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Calculation of Hazard Indicators for Some Materials Used in Construction and Selected from the Iraqi Market

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Abstract

The main objective of this study is to measure the levels of radioactivity in certain construction material samples by quantifying the amounts of natural radionuclides (238U, 232Th, 40K) and 137Sc using gamma-ray spectroscopy with a High Purity Germanium (HPGe) detector. The selected samples were collected and examined to ascertain the mean quantities of radionuclides present. Subsequently, these findings were juxtaposed with global benchmarks for additional examination. The efficiency results unveiled a spectrum of concentrations for different radionuclides, encompassing 238U with a concentration range of (2.53 - 8.2 Bq/kg) and an average concentration of (4.93 Bq/kg). Similarly, the concentration of 232Th ranged from (0.655 - 3.45 Bq/kg), with an average concentration of (1.74 Bq/kg). The radionuclide 40k exhibited a concentration range of (3.5 -1500 Bq/kg), with an average value of (386.4 Bq/kg). Furthermore, 137Sc displayed a concentration range of (0.51-0.22 Bq/kg) with an average concentration of (0.53 Bq/kg). The radium equivalent concentration was determined to be (40.45 Bq/kg), whereas the absorbed dosage was measured at (18.67 nGy/h). The external hazard index (Hout) was measured to equal (0.11 mSv/y), whereas the internal hazard index (Hin) was determined to be (0.17 mSv/y). Furthermore, the annual equivalent effective dose (AEDEout) was calculated to be (0.09 mSv/year). The annual dosage of (AEDEin) was determined to be (0.02 mSv/year). The gamma radiation index, denoted as Iγ, was determined to be (0.28 Bq/kg). The study results imply that the amounts of radionuclides fall within the defined normal limits worldwide, indicating that the natural radioactivity levels are within the internationally acceptable range.

Quantification of both natural and artificial radioactivity in specific building materials employed in constructing dwellings inside Salah Al-Din Governorate. A selection of seven distinct models was made. (Plaster, Bork, and Dust). The concentration of gamma-ray-emitting radionuclides in both the uranium-radium and thorium series, as well as 40K and 137Sc, was measured using a high-purity germanium (HpGe) detector. Subsequently, the spectrum underwent analysis for 3600 seconds. The concentrations of the radionuclides being investigated were determined to be as follows: The mean concentrations of 238U range from (2.53 - 8.2 Bq/kg), while for 232Th the range from (0.65 to 3.45 Bq/kg). The concentrations of potassium 40K range from (3.5 to 1500 Bq/kg), and for 137 Sc the range from 0.51 to 0.22 Bq/kg.

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1. Introduction

Radioactive elements occur naturally in soil, rocks, building materials, groundwater, air, and plants [1]. Radioactive pollution is a significant and intricate issue in nature. It arises from multiple sources and is compounded by the contrasting behaviours of the original nuclides in the soil and the newly deposited radioactive pollutants [2]. The

natural radionuclides are extensively distributed throughout the environment and are regarded as the primary source of ionizing radiation exposure for humans. The concentrations of radionuclides in the soil and surrounding environment increase due to the use of radioactive materials in medical applications, the fallout from nuclear tests, and the use of phosphate fertilizers containing high levels of radionuclides [4]. Recent research has indicated that nuclear radiation has significant biological consequences on human life and other species, particularly when these animals are exposed to levels exceeding the internationally recognized threshold [5]. Radon and thorium, which are natural radionuclides, are inhaled by humans. Additionally, radionuclides can also enter the body through the consumption of food. The presence of primordial radionuclides such as 238U and 232Th, along with their decay products and the naturally existing 40K, in the soil and rocks of the environment, is directly affected by terrestrial gamma radiation. The level of natural radioactivity and the subsequent exposure to external gamma radiation are mainly influenced by the specific geological and geographical characteristics of a given area, which exhibit varying degrees of intensity in different locations [7]. The primary sources of natural radiation exposures are high-energy cosmic ray particles that reach the Earth's atmosphere and radioactive nuclides found in the Earth's crust, which are also present in the environment and the human body. Moreover, industrial activities that involve Naturally Occurring Radioactive Materials (NORM) may present a radiological hazard. Therefore, it is crucial to identify and measure these risks [8].

The adulterated commodities consist of raw materials obtained from multiple sources that are unknown and potentially suspicious. These materials may contain trace elements of pollutants that are mistakenly introduced into the soil, along with authorized nutritious nutrients for plants [9]. Radioactive elements can be found in several states solid, liquid, or gaseous - and are typically coupled with other environmental elements including water, air, and soil. Gaseous materials in the air propagate at a higher velocity compared to liquids or solids, resulting in the rapid and extensive dispersion of radioactive pollution over large distances. The wind plays a crucial role in facilitating this process [10]. The soil and water have been affected by the deposition of radioactive dust. Subsequently, the radioactive substances permeate into the soil and subsequently migrate through it to the rivers and groundwater [11]. The migration of radioactive contaminants into groundwater, as well as their transfer to plants, air, and water, is mostly influenced by the rate of rainfall, irrigation water quantity, cultivated plant types, and soil management practices. The radioactive content in the soil is primarily found within the top 1-2 cm. Approximately 90% of the radioactive materials are eliminated by wind and rain during the initial months of soil contamination, together with the natural decay of these compounds [12]. The radioactive elements occurring naturally can be categorized into three broad groups. The first group comprises the primordial natural radionuclides that existed in nature prior to the formation of the Earth (their age exceeds that of the Earth). The second category consists of cosmic natural radionuclides, which are generated through the interactions of cosmic rays. The third category consists of radionuclides that have been artificially produced by human involvement, either directly or indirectly. However, these nuclides bear a resemblance to natural radionuclides to a little extent [13]. Natural radionuclides, which are found in many natural sources, are the primary contributors to the radiation dose that the population is exposed to. This presence has been recognized since the early 1930s. Nevertheless, it garnered minimal attention until recent decades, when the significance of terrestrial radiation in contributing to the global population's effective collective dosage was acknowledged [14]. The dosage levels differ based on the fluctuations in the concentrations of naturally occurring radionuclides like radium (226Ra) and thorium (232Th), as well as the concentration of radioactive potassium (40K) and other resultant radionuclides. The presence of these substances is determined by the soil composition, which is influenced by the geological characteristics of the land in the specified region [15]. It is crucial to measure the quantities of some man-made radioactive elements, such as 137Sc, in construction materials. This allows us to evaluate the impact of these artificial elements on the overall radiation exposure of the population, as well as determine the extent of radioactive contamination in the area [16].

The annual global estimate of gamma-ray emissions from building materials is around 0.4 mSv. These emissions have been detected in various regions worldwide, including India, Brazil, the United Kingdom, Nigeria, Egypt, and the United States of America [17]. Salah al-Din contains limited information on the levels and

concentrations of both natural and man-made radionuclides found in construction materials. Hence, this study aimed to quantify the quantities of radioactive substances in building materials commonly employed in residential construction in Salah al-Din. Building materials inherently possess varying levels of natural radioactivity, with those originating from soil and rock mostly including natural radioisotopes from the thorium 232Th series, uranium 238U, and potassium 40K radioisotopes. In the uranium series, the decay chain commences with radium 226Ra, which is the most significant radioactive element. Consequently, radium is frequently mentioned instead of uranium [18].

2. Experimental Measurements

2.1. Sample collection and preparation

The samples analyzed consisted of seven distinct varieties of building materials from Iraq, namely plaster, borax, and Ghubrah. Table (1) displays three specimens of plaster, three specimens of borax, and one specimen of dust, which are utilized in the fabrication of floors and structures. The specimens were gathered from various regions within the Salah al-Din Governorate. The samples were desiccated and amalgamated to get 1 kg of refined powder. Subsequently, these samples were hermetically enclosed in plastic vials. The samples were evaluated for gamma-ray spectra using a high-purity germanium (HpGe) detector. Each sample's spectra were recorded and studied for 7200 seconds.

Table 1. Names of the samples and their manufacturing regions

Sample No.	Sample type	Rigon
D1	plaster	Iraq -Najaf - Al-Amin Factory
D2	Plaster	Iraq – Samarra
D3	Plaster	Iraq - Mosul – Akwar
D4	Burke	Iraq- Alwaza brand, - Fallujah
D5	Burke	Iran - 5 stars Al-Ghazal brand
D6	Burke	Iraq - Al-Malaj brand
D7	Ghubrah or dust	Iraq - Mosul

2.2. Measurement setup

The gamma-ray spectrometer is an effective and efficient analytical tool for spectrum separation. It may generate analytical data for several unstable nuclides from a single sample. The investigation utilized a high-purity germanium (HPGe) PN-type detector, namely the BSI Baltic Scientific Instruments model No. 1734-11. This detector comprises a 2"2 crystal and a 4096 channel MCA analyzer, boasting an efficiency of 20%. This type of detector is cooled to a temperature of -196 degrees Celsius. It is operated with liquid nitrogen in a specialized tank and is surrounded by a lead shield measuring 4.5 cm in thickness. The inner surface of the lead shield is covered with a thin layer of copper, measuring 0.8 mm in thickness. This copper layer serves to attenuate the x-rays that result from the interaction of gamma rays with the lead shield, thereby reducing background radiation. The detector is used for both quantitative and qualitative analysis for samples of various materials. Its purpose is to calculate the specific activity of natural radionuclides such as 238U, 232Th, 40K, as well as industrial cesium 137Cs. The results obtained from the detector are analyzed using a computer equipped with Spectra Line software, which allows for appropriate adjustments and interpretations. The energy calibration of a gamma spectrometer was conducted using standard sources containing radionuclides with known energies (59.53, 661.6, 1173.1, and 1332.3) KeV for 214Am, 137C, and 60Co, respectively. The adoption of these energies was based on their ability to encompass the necessary range for measurement. Table (2) displays the radionuclides found in standard sources.

2.3. Theoretical calculations

In this study many parameters were calculated such as specific activity, Gamma index (I_γ), Radium equivalent activity (Raeq), Annual effective dose (AEDE), Hazard indices internal (Hin), and external (Hex).

Activity concentration (A):

The activity concentrations of natural radionuclides 228U, 232Th, and 40K, which represent the number of nuclear decays per second, can be determined using gamma-ray spectrometry using the formula [19]:

$$A = \frac{Net\ Count}{(\varepsilon \times I_\gamma \times T \times M)} \quad \ldots (1)$$

where ε: is the absolute gamma peak efficiency of the detector, Iγ: is the intensity for gamma-ray energy,

T: is the counting time for the measurement in seconds, M: weight mass in kg. The gamma index I_γ represents the decay intensity of the specific energy

peak and was determined by employing the equation [20]:

$$I_\gamma = \left(\frac{Au}{300}\right) + \left(\frac{ATh}{200}\right) + \left(\frac{Ak}{3000}\right) \quad \dots(2)$$

where Au refers to the specific activity of 228U, ATh refers to the specific activity of 232Th, and Ak refers to the specific activity of 40 K. Equation (2) represents the calculation of $I\gamma$, which is the sum of three terms. The gamma dose absorption (DR) refers to the measurement of radiation levels in the air, namely 1 meter above the ground surface. These measurements were conducted following the guidelines provided by UNSCEAR for the even distribution of naturally occurring radioactive materials [21].

$$D\left(\frac{nGy}{h}\right) = (Au \times 0.462) + (ATh \times 0.604) + (Ak \times 0.0417) \quad \dots(3)$$

The results of gamma dose absorption are reported in Table 3. Radium equivalent activity (Raeq): It represents the total radiation exposure from 228U, 232Th and 40K nuclides, expressed as radium equivalent activity (Raeq) as (Bq/kg). The radium equivalent activity of soil samples was calculated using the following formula [21]:

$$Raeq = (Au) + (1.43\,ATh) + (0.077Ak) \quad \dots(4)$$

The results of Radium equivalent activity are shown in Table 3.

Annual effective dose (AEDE): It is estimated from the absorbed gamma dose concentrations (DR) by using the dose conversion factor (F) of (0.7 mSv/y) with an AEDEout occupancy factor of 0.2 and 0.8 for AEDEin and determined using the following formula [22]:

$$AEDE\left(\frac{mSv}{y}\right) = DR\left(\frac{nGy}{y}\right) \times T \times F \quad \dots(5)$$

It represents the results of the annual effective dose shown in Table 3.

Hazard indices external (Hex) and internal (Hin): Described two indicators that describe internal and external radiation risks. The external hazard index is derived from the (Raeq) expression on the assumption that its permissible maximum value (equal to unity) corresponds to Raeq (370 Bq/kg) upper limit. The external hazard index (Hex) is then defined as follows [23]:

$$Hex = \frac{Au}{370} + \frac{ATh}{259} + \frac{Ak}{4810} \quad \dots(6)$$

$$Hin = \frac{Au}{185} + \frac{ATh}{259} + \frac{Ak}{4810} \quad \dots(7)$$

Table 2: Radionuclides in standard sources.

Radionuclide	Half-Life (days)	Activity (Bq/kg)	Combined Standard Uncertainty	Energy (keV)
Am-241	157800	4.433	1.1	59.3
Cd-109	4625	16.17	1.5	88.1
Ce-139	137.5	0.740	1.1	165
Co-57	271.26	0.855	1.1	122.1, 136
Co-60	1925.4	2.659	1.1	1173.1, 1332.3
Cs-137	11019	2.439	1.2	661.6
Sn-113	115.q	3.087	2.2	392
Sr-85	64.78	4.024	1.5	514
Y-88	106.6	3.995	1.2	898
Hg-203	46.72	2.064	2.4	898.02, 1836.08

3. Result and Discussion

Analysis of the radioactive isotopes in gypsum samples from Burke and Ghubra revealed the specific radioactivity values as follows:

The uranium 238U activity was highest in sample D2 (Iraq plaster - Samarra) and its lowest recorded value was 2.53 Bq/kg in sample D3 (Iraq plaster - Mosul - Akwar). The specific activity of 232Th was measured in several samples. The greatest value, 3.45 Bq/kg, was discovered in the D2 Samarra plaster sample. The lowest value, 0.655 Bq/kg, was found in the D4 Burke Alwaza brand sample from Fallujah, Iraq. Regarding the activity level of 40K, the sample with the greatest value was (1500Bq/kg), which was found in the D1 Iraq plaster from the Najaf region at the Al-Amin Factory. On the other hand, the lowest value was observed in the A28 plaster from the Mosul region

at the Akwar site. As indicated in Table 3. Figure (1) displays the precise activity levels of the examined plaster, labor, and dust samples.

Table (3): specific activity (Bq/kg) of radionuclides (^{238}U, ^{232}Th, ^{40}K and ^{137}Cs) and Evaluation of Radiological Risk Indicators

Sample No.	Specific activity (Bq/kg)			Hazard Index ($Bq.Kg^{-1}$)		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}		$AEDE_{in}$	$AEDE_{out}$		
D1	7.63	3.45	1500	0.37	0.35	68.16	0.08	0.33	1.09	128.06
D2	8.2	3.15	39	0.06	0.04	7.32	0.01	0.04	0.11	15.71
D3	2.53	0.95	3.5	0.02	0.01	1.89	ND	0.01	0.03	4.16
D4	2.9	0.655	400	0.1	0.09	18.42	0.02	0.09	0.29	34.64
D5	4.13	0.9	10	0.03	0.02	2.87	ND	0.01	0.04	6.19
D6	3.63	1.6	12	0.03	0.02	3.14	ND	0.02	0.05	6.84
D7	4.63	0.85	10	0.03	0.02	3.07	ND	0.02	0.05	6.62
Max	8.2	3.45	1500	0.37	0.35	68.16	0.08	0.33	1.09	128.06
Min	2.53	0.655	3.5	0.02	0.01	1.89	ND	0.01	0.03	4.16
a.v	4.93	1.74	386.4	0.11	0.10	19.44	0.02	0.10	0.31	37.16

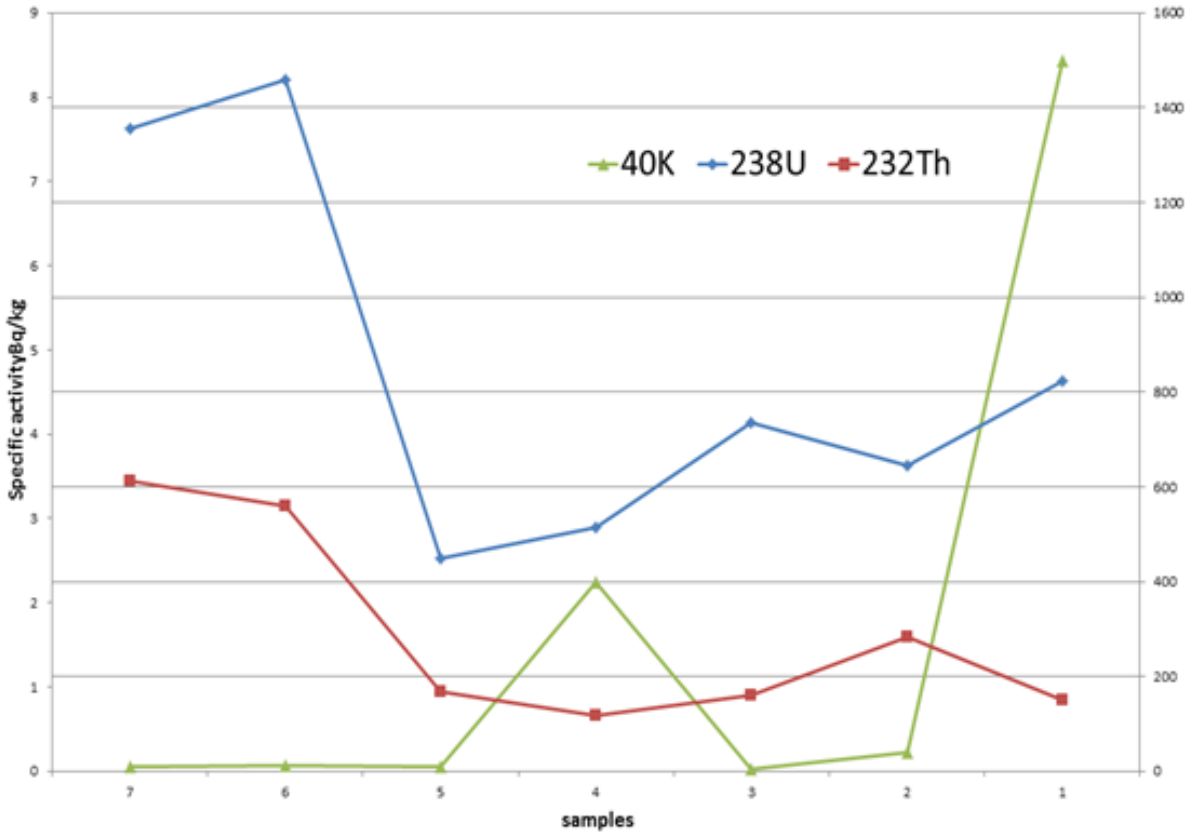

Figure (1): Shows the specific activity of the studied plaster, Burke, and Ghubrah or dust samples.

The danger indicators for the examined plaster, porcelain, and dust yielded the following results: Radium equivalent effectiveness (Raeq) refers to the measure of the radiation dose that is equivalent to the dose received from radium. The findings indicated that the sample with the highest value was (128.06 Bq/kg), specifically the D1 Iraq plaster from the Najaf region, as tested in the Al-Amin laboratory. Conversely, the sample with the lowest value was (4.16 Bq/kg), namely the D3 plaster of Iraq from the Mosul region, as tested in the Aqwar laboratory. The overall average equivalent radium

efficacy was determined to be (37.16 Bq/kg). The current findings suggest that the rate of equivalent radium effectiveness is lower than the global rate of equivalent radium effectiveness, which is 370 Bq/kg. Referring to Table 3.

The absorbed dose rate (DR) reaches its peak at 68.16 nGy/h in the sample (D1 Iraq plaster - Najaf - Al-Amin Factory), while the lowest value is recorded at 1.89 nGy/h in the sample (D3 Iraq plaster - Mosul - Akwar). The overall rate is 19.44 (nGy/h). The latest findings indicate that the absorbed dose rate in the air is lower than the global rate of 84 nGy/h, in Table 3 [25, 24]. Figure (2) represents the radium equivalent (Raeq) and absorbed dose rate (D) for the gypsum, Burke, and dust.

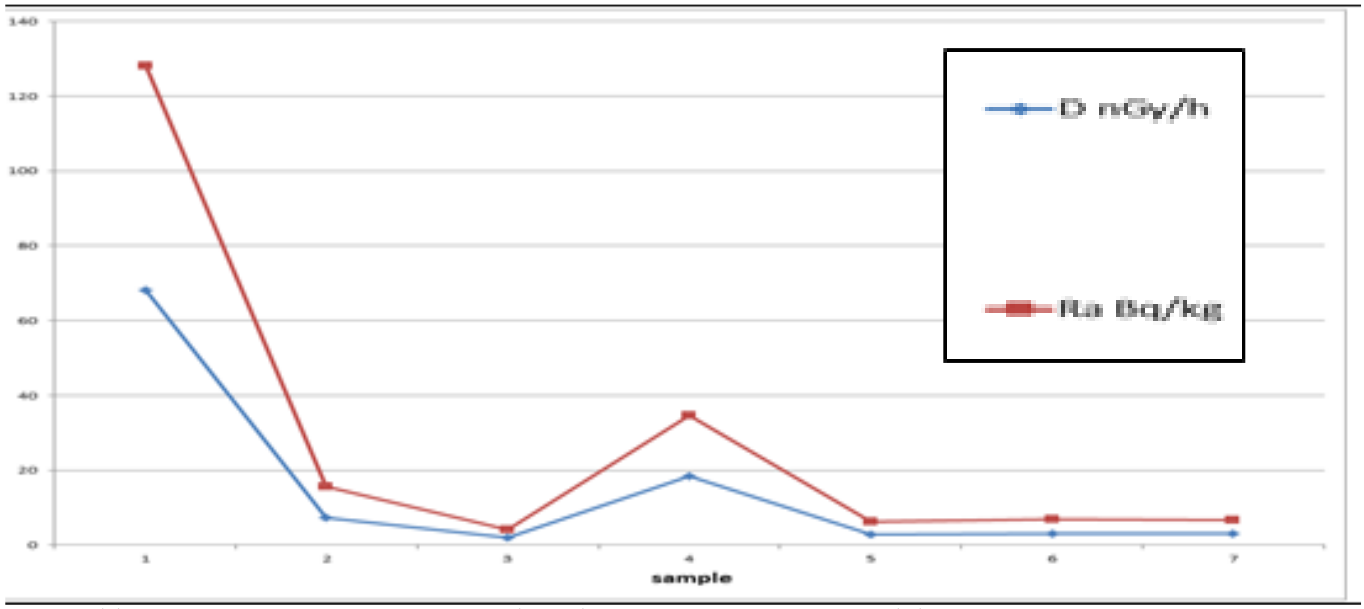

Figure (2): Shows the radium equivalent (Raeq) and absorbed dose rate (D) for the gypsum, Burke, and dust.

The rate of the Annual Effective Dose Indoor (AEDEin) is 0.08 (mSv/y). The sample with the highest value is (0.08 mSv/y), which is found in D1 Iraq plaster from the Najaf - Al-Amin factory. On the other hand, the lowest value is below the sensitivity of the device BDL for samples such as D7 Ghubrah Iraq - Mosul, D6 Burke Iraq - Al-Malaj brand, D5 Burke Iran - 5 stars Al-Ghazal brand D3, plaster Iraq - Mosul - Akwar. The overall rate is (0.02 µSv/y). According to Table (3), the current findings indicate that the yearly effective dose rate for internal exposure is below the global average of 1mSv/y [23]. Iγ gamma rays' hazard index: The findings indicate that the sample (D1) of Iraqi plaster from the Najaf - Al-Amin plant had the highest value of 1.09 Bq.Kg-1. On the other hand, the sample (D3) of Iraqi plaster from Mosul - Akwar had the lowest value of 0.03 Bq.Kg-1. The overall average value was 0.31 Bq/Kg. The results suggest that the external risk index rate is lower than the overall rate of (1 Bq/Kg) [23]. The AEDEout refers to the yearly effective dose resulting from outdoor exposure. The sample with the highest value recorded a dose of 0.33 mSv/y, specifically in the D1 Iraq plaster from the Najaf-Al-Amin factory. On the other hand, the two samples with the lowest values measured a dose of 0.01 mSv/y. These samples were the D5 Burke Iran - 5 Stars of Al-Ghazal sign D3 and the Iraq plaster from Mosul - Akwar. Based on the current findings, the external yearly effective dose rate is lower than the global average value of 1 mSv/y, as shown in Table 3 [23]. The internal radiation risk index Hin : The sample (D1 Iraq plaster - Najaf - Al-Amin Factory) had a value of (0.37 Bq.Kg-1), while the sample (D3 Iraq plaster - Mosul - Akwar) had the lowest value of (0.02 Bq/Kg). The overall average value is (0.11 Bq/Kg). Specifically, the internal risk index rate is below the worldwide rate of 1 (Bq.Kg-1). The table has three columns and is referenced as Table 3. Hexadecimal External Radiation Risk Index Hout: The sample with the greatest value was (0.35 Bq.Kg-1), specifically sample D1 from Iraq plaster - Najaf - Al-Amin plant. On the other hand, the sample with the lowest value was (0.01 Bq.Kg-1), specifically sample D3 from Iraq plaster -Mosul - Akwar. The overall average value was (0.10 Bq.Kg-1). The results suggest that the external risk index rate is lower than the overall rate of (1Bq.Kg-1).

Figure (3) represents the risk factors for the studied models of gypsum, Burke, and dust.

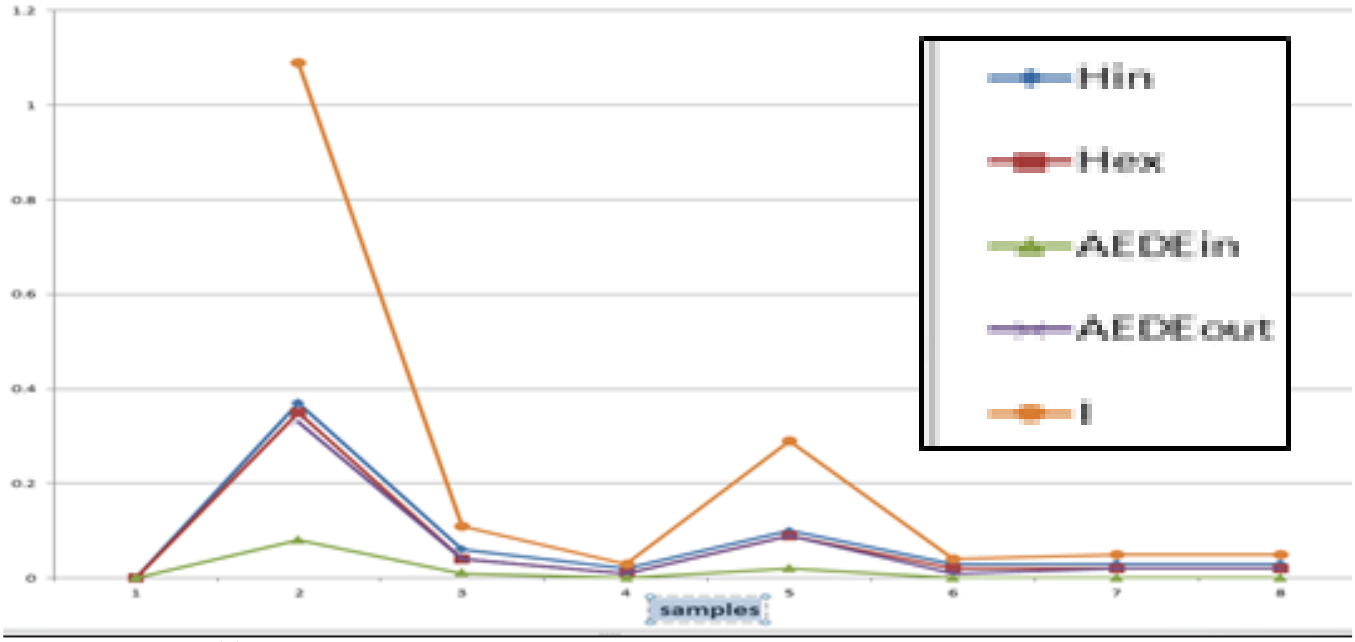

Figure (3): Represents the risk factors for the studied models of gypsum, Burke, and dust.

4. Conclusions

The findings of this study indicate that the absorbed dose rate in the samples collected from the districts of Salah al-Din Governorate was within the acceptable limits set by the International Commission on Radiological Protection (ICRP, 1993). The results of the risk indicators for the studied plaster, porcelain, and dust were as follows:

The results showed that the equivalent effectiveness of radium (Raeq) was (4.16 -128 Bq/kg). The general rate of equivalent effectiveness of radium was (37.16 Bq/kg). The current results indicate that the rate of equivalent effectiveness of radium is less than the global average of equivalent effectiveness of radium, which is 370 Bq/kg. Absorbed dose rate (D) was (68.16 - 1.89 nGy/h) and the general rate is 19.44 nGy/h. The current results showed that the absorbed dose rate in the air is less than the global average value of 84 nGy/h.

The results show that the risk index for Iγ gamma rays ranges between (1.09 - 0.03 Bq/Kg) and the general rate (0.31 Bq/Kg). The results indicate that the external risk index rate is less than the general rate of (1Bq/Kg). The Annual Effective Dose Indoor (AEDEin) is (0.08- BDL µSv/y) and the general rate is (0.02 µSv/y). The current results show that the annual effective dose rate for indoor exposure is less than the global rate of 1 mSv/y. The Annual Effective Dose Outdoor (AEDEout) reached (0.33 - 0.01 mSv/y) which is less than the maximum (1mSv/y). The results of the Internal Radiation Risk Index (Hin) showed a value of (0.37 - 0.02 Bq/Kg) and the general rate is 0.11 Bq/Kg, meaning that it is less than the global average of (1Bq/Kg). While the study showed that the value of the External Radiation Risk Index (Hex) was (0.35 - 0.011 Bq/Kg), and the general average is (0.10 Bq/Kg), the results indicate that the external radiation risk index rate is less than the general rate (1 Bq/Kg). The annual effective dose rates are below the internationally acceptable norms as defined by UNSCEAR (2000)[26]. Consequently, the utilization of certain varieties of plaster, ghubrah, Burke, and dust in construction was deemed secure.

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