EVALUATION OF THE GAMMA DOSE RATE INSIDE EGYPTIAN BUILDINGS UTILIZING THEORETICAL AND EXPERIMENTAL TECHNIQUES

by

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The indoor low gamma dose rate exposures due to Egyptian room building materials are assessed by means of three different techniques: experimentally by using a thermoluminescent dosimeter, theoretically by using the general room model and by the Monte Carlo simulation through the RESRAD-BUILD software. The present study aims at validating the theoretical methods so that it can be amply used for measuring the low dose rates usually associated with the building materials. The measured indoor dose rates were in the range of 55.92 14.47 to 86.89 16.68 nGyh^{-1} depending on the position inside the room as obtained by the thermoluminescent dosimeter after 5 months' accumulation. Lower dose rates are obtained near the door and windows while higher dose rates are obtained at the center of the room, and close to the extended walls. Comparable results of the dose rates at same positions inside the room are obtained by the RESRAD-BUILD software. The room model is restricted to the room center and also gives comparable results. The three methods showed comparable results, which in turn confirm the recommendation of using theoretical ones, with RESRAD-BUILD software being more accurate.

Key words: dose rate, Egyptian building material, room model, RESRAD-BUILD software, TLD dosimeter

INTRODUCTION

Ionizing radiations in the environment originated from a variety of sources, both natural and artificial. Measurement of the gamma dose rate in air is essential to identify the background levels, exposure and the risk to the public [1]. Gamma spectrometers (GS), thermoluminescent dosimeters (TLD), and portable survey meters (PSM) are three different techniques commonly used for monitoring the background gamma dose rate [2-4].

The GS technique is widely applied by collecting the samples and measuring the gamma rays emitted, analyzing the obtained spectrum and determining the radionuclide activity concentrations and then calculating the dose rate from the well-known Beck formula [5, 6]. In case of the building material, it is difficult to have a representative sample of the whole room; instead, mixed samples are used. The represented dose rate in air is usually estimated at one meter above the floor, assuming that the radiation is emitted from uniformly distributed natural radioactivity down to a 5 cm depth; and that both the U-series, and Th-series are in a state of secular equilibrium [7]. The TLD technique is widely used for environmental gamma dose rate monitoring, and also for dosimetry applications. High sensitivity is required to detect doses as low as 1 mGy and as high as 1 Gy with good linear and energy response characteristics [8-10].

A survey of gamma exposure in dwellings can been performed using TLD [11, 12]. The most commonly used TLD materials are LiF doped with Mg, Cu, or P; Ti, CaF_2 doped with Dy, and $CaSO_4$ doped with Dy. These TLD can accumulate radiation energy over exposure time and with the effect of heating, the absorbed radiation energy is released as a visible light. The integrated intensity of the emitted light is proportional to the exposure dose. Therefore, the cumulative gamma dose over a period of time can be estimated from the measured integrated thermoluminescence intensity. This can be considered more representative within the time interval with more meanings than the instant time values measured by PSM or area monitors [8, 11, 12].

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Several models have been introduced in the last 20 years to predict exposure of the population to the gamma dose due to natural radioactivity content in building materials [13-19]. Starting from the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in the building materials, models have been developed to make it possible to calculate the absorbed dose rate in air due to gamma radiation. Radioactive equilibrium is the main assumption for all these models; although, it is well known that radon and thoron escape from the walls, so that no real equilibrium in the natural series exists. In particular, it was evaluated that overestimation by models reaches up to 20 % in the case of strong radon exhalation [14, 20, 21]. Also, it was observed that the effect of changing the position and dimensions of the room causes low variability of the specific dose rate; while high variability with wall thickness and density are obtained [16]. All these effects in addition to the existence of doors and windows are recognized [15].

The RESRAD-BUILD is part of the RESRAD family of codes, which have been developed at the Argonne National Laboratory in order to investigate the likely impact to humans and biota due to radiation exposures from residual radioactive materials. The RESRAD-BUILD computer code has been built to simulate the dose received by an individual who works or lives in a building contaminated with radioactive material [22]. The external exposure calculations in RESRAD-BUILD are based on the dose conversion factors obtained from the US Federal Guidance Report-12 [23]. These factors are corrected considering the thicknesses, densities and the finite area of volume sources. The point-kernel method is used to derive the area and material factor [24].

The aim of the present study is to compare the three different techniques: experimental using TLD and theoretical techniques using the general room model and the Monte Charlo simulation through the RESRAD-BUILD software. This intercomparison is aimed at validating the theoretical methods as a rapid and reliable technique for evaluating the indoor gamma dose rate exposure due the Egyptian room building materials.

MATERIALS AND METHODS

Room geometry

The geometrical dimensions of the studied room are shown in fig. 1. This room has only one window and one side door. The room dimensions are 250 cm 320 cm 400 cm. All room walls,; including the floor and ceiling, had fixed thickness of 20 cm. The room floor and ceiling are constructed from concrete while the walls have some parts from concrete and other parts from red clay bricks. The space containing the window is completely covered with glass and has no building materials. The sequence of the Cartesian axis is taken from the smallest to the largest dimension.

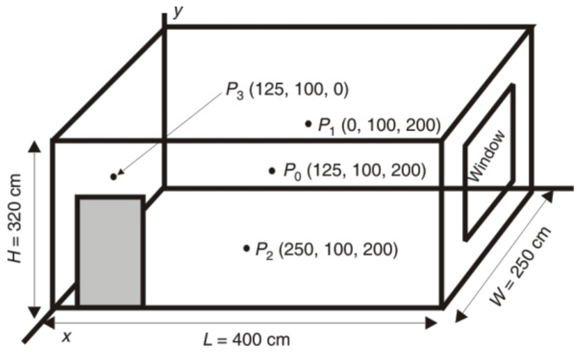

Figure 1. Study room dimensions and TLD measuring positions

Dose conversion factor calculation

The absorbed gamma dose rate, D, due to the natural radionuclides in building material, in air at the center of a room with geometrical dimensions x, y, z is given as [25]

$$D \quad q_{\mathrm{U}} A_{\mathrm{U}} \quad q_{\mathrm{Th}} A_{\mathrm{Th}} \quad q_{\mathrm{K}} A_{\mathrm{K}} \tag{1}$$

where A_{U}, A_{Th}, and A_{K} are the activity concentrations of the natural series ^{238}U, ^{232}Th, and ^{40}K, respectively, in Bqkg^{-1}, and q_{U}, q_{Th}, and q_{K} are its dose conversion factors (nGyh^{-1} per Bqkg^{-1}).

Taking the dimensions x, y, and z in the sequence of increasing values where x is the smallest and z is the largest one, the dose rate conversion factor is written as

$$\begin{aligned} q \quad d \quad a_1 x \quad a_2 x^2 \quad a_3 x^3 \quad b_1 y \\ b_2 y^2 \quad b_3 y^3 \quad c_1 z \quad c_2 z^2 \quad c_3 z^3 \end{aligned} \tag{2}$$

where x, y, and z have to be expressed in centimeters to obtain q in pGyh^{-1} (Bqkg^{-1})$^{-1}$. The values of 10 fitting parameters for q_{U}, q_{Th}, and q_{K}, given with six significant digits, are listed in tab. 1.

Table 1. The values of the fitting parameters in the fitting eq. (2)

Fitting parameter	Fitting parameter value [nGyh^{-1} per Bqkg^{-1}]		
	q_{U}	q_{Th}	q_{K}
d	690.299	816.252	61.4686
a_1	–0.482268	–0.603099	–0.0477798
a_2	1.00018 10^{-3}	1.20942 10^{-3}	9.0054 10^{-5}
a_3	–7.41711 10^{-7}	–8.76598 10^{-7}	–5.8282 10^{-8}
b_1	0.553443	0.764372	0.0750573
b_2	–1.10782 10^{-3}	–1.559157 10^{-3}	–1.57251 10^{-4}
b_3	7.45542 10^{-7}	1.12854 10^{-6}	1.10926 10^{-7}
c_1	0.169166	0.241437	0.0127244
c_2	–1.87233 10^{-4}	–2.7921 10^{-4}	–1.09355 10^{-5}
c_3	9.79737 10^{-8}	1.40905 10^{-7}	5.25216 10^{-9}

Table 2. Average content and specific activity of ^{238}U, ^{232}Th, and ^{40}K using ICP-MS [26]

Sample type	Specific activities [$Bqkg^{-1}$]					
	^{238}U		^{232}Th		^{40}K	
Red clay brick	32.59	0.37	34.28	0.45	316.19	2.63
Concrete	32.35	0.49	25.34	0.12	289.40	2.36
Average	32.47	0.17	29.81	6.32	302.80	18.94

Building material radioactivity concentration

The building material of the whole room is not homogenous. Therefore, it is impossible to measure the radioactivity concentrations of a sample which represents the building material. In the current study, most building materials of the studiedy room were concrete and red clay bricks. The average radioactivity concentration of these two components is the best representative for the building material radioactivity as shown in tab. 2.

Dose rate in air *vs*. the position in the room

The variability of the dose rate in air at a 1 m height by moving from the center of the room towards the walls can be estimated based on Markkanen's room model and assumptions. The calculated dose rate decreases with increasing the distance from the longer walls; up to a distance of 1 m. The increase from the center falls within 9.3 % and 17.3 % at 0.5 m. The room model is applied to the room shown in fig. 1. The variation of the dose rate in air, in relation to the position in the room is then determined. It is proved that there is a significant variation corresponding to building composition (18 %) *i. e*., the number of windows and doors, position inside the room (17 %) and density of the building materials (up to 32 %) [15].

Using RESRAD-BUILD software implies that, the receptors positions inside the study room and the room dimensions should be determined. The selected positions which are the same positions of measurements as shown in fig. 1 and the model realization for the room are shown in fig. 2.

The absorbed gamma dose rate measurement using TLD

Commercial LiF: Mg, Ti (TLD-700) chip thermoluminescent phosphors from Harshaw are used to measure the absorbed dose rate inside the study room with five thermoluminescent chips stacked for five months in each position. The dosimeters are high sensitivity tissue equivalent ones. The TLD batch homogeneity (maximum deviation measurements from

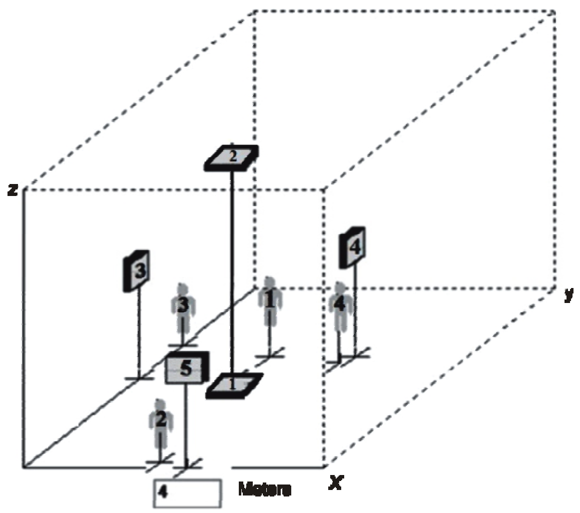

Figure 2. Room model in RESRAD-BUILD

minimum to maximum for the same irradiation dose) was less than 5 %, with reproducibility of 3 %.

The dosimetric properties such as dose calibration factor (linearity of response), fig. 3, and fading characteristics (2 % over five months) of the used TLD are determined. The irradiation of the used TLD is performed by using 37 10^{12} Bq of a well calibrated Cs^{137} source – model GB150, manufactured by Atomic Energy of Canada in 1970. This source is available at Egypt's National Institute of Standards (NIS). The irradiation dose rate was 936 μGy/h at the time of the TLD irradiation. Reading of the used TLD phosphors is achieved by using the Harshaw – 3500 TLD-reader (Thermo Scientific USA) available in NIS. The read out temperature range was from 50-300 °C at 2 $°Cs^{-1}$ of the heating rate.

Different sensitivity corrections and background subtraction for TL-700 chips are considered for these sensitive environmental measurements due to the long measuring time and the ambient factors (temperature, humidity and UV light). The average temperature at the time of measurements was 24 °C

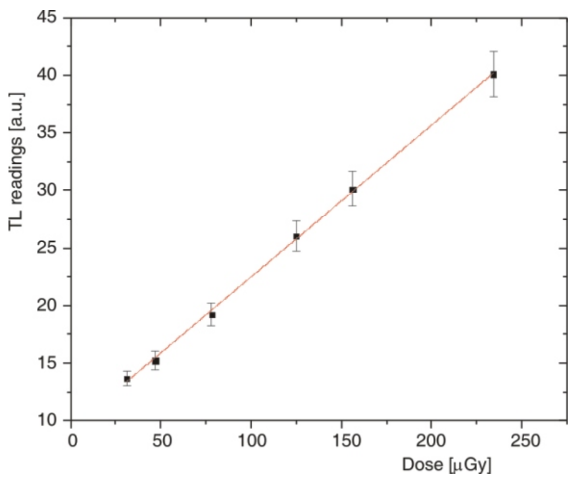

Figure 3. The TLD-700 calibration curve

and the mean relative humidity was less than 30 %. Also, all used phosphors are stored in good dark plastic envelopes which are prepared for such environmental measurements.

Thermoluminescence measurements are performed at specific points inside the room as indicated in fig. 1. Twenty annealed dosimeters were used and divided into four groups, each of 5 stacked phosphors being fixed at each position for five months. Taking into account the thermal fading during this long period of measurements, the obtained results are corrected against the thermal fading.

RESULTS AND DISCUSSION

The study room dimensions and the dose rate conversion factors are shown in tab. 3.

The measured and calculated absorbed dose rate at the selected positions inside the studied room and the corresponding annual effective dose rates, *E*, calculated according to the following formula [1], are shown in tab. 4.

$$E(\text{Svy}^{\ 1}) \quad D(\text{Gyh}^{\ 1})\ 8760\,\text{hy}^{\ 1}\ \ 0.8\ 0.7\ \text{SvGy}^{\ 1} \tag{3}$$

The calculated dose rates and the corresponding effective dose by the analytical room model are comparable and acting within the range of the measured values by the TLD technique. The large uncertainty in the TLD measurements is expected due to the small environmental dose rate.

As a consequence, the value of the indoor absorbed dose rate at the center of the room is 72.12 nGyh^{-1} is consistent with the world average value (70 nGyh^{-1}) [27, 28]. The percentage variation in the absorbed dose rate due to the position is up to about 20 %. The effective dose rates *et all* points are below the permissible dose rate.

Table 3. Dose conversion factor of the study room

Room dimensions [cm]	Dose rate conversion factors [nGyh^{-1} per Bqkg^{-1}]		
	q_U	q_{Th}	q_K
250 320 400	0.753	0.907	0.069

Table 4. The measured and calculated absorbed dose rate and effective dose

Position	Dose rate *D* [nGyh^{-1}]		
	RESRAD-BUILD	TLD	Room model
P_0 (125, 100, 200)	71.58	86.89 16.68	72.12
P_1 (0, 100, 200)	68.95	85.44 15.04	–
P_2 (250, 100, 200)	62.21	59.11 14.95	–
P_3 (125, 100, 0)	61.99	55.92 14.47	–
Average	65.09 7.37	71.84 16.60	72.12

The obtained results of the effective dose rate by the RESRAD-Build code depends on the building material radioactivity concentrations, the position inside the room (receptor) and the room air ventilation rate. The used ventilation rate for the above results is 4 h^{-1} which is the common natural ventilation for most buildings. This means the use of this code is restricted to the previous determination of the ventilation rate. The room model is able to calculate the dose rate at the center of the room only while the other points can be predicted based on its distance from the large wall and the position with respect to the room door and windows [15].

CONCLUSION

The general dimensional room model can be used as a rapid calculation method to predict the gamma dose rate at the center of dwelling rooms. The calculated values are close to those obtained by measurements for long exposure time (about five months) by using the conventional TLD-700. Regarding other points inside the room, the room model can also predict the reading based on its distance from the large wall and how close this point is to the room windows and door. The RESRAD-Build code is a successful simulation code for determining the average dose at any position inside the room on the assumption that, the radioactivity concentration in the building material is known and the room dimensions are fixed. Moreover, radon emanation can be involved and the ventilation rate can be controlled to obtain the full dose or dose rate for various room dimensions. The experimental work of the present study proved that radiation safety assessment in dwellings can be reliably and rapidly predicted utilizing the RESRAD-Build code even before construction, assuming the building material related properties are known.

AUTHORS' CONTRIBUTIONS

The idea for this research work was initiated by E. Salama. Measurements and computations were carried out by E. Salama and H. A. Soliman. Also, both authors analyzed and discussed the results.

REFERENCES

[1] ***, UNSCEAR, Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes. Vol. I, UNSCEAR 2000 Report, 2000

[2] Huang, Y. J., *et al*., A Comparative Study of Terrestrial Gamma Dose Rate in Air Measured by Thermoluminescent Dosimeter, Portable Survey Meter and HPGe Gamma Spectrometer, *J. Environ. Radioact., 164* (2016), Nov., pp. 13-18

[3] Bakshi, A. K., *et al*., Measurements of Background Radiation Levels Around Indian Station Bharati, During 33rd Indian Scientific Expedition to Antarctica, *J. Environ. Radioact., 167* (2017), Feb., pp. 54-61
[4] Shetty, P. K., Narayana, Y., Variation of Radiation Level and Radionuclide Enrichment in High Background Area, *J. Environ. Radioact., 101* (2010), 12, pp. 1043-1047
[5] Huang, Y. J., *et al*., Natural Radioactivity and Radiological Hazards Assessment of Bone-Coal from a Vanadium Mine in Central China, *Radiat. Phys. Chem., 107* (2015), Feb., pp. 82-88
[6] Karahan, G., Bayulken, A., Assessment of Gamma Dose Rates Around Istanbul (Turkey), *J. Environ. Radioact., 47* (2000), 2, pp. 213-221
[7] Beck, H. L., *et al*., In Situ Ge(Li) and Nal (Tl) Gamma-Ray Spectrometry, Report HASL-258, Health and Safety Laboratory, USAEC, New York, USA, 1972
[8] Benkrid, M., *et al*., Environmental Gamma Radiation Monitoring by Means of TLD and Ionization Chamber, *Radiat. Prot. Dosim., 45* (1992), Dec., pp. 77-80
[9] Olko, P., Advantages and Disadvantages of Luminescence Dosimetry, *Radiat. Meas., 45* (2010), Mar.,-July, pp. 506-511
[10] Ranogajec-Komor, M., *et al*., Characterization of Radiophotoluminescent Dosimeters for Environmental Monitoring, *Radiat. Meas., 43* (2008), Feb.-June, pp. 392-396
[11] Lee, J. S., *et al*., Evaluation of External Dose Equivalent with Thermoluminescent Dosimeters from Residents Living in Radiation-Contaminated Buildings, *Appl. Radiat. Isot., 48* (1997), Sept., pp. 1237-1243
[12] Quarto, M., *et al*., Gamma Dose Rate Measurements in Dwellings of Campania Region, South Italy, *J. Environ. Radioact., 115* (2013), Jan., pp. 114-117
[13] De Jong, P., Van Dijk, W., Modeling Gamma Radiation Dose in Dwellings Due to Building Materials, *Health Phys., 94* (2008), 1, pp. 33-42
[14] Stranden, E., Radioactivity of Building Materials and the Gamma Radiation in Dwellings, *Phys. Med. Biol., 24* (1979), 5, pp. 921-930
[15] Risica, S., *et al*., Radioactivity in Building Materials: Room Model Analysis and Experimental Methods, *Sci. Total. Environ., 272* (2001), May, pp. 119-126
[16] Koblinger, L., Calculation of Exposure Rates from Gamma Sources in Walls of Dwelling Rooms, *Health Phys., 34* (1978), 5, pp. 459-463
[17] Maduar, M. F., Hiromoto, G., Evaluation of Indoor Gamma Radiation Dose in Dwellings, *Radiat. Prot. Dosim., 111* (2004), 2, pp. 221-228
[18] Haber, D. A., *et al*., Modeling Background Radiation in Southern Nevada, *J. Environ. Radioact., 171* (2017), May, pp. 41-64
[19] Nikolić, M. D., *et al*., Modelling Radiation Exposure in Homes from Siporex Blocks by Using Exhalation Rates of Radon, *Nucl Technol Radiat, 30* (2015), 4, pp. 301-305
[20] Chauhan, R. P., *et al*., Distribution of Indoor Thoron in Dwellings Under Normal and Turbulent Flow Conditions Using CFD Simulation Technique, *Nucl Technol Radiat, 32* (2017), 2, pp. 180-184
[21] Abdalla, A. M., El-Gamal, S., Measurement of Indoor Radon Concentrations in Different Dwellings in Arar, Saudi Arabia, *Nucl Technol Radiat, 33* (2018), 3, pp. 293-300
[22] Yu, C., *et al*., User's Manual RESRAD-BUILD Version 3, 2003
[23] Eckerman, K. F., Ryman, J. C., Federal Guidance Report No. 12 External Exposure to Radionuclides in Air, Water, and Soil, US Environmental Protection Agency, 1993, 12, pp. 192
[24] Kamboj, S., *et al*., External Exposure Model in the RESRAD Computer Code, *Health Phys, 82* (2002), 6, pp. 831-839
[25] Manić, V., *et al*., Calculation of Dose Rate Conversion Factors for ^{238}U, ^{232}Th, and ^{40}K in Concrete Structures of Various Dimensions, with Application to Niš, Serbia, *Radiat. Prot. Dosim., 152* (2012), 4, pp. 361-368
[26] Moharram, B. M., *et al*., ^{238}U, ^{232}Th Content and Radon Exhalation Rate in Some Egyptian Building Materials, *Ann. Nucl. Energy, 45* (2012), July, pp. 138-143
[27] ***, UNSCEAR, Sources and Effects of Ionizing Radiation, UNSCEAR 2008 Report to the General Assembly with Scientific Annexes Volume 1, 2008
[28] Arvela, H., Population Distribution of Doses from Natural Radiation in Finland, *Int. Congr. Ser., 1225* (2002), Feb., pp. 9-14

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ОЦЕНА ЈАЧИНЕ ГАМА ДОЗЕ У ЕГИПАТСКИМ ЗГРАДАМА ПОМОЋУ ТЕОРЕТСКИХ И ЕКСПЕРИМЕНТАЛНИХ ТЕХНИКА

Излагања ниским јачинама гама доза у затвореним просторима, услед грађевинских материјала који се употребљавају у Египту, оцењено је помоћу три технике: експериментално – коришћењем термолуминисценције термолуминисцентних дозиметара, теоретски – коришћењем општег модела собе и Монте Карло симулацијом – помоћу RESRAD-BUILD програмског пакета. Ова студија има за циљ да потврди теоретске методе како би се могле користити за мерење ниских доза које се обично повезују са грађевинским материјалом. Измерене јачине унутрашње дозе биле су у опсегу од 55.92 14.47 до 86.89 16.68 nGyh^{-1}, у зависности од положаја унутар просторије, добијених термолуминисценцијом термолуминисцентног дозсиметра након 5 месеци акумулације. Ниже јачине дозе добијене су у близини врата и прозора, док се веће јачине дозе добијају у центру просторије и близу проширених зидова. Упоредиве резултате јачине дозе на истим положајима унутар просторије даје RESRAD-BUILD програмски пакет. Модел просторије је ограничен на центар собе и даје такође упоредиве резултате. Три методе показале су упоредиве резултате, што је потврдило препоруку да се користе теоретски модели, при чему је RESRAD-BUILD софтвер био тачнији.

Кључне речи: јачина дозе, египатски грађевински материјал, модел собе, RESRAD-BUILD програм, TLD дозиметар
