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RESEARCH ARTICLE

Indoor Radon Monitoring and Gamma Activity Levels Inside Some Ancient Egyptian Tombs in Luxor

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Abstract

In the present work, radon concentrations in five selected tombs in the valley of kings, Luxor city, have been evaluated utilizing a portable radon monitor RTM 1688-2, SARAD. Additionally, specific radioactivity concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in the samples taken from the selected tombs showing results lower than the average international radioactivity levels. Seasonal variations of radon concentration have been observed, with high summer average radon concentration values at the tomb of RAMESES II SONS (KV 5) of about 6365 ± 190 Bq.m^{-3} for the tomb's inner chamber and 5511 ± 276 Bq.m^{-3} for the tomb's middle chamber. The highest winter average radon concentration was observed at RAMESES VI tomb (KV9) with a value of 491 ± 16 Bq.m^{-3}. The tour guides are found to expose to an average associated annual effective doses ranging from 0.360 to 14.592 mSv.y^{-1} and the visitors from 0.001 to 0.029 mSv.y^{-1} while the corresponding results for workers ranging from 3.455 to 140.081 mSv.y^{-1} which exceed the world lower recommended level (3-10 mSv.y^{-1}). Accordingly, to avoid the health hazards associated with the exposure to radon during the long period of work inside these tombs, proposed solutions are introduced

INTRODUCTION

Egypt is a country famed for its ancient monuments and was the home to one of the oldest civilizations in the world. One of the most interesting cities that contains a lot of those ancient monuments is the city of Luxor that is located 600km south of Cairo, east bank of the Nile River. A royal burial ground for pharaohs, queens, and other elites of the 18th, 19th and 20th dynasties which lies on the Nile's west bank near Luxor is called the Valley of Kings. These burial ground tombs composed of limestone sedimentary rock varies from extremely fine and structurally sound to fractured and weak, containing considerable concentrations of natural radioisotopes. The emitted radiation resulting from the decay of these isotopes may expose workers and members of the public and/or tourists to significant doses from ionizing radiation. The health risks due to inhalation of radon and its progenies in particularly the lung cancer become evident [Nazaroff, et al., 1988; Darby, et al., 2005]. Accordingly, aspects related to control high radon concentrations are considered [ICRP, 1994; USEPA, 2004]. Therefore, several recommendations were made to guide evaluation of occupational exposures in all work areas including mines and tombs [UNSCEAR, 2008].

The objective of the present study is to survey the distribution of radon concentrations among different tombs in the Valley of Kings making use of a portable radon monitor RTM 1688-2, SARAD. To assess the current condition of radioactivity concentrations in the studied region, coming about because of radioisotopes of the naturally occurring radioactive uranium series and from ^{40}K, a gamma-rays spectrometer based on HPGe detector has been used. Estimation of the occupational exposure of workers or tourists at this site also considered to be one of the main objectives of present work. This study is considered to be a complementary study to the pilot study done previously at other Egyptian Luxor tombs in developing guidance rules for workers, tourist guides and visitors at Luxor region [Gruber, et al., 2011].

1. Measurements locations

At a distance of 600 km south of Cairo, east of Luxor, the burial ground for most of Egypt's New Kingdom rulers are located (Fig. (1)). The Valley of kings etched in mountains that consists of limestone and other sedimentary rocks of varying rock quality ranging from finely grained to coarse stone, surrounded by steep cliffs, and easily guarded.

The selected studied tombs were: RAMESES II SONS (KV5), RAMESES V and RAMESES VI (KV 9), BAY (KV13), TIA'A (KV 32), YUYA and THUYU tomb (KV46). All these tombs have just one entrance and extended to a tunnel between 11 and 445 m into the mountain which is a suitable reason for the low ventilation rate. The temperatures inside the tombs ranged from 28 to 32 ^{o}C and the humidity was between 50 and 65 %. Some of these tombs are opening for the visiting and others are closed for the restoration work. The selection of the measured tombs is restricted by the objective study and the available permissions.

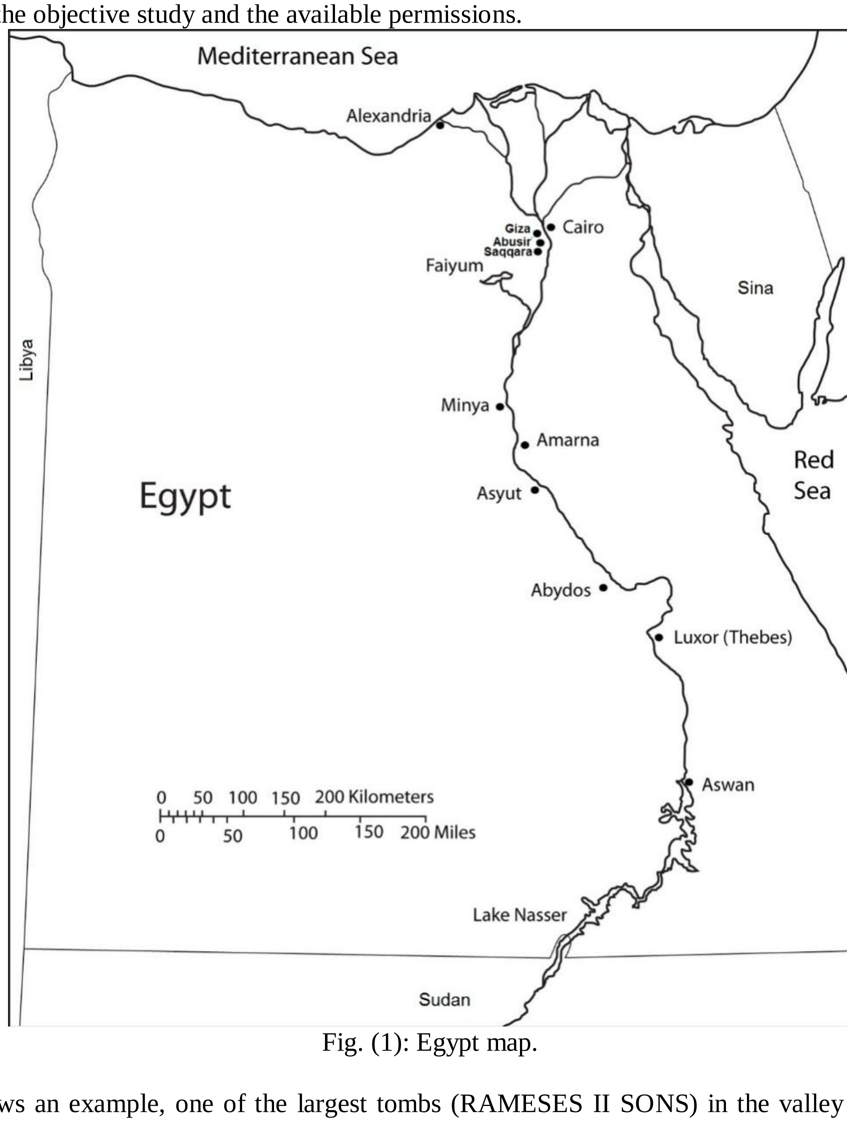

Fig. (1): Egypt map.

Fig. (2): Shows an example, one of the largest tombs (RAMESES II SONS) in the valley of kings. This tomb still under burrowing, making workers in a permanent existence. It has so far disclosed places of about 121 corridors and chambers.

2. Experimental work

3.1 Gamma spectroscopic analysis

Samples were gathered from the internal rocks of the studied elected tombs and others from the mountain at the passageway of tombs. Triplicate samples per tomb were gathered and completely mixed together to form one sample. The samples have been taken unified at depth 0-10 cm from the surface. The gathered samples were intended for radiation counting by sieving through 2 mm mesh size. The samples were homogenized and dried in a vacuum drier at 105^{o}C, weighted and moved to 350 ml Marinelli beakers, and after that it stored for one month to insure that secular equilibrium between the radioisotopes of the uranium series was gotten. The specific activities of ^{226}Ra and ^{232}Th were obtained indirectly from the gamma rays emitted by their progenies which were in secular equilibrium with each other, for ^{226}Ra [^{214}Pb (295.2 keV and 351.9 keV)] and for ^{232}Th [^{212}Pb (238.6 keV), ^{214}Bi (1120 keV), ^{208}Tl (583.1 keV and 2614 keV), and ^{228}Ac (911 keV and 968.9 keV)]. The specific activity of ^{40}K was determined directly from the 1460.7 keV gamma line.

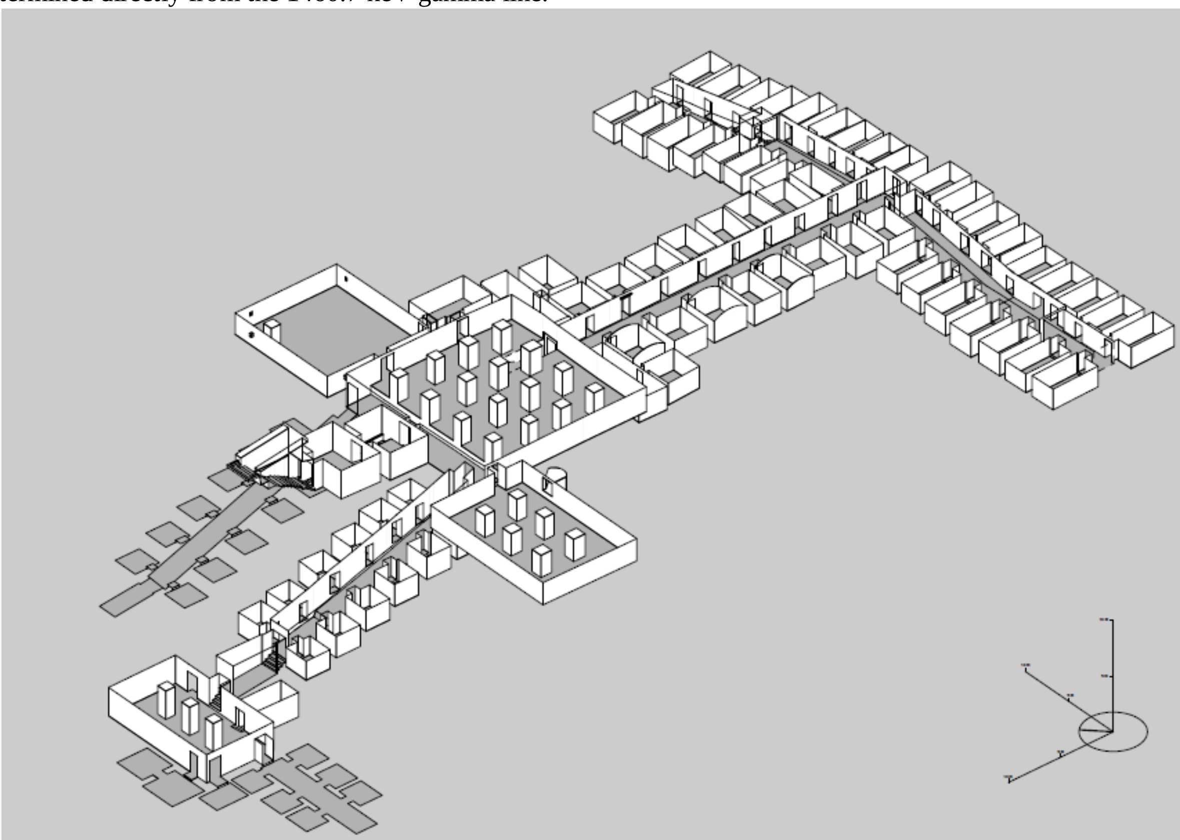

Fig. (2): Tomb (KV5) that is considered to be the largest tomb in the valley, which originally returned to 18th Dynasty and has been extorted by Ramesses II for burring his principal sons. [http://www.thebanmappingproject.com].

The specific activity (Bq/kg) of radionuclide content for the measured samples was determined using the following relation [Jibiri, et al., 2007]:

$$C(Bq/kg) = \frac{C_n}{\varepsilon \, P_\gamma \, M_s} \quad (1)$$

Where C_n, ε , P_γ ,and M_s are the counting rate under each photo peak resulting from each radionuclide, the detector efficiency of the specific gamma-ray, the absolute transition probability of the specific gamma-ray, and the sample mass (kg), respectively. The uncertainty of activity was calculated. The total uncertainty of the efficiency calibration was about 5%.

The lowest detection limits of the measuring system, which is required to estimate a minimum level of detection for appropriate determination of radionuclides using analytical technique in each sample, were obtained from the procedure of the environmental measurement laboratory using the following relation [Jibiri, et al., 2007; Akram, et al., 2006]:

$$Lowest\ detection\ limits = \frac{4.66\ S_b}{\varepsilon\ I_\gamma} \tag{2}$$

Where S_b is the estimated standard error of the net background count rate in the spectrum of the radionuclide, ε is the detector efficiency and I_γ is the abundance of gamma emission per radioactive decay. The lowest detection limits of the measuring system was defined as 1.31, 1.34 and 9.35 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K, respectively.

3.2 Health hazards

3.2.1 Radium equivalent activity (Ra_{eq})

Radium equivalent activity is a widely used index. It can be obtained as follows [Bereka and Mathew, 1985; Ravisankar, et al., 2012]:

$$R_{eq} = A_{Ra} + 1.43\ A_{Th} + 0.077\ A_K \tag{3}$$

Where A_{Ra}, A_{Th} and A_K are activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bq/kg. The maximum value of Ra_{eq} must be less than 370 Bq/kg, in order to keep the annual external absorbed dose less than 1.5 mSv/y [UNSCEAR, 2000; USEPA, 2004].

3.2.3 The absorbed dose rate (D)

The absorbed dose rate due to γ-radiation in air at 1m above the ground surface was also calculated. The conversion factors used for (D) calculations are 0.462 $nGyh^{-1}$ for ^{226}Ra, 0.621 $nGyh^{-1}$ for ^{232}Th, and 0.0417 $nGyh^{-1}$ for ^{40}K. Accordingly, (D) can be calculated as follows [UNSCEAR, 2000]:

$$D = 0.462\ A_{Ra} + 0.621\ A_{Th} + 0.0417\ A_K \tag{4}$$

Where A_{Ra}, A_{Th} and A_K are activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively in Bq/kg.

3.2.3 The annual effective dose (EAD)

The annual effective dose is a concept that allows the radiation doses from different radionuclides and from different types and sources of radioactivity to be added. The annual effective dose rate (mSv/y) can be calculated using the following equation [OECD, 1979; UNSCEAR, 2000]:

$$EAD = D \times 8760 \times 0.7 \times 10^{-6} \times 0.8 \tag{5}$$

Where 0.7 Sv/Gy is the conversion coefficient from absorbed dose to effective dose and 0.8 is the fraction of time spent indoors.

3.2.4 The external hazard index (H_{ex})

The external hazard index considers only the external exposure risk due to γ-rays and can be obtained by the following relation [Bereka and Mathew, 1985]:

$$H_{ex} = {}^{A_{Ra}}/_{370} + {}^{A_{Th}}/_{259} + {}^{A_K}/_{4810} \tag{6}$$

Where A_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bq/kg.

3.2.5 The representative level index ($I_{\Upsilon r}$)

The representative level index can be calculated using the following relation [Ebaid and Bakr, 2012]:

$$I_{\gamma r} = \frac{1}{150} A_{Ra} + \frac{1}{100} A_{Th} + \frac{1}{1500} A_K \quad (7)$$

Where A_{Ra}, A_{Th} and A_K are activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively in Bq/kg.

3.3 Radon concentration measurements

In the present study, a portable radon monitor RTM 1688-2, SARAD device. To insure, the results were compared with those of a reference device (Alpha Guard, Saphymo).

3.3.1 Equilibrium factor and working level

The ratio of the actual PAEC (potential alpha energy concentration) to the PAEC that would prevail if all the decay products in each series were in equilibrium with the parent radon is called equilibrium factor F [UNSCEAR, 2000].

The concentration of radon and its daughters in air may be reduced to a value lower than the equilibrium value because of the disintegration, ventilation, and deposition (plate-out) [Faj and Planinic', 1991; Metin, et al., 2010; Bernard and Emilie, 2014]. During the calculation of the dose equivalent from radon and its daughters, the equilibrium factor is considered to be a very important parameter [Planinic' and Faj, 1990], which depends strongly on the ventilation rate. At secular equilibrium F = 1 which means that radon and all its decay products are in radioactive equilibrium and therefore have the same radioactivity concentration [Nazaroff and Nero, 1988]. Otherwise, F is less than unity. In the present work, F-value of 1 was assumed. Thus, for the studied tombs, the deduced dose values represent an upper limit. The Working Level (WL) can be defined using the following equation [Bodanisky, 1987]:

$$WL = \frac{F\,C(Bq/m^3)}{3700} \quad (8)$$

$$1\ \mathrm{WL} = 100\ \mathrm{pCi/liter} \quad (9)$$

For many years, one WL was considered to be the allowable maximum activity concentration [NIOSH, 1987]. Recently, the maximum activity concentration has been reduced to about one third of 1 WL [EPA, 1988; NRC, 1991; USDOE, 1993].

3.3.2 Occupational radon exposures and effective doses

Recently published values of effective dose conversion coefficients for inhalation of radon progeny derived using the Human Respiratory Tract Model (HRTM) ranged from about 10 to 20 mSv per WLM (3–6 mSv per (mJh/m^3)) depending on the exposure scenario [ICRP, 2010]. It should be noted that these coefficients are larger by a factor of two or more than the conversion coefficients derived from Publication 65 [ICRP, 1993]. The typical annual residence times in a tomb were estimated to be about 2400 h and 250 h for workers and tour guides, respectively. Also a value of 0.5 h per visit for visitors was considered as a result from discussions with the workers and from their daily schedules, and also referring to the previous work [Hafez and Hussein, 2001].

Based on the mentioned time intervals, the effective dose rate was calculated using the following equation [UNSCEAR, 2000]:

$$Dose\ (nSv/h) = C_o(\varepsilon_r + \varepsilon_d F) \quad (10)$$

Where C_o is radon concentration in Bq.m^{-3}, ε_r (0.17 nSv/h per Bq m^{-3}) is the dose conversion coefficient for radon and ε_d (9 nSv/h per Bq m^{-3}) is the dose conversion coefficient for radon daughters [UNSCEAR, 2000, 2009; ICRP, 2010].

3.4 Results and Discussions

3.4.1 Gamma Spectroscopic analysis

The specific radioactivity of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in the samples taken from the selected tombs in Luxor region are shown in Table 1. The results show that the average activity concentration (Bq.kg^{-1}) of the naturally occurring radionuclides in the collected samples (Limestone) are 15.30 Bq.kg^{-1} for ^{226}Ra and 22.32 Bq.kg^{-1} for ^{40}k. The specific radioactivity of ^{232}Th was found to be below the detection limit. These results are also lower than the average international radioactivity levels, which are 35 Bq/kg, 50 Bq/kg and 500 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K, respectively [UNSCEAR, 2008].

Table 1: Specific activity of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg for the selected Luxor tombs.

Tomb	^{238}U (^{226}Ra)	^{232}Th	^{40}K
KV5	17.78 ± 1.9	BDL	18.2 ± 1.2
KV9	14.16 ± 1.6	BDL	18.05 ± 0.7
KV13	15.89 ± 1.2	BDL	16.42 ± 2.1
KV32	14.73 ± 1.4	BDL	14.7 ± 1.3
KV46	13.92 ± 1.1	BDL	44.23 ± 3.9
Average Value	15.30	BDL	22.32

* BDL: Below the Detection Level.

Table 2 shows that the Ra_{eq} values for the investigated samples taken from the selected Luxor tombs ranged from 15.55 ± 1.65 – 19.18 ± 1.99 Bq/kg with an average of 17.01 Bq/kg, which is also lower than the world maximum limit value (370 Bq/kg) [OECD, 1979; Huy and Luyen, 2006]. The values of the absorbed dose rates ranging from 7.29 ± 0.77 – 8.97 ± 0.93 nGy/h with an average of 8.01 nGy/h, which is lower than the world average value (57 nGy/h) [UNSCEAR, 2008]. Moreover, the values of the annual effective dose rates are less than the world indoor average values (0.45 mSv y^{-1}) [UNSCEAR, 2008].

Table 2: Radium equivalent activity (Ra_{eq}) in Bq/kg, External hazard index (H_{ex}) in Bq/kg, Representative level index ($I_{\gamma r}$) in Bq/kg, Absorbed dose rate (D) in nGy/h, and Annual effective dose (EAD) in mSv/y in the investigated locations inside Luxor region.

Tomb	Ra_{eq}	H_{ex}	$I_{\gamma r}$	Absorbed dose rate	Annual Effective dose rate
KV5	19.18 ± 1.99	0.05 ± 0.01	0.13 ± 0.01	8.97 ± 0.93	0.04 ± 0.00
KV9	15.55 ± 1.65	0.04 ± 0.00	0.11 ± 0.01	7.29 ± 0.77	0.04 ± 0.00
KV13	17.15 ± 1.36	0.05 ± 0.00	0.12 ± 0.01	8.03 ± 0.64	0.04 ± 0.00
KV32	15.86 ± 1.50	0.04 ± 0.00	0.11 ± 0.01	7.42 ± 0.70	0.04 ± 0.00
KV46	17.33 ± 1.40	0.05 ± 0.00	0.12 ± 0.01	8.28 ± 0.67	0.04 ± 0.00
Mean Value	17.01	0.05	0.12	8.01	0.04

The obtained average values of H_{ex} and $I_{\gamma r}$ were 0.05 and 0.12, respectively. These values are lower than the recommended limit (≤ 1) [Bereka and Mathew, 1985; Ebaid and Bakr, 2012].

3.4.2 Radon concentrations

The Seasonal variation of the radon concentrations for the selected Luxor tombs obtained and illustrated in Table 3.

From Table 3, one can find that the lowest summer average radon concentration was measured at the tomb of TIA'A (KV 32) with a value of 157±7 Bq.m^{-3}, while the highest summer average radon concentrations were observed at the tomb of RAMESES II SONS (KV 5) with a value of 6365 ± 190 Bq.m^{-3} for the tomb's inner chamber and 5511 ± 276 Bq.m^{-3} for the tomb's middle chamber. In winter, the lowest average radon concentration was measured at the tomb of TIA'A (KV 32) with a value of 18 ± 2 Bq.m^{-3}, while the highest winter average radon concentration was observed at RAMESES VI tomb (KV9) with a value of 491 ± 16 Bq.m^{-3}. The remarkable variation of radon concentration inside these tombs can be attributed to a complex architecture and elevation, which made the tomb completely isolated from the surrounding. As an example, TIA'A (KV 32) tomb consists of a tunnel leads straight to the sarcophagus of total length 39.67 m. Compared with the previous results [Gurber, et al., 2011], the present results are similar as those obtained previously for RAMESES V and RAMESES VI tomb (KV 9).

Table 3: Seasonal variation of average radon concentrations inside the studied Luxor tombs in Bq/m^3

Tomb	Summer measurements (2014) [Present Work]		Winter measurements (2013) [Present Work]		Summer measurements (2011) [Gurber, et al., 2011]	
	Average radon Conc. (Bq/m^3)		Average radon Conc. (Bq/m^3)		Average radon Conc. (Bq/m^3)	
	Inner Chamber	Middle Chamber	Inner Chamber	Middle Chamber	Inner Chamber	Middle Chamber
KV 5	6365 ± 190	5511 ± 276	---	---	---	---
KV 9	614 ± 24	---	491 ± 16	---	580 ± 50	---
KV 13	327 ± 16	---	72 ± 6	---	---	---
KV 32	157 ± 7	---	18 ± 2	---	---	---
KV 46	342 ± 27	---	83 ± 11	---	---	---

The individual radon effective dose rates in the studied Luxor tombs are given in Table 4. These dose rates are directly governed by the mean radon concentrations measured in these tombs (see Table 3 and Eq. (10)). Highest individual radon exposures were obtained in RAMESES II SONS (KV 5) that also showed the highest radon concentrations in air, while the lowest individual radon exposures were obtained in TIA'A (KV 32).

Using the aforementioned annual residence time in a tomb for workers (2,400 h), tour guides (250 h) and visitors (0.5 h per visit), the annual effective doses were calculated and listed in Table 5. For workers, the annual effective doses ranged from 3.455 to 140.081 mSv/y, while for tour guides, lower annual effective dose ranging from 0.360 to 14.592 mSv/y were obtained. Thus, for workers the dose range obtained exceeds the maximum recommended action level for workers (20 mSv/year) [ICRP, 2010]. In contrast, rather low dose levels below the maximum recommended level were obtained for visitors in all tombs ranging from 0.001 to 0.029 mSv/y.

Table 4: working level (WL) and effective dose rates for the studied selected tombs.

Tomb Name	**Working Level (WL)**	**Effective dose rate (μSv/h)**
KV5	1.72	58.37
KV9	0.17	5.63

KV13	0.09	3.00
KV32	0.04	1.44
KV46	0.09	3.14

The obtained results demonstrate that the occupational dose from radon exposure inside the tombs depends on tomb location, geometry and duration of stay inside the tomb.

Table 5: The annual effective dose for workers, tour guides and visitors.

Tomb Name	Annual Effective Dose (mSv/y)		
	Workers	**Tour guides**	**Visitors** (Per Visit)
KV5	140.081	14.592	0.029
KV9	13.513	1.408	0.003
KV13	7.197	0.750	0.001
KV32	3.455	0.360	0.001
KV46	7.527	0.784	0.002

Conclusion

The indoor radon concentrations in five selected ancient Egyptian tombs at the valley of kings have been evaluated utilizing a portable radon monitor RTM 1688-2, SARAD. Alpha GUARD devise was also used as a reference detector. The results of the present work showed that, the radon level was in general higher than the world recommended level. All the estimated effective doses to tour guides and visitors are found to be lower than the world recommended level. Whereas for workers the mean effective doses exceed the effective dose limit (20 mSv/y). However for workers, the high values of radon level should be taken into consideration and strictly safety techniques and/or rules should be applied. Moreover, the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the collected samples from the same studied tombs were evaluated using high resolution gamma spectroscopy. The obtained results for ^{226}Ra, ^{232}Th and ^{40}K are lower than the international levels.

References

Akram, M., Riffat, M., Qureshi, N.A. and J.S. Tariq, J.S. Determination of gamma-emitting radionuclides in the inter-tidal sediments off Balochistan (Pakistan) coast, Arabian Sea. Radiat. Prot. Dosim., 105: 1-6 (2006).

Bereka, J., Mathew, P.J. Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys., 48, 87-95 (1985).

Bernard Collignan, Emilie Powaga, 2014. Procedure for the characterization of radon potential in existing dwellings and to assess the annual average indoor radon concentration. Journal of Environmental Radioactivity 137, 64-70.

Bodanisky D., (1987). “Indoor radon and its hazards” University of Washington press. Seattle and London.

Darby S., Hill D., Auvinen A., Barros-Dios J. M., Baysson H., Bochicchio F., et al., 2005. Radon in Homes and Risk of Lung Cancer: Collaborative Analysis of Individual Data from 13 European Case-control Studies. British Medical Journal, 29, 330 (7485): 223.

Ebaid, Y.Y. and Bakr, W.F. Investigating the effect of using granite and marble as a building material on the radiation exposure of humans. Rad. Prot. Dosimetry, PP. 1-8 (2012).

Faj Z. and Planinic' J., (1991). “Dosimetry of radon and its daughters by two SSNTDs” Radiation Protection Dosimetry, Vol. 35, No4, 265-268.

Gruber E., Salama E. and W. Ruehm. Real-time measurement of individual occupational radon exposures in tombs of the valley of the kings, Egypt. Radiation Protection Dosimetry (2011), Vol. 144, No. 1–4, pp. 620–626.

Huy, N.Q., and Luyen, T.V. Study on external exposure doses from terrestrial radioactivity in southern Vietnam. Radiat. Prot. Dosimetry. V. 118, PP. 331-336 (2006).

ICRP, 1993. Protection against Radon-222 at Home and at Work. ICRP Publication 65. Ann. ICRP 23 (2).

ICRP, International Commission on Radiological Protection. Protection against 222Rn at Home and at Work. ICRP Publication 65, Oxford (1994a).

ICRP, 2010. Lung Cancer Risk from Radon and Progeny and Statement on Radon. ICRP Publication 115, Ann. ICRP 40(1).

Jibiri, N.N., P.I. Farai, K.S. Alausa. Estimation of annual effective dose due to natural radioactive elements in ingestion of foodstuffs in tin mining area of Jos-Plateau, Nigeria. J. Environ. Radiat., 94: 31-40 (2007).

Metin Mihci, Aydin Buyuksarac, Attila Aydemir, Nilgun Celebi, 2010. Indoor and outdoor Radon concentration measurements in Sivas, Turkey, in comparison with geological setting. Journal of Environmental Radioactivity 101, 952-957.

National Institute for Occupational Safety and Health (NIOSH), 1987. A Recommended Standard for Occupational Exposure to Radon Progeny in Underground Mines. Publication Number 88-101.

Nazaroff, W.W., Nero Jr., A.V., 1988. Radon and Its Decay Products in Indoor Air, vol 1. John Wiley & Sons. ltd, Canada. 6-44.

Organization for Economic Cooperation and Development (OECD), Exposure to radiation from the natural radioactivity in building materials. Report by a Group of Experts of the OECD Nuclear Energy Agency (OECD, Paris, France) (1979).

Planinic J. and Faj Z., (1990). “Equilibrium factor and dosimetry of radon by a nuclear track detector”, Health physics, Vol.59, No.3, 349-351.

Ravisankar, R., Vanasundari, K., Chandra sekaran, A., M. suganya. P. Vijayagopal. V.Meenakshisundram. Measurement of Natural radioactivity in building materials of Namakkal. Tamilnadu. India using gamma ray spectrometry. App. Radiat. and Isotop., 70, 699-704 (2012).

U.S. Environmental Protection Agency (EPA). Limiting values of radionuclide intake and air concentration and dose conversion factors for inhalation, submersion, and ingestion. Washington, DC: United States Government Printing Office; Federal Guidance Report 11; EPA-520/1-88-020; 1988.

U.S. Nuclear Regulatory Commission (NRC). Standards for protection against radiation. Washington, DC: United States Government Printing Office; Title 10, Code of Federal Regulations, Part 20, Appendix B; 1991.

UNSCEAR, (United Nations Scientific Committee on the Effects of Atomic Radiation), (2000). Vol. I, “Sources and Effects of Ionizing Radiation” United Nations, New York.

UNSCEAR. Exposure of the Public and Workers from Various Sources of Radiation, Report to General Assembly, with Scientific Annexes, United Nation, New York (2008).

UNSCEAR, (United Nations Scientific Committee on the Effects of Atomic Radiation), (2009).Annex E. “Sources-to-Effects Assessment for Radon in Homes and Workplaces”, United Nations, New York.

United States Environmental Protection Agency (USEPA). A Citizen’s Guide to Radon. The guide to protecting yourself and your family from Radon 402-k-02-006 (2004).

U.S. Department of Energy (USDOE). Occupational radiation protection standards. Washington, DC: United States Government Printing Office; Title 10, Code of Federal Regulations, Part 835 (1993).