Arab J. Nucl. Sci. Appl., Vol. 53, 1, 182-190 (2020)

Arab Journal of Nuclear Sciences and Applications

ISSN 1110-0451 | *Web site: ajnsa.journals.ekb.eg* | (ESNSA)

Detection of Radon, Radon Daughters and Thoron Daughters in Abu Tartur Open Pit Phosphate Mine, Egypt

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Received 16th Aug. 2019
Accepted 14th Nov. 2019

In this study, Abu Tartur open-pit Phosphate mine and underground tunnels have been studied from radiation safety point of view. Radon, radon daughters and thoron daughters were measured by collecting (31) samples from (5) main sites that represent the process of Phosphate mining. Results of radon, radon daughters and thoron daughters, in case of open-pit mining ranged from 1.37 to 131.52 Bq m-3, 0.000099 to 0.0024 WL, and 0 to 0.92 Bq.m-3 respectively. For postpone tunnels, results of radon, radon daughters, thoron daughters ranged from 411.55 to 2539.27 Bq m-3, 0.056 to 0.37 WL, and 1.26 to 3.89 Bq.m-3 respectively. Also, gamma radiation levels, surface contamination and effective annual dose were measured. Gamma radiation levels ranged from 0.07 to 0.6 mSv/h for open-pit mine and from 0.24 to 0.5 mSv/h for tunnels. Surface contamination measurements gave normal readings for open-pit mining and 7.1 in underground mine. The effective annual dose ranged from 0.033 to 0.153 mSv/y for open-pit and 4.948 mSv/y for tunnels. The results, in case of open-pit mine, are lower than permissible limits determined by UNSCEAR, 2010 while exceeds the permissible limits in case of underground tunnels. So the open-pit mining is much safer from the occupational radiation protection point of view.

Keywords: *Radionuclides; Nano-silica; Sorption; Primary coolant water treatment; Safety barriers*

INTRODUCTION

Phosphate mines in Egypt are distributed through the eastern and western desert where El Hamraween, Al Quser and Safaga mines are located in eastern desert 500 km south of Cairo. Abu-Tartor mine is located in the western desert 650 km south Cairo on El-Dakhla Oases road, 50 km west of El-Kharga city, capital of New Valley Governorate, Egypt.

The plateau is situated in the southwestern sector of Egypt in the western desert at 300 km west of Assiut city at River Nile, 650 km south of Cairo city and 700 km west of Safaga port at the Red Seacoast. Abu-Tartur plateau forms a part of the rugged stretch that separates Dakhla and Kharga Oases in the western desert of Egypt [1].

Abu-Tartor mine is a close cast mine. The current reserve estimate in the exhaustively investigated area is in the order of a billion tons of Phosphate ore. The planned ore rock annual production is 4 million tons which will be processed to produce 2.2 million tons per year of wet rocks. In the purification process, the ore rocks are crushed, sieved and transferred to the processing plant. In the processing plant, the ore rocks are washed, wet screened and flotation-separated to produce wet rocks and different rejects. These rejects include primary hand pick-up (clay and dolomite rocks), wet screening and magnetic separation and slime (clay suspension). The magnetic separation and primary rejects are returned back to the land. The slime is pumped to impoundment. The wet rocks are stocked in large open piles for sale or transport to a Phosphate chemical plant. Water is recycled to the greatest possible extent [2].

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DOI: 10.21608/ajnsa.2019.14897.1237

Open-pit mining offers some advantages over traditional deep shaft mining. Pit mining is more cost-effective than shaft mining because much more ore can be extracted and quickly processed. The working conditions are safer for the miners because there is no risk of the cave or toxic gases. An open-pit mine is cheaper, safer, and mechanically easier to operate. This is cheaper to operate because less manpower and equipment are required. Therefore, open-pit mining is more profitable .

This form of mining differs from extractive methods that require tunneling into the earth, such as long wall mining. Open-pit mines are used when deposits of commercially useful ore or rocks are found near the surface; this is where the overburden (surface material covering the valuable deposit) is relatively thin or the material of interest is structurally unsuitable for tunneling (as would be the case for sand, cinder, and gravel). For minerals that occur deep below the surface, where the overburden is thick or the mineral occurs as veins in hard rock, underground mining methods are used to extract the valued material.

Open-cast mines are dug on benches, which describe vertical levels of the hole. These benches are usually on four to sixty meter intervals, depending on the size of the machinery that is being used. Many quarries do not use benches, as they are usually shallow [3].

Left over waste from ore processing is called tailings, and is generally in the form of a slurry. This is pumped to a tailings dam or settling pond, where the water is reused or evaporated. Tailings dams can be toxic due to the presence of non-extracted sulfide minerals, some forms of toxic minerals in the gangue, and often cyanide which is used to treat gold ore via the cyanide leach process. If proper environmental protections are not in place, this toxicity can harm the surrounding environment [4].

Some studies discussed the radon concentration in some Phosphate mines. A typical concentration of ^{238}U in sedimentary Phosphate deposits is 121 mg/kg (1500 Bq/kg) with a range of 30–260 mg/kg (372–3224 Bq/kg) [5]. The uranium contents of some Egyptian Phosphate rocks in the Red Sea coast and several Nile valley sites are in the ranges of 19–142 mg/kg (235–1761 Bq/kg) and 48–185 mg/kg (595–2294 Bq/kg), respectively [6]. The average ^{238}U content in Abu-Tartor Phosphate rock is about 32.9 mg/kg (408 Bq/kg) [2].

In this study, due to the new technique of mining that Abu Tartour Phosphate mine follow where the workers are digging from the surface of the mountain making a huge shallow pit with depth nearly to 60 m instead of mining underground inside the mountain. In order to study, assess and document the activity of radon and radioactive airaccompanying digging and radiological hazards on the workers, Rn-222, Rn daughters and Rn-220 were measured through collecting (31) samples from (5) main sites that represent the process of Phosphate mining.

The overall objectives are first to determine if the radon concentrations in the mine area are within the acceptable limits determined by international organization for work places, then to assess if further measurements are necessary or not and finally to compare the results in the case of open-pit with postponing underground tunnels.

Experimental work:
Instrumentations and techniques

- **Radiation measurement instruments**

RDA-200 is used for measuring the ambient levels of radon and radon daughter concentrations in a variety of environments. It operates with a linear response over a wide range and with high sensitivity. Therefore, it can be used to measure levels in normal residential areas as well as high levels associated with uranium mining and milling operations. RDA-200 electronics console has been designed to measure the alpha particle activity originating from radon and its daughters. The alpha particles register on the ZnS (Ag) phosphor coating of the scintillator cell or tray in the form of light flashes. Each flash of light, as seen by the high gain photomultiplier tube, is transformed into an electrical impulse. These impulses are accumulated, counted and then digitally displayed by the scaler circuitry, after a present counting time has been completed.

A small battery-powered air pump was used for the collection of radon, radon daughters, thoron daughter's samples, which has a flow rate ranges from 1-10 $L.min^{-1}$.

Lucas cells (PYLON type RN-150A) with a volume of 160 mL were used in this work. The Lucas scintillation cell (LSC) is commonly used all over the world for the estimation of radon. The cell was originally devised by Vandilla and Taysum.[7]. The inner surface of the cell is coated by silver activated zinc sulfide, a phosphor which emits light flashes when struck by alpha particles. The cell is equipped with two valves, one for a small pump connection to draw the air sample through the cell (outlet valve) and the other for replacing the air in the cell with air from the environment (inlet valve). The valves are sealed before and after sample collection, and it is customary to connect a high efficiency filter to the inlet valve to prevent the entry of long lived alpha contamination during sampling.

Scintillator trays were used to measure the concentration of radon daughters by counting the deposited particles on the filters using EDA-200.

A Millipore type 25 mm diameter with 0.8 micron Millipore filter disc were used to filter out long lived radon daughters and allow only for gas to get into Lucas cell. Surface contamination monitor to detect the surface contamination was used in addition to Eberline survey meter which was used to detect the gamma dose rate [8].

- **Calibration of the instruments:**

All calibration processes were performed in Radon Gas Laboratory in the Egyptian Nuclear and Radiological Regulatory Authority. Potentials calibration of RDA for Ra, and Am were conducted according to the instrument manual [8]. Calibration of lucas cells was performed according to Pylon-150 calibration source manual. Scintillator trays were calibrated by Am^{241} point source [9].

According to the calibration results of RDA-200, the "Ra" potentiometer setting is equivalent to 500 volts and the "Am" potentiometer setting is equivalent to 600 volts.

- **Collection of Samples**

The samples were collected to cover all the sites of the mine, (8) samples were collected from sectors 2 and 5 (working places), (9) samples were collected from the crushers, (4) samples were collected from the storage area, and (5) samples were collected to cover the borders of the mine from east, west, north, and south, in addition to the middle area. In addition, (5) samples were taken from underground mine to assess its computability to permissible limit and compare the results of underground to the up ground results. In each site, the samples were collected from working area, control room and rest area. The coordinates of all sampling points were identified by the Global Positioning System device (GPS, eTrex, Personal Navigator, Garmin Ltd).

Measurements:

Radon concentration were measured using Kusnetz method using lucas cells where sample were collected for 10 minutes with a flow rate of 4 $L.m^{-1}$ using filter paper before the cell inlet. After delaying time of 3 hours, the cell is counted for 10 min using EDA-200 and radon concentrations were calculated using **Eq.1**.

$$\boldsymbol{Radon\ Activity} = \frac{\boldsymbol{CPM}}{\mathbf{1.612}(\boldsymbol{PCi/l/cpm})}\ (\boldsymbol{PCi/litre}) \quad \textbf{(Eq.1)}$$

Where 1.612 PCi/l/cpm is the average coefficient determined by AECB using randomly selected cells.

Radon daughters concentration or working level (any combination of short lived radon daughters in 1 liter of air that result in the ultimate release of 1.3×10^5 million electron volts of alpha energy, WL) were measured using Rolle method where radon daughters are collected on filter paper with 5µm pores and flow rate 4 L m^{-1} for 10 minutes. After 4.35 minutes delaying, the filters are measured for 5 minutes using EDA-200 with scintillating tray [10], WL is calculated using **Eq.2**.

$$\mathbf{WL} = \frac{\mathbf{CPM}}{\mathbf{E \times V \times t \times F}} \quad \text{(Eq.2)}$$

Where:
E: counting efficiency
V: volumetric sample rate
t: sampling time
F: conversion factor = 212 for sampling periods from 1 to 20 min

Due to their long half-life time (10.6 hours), thoron daughters are measured using the same filter used to collect and measure radon daughters, but after delaying time more than (5 hours). The filters are measured for 5 minutes using EDA-200 with scintillating tray, WL is calculated using **Eq.3** [11].

$$ThB = \frac{0.411 \times CPM \times e^{0.001086T}}{E \times V \times t} \quad \text{(Eq.3)}$$

Where:
T: time in minutes from the end of sampling to mid-point of the counting interval (<300 min)
E: efficiency of the scintillator tray material
V: volumetric sampling rate
t: sampling time

Surface contamination monitor to detect the surface contamination was used in addition to Eberline survey meter was used to detect the gamma dose rate.
The effective annual dose was calculated using **Eq.4** [12][13].

$$\text{Effective annual dose (mSv/y)} = \mathrm{C} \times \mathrm{F} \times \mathrm{T} \times \mathrm{DCF} \quad \text{(Eq.4)}$$

Where:
C : the arithmetic mean radon concentration in Bqm^{-1}
F :0.2 is the typical recommended equilibrium factor value used for Mines [10]
T : Occupancy time of 2000 h
DCF : a recommended value of 9 nSv (Bqm or 9 $nSv/Bqhm^{-3}$ or 9.0×10^{-6} mSv/h per Bqm^{-3} was used to convert radon equilibrium-equivalent concentration to population effective dose.

RESULTS AND DISCUSSION

The results of efficiency calibration of Lucas cells and trays are indicated in **Table (1)** and **Table (2)** respectively.

Table (1) the results of efficiency calibration of Lucas cells

Cell Number	Efficiency (%)
1	52
2	58.2
3	44
4	64
5	62

Table (2) the results of efficiency calibration of trays

Tray Number	Average Efficiency (%)
1	47.13
2	47.68
3	43.14

The results of radon, radon daughters and thoron daughters are indicated in **Table (3)**.

Samples Locations		Rn(Bq/m^3)	working level	Thoron Daughters (Bq/m^3)
Work Places	Sector 2	18.36	0.000247329	0.241
		10.56	0.000346260	0.517
		131.52	0.000643055	0.230
		9.18	0.000197863	0
	Sector 5	18.36	0.000480605	0.243
		15.30	0.000197863	0
		15.30	0.000213602	0
		40.40	0.000099000	0.239
Crusher s	Crusher 3	26.62	0.000263817	0.918
		11.48	0.000263817	0
		12.16	0.000197863	0
		13.38	0.000395726	0
	Crusher 7	21.346154	0.000445192	0.276
		7.5744417	0.000346260	0
		7.5744417	0.000296795	0
		7.5744417	0.000197863	0
		1.3771712	0.000346260	0.265
Storage	Storage 3	28.23201	0.000263817	0
		12.853598	0.000263817	0
	Storage 29	15.148883	0.000263817	0.299
		15.148883	0.000395726	0
Mine Directions	North	33.511166	0.002374357	0.229
	South	16.755583	0.000544123	0
	East	10.558313	0.000148397	0
	West	41.315136	0.000346260	0
	Middle	23.641439	0.001137713	0
Postpone Tunnels	RG3 (E)	516.43921	0.067520776	1.657
	A1	411.54467	0.055550059	1.264
	B4	2539.2742	0.369509300	3.891
	B2	2063.4615	0.230807281	3.321
	RG3 (W)	1341.8238	0.152107242	1.740

Table (3) Radon, radon daughters and thoron daughters' concentrations E, and W represents East, and West respectively.

Figures (1,2) and 3) show comparisons between average concentration of radon, radon daughters and thoron daughters respectively, for each site on logarithmic scale. Also standard deviation and standard errors were calculated and recorded in **Table (4).**

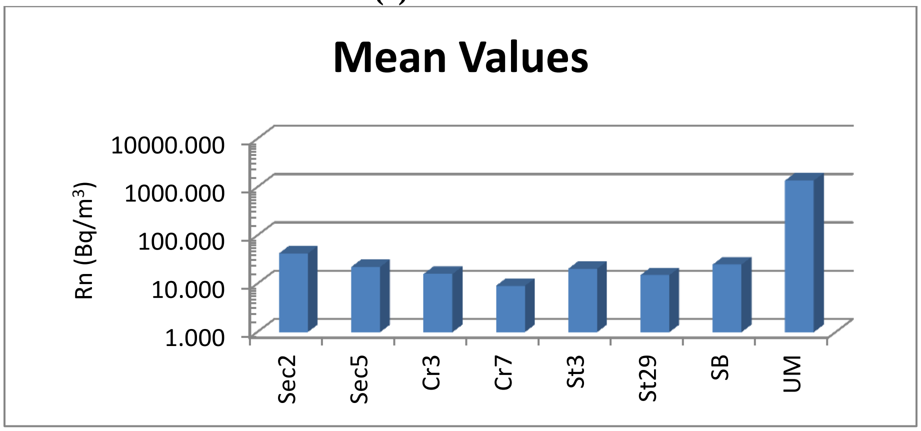

Fig. (1): Mean values of Radon gas concentration levels in all sites

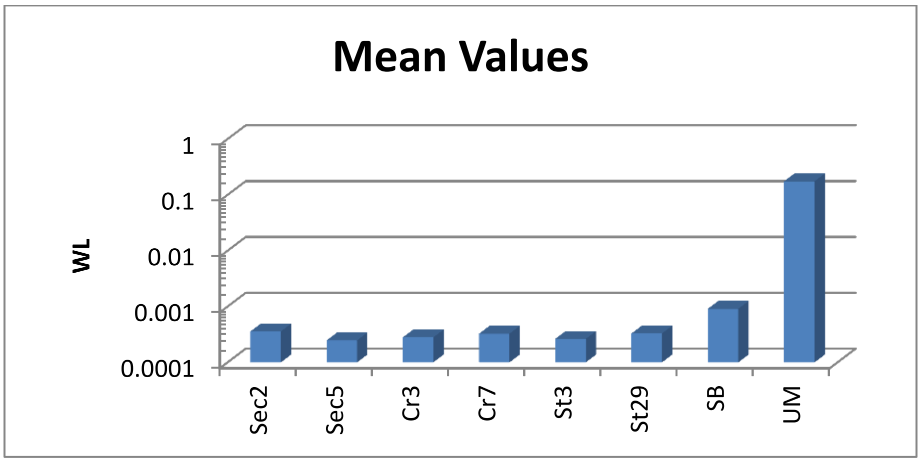

Fig. (2): Mean values of radon daughters concentration levels in all sites

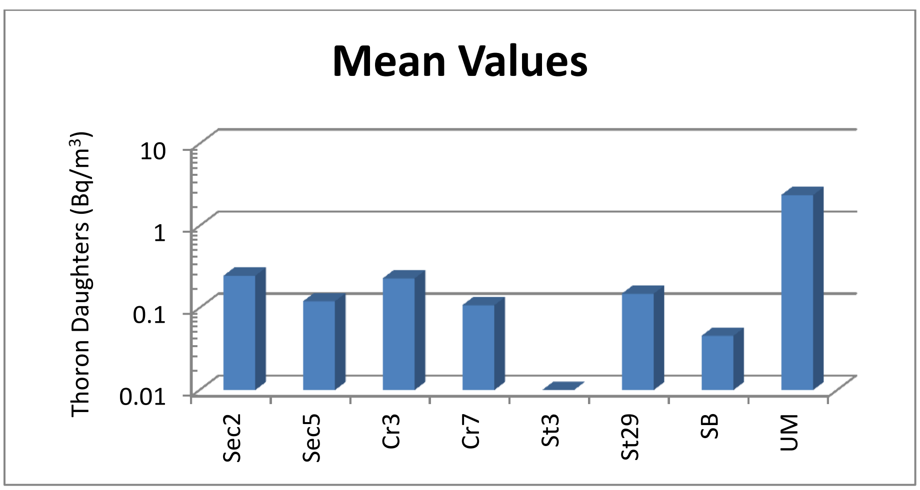

Fig (3): Mean values of Thoron daughters concentration levels in all sites

Table (4): Mean, standard deviation and standard error of radon, radon daughters and thoron daughters for each site

	Radon			Radon Daughters			Thoron Daughters		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
Sec2	42.40	59.55	34.38	0.000359	0.000199	0.000115	0.2468	0.2113	0.1057
Sec5	22.34	12.12	6.99	0.000247	0.000163	0.000094	0.1206	0.1393	0.0697
Cr3	16.01	7.14	7.26	0.00028	0.000083	0.000048	0.2296	0.4592	0.2296
Cr7	9.09	7.36	3.68	0.000326	0.000090	0.000045	0.1081	0.1481	0.0662
St3	20.54	10.87	10.87	0.000264	0	0	0	0	0
St29	15.15	0	0	0.00033	0.000093	0.000093	0.1494	0.2113	0.1494
SB	25.16	12.42	6.209	0.00091	0.000898	0.000449	0.0458	0.1024	0.0458
UM	1374.51	934.88	467.44	0.175099	0.129704	0.064852	2.3743	1.1562	0.5171

Radon results ranged from 1.377 to 131.52 Bq m^{-3}, the highest radon concentration in the mining area (131.52 Bq m^{-3}) was the nearest point to the ore.

Measurements in underground tunnels vary from 411.55 to 2539.27 Bq m^{-3} due to the variation in ventilation and air flow rate where (UM-1) and (UM-2) were collected from the western site of the underground mine where there was a good ventilation. On the other hand, in the eastern site the ventilation system was broke down which causes the highest level of radon concentration (2539.27 Bq m^{-3}) [14].

Radon daughters' concentration ranged from 0.000099 to 0.00237 WL. Measurements in postpone tunnel vary from 0.0555 to 0.3695 WL. The highest concentration was inside the eastern site (UM-3) due to the bad ventilation.

Thoron daughters' concentration ranged from 0 to 0.918 Bq.m^{-3}. Measurements in postpone tunnel vary from 1.264 to 3.891 Bq.m^{-3}. The highest concentration was inside the eastern site (UM-3) due to the bad ventilation.

The effective annual dose expected for the workers in the mine was calculated and recorded in Table (5) and ranged from 0.033 to 0.153 mSv/y for open-pit and 4.948 mSv/y for underground mine with an average annual dose of 0.687 mSv/y.

Table (5) Effective annual dose in (mSv/y) each site

Site	Mean Radon Concentration (Bq/m^3)	Effective annual dose (mSv/y)
Sec2	42.405	0.153
Sec5	22.341	0.080
Cr3	16.010	0.058
Cr7	9.089	0.033
St3	20.543	0.074
St29	15.149	0.055
UM	1374.509	4.948
SB	25.156	0.091
Average	**190.6502179**	**0.687**

Gamma radiation level and surface contamination measurements were measured for each site presented in **Table (6)**.

Table (6): Gamma radiation levels and surface contamination measurements

Site	Gamma radiation levels (mSv/h)	Surface contamination
Sec 2	0.19 - 0.6	B.G.
Sec 5	0.07 - 0.33	B.G.
Cr 3	0.26 - 0.35	B.G.
Cr 7	0.4 - 0.42	B.G.
St 3	-	-
St 29	-	-
UM	0.24 - 0.50	7.1
SB	0.08 - 0.19	B.G.

All of the maximum radon gas concentrations through the mine except postpone tunnels are in the acceptable limits (<1000 Bqm^{-3}) recommended in ICRP publication 115. The maximum radon daughters are lower than action limit (0.3 WL) proposed by ICRP 115 [15]. Also, all annual doses are within the acceptable range recommended by UNSCEAR in 2010 which ranges from 0.2 to 10 mSv/y [5].

For postpone tunnels, most of the maximum radon gas concentrations, radon daughters' concentrations, thoron daughters' concentration and effective annual dose exceed action levels, thus, the open-pit technique is much safer from occupational radiation protection point of view.

CONCLUSION

All the sites except underground tunnels have radon gas, radon daughters' concentrations and annual doses within the permissible limits recommended by UNSCEAR, 2010 [5]. For underground tunnels, most of the radon gas concentrations, radon daughters' concentrations, thoron daughters' concentrations and effective annual dose exceed the permissible limits. Therefore, the open-pit technique is much safer from the occupational radiation protection point of view.

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