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Radiological Impact Assessment due to Radioactivity Level in non-Nuclear Industries Waste (Abu Zaabal) Area; Egypt

Amaal A. Tawfik[*] *and A. Agha*

Nuclear and Radiological Regulatory Authority, 3 Ahmed El Zomor st., Nasr City, Cairo, Egypt.

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Abstract: The assessment of the environmental impact in Abu Zaabal city, Egypt has been studied. Gamma ray spectrometry survey was carried out to this assessment in order to evaluate the radiological hazard of the natural radioactivity. Environmental samples were collected from Abu Zaabal city and the surrounding regions. The radioactivity concentration of ^{238}U series, ^{232}Th series and ^{40}K were measured and analyzed using a hyper pure germanium detector. The analysis of the spectra was done using Gamma Vision analysis software. The specific activity concentrations ranged from < D.L. to 524 Bq/kg for ^{238}U, from < D.L. to 43.9 Bq/kg for ^{232}Th and from < D.L. to 270.88 Bq/kg for ^{40}K. The absorbed dose rate D ranged from 0.003 nGy/h to 235.25 nGy/h, the calculated annual effective dose (E) ranged from < D.L. to 1.44 mSv/y. The external hazard index (H_{ex}) ranged from 0.00002 to 1.47 and internal hazard index (H_{in}) have been calculated ranged from 0.00002 to 2.89. (Ra_{eq}) ranged from 0.0056Bq/kg to 71.22 Bq/kg. The Gamma index (I_{γ}) ranged from 0.00002 to 1.82.

Keywords: Gamma ray spectrometry; dose rate, radiological hazard, environment.

1 Introduction

Natural radioactivity contributes significantly to the radiation doses received by human beings coming from Terrestrial gamma rays in the ground, building materials, air, food, and even elements in their own bodies (K-40). The natural radionuclides, ^{238}U, ^{232}Th and ^{40}K and their daughters make the largest contribution to the total radioactive background dose. It is necessary to monitor release of radioactivity into the environment in order to be able to provide an appropriate protection of humans. The radioactivity of soil is essential for understanding changes in the natural radiation background. Soil contains quantities of radioactive elements from ^{238}U-series, ^{232}Th-series and ^{40}K. The main sources of the external ɣ-radiation are the radionuclides of the ^{238}U and ^{232}Th series and ^{40}K [1,2,3].

High levels of the natural radiation near radioactive deposits may make living conditions hazardous. A gamma-ray spectrometer based on high-purity germanium (HpGe) detector was used to determine the concentration of natural radionuclides in samples from Abu Zaabal city in Egypt. The annual effective dose rates and the gamma activity concentration index will be evaluated and compared to the average worldwide exposure limits represented in UNSCEAR 2000 and to the dose criteria recommended European Commission (EC, 1999), respectively [4,5]. The assessment of doses from natural materials is important as external radiation exposures from natural materials. The natural radioactivity in the environment is the main source of radiation exposure for humans and constitutes the background radiation level. The main natural contributors to external exposure from gamma rays are ^{226}Ra, ^{232}Th, and ^{40}K. Since ^{226}Ra(^{238}U), ^{232}Th, and ^{40}K radionuclides and their daughters are not uniformly distributed, the knowledge of their distribution in soil plays an important role in radiation protection and measurement. It is important to determine the different sources and their individual contributions to the total radiation dose. We have presented and compared the activity concentration of radionuclides and radiation doses resulting from the radiological effects and external doses from other non-nuclear industries which emit radionuclides. A comparison is also made of the total risk in the energy scene [1,2,3]. The aim of this study is to assess the Radiological health hazard the public live around the fertilizer production facility, located in Abu Zaabal city.

2 Experimental Techniques

2.1 Sampling

Thirty soil samples were collected from different zones around the fertilizer production facility at Abu Zaabal city,

[*]Corresponding author e-mail: amaaltawfik2004@yahoo.com

which is about 35 km from Cairo, as shown in Figure 1. Ten locations (S1-S10) were selected to represent the expected contaminated area as represented in table 1. Three samples from each location were collected and analyzed using high-purity germanium (HpGe) detector.

Table 1. The average measuring samples.

Sample Number	Location
S1	In front of ceramic factory (ceramic factory waste)
S2	50 meters from the remnants of the ceramic factory
S3	In front of AL Shaba Factory (AL Shaba Factory waste)
S4	50 meters from the remnants of AL Shaba Factory waste
S5	Of agricultural land opposite the fertilizer plant
S6	From the agricultural land opposite the fertilizer factory, the second side of the Nile, 50 meters away
S7	In front of Fertilizer plant directly (waste fertilizer plant) from the back
S8	In front of the fertilizer factory directly (waste fertilizer plant) From the west
S9	From the waste of the factory from the overflow of the factory from the east
S10	From the waste of the factory from the overflow of the factory from the west

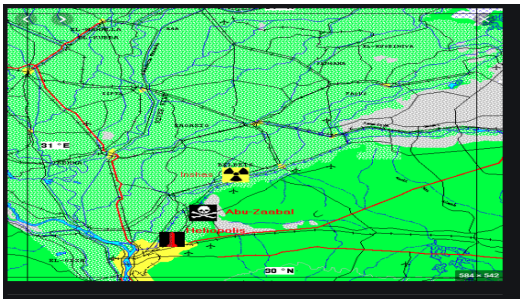

Fig.1: Abu Zaabal Map location .

2.2 Sample Preparation

30 Samples from 10 locations were weighted dried at 100 ºC for 24 h, re-weighted to determine the water content, grinned, and homogenized to pass through 1 mm meshes sieve. 100 ml of each sample was weighed, and transferred to Marinelli-beakers and sealed for 4 weeks (to obtain radioactive secular equilibrium) to be analyzed using gamma spectrometers. The samples were analyzed in the geometries used during the procedure of efficiency determination.

2.3 Gamma Ray Spectrometry

The samples from area of the study were analyzed using a high-resolution; low background gamma-ray spectrometry system based on a coaxial high purity germanium detector (HPGe). The gamma-ray spectra which were analyzed, were created through converting the event energy into a pulse height spectrum. The signal processing was done by connecting the detector to a preamplifier and a standard spectroscopy shaping amplifier. The resultant spectra were analyzed using Canberra Genie software "Genie-2000".

The activity concentration of ^{40}K was measured directly via its 1461 keV peak of the gamma ray spectra. To determine the activity concentration of ^{226}Ra, the average value of gamma ray lines 295.1 and 351.9 keV from ^{214}Pb, the average value of gamma ray lines 609.3 and 1764.5 keV gamma rays from ^{214}Bi are used. Activity concentration of ^{232}Th is determined using the average value of gamma ray lines 238.6 and 338.4 keV from ^{212}Pb, the average value of gamma ray lines [8] 727.65 and 1620.56 keV from ^{212}Bi., the average value of gamma ray lines , 911.1 and 968.9 keV from ^{228}Ac the average value of gamma ray lines 583.1 and 2614 keV from ^{208}Tl are used. The detector was calibrated for the efficiency using ^{226}Ra point source to first produce a relative efficiency curve followed by standardization using KCl as a standard solution [9,10,11]. Quality control and quality assurance of the measurements using International Atomic Energy Agency (IAEA) reference materials (Soil 6, IAEA-326). In addition, duplicate samples were added to insure the analysis consistency of the measurements. Blank samples were added to eliminate the cross-contamination occurrence in the samples.

3 Results and Discussion

3.1 The Specific Activity

The specific activity (in Bq/kg), $A_{E\gamma}$ of a radionuclide **(i)** and for a peak at energy **Eγ**, is given by Eq.(1):

$$A_{E\gamma} = \frac{NP}{tc.I\gamma(E\gamma).\varepsilon(E\gamma).M} \quad (1)$$

where NP is the number of counts in a given peak area corrected for background peaks of a peak at energy Eγ, Ɛ(Eγ) the detection efficiency at energy Eγ, tc is the counting lifetime , Iγ(Eγ) is the number of gammas per disintegration of this nuclide for a transition at energy Eγ, and M the mass in kg of the measured sample. The results of natural radionuclides distribution in samples are presented in Table 2.

The Minimum Detection Limit for ^{226}Ra, ^{232}Th and ^{40}K are 0 .7, 0. 6 and 3.0 Bq/kg, respectively. From table 2 it is clear that, the activity concentrations ranged from ‹ D.L. to 523.7 , 43.9 and 271 Bq/kg for (^{238}U) ^{226}Ra , ^{232}Th

and ^{40}K respectively. For ^{238}U (^{226}Ra), the maximum activity value was in sample (8) while the minimum activity value was in sample (7). For ^{232}Th, the maximum activity value was in sample (3) and the minimum activity value was in sample (7). For ^{40}K, the maximum activity value was in sample (9) and the minimum was in sample (7). The international average concentrations of ^{238}U, ^{232}Th and ^{40}K in soils are 50, 50 and 370 Bq/kg, while the range of Egypt (Nile Delta) is (13.7-27.9, 15.4-53.1 and 176-407 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K respectively) [12,13,14,15]. The results of the activity concentrations in present study for ^{238}U (^{226}Ra)-series, ^{232}Th-series and ^{40}K in soil samples are nearly higher than the worldwide average value.

3.2 Dose Rates (D) and Annual Effective Doses (E)

Conversion factors to transform specific activities A_{Ra}, A_{Th} and A_K of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in absorbed dose rate at 1m above the ground (in nGy/h by Bq/kg) are calculated using the formula of UNSCEAR 2000 [4]:

$$D = 043A_{Ra} + 0.66A_{Th} + 0.042A_k \quad (2)$$

The total calculated absorbed dose rates range from 0.003 nGy/h to 235.25nGy/h. The lowest value of absorbed γ-ray dose rate due to soil was observed for sample 7, and the highest value of absorbed γ-ray dose rate was observed for soil sample no^r 8. The analytical results for the total absorbed dose rate in air for each of the measured samples are also given in Table (3). To estimate the annual effective dose (E), one must take all the following into account: (a) the conversion coefficient (0.7 Sv/Gy) from absorbed dose in air to effective dose and (b) the indoor and outdoor occupancy factor (0.8) and (0.2) respectively proposed by OECD (1979) [7] and UNSCEAR (2000) [4]. The effective dose rate, E (nSv/year), was estimated using the following formula:

$$E_{in} = D.T_{in}.F \quad (3)$$

$$E_{out} = D.T_{out}.F \quad (4)$$

where D is the calculated dose rate (in nGy/h), T_{in} is the indoor occupancy time (0.8 ×24h ×365.25 d = 7012.8 h/year), and F is the conversion factor (0.7×10-6 mSv/Gy). T_{out} is the outdoor occupancy time (0.2 ×24h ×365.25 d = 1753.2 h/year), Where, the total annual effective dose ($E = E_{in} + E_{out}$).

3.3 Radium Equivalent Activity

The concentration and distribution of ^{226}Ra, (assuming equilibrium with ^{238}U), ^{232}Th-series and ^{40}K in the environmental samples is not uniform throughout the world. However, this non-uniformity in respect of exposure to radiation has been defined in terms of radium equivalent activity (radiation hazard index) (Ra_{eq}) in Bq/kg, when compared to the specific activities of samples containing different activities of ^{226}Ra, ^{232}Th and ^{40}K. The radium equivalent activity term was introduced as a common index by, Beretka and Mathew ,and can be calculated from the following relation suggested by Eq.(5) [6]:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_k \quad (5)$$

Where A_{Th} is the specific activity of ^{232}Th; A_{Ra} is the specific activity of ^{226}Ra; A_K is the specific activity of ^{40}K in Bq/kg. The values of calculated Ra_{eq} for collected samples are shown in Table (3). Values range from 0.006 Bq/kg to 71.22 Bq/kg, which are lower than the criterion limit of 370 Bq/kg [7].

3.4 Radiation Hazard Indices

In order to measure the hazards one can define radiation hazard indices (Beretka and Mathew 1985) [6]:

3.4.1 The External Hazard Index (H_{ex})

Is obtained from Ra_{eq} expression through the assumption that its maximum value allowed (equal to unity) corresponds to the upper limit of Ra_{eq} (370 Bq/kg). This index value must be less than unity in order to keep the radiation hazard insignificant; i.e. the radiation exposure due to the radioactivity from construction materials is limited to 1.0 mSv/year. Then, the external hazard index (H_{ex}) can be defined as:

$$H_{ex} = \frac{A_{Ra}}{370\ \text{Bq/kg}} + \frac{A_{Th}}{258\ \text{Bq/kg}} + \frac{A_k}{4810\ \text{Bq/kg}} \quad (6)$$

Where; A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively. It is observed from Table (2).

3.4.2 The Internal Hazard Index (H_{in})

In addition to the external hazard index, radon and its short-lived progeny are also hazardous to the respiratory organs. The internal exposure to radon and its daughter progenies is quantified by the internal hazard index H [4] The combined internal exposure to gamma-rays and radon has been defined by Krieger [8] as indoor external hazard criterion (H_{in}). The H_{in} is calculated from the formula given by Krieger [12]. It is observed from Table 3. For insignificant radiation hazard the indices should be less than unity this has been proposed by Krieger [12] and Beretka and Mathew [6].

Table 2. The main average value of the specific activity concentration (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K for collected samples.

code	Sample type	^{40}K	^{232}Th	^{238}U
S1	Sandy	13.03±0.04	9.67±0.09	189.80±0.02
S2	Sandy	31.46±0.02	24.1±0.04	130.50±0.04
S3	Sandy	54.54±0.01	43.9±0.03	104.54±0.05
S4	Sandy	13.84±0.04	9.59±0.08	167.87±0.03
S5	Sandy	257.9±0.55	12.3±0.05	194.19±0.03
S6	Sandy	147.17±0.0	7.54±0.12	187.93±0.02
S7	Sandy	0.0007±---	0.004±---	0.0070±----
S8	Sandy	523.74±0.0	8.38±0.13	107.55±0.06
S9	Sandy	99.95±0.01	8.99±0.02	270.88±0.02
S10	Sandy	41.15±0.01	8.51±0.01	190.75±0.04

Table 3: The absorbed dose rate (nGy/h), the annual effective dose E (nSv/y), the radium equivalent Ra_{eq}, the external hazard index H_{ex} and the internal hazard index H_{in} and the gamma index (I_γ).

Sample Code	D in nGy/h	Total E in nSv/y	Ra_{eq} in Bq/kg	H_{ex}	H_{in}	I gamma($I\gamma$)
S1	19.95966	122476.5	28.52552	0.112213	0.147294	0.155136
S2	34.90751	214199.5	44.70752	0.205627	0.290281	0.268975
S3	56.84916	348837.8	71.22581	0.33958	0.48633	0.436545
S4	19.32898	118606.5	26.7189	0.109491	0.146755	0.150067
S5	127.1791	780396.5	33.87847	0.785093	1.482112	0.9859
S6	76.15411	467296.9	26.05707	0.466076	0.86372	0.590945
S7	0.002987	18.32984	0.005682	1.74E-05	1.93E-05	2.28E-05
S8	235.2547	1443570	23.13194	1.470438	2.885813	1.823689
S9	60.29112	369958.4	34.26602	0.361335	0.631341	0.468467
S10	32.26511	197985.2	27.10315	0.183914	0.294994	0.243389

4 Gamma index (Iγ)

The European Commission has proposed an index called the gamma index (I_γ) defined by the following relation [5]. The gamma index (I_γ) has been introduced to account for the combined impact of ^{226}Ra, ^{232}Th and ^{40}K as radiological hazard associated with soil.

$$I_\gamma = \frac{A_{Ra}}{300\ Bq/kg} + \frac{A_{Th}}{200\ Bq/kg} + \frac{A_k}{3000\ Bq/kg} \leq 2 \quad (7)$$

5 Conclusions

The results of the present work indicate that:
1- The activity concentration of studied area were found to be nearby lower than the world average 50 Bq/kg.
2- The absorbed dose rate D ranged from 0.003 nGy/h to 235.25 nGy/h.
3- The calculated annual effective dose (E) ranged from < D.L.
4- The external hazard index (H_{ex}) ranged from 0.00002 to 1.47 and internal hazard index (H_{in}) ranged from 0.00002 to 2.89.
5- The Ra_{eq} ranged from 0.0056 Bq/kg to 71.22 Bq/kg.

6- The Gamma index ranged from 0.00002 to 1.82.
7- The ^{40}K activity concentration was observed to be lower than the world average value, however, the activity concentration ^{226}Ra and ^{232}Th was higher than the world average value.
8- The radiological hazards to the public are within the world average value.
9- The average indoor, outdoor effective dose and total annual effective dose due to natural radioactivity of soil samples is lower than the average national and world recommended value of 1.0 mSv/year (except Sample 8) with value 1.44 mSv/year which is nearly high.

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