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Determination of Natural Radioactivity and Radiological Risk assessment of Environment for Al-Dora Refinery and Surrounding Area

A Thesis

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

"إنَّا نَحْنُ نَرث الْأَرْض وَمَنْ عَلَيْهَا وَإِلَيْنَا يُرْجَعُونَ"

صدَقَ الله الْعَظِيمُ

سورة مريم : الاية (40)

Dedication

I dedicate this work

To

My parents who forward all they can in order to complete my studies

To

My brothers who pushed me forward

To

My friends who have helped to the success of this work

To

My uncle Kazem Sultan &My uncle Karim Sultan
My uncle Salam Sultan

To

My Injured country

Acknowledgement

Praise is to **Allah** *and peace and blessings on the Prophet* **Mohammed** *great of senders and* ***his family****.*

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List of Abbreviations

Abbreviate	Full Name
S.A	specific activity
NORM	Natural Occurring Radioactive Materials
IAEA	The International Atomic Energy Agency.
HPGe	Hyper-pure Germanium Detector for Gamma-ray Spectrometry
ICRP	The International Commission on Radiological Protection.
NCRP	The National Council on Radiation Protection and Measurements.
UNSCEAR	The United Nations Scientific Committee on the Effects of Atomic Radiation
AEDE	Annual Effective Dose Equivalent
ε_p	Full-energy peak efficiency
H_{ex}	External Hazard Index
H_{in}	Internal Hazard Index
Ld	Detection limit
SSNTD	Solid State Nuclear Track Detectors
WHO	World Health Organization
$I_{\gamma r}$	Gamma Level index
WL	The Working Level
CR-39	polyaillyldiglycol carbonate detector
λ	decay constant
ELC	Excess Lung Cancer per Million Persons per Year

Summary

The objectives of the present study were to measure the level of the radioactivity Al-Dora refinery and surrounding area. The study includes: The first. the radon gas concentration in soil samples from Al-Dora refinery and dust samples from surrounding area by using "sealed can technique" and CR-39 track detector to registration alpha tracks emitted from radon gas in (soil and dust) samples. The second. Detect of the radionuclides and measure the specific activities in soil and water samples using gamma ray spectroscopy system with HPGe detector. The measured soil, water and dust samples were taken from (40) samples, 27 soil samples (surface, 15 and 30 cm depth), 8 water samples and 5 dust samples. The detecting of naturally occurring radionuclides (^{226}Ra belong to ^{238}U series, ^{228}Ac belong to ^{232}Th series and one natural radionuclide ^{40}K) in the (soil and water). And estimate the radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), hazard index (H_{ex}, H_{in}) and annual effective dose equivalent (AEDE) in soil samples of Al-Dora refinery and surrounding area.

The radon concentration in surface soil samples ranged from (290.709 to 394.534 Bq/m^3 with an average 365.925 Bq/m^3). The radon concentration in soil at the depth 15 cm was ranged from (294.862 to 346.775 with an average 324.164 Bq/m^3) and at the depth 30 cm was ranged from (228.633 to 288.414with an average 254.947 Bq/m^3). The surface exhalation rate in surface soil samples ranged were ranged from (0.601, to 0.816 with average 0. 757Bq·m−2.h^{-1}), in soil samples at the depth 15 cm ranged from (0.61 to 0.717 with average 0.671 Bq·m^{-2}·h^{-1}) and in soil samples at the depth 30 cm ranged from (0.47 to 0.597 with average 0.527 Bq·m^{-2}·h^{-1}). The mass exhalation rate in surface soil samples were ranged from (0.469 to 0.639 with average 0.59 Bq·kg^{-1}·h^{-1}), in soil samples from depth 15 cm ranged from (0.457 to 0.559 with average 0.523 Bq·kg^{-1}·h^{-1}) and in soil samples at the depth 30 cm ranged from (0.368 to 0.465 with average 0.411 Bq·kg^{-1}·h^{-1}).

The specific activities for radionuclides (^{226}Ra, ^{٢28}Ac) in surface soil samples were ranged (from 11.725, 15.41 to 59.08, 36.17 Bq/kg respectively) with an average (33.621 and 22.375 Bq/kg respectively) and the specific activity of ^{40}K radionuclide ranged (from 328 to 424.9 with average ٣٦٣.٤٥ Bq/kg). At 15 cm depth ranged (from 18.047, 14.613 to 39.71, 21.673 Bq/kg respectively) with an average (30.527 and 19.66Bq/kg respectively), the specific activity of ^{40}K radionuclide ranged (from 201.3 to 391.3 with average ٣٢٦.٧٣ Bq/kg). At 30 cm depth ranged from 17.94, 12.89, to 45.766, 23 Bq/kg respectively) with an average (30.393 and 18.124 Bq/kg respectively), the specific activity of ^{40}K radionuclide ranged (from 231.4 to 351.3 with average ٣١٠.٩٤Bq/kg).

For water samples ranged (from 1.60, 1.025 to 8.805, 13.52Bq/kg respectively) with an average (5.031 and 2.925 Bq/kg respectively), the specific activity of ^{40}K radionuclide ranged (from 11.462 to 18.58 with average ١٥.٧٧٨Bq/L).

The average values of Ra_{eq}, H_{in}, H_{ex}, ADRA, and the annual effective indoor and outdoor doses in soil and water samples were, in surface (93.70 Bq/kg, 0.309, 0.226, 39.755 nGy/h, 0.198 mSv/y, 0.049 mSv/y), in 15cm depth (83.582 Bq/kg, 0.34, 0.2٥2, 44.34 nGy/h, 0.227 mSv/y, 0.055 mSv/y), in 30 cm depth (80.253 Bq/kg, 0.299, 0.217, 38.051 nGy/h, 0.189 mSv/y, 0.047 mSv/y), and in water (10.428 Bq/kg, 0.042, 0.028, 4.788 nGy/h, 0.024 mSv/y, 0.006 mSv/y).

1.1 Introduction

Man is continuously exposed to ionizing radiation from naturally occurring radioactive materials (NORM). Natural radioactivity is widely spread in the earth's environment and it exists in various geological formation e.g. soils, rocks, plants, water, air and in building materials.

Oil and gas deposit in geological formations also contain naturally - occurring radionuclides. Geologists have identified their presence and locations since the early 1930s and used them as a method for finding deposits. Some elements such as Uranium, Radium and Radon are found in naturally occurring radioactive materials, that are dissolved into very low concentrations during normal reactions between water and rock or soil. The deposits of oil and gas and underground water, that co-exist for extended periods may have unequal high concentrations of dissolved constituents build up in water/rock contact. NORM originated from the creation of earth, from cosmic rays and man-made activities and has many different path ways[1].

There are more one main sources of radiation found in the environment; natural radioactivity sources, symbolized NORM (which include terrestrial, cosmic rays, and cosmogenic), and man–made radioactivity sources, symbolized TENORM (which include medical, fallout, and nuclear power) [2,3].

1.2 Radioactivity

Radiation is a form of energy, such as light or heat. Radiation is characterized according to the frequencies of these wavelengths. Infrared waves, microwaves, and radio waves occur at the lowest frequencies. Ionizing radiation occurs at the highest frequencies. The process of transforming a neutral atom or molecule into an electrically charged component is known as ionization. Ions are either positively charged or negatively charged, depending upon the number of protons and electrons present in the atom[4].

The history of radioactivity really is begun with the discovery of X-rays by Wilhelm Roentgen in the end of the eighteenth century.

In 1896 Henri Becquerel found that the uranium salts could activate a photographic plate in that absence of light, also they could activate air so as to discharge an electroscope. He suggested the term “radioactivity” by referring to phenomenon of “Radiation Activity” [5].

In 1898 Marie Curie found out a radioactive element, one she named radium and the other polonium, and also discovered the radioactivity of uranium with her husband [6].

1.3 Radioactive Decay

The stability or instability of a given nuclide is determined by the ratio of its protons and neutrons. Heavy nuclei have a n/p ratio of approximately 1.4. If now either the number of neutrons or the number of protons too small the nuclei are unstable and will transform into a stable one. The largest part of the nuclides is unstable and called radioactive nuclides. Radioactivity is characterized by the spontaneous transformation of unstable atomic nuclei under delivery of energy in form of ionizing α-, β- and γ- radiation, which proceeds directly from the atomic nucleus. The transition to a stable nuclide can either be directly or take place in form of many transformations over several unstable intermediate stages [7].

Radionuclides are quantified according the rate of disintegration. This rate is defined by the Curie and the Becquerel [7].

$$1 \text{ Curie (Ci)} = 3.7 \times 10^{10} \text{ Bq}$$

1 Bq = 1 disintegration per second.

These units, however, incorporate neither the total amount of ionizing energy associated with each disintegration, nor the total existence of the radionuclide.

The main modes of radioactive transformation are:

- Alpha decay (α)
- Beta decay (β)
- Gamma decay (γ)

1.4 Natural Radioactivity Source

The natural radiation through our environment is due to primordial radionuclides, and can be found in certain industrial materials like ores and minerals [8].

The list of isotopes that contribute to natural radiation can be divided into those materials which come through the ground (terrestrial radioactivity) and those which are gave as a result of the interaction of atmospheric gases with cosmic rays (Cosmogenic radioactivity).

The international atomic energy agency (IAEA) known NORM as "Radioactive materials contain no significant amounts of radionuclide in compare with naturally occurring radionuclides" [9].The unstable nuclides of particular interest are $^{238,235}U$ and ^{232}Th and their decay progeny and the primordial radionuclide ^{40}K.

1.5 Naturally occurring radioactive materials (NORM)

Naturally occurring radioactive materials can be encountered through subsurface formations which originate during exploration of gas and oil, development and production operations. In that process, it may contain radioactive materials such as thorium and uranium and their daughter products, ^{226}Ra and ^{228}Ra.

NORM occurs in minerals, oil, coal and gas, mineral sands and bauxite. Processing and Mining of ores to extract minerals can alter the radioactivity concentration of the products, by-products, residues and wastes of the materials. Examples of bulk materials include: red mud (from bauxite processing) bricks; scales and sludge (from oil and gas production) [9]; phosphate rocks; and fertilizers. Accumulation of by products produced in fossil fuels burning and metal refining can also lead directly to the production of NORM.

There are more activities which can enhance NORM levels indirectly, for example the reuse and disposal of industrial waste (e.g. phosphorgypsum, fly ash and mine tailing). This means that exposures to ionizing radiation from NORM are common and that every country has to deal with estimating the risk from exposure to ionizing radiation arising from NORM to some form [10].

1.5.1 Cosmic Rays

The cosmic ray consists of more 85% protons, 11% α- particles, about 1% nuclei with low atomic number, and about 1% electrons of high kinetic energy. The cosmic rays have a high penetrating energy 10^{20} eV or more [11]. The interaction of cosmic ray in the atmosphere give a number of radionuclides known cosmogenic radionuclides, including ^{3}H, ^{7}Be, ^{14}C, ^{22}Na, etc.

NORM of cosmogenic origins is produced by interactions of cosmic rays with air, which is mostly from neutron capture and spallation. The production of cosmogenic radioactivity results from the spallation of atoms on the atmosphere in bombarded by cosmic rays. There are more one important cosmogenic radionuclides that are produced through the thermal neutron reaction: ^{14}C by the (n, p) reaction on ^{14}N has half-life (5,730 years) and ^{81}Kr by the (n, γ) ^{80}Kr has half-life (210,000 y. More nuclear species are widely produced mainly for cosmic ray reactions with earth and also from induced cosmic ray fissions. More one important radionuclides such as tritium (^{3}H) and ^{14}C can cause biological effects in people,while ^{7}Be, ^{22}Na and other cosmogenic nuclides are present in living things [12].

Recommendation produce by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) specified the world altitude and latitude average annual effective dose from cosmic rays is 460μSv/year and for neutrons is 120μSv/year. Most likely, the humans living at an altitude of 2000 to 3000 meters above the sea level will received an annual effective dose for cosmic rays up to 2000 μSv/year. [13].

1.5.2 Terrestrial source of Radiation

Terrestrial source of Radiation is originated from radio-nuclides, which are formed during the birth of plant. The original materials found are uranium and thorium and decay products which form part of characteristic decay chain series, or ^{40}K about 4.5 billion years ago. There are two main important chains which provide nuclides of significance in NORM; they are the thorium series and the uranium series. These radionuclides (NORM) in the Earth's crust have very long half-lives as they have been in existence earth's formation. The most important terrestrial NORM natural radionuclides originate from ^{232}Th, ^{238}U and ^{235}U[8].

Most natural elements with atomic numbers Z ≥ 83 are radioactive. We have 4 distinct natural decay series [8] ,which are represented in Table (1-1).

Table (1-1): Radioactive decay series. [14].

Series	First Isotopes	Half–Life [y]	Last Isotopes
Uranium	^{238}U	$4.49\text{x}10^{9}$	^{206}Pb
Actinium	^{235}U	$7.10\text{x}10^{8}$	^{207}Pb
Thorium	^{232}Th	$1.39\text{x}10^{10}$	^{208}Pb
Neptunium	^{237}Np	$2.14\text{x}10^{6}$	^{209}Bi

There are more one natural radioactive series, called thorium, uranium and actinium series. Neptunium series is included in this table too, which does not act in nature because it's half life "$2.1\text{x}10^{6}$ y" ,whichis much smaller than, the age of the universe "$3\text{x}10^{9}$ y" [14].

1.5.2.1 U-238 Series

This series start with U-238 nuclei (half-life $4.49\text{x}10^{9}$ y) and gradually converted to the Pb-206 which is a stable element through sequences of the emission of α and β- particles. most nuclides in this series are solid elements except Rn-222 nuclei, which is gas. The elements of this series which are represented in Table (1-2) are arranged according to the mass number indicated in (4n+2) system [15].

Table (1-2): U-238 Decay Series [15].

Nuclide	Half-life	Type of decay
U-238	$4.49x10^9$ y	Alpha
Th-234	24.1 d	Beta
Pa-234m	1.18 min	Beta
U-234	$2.48x10^5$ y	Alpha
Th-230	$7.52x10^4$ y	Alpha
Ra-226	1600 y	Alpha
Rn-222	3.825 d	Alpha
Po-218	3.05 min	Alpha
Pb-214	26.8 min	Beta,
Bi-214	19.7 min	Beta
Po-214	$1.6x10^{-4}$ s	Alpha
Pb-210	22 y	Beta
Bi-210	5.01 d	Beta
Po-210	138.4 d	Alpha
Pb-206	Stable	-

1.5.2.2 Actinium Series

This series start with ^{235}U nuclei (half-life $7.10x10^8$ y), which is the largest half-life comparing to other elements in this series and ends with ^{207}Pb. The elements of this series which are represented in Table (1-3) are arranged according to the mass number indicated in (4n+3) system [16].

Table (1-3): Actinium Decay Series [16].

Nuclide	Half-life	Type of decay
U-235	$7.10 x10^8$ y	Alpha

Th-231	25.6 h	Beta
Pa-231	3.98×10^{4} y	Alpha
Ac-227	22 y	Beta
Th-227 or Fr-223	18.17 d 22 min	Alpha Beta
Ra-223	11.7 d	Alpha
Rn-219	3.92 s	Alpha
Po-215	1.83×10^{-3} s	Alpha
Pb-211	36.1 min	Beta
Bi-211	2.15 min	Alpha
Po-211	0.52 sec	Alpha
Ti-207	4.79 min	Beta
Pb-207	Stable	-

1.5.2.3 Thorium Decay Series

Thorium was discovered by “Berzelius”, which is derived from the Scandinavian god “Thor”. This series start with Th-232 nuclei (half life 1.39×10^{10} y) and end with Pb-208 isotope. The elements of the series which are represented in Table (1-4) are arranged according to the mass number indicated in (4n) system [13].

Table (1-4): Thorium Decay Series [13].

Nuclide	Half-life	Type of decay
Th-232	1.39×10^{10} y	Alpha
Ra-228	6.7 y	Beta
Ac-228	6.13 h	Beta
Th-228	1.9 y	Alpha

Ra-224	3.64 d	Alpha
Rn-220	54.5 s	Alpha
Po-216	0.158 s	Alpha
Pb-212	10.6 h	Beta
Bi-212	60.6 min	Beta
Ti-208 or Po-212	3.1 min 3.0x10^{-7} s	Beta Alpha
Pb-208	Stable	-

1.5.2.4 Neptunium Decay Series

Np-237 has a half-life (2.14x10^{6} y), which is much smaller than the geological age of the earth. Virtually all neptunium decayed within the first 50 millions of years after the earth was formed. So ^{237}Np did not find in nature but it discovered in more stars spectrum [17].

1.6 Radon gas

Radon is a monatomic gas by a density of 9.73 kg/m^{3} at standard temperature and pressure about 8 times the density to the earth's atmosphere at sea level.

Radon emanation for the soil varies with soil type and surface uranium content, Uranium which is present to small amounts in more soil and rocks, breaks down to Radium, which then decay to radon. In more countries exposure in the house to short lived radioactive disintegration products of the chemically inert gas radon-222 is responsible on about half of all non-medical exposure to ionizing radiation. It has a half-life of more three days, allowing it to diffuse through soil and into the air before decaying by emission of an alpha particle into a series of short lived radioactive progeny[18].

polonium-214 and Polonium-218, also decay by emitting alpha particles.If inhaled, radon itself is mostly exhaled immediately. Its short lived progeny, however, which are solid, tend to be deposited to the bronchial epithelium, thus exposing cells to alpha irradiation. Air pollution by radon is ubiquitous. Concentrations are low outdoors and can build up indoors, especially in homes, where more exposure of the general population occurs.

Air pollution by radon is ubiquitous. Concentrations are low outdoors and can build up indoors, especially in homes, where more exposure of the general population occurs. The highest concentrations to which workers have been routinely exposed occur underground, particularly from uranium mines. Studies of exposed miners have consistently found associations between radon and lung cancer [18,19].

1.7 Potassium

Potassium is another major source of terrestrial sources. The long half-life of K-40 (1.25 billion years) means this it still exists in measurable quantities today. It β decays, mostly to calcium-40, and forms 0.012% of natural potassium. It is found in more foodstuffs (bananas for example), and indeed fills an important dietary requirement, ending up on our bones. (people have about 65 Bq/kg of K-40 and along with this foods are therefore correspondingly radioactive to a small degree. A 70 kg person has 4400 Bq of K-40 with 3000 Bq of carbon-14[20].

1.8 Man-made radiation

The main man-made contribution to the environmental exposure of the world's population has come from the testing of nuclear weapons in the atmosphere that occurred mainly since 1945. Since the previous UNSCEAR review of this topic in 1982 new information, previously classified, has become available on the numbers and yields of nuclear tests. An updated listing of atmospheric nuclear tests conducted at each of the test sites is included in this report. Although the total explosive yields of each test have been divulged, the fission and fusion yields are still mostly suppressed. Some general assumptions have been made to allow the evaluation of fission and fusion yields of each test in order to estimate the amounts of radionuclides produced in the explosions. The estimated total of fission yields of individual tests is in agreement with the global deposition of the main fission radionuclides ^{90}Sr and ^{137}Cs, as determined by worldwide monitoring networks. It has been calculated that the world average annual effective dose reached a peak of 150 µSv in 1963 and has since decreased to about 5 µSv in 2000, from residual radionuclides in the environment, mainly of ^{14}C, ^{90}Sr and ^{137}Cs. The contribution to man-made exposures from the generation of electrical energy by nuclear power reactors has been estimated using a collective (100 year truncated) dose of 6 man-Sv / GW year. Assuming the present annual generation of 250 GW years continues, the truncated collective dose per year of practice is 1500 man-Sv to the world population, giving an estimated maximum per output dose of less than 0.2 µSv per year [7].

The more significant source of man-made radiation exposure to the general public in medical procedures, such as diagnostic x-rays, nuclear medicine, and radiation therapy [21]. Most of the major isotopes would be I-131, Sr-90, Co-60, Cs-137, and others. In addition, members of the public are exposed to radiation from consumer gives, building materials, televisions, luminous watches and dials (tritium), airport X-ray systems, smoke detectors (americium), etc. [22]

1.9 Previous studies of NORM

1. Nasim Akhtar (2006) estimated the activity concentration using a high-resolution HPGe γ-spectrometry system of the concerned radionuclides for the soil and he found that for ^{232}Th was 57.18 Bq/kg, ^{226}Ra was 34.45 Bq/kg and ^{40}k was 643.60 Bq/kg [23].
2. Rasheed (2007) have been used HPGe detector to measure the emitted gamma lines from the radioactive isotopes. The specific activity of ^{238}U, ^{232}Th series as well as ^{40}K was determined in the studied samples which are consisted of eleven types of marble used as building material and the hazard index was between 0.031-1.41 [24].

3. El-Gamal et al. (2007) measured the activity concentrations from sediment samples collected along the Upper Nile River in Egypt. The measurement showed ranges of ^{238}U, ^{232}Th and ^{40}K concentration of 3.83-34.94, 2.88-30.10 and 112.31- 312.98 Bq/kg [25].
4. Mohammed (2008) measured uranium concentration in Al-Sulaimaniya and Erbil Governorates - Iraq. Uranium concentrations ranged from 0.120 – 0.151ppm in Al- Sulaimaniya Governorate and from 0.160-0.186ppm in Erbil Governorate [26].
5. Al- Hamarneh and Awadallah (2009) determined the radioactivity levels in various geological formations of soils in the northern Highlands of Jordan. The average radioactivity concentrations were 42.5, 49.9, 26.7 and 291.1 $\mathrm{Bq/kg}$ of ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K respectively [27].
6. Ibrahim F. Al-Hamarneh and Awadallah (2009) determined the radioactivity concentration of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in surface soil samples from Jordan. The samples measured by using an HPGe detector.The highest activity concentrations of ^{226}Ra and ^{238}U were found to be 1040 and 943.1 $\mathrm{Bq/kg}$ in Zarqa. The mean values for activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K were found to be 42 ±13, 49 ±15 and 27 ±9, 291 ± 98 $\mathrm{Bq/kg}$ respectively [28].
7. Ali (2009) estimated uranium concentration in soil samples taken from different sites on the national highway between Baghdad and Ramadi using SSNTDs. Uranium concentrations were varying from 1.03 ppm to 7.1 ppm [29].
8. Damla et al. (2010) estimated natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in soil and indoor radon concentration at dwellings in Batman, Turkey using SSNTD. They were found that the mean concentrations were 35 $\mathrm{Bq/kg}$ for ^{226}Ra, 25 $\mathrm{Bq/kg}$ for ^{232}Th, 274 $\mathrm{Bq/kg}$ for ^{40}K and 84 $\mathrm{Bq/m^3}$ for ^{222}Rn [30].

9. Al- Wasity (2010) measured uranium concentrations in soil sample in Wasit Governorate. Uranium concentrations ranged from 1.11 ppm to 1.84 ppm with an average value of 1.43 ppm [31].
10. Huda Abdulrahman Al-Sulaiti (2011) measured the natural radioactivity levels in the state of Qatar using high- resolution gamma-ray spectrometry. The mean values of ^{226}Ra, ^{232}Th and ^{40}K for the soil samples were found to be 17.22 ±1.55, 6.38 ±0.26 and 169 ±5 Bq/kg respectively. The value of Ra_{eq} was found to be just below the permissible value of Ra_{eq} of 370 Bq/kg [10].
11. Laith et al. (2011) measured the activity concentration of radionuclides using gamma spectroscopy and nuclear track detector in limestone rocks in northern Iraq. Concentration values measured by NaI(Tl) detector. The absorbed gamma dose rates in air due to the presence of ^{238}U, ^{226}Ra, ^{40}K and cosmic ray contribution varied between 105.3 and 223.11 nGy/h [32].
12. Todsadol – Santa wamaitre (2012) evaluated the level of natural radioactivity in river sediments and riverbank surface soils in Thailand.The activity concentrations were determined by using a hyper-pure germanium (HPGe) detector in a low background configuration. The ranges of activity concentrations of ^{238}U, ^{232}Th and ^{40}K were found to be 13.9±0.4↔76.8 ±1.7, 12.9 ± 0.3↔142.9 ±2.8 and 178.4± 6.1↔810.7 ± 26.7 Bq/kg respectively and D in air lie in the range 21.7±0.4 to 155.7±2.2 nGy/h [33].
13. Mohammed (2013) determined the activity concentrations of radionuclides ^{238}U, ^{232}Th and ^{40}K in mission surface soil by using (HPGe) detector. the mean value activity concentrations of ^{238}U, ^{232}Th and ^{40}K were (23 Bq/Kg), (31 Bq/Kg) and (300 Bq/Kg) respectively [34]

14. Attia et al, (2014) measured the natural radioactivity in soil samples in the industrial area of Port Said city Egypt. By using (HPGe) detector. the mean value activity concentrations of ^{238}U, ^{232}Th and ^{40}K were (398.33 Bq/Kg), (75.70 Bq/Kg) and (583.12 Bq/Kg) respectively[35]
15. Yousef et al, (2015) measured the natural radioactivity in soil samples in the east of Suleiman governorate. By using NaI(Ti) detector. the mean value activity concentrations of ^{238}U, ^{232}Th and ^{40}K were (38.337 Bq/Kg), (19.147 Bq/Kg) and (284.86 Bq/Kg) respectively [36]

1.10 Previous Studies of Radon

1. Rahman et al,(2008), study the effect of the moisture content on the radon exhalation rate from soil, sand and brick samples that were collected from the North West Frontier Province and Federally Administered Tribal Areas of Pakistan, using CR-39-based radon dosimeters, the result average radon exhalation rates of 385, 393 and 362 ± 36 mBq m^{-2} h^{-1}[37] .
2. Singh J et al, (2009), determined radon concentration was assessed in water samples taken from hand pumps by solid state nuclear track detectors (SSNTDs). the result The radon concentration in these samples was found to vary from 0.87 to 32.10 Bq/ L[38].
3. Ghosh D et al, (2010), we studied the alpha radioactivity in different cosmetics samples, such as lipsticks, nail-polish, toothpaste and vermilion in India, by solid state nuclear track detectors (SSNTDs). About seventy CR-39 detectors, the result The overall average radon concentration in the surveyed area was 0.5 to 29 Bq m^{-3}[39].
4. Obed RI et al,(2011), determined Radon measurements were performed in secondary schools in the Oke-Ogun area, South-west, Nigeria, by solid state nuclear track detectors (SSNTDs). About seventy CR-39 detectors, the result The overall average radon concentration in the surveyed area was 45 ± 27 Bq m^{-3} [40].

5. Kadeem, 2012, measurement the level of environmental contamination by radioactive elements (uranium ,radon gas) and some heavy matels (lead ,cadmium , zinc and copper) in 163 soil samples taken from Al-Nasiriya city ,the result had shown that the average of uranium concentration in Al-Nasiriya city was equal to(3.082 ppm).while the average concentration of radon gas in Al-Nasiriya city was equal to (1386.236 ppm) [41].
6. Ali ,2013, determined the radon concentrations in different dwelling in Al-Gazalia city . the result had shown that radon concentrations was varied from (38.7 Bq/m^3) to (200Bq/m^3) [42].
7. Shinen, 2015, determined the radon gas in the air of homes in karbala governorate by using CR-39 . the result had shown that radon concentrations was varied from (82.3 Bq/m^3) to (240.7Bq/m^3) [43].

1.11 The aim of the present work

The aim of the present study was to measure the level of the radioactivity in Al-Dora refinery and surrounding area. The study includes:

1. Determination of the radon gas concentration in soil samples from Al-Dora refinery and dust samples from surrounding area by using "sealed can technique" and CR-39 track detector to registration alpha tracks emitted from radon gas in (soil and dust) samples.
2. Detect of the naturally occurring radionuclides (^{226}Ra belong to ^{238}U series, ^{228}Ac belong to ^{232}Th series and one natural radionuclide ^{40}K) in the (soil and water) and measure the specific activities using gamma ray spectroscopy system with HPGe detector).
3. Estimate the radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), hazard index (H_{ex}, H_{in}) and annual effective dose equivalent (AEDE) in soil and water samples of Al-Dora refinery and surrounding area.

2-1 Introduction

The radioactive atoms in a radioactive material decay according to a random process. The probability of a nucleus decaying in any time interval is independent of time. It was noted that decay rate of any pure radioactive substance decreases in time according to an exponential law which is called the Radioactive Decay law. If no new nuclei are introduced into to given radioactive material, this law portend how the number of radioactive nuclei which is present at time t and it decreases with time. The number of nuclei N, dN/dt decaying in a time interval, is proportional to N can get by [44]

$$dN = -\lambda N dt \qquad (2-1)$$

where λ is a constant which can be called the decay constant. In addition, the decay constant represents the probability per unit time for the disintegration of an atom. The negative sign means that the amount of nuclei left without decay decreases as time increase.

The exponential law of radioactive decay can given by [44]

$$\int_{N(0)}^{N(t)} \frac{dN}{N} = -\int_0^t \lambda dt \ldots\ldots\ldots\ldots\ldots\ldots (2-2)$$

$$lnN(t) - lnN(0) = -\lambda t \ \ldots\ldots\ldots (2-3)$$

$$N_t = N_0 e^{-\lambda t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-4)$$

where N(0) is the number of radioactive atoms at t = 0 and N(t) the remaining number after a certain time t. Thus of initially N(0) atoms $\Delta N = N(0)(1-e^{-\lambda t})$ decay in average in the period [0, t].

The more common way to express lifetimes is the concept of half-life $T_{1/2}$. This is the time during which the initial number of radioactive isotopes is halved.

$T_{1/2} = \ln 2/\lambda = 0.693/\lambda$

One can only determine the rate of transformation called the activity by measuring the particles emitted. It is proportional to the number of atoms

$A = dN/dt = -\lambda N$……………………(2-5)

where A:the activity represent the number of disintegration per second remaining number after a certain time t[45].

$A_t = \lambda N_t = A_o e^{-\lambda t}$ ……………...(2-6)

٢-٢ Radioactive Equilibrium

In a radioactive decay the produced nuclei are often radioactive themselves. Such continued radioactive transformation processes lead to whole decay chains. The genetically following nuclides are called mother and daughter nuclides etc. The rate of the change of daughter atom depends on both the rate of growth from the parent and the rate of decay of the daughter [46]. Not all decay of parent nuclei to give stable nuclei directly and some nuclei need to secondary decay to search for stability, and so the process will continue (in chains radioactivity) to eventually reach the more stable nucleus and stop the decay series [7]. Assuming the first time that at time t = 0 we have N_A atoms of the unstable element and no atoms of the decay product are originally present, the number of parent nuclei decrease with time according to the Eq 2-1.

While the number of stable nuclei grow-up as a result of decays of the unstable nuclei and decreases as a result of its own decay, given by Eq. 2-7

$$\frac{dN_B}{dt} = \lambda_A N_A e^{-\lambda_A t} - \lambda_B N_B \qquad (2\text{-}7)$$

The solution of the first order differential equation (2-7) is of the form $N_B = A\mathrm{e}^{-\lambda_A t} + \mathrm{B}\mathrm{e}^{-\lambda_B t}$ and by substituting these initial conditions into equation (2-7), N_B given by [44]:

$$N_B = \frac{\lambda_A N_A}{\lambda_B - \lambda_A}\left(e^{-\lambda_A t} - e^{-\lambda_B t}\right) \qquad (2\text{-}8)$$

From Eqs.2-4 and 2-8 the relative activity ratio can be calculated by:

$$\frac{\lambda_B N_B}{\lambda_A N_{A0}} = \frac{\lambda_B}{\lambda_B - \lambda_A}\left(1 - e^{-(\lambda_B - \lambda_A)t}\right) \qquad (2\text{-}9)$$

If $\lambda_B \gg \lambda_A$: In this case when the half-life of nuclide A is much greater than the half-life of nuclide B, so the unstable nuclide decays at constant rate then the activity of stable nuclide given by:

$$\lambda_B N_B = \lambda_A N_A\left(1 - e^{-\lambda_B t}\right) \qquad (2\text{-}10)$$

This equation shows the secular equilibrium condition, where as t becomes large nuclei (B) decay at the same rate at which they are formed:$\lambda_B N_B = \lambda_A N_A$. This result can also be immediately obtained from Eq(2-4), taking $dN_B/dt = 0$. For practical purposes, equilibrium may be considered established after seven daughter half-lives (larger than 99% of daughter nuclides grow-up) [47].$\lambda_B > \lambda_A$: as t increases, the exponential term becomes smaller and the activity(Adel) ratio(A_B/A_A)approaches the limiting constant value $\lambda_B/\lambda_B - \lambda_A$.The activities themselves are variable, but the nuclei of type B decay (in effect) with the decay constant of type A. This situation is known as transient equilibrium condition [47]**.** $\lambda_A > \lambda_B$: in the case when the parent decay speedily, and the daughter activity rises to a maximum and then decays with its characteristic decay constant, if t is so long the number of nuclei type A is:

$\lambda_B N_B \approx (\lambda_B \lambda_A N_A/\lambda_A - \lambda_B)e^{-\lambda_B t}$.................(2-11)

which reveals that the type B nuclei decay approximately according to the exponential law .This situation is known as no equilibrium condition [46] **.**

There is a variety of possible decay schemes which depict the decays of the nuclei involved in measurements of naturally occurring radioactivity. Some nuclei may decay through a single decay mode, such as ^{210}Bi which decays only through β- decay to ^{210}Po. However some radionuclides undergo decay through more than one mode. For example, ^{40}K decays to ^{40}Ar by electron capture (10.7%) or to ^{40}Ca by β^- (89.3%), as in Fig.1-2 The branching ratio is defined as the ratio of the probability of nuclear decay by one mode to the total probability of decay by all the possible modes [46].

٢-٣ Decay Modes

The nuclei stable is nuclei no interaction with any it's around. The nuclei of unstable atoms throw out particles in order to become more stable systems, when interaction with other to transmuting to the more stable isobar (constant A) of that mass number; Alternatively, a nucleus in an excited state can give energy in the form of an electromagnetic quantum of energy to decaying toward the ground state configuration for this nuclear system, without changing the nuclear species[48]. There are more one primary decay kinds such.

2-3-1Alpha Decay

Alpha particles are very low-penetrating radiation and do not travel very far in the environment. They are considered the most dangerous type because the half-time are long and when you enter into the human body became very series impact. α- emitting radionuclides can be natural or man-made. α-emission is a Coulomb repulsion effect, which occurs predominantly in nature form heavy nuclei with $A \geq 210$[48].

Beta Decay ٢-٣-٢

Beta-decay provides a convenient decay mode for an unstable nucleus to increment down a mass parabola of constant atomic mass to approach the A beta-particle is much lighter than alpha-particle which means .stable isobar that for a given energy, Beta-particle is much more penetrating. There are three processes to which nuclei may undergo radioactive β- decay: β^- decay, β^+ decay and electron capture [49].

Gamma Decay ٣-٣-٢

Gamma is different from other electromagnetic radiation in terms of its wavelength, origin and frequency. It is similar to X-rays and visible light in its nature and it radiation is an electromagnetic radiation and has no mass and no electric charge [50]. Its emission is similar to the emission of atomic radiation, such as X-ray conversions . The emission of gamma-ray is observed in all nuclei that have excited bound states ($A > 5$).The γ- emission has half-lives which are usually quite short and generally less than 10^{-9}s, but sometimes the half-lives for gamma emission find significantly longer, even hours or days. These longer lived decays are known as isomeric transitions and the long-lived excitation states are called isometric states. Typical energies of γ- rays are in the range of 0.1 to 10 MeV. These corresponding to wavelengths which are far shorter than other types of electromagnetic radiations such as visible light which has wavelengths 10^6 times longer than gamma rays. γ- rays have energies typically in the range of

0.1 up to 10 MeV. It is a quantum of electromagnetic energy that travels at the speed of light and can travel up to hundreds of meters in air before being attenuated [7].

٢-٤ Interaction of Gamma with Matter

Understanding the gamma-ray interactions with a detector is an important issue in order to know how gamma-rays photons are detected and attenuated. From the number of possible interactions processes for gamma-ray in the matter, three mechanisms play the most significant roles in interactions with gamma-ray detectors to transfer their energy partially or completely to the detection medium [51]. These are: photoelectric effect, Compton scattering, and pair production.

Photoelectric interactions are dominant to low energies up to several hundred keV, and pair production at high energies (more than 5 MeV). Compton scattering being the most important interaction in the mid-energy range as shown in Fig. 2-1[52].

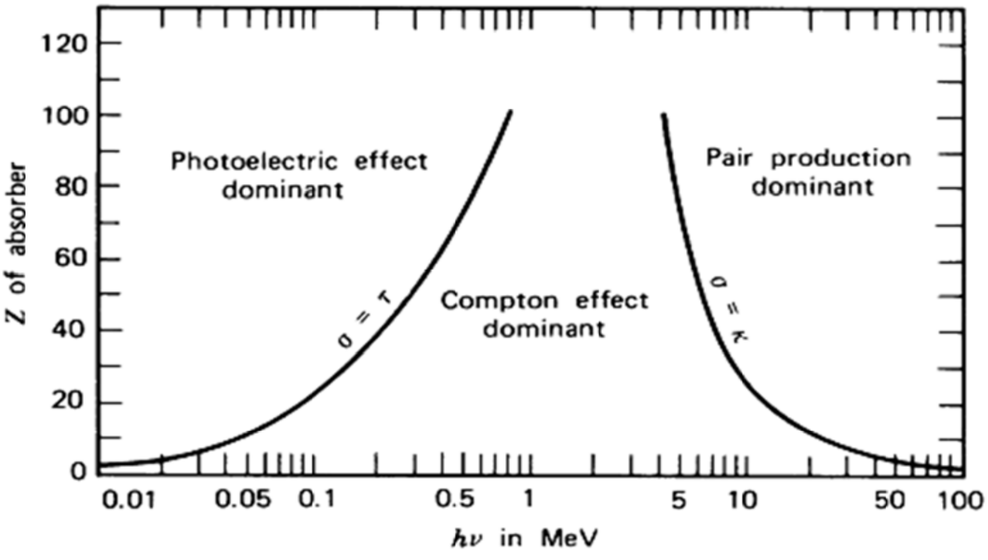


Figure 2-1: Relative importance of the three major types of γ-ray interaction [52].

2-5 Gamma Ray Attenuation

The gamma rays emitted from a sample may be attenuated by the sample itself. The measured γ-ray intensity will be less than the absolute intensity of the original emitted radiation [7] .The linear attenuation coefficient (μ) is a vital quantity for characterizing the penetration of γ- rays in a sample which may be a combination of different chemical compositions. It illustrates the portion of a coherent, focused, pencil-beam of gamma rays that is scattered or absorbed per unit thickness of the absorber [52], It can be defined as "the probability of a radiation interacting with a material per unit path length"[53], and depends on some parameters:

The incident photon energy. (i)

The average material atomic number. (ii)

The absorber material effective density. (iii)

Thickness of the sample. (iv)

The transmitted of gamma ray is given by:

$$I_x = I_0 \, e^{-\mu x} \qquad (2\text{-}12)$$

where μ is the linear attenuation coefficient; I_0 is the initial intensity of gamma-ray photons at a specific energy without attenuation; I_x is the gamma-ray intensity after attenuation through a sample of thickness x; μ for materials with known chemical composition [53].

٢-٦ Radioactive Contamination

The human in earth ingest and inhale radionuclides every day of our lives and radioactive material has been ubiquitous on earth since its creation. Traces of radionuclides are found in all side of earth such soil, air, water and human bodies. The presence of natural radioactivity in soil results in external and internal exposure to humans. Radioactive elements which can be found in nature are generally categorized in two distinct families, namely of arising from either ‘earthen’ Origin or ‘Cosmogenic’ [54]. The most commonly encountered radionuclides that irradiate the human body through external exposure (primarily by γ- radiation) are ^{235}U, ^{238}U and ^{232}Th and their subsequent radioactive decay products and ^{40}K [55]. Radioactive contamination in nature can be found in:

in Air ٢-٦-١

Radioactive Contamination in air such Radon is present everywhere, in soil and rocks, in subsurface and deep water and atmosphere, at different concentrations. That concentrations of radon in geological environments depend on the migration processes (by diffusion and advection) and the abundance of its unstable radium nucleus, located in minerals in the soils and rocks. Nearly migration of radon gas in soil is facilitated by the presence of faults with or without contribution of carrier different type of gas [56]. One of the radionuclides around human’s environment that contributes high amounts of potentially lethal dose is radon; which causes the majority of deaths resulting from lung cancer[57]. In the atmosphere reaches by diffusion to the surface, this exhalation forming the radon flux of the earth crust [58]. There are at least more one different issues of great importance in radon studies. The first aspect is related to the radon potential in soil and the flux from the soil surface. Studies performed on different uranium miners revealed a true correlation between radon concentrations and lung cancer risk [59]. Today, are ongoing epidemiological studies which seek to highlight the there connection between radon concentrations and lung cancer risk, even of normal indoor concentrations of 40-300 $Bq.m^{-3}$ [60].

in Soil ٢-٦-٢

The soil is important kind of Radioactive Contamination. Soil is the become of the earth's crust and is formed as a result of rock deformation by more complex processes, which include weathering decomposition, organic matter addition and water movement. Soil consists of minerals, organic matter, air and water; where their percentages vary widely according to soil type and particle size [61].

Natural radioactivity is wide spread in the all part of surface earth Contains of Radioactive Contamination such in plant, soil, water, air, coal and phosphate. Naturally occurring radioactive materials in soil are one of the components of external γ-ray exposure to which persons are exposed to regularly. Natural environmental radioactivity and the associated external exposure due to γ-radiation depend primarily on geological and geographical conditions and exist at different levels in the soils of each region in the world. The natural radioactivity in soil comes mainly from ^{232}Th series, ^{238}U series and ^{40}K. The specific levels of terrestrial environmental radiation are related to the geological composition for each lithological separated area, and to the content of thorium, uranium and potassium in the rock from which the soil originated in each area [62,63].

Elemental distribution in soil is determined by several factors including the parent material, leaching, migration of elements from or within the soil profile, and addition of elements from outside. The parent material is the starting material of the soil and primarily determines its elemental composition. Weathering will modify the elemental composition of the soil. For example, Si and Mg are apparently lost through leaching. Furthermore, the migration of elements within a profile will occur by processes such as eluviation and illuviation, and by bio cycling of animals and plants. These processes change the content of an element in the horizon. Addition of elements will happen by deposition of particles from the air onto the surface of the soil and by applying fertilizer, sewage sludge, or compost [64].

in Water ٢-٦-٣

Water is More than 65% of the Earth's surface is covered with water [65]. Lakes and rivers account for far less than a half percent of the fresh water reserves. Groundwater is the most highly used and widespread resource; however, its quality can be endangered. The increasing interest in radioactivity and its applications has brought about the need for an assessment of human exposure to radiation. It is, therefore, necessary to examine naturally occurring radioactivity in the environment, especially the occurrence of natural radioactivity in groundwater [66].

Drinking water comes from ground water, which was supplied through public drinking water systems. But humans rely on private, household wells and use groundwater as their source of fresh water. The quality of drinking water is affected by the depth of groundwater from the surface, because there is a chance of being polluted varies from place to place. Populace activities can alter the natural composition of groundwater causing undesirable change in groundwater quality in the form of contamination or pollution. Groundwater may contain some natural impurities or contaminants, even with no pollution or human activity. Natural contaminants can come from conditions in the ground or in the watershed. Water moving through underground soils and rocks may pick up magnesium, chlorides and calcium [67]. Radon gas provide one means of detecting the presence of natural radioactivity in groundwater, and, if the radioactivity level of groundwater is beyond tolerable limits, it could result into several health hazards among the humans [68].

Radon accumulates in groundwater due to two sources, firstly the radioactive decay of dissolved radium (radon's immediate parent in the uranium decay chain), and secondly the direct release of radon from the mineral matrix from minerals (in surrounding rocks) containing members of the uranium decay chain [60].

2-7 Gamma ray spectroscopy

Gamma ray spectroscopy measures electromagnetic radiation in the gamma ray spectrum of radioactive sources. This is performed through the process of the counting and measuring the energy of individual photons emitted from elements. The measurement of gamma rays is valuable for the determination of the elemental composition of a wide variety of sources. The measured energy of a gamma ray corresponds to the type of element and its isotope, while the number of counts corresponds to the abundance of the radioactive source [7].

2-8 Detection mechanism

In semiconductor detectors, ionizing radiation is measured by the number of charge carriers set free in the detector material which is arranged between two electrodes, by the radiation. Ionizing radiation produces free electrons and holes. The number of electron-hole pairs is proportional to the energy of the radiation in the semiconductor. As a result, a number of electrons are transferred from the valence band to the conduction band, and an equal number of holes are created in the valence band. Under the influence of an electric field, electrons and holes travel to the electrodes, where they result in a pulse that can be measured in an outer circuit. The holes travel in the opposite direction and can also be measured. As the amount of energy required to create an electron-hole pair is known, and is independent of the energy of the incident radiation, measuring the number of electron-hole pairs allows the intensity of the incident radiation to be determined.[69]

2-9 High purity germanium detector in gamma-ray spectrometry

Germanium semiconductor detectors were first introduced in 1962 (Tavendale and Ewan, 1963) and are now the detectors of choice for high energy-resolution γ-ray studies. These detectors directly collect the charges produced by the ionization of the semiconductor material. One electron-hole pair is produced on the average for every 3 eV absorbed from the radiation. These pairs drift under an external electric field to the electrodes where they generate the pulse.

The germanium crystal must be cooled by liquid nitrogen in order to minimize the thermal leakage current through the system which would have a negative impact on the energy resolution. Germanium detectors have good energy resolution, making it suitable for usage in many applications where complex gamma-ray spectra are studied [69].

Gamma spectrometry system that used in this study is a fully integrated data acquisition and computation system comprising the following [7]:

١. High purity germanium used the detector.

٢. Preamplifier is normally an integral part of detector unit and located very near to the detector when it is necessary for the operation of the detector to low noise.

Linear amplifier is usually built into the multichannel analyzer (MCA), .٣ amplifies the pulse to a factor of several hundred, it has a voltage of several volts, it also shapes the pulse so it can analyze most accurately.

Bias high voltage power supply is used to supply high voltage to the .٤ detector with a range from (0-5000) D.C volt, and must be more slowly to avoid damaging the detector.

Personal computer is used as the multi-channel analyzer (MCA). .٥

The (MCA) measures the magnitude of the output signal voltage which is fed into it. When the computer software is instructed by the MCA, it starts counting channels where the pulse is shown in the form of spectrum, and each channel corresponds to specific radiation energy. This allows the equipment to be calibrated and can be used for measurement to identify photons emitted from defined radionuclides by their energy as show in fig 2-2 [7].

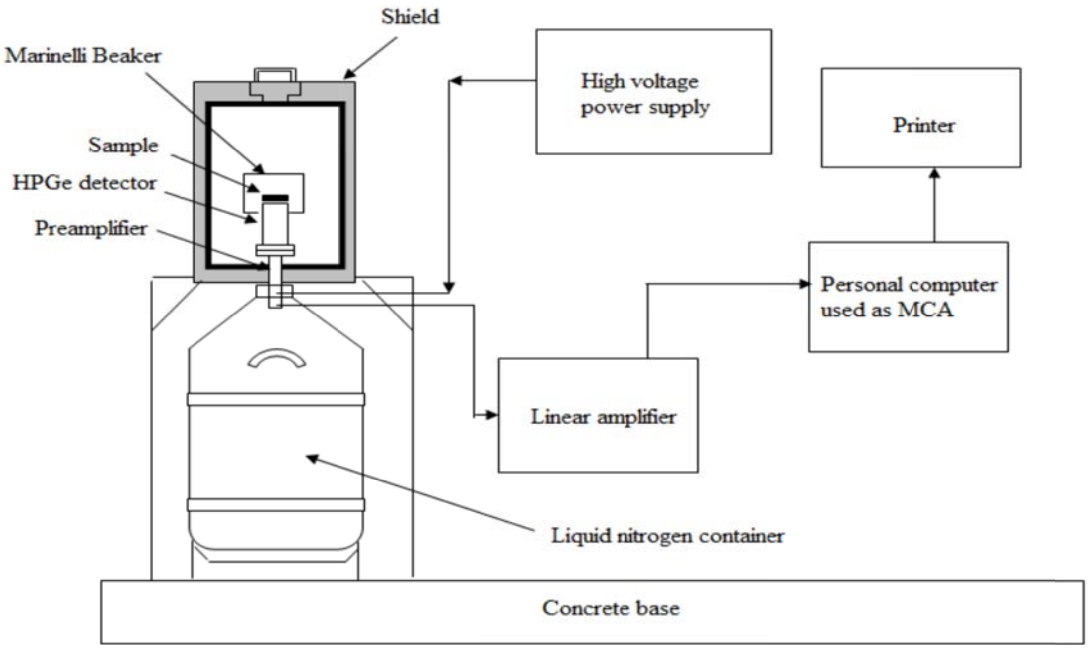


Figure 2-2: photo of (HpGe) detector (in central laboratories directorae) [7]

2-10 Solid State Nuclear Track Detectors SSNTDs

The branch of solid state nuclear track detectors popularly define as SSNTDs, has been so spectacular and extensive that there is hardly any area of science and technology when it’s actual. This track recording properties of insulating solid were first revealed at Annual Effective Dose Equivalent [70].

Solid state nuclear track detectors are essentially materials that are damaged in such away by energetic particles, that the particle tracks can be developed by subsequent etching and can observed microscopically [71].

SSNTD had its origin in the year 1958 when first observations were reported by D.A. Young at AERE Harwell (Young, 1958). He noticed that when lithium fluoride crystals LiF, held 1 mm away from uranium oxide film, were irradiated with thermal neutrons the crystal surface revealed a number of shallow etch pits after treatment with a chemical reagent. The damaged regions constituted more chemically active zones than the surrounding undamaged areas [72].

Silk and Barnes working in the same establishment had recorded direct observations of damage regions, as hair-like tracks, in mica [73], they were the first to be observed on a Transmission Electron Microscope (TEM). Then, in a very short period of time, a number of experiments were performed which led to the discovery of chemical etching technique and the optimum conditions of etching. These experiments led Fleischer, Price and Walker working together at the General Electric Research Laboratories (GERL) at Schenectady, New York, to extend the etching technique of Young (his work was unknown to them at that time) [74].

In 1962 Price and Walker, unaware of Young's paper, found that these track could be enlarged by etching the mica and Fleischer extend this to other materials substantiating it as a general phenomenon in dielectric solid [72].

Cartwright et al., 1978 first discovered the CR-39 Polyallyl diglycol carbonate a Nuclear Track Detector (NTD) [75]; CR stands for Columbia Resin. CR-39 has the widest dynamic range for detecting charged particles for a large range of Z values. Solid state nuclear tack detectors have found wide use in various domains of science and technology, e.g. in environmental experiments, they have been used successfully as detecting devices and a passive system to detect alpha contamination on different surfaces [76].

2-11. Mechanisms of Latent Track Formation

Many models have been proposed to explain the mechanism of track formation. They shall discuss the ones which are consistent with the characteristics of the tracks described a little earlier. The damaged track detectors can be considered to be the converse of scintillation, since, in this case the quantity of importance is the energy left near the particle trajectory, which determines the chemical track reactivity [71]. There are two types of solid state nuclear track detectors: -

2-11-1. Inorganic Detectors

Inorganic detectors are compounds where carbon and hydrogen do not enter in its structure, and created a "ionic bond" between its atoms. It is used to record the tracks of neutrons and fission fragments. Ion explosion spark model suggested by Fleischer and Walker in 1965[77] explaining of the latent track formation in inorganic solid materials. It states that the heavy charged particle produces a huge number of primary ionizations along its trajectory thereby generating positive ions as in the fig. (2-3) a. These ions intensively strike the electrons of the colliding atoms in the regions neibouring its trajectory thereby resulting in a cylindrical region filled with positive ions repelling each other intensively. If the force of repulsion is greater than the force of attraction of the solid material atoms then deformation occurs to the crystal of atoms leaving behind it an empty cylindrical core that can be seen by an electron microscope, or by the optical microscope after treating it chemically by the etching process [71].

2-11-2. Organic Detectors

Organic detectors are compounds where carbon and hydrogen enter in their structures, and created a "covalent bond" between its atoms, this type of SSNTDs has a sensitivity larger than inorganic detectors because the bonds of C-C and C-H which are causes to broken the long polymer chains in to short chains and result a new chain ends (Free Radicals) and other chemically reactive sites, as show in figure (2-3b)

The net effect on the plastic will be the production of many broken molecular chains, leading to reduction in the average molecular weight of the substance. Therefore, the rate of chemical etching attack on a plastic increases as the molecular weight decreases. It is likely that the damage region is more etch able than the bulk material which leads to the etching along the track and is greater in rate than that of the bulk material [78,71] as shown in (2-3). organic detectors have a high analytic power larger than inorganic detectors.

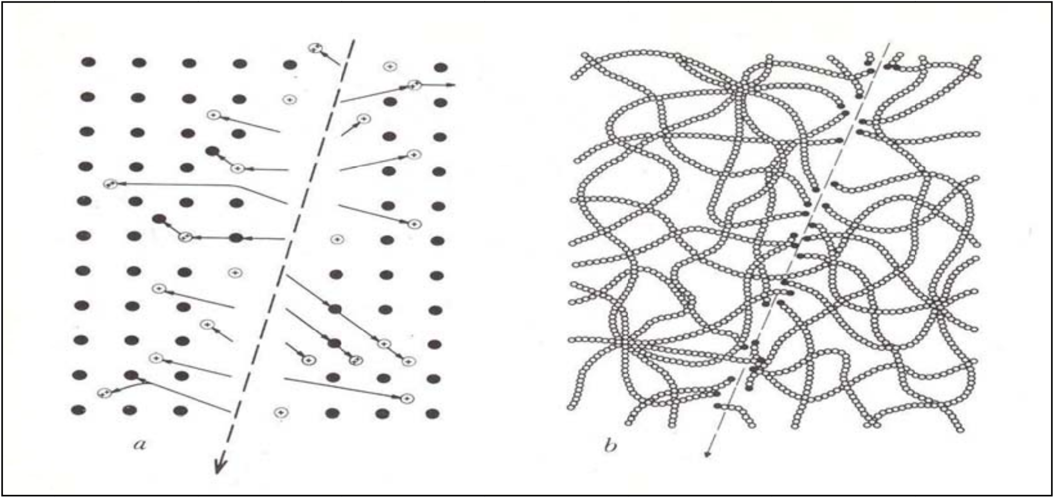


Figure (2-3):- The atomic character of a plastic track in (a) a crystal and (b) a polymer [71].

2-12. CR-39 detector

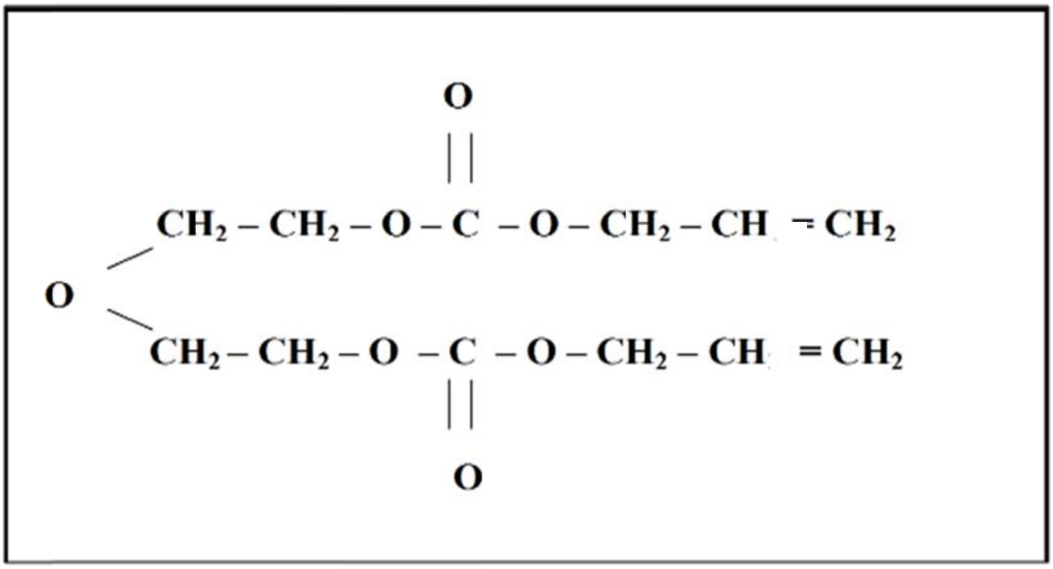
The chemical name for CR-39 is poly-allyldiglycol carbonate (PADC) with chemical formula $C_{12}H_{18}O_7$. CR-39 stands for Columbia Resin (trade name). It is an optically clear plastic and also finds great application as a major component in copolymers used for lenses in spectacles.

It was discovered in 1978 by Cartwright, Shirk and Price [74]. Its density is 1.32 g.cm^{-3}. which means that it contains the following functional group:

$$(C\,H_2 = C\,H - C\,H_2)$$

The chemical form for CR-39 may be written as ($C_{12}H_{18}O_7$). It is illustrated in Fig2-4 [78].

Figure. 2-4. The chemical form of CR-39 detector [79].



The detector (CR-39) has a high efficiency to record the tracks in comparison with other detectors and it has some specifications as [80]:

1- Optically transparent

2- Very sensitive to radiation

3- Highly isotropic and homogeneous

4- Not cross-linking after radiation damage has broken the chemical bonds

5- Having a non-solvent chemical etchant

6- This polymer is resistant almost to all solvents, and to the heating Weak links of Carbon increase the sensitivity of the detector to radiation because it breaks easily when exposed to radiation. The lowest rate of charge can be detected in CR-39 [80].

Several attempts were made to improve the sensitivity of CR-39. Tayler found in 1981 that the sensitivity and characteristics of pre-etching of CR-39 detector are possible improved by adding 1% of substance (dioctyl phthalate), the new detector is named CR-39. Also it was discovered detector developer for CR-39 called SR-86 which is made from (diethylene glycolbic (Allyl sulphenate)). SR-86 is polymer participants from CR-39, it also has the highest sensitivity [81].

The use of the CR-39 plastic as a nuclear particle detector has become generalized in the fields of dosimetry, spectroscopy and environmental science due to its high sensitivity. Most of the applications of this detector are in proton, alpha and neutron dosimetry and radiography as well as for radon dosimetry and cosmic ray's studies [81].

2-13 Track geometry

The geometry of track etching presented of the simplest case to the simultaneous action of two etching processes chemical dissolution along the particle track at a linear rate V_T with general attack on the etched surface and on the interior surface of the etched track at a lesser rate V_B as shown in Fig. 2-5.

There are more parameters were used to describe the geometry of etched track, these are [71]:

The full length of the latent track (L). -١

The thickness of the surface removed by etching (h). -٢

The diameter of the etch pit (D). -٣

The track length (L) at etching time (t) given to the following relation:

(2-13) $$L = V_T . t$$

The surface is also beginning removed to rate V_B, so that:

$$R = V_T . t - V_B . t$$ (2-14)

where: R is the range of charge particles.

V_T is the track etch rate, V_B is bulk etch rate.

When track etch rate (V_T) is constant and the particle penetrates normally, then the surface thickness (h) is given by:

$$h = V_B . t$$ ……..(2-15)

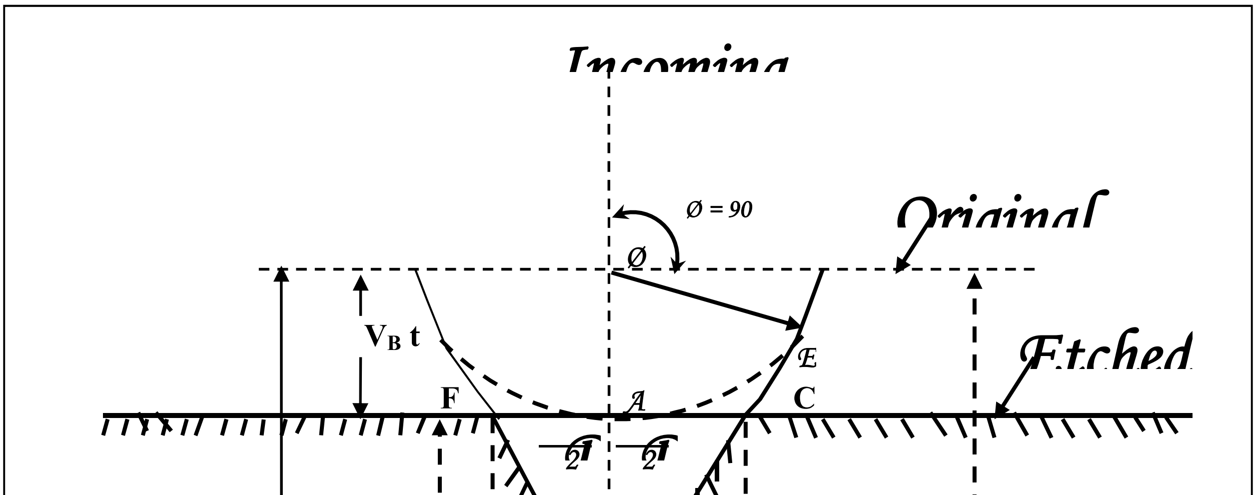


Figure 2-5: Track geometry for particle penetrates a detector material normally [79].

The diameter of etch pit (D) is related to V_B with V_T according to the following equation:

$$D = 2V_B . t[(V_T - V_B)/(V_T + V_B)]^{1/2} \qquad (2\text{-}16)$$

Equation (2-16) shows this the diameter of tracked (D) and the length of the etched (L) depend essentially to the competitive effect of V_T with V_B.

When $V_T = V_B$, both (L) , (D) vanishes and then no track produced [79].

2-14 The chemical etching

Ionizing particles passing in polymeric track detectors give latent track, which are trails of radiation damage. The best means of observing the tracks is by etching the Solid State Nuclear Track Detectors material with a chemical solution, which preferentially attacks the damaged material with enlarges the original track to a size, which is visible to the optical microscope. In general, etchants for polymeric detectors are frequently solutions of alkali hydroxides such as NaOH or KOH with (1-12) N at (40-60)°C [82]. For glasses and minerals crystals such as quartz, mica and certain pyroxenes etched in aqueous solutions of acids such as (HF) with ~ 48% concentration at 20°C [83].

Etching times can vary from few seconds to many hours. It varies according to the exact etching conditions; the temperature and the concentration of the etchant.

The chemical etching process depend on several parameters are [82].

1- Type and composition etching solution.

2- The concentration of the etching solution.

3- Temperature of the etching solution.

4- Etching time.

3-1 Introduction

In the present work, two techniques have been employed, namely, solid state nuclear track detectors SSNTDs technique to determine the radon gas concentrations in soil and dust samples from different sites in Al-Dora refinery and surrounding area, and gamma spectrometry with High Purity Germanium (HPGe) detector technique, for the detections and measurements the specific activities of the radioactive elements in soil and water samples from different sites in Al-Dora refinery and surrounding area.

3-2 Description of Study Area

Dora is located in the south-east of Baghdad near the Tigris revelry area nearly 250 hectares and is considered the refinery of the oldest refineries in Iraq represents the beginning the real advancement of the oil industry in Iraq in 1953. It was built with assistance of the worldwide companies and designed refinery transformational in order to get the maximum benefit crude oil to back the growing economy of the country.

It has a lot of units containing ranging from simple distillation units to units complex. It is surrounded by fat as important regions in the Karradah district of Baghdad, including the Al-Dora area, Zaafraniya, the Baghdad Al-Jadida area and others

3-3 Collection of the samples

Soil, water and dust samples were collected from many places in different locationsSoil samples were collected at three depths using Drilling tool. As the water has been collected with the help of employees in the water filtering unit inside the refinery and either outside the refinery has taken from water pipes inside homes . Has dust from the rooftops to collect the usual way to gather dust; the samples were stored for 30 days at normal laboratory conditions. This time is necessary to get a radiological equilibrating to the samples, before counting the concentration of natural radioactive material for samples.

3-3-1 Soil Samples

Twenty seven soil samples were taken from AL-Dora refinery and surrounding area in surface, 15cm and 30cm depth as shown in Table (3-1).

Table (3-1): Symbols and locations for soil samples sites in Dora refinery and surrounding area

Symbol	Location of samples
S1	Baghdad AL-Jadida
S2	Dora refinery near crude oil tanks)
S3	Dora refinery near diesel tanks
S4	Dora refinery near white oil tanks
S5	Dora refinery (garden)
S6	Dora refinery near oil pipes
S7	Dora
S8	Karada
S9	Zafraniya

3-3-2 Water Samples

Eight of water samples were taken from inside AL-Dora refinery and surrounding area shown in Table (3-2).

Table (3-2): Symbols and locations for water samples sites in

Dora refinery and surrounding area

Symbol	Location of samples
W1	**Dora (water Mechanical)**
W2	**Dora (water Biological)**
W3	**Dora(water)**
W4	**Baghdad new (water)**
W5	**Dora (in)**
W6	**Dora (Physics chemical)**
W7	**Karada(water)**
W8	**Dora (out)**

3-3-3 Dust Samples

Five of dust samples were taken from inside AL-Dora refinery and surrounding area shown in Table (3-3).

Table (3-3): Symbols and locations for dust samples sites in

Dora refinery and Surrounding Area

Sample code	Location of samples
D1	Dora dust
D2	Karada dust
D3	Safranin dust
D4	new Baghdad dust
D5	Dora refinery dust

3-4 Materials and Apparatus

3-4-1 CR-39 track detectors

Sheets of (250) µm thick of CR-39 plastic were used. These sheets were cut into pieces of (1 x 1) cm2 area, and stored at normal laboratory conditions.

3-4-2 Water bath

The processes were performed using water bath type "Labsco" in as show in figure (3-1) industrialization in Germany. It includes a thermostat, which can be operated over a range of (10–100)^{o}C. However, the chemical etching was carried out at 60^{o}C, and distilled water was used as the bath liquid.

Figure (3-1): Water Bath

3-5 Experimental procedure for the measurements of radon gas concentrations in (soil and dust) samples.

The determination of the radon gas concentrations in (soil and dust) for the study area were performed as follows:

A total of 27 soil samples were collected from Al-Dora refinery and surrounding area from surface, 15 cm and 30 cm depth from five locations in Al-Dora refinery and four locations surrounding area. These samples were dried and cleaned from the doping and crushed to fine powder by using electrical mill, the fine soil powder will convert to the grain size of (300 μm), all samples were kept for one month before measurements in order to achieve the secular equilibrium for ^{222}Rn and its daughters with their respective progenies, and were performed using the nuclear track detector (CR-39) of thickness of (250 μm).

The radon gas concentration in (soil and dust) samples were obtained using the sealed-cup (can) techniques as shown in Figure (3-2). The weight of the sample was about (5g) of each sample which placed inside a plastic cylindrical container facing CR-39 track detector into a diffusion chamber. Thin filter was used in order to prevent thoron gas from reaching the detector, however, leaving the radon gas to reach the detector. The container was then sealed for one months; during that time, α particles emitted by radon and their daughters bombarded the CR-39 track detectors.

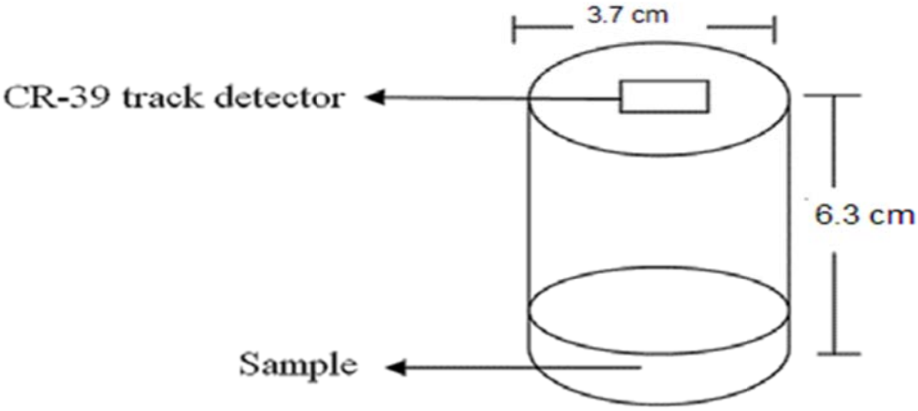


Figure (3-2) Sealed-cup (can) technique used for soil and water samples

3-6 Chemical Etching Process

After one month of exposure the track detectors etched by using sodium hydroxide solution NaOH with (6.25N) normality which prepared as in equation (3-1) [83]:

(3-1) $W = W_{eq} \times N \times V$ ………………

Where:

V: volume of distilled water = (250) ml.

N: normality = 6.25

W: weight of NaOH

Weq: equivalent weight of NaOH = 23 + 16 + 1 = (40) g / mole

The enchant compartment has a volume (250) ml contains of NaOH solution. This apparatus is closed assembly, except of small vent at the top to the condenser tube, which prevents any change of enchant normality concentration through the experiment due to evaporation. The etching time was (5) hr. as shown in Figure (3-3).

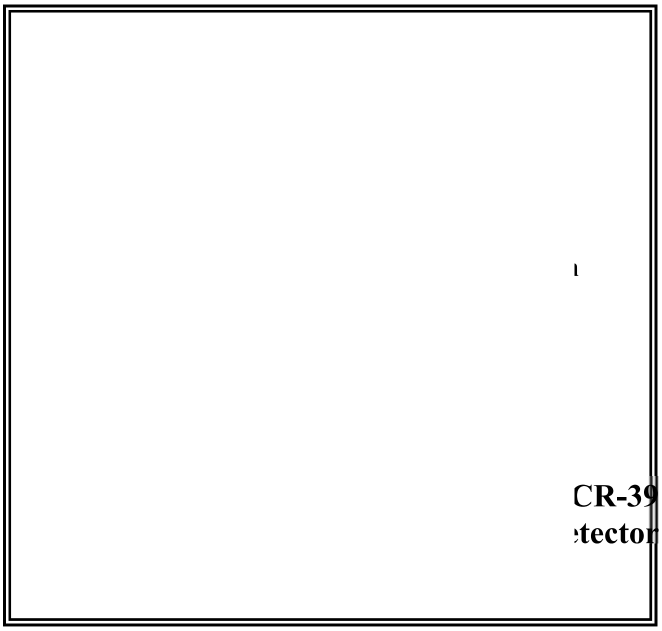


Figure (3-3) chemical etching process for (CR-39) track detector.

3-7 Measurements of Tracks Density

The counting of all the chemically etched tracks was carried out using an optical microscope. type (Motic) made in Malaysia. It is capable of giving magnifications of up to (400x).

The tracks density is measured from this equation:

$$\text{Tracks density } (\rho) = \frac{\text{Average number of total pits(track)}}{\text{Area of field view}} \quad \ldots\ldots\ldots\ldots(3\text{-}2)$$

The concentration of radon gas can be determined by the following equation:

$C_x/\rho_x = C_s/\rho_s$ ....(3-3)

where the subscripts x and s stand for the unknown and the standard, respectively; C, is the radon concentration; ρ_x and ρ_s are the densities of the alpha particles tracks for the unknown and the standard samples, respectively.

The density or the tracks (ρ) in the standard was calculated according of the following relation [84]:

By plotting the concentrations of radon (Bq/cm^3) with track densities for standard sample as show in figure (3-4) , the slope for the straight line is equal to

Slope = ρ_s / C_s …………..(3-4)

Then the eq(3-3) become

$C_x = \rho_x$ / slope …………….(3-5)

where ρ (tracks cm^{-2} day^{-1}) is the of track density rate,

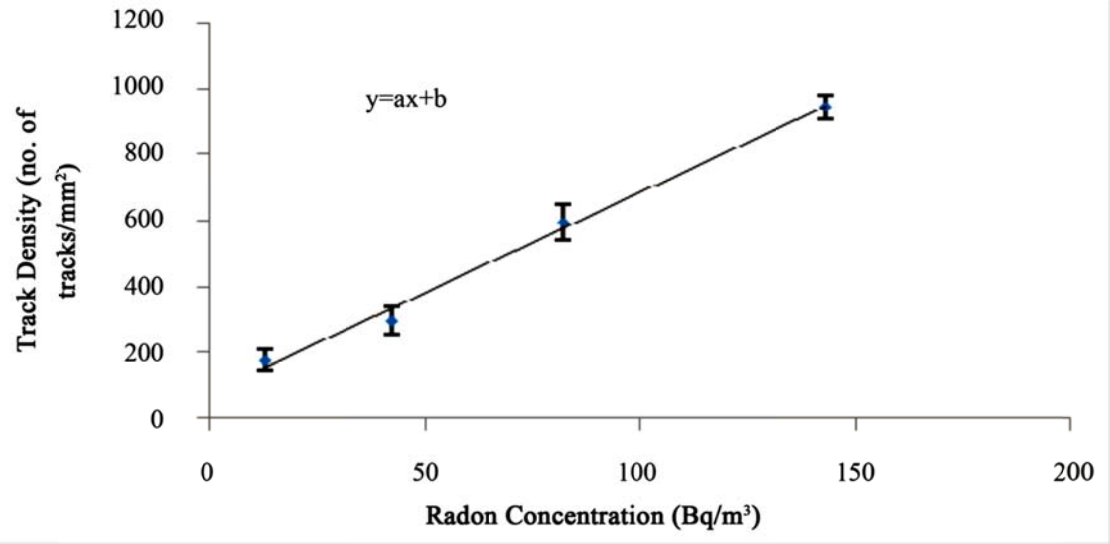


Figure (3-4). Radon concentration (Bq/m^3) and track density for standard samples [84].

The radon exhalation rate in terms of area E_x in (Bq.m^{-2}.h^{-1}) was calculated as follows [86]:

$$E_x = \frac{CV\lambda}{A[T + \lambda^{-1}(e^{-\lambda T} - 1)} \qquad \mathbf{(3-6)}$$

where C is the integrated radon exposure measured by the CR-39 SSNTD (Bq.m^{-3}.h), V is the effective volume of the container (m^3), λ is the decay constant of radon (h^{-1}), T is the exposition time (h), and A is the area covered by the container (m^2) .

The radon exhalation rate in terms of mass Em in (Bq kg^{-1}h^{-1}) was calculated as [86].

$$E_m = \frac{CV\lambda}{M[T + \lambda^{-1}(e^{-\lambda T} - 1)} \qquad \mathbf{(3-7)}$$

where M is the mass of the sample (kg).

3-8 Gamma-ray spectrometry system

Gamma- spectrometry is a good method of analysis that can yield analytical data for several more unstable nuclides in a single sample analysis, which need to shield the detector with suitable material as shown in figure (3-5).

The general specification of the system is show in table (3-4)

Figure (3-5): photo of (HPGe) detector (in central laboratories directorate)

Table 3-4: General specifications of Canberra system

System	The specifications
Type of detector	Semiconductor HPGe
Volume of crystal	(3.5×3.5) inch
Gas used	Liquid nitrogen at -196^{0}C
Operating voltage	(1500) V
No. of channel	(4096) ch
FWHM for (Co-60)	(1.33) MeV
Relative efficiency	65 %

Counting time for each sample	(3600) sec
Resolution	(1.8) keV
Diameter of crystal	(59.5) mm
Length of crystal	(58.5) mm
Distance from the window	(5) mm

The intensity of the γ- radiation per unit time can used to quantify the number of unstable nuclide atoms that have undergone decay. This sample had counted for the same geometry of the standard sample and an absolute efficiency curve obtained. Each radionuclide emits γ- rays more than one energy characterize to the certain nuclide and enabling the spectroscopic to identify unstable nuclides present in the sample uniquely.

If a nuclide emits a γ-ray of a specified energy in any time it decays and its transition probability will be 100%. Co-60, that was used for calibrating the system, because it has more than one γ-rays, (1.17) MeV and (1.33) MeV, that are emitted.

The experimental details for the samples before using (HPGe) involved:

All samples that had taken are stored in the laboratory for 30 days to get a radiological equilibrating. All samples were taken 1 litter putting in the standard Marnelle beaker, then tests for 3600 sec using high purity germanium detector.

For All samples that tested using high purity germanium has a report contains more data about the spectrum of the sample for example, energy lines, number of peaks, yield, FWHM, number of channels, efficiency, weight, area. The collected data to all the sample and the spectrum is very important to the programmer to calculate the specific activities of the radionuclides of the samples. The background of high purity germanium was calculated for 3600 sec then subtracted from spectrums and results.

3-9 Analysis of gamma spectrum

The output of the detector is a γ-ray spectrum, a plot of γ- ray intensity change energy that is typically divided into (4096) channels. Multiple γ- rays are detected, often more one from the same isotope, for example (1173) keV and (1332) keV peaks of Co-60. The area beneath these peaks is integrated; typically using computer code, for all samples and standard, and this area is proportional to isotope abundance.as shown in Appendix.A

The analysis of complex γ-spectrum is necessary because the spectrums entails first the determination of the number of counts (the area) for each peak and second the assignment of energy to the peak of the spectrum. [87] for example as shown in Figure (3-6).

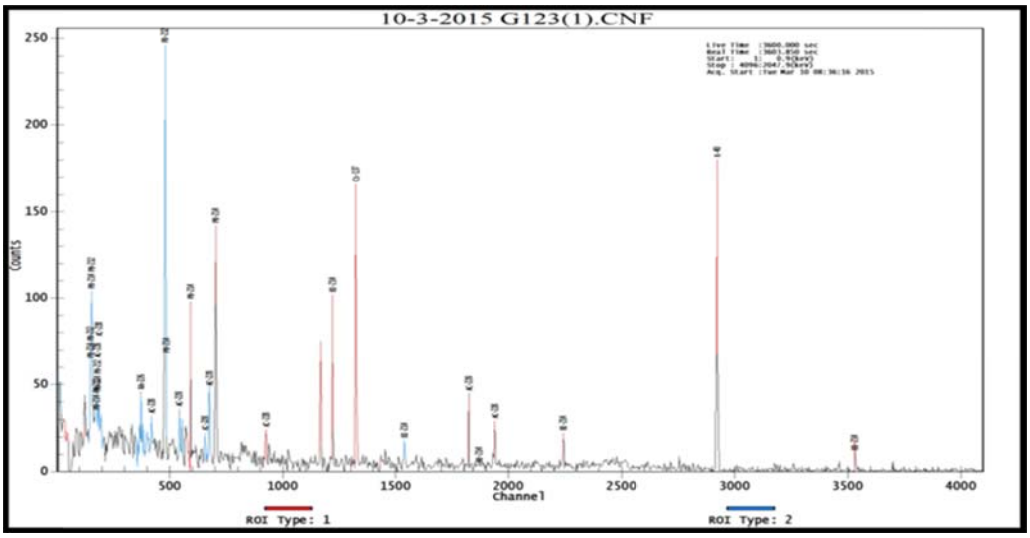


Figure (3-6): Typical gamma ray spectroscopy.

3-10 Energy Resolution

Energy resolution (R) is the parameter used to measure and to resolve small energy differences of incident gamma rays. It can be calculated using the formula as stated below; [87]

$$R=\frac{FWHM}{Ho}\,x100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3-8)}$$

where R is the energy resolution (keV), FWHM= full width at half maximum and H_o represent the centroid of the peak.

The energy resolution expressed in terms of its FWHM was 2keV at (1332) keV for Co-60 transition.

3-11 Detection Efficiency

In radiation detection, the counting efficiency is based on the ratio of number of counts incident on the detector. They are Absolute Efficiency and Intrinsic Efficiency. The absolute efficiency of a detector is defined as the number of counts recorded by the detector and the actual number of photons emitted by the source [7].

The efficiency of HPGe detector is defined as the ratio of the number of pulses (counts) recorded by the detector to the number of radiation quanta (photons) emitted by the source as shown in Equation (3-9).

$$\text{Efficiency\%} = \frac{CPS}{A} \times 100\% \ldots\ldots\ldots (3-9)$$

where cps: count by count per second and

A: Activity by disintegration per second

To determine the efficiency of the calibration, the spectra of standard radioactive sources with known energies and activities are accumulated for long enough time by the detector to produce well-defined photo peaks. To correct the activities of those sources at the date of measurement, the nuclear disintegration equation is used as follows [7]

$A= A_0 e^{-\lambda t} = A_0 e^{-0.693t/T}$ ……………………..(3-10)

where A_0: initial activity, λ : decay constant, T : half-life and t: is the time from the date of multisource to the date of test

Efficiency calibration for the specified geometries and energies was performed using a reference standard solution of multisource.as show as in Appendix. B

3-12 Detector Shielding

The main purpose of detector shielding is to reduce the amount of absorbed radiations between an object and radiation source. The amount of shielding required to protect against different kinds of radiation depends on how much energy they have and the type of materials used. In this context, Lead has high atomic number (Z=82) , density and it is a better shield for radiation [7].

It became in cases when the sample to be counted is low radiation source and its activity barely exceeds the background complete elimination of the background radiation is impossible, when reduction of it is feasible by using special shields. Common shields are made of lead with thickness are (0.1-0.15) m [87].

3-13 Energy Calibration

An important requirement for the measurement of gamma emitters is the precise identity of photon peaks presents in a spectrum that is produced by the detector system. The energy calibration of HPGe detector system was achieved by counting some standard radioactive sources with known energies as shown in Figure (3-7). These sources were calculated for long enough periods to generate concise and well-defined photo peaks which were calibrated according to their energies. Gamma ray transition probability will be 100%, if a nuclide emits it at a specified energy each time gamma ray decays. ^{60}Co has two gamma rays; 1.17 MeV and 1.33 MeV that are emitted. ^{22}Na (1.274 MeV) and ^{137}Cs (0.662 MeV) were used for calibrating the system with a period 3600 s

The energy calibration of (HPGe) detector was achieved by using the standard source of a capacity of one litter marinelli beaker of multi-source, is shown in Figure (3-7).

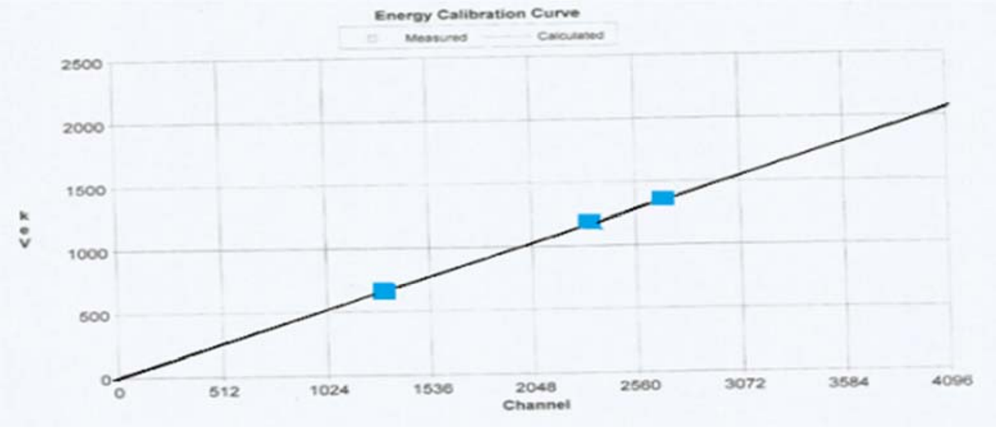


Figure (3-7): Energy calibration of HPGe detector system

3-14 Efficiency Calibration

Some points that must be considered in determining the efficiency calibration are:

Sample counting configuration (geometry). -١

Calibration method. -٢

Calibration sources. -٣

Analytical efficiency expression. -٤

The efficiency calibration of germanium detector system was made by using the multi-source, see Figure (3-8).

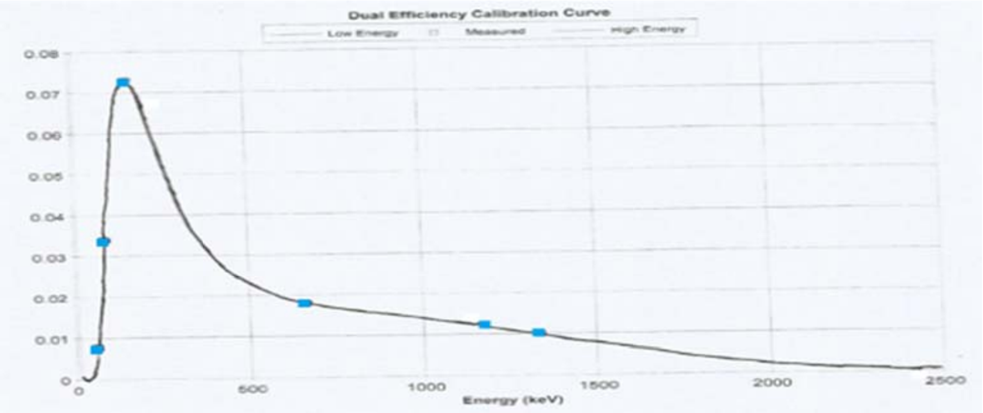


Figure (3-8): Efficiency Calibration of HPGe detector system Detection

3-15 limits of high purity germanium detector

General accepted expression for the estimation of limits, which is frequently referred to as the Detection Limit (DL) is given by the relation [89]:

$$(2.77 + 3.29\sqrt{B.G})\times\frac{\text{concentration}}{\text{net area}}$$

……..(3-11) DL=

One measure of the quality of a spectrum is the minimum detectable activity (MDA) of the detector system. The resolution, background and efficiency of the detector are related to the MDA. This relationship may be simply stated as [89]:

$$\text{MDA} = \frac{\sqrt{R - B.G}}{\text{Eff}} \quad \text{--------------------} \; (3\text{-}12)$$

Where R is the energy resolution of the detector as a function of energy,

B.G is the background counts per keV (unit energy) as a function of energy and Eff is the absolute efficiency of the detector as a function of energy.

3-16 Specific activity concentration of radionuclides

selected regions in Al Dora refinery and Samples were taken from some surrounding area. The samples were crushed into small pieces then to a fine powder by using electrical mill. A fine soil powder of a grain size of about (0.03 mm) was obtained by using special sieves (mesh).

The samples (1 kg) were dried at (60 °C) for two hours and were packaged in a capacity of one litter Marinelli beaker. The sealed Marinelli beaker were kept for one month before measurements in order to achieve the secular equilibrium for ^{238}U and ^{232}Th with their respective progenies.

The number of nuclear decay per unit time is called activity of material. The amount of radioactivity of a particular radionuclide per unit mass of the radionuclide is called Specific activity. In general, the higher a radionuclide's specific activity, the shorter its half-life (decay rate), and the more "radioactive" it is when compared to one with a lower specific activity. The specific activity of individual radionuclides in soil samples is given by using γ- spectroscopy technique [60].

$$A\left(\frac{\mathrm{Bq}}{\mathrm{kg}}\right) \text{ or } A\left(\frac{\mathrm{Bq}}{\mathrm{L}}\right) = \frac{\text{Net area under the peak}}{\text{Eff. } I_{\gamma}.(\text{ M or V}).t} \qquad (3\text{-}13)$$

where:

I_γ: is the percentage of gamma emission probability of the radionuclide under study. A: is the specific activity of the radionuclide. Eff: is the efficiency at photo peak energy. t: is the time of the sample spectrum collection in second.M: is the mass of the sample in kg.

V: is the volume of the sample in L. Net area under the peak = (Total counts – Background counts)

3-17 Radium Equivalent

The radium equivalent activity (Ra_{eq}) concept allows a single index or number to describe γ- output from different mixtures of ^{238}U (i.e. ^{226}Ra) ^{40}K and ^{232}Th in a material [90]. Ra_{eq} is an index used to compare the specific activities of materials containing ^{226}Ra, ^{40}K and ^{232}Th by a single quantity, which takes into account the radiation hazards associated with them [91].The external exposure due to gamma radiation and potential exposure path ways to humans from soil NORM, including internal radio contamination by radon gas progeny inhalation and external exposure to the highly penetrating radiation should be clearly defined. The distribution of ^{40}K, ^{232}Th, and ^{226}Ra in soil was random. Uniformity of exposure to radiation was identified in relation to radium equivalent activity (Ra_{eq}) in Bq/kg in order to compare the specific activity of materials that include dissimilar values of ^{40}K, ^{232}Th, and ^{226}Ra. Ra_{eq} was estimated [92].

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_k \qquad (3\text{-}14)$$

where C_{Ra}, C_{Th} and C_k are the activity concentration in $Bqkg^{-1}$ or BqL^{-1} of ^{226}Ra, ^{232}Th and ^{40}K, respectively the use of a material whose Ra_{eq} concentration exceeds 370Bq/kg is discouraged to avoid radiation hazards [92].

3-18 Gamma Dose Rate

The absorbed dose rate in air one meter above the ground surface express the received dose in the open air from the radiation emitted from radionuclides concentrations in soil or water. γ- dose rate can be calculated from more radioactive source in water or soil [66,93] This factor is important quantity to evaluate when considering radiation risk to a Biosystems. The γ- dose rate (D) in the outdoor air at 1 meter above the ground level can be calculated [94]:

$$AD = 0.461C_{Ra} + 0.623C_{Th} + 0.0414C_k \qquad (3\text{-}15)$$

where C_{Ra}, C_{Th} and C_K are the activity concentration in $Bqkg^{-1}$ or BqL^{-1} of ^{226}Ra, ^{232}Th and ^{40}K, respectively, 0.461, 0.623 and 0.0414 nGy h^{-1}/Bq kg^{-1} or Gy h^{-1}/Bq $L^{-1}$are the conversion factors of ^{226}Ra, ^{232}Th and ^{40}K are respectively[54].

3-19 Hazard in Studied Samples.

The human health of the important things that need to be addressed and knowledge of the risks that affect humans in the surrounds of the environment. To represent the activity levels of ^{226}Ra, ^{40}K and ^{232}Th by a single quantity, which takes into account the radiation hazards associated with each component[54].

3-20 Annual effective doses equivalent

Annual effective dose equivalent received by member was measurement using factor of 0.7 $SvGy^{-1}$, which was used to convert the absorbed dose rate to populace effective dose equivalent with occupancy factor for an outdoor of 20% and 80% for indoor The conversion coefficient from absorbed dose in air to effective dose received by an adult must be considered [88]. The annual effective dose rate in air outdoor and indoor can be calculated by using Eq. 3-16 a and b[95]:

To calculate annual effective doses, certain parameters were obtained which include: (a) the indoor holding factor and (b) the conversion coefficient from absorbed dose in air to effective dose. The predicted annual average effective dose equivalent (AEDE) received was calculated using a conversion factor of 0.7 Sv/Gy.

This factor was used to exchange the absorbed dose rate from the person effective dose equivalent to an indoor and outdoor holding of 80%and 20% consecutively.

The AEDE was found out as follows [96]:

AEDE indoor (Sv/y) = absorbed dose (Gy/h)×8760 h/y×0.7(Sv/Gy)×0.8 (3-16a)

AEDE outdoor (Sv/y) = absorbed dose(Gy/h)×8760h/y×0.7(Sv/Gy)×0.2 (3-16b)

The world average annual effective dose equivalent (AEDE) from outdoor or indoor terrestrial gamma radiation is 0.460 mSv/year [96].

3-21 Gamma Level index ($I_{\gamma r}$)

The representative, level index $I_{\gamma r}$, used to estimate the level of gamma-radiation hazard associated with the natural radionuclides in specific investigated samples, is defined using Eq. (3-17) [97].

$$I_\gamma = \frac{C_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_k}{1500} \leq 1 \qquad (3-17)$$

Hazard indices 3-22 external and internal

when some materials decay naturally and when these materials decay produces an external radiation field which exposed populace. Thorium and uranium head series of radionuclides that produce significant populice exposure. The main purpose of these Indices is to determine the radiation dose to the acceptable dose equivalent. These Indices are imprecating from

Ra_{eq} expression through the supposition that its maximum value allowed corresponding to the upper limit of Ra_{eq}(i.e. 370 $Bqkg^{-1}$ or BqL^{-1}). The Indices value must be less than unity for the radiation hazard to be negligible [96]. The external hazard index (H_{ex}) is calculated by Eq. 3-18a [98].

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \leq 1 \qquad (3-18\,a)$$

.

where C_{Ra}, C_{Th} and C_K, are the radioactivity concentrations in Bq/kg or Bq/L of ^{226}Ra, ^{232}Th and ^{40}K respectively. The value of this index must be less than unity for the radiation hazard to be negligible; H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} (370Bq/kg). Internal hazard index (H_{in}) can be calculated by Eq. (3-18 b) [98].

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \leq 1 \qquad (3-18\,b)$$

.

where C_{Ra}, C_{Th} and C_K, are the radioactivity concentrations in Bq/kg of ^{226}Ra, ^{232}Th and ^{40}K respectively. The value of this index must be less than unity for the radiation hazard to be negligible.

4-1 Introduction

In this chapter presented the results that including the measurement of the radon concentration in soil, radon exhalation rate and the specific activates of the radionuclides in soil, dust and water samples in AL Dora refinery and surrounding area. The measured soil, water and dust samples were taken from (17) locations. Moreover, discussions and conclusions extracted from the present results and suggestions for future works are also presented**.**

4-2 Radon specific activity using CR-39

In the present work radon concentrations were measured for soil samples (surface and from depth 15, 30 cm) in 9 different locations in Al-Dora refinery and surrounding. The dust samples were collected from five locations around Al-Dora refinery Table (3-1).

Tables 4-1,4-2,4-3 and Figures 4-1,4-2,4-3 summarize the results obtained in the present work for radon gas concentrations, the surface exhalation rate and the mass exhalation rate in (surface 15, 30 cm depth) soil samples.

It can be noticed that the radon concentration in surface samples ranged from 290.709 to 394.534 Bq/m^3 with an average 365.925 Bq/m^3, the highest was in Dora refinery near white oil tanks and the lowest in AL-Karada region as shown in Figure 4-1.

The radon concentrations in soil from depth 15cm ranged from 294.862 to 346.775 Bq/m^3 with an average 324.164 Bq/m^3, the highest concentration was in AL-Dora refinery near white oil tanks and the lowest in AL-Karada region as shown in Fig.4-2.

The radon concentration in soil from depth 30 cm ranged from 228.633 to 288.414 Bq/m^3 with an average 254.947 Bq/m^3, the highest concentration was in AL-Dora refinery near white oil tanks as shown in Fig.4-3.

The average of radon concentration for surface, 15 and 30cm soil samples were 365.925, 324.164 and 254.947 Bq/m^3 as shown in Figure 4-4.

The radon concentration in dust samples ranged from 249.015 to 396.611 Bq/m^3 with an average 368.37 Bq/m^3 as shown in table 4-4 and Figure 4-5. The surface exhalation rate ranged from 0.615 Bq.m^{-2} .h^{-1} to 0.82 Bq.m^{-2} .h^{-1} with average 0.762 Bq.m^{-2} .h^{-1} and the mass exhalation rate ranged from 0.482 to 0.64 Bq.kg^{-1}.h^{-1}with an average 0.594 Bq.kg^{-1}.h^{-1} as shown in Table 4-4 and Fig. 4-5.

The radon exhalation rate in term of area in surface soil ranged from 0.601 to 0.816 Bq.m^{-2} h^{-1} with average 0.757 Bq.m^{-2} .h^{-1} as shown in Table 4-1.

The radon exhalation rate in terms of area in soil samples from depth 15 cm ranged from 0.61 to 0.717 Bq.m^{-2} .h^{-1} with average 0.671 Bq.m^{-2} .h^{-1}.

The radon exhalation rate in terms of area in soil samples from depth 30 cm ranged from 0.472, to 0.597 Bq.m^{-2} .h^{-1} with average 0.527 Bq.m^{-2} .h^{-1}. Fig.4-6 shows the average surface exhalation rate for surface, 15cm and 30cm Al Dora soil samples.

Mass exhalation rate in surface soil samples ranged from 0.469 to 0.639 Bq.kg^{-1}.h^{-1}with average 0.59 Bq.kg^{-1}.h^{-1}. Mass exhalation rate in soil samples from depth 15 cm ranged from 0.457 to 0.559 Bq.kg^{-1}.h^{-1} with average 0.523 Bq.kg^{-1}.h^{-1}. Mass exhalation rate in soil samples from depth 30 cm ranged from 0.368 to 0.465 Bq.kg^{-1}.h^{-1} with average 0.411 Bq.kg^{-1}.h^{-1}. Fig.4-7 shows the average mass exhalation rate for surface, 15cm and 30cm Al Dora soil samples.

It can be noticed that the highest radon concentration in soil samples from different depth were in AL-Dora refinery near white oil tanks which indicate that this region contaminated with natural occurring radioactive material (NORM) comes from whit oil tanks.

The present results show that the radon concentration in soil samples (surface, 15cm and 30 cm depth) and dust samples was higher than the global permissibility limit of exposure to radon inside building for the population

(200 Bqm^{-3}) [98], this concentrations comes from (NORM) which are the main sources of radiation in soils and rocks.

Table 4-1. Radon Concentration, Surface exhalation rate, Mass exhalation rate for surface soils samples.

Symbols	Radon specific activities Bq/m^3	Ex (Bq.m^{-2} .h^{-1})	Em (Bq.kg^{-1}.h^{-1})
S1	363.387	0.752	0.586
S2	353.004	0.730	0.569
S3	373.769	0.773	0.603
S4	394.534	0.816	0.636
S5	377.922	0.782	0.609
S6	379.999	0.786	0.613
S7	384.152	0.795	0.620
S8	290.709	0.601	0.469
S9	375.846	0.778	0.606
Average	**365.925**	**0.757**	**0.590**
Max	**394.534**	**0.816**	**0.636**
Min	**290.709**	**0.601**	**0.4692**

Figure 4-1. Radon Concentrations for surface soil samples.

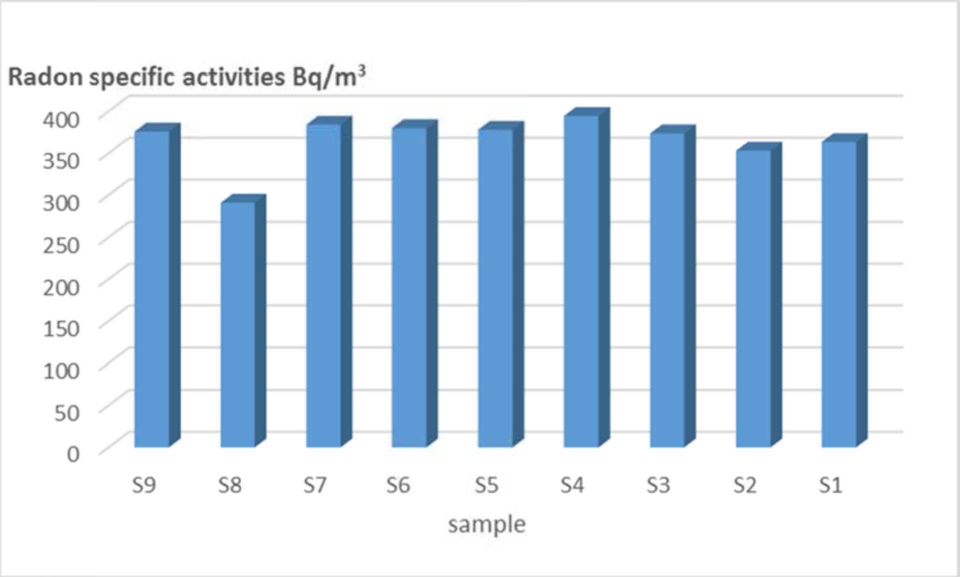


Table 4-2. Radon Concentration, Surface exhalation rate, Mass exhalation rate for soils samples from depth 15cm.

Symbols	Radon specific activities Bq/m^3	Ex (Bq.m^{-2}.h^{-1})	Em (Bq.kg^{-1}.h^{-1})
S1	328.086	0.679	0.529
S2	301.092	0.623	0.485
S3	332.239	0.687	0.536
S4	346.775	0.717	0.559
S5	342.622	0.709	0.552
S6	338.469	0.700	0.546
S7	321.857	0.666	0.519
S8	294.862	0.610	0.475
S9	311.474	0.644	0.502
Average	**324.164**	**0.671**	**0.523**
Max	**346.775**	**0.717**	**0.559**
Min	**294.862**	**0.610**	**0.475**

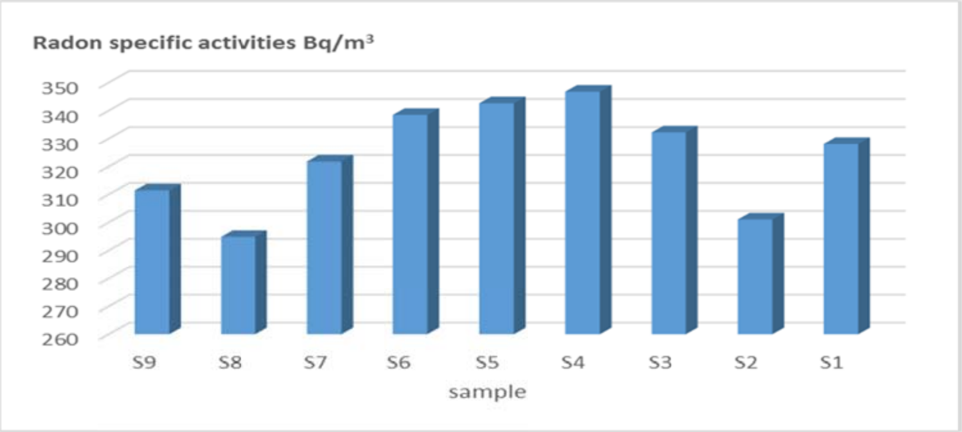


Figure 4-2. Radon Concentrations for soil samples from depth 15cm.

Table 4-3. Radon Concentration, Surface exhalation rate, Mass exhalation rate for soils samples from depth 30cm.

Symbols	**Radon specific activities Bq/m^3**	**Ex (Bq.m^{-2}.h^{-1})**	**Em (Bq.kg^{-1}.h^{-1})**
S1	228.414	0.472	0.368
S2	242.950	0.502	0.392
S3	269.944	0.558	0.435
S4	288.633	0.597	0.465
S5	259.562	0.537	0.418
S6	284.480	0.588	0.459
S7	249.179	0.515	0.402
S8	232.567	0.481	0.375
S9	238.797	0.494	0.385
Average	**254.947**	**0.527**	**0.411**
Max	**288.633**	**0.597**	**0.465**
Min	**228.414**	**0.472**	**0.368**

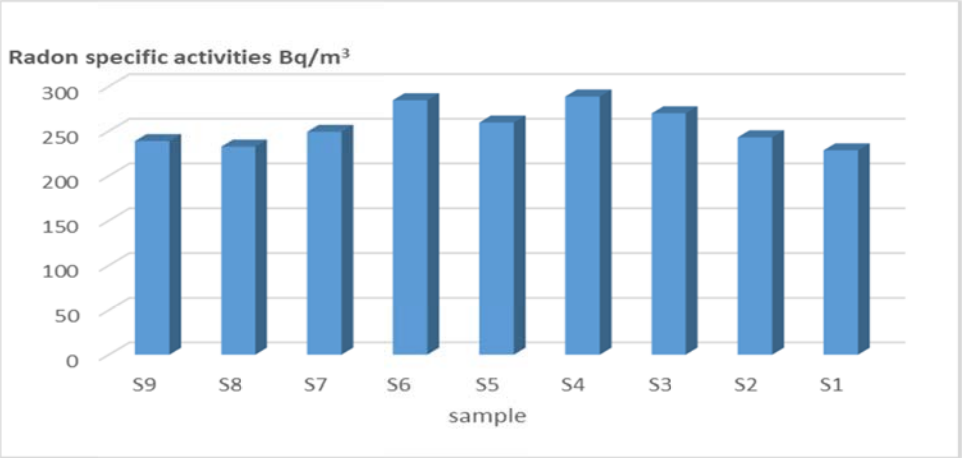


Figure 4-3. Radon Concentrations for soil samples from depth 30cm.

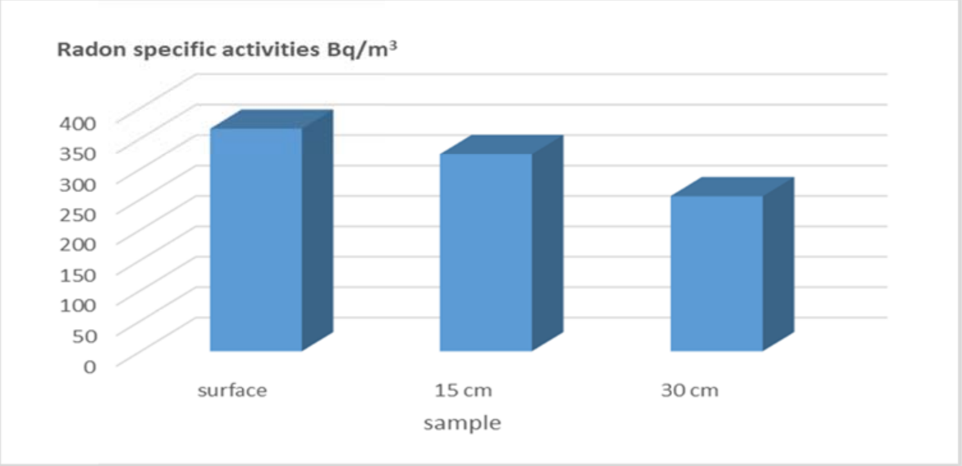


Figure. 4-4. Average Radon Concentration at surface, 15cm and 30 cm soil samples.

Table 4-4. Radon Concentration, Surface exhalation rate, Mass exhalation rate in dust samples.

Location	**Radon specific activities Bq/m^3**	**Ex (Bq.m^{-2}.h^{-1})**	**Em (Bq.kg^{-1}.h^{-1})**
D1	373.769	0.773	0.603
D2	396.611	0.820	0.640
D3	299.015	0.6189	0.482
D4	384.152	0.795	0.620
D5	388.305	0.803	0.626
Average	**368.370**	**0.7625**	**0.594**
Max	**396.611**	**0.820**	**0.640**
Min	**299.01579**	**0.618**	**0.482**

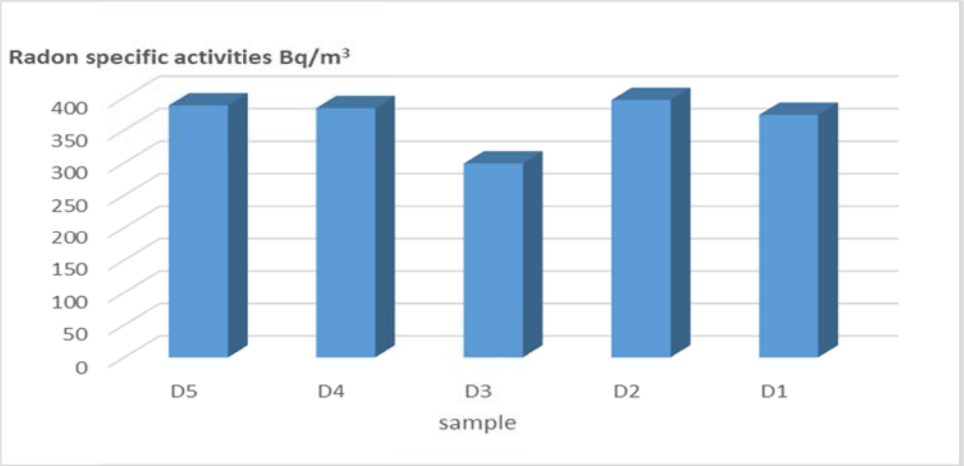


Figure 4-5. Radon Concentration dust for samples.

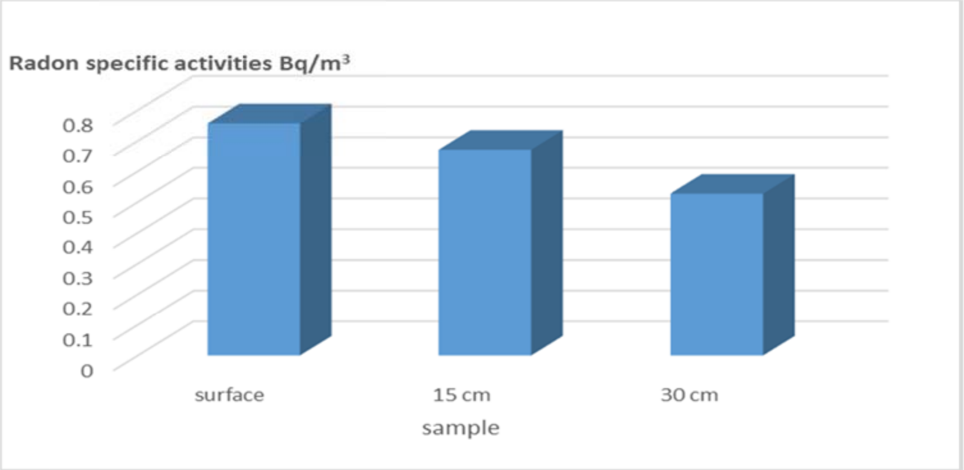


Figure 4-6. Average surface exhalation rate for surface, 15cm and 30cm Al Dora Soil Samples.

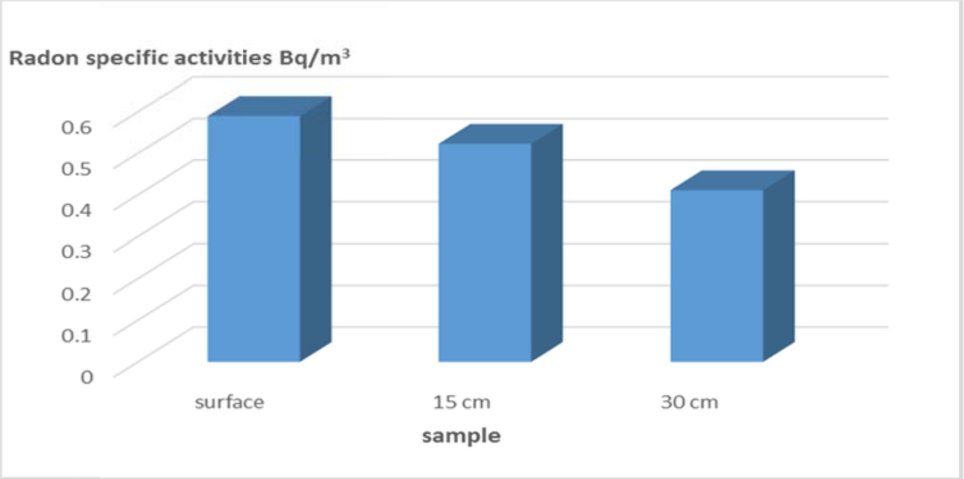


Figure 4-7. Average mass exhalation rate for surface, 15cm and 30cm Al Dora Soil Samples.

4-3 Specific activities of radionuclides using (HPGe) detector

Soil samples (surface and from depth 15, 30 cm) at 9 different locations in Al-Dora refinery and surrounding area as shown in Table 3.1.

4-3-1 Specific Activities of Radionuclides in Surface soil samples

The radionuclides detected in this study include: ^{226}Ra, belong to the ^{238}U series, and radionuclide ^{228}Ac belonging to ^{232}Th series, and one natural radionuclide ^{40}K were measured by using HPGe detector.

The specific activities of radionuclides, ^{40}K, ^{228}Ac and ^{226}Ra in the surface soil samples collected from the mentioned locations are given in Table 4-5 The range of activity concentration in the surface soil samples for ^{40}K varied from 328 to 424.9 Bq/kg with average 328 Bq/kg. The highest value was found in S4 (Dora refinery near white oil tanks) while the lowest value found in S1 (Baghdad AL-Jadida). The specific activity of ^{40}K in S4 soil sample was higher than the glouble value of (400 Bq/kg) given by [99].The range of activity concentration for ^{228}Ac radionuclide which belong to ^{232}Th series varied from 5.408 to 36.17 Bq/kg with average ٢٢.٣٧٥ Bq/kg. The highest value was found in sample S2 (Dora refinery near crude oil tanks) which can be referred to as the accumulation of this radionuclide in the soil and the minimum activity levels were found in S9 (Zafraniya). The specific activity of ^{232}Th in S2 soil samples was higher than the recommended value of (30 Bq/kg) given by [١٠٠].

The range of activity concentration for ^{226}Ra radionuclide which belong to ^{238}U series varied from 11.725 to 59.08 Bq/kg with average ٣٣.٦٢1 Bq/kg. The highest ^{226}Ra activity levels were found in sample S3 (Dora refinery near diesel tanks) which can be referred to as the accumulation of this radionuclide in the soil and the minimum activity levels were found in S2 (Dora refinery near crude oil tanks) as shown in Table 4-5. The specific activities of ^{238}U in (S3, S4 and S6) soil samples were higher than the globle value of (35 Bq/kg) given by [١٠٠].

Table 4-5. Specific activities (Bq/kg) of radionuclide's in surface soil samples

Symbols	**^{40}K (Bq/kg)**	**^{232}Th (Bq/kg)**	**^{238}U (Bq/kg)**
S1	328	17.053	26.42
S2	375.4	36.17	11.725
S3	379.2	28.18	59.08
S4	424.9	26.704	48.954
S5	348.6	19.305	28.101
S6	381.2	17.98	39.103
S7	334.4	18.2	31.668
S9	335.9	15.408	23.915
average	**٣٦٣.٤٥**	**٢٢.٣٧٥**	**٣٣.٦٢1**
max	**424.9**	**36.17**	**59.08**
min	**328**	**15.41**	**11.725**

4-3-2 Specific Activities of Radionuclides in Soil samples at 15 cm depth

The specific activities of radionuclides, ^{40}K, ^{228}Ac and ^{226}Ra in soil samples at 15 cm depth collected from the mentioned locations are given in Table 4-6.

The range of activity concentration in soil samples for ^{40}K varied from 201.3 to 391.3 Bq/kg with average ٣٢٦.٧٣ Bq/kg. The highest value was found in S5 (Dora refinery (garden) while the lowest value found in S9 (Zafraniya). The specific activities of ^{40}K in soil samples were less than the recommended value of (400 Bq/kg) given by [١٠٠].

The range of activity concentration for ^{228}Ac radionuclide which belong to ^{232}Th series varied from 14.613 to 21.673 Bq/kg with average ١٩.٦٦ Bq/kg. The highest value was found in sample S4 (Dora refinery near white oil tanks) which can be referred to as the accumulation of this radionuclide in the soil and the minimum activity levels were found in S8 (Karada). The specific activities of ^{232}Th in soil samples were less than the recommended value of (30 Bq/kg) given by [١٠٠].

The range of activity concentration for ^{226}Ra radionuclide which belong to ^{238}U series varied from 18.047 to 39.71 Bq/kg with average ٣٠.٥٢٧ Bq/kg. The highest ^{226}Ra activity levels were found in sample S3 (Dora refinery near diesel tanks) which can be referred to as the accumulation of this radionuclide in the soil and the minimum activity levels were found in S8 (Karada) as shown in Table 4-6. The specific activities of ^{238}U in (S3, S4, S5 and S6) soil samples were higher than the recommended value of (35 Bq/kg) given by (UNSCEAR, 2000).

Table 4-6: Specific activities (Bq/kg) of radionuclides in soils samples at depth 15 cm

Symbols	**^{40}K (Bq/kg)**	**^{232}Th (Bq/kg)**	**^{238}U (Bq/kg)**
S1	338.57	19.54	24.815
S2	376.8	20.879	25.518
S3	350.4	20.99	39.71
S4	337.9	21.673	39.689
S5	391.3	21.338	36.899
S6	317.1	19.342	37.497
S7	327	20.715	20.715
S8	300.2	14.613	18.047
S9	201.3	17.88	31.858
average	**٣٢٦.٧٣**	**١٩.٦٦**	**٣٠.٥٢٧**
max	**391.3**	**21.673**	**39.71**
min	**201.3**	**14.613**	**18.047**

4-3-3 Specific Activities of Radionuclides in Soil samples at 30 cm depth

The specific activities of radionuclides, ^{40}K, ^{228}Ac and ^{226}Ra in soil samples at 15 cm depth collected from the mentioned locations are given in Table 4-7.

The range of activity concentration in soil samples for ^{40}K varied from 231.4 to 351.3 Bq/kg with average ٣١٠.٩٤ Bq/kg. The highest value was found in S6 (Dora refinery near oil pipes) while the lowest value found in S5

(Dora refinery (garden)). The specific activities of ^{40}K in soil samples were less than the recommended value of (400 Bq/kg) given by [100].

The range of activity concentration for ^{228}Ac radionuclide which belong to ^{232}Th series varied from 12.89 to 23 Bq/kg with average ١٨.١٢4 Bq/kg. The highest value was found in sample S3 (Dora refinery near diesel tanks) which can be referred to as the accumulation of this radionuclide in the soil and the minimum activity levels were found in S5 (Dora refinery (garden)). The specific activities of ^{232}Th in soil samples were less than the recommended value of (30 Bq/kg) given by [100].

The range of activity concentration for ^{226}Ra radionuclide which belong to ^{238}U series varied from 17.94 to 45.766 Bq/kg with average ٣٠.٣٩٣ Bq/kg. The highest ^{226}Ra activity levels were found in sample S6 (Dora refinery near oil pipes) which can be referred to as the accumulation of this radionuclide in the soil. The specific activity of ^{238}U in S6 sample was higher than the recommended value of (35 Bq/kg) given by (UNSCEAR, 2000). The minimum activity levels were found in S2 (Dora refinery near crude oil tanks) as shown in Table 4-7.

The average specific activity of ^{40}K, ^{228}Ac and ^{226}Ra for soil samples were shown in Figure 4-8, 4-9 and 4-10.

The results have shown that the average values of specific activities of ^{40}K, ^{232}Th and ^{238}U in soil samples were less than the recommended value given by [100].

Table 4-7: Specific activities (Bq/kg) of radionuclides in soils samples at depth 30 cm

Symbols	**^{40}K (Bq/kg)**	**^{232}Th (Bq/kg)**	**^{238}U (Bq/kg)**
S1	304.6	17.394	31.987
S2	244	18.183	17.94
S3	348.8	23	34.252
S4	325.8	20.69	31.523

S5	231.4	12.89	24.896
S6	351.3	21.035	45.766
S7	338.66	14.642	39.097
S8	317.5	14.48	29.034
S9	336.4	20.8	19.046
average	**٣١٠.٩٤**	**١٨.١٢4**	**٣٠.٣٩٣**
max	**351.3**	**23**	**45.766**
min	**231.4**	**12.89**	**17.94**

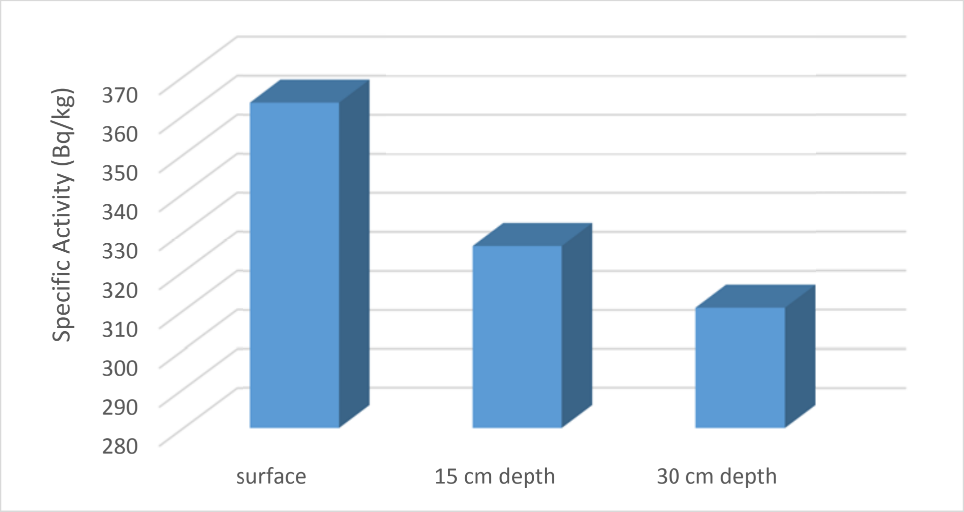


Figure 4-8: Average Specific Activity ^{40}K (Bq/kg) for soil samples

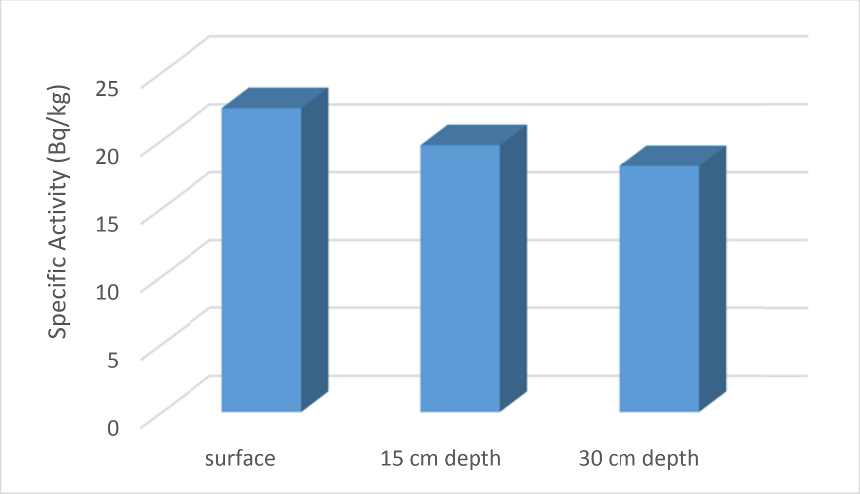


Figure 4-9: Average Specific Activity ^{228}Ac (Bq/kg) for soil samples

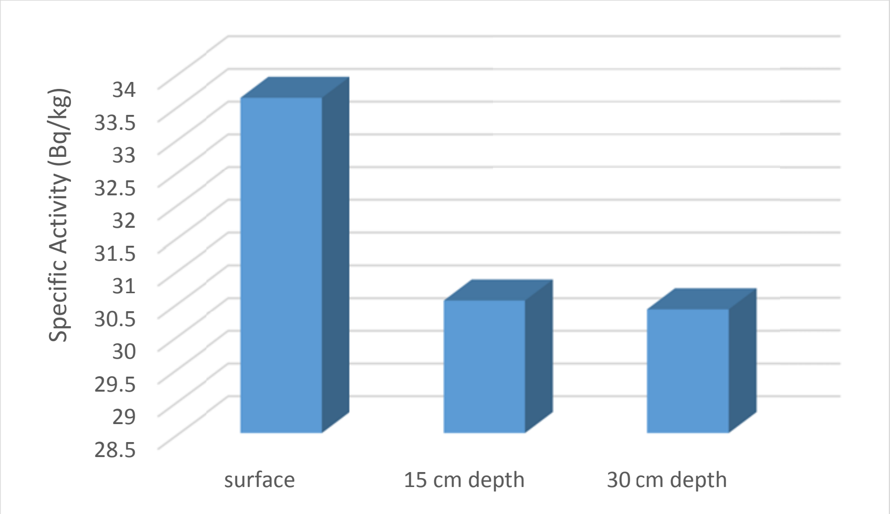


Figure 4-10: Average Specific Activity ^{226}Ra (Bq/kg) for soil samples

4-4 The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA),external hazard index (*H*ex) and annual effective dose equivalent (AEDE) in soil samples

Radium equivalent activity, Dose rate, External and internal hazard index and Indoor and outdoor annual effective dose in (surface 15, 30 cm depth) soil samples were measured using equations (3-13,3-14,3-15(a,b),3-16,3-17(a,b))

4-4-1 For surface soil samples

The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), internal hazard index (H_{in}), external hazard index (H_{ex}) and annual effective dose in surface soil samples were shown in table 4-8.

The lowest of the radium equivalent (Ra_{eq}) in surface soil samples was 71.81 Bq/kg for sample S9 while the highest was 129.29 Bq/kg for sample S3, with an average value of 93.70 Bq/kg. The radium equivalent (Ra_{eq}) in all samples were less than recommended value of 370 Bq/kg given by [100].

The lowest of an absorbed dose rate from the air (ADRA) in soil samples was 34.396 nGy/h for sample S9 while the highest was 60.3٤ nGy/h for sample S3 higher than UNSCEAR reference value of 55 nGy/h, while the average value of all samples 44.34 nGy/h.The lowest indoor annual effective dose equivalent (AEDE in) 0.171 mSv/y in S9 soil samples while the higher was 0.3 mSv/y for sample S3 with an average 0.227 mSv/y. The indoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value of 1.0 mSv/y given by [100].

The lowest outdoor annual effective dose equivalent (AEDE out) 0.043 mSv/y in S9 soil samples while the higher was 0.075 mSv/y for sample S3 with an average 0.227 mSv/y. The outdoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value of 1.5 mSv/y given by [99].

The lowest of an internal hazard index (H_{in}) in surface soil samples was 0.25٩ in S9 soil samples while the higher was 0.50٧ in for sample S3, with an average 0.34. The internal hazard index for all samples were less than recommended value of 1.0 given by [100].

The lowest of external hazard index (H_{ex}) in surface soil samples was 0.19٤ in S9 soil samples while the higher was 0.347 for sample S3, with an average 0.2٥2. The external hazard index for all samples were less than recommended value of 1.0 given by [100].

Table 4-8: The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), external, internal hazard index (H_{ex}) and annual effective dose equivalent (AEDE) in surface soil samples

Symbols	**Ra_{eq} (Bq/kg)**	**ADRA (nGy/h)**	**Hazard index**		**AEDE(mSv/y)**	
			H_{in}	**H_{ex}**	**Indoor**	**Outdoor**
S1	76.06	36.250	0.27٧	0.205	0.180	0.045
S2	92.35	43.330	0.281	0.249	0.216	0.054
S3	129.29	60.3٤0	0.50٧	0.347	0.30	0.075

S4	119.91	56.625	0.456	0.32٤	0.282	0.070
S5	82.55	39.270	0.29٩	0.222	0.195	0.049
S6	94.17	44.857	0.360	0.254	0.223	0.056
S7	83.48	39.64٨	0.31١	0.225	0.197	0.049
S9	71.81	34.39٦	0.25٩	0.19٤	0.171	0.043
average	**93.70**	**44.34**	**0.34**	**0.2٥2**	**0.227**	**0.055**
max	**129.29**	**60.3٤**	**0.50٧**	**0.347**	**0.30**	**0.075**
min	**71.81**	**34.396**	**0.25٩**	**0.19٤**	**0.171**	**0.043**

4-4-2 For soil samples at 15 cm depth

The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), internal hazard index (H_{in}), external hazard index (H_{ex}) and annual effective dose in soil samples at depth 15 cm were shown in Table 4-9.

The lowest of the radium equivalent (Ra_{eq}) in surface soil samples was 62.059 Bq/kg for sample S8 while the highest was 97.542 Bq/kg for sample S5, with an average value of 83.582 Bq/kg. The radium equivalent (Ra_{eq}) in all samples were less than recommended value of 370 Bq/kg given by [99].

The lowest of an absorbed dose rate from the air (ADRA) in soil samples was 29.732 nGy/h for sample S8 while the highest was 46.347 nGy/h for sample S5, with an average value of all samples 39.755 nGy/h. The absorbed dose rate was less than UNSCEAR reference value of 55 nGy/h [100].

The lowest indoor annual effective dose equivalent (AEDE in) 0.148 mSv/y in S8 soil samples while the higher was 0.263 mSv/y for sample S5 with an average 0.198 mSv/y. The indoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value of 1.0 mSv/y given by [100].

The lowest outdoor annual effective dose equivalent (AEDE out) 0.037 mSv/y in S8 soil samples while the higher was 0.058mSv/y for sample S5 with an average 0.049 mSv/y. The outdoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value of 1.5 mSv/y given by [100].

The lowest of an internal hazard index (H_{in}) in surface soil samples was 0.216 in S8 soil samples while the higher was 0.369 in soil S5 with an average 0.309. The internal hazard index for all samples were less than recommended value of 1.0 given by [100].

The lowest of external hazard index (H_{ex}) in surface soil samples was 0.168 in S8 soil samples while the higher was 0.263 in S5, with an average 0.226. The external hazard index for all samples were less than recommended value of 1.0 given by [100].

Table 4-9. The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), external, internal hazard index (H_{ex}) and annual effective dose equivalent (AEDE) in soil samples at depth 15 cm

Symbols	**Ra_{eq} (Bq/kg)**	**ADRA (nGy/h)**	**Hazard index**		**AEDE(mSv/y)**	
			H_{in}	**H_{ex}**	**Indoor**	**Outdoor**
S1	78.827	37.494505	0.280	0.213	0.187	0.0466
S2	84.389	40.220	0.297	0.228	0.20	0.050
S3	96.707	45.749	0.369	0.261	0.228	0.0569
S4	96.70	45.653	0.368	0.261	0.227	0.0568
S5	97.542	46.347	0.363	0.263	0.231	0.058
S6	89.573	42.337	0.343	0.242	0.211	0.053
S7	75.516	35.862	0.260	0.204	0.178	0.045

S8	62.059	29.732	0.216	0.168	0.148	0.037
S9	72.9265	34.396	0.283	0.197	0.171	0.043
average	**83.582**	**39.755**	**0.309**	**0.226**	**0.198**	**0.049**
max	**97.542**	**46.347**	**0.369**	**0.263**	**0.231**	**0.058**
min	**62.059**	**29.732**	**0.216**	**0.168**	**0.148**	**0.037**

4-4-1 For soil samples at 30 cm depth

The radium equivalent (Raeq), absorbed dose rate in air (ADRA), internal hazard index (H_{in}), external hazard index (H_{ex}) and annual effective dose in soil samples at depth 30 cm were shown in Table 4-10.

The lowest of the radium equivalent (Ra_{eq}) in surface soil samples was 61.146 Bq/kg for sample S5 while the highest was 102.896 Bq/kg for sample S6, with an average value of 80.253 Bq/kg. The radium equivalent (Ra_{eq}) in all samples were less than recommended value of 370 Bq/kg given by [100].

The lowest of an absorbed dose rate from the air (ADRA) in soil samples was 28.995 nGy/h for sample S5 while the highest was 48.606 nGy/h for sample S6 higher than UNSCEAR reference value of 55 nGy/h [100], while the average value of all samples 44.34 nGy/h.

The lowest indoor annual effective dose equivalent (AEDE in) 0.144 mSv/y in S5 soil samples while the higher was 0.241 mSv/y for sample S6 with an average 0.189 mSv/y. The indoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value of 1.0 mSv/y given by [100].

The lowest outdoor annual effective dose equivalent (AEDE out) 0.036 mSv/y in S5 soil samples while the higher was 0.060 mSv/y for sample S6 with an average 0.047 mSv/y. The outdoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value of 1.5 mSv/y given by [100].

The lowest of an internal hazard index (H_{in}) in surface soil samples was 0.218 in S5 soil samples while the higher was 0.402 in for sample S6, with an average 0.299. The internal hazard index for all samples were less than recommended value of 1.0 given by [100].

The lowest of external hazard index (H_{ex}) in surface soil samples was 0.165 in S5 soil samples while the higher was 0.278 for sample S6, with an average 0.217. The external hazard index for all samples were less than recommended value of 1.0 given by [100].

The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), internal hazard index (H_{in}), external hazard index (H_{ex}) and annual effective dose in surface soil samples were shown in Figures (4-11,4-12,4-13,4-14,4-15, 4-16). From Figures noticed that The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), internal hazard index (H_{in}), external hazard index (H_{ex}) and annual effective dose in soil samples decrease with depth from surface soil which indicate that the highest activities comes from contamination of these locations with NORM comes from petroleum oil.

Table 4-10: The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), external, internal hazard index (H_{ex}) and annual effective dose equivalent (AEDE) in soil samples at depth 30 cm

Symbols	**Ra_{eq} (Bq/kg)**	**ADRA (nGy/h)**	**Hazard index**		**AEDE(mSv /y)**	
			H_{in}	**H_{ex}**	**Indoor**	**Outdoor**
S1	80.315	38.071	0.303	0.2169	0.189	0.047
S2	62.730	29.602	0.218	0.169	0.147	0.037
S3	93.999	44.420	0.346	0.254	0.221	0.055
S4	86.196	40.780	0.318	0.233	0.203	0.051
S5	61.147	28.995	0.232	0.165	0.144	0.036
S6	102.896	48.606	0.402	0.278	0.241	0.060
S7	86.112	41.031	0.338	0.233	0.204	0.051
S8	74.188	35.423	0.279	0.20	0.176	0.044
S9	74.693	35.531	0.253	0.202	0.177	0.044

average	**80.253**	**38.051**	**0.299**	**0.217**	**0.189**	**0.047**
max	**102.896**	**48.606**	**0.402**	**0.278**	**0.241**	**0.060**
min	**61.146**	**28.995**	**0.218**	**0.165**	**0.144**	**0.036**

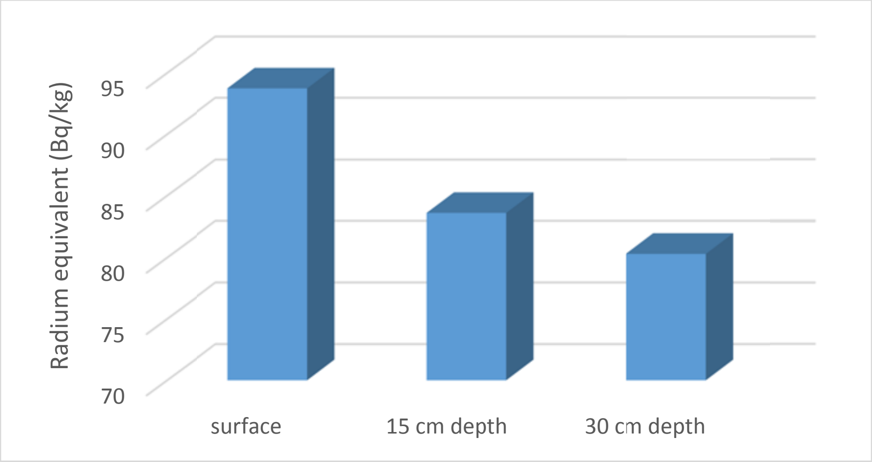


Figure 4-11: Average Radium equivalent (Bq/kg) for soil samples.

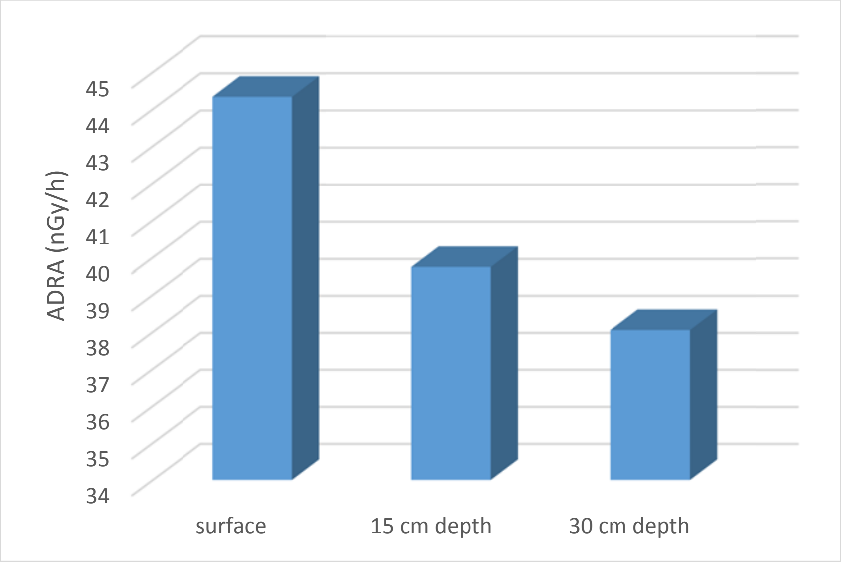


Figure 4-12: Average absorbed dose rate in air (ADRA) (nGy/h)

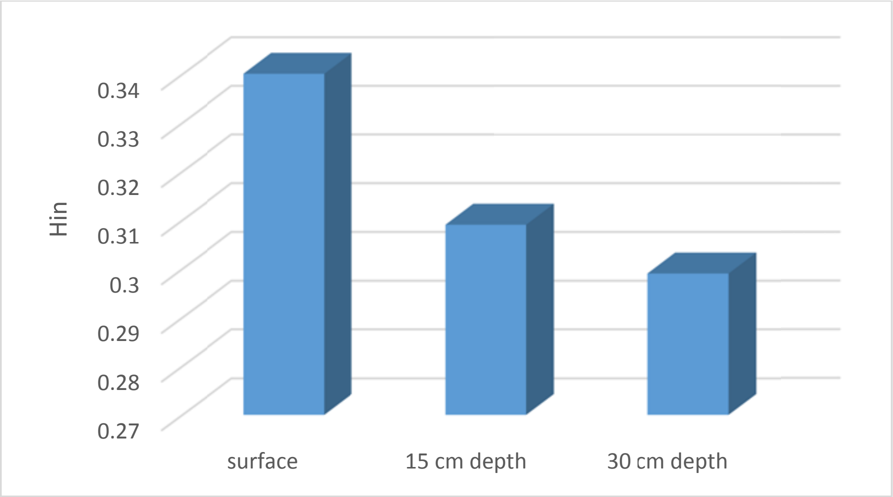


Figure 4-13: Average internal hazard index (H_{in}) for soil samples

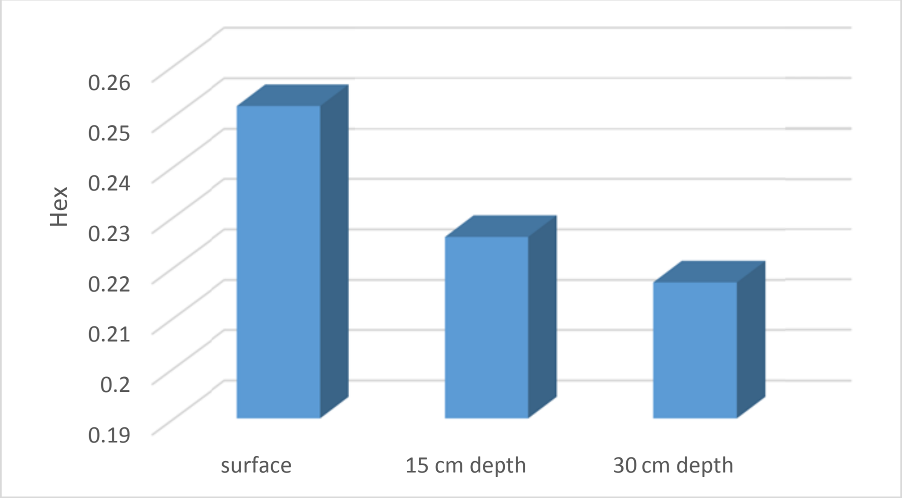


Figure 4-14: Average external hazard index (H_{ex}) for soil samples

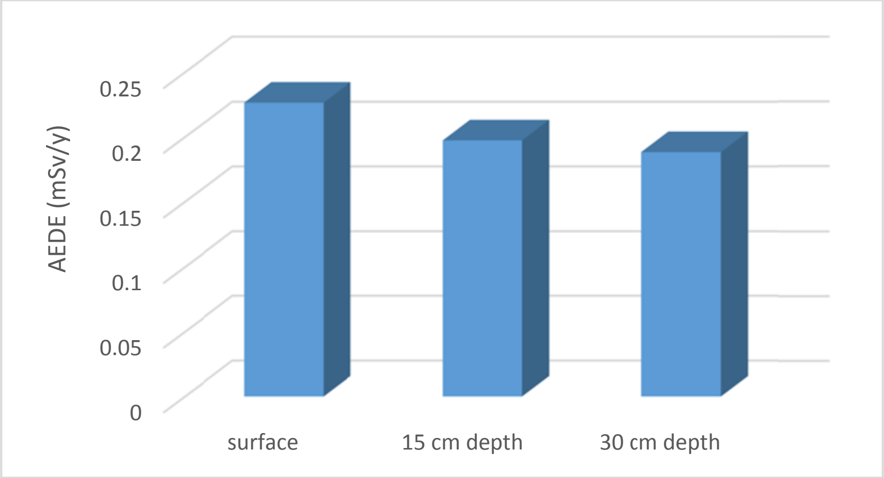


Figure 4-15: Average Annual Effective Dose Equivalent (AEDE) Indoor

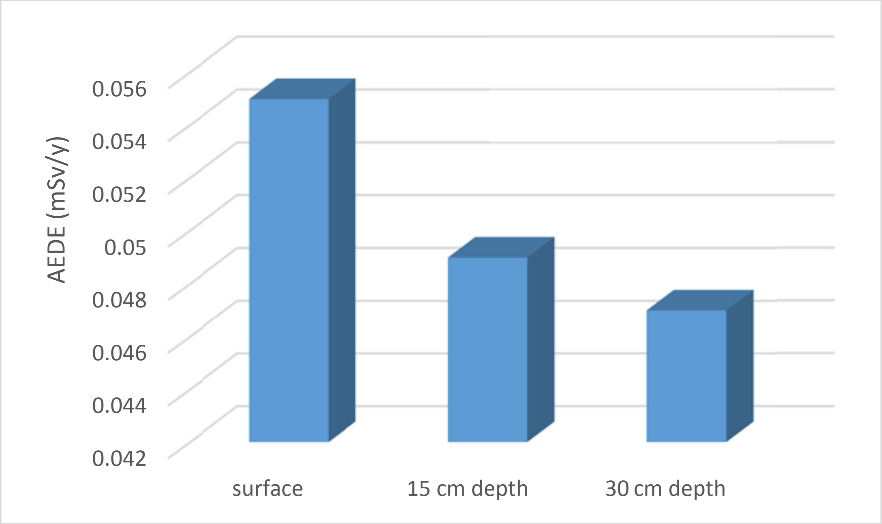


Figure 4-16: Average Annual Effective Dose Equivalent (AEDE) outdoor

4-5 Specific Activities of Radionuclides in Water samples

Water samples were collected from eight locations around Al-Dora refinery Table (3-2).

The specific activities of radionuclides, ^{40}K, ^{228}Ac and ^{226}Ra in water samples collected from the mentioned locations are given in Table 4-11.

The range of activity concentration in soil samples for ^{40}K varied from 11.46 to 18.58 Bq/l with average ١٥.٧٧٨ Bq/l. The highest value was found in W1 (Dora (Mechanic) while the lowest value found in W5 Dora (in).

The specific activities of ^{40}K in water samples were less than the recommended value of (Bq/1) given by [100].

The range of activity concentration for ^{228}Ac radionuclide which belong to ^{232}Th series varied from 1.025 to 13.52 Bq/l with average ٢.٩٢٥ Bq/l. The highest value was found in sample W7 (Karada) which can be referred to as the accumulation of this radionuclide in the water and the minimum activity levels were found in W4 (Dora (in)). The specific activities of ^{232}Th in water samples were less than the recommended value of (1 Bq/l) given by [100].

The range of activity concentration for ^{226}Ra radionuclide which belong to ^{238}U series varied from 1.60 to 8.805 Bq/l with average ٥.٠٣1 Bq/l. The highest ^{226}Ra activity levels were found in sample W7 (Karada) which can be referred to as the accumulation of this radionuclide in the water and the minimum activity levels were found in W8 (Dora (out)) as shown in Table 4-11.

Table 4-11: Specific activities (Bq/kg) of radionuclides in water samples

Symbols	**^{40}K (Bq/kg)**	**^{232}Th (Bq/L)**	**^{238}U (Bq/L)**
W1	18.58	1.305	6.8362
W2	14.25	1.259	3.922
W3	17.97	1.83	7.832
W4	16	1.025	4.31
W5	11.462	1.041	1.60
W6	16.419	1.367	5.315
W7	16.728	13.52	8.805
W8	14.818	2.051	1.629
average	١٥.٧٧٨	٢.٩٢٥	**٥.٠٣1**
max	**18.58**	**13.52**	**8.805**
min	**11.462**	**1.025**	**1.60**

4-6 The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), external hazard index (H_{ex}) and annual effective dose equivalent (AEDE) in water samples

The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), internal hazard index (H_{in}), external hazard index (H_{ex}) and annual effective dose in water samples were shown in Table 4-12.

The lowest of the radium equivalent (Ra_{eq}) in water samples was 3.970 Bq/l for sample W5 while the highest was 29.427Bq/l for sample W7, with an average value of 10.428 Bq/l. The radium equivalent (Ra_{eq}) in all samples were less than recommended value given by [100].

The lowest of an absorbed dose rate from the air (ADRA) in water samples was 1.856 nGy/h for sample W5 while the highest was 13.168 nGy/h for sample W7 with average 4.788 nGy/h which is within the range of values given in UNSCEAR (2000) report (57 nGyh^{-1}).

The lowest indoor annual effective dose equivalent (AEDE in) 0.009 mSv/y in W5 water samples while the higher was 0.066 mSv/y for sample W7 with an average 0.024mSv/y. The indoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value of 0.05 mSv/y given by [100].

The lowest outdoor annual effective dose equivalent (AEDE out) 0.0023 mSv/y in W5 water samples while the higher was 0.016mSv/y for sample W7 with an average 0.006 mSv/y. The outdoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value given by [100].

The lowest of an internal hazard index (H_{in}) in water samples was 0.015 in W5 water samples while the higher was 0.103 in for sample W7, with an average 0.042. The internal hazard index for all samples were less than recommended value of 1.0 given by [100]

The lowest of external hazard index (H_{ex}) in surface water samples was 0.010 in W5 water samples while the higher was 0.08 for sample W7, with an average 0.028. The external hazard index for all samples were less than recommended value of 1.0 given by [100].

Table 4-12: The radium equivalent (Ra_{eq}), absorbed dose rate in air (ADRA), external, internal hazard index (H_{ex}) and annual effective dose equivalent (AEDE) in water samples

Symbols	**Ra_{eq} (Bq/l)**	**ADRA (nGy/h)**	**Hazard index**		**AEDE(mSv/y)**	
			H_{in}	**H_{ex}**	**Indoor**	**Outdoor**
W1	10.13	4.726	0.0459	0.027	0.024	0.006
W2	6.819	3.176	0.029	0.018	0.016	0.004
W3	11.832	5.487	0.053	0.032	0.027	0.007
W4	7.008	3.281	0.031	0.019	0.016	0.0041
W5	3.970	1.856	0.015	0.011	0.009	0.0023
W6	8.534	3.975	0.037	0.023	0.020	0.0049
W7	29.427	13.168	0.103	0.08	0.066	0.016

W8	5.702	2.636	0.02	0.015	0.013	0.0033
average	10.428	4.788	0.042	0.028	0.024	0.006
max	29.427	13.168	0.103	0.08	0.066	0.016
min	3.970	1.856	0.015	0.010	0.009	0.0023

4-7 Conclusions

From the results presented in this work, which contain the measurements radon concentration and natural radioactivity of ^{226}Ra, ^{232}Th and ^{40}K using γ-ray spectroscopy system based on high purity germanium detector in soil, dust and water samples in AL Dora refinery and surrounding area.

1. The results of the present work provide an additional database on radon concentration in AL-Dora refinery soil samples (surface, 15 cm and 30 cm) depth.
2. The radon concentration in dust samples was found higher than the global permissibility limit of exposure to radon inside buildings for the population (200 Bq m^{-3}). The reason of this concentration comes from the chimney of AL-Dora refinery which release this dust.
3. The average radon concentration in surface soil samples was found higher than the radon concentrations in soil from depth 15 cm and 30 cm.
4. The highest specific activities for ^{40}K, ^{228}Ac and ^{226}Ra were found in Al-Dora refinery.
5. The most minimum specific activities of ^{40}K, ^{228}Ac and ^{226}Ra were found in Baghdad regions.
6. The specific activity of ^{40}K in Dora refinery near white oil tanks surface soil sample was higher than the recommended value of (400 Bq/kg) given by [99].
7. The specific activity of ^{232}Th in Dora refinery near crude oil tanks surface soil samples was higher than the recommended value of (30 Bq/kg) given by [99].

8. The specific activities of ^{238}U in (S3, S4, S5 and S6) in surface soil samples were higher than the recommended value of (35 Bq/kg) given by [99].
9. The average specific activities of ^{40}K, ^{228}Ac and ^{226}Ra in soil samples decrease with increasing depth from surface.
10. The average value of radium equivalent activities (Ra_{eq}) of gamma dose rate for surface soil samples were greater than 15 and 30 cm depth.
11. The radium equivalent (Ra_{eq}) in all samples were less than recommended value of 370 Bq/kg given by [99].
12. The average value of absorbed dose rate from the air (ADRA) in all soil samples were less than UNSCEAR reference value of 55 nGy/h [99].
13. The indoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value of 1.0 mSv/y given by [99].
14. The outdoor annual effective dose equivalent (AEDE in) in all samples were less than recommended value of 1.5 mSv/y given by [99].
15. The internal and external hazard index for all soil samples were less than recommended value of 1.0 given by [99].
16. The highest specific activity of ^{40}K, in water samples were in Dora (water Mechanical) Dora refinery and the minimum in Dora (in).
17. The average activity concentrations of ^{226}Ra and ^{232}Th in drinking water are compared to the World Health Organization proposed the following guidance levels (1Bq/L for ^{226}Ra and ^{232}Th) [100].The measured average activities of ^{226}Ra and ^{232}Th in the samples (٥.٠٣1 and 2.925 Bq/L) exceed the guidance level recommended by WHO (World Health Organization). [101]
18. The average of radium equivalent (Ra_{eq}) absorbed dose rate from the air (ADRA) and the internal and external hazard index for all water samples were less than recommended value of (UNSCEAR, 2000) report.

4-8 Future work

1. Measurement of specific activities of NORM and TENORM from all oil and gas fields and oil industry in Iraq.
2. Measurement of specific activities of NORM and TENORM from the produce water from oil industry in Iraq.
3. Measurement the concentration of radon gas inside all oil refineries in Iraq.
4. Study the Radon concentration in air using another detector such as RAD-7 detector.

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الخلاصة

الهدف من الدراسة الحالية هو قياس مستوى النشاط الاشعاعي في مصفى الدورة والمناطق المحيطة به. تم في هذه الدراسة: اولا قياس تركيز غاز الرادون في نماذج تربة مصفى الدورة والغبار من المناطق المحيطة به بأستخدام تقنية القدح المغلق "sealed can technique" وكاشف الأثر CR-39 لتسجيل اثار جسيمات الفا المنبعثة من غاز الرادون. ثانيا. الكشف عن النويدات المشعة وقياس الفعالية الاشعاعية النوعية في التربة والماء بأستعمال منظومة مطيافية اشعة كاما ذات كاشف الجرمانيوم عالي النقاوه (HPGe). تم جلب نماذج من ٤٠ موقع ونماذج المياه من ٥ مواقع ، ٢٧ من نماذج التربة (سطحي وأعماق ١٥و 30 cm) و٨ نماذج مياه و٥ نماذج غبار . تم الكشف عن النويدات المشعة طبيعية ألمنشأ ^{226}Ra والتي تعود الى سلسلة تحلل اليورانيوم ^{238}U و ^{228}Ac والتي تعود الى سلسلة تحلل الثوريوم ^{232}Th والنويدة الطبيعية المفردة ^{40}K في التربة والماء وتم حساب مكافئ الراديوم (Ra_{eq})، معدل الجرعة الممتصة في الهواء (ADRA)، معاملات الخطورة الداخلي والخارجي (H_{ex}, H_{in}) ومكافئ الجرعة المؤثرة (AEDE) في نماذج التربة والماء المؤخوذة من مصفى الدورة والمناطق المحيطة به.

تم قياس تراكيز غاز الرادون في نماذج التربة والغبار وتراوحت تراكيز غاز الرادون في نماذج التربة السطحية من (٢٩٠.٧٠٩ الى ٣٩٤.٥٢٤ وبمعدل ٣٦٥.٩٢٥ Bq/m^3) أما في نماذج التربة بعمق ١٥cm تراوحت من (٢٩٤.٨٦٢ الى 346.775 وبمعدل 324.164 Bq/m^3) وفي نماذج التربة بعمق ٣٠cm تراوحت من (٢٢٨.٦٣٣ الى ٢٨٨.٤١٤ وبمعدل 254.947Bq/m^3) ونماذج الغبار تراوحت من(٢٤٩.٠١٥ الى ٣٩٦.٦١١ وبمعدل ٣٦٨.٣٧ Bq/m^3) . معدل الانبعاث السطحي (Ex) لنماذج التربة السطحية تراوحت من (٠.٦٠١ ألى ٠.٨١٦ وبمعدل ٠.٧٥٧ $Bq\cdot m^{-2}.h^{-1}$) ، نماذج التربة بعمق 15 cm تراوحت من (0.601 ألى 0.717 وبمعدل ٠.٦٧١ $Bq\cdot m^{-2}.h^{-1}$) ولنماذج التربة بعمق 30 cm تراوحت من (٠.٤٧٢ ألى ٠.٥٩٧ وبمعدل 0.527 $Bq\cdot m^{-2}.h^{-1}$). معدل الانبعاث الكتلي (Em) لنماذج التربة السطحية تراوحت من (٠.٤٦٩ ألى ٠.٦٣٩ وبمعدل ٠.٥٩ $Bq\cdot kg^{-1}.h^{-1}$) لنماذج التربة بعمق 15 cm تراوحت من (٠.٤٥٧ ألى

٠.٥٥٩. وبمعدل ٠.٥٢٣ Bq·kg^{-1}.h^{-1}) ولنماذج التربة بعمق 30cm تراوحت من (٠.٣٦٨ ألى ٠.٤٦٥ وبمعدل 0.411 Bq·kg^{-1}.h^{-1}).

تم حساب الفعالية الأشعاعية النوعية للنويدات المشعة طبيعية المنشأ (^{226}Ra, ^{228}Ac) في التربة السطحية والتي تراوحت من (11.725, 15.41Bq/kg) الى (٥٩.٠٨، ٣٦.١٧Bq/kg) وبمعدل (٣3.621 Bq/kg, ٢٢.٣٧٥) على التوالي والفعالية الأشعاعية النوعية للنويدة الطبيعية ^{40}K تراوح من (328 الى 424.9 وبمعدل 363.45Bq/kg). أما الفعالية الأشعاعية النوعية للنويدات (^{226}Ra, ^{228}Ac) في التربة عمق 15cm تراوحت من(18.047, 14.613 Bq/kg) الى (39.71، 21.673 Bq/kg) وبمعدل (30.527، 19.66 Bq/kg) على التوالي والفعالية الأشعاعية النوعية للنويدة ^{40}K تراوح من (201.3 الى 391.3 وبمعدل 326.73Bq/kg). الفعالية الأشعاعية النوعية للنويدات (^{226}Ra, ^{228}Ac) في التربة عمق 30 cm تراوحت من (17.94, 12.89 Bq/kg)الى (45.766، 23 Bq/kg) وبمعدل (30.39، 18.124 Bq/kg) على التوالي والفعالية الأشعاعية النوعية للنويدة ^{40}K تراوح من (231.4 الى 351.3 وبمعدل 310.94 Bq/kg). أما في نماذج المياه فأن الفعالية الأشعاعية النوعية للنويدات (^{226}Ra, ^{228}Ac) فقد تراوحت من (1.60 , 1.025Bq/L)الى (8.805، 13.52 Bq/L) وبمعدل (5.031، 2.925 Bq/L) والفعالية الأشعاعية النوعية للنويدة ^{40}K تراوح من (11.462 الى 18.58 Bq/L وبمعدل 15.778 Bq/kg).

تم حساب معدل مكافئ الراديوم Ra$_{eq}$(Bq/kg) , معدل معاملات الخطورة الداخلية والخارجية H$_{in}$, H$_{ex}$, معدل الجرعة الممتصة ADRA(nGy/h) ومعدل الجرعة الفعالة السنوية الداخلية والخارجية AEDE(mSv/y) في نماذج التربة والمياه فقد كانت في نماذج التربة السطحية كما يلي :

(0.055 mSv/y, 0.227 mSv/y, 44.34 nGy/h, 0.252, 0.34, 93.70 Bq/kg), بعمق 15 cm فقد كانت: 0.49 mSv/y, 0.198 mSv/y, 39.755 nGy/h, 0.226, 0.309, 83.582 (Bq/kg), وبعمق 30 cm فقد كانت:

(0.189 mSv/y, 0.047 mSv/y, 38.051 nGy/h, 0.217, 0.299, 80.253 Bq/kg).

وفي نماذج المياه فقد كانت: (0.006 mSv/y, 0.024 mSv/y, 4.788 nGy/h, 0.028, 0.042, 10.428 Bq/kg).

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رسالة

مقدمةإلى كلية العلوم / جامعة النهرين
وهي جزء من متطلبات نيل درجة الماجستير
في علوم الفيزياء

من قبل
جعفر جليل سلطان الطائي
بكالوريوس جامعة النهرين ٢٠١٣

بأشراف
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