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RADIATION EXPOSURE LEVELS IN PHOSPHATE MINING ACTIVITIES

I. Othman, M. Al-Hushari and G. Raja
Department of Protection and Safety
Atomic Energy Commission
PO Box 6091
Damascus, Syria

Abstract — Radon, its daughters concentration and gamma ray exposure rate were measured at different places in the phosphate mining areas of Syria. The grab sampling method was used. For radon measurements discrete air samples without progeny were collected over short periods of time, whereas daughters were collected on filter paper. A three-count procedure was used for the measurement of radon daughters concentrations to improve accuracy. The measurements were carried out at 37 locations selected in the mines, factories, offices and homes in the mining area. The sampling was repeated monthly for a full calendar year. Workers and their families were classified in different categories according to the nature of their jobs. The doses were estimated using proper occupancy factors. The dose equivalent from radon daughters varies from 1 $mSv.y^{-1}$ to a maximum of 10 $mSv.y^{-1}$. Radon concentrations vary from 100 $Bq.m^{-3}$ to several hundreds.

INTRODUCTION

The main phosphate mines in Syria are sited near the ancient city of Palmyra. The two open pit mine regions are separated by about 25 km. The depth of the mines averages from a few metres to several tens of metres. They produce about 2.5×10^6 $t.y^{-1}$, most of which is exported. The rocks are milled and treated on site to enrich the ore up to 30% P_2O_5.

More than 2000 workers are employed in this industry. The climate is very hot and dry and strong winds raise dust, especially in the autumn.

Laboratories, control rooms and offices are built only 2–3 km from the mine landscape and not far from milling waste dumping areas.

It is well known that phosphate rocks contain the trace elements of uranium, thorium and their decay products in equilibrium. The phosphate rocks in Syria are of marine origin and their uranium concentrations vary from 60 ppm in the Al-Sharkeia mines to 120 ppm in the Khnefees mines[1].

All technical processing of ore leads to a high release of long and short half-life radionuclides from uranium decay products[2]. But radon, its daughters and total gamma ray exposure needs to be examined in detail.

A comparison of the radiological impacts associated with the phosphate industry with those of uranium mining and milling indicates that most impacts are within one order of magnitude of each other per unit uranium production[3]. If the magnitude of various impacts is normalised per unit of U_3O_8 production, the impacts may be comparable.

In this study a radiation monitoring programme was carried out in the mining areas, ore processing plants and villages built at the site for the workers. The radon gas release is associated with drilling, blasting, transportation, waste products pile, phosphate drying plants and phosphate storage. However, milling may lead to the greatest release of this radioactive gas and particulates. Thus, all areas, persons and workers' families have been included in the monitoring programme.

INSTRUMENTS AND METHODS

Radiation monitoring of workers and their working environment is an important part of this work. In spite of the fact that monitoring does not itself improve working conditions, it demonstrates that operational radiation protection measures do function as intended or we should consider further protective measures.

Two types of monitoring were employed: area monitoring (radon and its daughters) and area and personal monitoring (total gamma).

For external radiation, only gamma rays are of significance in considering the risk in the mining areas. TLDs were used as inexpensive personal dosemeters. Monthly changes of dosemeters were found to be sufficient in this work. 120 mg of $CaSO_4$:Dy powder and two LiF discs mounted on cards packed in black plastic and placed in a holder were used. The powder and one disc were under a Teflon window and the second disc was under an open window. A Toledo TL reader was used.

A scintillation survey meter (Saphymo-SPP2) was used to measure gamma radiation levels at the measuring points. The survey meter was calibrated and daily checked for stability using a small ^{137}Cs source (0.037 MBq).

To monitor the levels of radon and its daughters 37 points were selected. These measuring points cover all types of activities in phosphate mining. A grab sample of air was taken each month.

An alpha scintillation cell (Lucas cell) of 160 ml volume coated with silver activated zinc sulphide phosphor was used. Air was passed through high-efficiency filter paper (millipore) before reaching the cell to trap radon daughters.

Sampling continued for 10 min with a flow rate during sampling of 10 $l.min^{-1}$. Scintillations from Lucas cells were counted using a photomultiplier tube in a light-tight enclosure and a counting system made by EDA of Canada. Filter papers were counted using the same counting system by placing the filter paper on a scintillation tray coated with the same material as the Lucas cell. To estimate radon concentrations all counts took place 3 h after the end of sampling for equilibrium to be reached between radon and its daughters. Whereas for radon daughters the three counts method was used, concentrations of Ra-A, Ra-B and Ra-C were calculated using the well-known formula[4,5].

The counting efficiency was about 75% and the applied method has a sensitivity of about 17 $Bq.m^{-3}$ with a total relative standard deviation of 50% at this level of concentrations.

RESULTS AND DISCUSSION

The results of radon and radon daughters concentrations, working levels and thoron-B concentrations are arranged in tables for each of the 37 measuring points and for each month of the monitoring period. The average, maximum and minimum of these values are reported. Table 1 gives an example of these results. Figure 1 shows an example of monthly variations of radon concentrations at one of the measuring points. Also, Figure 2 shows the variation of mean radon concentration between the different measuring

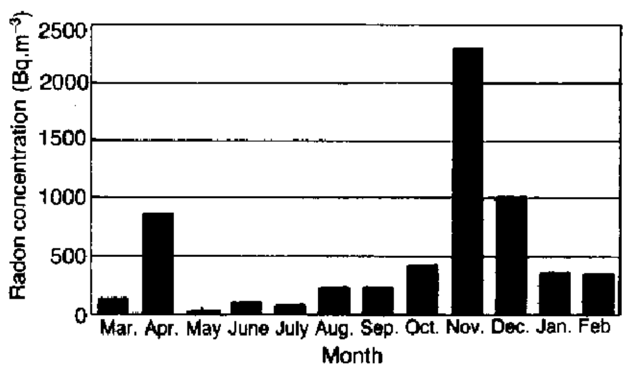

Figure 1. Variation of Radon concentration, March 1989–February 1990. Al-Sharkeia administration area, office 1, laboratory.

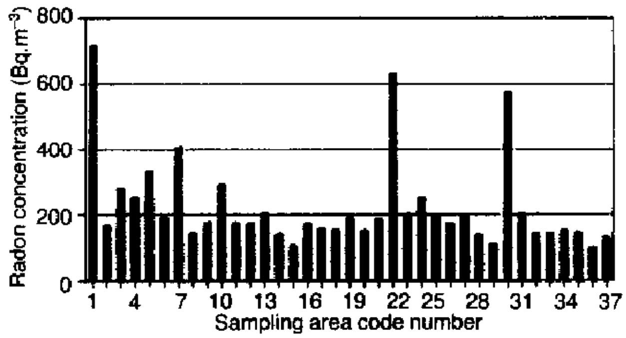

Figure 2. Variation of mean Radon concentration. 1-4, Al-Sharkeia mines; 5–8 Al-Sharkeia administration area; 9–14, Al-Sharkeia factories; 15–20, Al-Sharkeia houses; 21–23, Khnefees mines; 24–27, Khnefees administration area; 28–31, Khnefees factory; 32–37, Khnefees houses.

Table 1. Khnefees factory site No. 3, general control hall. Concentration of radon, radon daughters and Th-B in $Bq.m^{-3}$. Dose equivalent He calculated from WLM using 5.5 $mSv.WLM^{-1}$ and an occupancy factor of 1.

Month	^{222}Rn	SD	Ra-A	Ra-B	Ra-C	mWL	mWLM	He	Th-B
Mar.	438	29.6	372	253	84	53.6	226.9	14.9	2.6
Apr.	528	32.5	148	79	41	19.1	80.9	5.3	7.9
May	1149	47.9	171	79	64	27.1	114.8	7.6	1.3
June	869	37.1	167	116	48	27.4	115.8	7.6	5.3
July	528	32.5	175	52	34	15.4	65.3	4.3	2.3
Aug.	477	30.9	232	124	50	28.5	120.8	8.0	2.3
Sep.	295	24.3	109	97	55	21.8	92.4	6.1	7.9
Oct.	696	37.3	250	209	148	50.5	213.9	14.1	11.9
Nov.	230	21.4	116	123	80	28.1	118.8	7.8	11.9
Dec.	929	43.1	271	233	158	55.5	234.9	15.5	2.3
Jan.	617	35.1	196	211	140	48.5	205.3	13.5	6.6
Feb.	346	26.3	127	92	87	24.9	105.6	7.0	5.3
Max.	1149	32.08	372	253	158	55.5	234.9	15.5	11.9
Min.	230	2.72	109	52	34	15.4	65.3	4.3	1.3
Avg.	577	16.57	195	140	82	33.4	141.3	9.3	5.6

points. The variation in working level (WL) is presented in Figure 3.

To calculate the dose equivalent the populations in the mining areas were divided into the following categories: (a) field workers, (b) factory workers, (c) administration workers, (d) maintenance workshop workers, (e) public service workers in the city, (f) women and children in the city.

An occupancy factor was given to each category taking into account the occupancy time spent in any area of the mines.

Table 2 gives the effective dose to these groups from radon, radon daughters and gamma rays for the Al-Sharkeia mines. Table 3 summarises the same values for the Khnefees mines. It can be seen that administration workers in Al-Sharkeia receive the highest effective dose from radon. This was expected since the offices are built on phosphate sands and they are poorly ventilated especially in winter.

The effective dose from radon to field workers is comparable with that to members of the public living in the area because the mines are of open

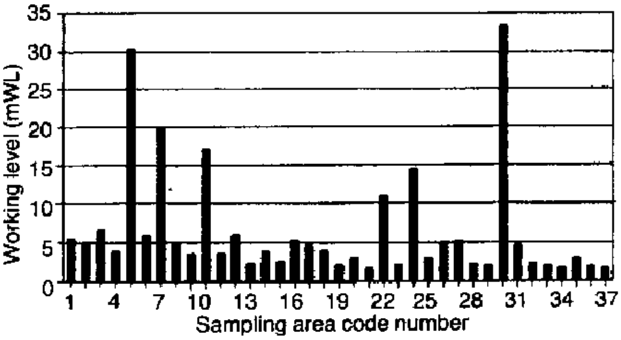

Figure 3. Variation of mean Radon daughters concentration. 1-4, Al-Sharkeia mines; 5-8, Al-Sharkeia administration area; 9-14, Al-Sharkeia factories; 15-20, Al-Sharkeia houses; 21-23, Khnefees mines; 24-27, Khnefees administration area; 28-31, Khnefees factory; 32-37, Khnefees houses.

Table 2. A summary of exposure rates and effective doses according to categories in the Al-Sharkeia mine.

Category	Occupancy factor	Exposure rate ($\mu Sv.h^{-1}$) (TLD)	$mWLM.y^{-1}$ from Rn D		Eff. dose equiv. from radon ($mSv.y^{-1}$)	
			Mean	Max.	Mean	Max.
(a) Field workers						
Mines	0.37	0.36	98.7	339.80	0.53	1.87
Factory and waste	0.03	0.28	5.72	17.47	0.03	0.10
Open area near the offices	0.04	0.18	7.63	23.30	0.04	0.13
Open area in the city	0.13	0.11	15.49	58.80	0.09	0.32
Houses	0.40	0.10	77.21	178.3	0.42	0.98
Total			204.8	617.7	1.11	3.40
(b) Factory workers						
Factories	0.30	0.18	110.8	733.5	0.61	4.03
Open area near factories	0.10	0.28	19.07	58.24	0.11	0.32
Open area near waste	0.05	0.28	9.54	29.12	0.05	0.16
Open area in the city	0.10	0.11	11.92	45.23	0.07	0.25
Houses	0.40	0.10	77.21	178.34	0.42	0.9
Total			228.5	1044.4	1.26	5.74
(c) Admin. workers						
Offices	0.36	0.10	279.6	1425.9	1.49	7.84
Open area near the offices	0.10	0.11	19.07	58.24	0.11	0.32
Open area in the city	0.12	0.11	14.30	54.27	0.08	0.30
Houses	0.40	0.10	77.21	178.34	0.42	0.98
Total			390.2	1716.8	2.10	9.44
(d) Maint. workers						
Workshop	0.30	0.11	89.7	330.4	0.49	1.82
Houses	0.40	0.10	77.21	178.34	0.42	0.98
Open area in the city	0.10	0.11	11.92	45.23	0.07	0.25
Total			178.8	554.0	0.98	3.05
(e) Public services						
Houses and offices	0.65	0.10	315.1	1432.2	1.70	7.88
Open area in the city	0.30	0.11	35.75	135.68	0.20	0.75
Administration offices in the mine	0.05	0.10	38.83	198.0	0.21	1.09
Total			389.7	1765.9	2.11	9.72
(f) Women and children						
Houses	0.80	0.10	154.4	356.7	0.85	1.96
Open area in the city	0.20	0.11	23.83	90.46	0.13	0.50

type. Only gamma ray exposure is higher in the field and the factories.

It can be seen from Tables 2 and 3 that women and children receive considerable dose equivalent from radon. This is again due to phosphate in the soil layer underneath the houses.

ICRP[6] recommended three types of reference levels based on received fractions of the annual dose limit. These were considered by the competent authority in Syria which recommended the following levels for radon and radon daughters as a national standard.

(a) For radon daughters:
 0.5 $mSv.y^{-1}$ — recording level,
 1.5 $mSv.y^{-1}$ — investigation level,
 5 $mSv.y^{-1}$ — intervention level.

(b) The intervention level for radon concentration is 200 $Bq.m^{-3}$.

(c) Remedial actions for radon daughters are needed as follows:

Level of radon daughter	Recommendation
0.5 WL	remedial action in 2 weeks
0.1–0.5 WL	remedial action in 3 months
0.02–0.1 WL	remedial action in 2 years

No need for remedial action if values are below 0.02 WL.

It is concluded that it is clear from the results obtained for radon, radon daughters concentrations and gamma exposure rates that most values are

Table 3. A summary of exposure rates and effective doses according to categories in the Khnefees mine.

Category	Occupancy factor	Exposure rate ($\mu Sv.h^{-1}$) (TLD)	$mWLM.y^{-1}$ from Rn D		Eff. dose equiv. from radon ($mSv.y^{-1}$)	
			Mean	Max.	Mean	Max.
(a) Field workers						
Mines	0.37	0.45	93.48	481.59	0.514	2.65
Open area near the factory	0.03	0.30	5.33	29.67	0.029	0.16
Open area near admin.offices	0.04	0.11	7.1	39.56	0.04	0.22
Open area in the city	0.12	0.09	13.3	34.16	0.07	0.19
Houses	0.40	0.09	42.6	100.14	0.24	0.63
Total			161.8	685.1	0.89	3.85
(b) Factory workers						
Factories	0.30	0.11	270.4	457.56	1.49	2.52
Open area near factories	0.10	0.30	17.77	98.90	0.10	0.54
Open area near phosphate store and waste	0.05	0.50	8.89	49.45	0.05	0.27
Open area in the city	0.10	0.10	11.10	28.46	0.06	0.16
Houses	0.40	0.09	42.56	100.14	0.24	0.63
(c) Admin. workers						
Offices	0.31	0.11	108.4	348.4	0.60	1.92
Open area near the offices	0.10	0.10	6.7	98.90	0.10	0.54
Open area in the city	0.13	0.10	14.43	37.00	0.08	0.20
Houses	0.40	0.09	42.56	100.14	0.24	0.63
(d) Maint. workers						
Workshop	0.30	0.11	80.5	433.33	0.44	2.38
Houses	0.40	0.09	42.56	100.13	0.24	0.63
Open area in the city	0.10	0.11	11.10	28.46	0.06	0.16
Total			134.2	561.9	0.74	3.1
(e) Public services						
Houses and offices	0.65	0.09	148.3	446.86	0.82	2.46
Open area in the city	0.30	0.10	33.30	85.4	0.18	0.47
Administration offices in the mine	0.05	0.11	17.5	56.23	0.10	0.31
Total			199.1	588.5	1.10	3.24
(f) Women and children						
Houses	0.80	0.09	85.11	200.3	0.47	1.10
Open area in the city	0.20	0.11	22.20	56.93	0.12	0.31
Total			107.3	257.2	0.59	1.41

within the recommended limits and do not require remedial action. However, there are some exceptions where radon and radon daughters concentrations exceed the above-mentioned recommendations.

Table 4. Recorded radon and radon daughters concentrations in exceptional sites.

Site	Avg. radon ($Bq.m^{-3}$)	Radon daughters (mWL)
Al-Sharkeia mine (A)		
Open working area	713	<20
Al-Sharkeia mine (B)		
Open working area	279	<20
Al-Sharkeia laboratory	334	30
Al-Sharkeia office	407	21
Al-Sharkeia factory	292	20
Khnefees		
Open working area	635	<20
Khnefees laboratory	255	20
Khnefees factory	277	34

Table 4 shows the values of radon and radon daughters concentrations in these exceptional sites.

Remedial action has to be taken in offices, laboratories and control rooms, whereas no action is required for the mines.

The following actions were recommended to the phosphate mining company:

(1) Some offices need enforced ventilation.
(2) Cracks in the walls and ground need to be closed.
(3) Air filtration is required where there is no natural ventilation.

For open areas like the mines, the most acceptable procedures are to keep workers away when the maximum emission of radon occurs.

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