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Radiological impacts of the usability of clay and kaolin as raw material in manufacturing of structural building materials in Turkey

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Abstract

The aim of the present study is to measure the natural radioactivity due to the presence of radionuclides in clay and kaolin, used widely as raw materials in ceramics, bricks and cement industries, and to assess the possible radiological hazards associated with these raw materials. The activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K in 50 samples collected from different quarries were measured by means of gamma-ray spectrometry with an HPGe detector. The mean values of the measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for clay samples were found to be 39.3 ± 22.7 Bq kg^{-1}, 49.6 ± 27.9 Bq kg^{-1} and 569.5 ± 181.0 Bq kg^{-1}, and for kaolin samples 82.0 ± 37.3 Bq kg^{-1}, 94.8 ± 49.2 Bq kg^{-1} and 463.6 ± 544.9 Bq kg^{-1}, respectively. These levels are comparable to those appearing in clays of European countries. The radium equivalent activity and the external (gamma) and internal (alpha) hazard indices were calculated to assess the potential radiological hazard. The calculated gamma and alpha indices varied from 0.19 to 1.17 and from 0.04 to 0.47 for clay samples and from 0.36 to 1.75 and from 0.08 to 0.63, respectively. The mean value of the gamma index for the clay samples (0.57±0.24) is slightly above the criterion of 0.5 corresponding to an annual effective dose of 0.3 mSv, while the mean value of the gamma index for the kaolin samples (0.90±0.49) is below the criterion of unity corresponding to an annual effective dose of 1 mSv. The calculated alpha index values for all samples are below the recommended upper level.

1. Introduction

All building raw materials derived from rock and soil, such as clay, kaolin, gypsum, limestone and pumice, contain natural radionuclides, including uranium (^{238}U) and thorium (^{232}Th),

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and their decay products, and the radioactive isotope of potassium (^{40}K). In the ^{238}U series, the decay chain segment starting from radium (^{226}Ra) is radiologically the most important and, therefore, reference is often made to ^{226}Ra instead of ^{238}U. 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. 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 recent decades, there has been an increasing interest in the study of the radioactivity in various building raw materials such as clay, kaolin, red mud, limestone, fly ash, phosphogypsum, etc [1–18].

Due to inherently complex physical, chemical and mineralogical characteristics, clays are used mainly in the manufacture of extruded and other bricks, Portland and other cements, concrete blocks and structural concrete, refractories and ceramics (electrical porcelain, fine china and dinnerware, floor and wall tiles, and pottery). Kaolin, commonly referred to as china clay, is a clay that usually contains 85–95% of kaolinite, which is formed by rock weathering. In addition to kaolinite, it frequently contains quartz, mica, feldspar and illite. Kaolin is widely used as a raw material in the paper industry, ceramics, refractory bricks, cement, textiles, rubber, medical industries and special types of plastics. Turkish Clay Industry is one of major producers in the European countries, based on a capacity and annual production of 1.34 million tons. Turkey has an estimated 1.75 billion tons of clay reserve and 100 million tons of kaolin reserve [19].

In Turkey, the use of kaolin in the construction industry as a raw material in the production of white cement clinker and as an artificial pozzolanic additive for concrete (in the form of metakaolin) has been growing in recent years [20, 21]. Nowadays several studies related to the possible use of clay and kaolin as raw materials in cement and ceramic industries and the mechanical and swelling properties of them have been reported [20–24]. However, detailed information on the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in clay or kaolin raw materials in Turkey is not available in the literature. In the present study, a total of 50 clay and kaolin samples were analysed using gamma-ray spectrometry to determine the specific activity of ^{226}Ra, ^{232}Th and ^{40}K. The results are used to assess the potential radiological hazards associated with these materials by computing the radium equivalent activity and the external (gamma) and internal (alpha) hazard indices.

2. Materials and method

2.1. Sampling and sample preparation

Fifty samples weighing from to 0.5 to 1 kg were collected, catalogued and coded properly. The clay and kaolin specimens were collected from the Istanbul region (Şile and Kemerburgaz quarries), Söğüt region (Küre, Çatı, Yakacık and İnhisar quarries), and Balıkesir (Sındırgı quarry), Bilecik (Söğüt quarry), Kütahya (Altıntaş quarry) and Eskişehir (Mihalıççık quarry), respectively. Each sample was ground into a fine powder with a particle size less than 1 mm. The samples were then dried in a temperature-controlled furnace at 110 °C for 20–24 h to remove moisture. After moisture removal, these samples were cooled in a moisture-free atmosphere. Each sample was then placed into cylindrical plastic containers ($\phi = 5$ cm, $h = 6$ cm), weighed and hermetically sealed. The geometrical dimensions of the samples were kept identical to that of the reference materials which were used for the efficiency calibration of

the gamma-spectrometry system. The sealed samples and the reference materials were stored for more than 30 days before counting to allow ^{226}Ra and its short-lived decay products to reach secular equilibrium.

2.2. Radiometric analysis

Two commercially available high-resolution gamma-spectrometry systems with p-type coaxial HPGe detectors manufactured by Canberra Inc. were used to measure the natural radioactivity in the clay and kaolin samples. One of the counting systems was equipped with an HPGe detector with an active volume of 451 cm^3. The detector has a relative efficiency of 110% relative to a 7.62 cm × 7.62 cm NaI(Tl) detector, an energy resolution of 2.1 keV at 1332.5 keV of ^{60}Co and of 1.3 keV at 122 keV of ^{57}Co, and a peak-to-Compton ratio of 85:1. The other counting system was equipped with an active volume of 57 cm^3. The detector has a relative efficiency of 11.4% relative to a 7.62 cm × 7.62 cm NaI(Tl) detector, an energy resolution of 1.96 keV at 1332.5 keV of ^{60}Co and a peak-to-Compton ratio of 42.1:1. The detectors were shielded to reduce the gamma-ray background.

Energy calibration of the detector was performed using point sources (^{60}Co, ^{137}Cs and ^{241}Am). The absolute efficiency calibration of the gamma-spectrometry systems was carried out using the radionuclide specific efficiency method in order to reduce the uncertainty in gamma-ray intensities, as well as the influence of coincidence summation and self-absorption effects of the emitting gamma photons [12]. The IAEA reference materials RGU-1 (U ore) RGTh-1 (Th ore) and RGK-1 (K_2SO_4), with densities similar to the samples to be measured after pulverisation, were employed for the efficiency calibration of the system. The sample containers were placed on top of the detector for counting. The same geometry was used to determine the peak areas of samples and references. On average, the counting time was 8 and 24 h for the 10% and 110% HPGe detectors, respectively. Background measurements were taken under the same conditions as sample measurements and subtracted in order to get net counts for the sample.

The specific activities were averaged from gamma-ray photopeaks at several energies. The gamma-ray lines at 295.2 keV and 351.9 keV from ^{214}Pb and at 609.3 keV and 1764.5 keV from ^{214}Bi were used to determine the specific activity of ^{226}Ra. The gamma-ray lines of 338.4 keV, the 911.2 keV from ^{228}Ac, the 727.3 keV from ^{212}Bi and 583.2 keV from ^{208}Tl were used to determine the specific activity of ^{232}Th. The specific activity of ^{40}K was measured directly by its own gamma-ray at 1460.8 keV.

The statistical uncertainty of the radioactivity measurements was calculated by taking into consideration the systematic errors in the efficiency calibration (0.5–5%) and counting statistical error (up to 8%).

3. Results and discussion

3.1. Activity concentration

The activity concentration values of ^{226}Ra, ^{232}Th and ^{40}K measured in Bq kg^{-1} in the samples studied, together with the statistical uncertainty (1σ) and standard deviation (SD), are shown in tables 1 (clay samples) and 2 (kaolin samples). As can be seen from tables 1 and 2, the highest values of the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K are 125.9 ± 3.1 (KAO-3), 184.0 ± 6.4 (KAO-8) and 1635.2 ± 32.7 (KAO-15) Bq kg^{-1}, respectively, measured in the kaolin samples, while the lowest values of the activity concentration of the same radionuclides are 8.6 ± 0.2 (CLA-7), 5.7 ± 0.4 (CLA-29) and 15.0 ± 0.6 (KAO-6) Bq kg^{-1}, respectively.

Table 1. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K measured in the clay samples.

	Activity concentration (in Bq kg^{-1} $\pm$ 1σ)		
Sample code	A_{Ra}	A_{Th}	A_K
CLA-1	72.9 ± 1.8	9.2 ± 0.9	112.2 ± 2.5
CLA-2	50.2 ± 1.5	62.5 ± 2.5	691.7 ± 8.5
CLA-3	24.8 ± 0.7	35.5 ± 1.1	640.8 ± 17.5
CLA-4	16.6 ± 0.6	23.4 ± 1.0	535.4 ± 16.1
CLA-5	12.2 ± 0.3	15.8 ± 0.4	365.7 ± 8.9
CLA-6	19.9 ± 0.6	34.3 ± 1.3	551.1 ± 16.2
CLA-7	8.6 ± 0.2	23.7 ± 0.6	316.5 ± 8.1
CLA-8	19.6 ± 0.6	53.3 ± 1.5	670.9 ± 17.8
CLA-9	13.5 ± 0.4	17.9 ± 0.7	381.9 ± 10.9
CLA-10	61.4 ± 1.2	78.9 ± 1.8	621.5 ± 16.5
CLA-11	36.7 ± 0.7	55.6 ± 1.1	1103.6 ± 24.8
CLA-12	22.2 ± 0.8	35.9 ± 1.6	662.9 ± 19.8
CLA-13	21.8 ± 0.7	25.7 ± 1.2	451.9 ± 13.9
CLA-14	22.2 ± 0.4	26.7 ± 0.8	461.9 ± 11.2
CLA-15	43.1 ± 0.8	75.3 ± 1.3	895.3 ± 20.3
CLA-16	15.2 ± 2.0	18.9 ± 2.4	475.6 ± 20.6
CLA-17	52.4 ± 3.0	50.5 ± 4.2	459.4 ± 12.9
CLA-18	74.0 ± 2.8	96.2 ± 4.9	577.7 ± 11.0
CLA-19	65.2 ± 2.3	88.2 ± 4.1	559.6 ± 9.4
CLA-20	54.8 ± 1.9	51.0 ± 2.8	600.6 ± 9.7
CLA-21	43.2 ± 2.0	46.6 ± 3.1	582.5 ± 10.9
CLA-22	51.1 ± 1.9	41.2 ± 2.5	498.8 ± 8.3
CLA-23	60.8 ± 2.4	79.5 ± 4.3	624.2 ± 11.8
CLA-24	48.0 ± 1.7	50.0 ± 2.4	572.9 ± 18.5
CLA-25	93.6 ± 2.1	118.7 ± 5.9	797.9 ± 19.3
CLA-26	21.6 ± 0.6	81.0 ± 4.0	722.2 ± 16.6
CLA-27	11.1 ± 0.6	17.7 ± 1.4	514.1 ± 15.8
CLA-28	18.2 ± 0.7	33.5 ± 2.0	387.8 ± 11.8
CLA-29	14.1 ± 0.4	5.7 ± 0.4	351.5 ± 8.4
CLA-30	31.2 ± 0.9	49.9 ± 2.7	844.6 ± 21.1
CLA-31	57.9 ± 1.6	66.6 ± 2.6	639.7 ± 7.8
CLA-32	48.6 ± 1.3	59.3 ± 2.2	577.8 ± 6.6
CLA-33	70.4 ± 1.9	92.5 ± 3.4	531.4 ± 6.9
CLA-34	59.0 ± 1.6	66.2 ± 2.6	581.7 ± 7.4
Mean ± SD	39.3 ± 22.7	49.6 ± 27.9	569.5 ± 181.0

The mean values of the measured activity concentration of ^{226}Ra, ^{232}Th and ^{40}K for the clay samples were found to be 39.3 ± 22.7, 49.6 ± 27.9 and 569.5 ± 181.0, and for the kaolin samples 82.0 ± 37.3, 94.8 ± 49.2 and 463.6 ± 544.9, respectively. In the UNSEAR 2000 report, the population weighted values are given as 32, 45 and 420 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively [25]. The mean concentration values of ^{226}Ra and ^{232}Th measured in the clay samples are slightly higher than the population weighted averages of 32 and 45 Bq kg^{-1}, respectively, while the mean concentration values of ^{226}Ra and ^{232}Th measured in the kaolin samples are significantly (two times) higher than the quoted values. At the same time the mean values of ^{40}K measured in the clay and kaolin samples are slightly (about 36% for clay and 10% for kaolin) higher than the population weighted average value of 420 Bq kg^{-1}. However, the mean concentration values of ^{226}Ra, ^{232}Th and ^{40}K measured for the clay samples are lower than typical concentration values measured in clay samples used as building raw materials in

Table 2. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K measured in the kaolin samples.

	Activity concentration (in Bq kg^{-1} $\pm$ 1σ)		
Sample code	A_{Ra}	A_{Th}	A_K
KAO-1	105.9 $\pm$ 3.4	62.1 $\pm$ 3.7	687.9 $\pm$ 14.2
KAO-2	73.0 $\pm$ 1.8	78.1 $\pm$ 2.9	173.5 $\pm$ 3.2
KAO-3	125.9 $\pm$ 3.1	89.9 $\pm$ 3.7	135.2 $\pm$ 3.7
KAO-4	20.0 $\pm$ 2.0	56.0 $\pm$ 6.0	28.0 $\pm$ 3.0
KAO-5	107.4 $\pm$ 2.6	65.2 $\pm$ 2.6	976.2 $\pm$ 11.0
KAO-6	80.4 $\pm$ 2.0	24.0 $\pm$ 1.3	15.0 $\pm$ 0.6
KAO-7	28.9 $\pm$ 1.6	60.6 $\pm$ 3.8	106.9 $\pm$ 4.6
KAO-8	120.0 $\pm$ 2.9	184.0 $\pm$ 6.4	663.0 $\pm$ 8.0
KAO-9	124.4 $\pm$ 3.8	161.1 $\pm$ 6.8	1467.0 $\pm$ 22.4
KAO-10	58.1 $\pm$ 2.0	82.3 $\pm$ 3.7	52.2 $\pm$ 1.1
KAO-11	88.6 $\pm$ 4.4	101.5 $\pm$ 7.0	34.7 $\pm$ 1.3
KAO-12	114.9 $\pm$ 2.9	176.1 $\pm$ 6.1	1026.1 $\pm$ 12.1
KAO-13	58.5 $\pm$ 2.2	63.8 $\pm$ 3.4	38.4 $\pm$ 0.9
KAO-14	16.5 $\pm$ 1.0	56.6 $\pm$ 3.3	263.4 $\pm$ 4.9
KAO-15	116.3 $\pm$ 4.7	164.3 $\pm$ 8.5	1635.2 $\pm$ 32.7
KAO-16	73.6 $\pm$ 1.7	91.5 $\pm$ 3.0	115.2 $\pm$ 2.0
Mean $\pm$ SD	82.0 $\pm$ 37.3	94.8 $\pm$ 49.2	463.6 $\pm$ 544.9

the European Union (EU) countries, which are 50, 50 and 670 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively [26].

3.2. Assessment of radiation hazard from the clay and kaolin samples

In the present study, radiological parameters such as the radium equivalent activity, the gamma index and the alpha index were determined to assess the radiation hazards associated with the clay and kaolin samples.

3.2.1. Radium equivalent activity. The distribution of natural radionuclides in samples under investigation is not uniform. Therefore, a common radiological index has been introduced to evaluate the actual activity level of ^{226}Ra, ^{232}Th and ^{40}K in the samples and the radiation hazards associated with these radionuclides. This index is usually known as radium equivalent (Ra_{eq}) activity [27].

$$Ra_{eq} = A_{Ra} + \left(\frac{10}{7}\right) A_{Th} + \left(\frac{10}{130}\right) A_K \quad (1)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bq kg^{-1}. The Ra_{eq} results for all clay and kaolin samples are summarised in tables 3 and 4, respectively. The calculated Ra_{eq} values range from 49.3 to 324.5 Bq kg^{-1} with a mean of 154.0 $\pm$ 66.5 Bq kg^{-1} for all clay samples, and from 102.2 to 476.8 Bq kg^{-1} with a mean of 253.1 $\pm$ 132.5 Bq kg^{-1} for all kaolin samples. The mean Ra_{eq} values calculated for the clay and kaolin samples are lower than the recommended maximum value of 370 Bq kg^{-1} for building materials, which is equivalent to an external dose of 1.5 mSv y^{-1} [28].

3.2.2. Gamma index. A number of indices dealing with the assessment of the excess gamma radiation originating from building materials such as external health indices and gamma concentration indices have been proposed by several investigators [7]. In this study, the

Table 3. The calculated radium equivalent (Ra_{eq}) activity, gamma index (I_γ) and alpha index (I_α) values for the clay samples.

Sample code	Ra_{eq} (in Bq kg^{-1})	I_γ	I_α
CLA-1	94.7	0.33	0.36
CLA-2	192.7	0.71	0.25
CLA-3	124.9	0.47	0.12
CLA-4	91.2	0.35	0.08
CLA-5	62.8	0.24	0.06
CLA-6	111.3	0.42	0.10
CLA-7	66.8	0.25	0.04
CLA-8	147.3	0.56	0.10
CLA-9	68.4	0.26	0.07
CLA-10	222.0	0.81	0.31
CLA-11	201.1	0.77	0.18
CLA-12	124.5	0.47	0.11
CLA-13	93.3	0.35	0.11
CLA-14	95.9	0.36	0.11
CLA-15	219.5	0.82	0.22
CLA-16	78.8	0.30	0.08
CLA-17	159.8	0.58	0.26
CLA-18	255.9	0.92	0.37
CLA-19	234.3	0.84	0.33
CLA-20	173.8	0.64	0.27
CLA-21	154.7	0.57	0.22
CLA-22	148.3	0.54	0.26
CLA-23	222.3	0.81	0.30
CLA-24	163.4	0.60	0.24
CLA-25	324.5	1.17	0.47
CLA-26	192.8	0.72	0.11
CLA-27	75.9	0.30	0.06
CLA-28	96.0	0.36	0.09
CLA-29	49.3	0.19	0.07
CLA-30	167.4	0.63	0.16
CLA-31	202.3	0.74	0.29
CLA-32	177.8	0.65	0.24
CLA-33	243.4	0.87	0.35
CLA-34	198.3	0.72	0.30
Mean $\pm$ SD	154.0 ± 66.5	0.57 ± 0.24	0.20 ± 0.11

activity index or gamma index was calculated as proposed by the European Commission [26]. The Commission suggests that building materials should be exempted from all restrictions concerning their radioactivity if the excess gamma radiation originating from them increases the annual effective dose of a member of the public by 0.3 mSv at most. Controls should be based on a dose criterion, which was established considering the overall national circumstances. It is therefore recommended that controls should be based on an annual effective dose in the range 0.3–1 mSv. When raw materials such as clay, kaolin, limestone, fly ash, phosphogypsum, bauxite, slag, etc, are incorporated in building materials and there is reason to suspect that these contain enhanced levels of natural radionuclides, the activity concentrations of these nuclides in the final product should be measured or assessed reliably from the activities of all component materials. The gamma index (I_γ) was calculated using the following formula proposed by the

Table 4. The calculated radium equivalent (Ra_{eq}) activity, gamma index (I_γ) and alpha index (I_α) values for the kaolin samples.

Sample code	Ra_{eq} (in Bq kg^{-1})	I_γ	I_α
KAO-1	247.5	0.9	0.5
KAO-2	197.9	0.7	0.4
KAO-3	264.8	0.9	0.6
KAO-4	102.2	0.4	0.1
KAO-5	275.7	1.0	0.5
KAO-6	115.7	0.4	0.4
KAO-7	123.7	0.4	0.1
KAO-8	433.9	1.5	0.6
KAO-9	467.4	1.7	0.6
KAO-10	179.8	0.6	0.3
KAO-11	236.2	0.8	0.4
KAO-12	445.4	1.6	0.6
KAO-13	152.6	0.5	0.3
KAO-14	117.6	0.4	0.1
KAO-15	476.8	1.8	0.6
KAO-16	213.2	0.7	0.4
Mean ± SD	253.1 ± 132.5	0.90 ± 0.49	0.41 ± 0.19

European Commission [26]:

$$I_\gamma = \frac{A_{Ra}}{300\ \text{Bq kg}^{-1}} + \frac{A_{Th}}{200\ \text{Bq kg}^{-1}} + \frac{A_K}{3000\ \text{Bq kg}^{-1}}, \tag{2}$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bq kg^{-1}. The activity index should be used only as a screening tool for identifying materials which might be of concern. For materials used in bulk amounts, e.g. concrete, $I_\gamma \leqslant 1$ corresponds to an annual effective dose less than or equal to 1 mSv, while $I_\gamma \leqslant 0.5$ corresponds to an annual effective dose less than or equal to 0.3 mSv. The ranges and mean values of the calculated I_γ for the clay and kaolin samples are shown in the third column of tables 3 and 4, respectively. It is observed in table 3 that the mean value of I_γ for the clay samples (0.57 ± 0.24) is slightly above the criterion of 0.5 corresponding to an effective dose of 0.3 mSv, while the mean value of I_γ for the kaolin samples (0.90 ± 0.49) is below the criterion of unity corresponding to an effective dose of 1 mSv.

3.2.3. Alpha index. So far, several indices dealing with the assessment of the excess alpha radiation due to inhalation originating from building materials such as alpha indices and internal health indices have been developed [7]. In the present study, the alpha index was determined by the following formula:

$$I_\alpha = \frac{A_{Ra}}{200\ \text{Bq kg}^{-1}}, \tag{3}$$

where A_{Ra} is the activity concentration of ^{226}Ra in Bq kg^{-1}. When the activity concentration of ^{226}Ra in a building material exceeds the value of 200 Bq kg^{-1}, it is possible that radon exhalation from this material could cause an indoor radon concentration exceeding 200 Bq m^{-3}. The recommended upper level for ^{226}Ra activity concentration suggested by the European Commission is 200 Bq kg^{-1} in building materials [7]. $I_\alpha \leqslant 1$ corresponds to a ^{226}Ra activity concentration less than or equal to 200 Bq kg^{-1}.

The ranges and mean values of the calculated I_α for the clay and kaolin samples are shown in the last column of tables 3 and 4, respectively. The calculated I_α varied from 0.04 to 0.47 for the clay samples and from 0.08 to 0.63 for the kaolin samples. It is observed in tables 3 and 4 that the calculated I_α values for all the samples studied are below the recommended upper level.

4. Conclusions

For each sample in this study, the natural radionuclide (^{226}Ra, ^{232}Th and ^{40}K) content, the radium equivalent activity, the gamma index and the alpha index have been determined to assess the radiological hazards from clay and kaolin samples commonly used as building raw materials in Turkey. These indices should be used only as screening tools for ready-to-use building materials. Any actual decision on restricting the use of a material should be based on a separate dose assessment. Turkey applies a strict criterion based on a dose in the range 0.3–1 mSv y^{-1} for building materials used in bulk amounts, e.g. concrete. It is concluded that the calculated mean values of I_γ for all the clay and kaolin samples studied are below the criterion limit of unity corresponding to a dose rate 1 mSv y^{-1}. Also, the calculated values of I_α for all the clay and kaolin samples studied are below the recommended upper level. In fact, 14 of the 34 clay samples have an activity index below 0.5, one of them even above 1 (CLA-25). As for the kaolin samples, 4 out of 16 have an activity index below 0.5, and 5 have an activity index of 1.0 or more. Clay and kaolin, as pointed out earlier, are used as raw materials or additives in building materials. However, clay and kaolin constitute only up to 30% by weight of the total materials, e.g. concrete, used in buildings.

In conclusion, the present study shows that the measured clay and kaolin samples are within the recommended safety limit and do not pose any significant source of radiation hazard.

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