International Journal of Physics, 2016, Vol. 4, No. 6, 146-151
Available online at http://pubs.sciepub.com/ijp/4/6/1

DOI:10.12691/ijp-4-6-1

Science & Education Publishing

Measurement of Radon Exhalation Rate from Destroyed Building Material in the Gaza Strip

M.O. El-Ghossain*

Department of Physics, The Islamic University of Gaza, Gaza, Palestine
*Corresponding author: ghossain@iugaza.edu.ps

Abstract Building materials are one of the potential sources of indoor radioactivity because of the naturally occurring radionuclides in them. Radon exhalation rate is one of the most important factors for evaluation of the environmental radon level. Radon contributes more than half of the total ionizing radiation dose Indoor radon has been recognized as one of the health hazards for mankind because long-term exposure to radon increases the risk of developing lung cancer. This study aims at assessing the contribution of destroyed building materials in war 2014 towards the total indoor radon exposure to the inhabitants of in Gaza. 40 Samples have been collected from common destroyed building materials in Jabalia district. The closed-can technique has been employed in this study using solid state nuclear track detectors (CR-39). After 124 days of exposure to radon, CR-39 detectors were etched chemically by (6 N) NaOH solution at 75°C for three months and then counted under an optical microscope. Results obtained from the current study show that radon exhalation rates from concrete and asbestos have relatively high values as compared to other building materials while glass, marble and a red brick contribute less to radon exhalation rate. The average radon exhalation rate in term of area in the studied samples ranged from (86.506) mBq.m^{-2}.h^{-1} for glass samples to (469.017) mBq.m^{-2}.h^{-1} for Concrete samples. In general, the annual effective doses from the investigated building materials are low and under the global value (from 1 to 5 mSv/y) except for Concrete and asbestos samples with average values (9.464) and (9.3528) mSv/y, respectively.

Keywords: *radon, CR39, calibration, building materials*

Cite This Article: M.O. El-Ghossain, “Measurement of Radon Exhalation Rate from Destroyed Building Material in the Gaza Strip.” *International Journal of Physics*, vol. 4, no. 6 (2016): 146-151. doi: 10.12691/ijp-4-6-1.

1. Introduction

All building materials contain various amounts of main natural radionuclides of the uranium (^{238}U) and thorium (^{232}Th) series, and since those radionuclides are sources of Radon gas then the knowledge of the natural radioactivity of building materials is important for the determination of population exposure to radiations. For the aforementioned reasons we intend to study the concentration of Radon and the exhalation rate from destroyed building materials in the 2014 war used in the districts of Jabalia in the northern Gaza Strip [1,2,3,4,5]. It will then be compared to results obtained with the results of previous studies. Then we will study the health risks of radon gas.

In this study, we present our data concerning measurement of the radon exhalation rate from destroyed building material samples collected from Jabalia district in the Gaza strip in Palestine using close vessel technique. The location of this district is shown in Figure 1. Houses in this district are mainly constructed from soil, bricks, cement, sand, granite and marble. This district is located in the northern part of the Gaza strip of Palestine.

This study was done during the month of March to July 2015, which includes the following main stages, where the samples are collected from destroyed building materials.

The purpose of this study is to measure the Radon exhalation rates from destroyed building materials during 2014 war against Gaza, Palestine. Our study will include samples of a red brick, marble, ceramic, concrete, tiles, asbestos, glass and building stones from different origins used in the mentioned area of study.

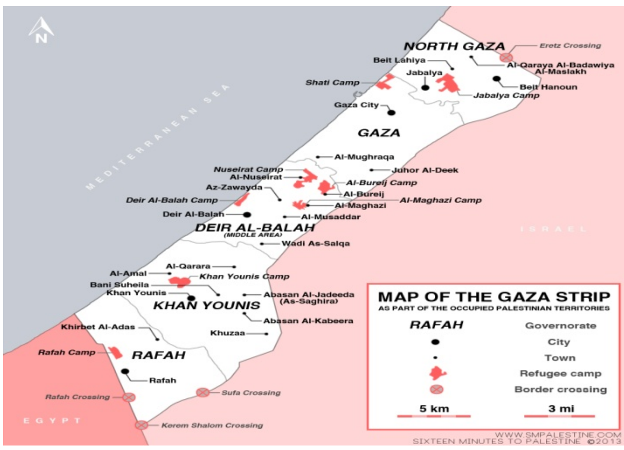

Figure 1. The figure shows the map of the Gaza strip

In a previous studies, in Egypt, a study on ^{222}Rn exhalation rate from Egyptian building materials was performed in 2009 and found that the radon exhalation rate in the studied samples ranged from (2.2 x 104 ± 7.2 x102) µBq m^{-2} s^{-1}, for granite sample, to (3.4x101 ± 9.0x100) µBqm^{-2} s^{-1}, for portland cement with an average value (1.8x103 ± 6.5x101) µBq m^{-2} s^{-1} [6]. In Nablus district, Palestine, They measured Radon exhalation rates from granite and marble have relatively high values as compared to other building materials followed- in order- by cement, ceramic, concrete, building stones, and porcelain, while gypsum, sand, gravel and bricks contribute less to radon exhalation rate which was found to range from (55.37 ± 15.01) mBq/m^2h for gypsum samples to (589.54 ± 73.24) mBq/m^2h for granite samples, with a total average value of (268.56 ± 166.21) mBq/m^2h. The corresponding radon concentration, effective radium content, and annual effective dose average values were (148.49 ± 91.13) Bq/m^3, (1.93 ± 1.20) Bq/Kg and (3.74 ± 2.30) mSv/y [7].

2. Materials and Experimental Methods

Different samples of destroyed building materials after the 2014 war against Gaza were collected randomly from different destroyed buildings, like, houses, commercial companies, and factories, all around the area of study during the month of March to July. Samples were a red brick, marble, ceramic, concrete, tiles asbestos, glass and building stones, samples were from different origins, used in construction of building in Jabalia district, Gaza Strip, Palestine. Samples were then identified and given a number and an identifying symbol which identify the location of the samples, as in Table 1. 5 kg from each sample were collected and dried in a temperature controlled furnace (oven) at a temperature100°C for two hours to ensure that moisture was completely removed. And then the samples were crushed to a fine powder and sieved through a small mesh size to remove the larger grains size and render them more homogenous. The respective net weights of the samples ready for measurement were recorded.

Table 1. List of numbers and codes for samples studied in this research

Sample NO.	Sample code	Type	Sample NO.	Sample code	Type
1	G1	ceramic	21	A1	building stones
2	G2	ceramic	22	A2	building stones
3	G3	ceramic	23	A3	building stones
4	G4	ceramic	24	A4	building stones
5	G5	ceramic	25	A5	building
6	F1	red brick	26	D1	marble
7	F2	red brick	27	D2	marble
8	F3	red brick	28	D3	marble
9	F4	red brick	29	D4	marble
10	F5	red brick	30	D5	marble
11	B1	concrete	31	H1	asbestos
12	B2	concrete	32	H2	asbestos
13	B3	concrete	33	H3	asbestos
14	B4	concrete	34	H4	asbestos
15	B5	concrete	35	H5	asbestos
16	E1	tiles	36	C1	glass
17	E2	tiles	37	C2	glass
18	E3	tiles	38	C3	glass
19	E4	tiles	39	C4	glass
20	E5	tiles	40	C5	glass

The close vessel technique was used in this study “can technique” or we call them “Dosimeters”. Dosimeters are plastic cylindrical vessels of volume (7.93×10^{-4}) m^3 with cross sectional area of ($5.02\times10^{-3}\,m^2$) as shown in figure 2. The destroyed building material samples were put at the bottom of these vessels. About 200 g of each sample was placed in a plastic can of dimensions15.8 cm in height and 8 cm in diameter.

The use of plastic solid-state nuclear track detectors, SSNTDs of type CR-39, which were cut into small pieces, 2cm×2cm and fixed on the top of inner surface of the can, in such a way that its sensitive surface always facing the sample. The can was sealed air tight with adhesive tape and kept for assessment of radon exhalation for exposure evaluation over four months. During the exposure period (one hundred and twenty four days), the detector was exposed freely to the emergent radon from the sample in the can so that it could record alpha particles resulting from the decay of radon in the remaining volume of the can [3,4,5,6,7,8].

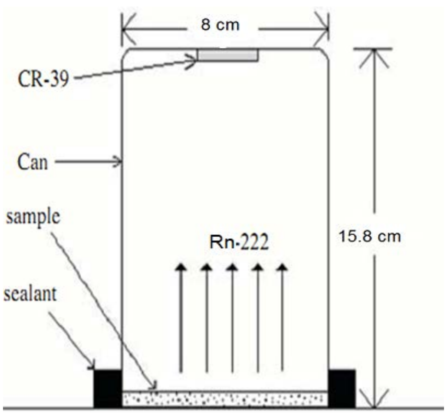

Figure 2. CR-39 set up for Radon Detection

After the mentioned period, forty detectors were taken out of the dosimeters. The detectors were then chemically etched in 6 N-solution of Sodium Hydroxide (Na OH) at a temperature of 70 C for four hours and one third of an hour. The etching process was performed at chemistry Laboratories at An-Islamic University using the setup. In addition, the function of the condenser is to keep the concentration of the Na OH solution constant, and the function of the thermometer is to make sure that the temperature is constant during the whole period of the etching process. After four hours and one third of an hour detectors were washed by running and distilled water and then dried to remove any remaining amount of the etchant from the surface of the detectors. By now alpha tracks formed on the detectors were ready for scanning and counting.

A digital optical microscope with 400 times magnification was used to count the number of tracks per field of view; about ten fields of view were scanned randomly for each detector. Tracks of alpha particles emitted by radon in a CR-39 detector were scanned by the microscope as shown in Figure 3. The area of the field of view was calculated by the digital microscope and found to be equal about 5.3×10^{-3} cm^2 ; the average number of tracks per field of view was used to calculate the track density. The calculated track density was converted into radon concentrations in Bq/m^3 using the calibration factor (k) obtained by the standard manufacturer, where every track per cm^2 per day on the CR-39 detectors corresponds to an exposure of 12.5 Bq/m^3 for the activity of radon gas and its daughters and we use previous calibrations [6,7,8].

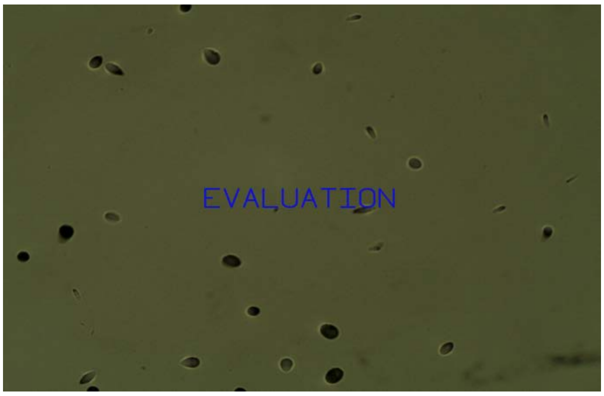

Figure 3. Tracks of alpha particles emitted by radon in a CR-39 detector. One viewing field from the microscope has the area of about 0.53 mm^2

Calculations:

The radon concentrations, radon exhalation rate were calculated using the experimental measured average track densities according to the following relations from previous studies [7,8,9,10].

2.1. Determination Radon Concentration:

$$C_{Rn} = k\frac{\rho}{T_{eff}} \qquad (1)$$

C_{Rn}: is the radon concentration (Bq/m^3)
K: is the calibration factor = 12.5 Bqm^{-3}/tracks $cm^{-2}h^{-1}$.
ρ : Is the track density (tracks/ cm^2)
T_{eff}: effective time = $[t + (e^{-\lambda t} - 1)/\lambda]$
t: exposure time

2.2. Determination Radon Exhalation Rate in Area

The radon exhalation rate (Ex) of any sample is defined as the flux of radon released from the surface of material. The surface exhalation rate in the building material samples was calculated using equation (2), the radon exhalation rate in terms of area (surface exhalation rate) in units of $Bq{\cdot}m^{-2}{\cdot}h^{-1}$ can be obtained by as [8,9,10,11,12].

$$E_x = \frac{CV\lambda}{A[t + (e^{-\lambda t} - 1)/\lambda]} \qquad (2)$$

Where:
C: is the integrated radon exposure ($Bq{\cdot}m^{-3}{\cdot}h$);
V: is the volume of air in the cup (m^3) = $7.942\times10^{-4}m^3$
λ: is the decay constant for Rn^{222} (h^{-1}) = $7.56\times10^{-3}h^{-1}$
A: is the surface area of the sample (m^2) = $5.0265\times10^{-3}m^2$
t: is the exposure time (h) = 124 days = 2976h

2.3. Determination Radon Exhalation Rate in Mass

The mass exhalation rate ($Bqkg^{-1}{\cdot}h^{-1}$) in the building material samples is calculated using the following formula 3:

$$E_M = \frac{CV\lambda}{M[t + (e^{-\lambda t} - 1)/\lambda]} \qquad (3)$$

Where E_M is the mass exhalation rate in ($Bqkg^{-1}{\cdot}h^{-1}$) and M is the mass of sample (kg) [8-15].

2.4. Determination the Annual Effective Dose

The following equation was used to calculate the annual effective dose as in equation 4:

$$\text{Dose} = \epsilon f_{Rn} T_y C_{Rn} \qquad (4)$$

Where:
f_{Rn}: is the conversion factor = 9 nSv / (Bq h m-3).
T_y: is the time spent indoors per year = 7000 hours
□: is the equilibrium factor (= 0.4)
C_{Rn} : is the radon concentration.

Substituting the previous parameters in equation (4) we can evaluate the annual effective dose simply according to the following relation 5 [16,17,18].

$$\text{Dose}(\text{mSv/y}) = 0.0252\text{x}C_{Rn}. \qquad (5)$$

3. Results and Discussion

Results and discussion for radon concentrations, radon exhalation rate in terms of area E_x, and radon exhalation rate in term of mass E_m for destroyed building material samples used in Jabalia city are given in this chapter. Equations 1, 2, 3 and 5 respectively were used for calculating radon concentrations, radon exhalation rate in term of area, E_x, radon exhalation rate in terms of mass, E_m, and Annual Dose for destroyed building material samples used in this study which include a red brick, marble, ceramic, concrete, tiles, asbestos, glass, and building stones. The results of Radon concentration only is shown in Table 2 for all building materials.

But radon exhalation rate in terms of area E_x, and radon exhalation rate in term of mass E_m, and annual effective dose for Ceramic is shown in Table 3.

The radon exhalation rate in terms of area E_x, and radon exhalation rate in term of mass E_m, and annual effective dose for each individual sample collected from Jabalia area are summarized in Table 3.

Table 2. Radon concentration only is shown in Table 2 for all building materials

NO.	code	Type	C_{Rn} Bq/m^3	NO.	code	Type	C_{Rn} Bq/m^3
1	G1	Ceramic	64.19	21	A1	stones	90.34
2	G2	Ceramic	80.83	22	A2	stones	145.82
3	G3	Ceramic	114.12	23	A3	stones	128.38
4	G4	Ceramic	205.41	24	A4	stones	209.22
5	G5	Ceramic	73.70	25	A5	stones	186.40
Average 107.65				**Average 152.03**			
6	F1	red brick	104.61	26	D1	marble	39.78
7	F2	red brick	114.12	27	D2	marble	77.98
8	F3	red brick	99.85	28	D3	marble	76.08
9	F4	red brick	66.57	29	D4	marble	124.49
10	F5	red brick	38.04	30	D5	marble	102.23
Average 84.63				**Average 84.11**			
11	B1	Concrete	337.60	31	H1	asbestos	267.86
12	B2	Concrete	274.20	32	H2	asbestos	395.96
13	B3	Concrete	383.57	33	H3	asbestos	408.93
14	B4	Concrete	422.24	34	H4	asbestos	492.93
15	B5	Concrete	460.28	35	H5	asbestos	290.05
Average 375.58				**Average 371.14**			
16	E1	Tiles	133.14	36	C1	glass	49.92
17	E2	Tiles	177.52	37	C2	glass	48.90
18	E3	Tiles	190.20	38	C3	glass	114.12
19	E4	Tiles	180.69	39	C4	glass	98.90
20	E5	Tiles	134.87	40	C5	glass	34.23
Average 163.28				**Average 69.21**			

Table 3. Summary of results of the average radon exhalation rate in terms of area Ex, radon concentration, radon exhalation rate in terms of mass Em and the annual effective dose from all destroyed building materials used in Jabalia district using standard calibration [6,7,8,9,10]

Sample Type	C_{Rn} (Bq/m^3)	E_x (mBq.m^{-2}.h^{-1})	E_m (mBq.Kg^{-1}.h^{-1})	Dose (mSv.y^{-1})
Concrete	375.58	469.017	11.799	9.464
asbestos	371.14	463.895	11.659	9.3528
Tiles	163.28	204.087	5.129	4.1144
building stones	152.03	190.025	4.776	3.831
Ceramic	107.65	133.92	3.57	2.7126
red brick	84.63	105.945	2.658	2.1324
Marble	84.11	105.130	2.642	2.1194
glass	69.21	86.506	2.174	1.744
Aver.	175.95	219.815	5.550	4.433

The data listed in Table 1 clearly show that concrete, tiles, building stones and asbestos are have high radon exhalation rate in terms of area E_x, radon concentration, radon exhalation rate in terms of mass E_m and the annual effective dose. But the glass have low radon exhalation rate in terms of area E_x, radon concentration, radon exhalation rate in terms of mass E_m and the annual effective dose.

The Figure 4 shows the comparison between destroyed building materials in terms of the average radon exhalation rates in term of area where the concrete have the highest value with 469.017 mBq.m^{-2}.h^{-1} then asbestos with 463.895 mBq.m^{-2}.h^{-1} then (tiles, building stones, ceramic, a red brick, marble and glass) with (204.087, 190.025, 133.92, 105.945, 105.130 and 86.506) mBq.m^{-2}.h^{-1} respectively. Note that the glass have the lowest value of the materials studied.

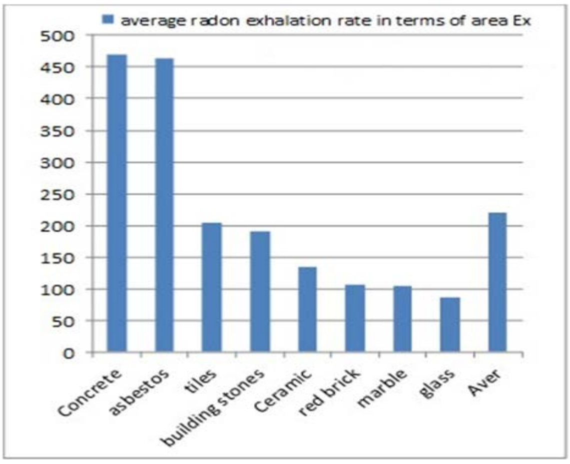

Figure 4. This figure shows the Comparing histogram for the average radon exhalation rates in term of area.

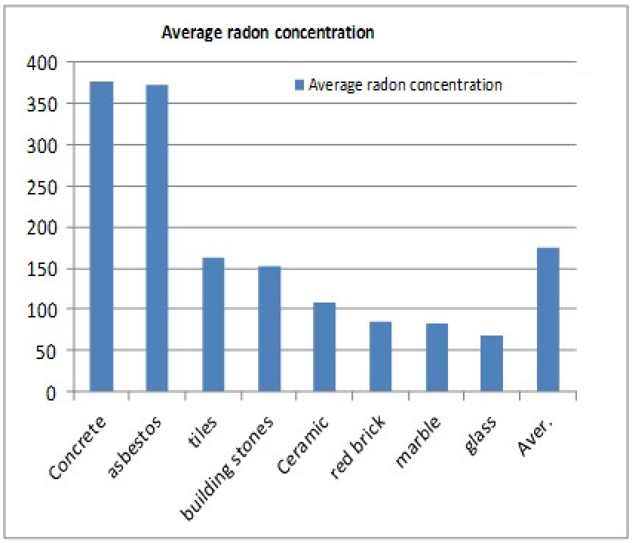

Figure 5. This figure shows the Comparing histogram for the average radon concentration rates

The Figure 5 shows the comparison between destroyed building materials in terms of the average radon concentration rates where the concrete have the highest value with 375.580 By/m^3 then asbestos with 371.140 By/m^3 then (tiles, building stones, ceramic, a red brick, marble and glass) with(163.280, 152.030, 107.650, 84.630, 84.110 and 69.210) respectively. Note that the glass has the lowest value of the materials studied.

The Figure 6 shows the comparison between destroyed building materials in terms of the average radon exhalation rates in term of mass where the concrete have the highest value with 11.799 mBq.kg^{-1}.h^{-1} then asbestos with 11.659 mBq.kg^{-1}.h^{-1} then (tiles, building stones, ceramic, a red brick, marble and glass) with (5.129, 4.776, 3.570, 2.658, 2.642 and 2.174) mBq.kg^{-1}.h^{-1} respectively. Note that the glass has the lowest value of the materials studied.

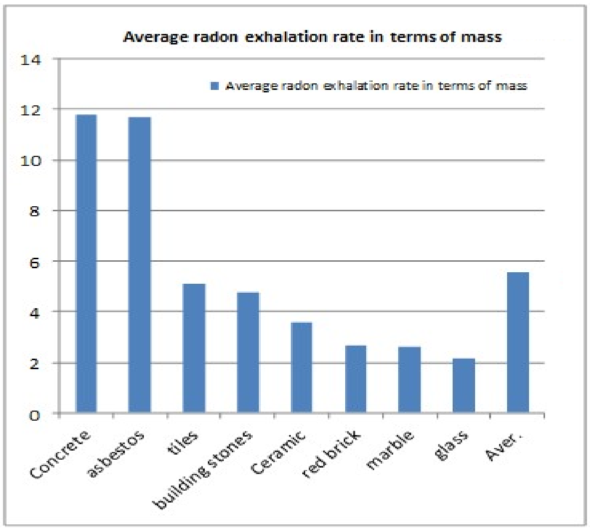

Figure 6. This figure shows the Comparing histogram for the average radon exhalation rates in term of mass

The Figure 7 shows the comparison between destroyed building materials in terms of the average annual effective dose for radon gas where the concrete have the highest value with 9.464 msv.y^{-1} then asbestos with 9.352 msv.y^{-1} then (tiles, building stones, ceramic, a red brick, marble and Glass) with (4.114, 3.831, 2.712, 2.132, 2.119 and 1.744) msv.y^{-1} respectively. Note that the glass has the lowest value of the materials studied.

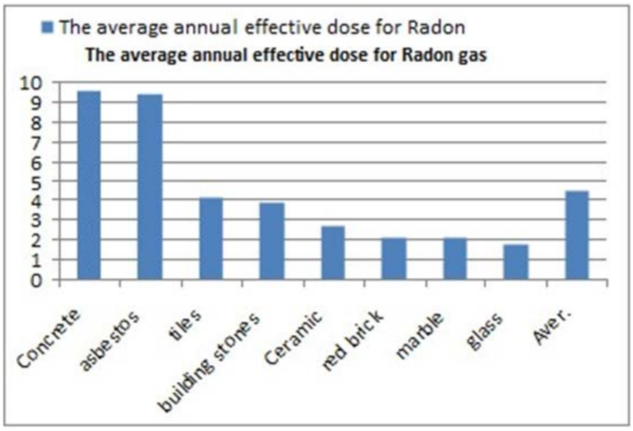

Figure 7. This figure shows the Comparing histogram for the average annual effective dose for radon gas

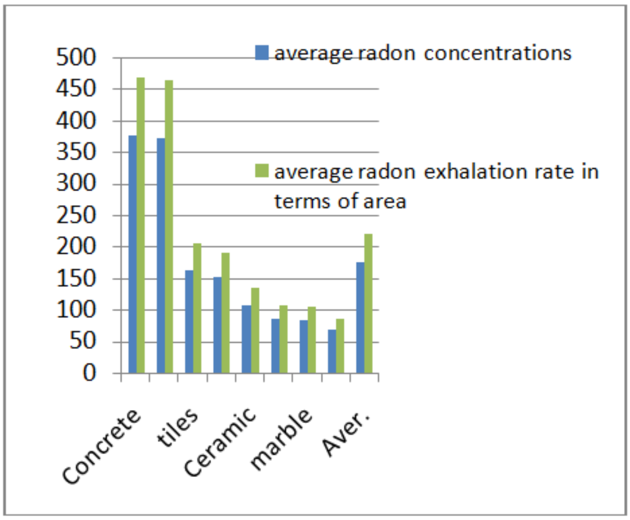

Figure 8. This figure shows the Comparing histogram for the average radon concentrations (C_{Rn} Ave.) and exhalation rates (E_x Ave.) from building materials used in Jabalia district

In Figure 8 We notice that, the concrete have the highest value of the average radon concentration and the average radon exhalation rate in term of area E_x, then (asbestos, tiles, building stones, ceramic, a red brick, marble and glass) respectively.

4. Conclusion

Using the closed can technique and the solid state nuclear track detectors (CR-39), we measured the radon exhalation rate from building material samples used in Jabalia in order to assess the contribution of individual material (e.g. red brick, marble, ceramic, concrete, tiles, asbestos, glass, and building stones) to the total indoor radon exposure of the inhabitants of Jabalia district. The corresponding radon concentration, and the annual effective dose were determined and compared with the effective dose limit values recommended by the National Council on Radiation Protection which (from 1 to 5 mSv/y). Results obtained from the current study show that the radon exhalation rates from asbestos and concrete have relatively high values as compared to other building material samples followed red brick, marble, ceramic, tiles, glass, and building stones contribute less to the indoor radon. From the results of our study we can conclude that the Concrete have the maximum values of radon concentrations 375.58Bq/m^3, radon exhalation rate in term of area469.017mBq.m^{-2}.h^{-1}, radon exhalation in term of mass 11.799 mBq.Kg^{-1}.h^{-1} and the annual effective dose 9.464 mSv.y^{-1},also asbestos have maximum values of radon concentrations 371.14 Bq/m^3, radon exhalation rate in term of area 463.895 mBq.m^{-2}.h^{-1}, radon exhalation rate in term of mass 11.659 mBq.Kg^{-1}.h^{-1} and the annual effective dose 9.3528 mSv.y^{-1}. But the glass have the minimum values radon concentrations 69.21 Bq/m^3, radon exhalation rate in term of area 86.506 mBq.m^{-2}.h^{-1}, radon exhalation rate in term of mass 2.174 mBq.Kg^{-1}.h^{-1}and the annual effective dose 1.744 mSv.y^{-1}. In comparison with the annual effective dose of Radon by NCRP, we found that concrete and asbestos are 9.46 and 9.35 mSv/y, are much higher than the proposed limit which is 1 to 5 mSv/y, and all other material are below the limit. There are many researchers studied radon gas for building materials, comparison with previous studies will be shown in following tables, the results obtained in Sudan are in Table 4 [19]:

Table 4. Results from Sudan (Elzain) [19]

Sample Type	CRn (Bq/m^3)	Ex (mBq.m^{-2}.h^{-1})	Em (mBq.Kg^{-1}.h^{-1})	Dose (mSv.y^{-1})
Ceramics	128	240	2.84	3.59
Red brick	190	355	4.21	5.32
Block	197	369	4.37	5.52
Ispistos	214	402	4.76	6.01

The results obtained in Palestine are in Table 5 [7]:

Table 5. Results from Palestine (Shoqwara) [7]:

Sample Type	CRn (Bq/m^3)	Ex (mBq.m^{-2}.h^{-1})	Em (mBq.Kg^{-1}.h^{-1})	Dose (mSv.y^{-1})
marble	240.55	438.79	3.01	6.06
ceramic	193.71	347.42	2.59	4.88
concrete	179.37	325.38	2.46	4.52
building stones	147.00	268.59	1.95	3.70

All these results are close to the values we have for the building materials we studied.

References

[1] Maher O. El-Ghossain, Abedalqader A. Abu Shammala, “Radioactivity measurements in tap water in Gaza Strip (Al-Naser Area)” Journal of the Association of Arab Universities for Basic and Applied Sciences (2012) 11, 21-26.

[2] El-Ghossain, M.O., Abusaleh, Raed M., 2007. Measurement of radiation concentration in soil at middle of Gaza Strip using different type of detectors. The Islamic University Journal 15 (1), 23-37.

[3] Raed.M.Abusaleh, "Measurement of Radiation concentration in Soil at middle Gaza strip", Islamic University of Gaza, 2005.

[4] Mahmoud Rasas. Measurement of Radon and its Daughter’s Concentration Indoor and Outdoor throughout Gaza Strip, thesis, Islamic University of Gaza, 2003.

[5] Nabil Hamed, Measurement of Radon Concentration in Soil at North Gaza, thesis, Islamic University of Gaza, 2005.

[6] Nabil M. H., Masahiro H., Tetsuo I., Shinji T., Masahiro F., Abdel Fattah H. and Emad K., ^{222}Rn exhalation rate from Egyptian building materials using active and passive methods, *Jpn. J. Health Physics*, 44(1): 106-111, 2009.

[7] Measurement of Radon Exhalation Rate from Building Materials F. Shoqwara, N. Dwaikat, G. Saffarini, Research & Reviews: Journal of Physics Volume 2, Issue 1, ISSN: 2278-2265.

[8] Measurement of Radon-222 concentration levels in water samples in Sudan Abd-Elmoniem A. Elzain1, Department of Physics, University of Kassala, Kassala, Sudan, Pelagia Research Library, Advances in Applied Science Research, 2014, 5(2):229-234.

[9] Krewski, D., J.H. Lubin, J.M. Zielinski et al. Residential radon and risk of lung cancer: a combined analysis of 7 North American case -control studies. Epidemiology, 16(2): 137-145, 2005.

[10] El-Zain, A.-E.A. A Study of Indoor Radon Levels and Radon Effective Dose in Dwelling of Some Cities of Gezira State in Sudan. Journal of Nuclear Technology and Radiation Protection, 29, 307-312, 2014.

[11] Darby, S., Hill, D., Auvinen, A. et al. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. BMJ, 330: 223, 2005.

[12] Markkanen M. Radiation Dose Assessments for Materials with Elevated Natural Radioactivity. Report STUK-B-STO 32, Radiation and Nuclear Safety Authority – STUK, 1995.

[13] NCRP, National Council on Radiation Protection and Measurements, Recent applications of the NCRP public dose limit recommendation for ionizing radiation, NCRP Statement No. 10, December, 2004.

[14] Karim, M.S., Abdullah, M.H. and Abass, W.H. Measurement of Radon Gas Concentration in Cement Samples by Using Nuclear Track Detector (CR-39). Diyala Journal for Pure Sciences, 8, 2222-8373, 2012.

[15] Saad, A.F., Abdalla, Y.K., Hussein, N.A. and Elyaseery, I.S. Radon Exhalation Rate from Building Materials Used on the Garyounis University Campus, Benghazi, Libya. Turkish Journal of Engineering Environmental Sciences, 34, 67-74, 2010.

[16] Measurement of Radium Content and Radon Exhalation Rates in Building Material Samples using Passive and Active Detecting Techniques published by Zakariya A. Hussein, Mohamad S. Jaafar and Asaad H. Ismail, Medical Physics, Physics Department, Education College, Salahaddin University -Erbil, 44002, Iraqi Kurdistan, IRAQ, published on September-2013.

[17] Hesham A. Yousef, A. H. El-Farrash, A. Abu Ela, Q. Merza Measurement of Radon Exhalation Rate in Some Building Materials Using Nuclear Track Detectors World Journal of Nuclear Science and Technology, 2015, 5, 141-148.

[18] Radon Concentration in Some Building Materials in Iraq Using CR-39 Track Detector International journal of Physics, Vol.1, No, 3, 2013, 73-76.

[19] Radon exhalation rates from some building materials used in Sudan published by Abd-Elmoniem A. Elzain, Indoor and Built Environment 2015, Vol. 24(6) 852-860 published on 5 June 2014.