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INVESTIGATION OF GAMMA-RAY ACTIVITY AND RADIOLOGICAL HAZARDS OF THE BRICKS FABRICATED AROUND LAHORE (PAKISTAN)

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Employing state of art measurement techniques and software, gamma-ray activity due to ^{224}Ra, ^{232}Th and ^{40}K have been measured from bricks fabricated around Lahore, Pakistan. External and internal hazards due to dose rate from radioactivity of bricks have been calculated for several samples and compared with already published work for Kasur, Pakistan.

Key words: Gamma-ray activity, Radiation hazard, Radium equivalent activity bricks.

Introduction

Possible radiological hazards to human health can be avoided through the assessment of radioactivity levels in building materials [1]. The assessment is very important for the development of guidelines to use and manage these materials specially when high material costs and difficulty in removing or re-locating these materials are involved [2]. Many countries have reported specific radioactivity from building materials and several materials have been proven to be having substantially large amount of radioactivity [3].

Bricks made of soil are in use as a building material from the days of Moenjodaro in the Indo-Pak subcontinent. Bricks of age 4000 yrs have been seen in some sites of Middle East and other parts of Asia [4]. In Pakistan bricks are the major component of building material. They are made of soil and baked in kilns. The bricks fabricated in the surroundings of Lahore are made from the sediments which were deposited by the rivers flowing from the Himalaya into the Indus basin. The sediments contain naturally occurring radionuclides ^{238}U and ^{232}Th decay series and ^{40}K.

There has been little effort to investigate the chemical, physical and nuclear properties of materials used in the construction of dwellings in Pakistan. Some physico-chemical properties of bricks fabricated in Lahore and Kasur areas have been reported [5] and the bricks have been found suitable for construction. However, the studies related to the gamma activities in these bricks and radiological hazards associated with them have not been performed. This paper deals with the gamma-ray activity measurements of bricks of Lahore area to assess the radiological hazard associated with them and results are discussed in accordance with the standard laid down by the Organization for Economic Cooperation and Development, Nuclear Energy Agency [6].

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Radiological hazards from construction materials. It has been reported [7] that construction materials made of naturally occurring materials contribute to external exposure to gamma rays and internal exposure to radon. Gamma-rays are emitted by daughter products of ^{238}U and ^{232}Th decay series. The ^{222}Rn and ^{220}Rn are the inert-gaseous and decay products of ^{238}U and ^{232}Th respectively. The ^{222}Rn has longer half life (3.82 d) compared with that of ^{220}Rn (55 s), there, ^{222}Rn can diffuse out of materials [8] and accumulates in poorly ventilated buildings [9]. Since the ^{238}U, ^{232}Th and ^{40}K are naturally occurring nuclides and are distributed in the earth's crust in variable amount [10], therefore, the activity measurements due to these isotopes and their decay products are important to assess the radiation hazards associated with the building materials. The hazards can be assessed on the bases of a model presented by Hamilton [11]. According to this model a common index is defined which gives the collective activity due to ^{226}Ra, ^{232}Th and ^{40}K for the assessment of radiological hazards. The common index is called radium equivalent activity (Ra_{eq}) defined as:

$$Ra_{eq} = A^{226} + \frac{10}{7} A^{232} + \frac{10}{130} A^{40} \quad \text{.....................(1)}$$

where, A^{226}, A^{232} and A^{40} are gamma ray activity in Bq/kg of ^{226}Ra, ^{232}Th and ^{40}K, respectively. This relation involves the estimation that 10 Bq/kg of ^{226}Ra, 7 Bq/kg of ^{232}Th and 130 Bq/kg of ^{40}K produce the same gamma-ray dose. The Ra_{eq} is related with external gamma ray dose and internal dose due to radon and its daughters.

(a) External gamma dose rate. In this work the model developed by Krisiuk *et al.* [12] has been used to calculate external gamma dose rate. This model proposes that the gamma dose from building materials is limited to 1.5 mGy per year if the hazard index, H_{ex}, obeys following inequality:

$$H_{ex} = \frac{A^{226}}{370} + \frac{A^{232}}{259} + \frac{A^{40}}{4810} \leq 1 \quad \text{..........................(2)}$$

This relation remains valid upto a maximum gamma-ray specific activity Ra_{eq} of 370 Bq/kg for the material.

(b) Internal dose due to radon and its daughter products. To calculate the dose rate due to radioactivity in the building materials a criterion suggested by Krieger [13] has been used. According to Krieger, the radiation hazards to respiratory organs due to radon and its short-lived decay products in terms of hazard index H_{in} is

$$H_{in} = \frac{A^{226}}{185} + \frac{A^{232}}{259} + \frac{A^{40}}{4810} \leq 1 \qquad (3)$$

This formula has been suggested to reduce the maximum concentration of radium to half the normal limit.

TABLE 1: SAMPLE COLLECTION DATA FOR THE AREA AROUND LAHORE, PAKISTAN.

Sample code	Location	Kiln owner	Sample collection date (d-m-y)
LA-1	G.T. Road	Allah Malik	4.6.90
LA-2	G.T. Road	Haji Feroze Din	4.6.90
LA-3	G.T. Road	Malik Shekih	4.6.90
LA-4	Moman Pura	Mian Hameed	7.6.90
LA-5	Sharif Pura	Mustafa	7.6.90
LA-6	Taizghar	Mohsan	7.6.90
LA-7	Taizghar	Ch. M. Aslam	7.6.90
LA-8	Hando Gujar	Mian Hameed	7.6.90
LA-9	Depalpur	Moshan	7.6.90
LA-10	Rampura	Malik Noor	7.6.90
LA-11	Pul Bagh Ali	Qamar	7.6.90
LA-12	Gopal Pura	Anwar	7.6.90
LA-13	Gopal Pura	Malik Naeem	7.6.90
LA-14	Manwan	Ahsan Quasoori	7.6.90
LA-15	Jallo Pind	Hafeez Munir	7.6.90
LA-16	Hakiman Da Dera	Mian Hameed	7.6.90
LA-17	Rani Pind	Nazir	11.6.90
LB-18	Multan Road	Munawar	11.6.90
LB-19	Nawan Pind	Sardar	11.6.90
LB-20	Chohang	Abdul Rahim	11.6.90
LB-21	Chota Moniwal	Inayatullah Niazi	11.6.90
LB-22	Movinowan	A.S. Niazi	11.6.90
LB-23	Dhamaran Wali	Ghulam Barri	11.6.90
LB-24	Bara Moniwal	Atta Muhammad	11.6.90
LB-25	Sheikh Da Koat Road	Muzaffar	11.6.90
LB-26	Sheikh Da Koat Road	Muzaffar	11.6.90
LB-27	Sheikh Da Koat Road	Mian Ali Bakhsh	11.6.90
LB-28	Dhoop Sari	Faryiad	11.6.90
LB-29	Ram Ran Koat	Mian Ali Baksh	12.6.90
LC-30	Sheikhupura Road (Nai Abadi)	Yousaf	12.6.90
LC-31	Moman Pura	Mehdi Shah	12.6.90
LC-32	Begham Koat	Haji Mashooq	12.6.90
LC-33	Mandhali	Nazir Ahmad	12.6.90
LC-34	Mandhali	Amjad	12.6.90
LC-35	Masjad Wala	Akhter Hussain	12.6.90
LC-36	Johian Wala	Aashiq	12.6.90
LC-37	Vastti	Haji Ashraf	12.6.90
LC-38	Vastti	Farooq	12.6.90
LC-39	Koat Saleem	M.A. Alvi	12.6.90
LC-40	Kanezarwala	Nazir Ahmad	12.6.90

Experimental

Unbaked soil bricks were collected from different kiln sites around Lahore. The name of the kilns with respect to their owners are given in Table 1. The samples were crushed to small pieces and dried in furnace at a temperature of 110° until the sample weight became constant. The samples were dried in moisture free atmosphere. They were pulverized and packed in radon impermeable container.

Reference materials similar to the materials to be analyzed were provided by the Analytical Quality Control Services (AQCS) programme of the International Atomic Energy Agency (IAEA). Such reference standards are necessary since the results of analytical and experimental activities may form bases for various decisions. IAEA reference material Soil-6 has been employed for inter comparison runs in this work. The geometrical dimensions of the samples were kept fixed and equal to that of the standard Soil-6 IAEA reference material.

The specifications of the electronics used for gamma-ray activity measurements are given in Table 2 and their details can be found elsewhere [14]. The system was calibrated with IAEA standard calibration material Soil-6. The detection efficiencies η were plotted as a function of gamma-ray energies E and a polynomial of degree 3 was fitted to log (η) versus log (E) for E > 100 keV. The samples were stored for 40 days to bring the daughter nuclides in equilibrium with the parents. These were then measured for a counting time of 40,000 seconds and gamma- ray activities were calculated using the Intertechnique (France) Software "Intergamma" version Oct., 1989. This software has been run on PC/AT compatible microcomputer providing CPU memory larger than 512 bytes,

TABLE 2: SPECIFICATIONS OF THE ACTIVITY MEASURING SYSTEM.

S. N.	Component	Manufacturer/Supplier	Specifications
1.	HPGe detector	Intertechnique	Resolution at 1.3 MeV < 2 ke V
2.	High voltage power supply	ORTEC (556)IG+G	Range 0-3000V
3.	Pre-amplifier	Intertechnique 314	Charge sensitive
4.	Amplifier	Canberra 2021	Spectroscopic type
5.	PC based MCA	Intertechnique/Compaq	4 K-channels
6.	Printer	Microline 292	
7.	Plotter	HP color plotter	

Table 3. Comparison of Gamma-Ray Activities and Hazard Index for Brick Samples Around Lahore, Pakistan.

Sample	Activity (Bq/kg)				A^{232}	Ra_{eq}	
Code	A^{40}	A^{226}	A^{232}	Total	A^{226}	(Bq/kg)	H_{in}
LR-1	924.0±36.6	53.30±3.2	73.37±3.8[M]	1050.67	1.38	229.19	0.76
LR-2	742.5±35.2	53.17±3.5	64.35±3.3	860.02	1.21	202.21	0.69
LR-3	803.8±33.4	47.10±2.9	63.57±2.9	914.47	1.35	199.75	0.67
LR-4	707.7±32.4	46.46±3.0	62.55±3.1	816.71	1.35	190.26	0.64
LR-5	724.9±32.7	50.32±3.2	65.25±3.0	840.47	1.30	199.30	0.67
LR-6	742.7±31.8	50.86±2.9	57.43±2.8[m]	850.99	1.13[m]	190.03	0.65
LR-7	856.8±34.4	55.34±3.3	66.21±3.3	978.35	1.20	215.83	0.73
LR-8	757.4±31.6	49.14±3.0	59.97±2.7	866.51	1.22	193.07	0.65
LR-9	833.9±32.4	53.48±2.9	63.34±2.9	950.72	1.18	208.11	0.71
LR-10	912.0±32.9	48.59±2.9	61.04±2.9	1021.63	1.26	205.94	0.69
LR-11	782.6±31.3	51.22±3.0	65.35±2.6	899.17	1.28	204.78	0.69
LR-12	691.6±28.8	46.29±3.0	57.52±2.3	795.41	1.24	181.66	0.62
LR-13	994.9±34.5	57.23±3.6	72.16±2.8	1124.29	1.26	236.85[M]	0.79[M]
LR-14	731.7±32.6	55.40±3.9	64.37±2.7	851.47	1.16	203.64	0.70
LR-15	795.5±31.7	49.68±3.0	63.46±2.5	908.64	1.28	201.53	0.68
LR-16	849.8±31.6	50.07±2.9	66.96±2.6	966.84	1.34	211.11	0.71
LR-17	758.0±30.8	51.71±3.0	68.18±2.6	877.89	1.32	207.42	0.70
LR-18	859.9±31.0	53.48±3.0	65.60±2.7	978.98	1.23	213.34	0.72
LR-19	1024.0±39.4[M]	55.86±4.2	68.07±3.0	1147.93[M]	1.22	231.87	0.78
LR-20	831.1±32.1	50.92±3.5	65.83±2.5	947.85	1.29	208.89	0.70
LR-21	791.5±31.0	47.45±3.0	62.68±2.6	901.63	1.32	197.88	0.66
LR-22	963.7±37.0	58.69±3.5[M]	71.28±2.9	1093.67	1.21	234.65	0.79
LR-23	758.4±32.8	50.43±3.1	64.04±2.8	872.87	1.27	200.25	0.68
LR-24	760.1±30.5	48.28±2.9	64.82±2.5	873.20	1.34	199.35	0.67
LR-25	753.3±30.6	52.69±3.2	65.75±2.4	871.73	1.25	204.56	0.70
LR-26	740.9±31.4	50.66±3.3	61.16±2.7	852.71	1.21	195.02	0.66
LR-27	886.0±33.4	50.85±3.3	65.58±2.6	1002.43	1.29	212.69	0.71
LR-28	716.8±29.7	46.46±2.8	65.76±2.7	829.02	1.42	195.54	0.65
LR-29	740.7±29.7	48.95±2.9	64.28±2.5	853.93	1.31	197.76	0.67
LR-30	808.6±30.9	43.64±3.1	62.51±2.5	914.75	1.43	195.14	0.65
LR-31	883.8±35.0	49.42±3.5	61.36±2.4	994.58	1.24	205.06	0.69
LR-32	759.3±33.5	47.31±3.3	65.16±2.9	871.77	1.38	198.80	0.67
LR-33	693.5±31.4	45.70±3.3	66.14±3.8	805.34[M]	1.45	193.53	0.65
LR-34	647.7±32.7	47.01±3.8	63.18±2.8	757.89	1.34	187.09	0.63
LR-35	818.7±34.0	47.56±3.4	63.72±3.0	929.98	1.34	201.57	0.67
LR-36	697.5±31.6	48.87±3.3	64.75±2.8	811.12	1.32	195.02	0.66
LR-37	633.1±29.4[m]	44.42±3.2	62.63±2.7	740.15	1.41	182.59	0.61
LR-38	796.1±31.4	47.59±3.3	60.43±2.4	904.12	1.27	195.16	0.66
LR-39	731.3±30.7	40.59±3.1	60.85±2.7	832.74	1.50	183.76	0.61
LR-40	674.9±32.6	39.72±3.3[m]	60.63±3.2	775.25	1.53[M]	178.25[m]	0.59[m]

m and M stand for the minimum and the maximum values in the data.

thereby employing an overall optimal solution proposed by Intertechnique system. This software allows the energy calibration after multiplet separation deconvolution. This technique first separates a peak common to two or more isotopes and then performs the deconvolution of the peak. The method is fast and yields quite reliable results for gamma-ray spectrometry and concentration measurements [15]. The accuracy of our measurements is ±20%. Using eq. 1 and eq. 3, the radium equivalent activity (Ra_{eq}) and hazard index (H_{in}) due to internal dose were calculated.

Results and Discussion

Gamma ray activities due to ^{40}K, ^{226}Ra, ^{232}Th in 40 soil samples used for making bricks have been determined and these are given in Table 3. From these activities, total activity, radium equivalent activity (Ra_{eq}), the ratio of thorium to radium activities, and internal hazard index (H_{in}) have been calculated and are also represented in Table 3. The minimum and maximum values observed are indicated by 'm' and 'M', respectively. The Table shows that the maximum contribution to total activity is from ^{40}K. The values of the activities due to ^{226}Ra and ^{232}Th remain below 70 Bq/kg. The ratio (A^{232}/A^{226}) for all the samples is greater than unity indicating that the activity due to ^{232}Th is 13 to 53% higher than the activity due to ^{226}Ra. The minimum values, maximum values and average values with standard deviation alongwith percentage deviations of average value from minimum and maximum values of activities due to ^{40}K, ^{226}Ra and ^{232}Th are given in Table 4. The total activities due to ^{40}K, ^{226}Ra, and ^{232}Th, thorium to radium activity ratios, Ra_{eq} and H_{in} are also given in Table 4. The Ra_{eq} which can give a dose of 1.5 mGy per year is 370 Bq/kg [12]. As seen from Table 3 and Table 4. The maximum value of Ra_{eq} is less than 370 Bq/kg which means that H_{ex} remains less than unity so the bricks fabricated around Lahore can be used without much danger of external gamma radiation hazards. Similarly, the maximum value of internal hazard index (H_{in}) is less than 1 which indicates that the internal hazards are less than the critical value. This is a good sign that the bricks are also safe from the internal dose point of view.

Similar studies have been carried out for bricks of Kasur area [14]. The summary of the results of this area have been compared with results for Lahore and are shown in Table 4. The comparison indicates that in both Lahore and Kasur areas the maximum contribution to the total gamma activity is from ^{40}K. This contribution is nearly 14 to 17 times higher than individual activities due to ^{226}Th and ^{226}Ra. The maximum value of the total activity in Kasur area is about 5% lower than the maximum value for Lahore area. However, this difference is within our experimental accuracy. The measurement in both areas shows that results have smaller dispersion around the minimum values of Ra_{eq} and H_{in} and therefore the sample values are close to the minimum values. The reason for such behaviour is the geological location of these areas. Both the areas are situated in the Indus Plains. The origin of the sediments is Himalaya and these have been brought by the rivers from Himalaya into Indus basin.

TABLE 4. COMPARISON OF STATISTICAL ANALYSIS RADIOACTIVITY MEASUREMENTS OF BRICK SAMPLES FROM LAHORE WITH KASUR AREA.

Quantity	Minimum value	Maximum value	Average± std. dev.	% deviation from	
				minimum	maximum
A^{40}(Bq/kg)	633.10*	1024.00	789.52±89.48	19.81	29.70
	(698.90)#	(957.70)	(876.46±61.62)	(20.26)	(9.27)
A^{226}(Bq/kg)	39.72	58.69	49.65±4.03	20.00	18.21
	(45.86)	(62.27)	(54.59±4.05)	(15.99)	(14.07)
A^{232} (Bq/kg)	57.43	73.37	64.28±3.34	10.66	14.14
	(62.66)	(79.60)	(69.61±4.11)	(9.98)	(14.35)
Total activity(Bq/kg)	740.15	1147.93	903.45±93.99	18.08	27.06
	(815.95)	(1089.96)	(960.65±65.68)	(15.06)	(13.46)
Ratio(A^{232}/A^{226})	1.13	1.53	1.30±0.09	13.08	17.68
	(1.15)	(1.52)	(1.28±0.08)	(10.16)	(18.75)
Ra_{eq}(Bq/kg)	178.25	236.85	202.21±13.44	11.85	17.13
	(194.81)	(244.15)	(218.36±12.26)	(10.78)	(11.81)
H_{in}	0.59	0.79	0.68±0.05	13.24	16.18
	(0.65)	(0.83)	(0.74±0.04)	(12.16)	(12.16)

* Values correspond to current measurements around Lahore area.

Values in brackets correspond to measurements around Kasur area [14].

Conclusion

The external exposure to gamma rays and internal exposure to radon and its daughters from the bricks of Lahore region is below the maximum permissible limits. The bricks are suitable not only for their physico-chemical properties [5] but also are safe from the radiological hazards point of view.

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