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# ANN-Based Concrete Mix Design to Achieve Radiation Safety Criteria

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**ملخص البحث**

يعيش الإنسان في وسط مشع فهو يتعرض باستمرار للإشعاعات المؤينه التي تنطلق من المواد المشعه. النشاط الإشعاعي الطبيعي ينتشر على نطاق واسع في بيئة الأرض التي توجد في تشكيلات جيولوجيه مختلفه و بما أن مواد البناء مستمده من كل من المصادر الطبيعيه (الصخور- التربه) و نفايات الإنتاج (الرماد المتطاير- غبار السيليكا- رماد قش الأرز- خبث الأفران) فهي تحتوي على نويدات مشعه من سلسلة اليورانيوم ($^{238}U$) و سلسلة الثوريوم ($^{232}Th$) و نظائر البوتاسيوم المشعه ($^{40}K$) و لذلك فإن قياسات تركيز النويدات المشعه ومعدل انبعاث غاز الرادون من مواد البناء في غاية الأهميه و يجب ان تؤخذ هذه القياسات في الإعتبار أثناء اختيار مواد البناء و أثناء تصميم الخلطات الخرسانيه إلي جانب التحقق من الخصائص الميكانيكيه و الفيزيائيه من أجل التقليل – بقدر الإمكان – من تعرض الإنسان للنشاط الإشعاعي الطبيعي داخل المنشآت.

نظرا للأسباب المذكوره و الحاجه المتزايده لإنقاذ صحة الإنسان من خلال حمايته من مخاطر الإشعاع، فإن الهدف الرئيسي لهذا البحث هو الإهتمام بالمخاطر الإشعاعيه نتيجة استخدام مواد البناء في مصر، و ذلك باختيار مواد التشطيبات الداخليه و مواد صناعة الخرسانه ذات النشاط الإشعاعي المنخفض و ذلك قبل عملية الإنشاء.

لتحقيق أهداف هذا البحث تم جمع بيانات لمعدل انبعاث غاز الرادون ($Bq\ m^{-2}\ h^{-1}$) و محتوى النويدات المشعه (Bq/kg) لكل مكونات الخرسانه و مواد التشطيبات التي تستخدم بشكل عام في مصر. تم تحديد مكافئ الراديوم ($Ra_{eq}$) لكل ماده و ذلك لتقييم انبعاث أشعة غاما من كل مكونات الخرسانه و مواد التشطيبات. استخدمت البيانات المجمعه و المحسوبه لإنشاء نموذج للشبكه العصبيه الإصطناعيه (ANN) و ذلك للتنبؤ بمكافئ الراديوم و معدل انبعاث غاز الرادون من خلطات خرسانيه مختلفه في محتوى الأسمنت (350،400،450) $Kg/m^3$ و في نوع الركام الخشن (الحجر الجيري- الحصى- الدولوميت- الجرانيت).

استخدمت مخرجات البرنامج لمعدل انبعاث غاز الرادون من الخرسانه لتقدير تركيزات غاز الرادون في الأماكن المغلقه و ذلك داخل غرفه افتراضيه.

## Abstract

Every material found in nature has a specific feature of radioactivity. Since construction materials are derived from natural sources and waste product, it is required to measure the concentration of natural radionuclides, namely Uranium ($^{238}U$) series, Thorium ($^{232}Th$) series and Potassium ($^{40}K$) in order to control the natural radiation exposure for residents of dwelling.

Concrete is a man-made construction material consists of different components with high degree of non-homogeneity. The individual radiological properties of each component affect the radium equivalent and radon exhalation rate of concrete. Consequently, the knowledge about natural radionuclides content and radon exhalation rate of concrete as well as other building materials before concrete mix design and construction process will promote the assessment of radon gas and gamma rays emission inside buildings.

In this work, data about radon exhalation rate ($Bq\ m^{-2}\ h^{-1}$) and natural radionuclides content (Bq/kg) in concrete ingredients and finishing materials used in Egypt were collected. Then, radium equivalent ($Ra_{eq}$) was calculated to assess gamma ray emission from each concrete ingredient and finishing material. All data are set in an excel sheet for different concrete mixes to train and validate an Artificial Neural Network (ANN) to predict radium equivalent and surface radon exhalation rate from concrete. The created ANN appears a good response in which the outputs are very close to the target. The created ANN model has a best validation performance (MSE) 0.000010618 at Epochs 1 and a maximum correlation coefficient close to 1. Different concrete mixtures using different cement content (350, 400, and 450 $Kg/m^3$) and different types of coarse aggregates commonly used in Egypt (limestone, dolomite, gravel and granite) were set as a simulation data in the created ANN model to predict radon exhalation rate and radium equivalent. Indoor radon concentrations were estimated using the predicted values of radon exhalation rate from concrete beside radon exhalation rate from some finishing materials.

**Key words:** *Artificial Neural Network, Concrete Mixes, Radiation Safety*.

## 1. Introduction

The most important reasons that make building materials have a detrimental effect to human health are the content of natural radionuclides namely, Radium $^{226}$R, Thorium $^{232}$Th and Potassium $^{40}$K. These contents contribute in the harmful radiation that would affect human health.

Knowledge about radon levels in buildings is the first step for protecting the health of anyone breathing the air. The World Health Organization declares that the pluralities of lung cancer are caused by inhalation of radon gas [1].

The relative indoor radon concentration and gamma radiations attributable to various sources which are: Building materials (80%), outside air (10%), water (5%), natural gas (1%) and liquefied petroleum gas (< 1%), [2]. Thus, in the present study, the contribution of building material as the main source of indoor radon concentration will be considered in order to assess the radiological hazards received by human and so satisfies the green construction criteria.

Recently, many studies have been carried out to determine the activity concentration in some building and finishing materials that commonly used in Egypt such as cement, coarse aggregate, sand, bricks, gypsum, ceramic, granite and marble. Measurements of activity concentrations in ordinary portland cement, sand, gravel, limestone, granite, marble, gypsum, clay bricks, cement bricks and ceramic have been carried out by Higgy (1995) [3]. Moreover, radium equivalents (Raeq) for all studied building materials were calculated. The results show that the average radium equivalents were 48.5, 18.5, 16.4, 20.2, 184, 10.4, 4.6, 78.2, 19.1 and 145 Bq/kg, respectively. It is clear that granite and ceramic have higher values of radium equivalent relative to other studied materials. Despite these higher values, they are less than the recommended value by UNSCEAR (370 Bq/kg) [4].

The variations of radon level in some houses in Alexandria city, Egypt were investigated by Abd El-Zaher, *et al.*, (2008) [5]. In this work a set of indoor radon measurements was carried out in different houses built with the same type of building materials. The results show that, the radon concentration and the annual effective doses varied from (20.39 to 38.62) $Bq/m^3$ and (0.96 to 3.06) mSv/y, respectively. The average values of radon concentrations in kitchens, bathrooms, bedrooms and living rooms were (82.38 ± 8.35), (105.36 ± 14.67), (63.75 ± 7.63) and (50.93± 7.14) $Bq/m^3$, respectively. Also, the average values of annual effective does were (2.05 ± 0.20), (2.63 ± 0.36), (1.58 ± 0.185) and (1.26 ± 0.17) mSv/y, respectively. The overall average value of radon concentration was (75.60 ± 9.44) $Bq/m^3$, which is much less than the recommended ICRP, (1993) [6] action level 200-400 $Bq/m^3$. Furthermore, the annual effective dose received by the resident is less than the range of action level (3-10 mSv/y) recommended by ICRP (1993) [6].

Furthermore, indoor radon survey of a total 15 randomly selected houses in Qena city, Upper Egypt was carried out by Hussein, (2006) [7]. The measured indoor radon level varied from 19 to 59 $Bq/m^3$ with an average of 40 $Bq/m^3$. An average annual effective dose of 0.56 mSv/y has been estimated and was found to be lower than the ICRP [6] action level (3- 10 mSv/y).

The harmful radiation effect of building materials comes from two ways: First by gamma radiation from $^{226}Ra$, $^{232}Th$, $^{40}K$ and their progenies and secondly, by releasing of radon and radon daughter. It is recommended that while characterizing the radiological hazard of the materials containing natural radioactivity, there should be no need to calculate annual effective dose due to gamma emission if Raeq has already been determined or vice versa [8]. Moreover, it will be sure that the value of external hazard Hex of building material is less than unity when, the corresponding value of Raeq is less than the upper limit (370 Bq/kg), [9].

Due to the above-mentioned reasons and the growing need to save man health by protecting residents of residential buildings from radiation hazards to satisfy green construction requirements. Also, due to the fact that aggregates provide about 75 per cent of concrete and hence its influence is extremely important, this research will concern with two objectives:

- Studying the effect of utilizing different types of coarse aggregate commonly used in Egypt like limestone, granite, dolomite and gravel in concrete manufacturing on its radiation hazards. This can be done by creating an Artificial Neural Network model (ANN) to predicted radium equivalent and radon exhalation rate of the designed concrete.
- Performing a theoretical study to estimate radon concentration ($Bq/m^3$) inside a virtualized room to assess and prevent the radiation hazards before the construction process.

Data about concrete with different mix proportions and different types of coarse aggregates and mineral admixtures used in Egypt were collected. Furthermore, data about natural radioactivity ($^{226}Ra$, $^{232}Th$, $^{40}K$) in concrete ingredients and interior finishing materials were also collected as well as radon exhalation to study the effect of using these materials on radon concentration and gamma emission inside buildings.

## 2. Methodology

Artificial neural network (ANN) is an information processing model inspired by biological system and possessed of a large number of highly interconnected processing elements (neurons) working in conformity to solve specific problems. Like people, artificial neural networks (ANNs) learn by examples. Thus, data for concrete with different mixes in term of proportions of ingredients and type of aggregate used as well as the type of admixtures were collected. Ordinary Portland cement type I was used in all mixtures and sand also was used in all mixtures as a fine aggregate.

Furthermore, data about the average activity concentration of $^{226}Ra$, $^{232}Th$ and $^{40}k$ in some concrete ingredients and finishing materials used in Egypt constructions were collected and radium equivalent index, $Ra_{eq}$ (Bq/kg) were calculated according to the following equation [4].

$$Ra_{eq}\ (Bq/kg) = C_{Ra} + 1.43C_{Th} + 0.077C_{k} \quad \ldots\ldots\ldots\ldots (1)$$

The values of radium equivalent for concrete components are illustrated in Table (1).

**Table (1): Mean Radium Equivalent of concrete components**

| Material | Radium Equivalent ($Ra_{eq}$) Bq/kg | References |
|---|---|---|
| Cement | 43.3 – 162.51 | [3], [10], [11] |
| limestone | 20.2 | [3] |
| Gravel | 11.4 - 24.3 | [3] |
| Granite | 97.9 - 240.0 | [3], [9] |
| Dolomite | 60 | [12] |
| Sand | 7.7 -44.9 | [3], [9] |

Surface radon exhalation rate (Bq $m^{-2}$ $h^{-1}$) of all studied materials were searched. The collected data of radon exhalation rate and the calculated data of radium equivalent were used to create and train an artificial neural network (ANN) model to predict radon exhalation rate and radium equivalent of the manufactured concrete. Radon exhalation rate of concrete components and finishing material are illustrated in Table (2).

**Table (2): Radon exhalation rate of concrete components and finishing material**

| Material | Exhalation Rates Bq $m^{-2}$ $h^{-1}$ | References |
|---|---|---|
| Cement | 0.238 | [10], [13], [17] |
| limestone | 0.410 | [10] |
| Gravel | 0.113 | [10] |
| Granite | 1.059 | [10], [15], [17] |
| Dolomite | 0.05 | [14] |
| Sand | 0.331 | [10], [17] |
| Marble | 0.980 | [10], [15], [16], [17] |
| Ceramic | 0.107 | [10], [17] |
| Porcelain | 0.246 | [16] |
| Cement Bricks | 0.140 | [10], [13] |
| Clay Bricks | 0.197 | [17] |

## 3. ANN Development

In this study, the collected data are used to create and train an artificial neural network (ANN) model to predict the concrete radium equivalent as well as radon exhalation rate of concrete by using the previous collected and calculated data. The predicted radon exhalation rate indicates that the contribution of concrete in indoor radon concentration while, radium equivalent value indicates the level of gamma ray.

Eighty different samples are sorted in an excel sheet and equation (2) was applied so that the values of input and output data are between 0.0 and 1.0.

$$I_n = I_{actual} \ / \ I_{max} \ \ldots\ldots\ldots\ldots\ldots.. (2)$$

Where $I_n$ is input value for training and testing, $I_{actual}$ is the actual input data, $I_{max}$ is the maximum value of a set of input data. The model was implemented using NN Toolbox which is one of the commonly used software tool for the development and design of artificial neural network. The number of training and validation data is 80 parameters, input and output data classifications of ANN are illustrated in Table (3).

**Table (3): Parameters, Input and Output Data Classifications for ANN**

| Input Parameters | Input data classifications | Output data |
|---|---|---|
| Cement (OPC)<br>Coarse aggregate**<br>Fine aggregate (Sand)<br>Fly ash<br>Silica fume<br>Rice husk ash<br>Blast furnace slag | ** Type<br>Content, Radon exhalation rate and Radium equivalent | Radon exhalation rate,<br>Radium equivalent<br>of concrete |
| w/c ratio<br>Water reducer<br>Super plasticizer | - | |

** Types of coarse aggregate was included as an input parameter

The parameters selected in to create the Network were as follows:

- Network Type = Feed-forward Backprop
- Train Function = TRAINLM
- Adaption Learning Function = LEARNGDM
- Performance Function = MSE
- Numbers of hidden Layers = 1 with 28 neurons and tansig transfer function.

As displayed in Table (3), twenty five parameters were taken as the input parameters: content, radon exhalation rate and radium equivalent for cement, coarse aggregate, fine aggregate, fly ash, silica fume, rice husk ash and blast furnace slag. In addition, type of coarse aggregate was included. Water cement ratio and the content of chemical admixture were also taken as input parameters. Our target/output was surface radon exhalation rate and radium equivalent.

On training parameters, the following were selected: Epochs = 500, goal = 0, max. fail = 50 and min. grad = 1× $e^{-15}$. The training process was repeated until the actual outputs (predicted) close to the target (measured). The best network is achieved when the following two conditions satisfied: First, the minimum error in training data and second, the high correlation coefficient of data. The minimum error was represented by the MSE method. The created model has a best validation performance (MSE) 0.000010618 at Epochs 1 and a maximum correlation coefficient close to 1.

### Simulation data

Coarse and fine aggregate generally represent about 75% of concrete volume so, they have a high impact on natural radioactivity of concrete. Knowledge about radioactivity of aggregate is very important to assess the radiological risk to human due to the utilization of different types of aggregate in concrete manufacture.

Furthermore, different types of aggregate may contain significant quantities of naturally or technologically enhanced levels of radioactivity. These levels of radioactivity depend on geological and geographical conditions as well as geochemical characteristics. In this research, different types of coarse aggregates commonly used in concrete manufacture in Egypt were studied. These types are limestone, dolomite, gravel and granite. Different concrete mixtures using different cement content (350, 400, and 450 Kg/$m^3$) and different types of coarse aggregates were set as a simulation data in the created ANN model.

**Table (4): Concrete Mixes Designed Using Different Types of Aggregate**

| Mix No. | OPC Kg/$m^3$ | Coarse Aggregate Kg/$m^3$ | Coarse Aggregate (Type) | Sand Kg/$m^3$ | w/c |
|---|---|---|---|---|---|
| $C_1$ | 350 | 1099 | Limestone | 780 | 0.55 |
| $C_2$ | | 1099 | Gravel | | |
| $C_3$ | | 1099 | Granite | | |
| $C_4$ | | 1204 | Dolomite | | |
| $C_5$ | 400 | 1320 | Limestone | 630 | 0.5 |
| $C_6$ | | 1320 | Gravel | | |
| $C_7$ | | 1320 | Granite | | |
| $C_8$ | | 1447 | Dolomite | | |
| $C_9$ | 450 | 1392 | Limestone | 520 | 0.55 |
| $C_{10}$ | | 1392 | Gravel | | |
| $C_{11}$ | | 1392 | Granite | | |
| $C_{12}$ | | 1525 | Dolomite | | |

**Table (5): Effect of Different Types of Coarse Aggregate on Radon Exhalation Rate and Radium Equivalent of Concrete**

| Mix No. | Radium Equivalent Bq/kg | | Exhalation Rate Bq $m^{-2}h^{-1}$ | |
|---|---|---|---|---|
| | Target | Predicted | Target | Predicted |
| $C_1$ | 31.048 | 30.803 | 3.835 | 3.215 |
| $C_2$ | 30.210 | 27.451 | 2.089 | 2.682 |
| $C_3$ | 105.153 | 108.563 | 7.657 | 6.484 |
| $C_4$ | 51.326 | 40.031 | 1.513 | 1.842 |
| $C_5$ | 32.502 | 32.511 | 3.916 | 3.307 |
| $C_6$ | 31.547 | 29.395 | 1.927 | 2.696 |
| $C_7$ | 116.926 | 119.782 | 8.111 | 6.998 |
| $C_8$ | 56.256 | 48.491 | 1.327 | 1.777 |
| $C_9$ | 34.389 | 32.722 | 3.934 | 3.299 |
| $C_{10}$ | 33.387 | 29.203 | 1.848 | 2.684 |
| $C_{11}$ | 122.963 | 121.856 | 8.276 | 7.247 |
| $C_{12}$ | 58.583 | 50.139 | 1.244 | 2.100 |

From the data listed in Table (5), it appears that the output results obtained from the simulation process are close to the target. Figures (1) and (2) shows the good response of the created artificial neural network to predict radium equivalent (Bq/kg) and surface radon exhalation rate (Bqm-2 h1) of concrete manufactured of different mixes using limestone, gravel, granite and dolomite coarse aggregates.

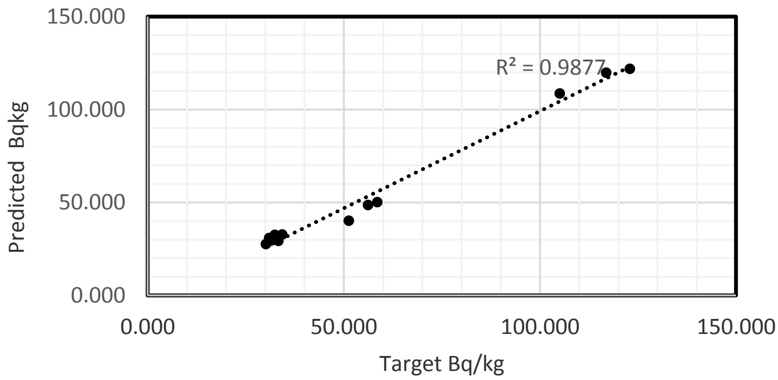


**Fig. (1): ANN Response for Prediction of Radium Equivalent**

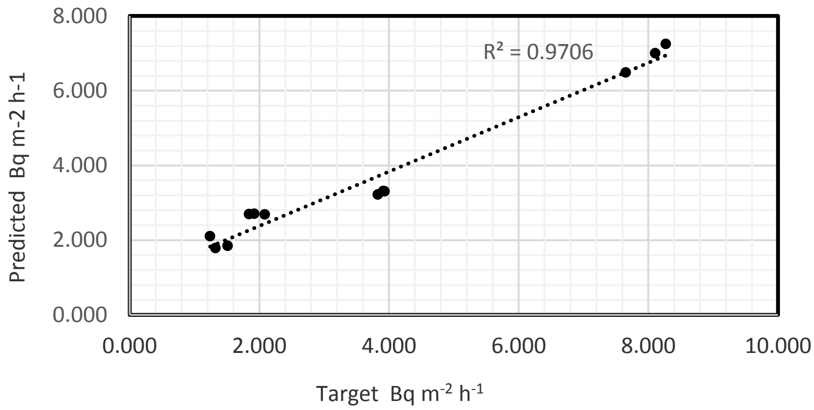


**Fig. (2): ANN Response for Prediction of Radon Exhalation Rate**

It can be seen from Table (5), Figures (3 & 4) that the highest values of concrete radium equivalent and radon exhalation rate are at a concrete in which granite was used as a coarse aggregate and 450 Kg/m$^3$ cement content (122.963 Bq/kg and 8.276 Bq m$^{-2}$ h$^{-1}$, respectively). While, the lowest value of concrete radium equivalent (30.210 Bq/kg) was at concrete manufactured by using gravel and 350 Kg/m$^3$ cement content. Also, it can be noticed that the lowest value of radon exhalation rate is for concrete manufactured by using dolomite and 450 kg/m$^3$ cement content (1.244 Bq m$^{-2}$ h$^{-1}$). These results are an indication that the gamma rays and radon gas emitted from concrete that manufactured using granite are the highest values relative to concrete manufactured of gravel, limestone and dolomite.

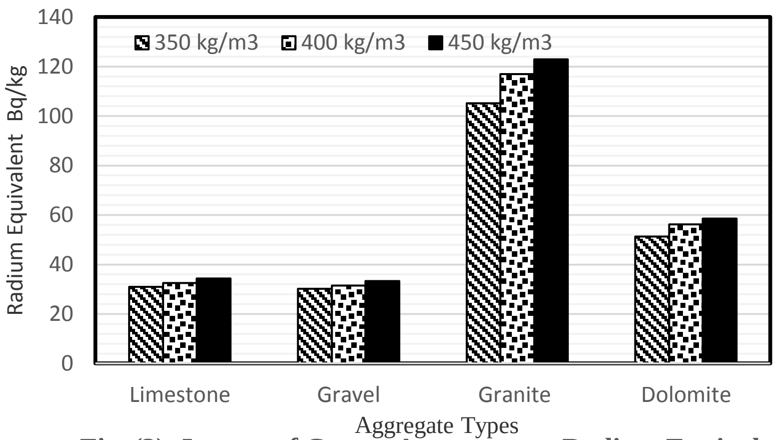


**Fig. (3): Impact of Coarse Aggregate on Radium Equivalent of Concrete**

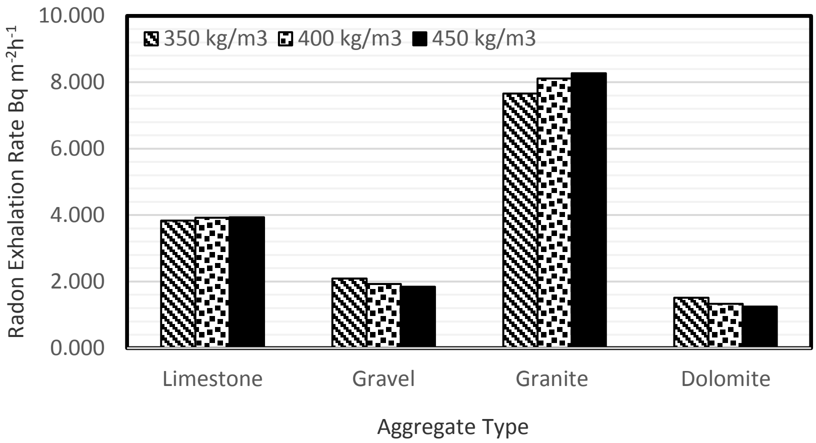


**Fig. (4 ): Impact of Coarse Aggregate on Radon Exhalation Rate of Concrete**

Despite the high values of radium equivalent in granite (Table 1) granite concrete (Table 5), they are still lower than the maximum levels of $Ra_{eq}$ for building materials to be used in dwellings (370 Bq/kg) [4]. It is obvious that, radium equivalent values in concrete using gravel, limestone and dolomite are much less than the maximum level.

## 4. Estimation of Indoor Radon Concentration and Radon Doses

An extensive theoretical study was performed on a virtualized domestic room built and decorated using the studied materials. Radon exhalation rate of building and finishing material as well as the ANN predicted radon exhalation rates of concrete using granite as a coarse aggregate and cement content 450 kg/$m^3$ to get the worst case of radioactive concrete in this study (Table 5) were utilized to estimate radon concentration inside virtualized domestic room. The following assumptions have been applied to the virtualized room:

- The room is in the second floor in order to exclude the possibilities of radon penetration from the soil into the building through foundation.
- The dimensions of the room are 4×4×2.75m
- The room has one door its dimensions 0.90×2.1m and one window its dimensions 1×1.4m
- The room has four 0.3 × 0.3m columns
- Walls net area is 37.41 $m^2$.

The estimation of indoor radon concentration in a room due to radon exhalation rates from building materials could be calculated by equation (3), [18].

$$C_{Rn}\ (Bq/m^3) = \frac{Ex \times A}{V\ (\lambda Rn + \lambda v)} \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where,

$E_x$ = Surface exhalation rate of building and decoration Materials (Bq $m^{-2}$ $h^{-1}$).
A = Area of exhalation rate surface ($m^2$).
V = Volume of the room ($m^3$).
$\lambda_{Rn}$ = Decay constant of radon gas ($h^{-1}$).
$\lambda_v$ = Ventilation rate (circulations/hour).

To apply equation (1) some assumptions were set [19]:

1. Radon gas is homogeneously mixed with room air
2. Minor sources of radon such as water and natural gas are negligible.
3. Radioactive equilibrium state. In which equilibrium between the $^{222}Rn$ gains (exhalation from walls, ceiling and floor) and loss (ventilation and $^{222}Rn$ decay) is assumed to be achieved.
4. Radon decay constant $\lambda_{Rn}$ is 0.00755 ($h^{-1}$).
5. Ventilation rate $\lambda_v$ is 0.5 ($h^{-1}$).

Annual absorbed dose (D) and annual effective dose ($H_E$) were calculated according to equation (4) and (5) respectively [4].

$$D\ (mSv/y) = C_{Rn} \times D_f \times H \times F \times T \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where, $C_{Rn}$ is the indoor radon activity concentration, $D_f$ is the dose conversion factor ($9 \times 10^{-6}$ $mSvh^{-1}$ per Bq/$m^3$), H is the indoor occupancy factor (0.4), F is the indoor equilibrium factor between radon and its progeny (0.4) and T is the indoor exposure time in h/y (≈ 7013

$$H_E\ (mSv/y) = D \times W_R \times W_T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where D is the annual absorbed dose, $W_R$ is radiation weighing factor for alpha particles [20] and $W_T$ is tissue weighing factor for lungs (0.12).

In this study, eight room construction models were assumed. These models differ on its wall and floor construction material. Otherwise, ceiling and columns are assumed to be constructed with granite concrete ($C_{11}$) to get the worst case of radioactive concrete in this study. Table (6) displays the eight assumed models.

**Table (6): Construction Models for the Virtualized Room**

| Model | Walls | Ceilings & Column | Floor |
|---|---|---|---|
| **1** | Cement Bricks | Concrete ($C_{11}$) | Marble |
| **2** | Cement Bricks | Concrete ($C_{11}$) | Granite |
| **3** | Cement Bricks | Concrete ($C_{11}$) | Ceramic |
| **4** | Cement Bricks | Concrete ($C_{11}$) | Porcelain |
| **5** | Clay Bricks | Concrete ($C_{11}$) | Marble |
| **6** | Clay Bricks | Concrete ($C_{11}$) | Granite |
| **7** | Clay Bricks | Concrete ($C_{11}$) | Ceramic |
| **8** | Clay Bricks | Concrete ($C_{11}$) | Porcelain |

The calculated radon activity concentrations inside the virtualized room are found to be ranged from 47.638 Bq/m$^3$ to 50.889 Bq/m$^3$ as illustrated in Table 7. The values of annual absorbed dose and annual effective dose are ranged from 0.514 to 0.481 mSv/y and from 1.234 to 1.155 mSv/y, respectively. The maximum radon concentration, annual absorbed dose and annual effective dose are observed at concrete model 6.

**Table (7): Indoor Radon Concentration and Radon Doses**

| Model | $C_{Rn}$ Bq/m$^3$ | D mSv/y | HE mSv/y |
|---|---|---|---|
| **1** | 50.459 | 0.510 | 1.223 |
| **2** | 50.714 | 0.512 | 1.229 |
| **3** | 47.638 | 0.481 | 1.155 |
| **4** | 48.087 | 0.486 | 1.165 |
| **5** | 50.643 | 0.511 | 1.227 |
| **6** | 50.899 | 0.514 | 1.234 |
| **7** | 47.822 | 0.483 | 1.159 |
| **8** | 48.271 | 0.487 | 1.170 |

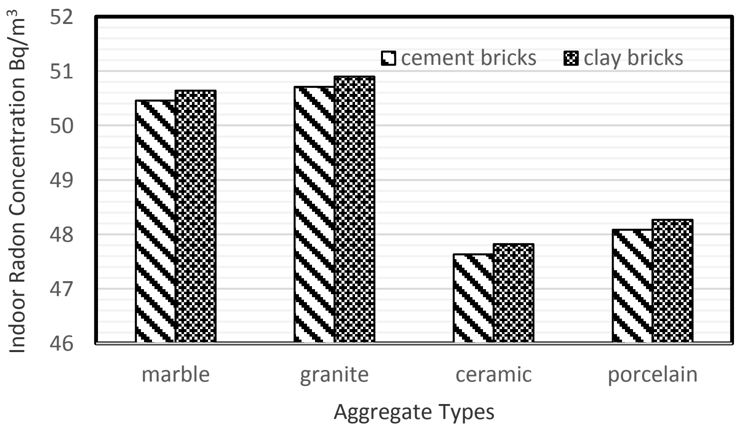


**Fig. (5): Effect of Flooring and Wall Material on Indoor Radon Concentration**

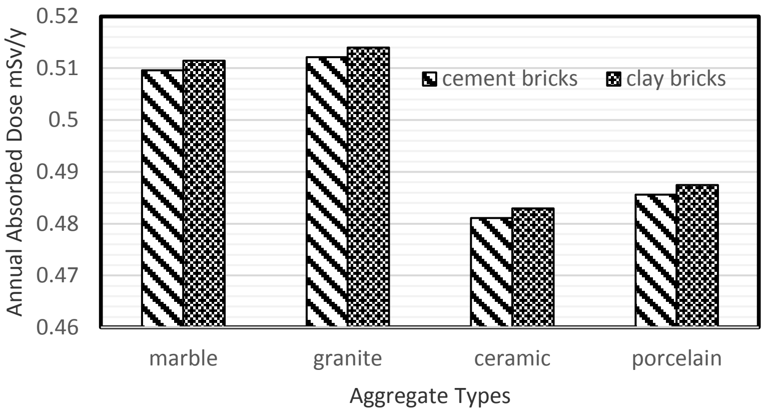


**Fig. (6 ): Effect of Flooring and Wall Material on Annual Absorbed Dose**

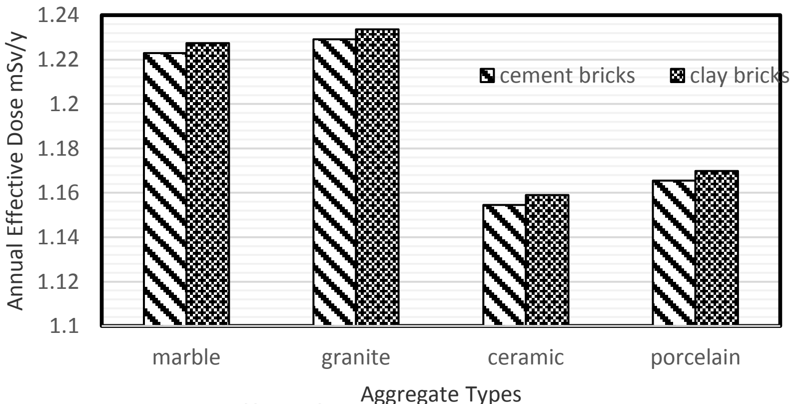


**Fig. (7): Effect of Flooring and Wall Material on Annual Effective Dose**

## 5. Conclusion and Recommendations

The results of the present research led to the following conclusions:

- It has been observed that granite has the higher values of radium equivalent and radon exhalation rate relative to limestone, gravel and dolomite. Hence, these high values indicate high emission rate of radon gas and gamma ray. Nevertheless, granite radium equivalent value $Ra_{eq}$ (240 Bq/kg) is less than the recommended value (370 Bq/kg).
- The maximum values of radium equivalent and radon exhalation rate is observed at concrete manufactured by using granite and 450 kg/m$^3$. Consequently, the utilization of granite in construction and decoration purposes should be minimized.
- The lowest value of concrete radium equivalent (30.21 Bq/kg) was at concrete manufactured by using gravel whereas; the lowest value of radon exhalation rate is for concrete manufactured by using dolomite (1.244 Bq m$^{-2}$h$^{-1}$).
- All calculated values of radon concentration are greater than the worldwide median value (46 Bq/m$^3$) [3]. On the other hand, the maximum radon concentration (50.889 Bq/m$^3$) is below the level allowed by the World Health

Organization (100 Bq/m$^3$) [1]. Also, it is much less than the reference level for homes (300 Bq/m$^3$) recommended by [20], (2014).

- All the estimated values of radon concentration inside the virtualized room are approaching the values measured by Abd El-Zaher, *et al*. [21] in which the mean values of radon concentration in bedrooms and living rooms were 63.75 and 50.93 Bq/m$^3$, respectively. Also, they are approaching the values measured by Abdel Ghany [22] in which the mean values of radon concentration in bedrooms and living rooms were 53.18 and 50.98 Bq/m$^3$, respectively.
- The estimated annual effective doses are less than the lower limit of the recommended action level (3-10 mSv/y) [20].
- Using cement bricks instead of clay bricks lead to a slight reduction in radon concentration, annual absorbed dose and annual effective dose. So, other benefits from using each type should be studied.
- Using granite as coarse aggregate in concrete manufacturing with granite and marble as flooring material leads to increased radon concentration.
- There is a necessity for more detailed studies related to this subject in order to provide information about the effect of mineral admixtures, fine aggregate, cement and water on natural radioactivity of concrete used in Egypt.
- Also, there is a necessity to establish regularly data base about different concrete mixes and radionuclides content in all building materials used in Egypt. This data base can enhance the development of artificial neural network (ANN) model to predict the natural radioactivity of concrete mixes with high accuracy before the construction process. The completion of the construction process should be followed by periodically field measurements for radon concentration to enhance the implementation of ANN model to predict indoor radon concentration associated to each construction material to control natural radiation exposure for the residents of dwelling.

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