height) was used as the air-tight accumulator device for transient-diffusion measurements [3]. The tailings (e.g. the soil containing radium) was placed in the radon chmaber and covered with a fine metal mesh plate. The soil sample can be placed on the tailings layer at different thicknesses. The detection system was sealed to the container to measure the radon concenration in the air flow above the soil sample. The exhalation rate was determined through the measured radon concentration buildup inside of the accumulator. Once the measurement system was equilibrated, the time-dependent radon concentrations were recorded by the AlphaGUARD over 2-3 hours. This exposure time was obtained as an optimal measurement time to minimize the back diffusion [3]. The AlphaGUARD also records pressure, humidity and air temprature inside of the accumulator.

At the closed measurement system, the radon detector collects variable concentrations with the growth curve given by

$$C(t) = C_0 + \frac{J\,A}{V\lambda_e}(1 - e^{-\lambda_e t}) \qquad (1)$$

where C_0 is the initial radon concentration J is the unbounded radon flux ($Bq \cdot m^{-2} \cdot s^{-1}$), A is the cross-section area of the accumulator (m^2), λ_e is the effective time constant (s^{-1}), and V is the volume of the accumulator (i.e., air volume above the soil) (m^3). The radon flux density was calculated by the fitting the measured values of concentrations at various times to Eq. (1). With no radon leackage, the effective time constant can estimate the back diffusion effect. The relaxation time (λ_e^{-1}) modifies the unbound flux density to the free flux density. It gives a factor of underestimation of radon free exhalation rate.

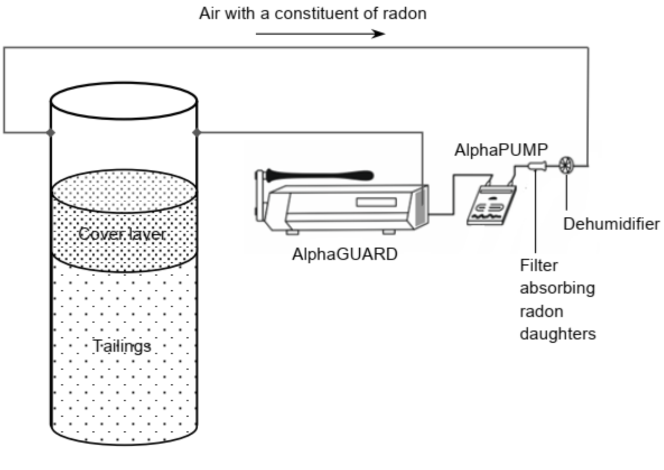

FIG. 1. Setup for short-time measurement of radon exhalation rate and diffusion coefficient.

3. EVALUATED RADON EXHALATION RATES

The regression of measured values gives the radon flux density from bare tailings with 95% confidence and close fit ($R^2 = 0.97$). The exhalation rate was $1.05 \pm 0.23 \; Bq \cdot m^{-2} \cdot s^{-1}$ for the bare tailings. FIG. 2 shows the values of growing radon concentrations in air collected in the measuring chamber. The radon exhalation rate is dependent on cover layer thickness and the effective diffusion coefficient of radon for the material used. In contrast to the flux which decreases with the sample thickness, the diffusion coefficient is independent of the thickness. For the chosen clayey soil, the radon diffusion coefficient was measured in the previous study and was $(1.78 \pm 0.24) \times 10^{-6} \; m^2 \cdot s^{-1}$ [4].

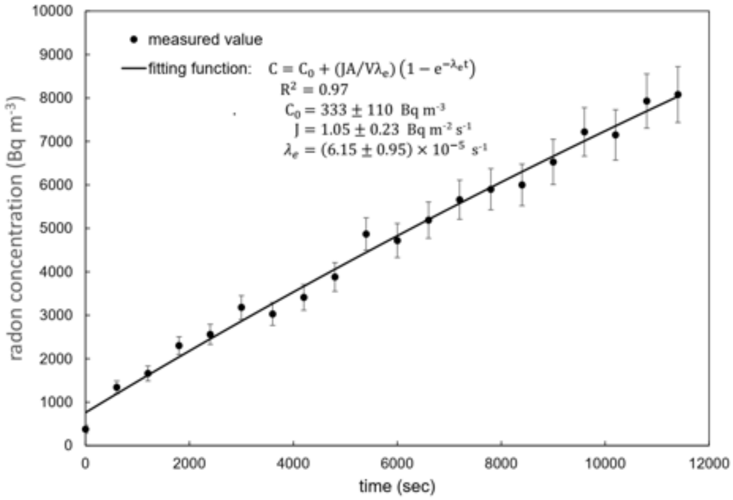

FIG. 2. Measured transient-diffusion radon concentration for bare tailings.

Fitting the time variation of radon concentrations for the covered tailings by clay sample with thickness of 0.5 *m* determined the flux density as $0.61 \pm 0.12 \; Bq \cdot m^{-2} \cdot s^{-1}$ with 95% confidence and $R^2 = 0.97$ (FIG. 3). For the cover layer of 1 *m* thickness, the best fitting ($R^2 = 0.98$) of the radon concentration values to Eq. (1) gives the flux density $0.37 \pm 0.06 \; Bq \cdot m^{-2} \cdot s^{-1}$ (FIG. 4). It is expected that the radon exhalation rates would be of the same order of magnitude, but are about 10 times higher than those from the natural soil. Thus, the short accumulation times can be used at tailings repository sites.

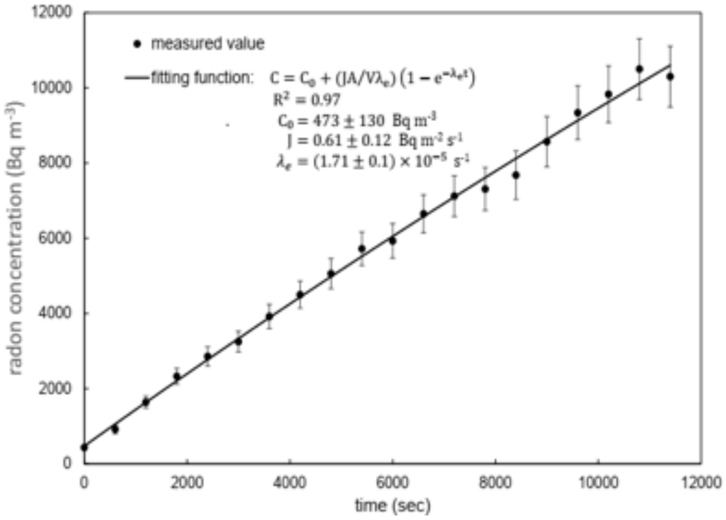

FIG. 3. Measured transient-diffusion radon concentration and evaluated fitting parameters for tailings with cover layer thickness of 0.5 m.

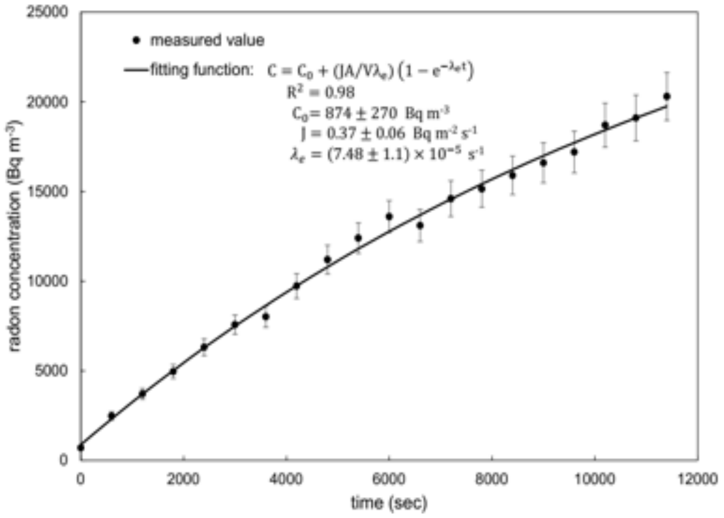

FIG. 4. Measured transient-diffusion radon concentration and evaluated fitting parameters for tailings with cover layer thickness of 1 m.

To get an assessment of the reduction factor of the exhalation rate with a thickness-independent parameter, we use a dimensionless parameter of the radon diffusion length and soil sample thickness. The effective diffusion length of radon is a function of diffusion coefficient and to be calculated $0.92 \pm 0.12\ m$. Measurement procedure was performed for cover layer with different sample thicknesses. The results of the measurements of flux reduction factor as a function of cover thickness is shown in FIG. 5. It can be seen that after 0.5 *m* and 1 *m* cover layer the radon exhalation rate decreases by a factor of 1.7 and 2.8, respectively. The reduction factor increases to 10 for 1.6 *m* clay over layer. Further, the effectiveness of the cover layer is 3, which is in consistent with the theoretical and experimental results in uranium tailings repository [6].

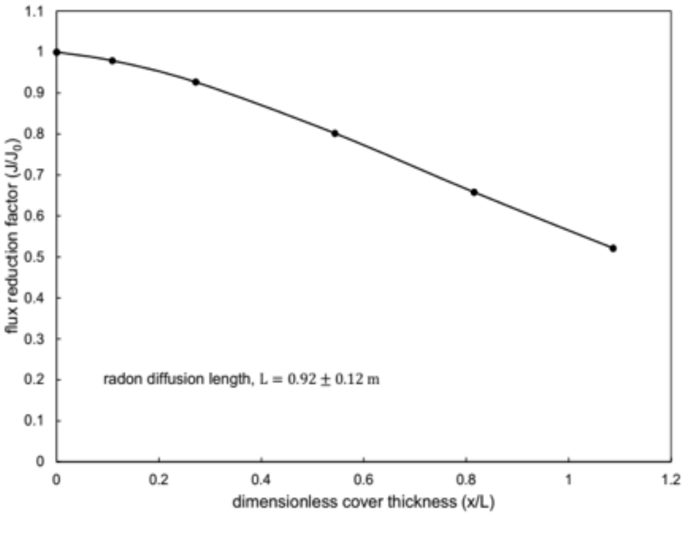

FIG. 5. Radon flux reduction factor for various cover thickness.

4. CONCLUSIONS

The radon release from bare and covered tailings model was estimated using diffusion theory to calculate the adequate thickness of a radon cover system. It was observed that after 0.5 m and 1 m clay cover layer with diffusion coefficient $(1.78 \pm 0.24)\ \mathrm{m}^{-2} \cdot s^{-1}$, the measured radon flux density from bare waste,

$1.05 \pm 0.23\ \mathrm{Bq \cdot m^{-2} \cdot} s^{-1}$, decreases by a factor of 1.7 and 2.8, respectively, to $0.61 \pm 0.12\ \mathrm{Bq \cdot m^{-2} \cdot} s^{-1}$and $0.37 \pm 0.06\ \mathrm{Bq \cdot m^{-2} \cdot} s^{-1}$ Concerning to the measured radon diffusion length, the radon flux reduction factor increases to 10 for 1.6 m clay cover layer. The results show that the effectiveness of the studied cover layer is 3, which is similar to theoretical and experimental results in uranium tailings pond [6].

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