ISSN: 0975-766X
CODEN: IJPTFI
Available through Online ***Review Article***
www.ijptonline.com

A REVIEW ON DIFFERENCE EFFECTIVE DOSE OF RADON 222 AND THORON OF INDOOR AIR BETWEEN BLACK CEMENT WAREHOUSES AND STONE MASONRY WORKSHOPS

Yadolah Fakhri[1], Abotaleb Bay[2], Bigard Moradi[3], Yahya Zandsalimi[4], Leila Rasouli Amirhajeloo[5], Ghazaleh Langarizadeh[6], Hassan Keramati [7,*]

[1]Students research office,Department of Environmental Health Engineering, School of Public Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[2]Environmental Health Research Center, School of Public Health, Golstan University of Medical Sciences, Golstan, Iran.
[3]Department of Health Public, Kermanshah University of Medical Sciences, Kermanshah, Iran.
[4]Environmental Health Research Center, Kurdistan University of Medical Sciences, Sanandaj, Iran.
[5]Department of Environmental Health Engineering, School of Public Health, Qom University of Medical Sciences, Qom, Iran.
[6]Food and Drugs Research Center, Bam University of Medical Sciences, Bam, Iran.
[7]Department of environmental Health Engineering, School of Public Health, Semnan University of Medical Sciences, Semnan, Iran.
Email: Hkramatee@gmail.com

Received on 19-02-2016 *Accepted on 22-03-2016*

Abstract

Radon 222 and thoron are of the colorless, odorless and radioactive gases which emissions from the building materials such as black cement and granitic stones. Long term inhalation of Radon increase the risk of lung cancer. In this study, it was tried to compare the effective dose of radon 222 and thoron of indoor air in the black cement warehouses and stone masonry workshops (mainly granite stone) by statistical tests using the results of previous studies. The mean of radon 222 and thoron in the cement storage warehouses were 133.6±33.2 Bq/m^3 and 21.8±10 Bq/m^3 and in stone masonry workshops were 134±33 Bq/m^3 and 47±11.5 Bq/m^3, respectively. The effective dose of radon 222 and thoron in black cement warehouses were 1.4±0.3 mSv/y and 0.05±0.02 mSv/y with sum of 1.45±0.32 mSv/y and in stone masonry workshops were 1.41±0.34 mSv/y and 0.11±0.025 mSv/y with sum of 1.52±0.18 mSv/y, respectively. The effective doses of radon 222 black cement warehouses and stone masonry workshops was less than the ICRP standard limits ($P<0.001$). The effective doses of radon 222 in the black cement warehouses with stone masonry workshops was not different significantly (P value = 0.94), but the effective dose of thoron in stone masonry workshops was higher significantly (P value<0.001). So, measuring and calculating effective dose of thoron indoor air in the stone masonry workshops and storage of decorative stones (mainly granite) are more important.

Keywords: Radon 222, thoron, effective dose, review, black cement and granite stones.

1. Introduction

Recently, inhalation of the colorless, odorless and radioactive radon gas has become an international concern [1-3]. Radon 222 and thoron are the results of radium 226 decay in uranium 238 chain and radium 224 decay in thorium 232 chain, respectively [4,5]. The half-life of radon 222 and thoron is 3.82 days and 56 seconds respectively that emissions from water, soil and stones [6-8]. According to the information provided by the National Radiation Protection Board (NRPB), 85% and 15% of the effective doses by human are from the natural and synthetic (man-made) exposures, respectively [9]. The alpha radiation emitted from Radon 222 and its daughters (^{218}Po and ^{214}Po) and thoron in the long term can damage the DNA of pulmonary cells and eventually causes lung cancer in humans [10, 11]. Studies have also shown that there is a direct association of between the cardiovascular diseases and long term exposure with high concentration of indoor air radon [12]. The World Health Organization (WHO) has approved the direct significant association of prevalence of lung cancer and radon indoor air [13]. Environmental Protection Agency (EPA) has announced nearly 21000 people deaths due to indoor air radon that is 10 times higher than the mortality rate of air pollution [14]. The global mean concentration of radon in the air inside and outside are 48 Bq/m^3 and 15 Bq/m^3, respectively [15]. EPA and WHO have proposed the standard concentration of radon 148 Bq/m^3 and 100 Bq/m^3 indoor air, respectively [14,16]. The maximum annual effective dose of Radon for staffs is 20 mSv/y [17]. Concentration of radon Indoor mainly depends on the emission from building materials, surrounding soils and water resources [18]. All building materials have radioactive materials although in small amounts. In the recent years, a lot of attention is dragged to the emission from radioactive materials from the construction materials [19,20]. Many studies have shown that cement (black and white powder, plasters, concrete, etc.) emission more radioactive materials especially radium 226, radon 222 and thoron relative to the other construction materials [21,22]. However, some other studies show that granite stones emission more radon relative to the other building materials [23-25]. So in this study, it was tried with a review of studies in this area to compare the effective doses of radon 222 and thoron in black cement warehouses and stone masonry workshops (mainly granite).

2. Materials and Methods

2.1. Measurement concentration of radon 222 and thoron

2.1.1. Black cement warehouses

In Fakhri et al study, measuring indoor air radon 222 and thoron of cement warehouses was carried out in 5 large and important black cement warehouses storage in Minab city. Measuring was performed in each three stages from March

2012 to May 2012 (One stage per month). At each stage of every warehouse, two 24-hours measurements and two 48-hours measurements were performed. Totally, 30 of 24-hours indoor air concentration were measured from three of 5 storage warehouses [26].

2.1.2. Stone masonry workshops

In Fakhri et al study, 2 masonry workshops were selected in Minab city. Both of these workshops had the area of 20 m^2 and the height of 2.5 m. measuring was performed in 2 stage from December 2012 to January 2013 (one stage per month). Indoor air radon 222 and thoron concentration were measured for 24 hours. According to the measuring instruction provided by SARAD Company, in continuous measurement more than 2 hours, the device must be on slow mode to reduce the statistical error and double the measurement accuracy [27,28]. The device was placed at a height of 1 meter and at the center of masonry room. Two 24-hours concentration of radon 222 and thoron were measured from each stone masonry workshops [29].

Measuring concentration of radon 222 and thoron was conducted by portable Radon detector model RTM1688-2 made in SARAD Company, Germany.

Since the variable of air conditioner was effective in indoor air radon 222 and thoron concentration, thus it was tried to make the black cement warehouses and stone masonry workshops similar in terms of natural and artificial air conditioner to eliminate its intervention effects.

2.2. Calculating the effective dose of radon 222 and thoron

2.2.1. Effective dose of radon 222

The effective dose of radon 222 was calculated by the provided UNSCEAR equation 1:

Equation-1: $E_{Rn}=C_{Rn}\times 0.4\times T\times 9\times 10^{-6}$

In this equation, E_{Rn}: the effective dose (mSv/y), C_{Rn}: geometric mean of radon 222 concentration (Bq/m^3). 0.4 the balance factor, T: time of daily work which is 8 hours (h/y2920), 9 is the conversion coefficient of radon 222 concentration to the effective dose ($nSv/Bq.m^3.h$) and 10^{-6} is Nano SV conversion coefficient to mSv [30].

2.2.2. Effective dose of thoron

The effective dose of thoron indoor air was calculated by UNSCEAR equation 2:

Equation-2: $E_{Tn}= C_{Tn}\times 0.02\times T\times 40\times 10^{-6}$

In this equation, $E_{Tn:}$ the annual effective dose (mSv/y), C_{Rn}: geometric mean concentration of thoron (Bq/m^3). 0.02 the balance factor, T: time of daily work which is 8 hours (2920 h/y), 40 is the conversion coefficient of thoron concentration to the annual effective dose (nSv/Bq.m^3.h) and 10^{-6} is Nano SV conversion coefficient to mSv [30]. The duration of workers' exposure in both studies was considered as 8 hours. Also, the coefficient of 0.11 was used to convert the emission rate of radon gas in Bq/m^3 to mBq/kg^{-1}.h^{-1} [31].

2.3. Statistical analysis

The statistical tests were done through SPSS16 software. Data were normally distributed by Kolmogorov-Smirnov test. The difference between the effective doses of radon 222 and thoron in the cement warehouses with stone masonry was examined by independent sample t test and compare to standard limits with one sample t test. The significance level was considered as P value<0.05 (α=5%).

3. Results

The mean of concentration radon 222 of BCW1, BCW2, BCW3, BCW4 and BCW5 was 122.33±56, 160.67±17, 96.33±26, 175.67±27 and 113.33±28 Bq/m^3 and thoron was 36.33±10, 23.33±4, 24.33±11 and 10.33±23 Bq/m^3, respectively. The mean of concentration radon 222 and thoron in 5 cement storage warehouses were 33.21±33.6 Bq/m^3 and 21.8±10 Bq/m^3, respectively. The mean of effective dose of radon 222 and thoron was 1.4±0.3 mSv/y and 0.05±0.02 mSv/y and sum 1.45±0.32 mSv/y (Table 1).

Table-1: Concentration of radon 222 and thoron in the black cement warehouses and Effective Dose.

	Concentration of radon (Bq/m^3)		Sum of radon 222 and thoron	Effective Dose (mSv/y) Work time 8hr	
	Radon 222	Thoron		Radon 222	Thoron
BCW1	122.33	36.33	158.33±28	1.29	0.08
BCW2	160.67	23.33	183.67±32	1.69	0.05
BCW3	96.33	14.67	111.25±19	1.01	0.03
BCW4	175.67	24.33	199.67±35	1.85	0.06
BCW5	113.33	10.33	123.33±22	1.19	0.02
M±SD	133.6±33.2	21.8±10	155.4±27	1.4±0.3	0.05±0.02

The range and mean of concentration radon 222 in the stone masonry workshops 1 and 2 were 76-186 Bq/m^3 and 120±29 Bq/m^3 and 95-214 Bq/m^3 and 148±38 Bq/m^3, respectively (Table 2).

The range and mean of concentration thoron in the stone masonry workshops 1 and 2 were 27-65 Bq/m^3, and 33-75 Bq/m^3 and 42±10 Bq/m^3 and 52±13 Bq/m^3, respectively (Table 2). The effective dose of radon 222 in the stone masonry workshops 1 and 2 was 1.26 mSv/y and 1.56 mSv/y and the mean was 1.41 mSv/y, respectively. Also, the effective dose of thoron in the stone masonry workshops 1 and 2 was 0.1 mSv/y and 0.12 mSv/y and the mean was 0.11 mSv/y. The total effective dose of radon 222 and thoron in the stone masonry workshop was 1.52 (Table 2).

Table-2: The effective dose of radon 222 and thoron in the stone masonry workshops.

		Radon 222 (Bq/m^3)		Effective dose (mSv/y)	
		Radon 222	Thoron	Radon 222	Thoron
SMW1	Mean	120.00	42.00	1.26	0.10
	SD	29.00	10.00	0.30	0.02
SMW2	Mean	148	52.00	1.56	0.12
	SD	36.00	13.00	0.38	0.03
Mean	Mean	134	47	1.41	0.11
	SD	32	11.5	0.34	0.025

Table-3: Statistical analysis of radon 222 and thoron effective doses in the black cement warehouses and stone masonry workshops.

	t	df	P Value	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
Radon 222	-0.067	25.6	0.94	-0.87	12.9	-27.4	25.7
Thoron	-6.6	32	<0.001	-25	3.7	-32.7	-17.3

As it is seen in table 3, although the effective dose of radon 222 in black cement warehouses was less than stone masonry workshops, but the difference was not significant (P value>0.05). The effective dose of thoron in the stone masonry workshop was significantly higher than black cement warehouses (P value<0.05)

4. Discussion

This study showed that the effective dose of radon 222 in black cement warehouses did not have a significant difference with masonry workshop, but effective dose of thoron in the stone masonry workshop was significantly higher than cement warehouses.

The ratio of the mean concentration of radon 222 to the EPA standard in BCW1, BCW2, BCW3, BCW4 and BCW5 cement warehouse was 106.7, 123.6, 75, 134.8 and 83.3%, respectively. The mean concentration of radon 222 in the BCW3 and BCW5 was less than EPA standard limits and BCW1, BCW2 and BCW4 was higher that EPA standard limits. Also, the ratio of mean concentration of radon to WHO standard in BCW1, BCW2, BCW3, BCW4 and BCW5 cement warehouse was 158.3, 183.6, 111.2, 199.6 and 123.3%, respectively. The mean concentration of radon 222 in the all black cement warehouses is higher than WHO standard limit.

The high concentration of radon and following that the effective dose in black cement warehouses are due to the difference in air conditioning rate (natural and artificial), the stored cement volume, the volume of storage (air exchange) and different brands of black cement [32-34]. Whatever the size of stored volume of cement is more and ventilation and air exchange is less, the concentration of radon is increased. The effective dose of staffs was less than ICRP standards (20 mSv/y). The maximum and minimum effective dose of staffs was related to BCW4 and BCW3, respectively.

The staffs of masonry center during the day are exposed to radon gas. So, the mean concentration of radon 222 and thoron during the day (working hour) was considered as the base of effective dose calculation. The ratio of total effective dose of radon 222 and thoron (1.57 mSv/y) to ICRP standard limit was 7.8% (P value<0.05) [17]. The effective dose of radon 222 and thoron in both workshops 1 and 2 as well as the mean of both of them was less than ICRP standard limit.

The difference in radon 222 and thoron emitted by granite stones and black cements due to the difference in porous building materials [35]or the content of uranium 238 and thorium 232 [36-37].

The effective dose of radon 222 in stone masonry workshop was higher than thoron (8.8 times more) and share of dose of thoron from the total dose is only 10 percent. But the important point was the higher effective dose of thoron in stone masonry workshops compared to the black cement warehouses.

In Chauhan study, the concentration of radon 222 emitted by the soil and stone samples from Aravali hill was measured. Although the building materials in Chauhan study were similar to our study, but the range and concentration of radon 222 emitted by the materials such as granite, granite weathered, granite coarse grain and granite igneous stones was 729 Bq/m^3 to 1958 Bq/m^3 and 1440±134 Bq/m^3 respectively that were higher than our study (p<0.001).

Since in Chauhan study, the emission rate of radon from the materials in a box without air conditioning, along with passive indicator of LR-115 type II plastic track detectors was held for 100 days hence concentration of radon was high. In other words, higher concentration of radon 222 emitted by the sample of Chauhan study due to the higher of Radium and Uranium in the stones samples [38].

In Saad et al study, the concentration of radon 222 emitted by the building materials including black cement was measured through CR-39 nuclear track detectors (NTDs). The mean concentration of radon 222 emitted by black cement was 533.07±18.6 Bq/m^3. Also, the concentration of indoor air Radon 222 was 2.1±0.1 Bq/m^3 which was less than our study in indoor air (155.4±27 Bq/m^3). Thus, the effective dose of black cement (0.0852±0.003 mSv/y) was less than our study (1.45±0.3 mSv/y) [31].

In Ahmad et al study, the ranges of concentration of radon 222 emitted by black cement by RAD7 active and CR-39 NTDs passive devices was 65±21 Bq/m^3 to 79±21 Bq/m^3 and 68±19 Bq/m^3 to 45±16 Bq/m^3, respectively. The results of this study was close to our study [39].

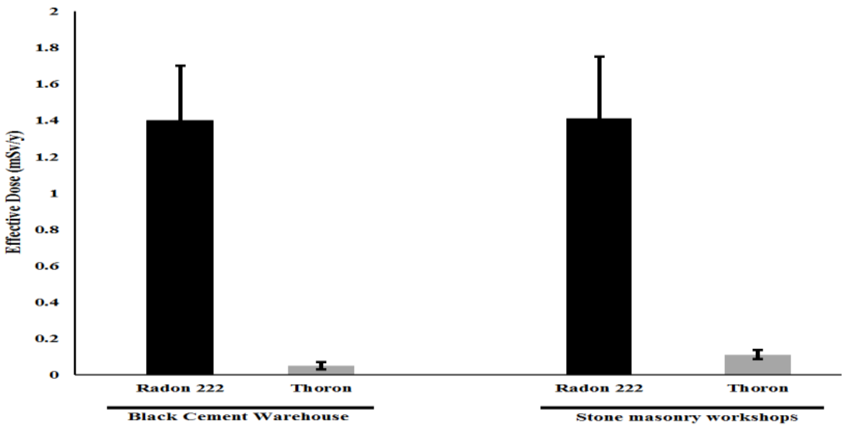

Figure-1: Comparison of the effective dose of indoor air radon 222 and thoron in the and black cement warehouse and stone masonry workshops.

Radon 222 emitted by granite stones and indoor air was 965.1±33.7 Bq/m^3 and 2.9±0.1 respectively which was less than indoor air in our study (134±33 Bq/m^3). Since our study, other materials were shared in concentration of radon, so radon 222 concentrations was higher [31].

In Saad et al study like our study, concentration of radon 222 in the decorative stones especially granite was higher than black cement but in our study, higher concentration of radon 222 was not significant.

Table-4: Comparison of emission rate of radon 222 and thoron from granite to indoor air (mBq.kg^{-1}.h^{-1}) in this study with other countries.

Countries	**Randon 222**	**Thoron**	**References**
Palestine	35.1	20.5	[40]
Saudi Arabia	23	30	[41]
Brazil	48.6	288.2	[40]
Hang Kong	202	140	[40]
France	90	80	[41

Egypt	32.46	47.76	[42]
Iran[1]	14.74	14.74	[29]

Thoron higher emission from granite stones is due to higher thorium-232 in the soil layers of these countries [43]. Share of radon 222 in the countries of Iran, Palestine, France and Hong Kong were higher, but thoron was higher in countries of Saudi Arabia, Brazil and Egypt (Table 4). It shows that when calculating the effective dose of radon should also consider the share of thoron because the concentration of thoron can be more than radon 222 in some places especially mining and granite masonry workshops [44,45].

5. Conclusions

The effective dose of cement warehouses and stone masonry workshops was less than ICRP standard limits (P value<0.001), although in both studies, the effective dose of thoron was less than radon 222, effective dose of radon 222 in black cement warehouses was not different from stone masonry workshops. Effective dose of thoron in the stone masonry workshops was higher than cement warehouses (P<0.001). So, measuring concentration of thoron and calculating the effective dose it in the warehouses and workshops with decorative stones especially granite, is important and essential.

6. Acknowledgement

Student's research office of Shahid Beheshti University of Medical Science was the financer of this review research (Code 2660, Date: 2016/03/01)

7. References

1. Ju, Y.-J., et al., A Study on Concentration Measurements of Radon-222 (Uranium Series) and Radon-220 (Thoron Series) Emitted to the Atmosphere from Tex (Cementitious), Red Brick, and Ecocarat among Construction Materials. Korean Physical Society, 2012. 60: p. 1177-1186.
2. Al-Khateeb, H.M., et al., Radon concentration and radon effective dose rate in dwellings of some villages in the district of Ajloun, Jordan. Applied Radiation and Isotopes, 2012. 70: p. 1579-1582.
3. Taylor-Lange, S.C., et al., The contribution of fly ash toward indoor radon pollution from concrete. Building and Environment, 2012. 56: p. 276-282.
4. Cohen, B.S., et al., Deposition of charged particles on lung airways. Health Physics, 1998. 74(5): p. 554-560.
5. Cothern, C.R. and J.E. Smith, Environmental radon. Vol. 35. 1987: Springer.

6. Topçu, N., et al., Radon exhalation rate from building materials using CR-39 nuclear track detector. Indoor and Built Environment, 2013. 22(2): p. 384-387.
7. Fakhri, Y. and M. Mirzaei, Effective dose Radon 222 tap drinking water in the Age groups humans.
8. Fakhri, Y., et al., Effective Dose Radon 222 of the Tap Water in Children and Adults People; Minab City, Iran. Global Journal of Health Science, 2015. 8(4): p. 234-243.
9. Green, B., P. Lomas, and F. Luykx, Natural radiation atlas of Europe. Radiation Protection Dosimetry, 1991. 36(2-4): p. 85-88.
10. Kávási, N., et al., Estimation of effective doses to cavers based on radon measurements carried out in seven caves of the Bakony Mountains in Hungary. Radiation Measurements, 2010. 45(9): p. 1068-1071.
11. Zeeb, H. and F. Shannoun, eds. WHO handbook on indoor radon, A PUBLIC HEALTH PERSPECTIVE. 2009, World Health Organization: Geneva ,Switzerland.
12. Bajwa, B. and H. Virk, Environmental radon monitoring in dwellings near the radioactive sites. Amristar-143005, india. radiation measurement, 1997. 26(1): p. 457-460.
13. Torres-Durán, M., et al., Residential radon and lung cancer in never smokers. A systematic review. Cancer Lettersjournal of environmental radioactivity, 2014. 345: p. 21-26.
14. Environmental Protection Agency, Consumer's Guide to Radon Reduction. 2010.
15. FARID, S.M., A study on the radon concentration in tobacco in Jeddah (Saudi Arabia) and the associated health effects. Medical Journal of Islamic World Academy of Sciences, 2012. 20(3): p. 84-93.
16. World Health Organization, Sets radon action level of 2.7 - less lung cancer risk than EPA 4.0. Global Press Release Distribution. . 2009.
17. Protection, I.C.o.R. and ICRP, ICRP Publication 66: Human Respiratory Tract Model for Radiological Protection. 1994: Elsevier Health Sciences.
18. Ramasamy, V., et al., Natural radioactivity measurements in beach-stones samples of south-east coast of Tamilnadu, India. Radiation protection dosimetry, 2004. 111(2): p. 229-235.
19. Kovler, K., et al., Consideration of Radon Leakage From Marinelli Beakers for Accuratedetermination of 226Ra activity Concentrationin Building Materials. 2012.
20. Miro, C., M. Madruga, and M. Reis, Natural Radioactivity in some building materials from Spain. 2014.

21. Ju, Y.-J., et al., Study on measurement and quantitative analysis of Radon-222 emitted from construction materials. Annals of Nuclear Energy, 2012. 49: p. 88-95.
22. Sharma, N., et al., A study of the natural radioactivity and radon exhalation rate in some cements used in India and its radiological significance. Journal of Radiation Research and Applied Sciences, 2016. 9(1): p. 47-56.
23. Kumar, A., et al., Modeling of indoor radon concentration from radon exhalation rates of building materials and validation through measurements. Journal of environmental radioactivity, 2014. 127: p. 50-55.
24. Sapra, B. and B. Bajwa, A study of indoor radon, thoron and their progeny measurement in Tosham region Haryana, India. 2015.
25. Koike, K., et al., Controls on radon emission from granite as evidenced by compression testing to failure. Geophysical Journal International, 2015. 203(1): p. 428-436.
26. Fakhri, Y., et al., Assessment Risk of Lung Cancer from Inhalation of Radon 222 and Thoron (Radon 220) of Indoor Air in Staff Cement Storage Warehouses; Minab city, Iran. International Journal of Current Microbiology and Applied Sciences 2015. 4(2): p. 814-824.
27. Ursulean, I., et al. estimation of indoor radon concentration in the air of residential houses and mines in the republic of moldova. in paper presented at the first east european radon symposium–feras. 2012.
28. GmbH, s. application note an-003_en: Measurement of the Radon concentration of water samples. June 2007; Available from: www.sarad.de.
29. Fakhri, Y., B. Moradi, and M. Mirzaei, Survey on differences in effective dose radon 222 with Thoron indoor air in masonry workshops. Journal of Dental and Medical Sciences (IOSR-JDMS), 2015. 14(10): p. 68-73.
30. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Sources and Effects of Ionizing Radiation; United Nations Scientific Committee on the Effects of Atomic Radiation. 2000: USA.
31. Saad, A., H.H. Al-Awami, and N. Hussein, Radon exhalation from building materials used in Libya. Radiation Physics and Chemistry, 2014. 101: p. 15-19.
32. Perrier, F., et al., Radon-222 signatures of natural ventilation regimes in an underground quarry. Journal of environmental radioactivity, 2004. 71(1): p. 17-32.
33. Alsaedi, A.K., B. Almayahi, and A. Alasadi, Cement 222Rn and 226Ra concentration measurements in selected samples from different companies. Asian Journal of Natural & Applied Sciences (AJSC), 2013. 2(4): p. 95-100.

34. Nain, M., R. Chauhan, and S. Chakarvarti, Alpha radioactivity in Indian cement samples. Iran J. Radiat Res, 2006. 3: p. 1-71.
35. Folkerts, K., G. Keller, and H. Muth, An experimental study on diffusion and exhalation of 222Rn and 220Rn from building materials. Radiation Protection Dosimetry, 1984. 9(1): p. 27-34.
36. Ramachandran, T. and M.S. Ramu, Estimation of indoor radiation exposure from the natural radioactivity content of building materials. Oncology, 1989. 3: p. 20-25.
37. Turhan, Ş. and A. Varinlioğlu, Radioactivity measurement of primordial radionuclides in and dose evaluation from marble and glazed tiles used as covering building materials in Turkey. Radiation protection dosimetry, 2012: p. ncs041.
38. Pili, E., et al. Radon emanation during compression, fracturing and heating of granites. in AGU Fall Meeting Abstracts. 2013.
39. Ahmad, N., et al., Measurement of radon exhalation rate, radium activity and annual effective dose from bricks and cement samples collected from Dera Ismail Khan. American Journal of Applied Sciences, 2014. 11(2): p. 240.
40. Dabayneh, K., Radioactivity measurement in different types of fabricated building materials used in Palestine. 2007.
41. El-Taher, A., Assessement of natural radioactivity levels and radiation hazards for building materials used in Qassim area, Saudi Arabia. Romanian journal of physics, 2012. 57(3/4): p. 726.
42. Shoeib, M. and K. Thabayneh, Assessment of natural radiation exposure and radon exhalation rate in various samples of Egyptian building materials. Journal of Radiation Research and Applied Sciences, 2014. 7(2): p. 174-181.
43. Anjos, R.M.d., et al., External gamma-ray dose rate and radon concentration in indoor environments covered with Brazilian granites. Journal of environmental radioactivity, 2011. 102(11): p. 1055-1061.
44. Janik, M., Y. Omori, and H. Yonehara, Influence of humidity on radon and thoron exhalation rates from building materials. Applied Radiation and Isotopes, 2015. 95: p. 102-107.

Corresponding Author:

Hassan Keramati *,

Email: *Hkramatee@gmail.com*