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Multilayer Stack Method for Precise Measurement of Radon Diffusion Coefficient of Different Materials

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Radon-resistant materials are of great importance for High Background Radiation Areas. Depending on the radon diffusion coefficient, waterproofing and radon-resistant materials with thicknesses ranging from a few microns to several centimeters are used in various parts of the world. The cost of installation of an effective radon mitigation system varied with material properties, *i.e.*, thickness and diffusion coefficient. The present study is concerned with the measurement of the radon diffusion coefficient through single and multilayer homogeneous and heterogeneous stacks of various waterproofing materials. One, two, and three layers of polyethylene, printing paper, mica sheets, PVC sheets, Mylar sheets and aluminum foil of varying thicknesses are tested for determination of diffusion length by the two-chamber method and the active scintillation radon monitor. The radon diffusion coefficient of materials varies from 10^{-13}m^2/s to 10^{-8}m^2/s for PVC sheet to paper sheet when a single layer is used and 10^{-11} m^2/s to 10^{-13} m^2/s for aluminum and polyethylene sheets in multi-layer stack arrangement. The radon diffusion coefficient for most of the materials reduces with increasing layers in the stack. By the use of these materials, 85-90 % of radon can be reduced by using single or multi-layer stack combination.

Keywords: Radon diffusion coefficient; waterproofing materials; Multi-layer stack

1 Introduction

Radon is a radioactive gas present in the environment and emitted from geological samples like soil, stone and granite due to the presence of varying amounts of radium and thorium[1]. The radon gas diffuses from a few meters underneath to the indoor environment due to its long half-life of 3.824 days by diffusion and advection[2,3]. The advective flow of radon is dominant under large pressure differential conditions, while under normal conditions diffusive flow significantly contributes to indoor radon[4]. Radon is identified as a carcinogen due to its ability to emit alpha particles in the lung when inhaled through the nose and mouth and causes cancer[5]. The ventilation of the indoor environment is one of the important factors along with construction type that determine the indoor radon levels 6. The International Commission of radiation Protection limits the indoor radon level 100 Bq/m^3 in dwellings. In High Background Areas, the indoor radon levels are found much higher as compared to recommended limits due to higher radium and thorium contents in soil and building material[7]. Thus, construction strategies of dwelling should be reinvestigating to lower down the radon levels. In HBRAs Radon and waterproofing materials are used to restrict the ingress of radon from underneath to indoor. The cost and effectiveness of a radon shielding project depends upon the accurate and precise measurement of radon diffusion through these materials. Various methods and techniques were used by many investigators in the past for the measurement of radon diffusion through waterproofing and radon resistant materials[8-15]. Many studies were performed by many investigators to determine the diffusion coefficient by simultaneous measurement of radon growth in two chambers, by measurement of radon growth in one chamber keeping radon concentration constant at the other end, and by measuring the gamma count in radon absorbed on the surface of a single layer of materials with varying thickness[16-19]. But the effect of multiple layers stacking with homogenous and heterogeneous materials combination is still a question for investigator. In this work, an attempt is made to determine the diffusion coefficient through different

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*Corresponding author: (E-mail: amit.vera@gmail.com) materials using single and multilayers stack method with homogenous and heterogeneous combination. The materials selected for the diffusion studies are polyethylene, printing paper, mica sheets, PVC sheets, Mylar sheets, and aluminum foil, which are available at a low cost. The use of these materials individually or in combination may be used for radon shielding purposes to reduce the cost of construction.

2 Materials and Methods

2.1 Materials Specification

The specimens used for the radon diffusion study are the common materials which are used as radon resistant materials and for decoration purposes. The specimens are collected from the market shop, online store and bookshops. The thickness of the specimen used in the experiment is supplied by the manufacturer. The details of the specimen used in the present study are listed in Table 1

2.2 Radon Diffusion Set-up

The determination of radon diffusion coefficients of different materials is based on the measurement of the radon flux through the tested material placed between two cylindrical containers as used by various investigators[8-10, 16-18]. The specimens are provided with four holes for attachment with diffusion set as shown in Fig. 1. Pressure gaugue, vacuum pump and air circulation pump are added in the system for multiple studies like effect of advective flow.

The specimens are fixed with an attachment provided in between two chambers and rubber gaskets are used to avoid any leakage. It was assumed in the present investigation that the leakage of radon from the source chamber does not affect the measurement as we are interested in equilibrium radon concentration only. Because once equilibrium is attained, it remains constant until the sealing of the chamber is disturbed. The 100 gm of uranium ore of specific activity, 35 kBq/Kg, was used as a radon source in the source chamber that creates the radon concentration upto 100 kBq/m^3 within this chamber. The growth of radon in the source chamber was measured using a Lucas cell coupled scintillation radon monitor. The measurement of the radon diffusion coefficient and diffusion length of the

Table 1 — Materials Specification

S. No	Specimen	Thickness in mm (d)
1	PVC Sheet	6.000
2	Paper (P)	0.120
3	Mica Sheet (MS)	0.100
4	Mylar Sheet (MLS)	0.050
5	Aluminium Sheet (AL)	0.015
6	Polyethylene (PE)	0.010
7	MLS-AL-MLS	0.115
8	MLS-PE-MLS	0.110
9	P-MS-P	0.400
10	P-MS-P-MS-P	0.800
11	PE-AL-PE	0.035
12	PE-AL-PE-AL-PE	0.060

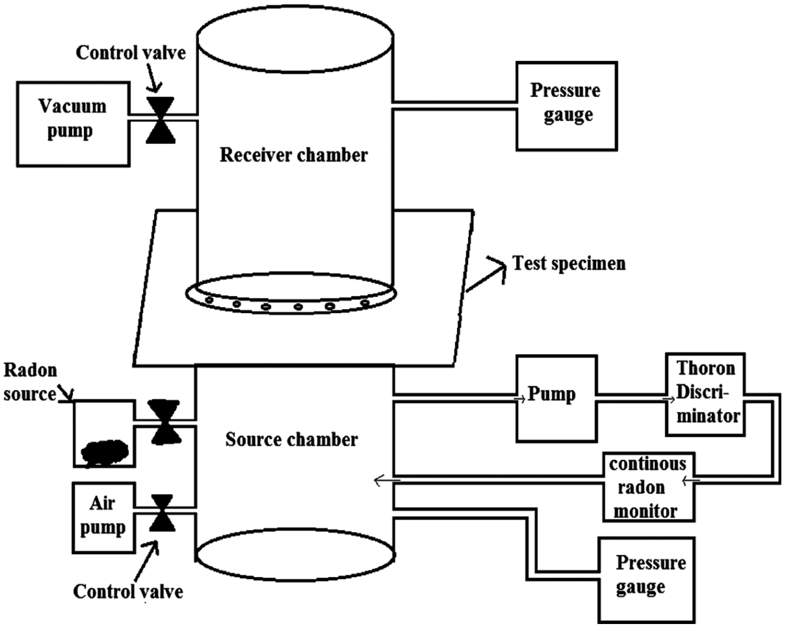

Fig. 1 — Experimental set up used in radon diffusion study.

specimen can be determined by the procedure discussed elsewhere[9-11]. The method of measurement involved growing a steady state radon concentration in the source chamber and then measuring growth of radon in receiver chamber for the determination of radon diffusion coefficient as discussed in9. In order to determine the percentage reduction of radon transport from source chamber to receiver chamber, a time series growth of radon in both chambers was carried out with the help of Scintillation Radon Monitor.

3 Results and Discussion

The leakage of radon from both chambers is ensured by measuring the radon decay curve discussed by Kumar and Chauhan[20] and found negligible (10^{-4} h^{-1}) as compared to the radon decay rate 10^{-3} h^{-1}. However, there is diurnal variation in indoor and outdoor temperatures during the measurements but the average temperature variation during all the measurements is 2-3 °C. The growth of radon in source and receiver chambers with time in the case of aluminum foil samples is shown in Fig. 2.

The radon growth in the source chamber, simultaneous measured value of radon in the receiver chamber, diffusion coefficient, diffusion length and percentage reduction in the radon due to shielding materials are listed in Table 2.

3.1 Single layered radon resistant materials

The steady state radon concentration in the source chamber due to uranium ore varied from 32.2 to 76.3 kBq/m^3. The d/L ratio of the specimen under study varied from 0.01 to 2.16 showing the wide difference

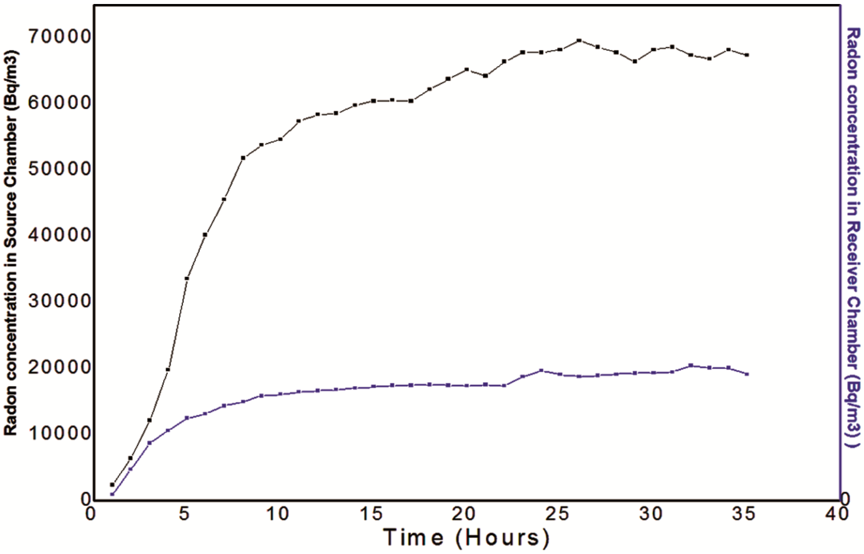

Fig. 2 — Radon concentration in source and receiver chamber for PE-AL-PE multilayers stack test.

Table 2 — Steady state radon concentration, diffusion coefficient, diffusion length and percentage reduction

S. No	Materials	Radon concentration in Source Chamber (kBq/m^3)	Radon concentration in Receiver Chamber (kBq/m^3)	Percentage reduction	Radon Diffusion coefficient (m^2/s)	Radon Diffusion Length (L) (mm)	d/L
1	PVC Sheet	62.1	5.6	90.9	$(8.62 \pm 1.32)\times10^{-13}$	0.083	0.72
2	Paper (P)	32.2	27.7	13.9	$(1.64 \pm 0.21)\times10^{-8}$	0.115	0.01
3	Mica Sheet (MS)	76.3	7.69	89.9	$(7.91 \pm 2.34)\times10^{-10}$	2.521	0.04
4	Mylar Sheet (MLS)	52.2	19.3	63.0	$(9.65 \pm 3.11)\times10^{-10}$	2.78	0.02
5	Aluminium Sheet (AL)	56.9	15.3	73.1	$(4.72 \pm 1.67)\times10^{-12}$	0.194	0.08
6	Polyethylene (PE)	54.3	16.5	69.6	$(1.93 \pm 0.56)\times10^{-11}$	0.393	0.03
7	MLS-AL-MLS	57.5	9.77	83.0	$(1.12 \pm 0.42)\times10^{-12}$	0.095	1.21
8	MLS-PE-MLS	62.7	12.6	79.9	$(0.78 \pm 0.23)\times10^{-12}$	0.079	1.39
9	P-MS-P	56.8	22.6	60.2	$(7.31 \pm 1.01)\times10^{-11}$	0.765	0.52
10	P-MS-P-MS-P	63.4	14.9	76.5	$(1.72 \pm 0.42)\times10^{-11}$	0.371	2.16
11	PE-AL-PE	65.3	12.9	80.2	$(3.45 \pm 0.98)\times10^{-12}$	0.166	0.21
12	PE-AL-PE-AL-PE	67.6	8.6	87.3	$(9.72 \pm 2.98)\times10^{-13}$	0.088	0.68

in the thickness and cost for using these materials as radon resistant materials[11]**.** The radon concentration in the source chamber for a single layer of PVC and Polyethylene–Aluminum multi-stack are minimum of the order of10^{-13} shows their potential application as radon resistant. The d/L ratio for the PVC sheet is 0.72 shows that a single layer can be used for optimum resistance of radon. The percentage reduction of radon for these two materials is approximately 90 % shows their effective use asaradon barrier. The maximum radon diffusion coefficient (10^{-8} m^2/s) is found for paper which is highly porous as compared to other materials and poses a very small resistance to flow of radon through it and 80-85 % of the gas can pass through it however increasing the thickness of specimens can results in the more reduction in radon which increase the cost of use as d/L ratio is 0.01. The average radon diffusion coefficient for mica sheet and Mylar sheet is 7.91 $\times10^{-10}$ and9.65×10^{-10} m^2/s and percentage reduction 89% and 63 % respectively. The d/L ratio for Mylar sheet is 0.02 shows that much more thickness is required for effective use of this material for insulation purposes. Except PVC the d/L ratio of the single layer specimen show d/L ratio smaller than 1.0 show that much more thickness or a multilayer stack arrangement is required for radon resistance application.

3.2 Multi-layer Stack arrangement of radon resistant materials

Table 2 shows the average radon diffusion coefficient for the multilayer stack of different materials varying from 9.72×10^{-13} to 7.31×10^{-11} m^2/s while radon diffusion length varies from 88 micron for the polyethylene-aluminum stack to 765 micron for paper mylar sheet stack. An increase in the number of layers in the stack causes a decrease in the diffusion coefficient and diffusion length. This may be because the layers impose much more resistance to transport of radon. Another possibility for decrease in radon diffusion efficiency can be attributed as radon is trapped in the gap between two layers and decays before escaping out of the receiver chamber. The d/L ratio for the stack where two sheets of paper and one mylar sheet is involved is much smaller than the arrangement of three sheets of paper and two mylar sheets. This may be because the diffusion coefficient of mylar sheet is 10 times smaller than that of paper, while the thickness of paper is 2.5 times more than that of mylar sheet. Similar trends are observed in the case of a multi-layer stack of aluminum and polyethylene. The difference in the d/L ratio mainly arises due to the difference in the diffusion coefficient of aluminum and polyethylene. The d/L ratio for aluminum and polyethylene is smaller than one, but these stacks can reduce 80-85 % of radon so the thickness to be used for radon insulation should be optimized[11]. From the data shown Table 2 it is not confirmed that the percentage reduction in the radon through single and multilayer stack is linear or non-linear. The hetro-junction formed between the different layers of materials may cause delay in the radon transfer across the materials and affect the diffusion coefficient and length. So more detailed investigation is required to understand the behaviour of multilayer stacks or single layer of the same material with different thicknesses.

4 Conclusions

Radon transport through different materials in single and multi-layers is investigated to study the resistant behaviours. The radon diffusion coefficient of materials varies from 10^{-13} m^2/s to 10^{-8} m^2/s for PVC sheet to paper sheet when a single layer is used and 10^{-11} m^2/s to 10^{-13} m^2/s for aluminum and polyethylene sheets in multi-layer stack arrangement. The radon shielding by aluminum foil and polyvinyl chloride sheets showed excellent results for radon reduction in multilayers. A combination of both may be used for effective radon shielding and cost effectiveness in high background radiation areas. The radon diffusion coefficient for most of the materials reduces with increasing layers in the stack. The d/L ratio of the materials suggests that the percentage reduction in radon through specimens shows uncertainty in understanding the behaviour of radon transport through single and multi-layer stacks. A detailed investigation is required to understand the behaviours. By the use of these materials, 85-90 % of radon can be reduced by using a single or multi-layer stack combination.

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