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Estimation of Radon Exhalation Rate, Natural Radioactivity and Radiation Doses in Mosaic Samples

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Abstract:
In the present study we have made measurement of radon exhalation rate from mosaic of different brands and colours, commonly used as building construction materials in India. Out of total 27 samples collected 10 were from Jaipur, 8 from Kishangarh and 9 from Ajmer. Can technique using LR-115 type II solid state nuclear track detector has been employed for the measurement of radon activity and radon exhalation rate. Radon activity varies from 27.52 Bq m^{-3} to 101.12 Bq m^{-3} with an average value of 54.95 Bq m^{-3}, exhalation rate varies from 491.43 mBq m^{-2} h^{-1} to 1805.71mBq m^{-2} h^{-1} with an average value of 981.27 mBq m^{-2} h^{-1} while effective dose equivalent varies from 34.68 µSv y^{-1} to 127.44 µSv y^{-1} with an average value of 69.26 µSv y^{-1}. Natural radioactivity in mosaic samples has been measured by low level gamma ray spectrometer. The activity concentrations of ^{238}U and ^{232}Th varies from 3.33± 1.8 to 128.18± 2.44 Bq kg^{-1} with an average value of 30.67± 1.06 Bq kg^{-1} and from 6.25±0.28 to 51.69± 1.42 Bq kg^{-1} with a mean value of 24.39±0.83 Bq kg^{-1} respectively. ^{40}K in mosaic samples ranges from 0 to 833.67± 9.7 Bq kg^{-1} with an average value of 270.29± 3.74 Bq kg^{-1}. Absorbed gamma dose rate varies from min. value of 5.31 nGy h^{-1} to max. value 125.20 nGy h^{-1}. The corresponding indoor and outdoor annual effective doses vary from 0.03 to 0.25 mSv y^{-1} and 0.01 to 15 mSv y^{-1}. The calculated values of H_{ex} for mosaic samples vary from 0.03 to 0.71.

Keywords: *Radon exhalation rate, Effective dose, Gamma ray spectroscopy, Radium equivalent activity, LR-115 type II detector.*

1. Introduction

Radon an inert radioactive gas whose predecessor is uranium, is emitted from soil beneath the house and from building materials. Noble radon gas (^{222}Rn) originates from radioactive transformation of ^{226}Ra in the ^{238}U decay chain in the earth's crust [1]. The assessment of radiological risk related to inhalation of radon and radon progeny is based mainly on the integrated measurement of radon in both indoor and outdoor environments. The exhalation of radon from the earth crust and building materials forms the main source of radon in indoor environment [2]. Radioactivity is a part of the natural environment [3]. Environment contains some naturally occurring radioactive materials (NORM) which are found in soils, rocks, vegetation, air, water and also in building materials [4]. All building materials such as concrete, cement, brick, sand, aggregate, marble, granite, limestone, gypsum, etc. contain mainly natural radionuclides including Uranium (^{238}U) and Thorium (^{232}Th) and their decay products and the radioactive isotope of potassium (^{40}K). The naturally occurring radionuclides in the building materials contribute to radiation exposure, which can be divided into external and internal exposure. External exposure is caused by direct gamma radiation while internal exposure is caused by the inhalation of the radioactive inert gas radon (^{222}Rn, a daughter product of ^{226}Ra) and its short-lived secondary decay products. Gamma radiation has always been existed in environment since the big-bang occurred due to the long half-lives of the radionuclides from the ^{238}U and ^{232}Th series, and their decay products [5]. Historical antecedents of studies conducted on natural radioactivity have established that the presence of the uranium-thorium series and potassium-40 in various materials constitute potential exposure to the global population [6].

Radon emanation from building materials has been the subject of many studies [7-9]. Knowledge of the level of natural radioactivity in building materials is therefore important to assess the possible radiological hazards to human health and to develop standards and guidelines for the use and management of these materials. During the past few years, lot of attention has been devoted to the control of natural radiation in building materials in European, Asian and some African countries [10-19].

Mosaic slabs and mosaic pieces are commonly used as flooring material in the buildings. These mosaic slabs are decorative tiles used as wall tiles and also used in interior, exterior, garden and swimming pools of residential, commercial, multiplexes, Malls, public buildings and road sides and others. The colours of these mosaic tiles are of permanent nature. The state of Rajasthan produces wide variety of mosaic slabs. In the present paper radon exhalation rates have been measured in mosaic samples. The analysis of radioactivity in mosaic samples used as ornamental purpose and flooring materials in building construction has been measured by low level gamma ray spectrometer. In addition, absorbed radiation doses and radiation risk have also been estimated.

2. Experiment

2.1. Radon Exhalation Rate

Radon exhalation rate is of prime importance for the estimation of radiation risk from various materials. In such measurements, it is expected that the exhalation rate depends upon the material and its amount as well as on the geometry and dimension of the can. Collected granite samples were dried and sieved through a 100- mesh sieve. They were placed in the cans (7.5cm height and 7.0 cm diameter) similar to those used in previous calibration experiment [20]. In each can a LR-115 type II plastic detector (2cm × 2cm) was fixed at the top inside of the can, such that the sensitive surface of the detector faces the material and is freely exposed to the emergent radon. Radon decays in the volume of the can record the alpha particles resulting from the Po ^{218} and Po ^{214} deposited on the inner wall of the can. Radon and its daughters will reach an equilibrium in concentration after one week or more. Hence the equilibrium activity of the emergent radon can be obtained from the geometry of the can and the time of exposure. The detectors were exposed to radon for 100 days. After the exposure the detectors were etched in 2.5 N NaOH at 60^{0}C in a constant temperature water bath for revelation of tracks. The resulting alpha tracks on the exposed face of the track detector were counted using an optical microscope at a magnification of 400X. The radon exposure inside the can was obtained from the track density of the detector by using calibration factor of 0.56 tracks cm^{-2} d^{-1} obtained from an earlier calibration experiment [21]. The exhalation rate is found from the expression [22,23]:

$$Ex = \frac{CV\lambda}{A[T + \frac{1}{\lambda}(e^{\lambda t} - 1)]}$$

Where,

Ex = Radon Exhalation rate (Bq m^{-2} h^{-1})
C = Integrated radon exposure as measured by LR-115 type II solid state nuclear track detector (Bq m-^{3} h^{-1}).
V = Volume of can (m^3)
λ = Decay constant for radon (h^{-1})
T = Exposure time (h)
A = Area covered by the can (m^2)

2.2. Radiometric Analysis

Gamma ray spectrometric measurements were carried out at Inter-University Accelerator Centre, New Delhi, India using a coaxial n-type HPGe detector (EG&G, ORTEC, Oak Ridge, USA) for estimation of the natural radionuclides, Uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K). The samples were crushed into fine powder by using Mortar and Pestle. Fine quality of the sample is obtained by using scientific sieve of 150 micron-mesh size. Before measurements samples were oven dried at 110ºC for 24h and the samples were then packed and sealed in an impermeable airtight PVC container to prevent the escape of radiogenic gases radon (^{222}Rn) and thoron (^{220}Rn). About 300g sample of each material was used for measurements. Before measurements, the containers were kept sealed about 4 weeks in order to reach equilibrium of the ^{238}U and ^{232}Th and their respective progenies. After attainment of secular equilibrium between ^{238}U and ^{232} Th and their decay products, the samples were subjected to high resolution gamma spectroscopic analysis. HPGe detector (EG&G, ORTEC, Oak Ridge, USA) having a resolution of 2.0 keV at 1332 keV and a relative efficiency of 20% was placed in 4″ shield of lead bricks on all sides to reduce the background radiation from building materials and cosmic rays [24]. The detector was coupled to a PC based 4K multi channel analyzer and an ADC for data acquisition.

The calibration of the low background counting system was done with a secondary standard which was calibrated with the primary standard (RGU-1) obtained from the International Atomic Energy Agency (IAEA). The efficiency for the system was determined using secondary standard source of uranium ore in the same geometry as available for the sample counting. For activity measurements the samples were counted for a period of 72000 seconds. The activity concentration of ^{40}K (C_K) was measured directly by its own gamma ray of 1461 keV. As ^{238}U and ^{232}Th are not directly gamma emitters, their activity concentrations (C_U and C_{Th}) were measured through gamma rays of their decay products. Decay products taken for ^{238}U were ^{214}Pb: 295 and 352 keV and ^{214}Bi: 609, 1120 and 1764 keV whereas for ^{232}Th were ^{228}Ac: 338, 463, 911 and 968 keV, ^{212}Bi : 727 keV, ^{212}Pb : 238 keV and ^{234}Pa : 1001 keV gamma ray by assuming the decay series to be in equilibrium [25]. Weighted averages of several decay products were used to estimate the activity concentrations of ^{238}U and ^{232}Th. The gamma ray spectrum was analyzed using the locally developed software "CANDLE" (Collection and Analysis of Nuclear Data using Linux Net work)".

The net count rate under the most prominent photo peaks of radium and thorium daughter peaks are calculated from respective count rate after subtracting the background counts of the spectrum obtained for the same counting time. Then the activity of the radionuclide is calculated from the background subtracted area of prominent gamma ray energies. The concentration of uranium, thorium and potassium is calculated using the following equation:

$$Activity\ \ (Bq.kg^{-1}) = \frac{(S \pm \sigma) \times 100 \times 1000 \times 100}{E \times W \times A} \qquad (1)$$

Where S is the net counts/sec (cps) under the photo peak of interest, σ the standard deviation of S, E the counting efficiency (%), the gamma abundance or branching intensity (%) of the radionuclide and W is the mass of the sample (Kg).

The concentrations of Uranium, Thorium and Potassium are calculated using the following equation:

Activity(Bq) =CPS × 100 × 100/B.I × Eff ± CPS_{error} × 100 × 100/ B.I × Eff (2)

Where, CPS - Net count rate per second

B.I. - Branching intensity, and

E - Efficiency of the detector

3. Results and Discussion

Table 1 presents the results of measured data for radon exhalation from different mosaic samples.

Sample Details	Track Density (track/cm^2 d)	Radon activity (Bq m^{-3})	Radon Exhalation Rate (mBq m^{-2} h^{-1})	Effective dose equivalent (µSv y^{-1})
From Jaipur				
1. Kasara Marble (Brown)	56.32	1005.71	601.93	70.98
2. Kasara Marble (Gray with white)	35.04	625.71	374.49	44.16
3. Kasara Marble (Light brown with white)	69.44	1240.00	742.16	87.52
4. Kasara Marble (Cream with Brown)	64.00	1142.86	684.02	80.66
5. Mukesh Marble (light brown)	73.92	1320.00	790.04	93.16
6. Mukesh Marble (Light yellow)	65.76	1174.29	702.83	82.88
7. Kota Stone Mukesh Marbles arts (Gray colour)	45.60	814.29	487.36	57.47
8. Mukesh Marble (Brown with white)	70.72	1262.86	755.84	89.13
9. Shivshakti Marble (Cream with Gray)	56.48	1008.57	603.64	71.18
10. Shivshakti Marble (Cream with Brown)	45.60	814.29	487.36	57.47
From Kishangarh (Wall Tiles)				
11. Kishangrah (Orange Colour)	39.52	705.71	422.38	49.81
12. Galaxio (Red Colour)	35.36	631.43	377.92	44.56
13. Galaxio (Cream Colour)	61.60	1100.00	658.37	77.64
14. Unique (Red Colour)	38.40	685.71	410.41	48.39
15. Unique (Cream Colour)	27.52	491.43	294.13	34.68
16. Chocobar (Red Colour)	36.96	660.00	395.02	46.58
17. Chocobar (Gray colour)	51.68	922.86	552.34	65.13
18. Fancy (Cream with Red Wonder)	31.68	565.71	338.59	39.93
From Ajmer				
19. Red Colour	77.60	1385.71	829.37	97.80
20. Gray with White	66.24	1182.86	707.96	83.48
21. White	101.12	1805.71	1080.74	127.44
22. Cream	49.76	888.57	531.82	62.71
23. Gray Dark	40.64	725.71	434.35	51.22
24. Light Gray	69.6	1242.86	743.87	87.72
25. Brown with white	64.48	1151.43	689.15	81.27
26. White, yellow, brown, Green	45.76	817.14	489.07	57.67
27. White, Brown, Gray, Phirozi	62.88	1122.86	672.05	79.25
Min	27.52	491.43	294.13	34.68
Max.	101.12	1805.71	1080.74	127.44
Average Value	54.95	981.27	587.30	69.26
S.D.	17.12	305.66	182.94	21.57
R. S. D.%	31.16	34.15	31.15	31.14

Table 1: Radon activity concentration, radon exhalation rate and indoor inhalation exposure (radon)-effective dose from mosaic samples

It is apparent from Table 1, that the radon activity varies from 491.43 Bq m^{-3} to 1805.71 Bq m^{-3} with an average value of 981.27 Bq m^{-3}, exhalation rate varies from 294.13 mBq m^{-2} h^{-1} to 1080.74mBq m^{-2} h^{-1} with an average value of 587.30 mBq m^{-2} h^{-1}, while effective dose equivalent varies from 34.68 µSv y^{-1} to 127.44 µSv y^{-1} with an average value of 69.26 µSv y^{-1}. Thus radon emanation from mosaic samples shows a wide variation in the values of radon activity, radon exhalation rate and effective dose equivalent. It is observed that mosaic used for the purpose of building construction may have less radiation risk. The frequency distribution of radon exhalation rate from mosaic samples is given in Figure 1.

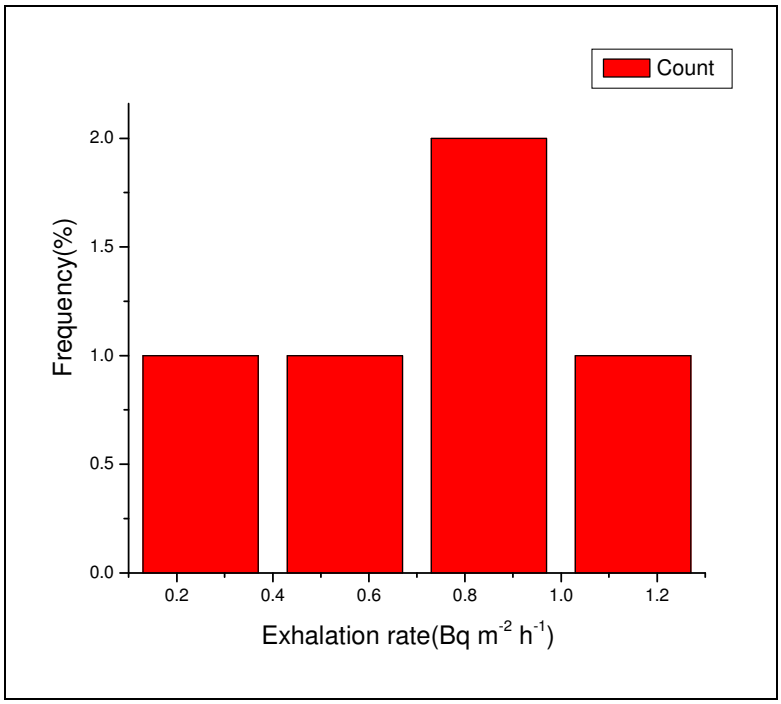

Figure 1: Frequency distribution of radon exhalation rates from mosaic samples

It is apparent from Figure 1, that the distribution does not seem to be lognormal.

The gamma ray spectrum recorded with the spectrometer of a typical mosaic sample is shown in Figure 2

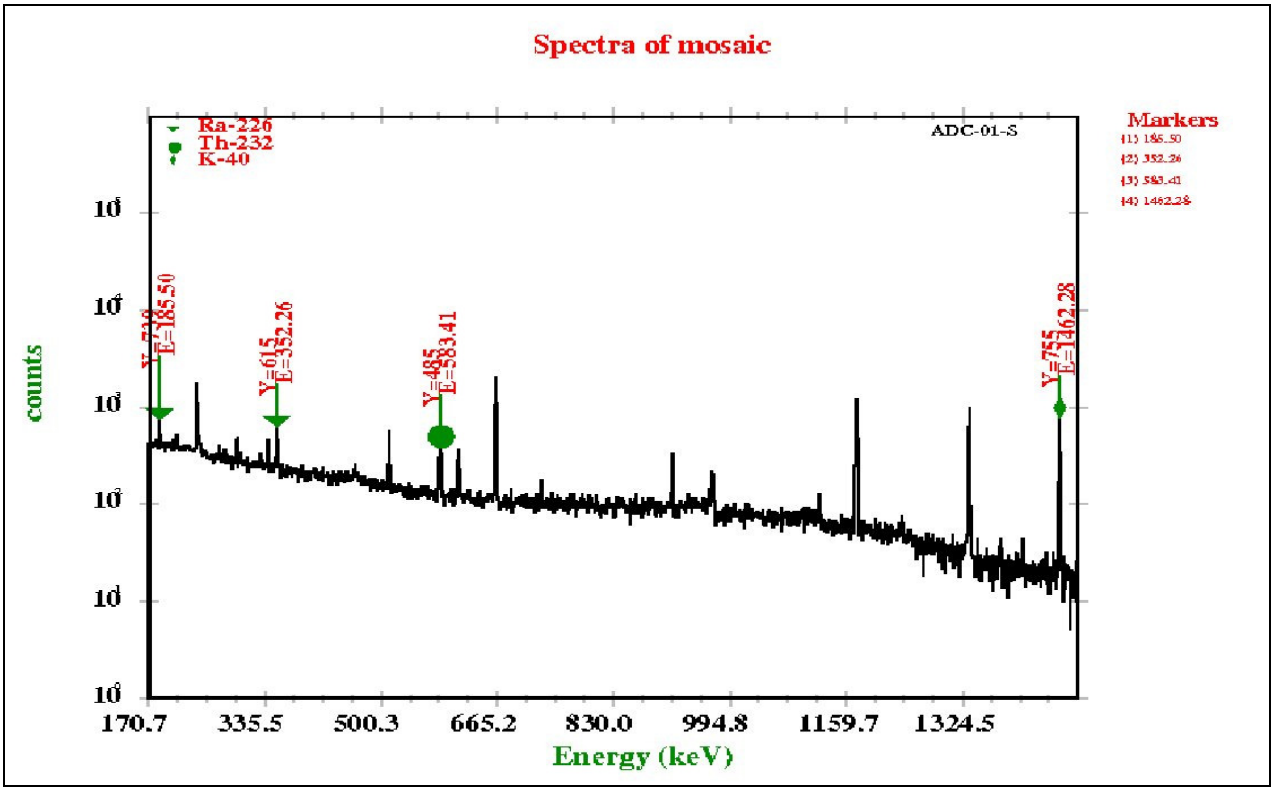

Figure 2: gamma ray spectrum of a mosaic sample

Measured ^{238}U, ^{232}Th, and ^{40}K activity concentrations in the mosaic samples are shown in Table-2 and computed Radium equivalent activity, absorbed gamma dose rate, annual effective doses, external hazard index and internal hazard index in mosaic samples are presented in Table 3.

Sample Code	^{238}U (Bqkg^{-1})	^{232}Th (Bq kg^{-1})	^{40}k (Bq kg^{-1})
M1	25.69 ± .97	23.45 ± .83	271.55 ± 3.81
M2	3.33 ± .018	6.25 ± .28	BDL
M3	15.63 ±.29	27.09 ± .66	475.21 ± 6.18
M4	128.18 ± 2.44	51.69 ± 1.42	833.67 ± 9.70
M5	21.18 ± .89	18.72 ± 0.70	BDL
M6	29.71 ± 1.10	33.87 ± 1.08	417-09 ± 5.54
M7	25.27 ± 1.21	12.39 ± .35	252.53 ± 3.60
M8	18.36 ± .80	20.46 ± .86	51.95 ± .85
M9	25.92 ± .88	35.52 ± 1.26	327.82 ± 4.51
M10	29.99 ± 1.17	29.78 ± 1.09	410.29 ± 5.46
M11	34.68 ± 1.28	15.89 ± 0.64	217.52 ± 3.15
M12	22.27 ± 0.87	23.61 ± 0.82	399.19 ± 5.33
M13	19.36 ± 1.49	BDL	BDL
M14	28.35 ± 1.19	20.37 ± 0.76	253.24 ± 373
M15	32.13 ± 1.26	22.40 ± 0.85	291.13 ± 4.18
Min	3.33± .18	6.25± .28	BDL
Max	128.18± 2.44	51.69± 1.42	833.67± 9.7
Average value	30.67± 1.06	24.39± .83	270.29± 3.74
S.D	28.06± 0.54	11.13± .31	226.95± 2.69

Table 2: Activity concentration of ^{238}U, ^{232}Th, and ^{40}k, in Mosaic Samples

BDL Below detection limit

It is apparent from Table 2 that the activity concentrations of ^{238}U and ^{232}Th varies from 3.33± 1.8 to 128.18± 2.44 Bq kg^{-1} with an average value of 30.67± 1.06 Bq kg^{-1} and from 6.25±0.28 to 51.69± 1.42 Bq kg^{-1} with a mean value of 24.39±0.83 Bq kg^{-1}, respectively. ^{40}K activity concentration in mosaic samples ranges from 0 to 833.67± 9.7 Bq kg^{-1} with an average value of 270.29± 3.74 Bq kg^{-1}.

The correlation between ^{238}U and ^{232}Th activity concentration and ^{232}Th and ^{40}K activity concentration in the mosaic samples is shown in Fig 3 and Fig4, respectively.

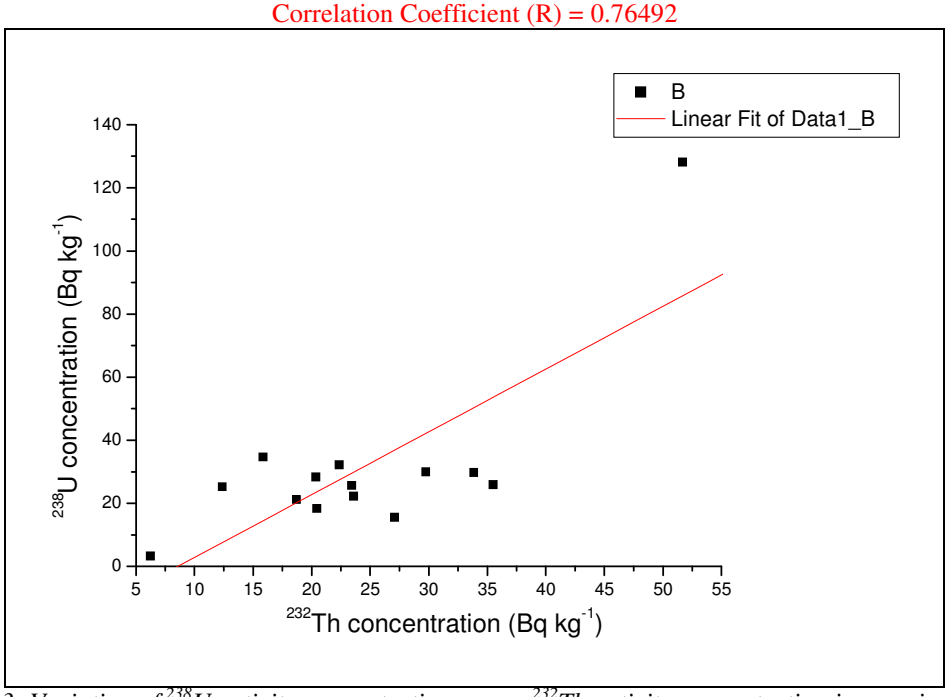

Figure 3: Variation of ^{238}U activity concentration versus ^{232}Th activity concentration in mosaic samples

Correlation Coefficient (R) = **0.8378**

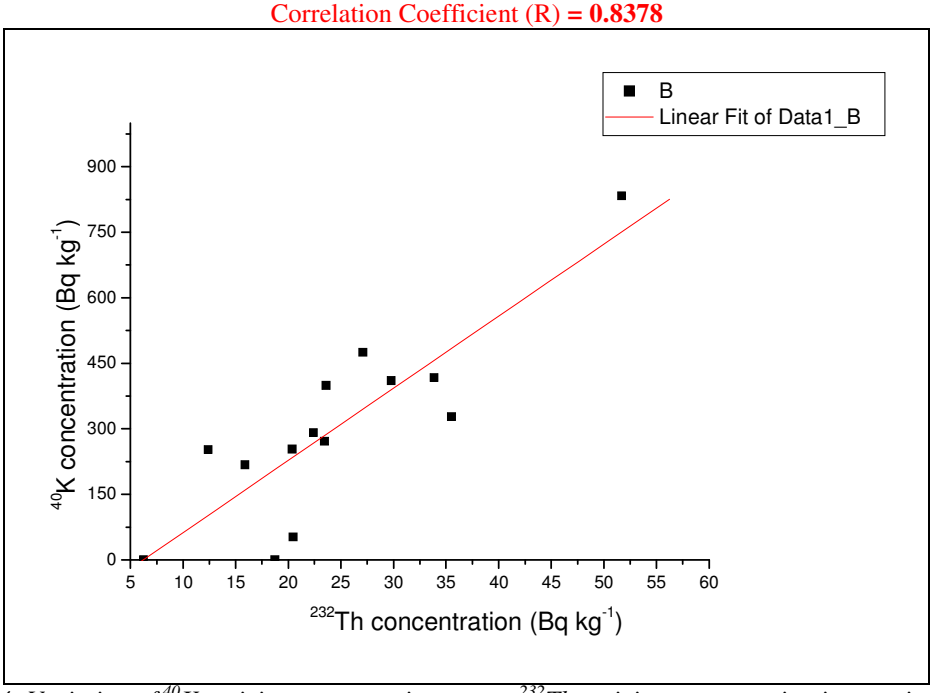

Figure 4: Variation of ^{40}K activity concentration versus ^{232}Th activity concentration in mosaic samples

A positive correlation exists between ^{238}U and ^{232}Th activity concentration and between ^{232}Th and ^{40}K activity concentration in the mosaic samples studied here.

3.1 Radium Equivalent Activity (Raeq)

Exposure to radiation is defined in terms of radium equivalent activity (Ra_{eq}) in Bq kg^{-1} to compare the specific activity of materials containing different amounts of ^{238}U (^{226}Ra), ^{232}Th and ^{40}K. It is calculated by the following expression [26,27]:

$$Ra_{eq} = C_U + 1.43\, C_{Th} + 0.07 C_K \quad (3)$$

Where C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq kg^{-1} respectively. In the above equation for defining Ra_{eq} activity it has been assumed that the same gamma dose rate is produced by 370 Bq kg^{-1} of ^{238}U or 259 Bq kg^{-1} of ^{232}Th or 4810 Bq kg^{-1} of ^{40}K. There will be variations in the radium equivalent activities of different materials and also within the same type of materials. The results may be important from the point of view of selecting suitable materials for use in building construction materials.

3.2. Absorbed gamma dose rate measurement (D)

Outdoor air absorbed dose rate D in nGy h^{-1}due to terrestrial gamma rays at 1m above the ground can be computed from the specific activities, C_U, C_{Th} and C_K of ^{238}U/^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively by Monte Carlo method [28] :

$$D\ (nGy\ h^{-1}) = 0.462 C_U + 0.604 C_{Th} + 0.0417 C_K \quad (4)$$

To estimate the annual effective dose rate, E, the conversion coefficient from absorbed dose in air to effective dose (0.7 Sv Gy^{-1}) and outdoor occupancy factor (0.2) proposed by UNCSEAR (2000) were used. The indoor effective dose rate in units of mSv y^{-1} was calculated by the following relation:

$$E\ (mSv\ y^{-1}) = \text{Dose rate}\ (nGy\ h^{-1}) \times 8760\ h \times 0.8 \times 0.7\ Sv\ Gy^{-1} \times 10^{-6} \quad (5)$$

The outdoor effective dose rate in units of mSv y^{-1} was calculated by the following relation:

$$E\ (mSv\ y^{-1}) = \text{Dose rate}\ (nGy\ h^{-1}) \times 8760\ h \times 0.2 \times 0.7\ Sv\ Gy^{-1} \times 10^{-6} \quad (6)$$

3.3. External (H_{ex}) and Internal (H_{in}) hazard index

The external hazard index is obtained from Ra_{eq} expression through the supposition that its allowed maximum value (equal to unity) corresponds to the upper limit of Ra_{eq} (370 Bq kg^{-1}). For limiting the radiation dose from building materials in Germany to 1.5 mGy y^{-1} . Krieger (1981) proposed the following relation for H_{ex}:

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (7)$$

This criterion considers only the external exposure risk due to γ-rays and corresponds to maximum Ra_{eq} of 370 Bq kg^{-1} for the material. These very conservative assumptions were later corrected and the maximum permission concentrations were increased by a factor of 2 [29] which gives

$$H_{ex} = \frac{C_U}{740Bqkg^{-1}} + \frac{C_{Th}}{520Bqkg^{-1}} + \frac{C_K}{9620Bqkg^{-1}} \leq 1 \quad (8)$$

Internal exposure to ^{222}Rn and its radioactive progeny is controlled by the internal hazard index (H_{in}) as given below [30].

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (9)$$

3.4 Effective Dose Equivalent (E_P)

The risk of lung cancer from domestic exposure of ^{222}Rn and its daughters can be estimated directly from the indoor inhalation exposure (radon) effective dose. The contribution of indoor radon concentration from the samples can be calculated from the expression [31]:

$$C_{Rn} = \frac{E_X \times S}{V \times \lambda_V}$$

Where C_{Rn}, E_x, S, V, and λ_V are radon concentration (Bq m^{-3}), radon exhalation rate(Bq m^{-2} h^{-1}), radon exhalation area (m^2), room volume (m^3) and air exchange rate (h^{-1}) respectively. In these calculation, the maximum radon concentration from the building material was assessed by assuming the room as a cavity with S/V= 2.0 m^{-1} and air exchange rate of 0.5 h^{-1}. The annual exposure to potential alpha energy E_p (effective dose equivalent) is then related to the average radon concentration C_{Rn} by the following expression:

E_p (WLM yr^{-1}) = $8760 \times n \times f \times C_{Rn} / 170 \times 3700$

Where C_{Rn} is in Bq m^{-3}; n, the fraction of time spent indoors; 8760, the number of hours per year; 170, the number of hours per working month and F is the equilibrium factor for radon. Radon progeny equilibrium factor is the most important quantity when dose calculations are to be made on the basis of the measurement of radon concentration. Equilibrium factor F quantifies the state of equilibrium between radon and its daughters and may have values 0< F < 1. The value of F is taken as 0.4 as suggested by UNSCEAR (1988). Thus the values of n = 0.8 and F= 0.4 were used to calculate E_P. From radon exposure, effective dose equivalents were estimated by using a conversion factor of 6.3 mSv WLM^{-1} [32].

From Table 3, it is apparent that absorbed gamma dose rate varies from min. value of 5.31 nGy h^{-1} to max. value 125.20 nGy h^{-1}. Fig 5 shows a frequency plot of the variation of ^{238}U, ^{232}Th, ^{40}K and absorbed dose rate in these mosaic samples.

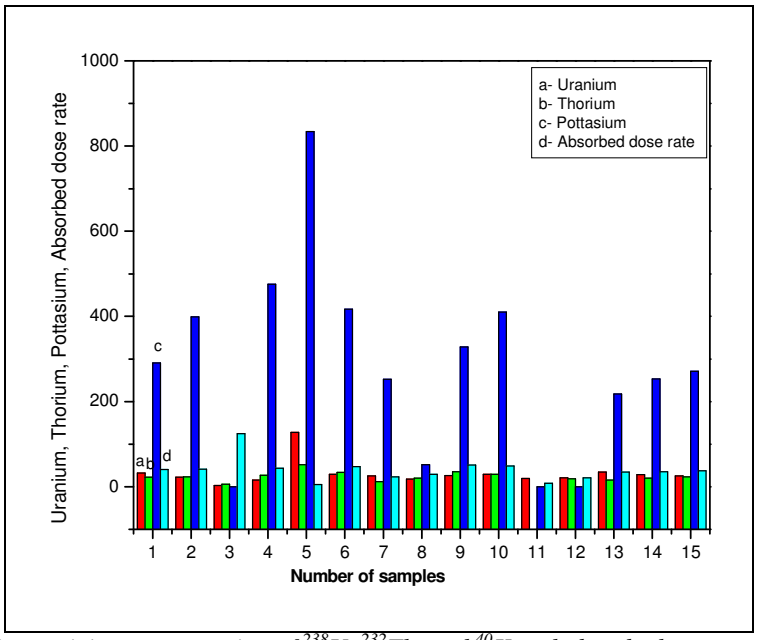

Figure 5: Bar diagram showing activity concentration of ^{238}U, ^{232}Th, and ^{40}K and absorbed gamma dose rate in different samples

The corresponding indoor and outdoor annual effective doses vary from 0.03 to 0.25 mSv y^{-1} and 0.01 to 15 mSv y^{-1}. The calculated values of H_{ex} for mosaic samples vary from 0.03 to 0.71 (shown in Fig 6). Since all these values are lower than unity, the mosaic is safe and can be used as a construction material without posing significant radiological threat to population.

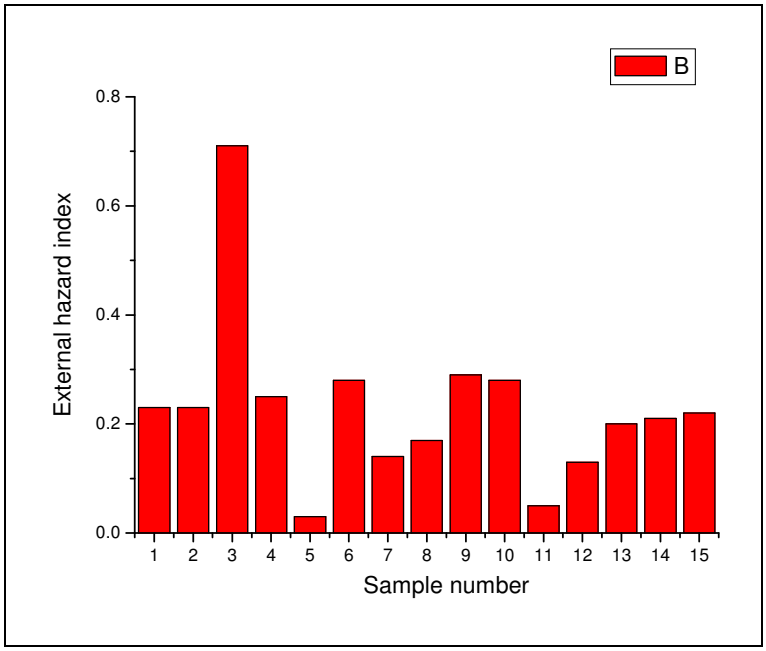

Figure 6: Bar diagram showing the values of external hazard index

4. Conclusion

Thus radon emanation from mosaic samples shows a wide variation in the values of radon activity, radon exhalation rate and effective dose equivalent. It is observed that mosaic used for the purpose of building construction may have less radiation risk.

Samples Code	Radium equivalent activity Ra_{eq} (Bq kg^{-1})	Absorbed gamma dose rate D(nGy h^{-1})	Annual effective dose (mSv y^{-1})		External Hazard Index (H_{ex})	Internal Hazard Index (H_{in})
			Indoor	Outdoor		
M1	78.23	37.36	0.18	0.05	0.22	0.29
M2	12.27	5.31	0.03	0.05	0.03	0.04
M3	87.63	43.39	0.21	0.05	0.25	0.29
M4	260.45	125.20	0.61	0.15	0.71	1.07
M5	47.95	21.09	0.10	0.03	0.13	0.19
M6	107.34	51.58	0.25	0.06	0.29	0.38
M7	60.66	29.69	0.15	0.04	0.17	0.24
M8	51.25	23.00	0.11	0.03	0.14	0.19
M9	99.66	47.09	0.23	0.06	0.28	0.35
M10	101.29	48.95	0.24	0.06	0.28	0.36
M11	72.63	34.69	0.17	0.04	0.20	0.33
M12	83.98	41.19	0.20	0.05	0.23	0.29
M13	19.36	8.94	0.04	0.01	0.05	0.10
M14	75.21	35.96	0.18	0.04	0.21	0.28
M15	84.54	40.51	0.19	0.05	0.23	0.32
Average value	82.83	39.59	0.19	0.051	0.23	0.31
S.D	56.50	27.39	.13	.030	0.15	0.23
R.S.D%	68.21	69.18	68.42	58.82	65.22	74.19

Table 3: Radium equivalent activity, absorbed gamma dose rate, annual effective doses, External hazard index and internal hazard index in mosaic samples.

The radium equivalent activity in mosaic samples is less than 370 $BqKg^{-1}$, which are acceptable for safe use [33,34]. Since all the values of H_{ex} are lower than unity, therefore the mosaic is safe and can be used as a construction material without posing significant radiological threat to population.

5. Acknowledgement

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6. References

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