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Characterization of the Radioactivity of Natural Radionuclides in Some Building Materials using a High-Purity Germanium Detector

The main objective of the current study is to characterize radioactivity in selected samples of building materials by measuring the amounts of natural radionuclides (^{238}U, ^{232}Th, ^{40}K) using gamma spectroscopy with a high-purity germanium (HPGe) detector. Samples selected for the models were collected from different origins and subjected to analysis to confirm average concentrations of radionuclides. Then, risk factors were calculated and these results were compared to international values for further analysis. The results of the study indicate that the quantities of radionuclides fall within the established global natural limits, which indicates that the levels of natural radioactivity fall within the globally accepted range.

Keywords: Building materials; Radioactivity; Ceramics; Marble substitute
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1. Introduction

Soil is a critical environmental component that plays a vital role in providing humans with a livelihood. When contamination occurs as a result of the addition or removal of certain components, it results in defects that alter inherent natural, biological, or chemical characteristics. These changes have direct or indirect effects on both humans and other species living in the affected environment [1]. The increasing number of sophisticated scientific inquiries pertaining to the generation of radioactive elements and the wide range of applications they possess in everyday existence poses a significant peril to the environment and its contamination [2]. Hence, it has become essential for researchers to gain knowledge regarding the properties and risks associated with these substances, as well as appropriate protocols for their safe handling and management. Radionuclides make up a large portion of naturally occurring radioactive materials [3]. The presence of these nuclides can be observed in various geological formations within the Earth's environment, encompassing the Earth's crust, subsurface rocks, soil, vegetation, hydrosphere, and atmosphere. The relative proportions of these nuclides, which serve as sources of radioactivity [4], show variations based on factors such as the geographic and geological characteristics of a given area, the spatial distribution of radionuclides, and the existing radiochemical conditions. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 2000 stated that [5]. Radioactive contamination is widely recognized as an extremely dangerous form of environmental pollution. When radioactive elements infiltrate the body's cells, they cause visible and internal imbalances [6].

Building materials contribute to the construction of buildings and residential homes in which people live and spend most of their lives for a long period. These materials are made or taken from natural sources, whether rocks or soil from different regions. [7]. They have natural radioactivity that affects human life. This effect depends on the amount of radiation to which he/she is exposed, the type of ionizing rays contained in these materials, and the manner in which a person is exposed to them, whether internally or externally [8]. Among the health risks to which a person is exposed that are related to exposure to radiation are cancerous diseases that occur as a result of genetic mutations resulting from a change in the genetic codes due to exposure of living cells to radiation. Because of these and other effects, it has become important to focus on the control factor for these materials and examine them periodically to determine the extent of their danger and their impact on humans [9]. This is done by measuring their radioactivity and comparing it with international values for the amount of radiation permitted to be exposed to according to statistics set by the relevant international bodies.

This study seeks to validate the levels of inherent radioactivity and assess the radiation levels found in samples of the building materials under investigation [10]. To achieve this goal, measurements were carried out on five samples, including those sourced from different companies, to determine radium equivalents, internal and external risk indicators, annual absorbed dose, and gamma radiation risk indicators.

2. Experimental Part

A high-purity germanium detector (HPGe) it has an efficiency of 20% and an operating voltage of

400keV located in Al-Nahrain University, Al-Nahrain Research Center for Renewable Energy was used for quantitative and qualitative analysis of the samples of the studied materials in order to calculate the specific activity of natural radionuclides (^{238}U, ^{232}Th, ^{40}K) and industrial cesium (^{137}Cs) and analyze these results using a computer equipped with (SpectraLineGP) software to make appropriate changes.

The study included 5 samples of different types of ceramic, porcelain, and marble substitutes, as distributed in table (1). Samples were collected from different types in Iraqi local markets and from different industries. One kilogram for each sample is taken, after using a small-diameter sieve to obtain a homogeneous mixture, and then the samples are transferred to the laboratory to preserve them and measure the exact mechanism of action of radionuclides. In order to begin the measurement, an empty plastic container was placed in the detector system and the gamma ray spectrum was collected for a duration of 60 min. Following this, the radiation background of the laboratory was measured. After that, the device was calibrated as needed. Then, the samples under study were measured, The lead isotope ^{214}Pb specific activity was determined at an energy level of 351.9 keV, bismuth ^{214} Bi at an energy level of 609.32 keV, and radium ^{226}Ra at an energy level of 185.6 keV, which is equivalent to the specific activity of the uranium ^{238}U series. The most effective value was selected. The specific activity of ^{212}Pb was determined at an energy level of 238.6 keV, the specific activity of actinium isotope ^{214}Ac at an energy level of 911.16 keV, which is equivalent to the specific activity of the thorium series ^{232}Th, and the specific activities of potassium ^{40}K at an energy level of 1460.8 keV [11].

3. Results and Discussion

According to the results listed in table (1), sample Y3 had the greatest specific activity of uranium ^{238}U at 54.6 Bq/kg, while sample Y5 had the lowest at 7.80 Bq/kg, according to the findings of the specific radioactivity of radioactive isotopes acquired from ceramic, porcelain, and marble substitution samples. Sample Y3 had the greatest specific activity of ^{232}Th (42.25 Bq/kg), whereas sample Y5 had the lowest (1.1 Bq/kg). As indicated in Fig. (1), the specific activity of ^{40}K had a maximum value of 300 Bq/kg in sample Y5 and a minimum value of 100 Bq/kg in sample Y1. Radium equivalent effectiveness (Ra_{eq}). The results showed that the highest value is sample Y5 had the lowest value at 35.67 Bq/kg, whereas the overall rate of comparable radium efficacy was 83.21 Bq/kg. Sample Y3 had the highest value at 131.26 Bq/kg. The findings presented here show. There is a discrepancy between the radium equivalent efficacy rate and the worldwide average of 370 Bq/kg.

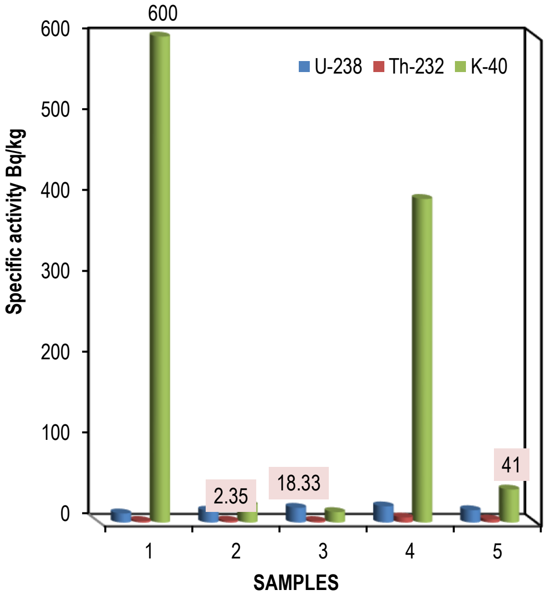

Fig. (1) Effect Hazard Index for the studied ceramic, porcelain, and marble substitute samples

The values of the absorption dose rate (D) range from 18.26 nGy/h in sample Y5 to 59.54 nGy/h in sample Y3. The average rate is 38.05 nanograms per hour. According to the latest findings, as seen in Fig. (2), the airborne absorbed dose rate is lower than the average worldwide value of 84 nGy/h.

In terms of the Annual Effective Dose Indoor ($AEDE_{in}$), the sample Y5 had the lowest value at 0.02 mSv/y, while Y3 had the highest value at 0.07 mSv/y. On average, it's 0.05 mSv/y. A lower value of 0.09 mSv/y was found in Y5, while the highest value of 0.29 mSv/y was in sample Y3, indicating that the present findings demonstrate that the yearly effective dose rate for internal exposure is lower than the worldwide average of 1 mSv/y. On average, it's 0.19 mSv/y. According to the latest findings, the yearly effective dosage rate from the outside is lower than the worldwide norm (1 mSv/y) .

Nuclear danger index for the interior H_{in} In sample Y3, the maximum value was 0.5 Bq/kg, whereas in sample Y5, the lowest value was 0.13 Bq/kg. The internal risk index rate is lower than the world average, which is 1 Bq/kg, with a typical rate of 0.32 Bq/kg. Additionally, the Hout external radiation risk index With a value of 0.35 Bq/kg, sample Y3 had the highest concentration. Also, in sample Y5 the lowest value was 0.10 Bq/kg). The findings show that the external risk index rate is lower than the general rate of 1 Bq/kg, whereas the general average is 0.22 Bq/kg.

Index of danger for Iγ gamma radiation. While the overall average was 0.59 Bq/kg, the findings showed that sample Y3 had the greatest value at 0.93 Bq/kg and sample Y5 had the lowest value at 0.28 Bq/kg. Figure (3) shows that the overall rate is 1Bq/kg, but the external risk index rate is lower [12].

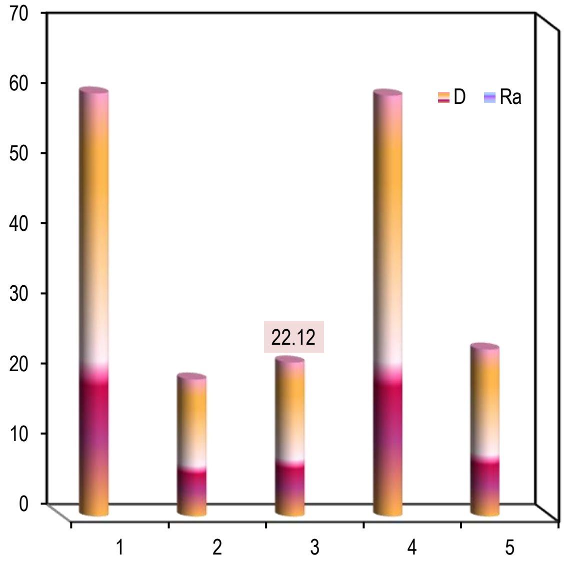

Fig. (2) Specific effectiveness for the studied ceramic, porcelain, and marble substitute samples

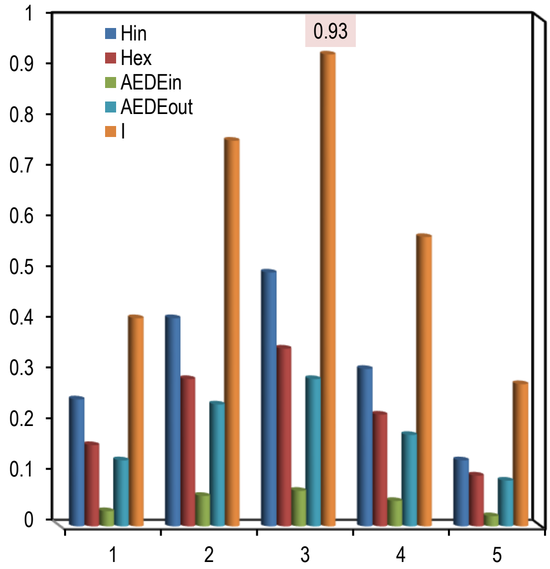

Fig. (3) Risk factors for the studied ceramic, porcelain, and marble substitute samples

4. Conclusions

Based on the data collected, the absorbed dose rate did not exceed the limitations set by UNSCEAR (2000) [22]. Internationally permitted levels, as determined by UNSCEAR (2000), are lower than the yearly effective dose rates. The radium equivalent likewise fell under the 370 Bq/kg level that is considered acceptable worldwide. The findings of this study indicate that the absorbed dose rate in the samples collected was within the acceptable limits set by the International Commission on Radiological Protection (ICRP, 1993). Hence, these varieties are deemed safe for use in building.

References

[1] F.F. Kaddoori et al., “Measurement of specific activity of natural radioactive materials and Cs-137 in soil samples for some areas in Al-doura city in Baghdad governorate”, *Iraqi J. Sci.*, 62(9) (2021) 2940-2947.

[2] Z.J. Kazem, “Radioactive contamination with uranium and radon gas, and concentrations of some heavy elements in the soil of the city of Nasiriyah”, MSc thesis, University of Baghdad (2012).

[3] Y.S. Khalf and K.K. Mohammad, “Measurement of natural radioactivity level in selected phosphate fertilizer samples collected from Iraqi Markets”, *Al-Nahrain J. Sci.*, 24(3) (2021) 43-49.

[4] IAEA Safety Glossary, “Terminology used in nuclear safety and radiation protection”, *Vienna* (2007).

[5] UNSCEAR Sources, “Effects of Ionizing Radiation”, United Nations (NY, 2000), 453-487.

[6] R.L. Clark, “US Environmental Protection Agency Radiation Protection Programs for Waste Management and Site Cleanup”, WM Symposia, 1628 E. Southern Avenue, Suite 9-332, Tempe, AZ 85282 (United States, 2008).

[7] IAEA, “Communications on nuclear radiation transport and waste safety”, Practical Handbook, (Vienna, 1999).

[8] N.F. Tawfiq, H.L. Mansour and M.S. Karim, “Natural radioactivity in soil samples for selected regions in Baghdad governorate”, *Int. J. Recent Res. Rev.*, 8(1) (2015) 1-7.

[9] M. Miglierini, “Detectors of radiation”, *React. Phys. Exper. J.*, 2(4) (2004) 1-67.

[10] Measurements, Scientific Committee 46-2 on Uranium Mining and Milling--Radiation Safety Programs, *Radiation Protection in the Mineral Extraction Industry: Recommendations of the National Council on Radiation Protection and Measurements*. No. 118. Ncrp, 1993.

[11] UNSCEAR Sources, “Effects of Ionizing Radiation”, United Nations (NY, 2000) 453-487.

[12] IAEA., “Communications on nuclear radiation transport and waste safety”, Practical handbook, Vienna, 1999. Angell, James Ross. "Practical perspectives on spent nuclear fuel transportation risks”, (2005).

Table (1) Specific effectiveness and risk factors for the studied ceramic, porcelain, and marble substitute samples

Sample	Samples name	Specific activity (Bq/kg)			HazardIndex (Bq/kg)		absorbed dose rate D(nGy/h	Annual effective dose (mSv/y)		I_γ (Bq/kg)	Ra (Bq/kg)
		^{238}U	^{232}Th	^{40}K	H_{IN}	H_{EX}		$AEDE_{IN}$	$AEDE_{OUT}$		
Y1	Ceramic Indian	33.2	16	40	0.25	0.16	26.67	0.03	0.13	0.41	59.16
Y2	Porcelain Indian	41.3	39.8	136	0.41	0.29	48.82	0.06	0.24	0.76	108.76
Y3	Ceramic Iranian	54.6	42.2	211	0.50	0.35	59.54	0.07	0.29	0.93	131.26
Y4	Porcelain Iranian	34.3	25.1	141	0.31	0.22	36.95	0.05	0.18	0.57	81.19
Y5	Marble alternative Turkish	7.8	1.1	300	0.13	0.10	18.26	0.02	0.09	0.28	35.67
Max		**54.6**	**42.2**	**300**	**0.5**	**0.35**	**59.54**	**0.07**	**0.29**	**0.93**	**131.26**
Min		**7.80**	**1.10**	**40.0**	**0.13**	**0.10**	**18.26**	**0.02**	**0.09**	**0.28**	**35.67**
Mean		**34.25**	**24.8**	**165.6**	**0.32**	**0.22**	**38.05**	**0.05**	**0.19**	**0.59**	**83.21**