EG0500298

Passive and Active Measurements of Radon Related Parameters Inside Ancient Egyptian Tombs in Luxor

M. Abo-Elmagd*, S. M. Metwally, S. A. El-Fiki**, H. M. Eissa*, E. Salama****

***** *National Institute for Standard, Radiation Measurements Department, Giza, Egypt.*

****** *Faculty of Science, Department of Physics, Ain Shams University, , Cairo, Egypt.*

E-mail: s_m_metwally@yahoo.com

ABSTRACT

Radon concentration and its exhalation rate were measured using active (Alpha-Guard analyzer) and passive (CR-39) techniques inside seven ancient Egyptian tombs of the Kings valley in Luxor. The measurements were performed during the winter season of tourism (15/10/2003 up to 09/02/2004). The real radium content was determine for all examined tombs by HPGe detector, while the effective radium content was obtained by Alpha-Guard and sealed cup techniques. The average radon concentration inside the tombs based on the active technique ranges from 116±42 to 362±115 Bq m^{-3} and the exhalation rate ranges from 0.68 ± 0.30 to 1.47 ± 0.27 Bq m^{-2} h^{-1}. For passive measurements, the average radon concentrations inside the tombs vary from 88±5 to 517±38 Bq m^{-3} while the exhalation rate ranges from 0.60 ± 0.03 to 1.42 ± 0.05 Bq m^{-2} h^{-1}. Because of the variations of tombs dimensions and their ventilation systems, the equilibrium factor between radon and its progeny ranges from 0.10±0.04 to 0.99±0.14 based on Can and Bare measurement method. The effective dose rate inside the tombs varies from 0.11± 0.04 to 4.28±0.68 µSv/h, based on UNSCEAR 2000 dose conversion factors for radon and its progeny. Radon exhalation rate was correlated with the real radium content. Moreover, a good correlation was found between active and passive measurements. So it may be useful to use passive technique in large scale instead of the active one.

Key words: Radon/ Passive and active measurements/ exhalation rate/ effective dose and Egyptian tombs.

INTRODUCTION

Some ancient Egyptian tombs have been build and closed since more than 5000 years old and many of them were disclosure and opened for the visitors in the last century. Many of accidental deaths or diseases were observed among the discoverers and their assistances in different tombs. Some people attributed these accidents to the curse of Pharaohs. After extensive study of radiation and its health hazards, these accidents were attributed to the curse of radon gas.

Nowadays, it is well established that radon (^{222}Rn) is the only radioactive gas member in the middle part of the long radioactive series of ^{238}U. Radon daughters can be trapped in the lung via inhalation. Consequently either deposit the associated energy in the surrounding tissues [(1)] or transferred through the blood vessels to other organs, then produce different types of chromosomal aberrations which in turn increase the chance of cancer incidence, specially in organs that have high fats content like bone marrow.

Ancient Egyptian tombs of the valley of kings (more than 3000 years old) were cut in the limestone rocks of the west bank of the Nile river at Luxor (650 km far south of Cairo) [(2)]. These tombs attract thousands of visitors each year. Visitors, tour guides and tombs workers inhaled unknown radon doses because there is no adequate data available for these places. The aim of this work is to estimate these doses in winter season of tourism in Egypt. The measurements were taken place with the aid of passive and active techniques. Moreover, some of the radon related parameters like radon concentration, exhalation rate, real and effective radium content, emanation power and the effective dose rate were either measured or calculated.

EXPERIMENTAL WORK

1: Field Measurements

Alpha-Guard analyzer of type PQ2000Pro was used for measuring radon concentration inside the examined tombs. The Alpha-Guard was operated by diffusion mode with a cycling time interval of 10 minutes. The measurement duration is one day per tomb. The passive device used for measuring radon concentration is a diffusion cup (7 cm diameter and 5 cm high) fitted with CR-39 detector at its bottom while the open end was covered with filter paper of 170 µm thickness and 112.7×10^{-8} cm^2 s^{-1} permeability. Moreover, an external (bare) CR-39 detector was fixed outside the cup. For getting on good statistics, the diffusion cups with their external detectors were distributed in different positions inside each examined tomb. The measuring time with the passive device in every tomb extends from 15/10/2003 up to 09/02/2004.

The track density ratio (D/D_o) was used for calculating the equilibrium factor F

$$F = \exp\left[a + b\left(\frac{D}{D_o}\right) + c\left(\frac{D}{D_o}\right)^3\right] \tag{1}$$

Where D_o is the filtered track density while D the external one. The free parameters a, b and c have the values of –5.902, 3.059 and -0.118 respectively [(3)].

The radon concentration C_o inside each tomb was calculated by the following equation [(4)]

$$C_o = \frac{D_o}{K_T\ t} \tag{2}$$

Where K_T is the total detector response of the used diffusion cup, it equals 0.18 ± 0.02 track cm^{-2} per Bq m^{-3} [(5)], and t is the exposure time in days.

Using a dose conversion factor of 6.30 mSv /WLM [(6)], the effective dose rate was calculated using F and C_o as

$$Dose\ (\mu Sv/h) = 0.01\, F.\ Co \tag{3}$$

For comparison, the effective dose rate was calculated using the following equation [(7)]

$$Dose\ (nSv/h) = C_o(\varepsilon_r + \varepsilon_d F) \tag{4}$$

Where ε_r (0.17 nSv/h per Bq m^{-3}) and ε_d (9 nSv/h per Bq m^{-3}) are the dose conversion factors for radon and its daughters respectively.

2:Laboratory Measurements

Samples from all studied tombs were collected, then ground and sieved to be suitable for laboratory measurements of radon related parameters.

The real radium content C_{Ra}^{real} (Bq kg^{-1}) is the real specific concentration of radium in a given sample. It was measured by using P-type HPGe detector (CANBERRA, model: GC5019, of 50 % efficiency at 0.662 MeV and 218 cc of volume).

2.1 Active Measurements

Alpha-Guard chamber (0.05 m^3) was equipped with the Alpha-Guard analyzer and the prepared sample of surface area 442 cm^2. The concentration of radon emanated from the sample was allowed to build up with time t (hours). The build up of radon concentration (atom m^{-3}) inside the chamber can be represented by the following equation

$$V\frac{dC}{dt} = -\lambda VC + A_S + DS\frac{dC}{dx} \qquad \textbf{(5)}$$

Where V is the chamber volume, λ is the decay constant of radon, A_S is the source activity, S is the internal surface area of the chamber. Assuming no background in the chamber and no diffusion through the chamber surfaces, i.e. D equals zero, then equation (5) reduces to

$$V\frac{dC}{dt} = -\lambda VC + A_S \qquad \textbf{(6)}$$

Based on the above boundary conditions, equation (6) has the solution

$$C(t) = \frac{A_S}{V\lambda}(1 - e^{-\lambda t}) \qquad \textbf{(7)}$$

Comparing equation (7) with the well-known formula [8]

$$C(t) = C_o(1 - e^{-\lambda t}) \qquad \textbf{(8)}$$

Then $C_o = \frac{A_S}{V\lambda}$, from which one can determine the source activity as $V\lambda C_o$ and radon exhalation rate Φ_A, which is defined as the flux of radon releases from a sample of activity A_S and surface area A (m^2) i.e.

$$\Phi_A\ (\mathrm{Bq\ m^{-2}\ hr^{-1}}) = \frac{A_S}{source\ surface\ area} = \frac{C_o\ V\ \lambda}{A} \qquad \textbf{(9)}$$

The effective radium content C_{Ra}^{eff} (Bq kg^{-1}) is the specific concentration that produces radon able to escape from the sample to the surrounding space. It can be calculated by using

$$C_{Ra}^{eff} = \frac{C_o\ V}{W} \qquad \textbf{(10)}$$

where W is the sample weight in kg.

2.2 Passive Measurements

A weight of 100 gm of each studied sample was equipped on the base of a tightly closed glass cup with a metal cover of volume 375 cm^3 and mouth area 45 cm^2. CR-39 detectors of surface areas 1 cm^2 were fixed on the inner top of the cup and sealed for 155 days. The lower surface of the CR-39 detector is exposed freely to the emanated radon gas from the source so that it can record the emitted α-particles from the decay of radon gas in the remaining volume. After ending the exposure interval, the detectors were etched under their optimum conditions of 6 hours etching time in 6.25 N NaOH etchant normality at 70 ^oC temperature. The resulting track densities were counted under an ordinary optical microscope of 400X magnification power. From the geometry of the cup, the exhalation rate Φ_A (Bq m^{-2} hr^{-1}) and the effective radium content C_{Ra}^{eff} (Bq Kg^{-1}) can be estimated by using the following equations [9-11]

$$\Phi_A = \frac{D_o\ V\ \lambda}{K_T\ A\left[t - \frac{1 - e^{-\lambda t}}{\lambda}\right]} \qquad \textbf{(11)}$$

$$C_{Ra}^{eff} = \frac{D_o\, V}{K_T\, W \left[t - \frac{1 - e^{-\lambda t}}{\lambda} \right]} \qquad \textbf{(12)}$$

Where D_o is the registered track density (Track cm^{-2}). V, A are the cup volume (m^3) and surface area (m^2) respectively. t, λ are the exposure time (in days) and the radon decay constant (7.55 x 10^{-3} hr^{-1}) respectively. K_T is the used detector response (Track cm^{-2} per Bq m^{-3} d).

The emanation power can be calculated using the following relation

$$a = \frac{C_{Ra}^{eff}}{C_{Ra}^{real}} \qquad \textbf{(13)}$$

RESULTS AND DISCUSSION

The Alpha-Guard analyzer (active method) registered radon concentrations inside 4 of the examined tombs while track densities registered by CR-39 detectors (passive method) were used for calculating radon concentrations inside all examined tombs with the aid of equation (2). The average radon concentrations with the experimental error as measured by Alpha-Guard analyzer were 116 ± 42 (Ramses III), 167 ± 52 (Merenmbtah), 353± 71 (Tut Ankh amon), and 362 ± 115 Bq m^{-3} (Thotmus III) while that due to CR-39 detectors were represented in figure (1) arranged based on their values.

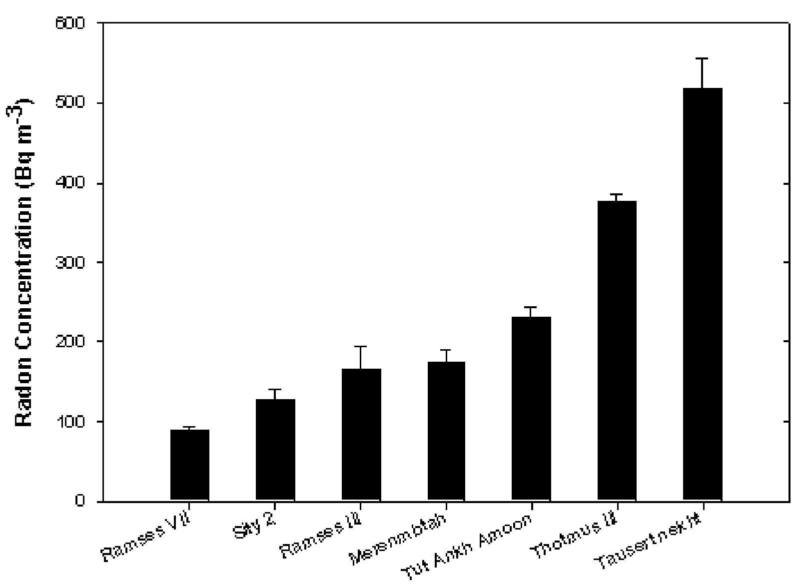

Figure (1): The average radon concentrations inside the depicted tombs as determined by CR-39 detectors. The tombs were arranged based on their values only.

The individual results due to the active and passive methods have a general correspondence while the experimental errors in the active measurements are larger than that in the passive one. This may be due to the short interval of measurements, one day for each tomb, in comparison with the 114 day for the passive measurements.

Table (1) lists the passive measurements of the equilibrium factor (F), and the effective dose rate. A good agreement is obtained between the dose rate measurements using equation (3) and (4) where the relative difference is less than 10%.

The tomb dimensions and its ventilation system represent important factors for controlling the radon concentration and the related parameters. The concentration of radon increases as S/V value, where S is the tomb walls surface area while V is its volume. On the other hand, the ventilation system affects the value of the equilibrium factor, where F decreases as ventilation rate increase. The measurements were performed at winter, where the temperature inside the tombs is greater than the surrounding environment. So the warm air inside the tomb is lift up to outside environment and the outside cold air of low radon concentration flows into the measuring region consequently makes a winter minima [(12)]. Therefore, higher concentrations were registered in the rest of the year, especially in the worm months of summer [(2)].

Table (1): Passive measurements of the equilibrium factor and the effective dose rates in different tombs (± 1 S.D.).

Tombs Names	**D_o** Track cm^{-2}	**D** Track cm^{-2}	**F***	**Dose rate** μSv/h	
				ICRP ** **(1987)**	**UNSCEAR** *** **(2000)**
Ramses III	3384±604	8859±508	0.99±0.14	1.66±0.52	1.52±0.47
Merenmbtah	3565±314	5999±498	0.27±0.09	0.48±0.21	0.46±0.19
Tut Ankh amon	4690±297	5819±484	0.10±0.04	0.23±0.10	0.24±0.09
Thotmus III	7718±188	20173±1332	0.99±0.06	3.71±0.30	3.41±0.27
Sity II	2615±249	5317±356	0.51±0.13	0.66±0.23	0.62±0.21
Ramses VII	1813±110	2398±174	0.12±0.04	0.11±0.04	0.11±0.04
Tausert nekht	10611±770	26437±833	0.90±0.08	4.67±0.75	4.29±0.68

* (Eq. 1), ** (Eq. 3), *** (Eq. 4)

The mean time spent in a tomb by the workers and the tour guides in the winter season is 750 h and 78 h respectively and 0.5 h per visit for the visitors [(2)]. The expected effective doses per winter season for every individual based on the mentioned time intervals will be as given in table (2).

Table (2): The expected effective doses (± 1 S.D.) from radon and its decay products for workers, tour guides and visitors during the winter season of tourism based on ICRP [(6)] and UNSCEAR formula [(7)].

Tombs Names	Effective dose (μSv)					
	ICRP(1987)			UNSCEAR (2000)		
	Workers	Tour guide	Visitors $\times 10^{-2}$	Workers	Tour guide	Visitors $\times 10^{-2}$
Ramses III	1223±391	127±41	82±26	1122±355	119±37	75±24
Merenmbtah	349±154	36±16	23±10	336±140	35±15	22±9
Tut Ankh amon	166±73	17±8	11±5	179±67	19±7	12±4
Thotmus III	2783±228	289±24	186±15	2553±206	265±21	170±14
Sity II	487±171	51±18	32±11	455±156	47±16	30±10
Ramses VII	79±31	8±3	5±2	82±28	9±3	5±2
Tausert nekht	3490±564	363±59	233±38	3207±512	334±53	214±34

The laboratory measurements of radon exhalation rate (Eq. 9 & Eq. 11), effective Radium content (Eq. 10 & Eq. 12), and the emanation power (Eq. 13) are listed in table (3). The correlation between real Radium content and the exhalation rate for both active and passive measurements is shown in figure (2).

Using the concept of correlation coefficient, which is defined as

$$r_{x,y}^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{n \times \sigma_x \times \sigma_y} \quad \textbf{(14)}$$

Where $\bar{x}$ and $\bar{y}$ are the means of two sets of data x_i and y_i, each of length n and standard deviation σ. It is found that, The correlation between real radium content and exhalation rate for passive technique (r^2 =0.82) is approximately equals that for the active one (r^2 =0.83). The short period of measurements with the Alpha-Guard analyzer (7 days for each sample) introduced high uncertainty for the measurement of low level radioactivity in contrast with the very small uncertainty introduced by the passive technique.

Table (3): Active and passive results of radon related parameters.

Tombs Names	C_{Ra}^{real} (Bq/Kg)	C_{Ra}^{eff} (Bq Kg^{-1})		Emanation power	
		Active	Passive	Active	Passive
Ramses III	29.50±3.00	7.45±1.91	5.03±0.17	0.25±0.15	0.17±0.07
Merenmbtah	22.29±2.70	5.79±2.11	3.17±0.11	0.26±0.24	0.14±0.19
Tut Ankh amon	20.73±2.29	3.70±1.08	2.20±0.06	0.18±0.18	0.11±0.08
Thotmus III	17.43±2.69	4.76±1.75	3.37±0.08	0.27±0.21	0.19±0.13
Sity II	15.50±0.97	4.79±1.20	2.14±0.10	0.31±0.19	0.14±0.02
Ramses VII	18.84±1.90	5.16±1.32	2.61±0.11	0.27±0.15	0.14±0.06
Tausert nekht	16.11±1.67	5.06±1.32	2.76±0.12	0.31±0.16	0.17±0.06

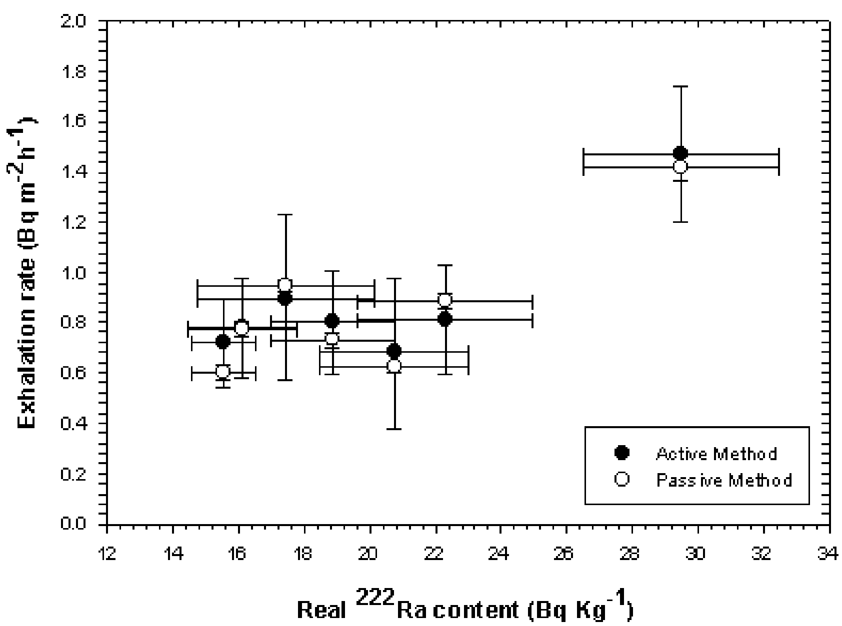

Figure (2): Exhalation rate for passive and active techniques as a function of real radium content. The passive exhalation rate has very small uncertainty in comparison with that of both the active technique and the real radium content.

Also, a good correlation between active and passive measurements, (r^2 =0.94), is obtained for the measurement of exhalation rate as shown in figure (3). The inset equation of regression line, shows that the line has a very small deviation from the origin with a slope of 1.008, while the confidence interval of 95% include approximately all the experimental data. The correlation enhances to 0.97, if the uncertainties are neglected. This means that, it will be useful to use passive technique in large scale instead of the active one in such studies.

CONCLUSION

Active measurement is precise and gives fast results, but it can not be used for a long time. The advantages of CR-39 come from its ability for integrating the results, over long exposure periods. So it is useful in low radioactive level measurements which introduce high uncertainties in active measurements. Extensive study of passive technique and its correlation with active one is important to substitute the active technique.

A good estimation of the radon exhalation rate is advantage for the calculation of radon doses by knowing the tomb dimensions. This measurement can be performed in the laboratory for a large sample numbers using simple equipment.

The workers in Tausert nekht and Thotmus III tombs may receive excess of some mSv per year. Therefore, advanced and efficient ventilation systems must be used in these tombs. On the other hand, the tomb of Ramses VII has the lower radon concentration (88 Bq m^{-3}) and equilibrium factor (0.12) which in turn leads to the lower effective dose for the worker. This may be due to the glass cover of the wall as well as its small surface to volume ratio.

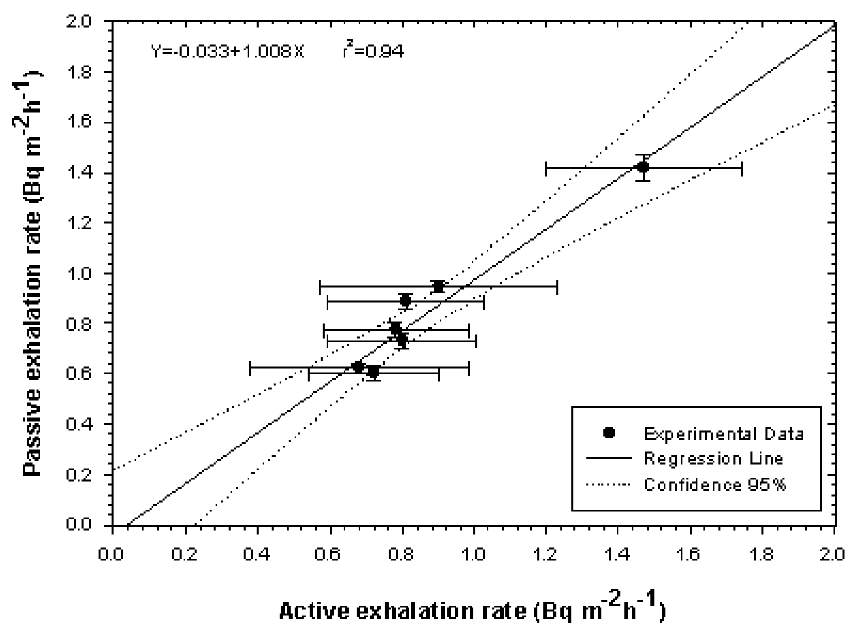

Figure (3): Correlation between active and passive measurements for exhalation rate. The solid lineisthe best fit while the dotted curves limit the 95% confidence interval about the mean line.

ACKNOWLEDGMENTS

The authors appreciate the full cooperation given by the Supreme Council of Antiquities Ministry of Culture and the assistance of the tour guides throughout the survey. Also, they introduce their deep thanks to the faculty of science, Ain Shams University for the partial support.

REFERENCES

(1) H.A. Khan;Nuclear Track Radiation Measurements; **19**, Nos. 1-4, 353 (1991).
(2) A. F.Hafez, and A. S. Hussein; Applied Radiation and isotopes; **55**, 355 (2001).
(3) M. Abo-Elmagd; Radiation Measurements; Article in Press, (2004).
(4) D.Nikezic; Nuclear Instruments and Method; **A 344**, 406-414, (1994).
(5) M.Mansy, S. A. El Fiki, M. Abo- El Magd, and M. A. El Fiki; Egyptian J. of BioPhysics; 4, 91 (1998).
(6) ICRP (International Commission on radiological protection), Lung cancer risk from indoor exposure to radon daughters. A report of a task group of the ICRP, Pergamon press, Oxford. ICRP publication 50, (1987).
(7) UNSCEAR, (United Nations Scientific Committee on the Effects of Atomic Radiation). "Sources and Effects of Ionizing Radiation", United Nations, New York, (2000).
(8) M. H. Al-Jarallah, F. abu-Jarad, and Fazal-ur-Rahman; Radiation Measurements; **34**, 491 (2001).
(9) R. Mustonem;Radiation Protection Dosimetry; **7**, 235 (1984).
(10) G. Somgy, Abdel-fattah Hafez, I., Hunyadi, and M. Toth-Szilagyi; Nuclear Track Radiation Measurements; **12**, 701 (1986).
(11) K. Singh, D. Sengupta, and Rajendra pressad; Applied Radiation and Isotopes; **51**, 107 (1999).
(12) A. F. Hafez, M. A. Kotb, and G. I. Khalil; Radiation Measurements; **28**, Nos. 1-6, 671-674, (1997).