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Cancer Risks of Transferred Radionuclides from Soil to Plants in Karbala Governorate Iraq

A Thesis

Submitted to the Council of College of Science, University of Kerbala, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Physics

By

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صَدَقَ اللهُ العَلِيُّ العَظيم

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Alaa

DEDICATION

To my father

To my mother

To my brother and sisters

To all those who pray for my success..

Dedicate to you my humble work

Alaa

ABSTRACT

Soil contains many natural radioactive isotopes such as uranium-238, thorium-232, and potassium -40. These radioactive elements are transferred to plants from the soil in which they are grown, which in turn is transferred to humans from the food they eat. Radiation doses depend on the concentration of natural radioactive isotopes and their strains in food materials, and therefore the assessment of radioactivity in plants has great importance from the point of view of radiation safety. One hundred samples were collected, 50 plant samples each of alfalfa, barley, spinach, radish, and chard, and 50 soil samples from the same plant site, including agricultural areas in Karbala Governorate, namely Al-Hindiyah District, Al-Hussainiyah District, Al-Hur District, and Ain Al-Tamr District, as these areas supply local markets with agricultural crops.

Radioisotopes (^{238}U, ^{232}Th, ^{40}K) were measured using a thallium doped sodium iodide detector NaI(Tl) and radioisotopes (^{222}Rn, ^{226}Ra, ^{238}U) using a detector CR-39. The results showed that the average values of specific activity for ^{238}U, ^{232}Th, and ^{40}K in soil samples were (10.136± 1.040, 10.392±0.654, 347.777 ±6.151) Bq/kg respectively, while in plant samples the results were (2.235±0.489, 3.158±0.336, 247.593±5.147) Bq/kg respectively. These values were compared with the average global values of the UNSCEAR (2008) where they were found to be less than the globally permissible values.

As for the results of internal hazard index (H_{in}), external hazard index (H_{ex}), absorbed dose rate in air (D_r), radium equivalent Ra_{eq}, excess life-time cancer risk (ELCR), annual effective dose equivalent (AEDE), annual gonadal equivalent dose (AGED), exposure rate ($\dot{X}$), alpha index (I_α), and gamma index (I_γ) for gamma ray emitters in soil and plant samples, they were within the globally permissible limits. Also, the results of the annual effective dose (AED) and hereditary cancer risk (HCR) in vegetable samples were within the globally permissible limits, while the results of (AED) and (HCR) in alfalfa and barley samples eaten by cows and sheep were higher than the permissible values due to the increase in their annual consumption.

The average values of concentrations of (^{222}Rn, ^{226}Ra, and ^{238}U) in soil samples were found to be (2.791±1.030, 0.174±0.064, 2.849±1.052) Bq/kg respectively, while the average values in plant samples were (1.083±0.283, 0.067 ±0.017, 1.106±0.289) Bq/kg respectively. They were found within the global

permissible limit according to UNSCEAR. The results of mass exhalation rate (E_M), surface exhalation rate (E_S), effective annual dose (D_{eff}), alpha index (I_α), excess lifetime cancer rick (ELCR), annual average internal dose (AD), and risk of an excess cancer (REC) for soil and plant samples were found to be less than the permissible limits according to UNSCEAR and ICRP. The results of the transfer factor for (^{238}U, ^{232}Th, ^{40}K) and (^{222}Rn, ^{226}Ra, ^{238}U) from soil to plant were (0.234, 0.304, 0.720), and (0.4098, 0.4097, 0.4095) respectively.

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List of symbols

Symbol	Description
^{238}U	Uranium-238
^{235}U	Uranium-235
^{234}U	Uranium-234
^{232}Th	Thorium-232
^{40}K	Potassium-40
^{226}Ra	Radium-226
^{222}Rn	Radon-222
^{87}Rb	Rubidium-87
^{206}Pb	Lead-206
^{207}Pb	Lead-207
^{208}Pb	Lead-208
^{237}Np	Neptunium
^{241}Pu	Plutonium
^{14}C	Carbon -14
^{235}Ac	Actinium
^{214}Bi	Bismuth-214
^{137}Cs	Cesium-137
^{60}Co	Cobalt-60
γ	Gamma-Ray
NaI(Tl)	Thallium doped Sodium Iodide Detector

CR-39	Polyallyl altelea diglyol carbonate
SSNTD	Solid State Nuclear Track Detectors
GPS	Global Positioning System
^{o}C	Degree centigrade
MCA	Multi-Channel Analyzer
ε	Efficiency
NaOH	Sodium Hydroxide
λ	Decay constant
eV	Electron volt
MeV	Million electron volt
keV	Kilo electron volt
Ci	Cure
Sv	Sievert
mSv/y	Mille Sievert per year
Gy	Gray
$nGyh^{-1}$	Nano gray/hour
Bq	Becquerel
ppm	Part Per million
DL	Detection Limit
BDL	Below Detection Limit
A	Specific Activity
H_{ex}	External hazard index
H_{in}	Internal hazard index

I_γ	Gamma Index
I_α	Alpha Index
Ra_{eq}	Radium Equivalent Activity
$\dot{X}$	Exposure Rate
D_r	Absorbed Dose Rate in Air
AGED	Annual Gonadal Equivalent Dose
AEDE	Annual Effective Dose Equivalent
AED	Annual Effective Dose
ELCR	Excess Lifetime Cancer Risk
HCR	Hereditary Cancer Risk
ρ	Track density
C_{Rn}	Concentration of Radon
C_{Ra}	Concentration of Radium
C_U	Concentration of Uranium
E_M	The mass exhalation rate
E_S	The surface exhalation rate
D_{eff}	Effective annual dose
AD	Annual average internal dose
REC	Risk of an excess cancer fatality
UNSCEAR	United national scientific committee on the effects of atomic radiation
ICRP	International Commission on Radiological Protection

Chapter One

General Introduction

1.1 Introduction

Radioactive contamination is a very important environmental problem and poses a threat to all living organisms on our planet. Radiation and radioactive materials pose a serious risk to life. The process of unstable nuclei emitting various forms of radiation including (alpha particles, beta particles, and gamma rays), whether occurring naturally or induced for industrial use, is referred to as radioactivity. Natural radionuclides are present in every human environment. Earth materials, water, air, food, and even our bodies contain naturally occurring radioactive substances. The radionuclides found in the environmental are usually at extremely low concentration of activity. Natural radioactive background originates from the uranium and thorium series, as well as potassium-40 [1].

The weathering of the earth's crust is the ultimate mechanism for releasing primordial radionuclides into the soil, which constitutes the primary source of natural background radiation. Plants absorb these radionuclides through their roots or leaves, and animals acquire them by consuming plants or phosphate based mineral supplements and soil. Eventually, these radionuclides are transferred to humans either through the consumption of animal meat, milk, or directly from plants used as food. Radionuclides ingested through food, and to a lesser extent water, contribute significantly to the average radiation doses received by various human body organs, particularly the skeletal system. Analyzing these radionuclides in food-stuffs is a critical part of environmental monitoring programs. These natural radioactive sources represent the largest contributors to the radiation doses received by humans. Among natural sources, the most significant are ^{40}K and member of the ^{238}U and ^{232}Th decay series [2,3].

Thorium is naturally found in the earth's crust, primarily in minerals such as monazite. It occurs in nature as thorium-232, a weakly radioactive isotope with a very long half-life. Due to its radioactive properties, thorium is often found in trace amounts in rocks, soil, and even water.

Uranium, radium, and radon belong to the group of primordial radionuclides, and these nuclides are always present on earth. The radionuclides uranium-238, uranium-235, and thorium-232 decay into other nuclei by emitting nuclear radiation and particles through three distinct series of radionuclides. Similarly, these radionuclides are found in the human body in very

small quantities. There are three natural isotopes of uranium that have great importance in relation to the mining of this element and the nuclear industry. These include ^{238}U, which constitutes the majority of this element in the earth's crust, ^{235}U, and ^{234}U, which together constitute a much smaller fraction. Uranium is a heavy metal with a density of 19.0 g/cm^3 and has significant chemical toxicity. The health effects of uranium, which include lung cancer, kidney damage, and DNA damage. The World Health Organization and most national regulatory bodies have set recommended or permissible minimum exposure limits for soluble and insoluble uranium compounds by ingestion and inhalation, where the public intake of soluble uranium compounds should not exceed 0.5 μg/kg body weight per day by ingestion and 1 μg/m^3 by inhalation [4,5].

Radium is widely distributed in the environment, where it is found in various concentrations in water and soil. Radium is absorbed into the blood from the gastrointestinal tract and lungs, and behaves similarly to calcium, which is mainly deposited in the bones. Microscopic amounts of radium in the environment can lead to some accumulation of radium in bone tissue due to ingestion or exposure of the body to radium, leading to serious health effects including anemia, ulcers, bone cancer, and other disorders, where the normal level of radium in the blood from food and water is 0.003 picocuries/kg . Radon gas ^{222}Rn is a decay product of radium-226 with a half-life of 3.8 days. Humans are exposed to radon by eating and digesting contaminated plant and animal foods or by breathing air contaminated with radon gas. Epidemiological studies have shown that exposure to radon gas at doses higher than the permissible dose increases the risk of leukemia and lung cancer [6].

^{40}K, can be found in a variety of location, including human and animal tissues, soil, and the oceans, in various amounts. The average annual effective dose of natural background radiation to a person is general found in most foods and is an essential component of biological materials. In the general population, K, an essential cellular component, contributes an average of about 180 Sv/y. given the fact that the average human body contains about 0.14 kg of natural potassium, K is the most common naturally occurring radioactive chemical found in the human body.[7].

1.2. Sources of Radiation

The sources of radiation to which humans are exposed can be divided into two main sources: Natural sources and industrial sources [8].

1.2.1. Naturally Sources

1.2.1.a Cosmic Radiation

Cosmic rays are produced as a result of the earth and the atmosphere being bombarded with a powerful stream of radiation from the sun and other stars. However, most of this radiation is absorbed in the earth's outer atmosphere, which acts as a radiation shield, and only a small part of it reached us. Cosmic rays contain 87% protons, about 11% heavy nuclei, and 1% electrons. Energy of this radiation beam ranges from 10 Mev to 100 Gev [8].

Secondary radiation result from the interaction of heavier charged particles and neutrons with gas atoms in the atmosphere, producing secondary radiation such as gamma, beta, and positron rays, as a result of the collision of neutrons with gas atoms in the air, such as nitrogen and oxygen, leading to a nuclear reaction. These atoms become radioactive isotopes such as carbon-14 and other Radioactive gas isotopes [9].

1.2.1.b Terrestrial Radiation

Terrestrial radiation is the portion of natural background radiation that is emitted by naturally occurring radioactive materials on earth, and it is responsible for approximately 3% of the average person's annual received dose. The physical earth, including soil and sedimentary and igneous rock, contains common elements like uranium, thorium, and radium. These naturally occurring radioactive materials, which have existed as part of the earth's crust since the earth was formed, are released into the water, vegetation, and the atmosphere as they breakdown at different rates. In terms of dose the principal primordial radionuclides are ^{40}K, ^{232}Th and ^{238}U whereas ^{87}Rb and ^{235}U of secondary importance [10]. Potassium of the former the most important, with a half-life of (1.27×10^{9} year), which emits both beta and gamma radiation. The first one begins with the decay of ^{238}U half-life (4.5×10^{9}year) and is called the uranium series. The second begins with (^{232}Th) half-life (1.4×10^{10}year), which is called the thorium series, and the third begins with ^{235}U half- life (7.1×10^{8} year), which called actinium series. The three complex chains decay into stable

isotopes of lead (^{206}Pb, ^{208}Pb and ^{207}Pb) respectively. There is fourth series called Neptunium series ^{237}Np, this series was recreated after ^{241}Pu was made in nuclear reactors. This series does not occur naturally since the half- life of the longest lived member of the series ^{237}Np is only (2.14×10^{6}y), much shorter than the lifetime of the earth [11].

1.2.1.c Internal Radioactivity

Radioactive material in the environment can enter the body through different routes of exposure, for example, through the air people breathe and the food they eat; or through an open wound. Natural radionuclides that can enter the body include isotopes of uranium, thorium, radium, radon, polonium, bismuth, and lead in the ^{238}U and ^{232}Th decay series. In addition, the body contains isotopes of potassium (^{40}K), rubidium (^{87}Rb), and carbon (^{14}C) [12].

1.2.2 Man-made Radiation Sources

The most significant source of man-made radiation exposure to the public is from medical procedures, such as diagnostic X-rays, nuclear medicine, and radiation therapy[13].

1.3. Series of Natural Radionuclide

Regarding the isotopes related to terrestrial radiation, notable ones include the ^{238}U and ^{232}Th series, as well as ^{40}K.

1.3.1 ^{238}U Series

Natural uranium is happening in the form of (^{234}U, ^{235}U, ^{238}U). The relative abundance of ^{238}U is (99,274%) and the equilibrium concentration of granddaughter ^{234}U is (0.0054%). The relative abundance of ^{235}U is (0.7205 %) on the medium.^{238}U is the longest- lived member of (4n+2) series (n) varying from (51 to 59), which includes ^{234}U as a member [14], as shown in figures (1.1) and (1.2).

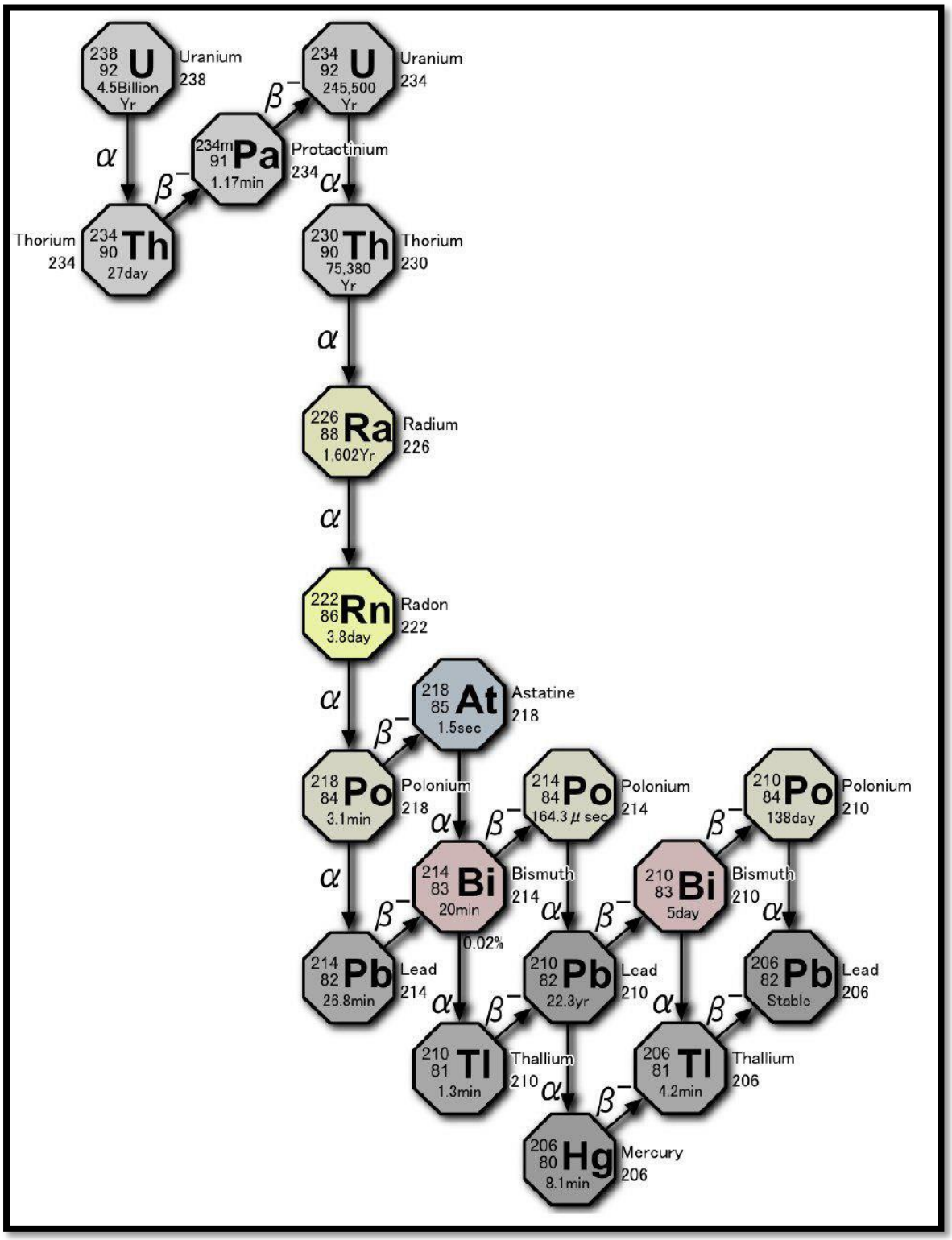

Figure 1.1 Decay Series of ^{238}U [15].

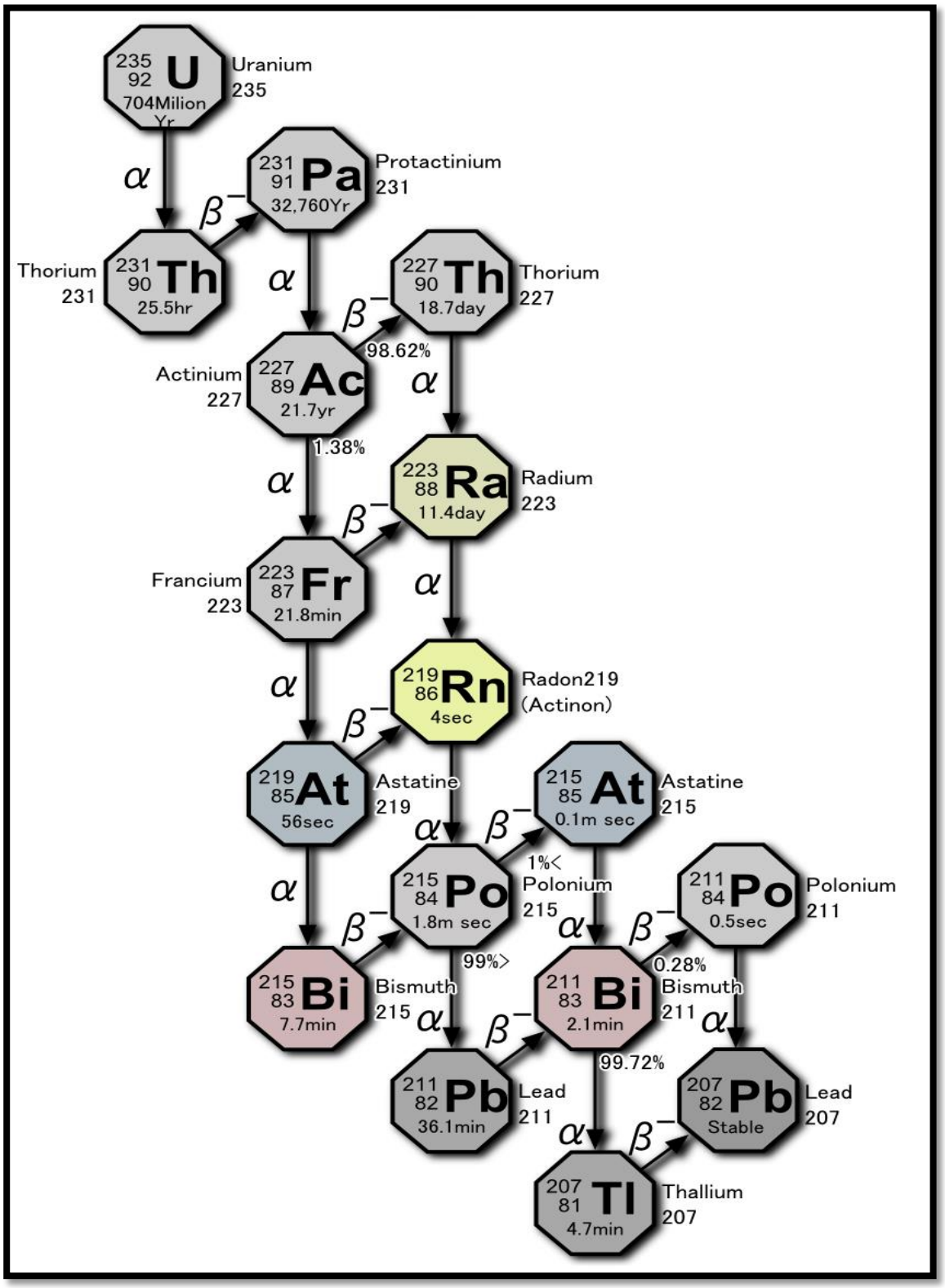

Figure 1.2 Decay Series of ^{235}U [15].

1.3.2 ^{232}Th Series

The main naturally occurring isotope of thorium, with a relative abundance of 99.98%. It has a half-life of (1.4×10^{10} y), the parent of the $(4n)$ radio-activity decay series is ^{232}Th, with n varying from $58\ to\ 52$ [16]. As shown in figure (1.3)

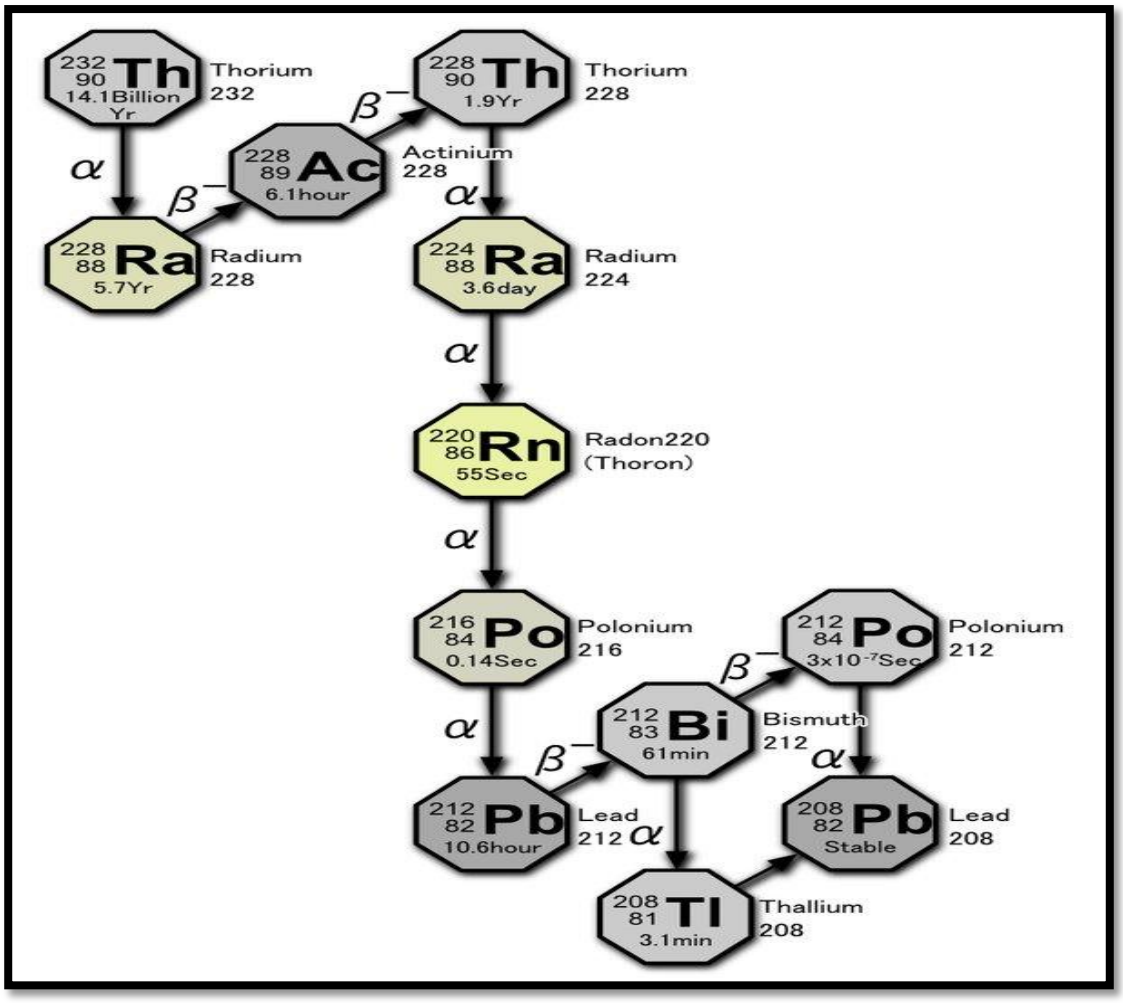

Figure 1.3 Thorium-232 decay series [15].

1.3.3 Potassium-40 Radionuclide

Potassium-40 has a half-life of approximately (1.2×10^9 y). It exists with an isotopic abundance of 0.0118%. The decay of ^{40}K predominantly occurs through beta decay, where 89% of the time it decays into ^{40}Ca. The remaining 10.72% of ^{40}K undergoes β^+ and electron capture to transform into the stable isotope ^{40}Ar. This decay process releases gamma rays at a characteristic energy of 1.461 MeV [17], as in figure (1.4)

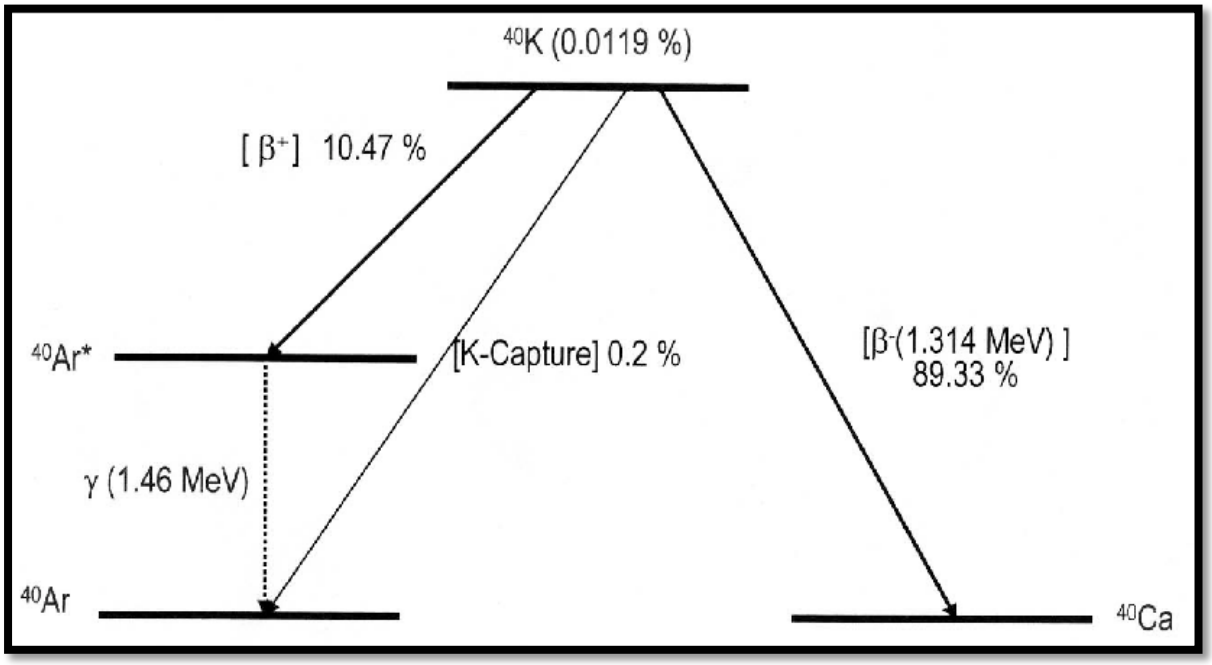

Figure 1.4 Decay-scheme of ^{40}K [18].

1.4 Radon Isotopes

Radon is a colorless and odorless radioactive gas with a density of 9.7 kg/m^3. It is one of the heaviest known gases in nature, with an atomic number of (86) [19]. Radon is a chemically inert gas that does not combine with any other element or compound in nature [19]. It is one of the sources of natural atomic radiation that is generated in the decay chain of uranium-238, which is the only metal that exists in a gaseous state. It is heavier than air and is found in all places and at all times, as it is found in soil, air, water, and building materials. Inhaling radon gas is a major cause of lung cancer. Radon-222 is the direct offspring of radium-226, as radon decays, emitting an alpha particle (helium nucleus) with a kinetic energy of (5.49) MeV [20]. Radon has three isotopes:

1- Actinium (^{219}Rn) which belongs to the actinium series(^{235}Ac). Its half-life is (4sec). It is found in very small quantities in nature due to the scarcity of uranium (^{235}U) and its short half-life [21].
2- Thoron (^{220}Rn) which belongs to the thorium series(^{232}Th). Its half-life is (55sec). Thoron is considered the most abundant isotope of radon due to the high abundance of thorium compared to uranium, but it disappears from the atmosphere quickly due to its short half-life [21].
3- Radon (^{222}Rn) and belongs to the uranium series (^{238}U). This isotope is the longest-lived of the radon isotopes, as its half-life is (3.8 days). This age gives the ability to spread over limited distances in the atmosphere, despite the fact that it is emitted from the soil in smaller quantities than thoron [21], as shows in figure (1.5).

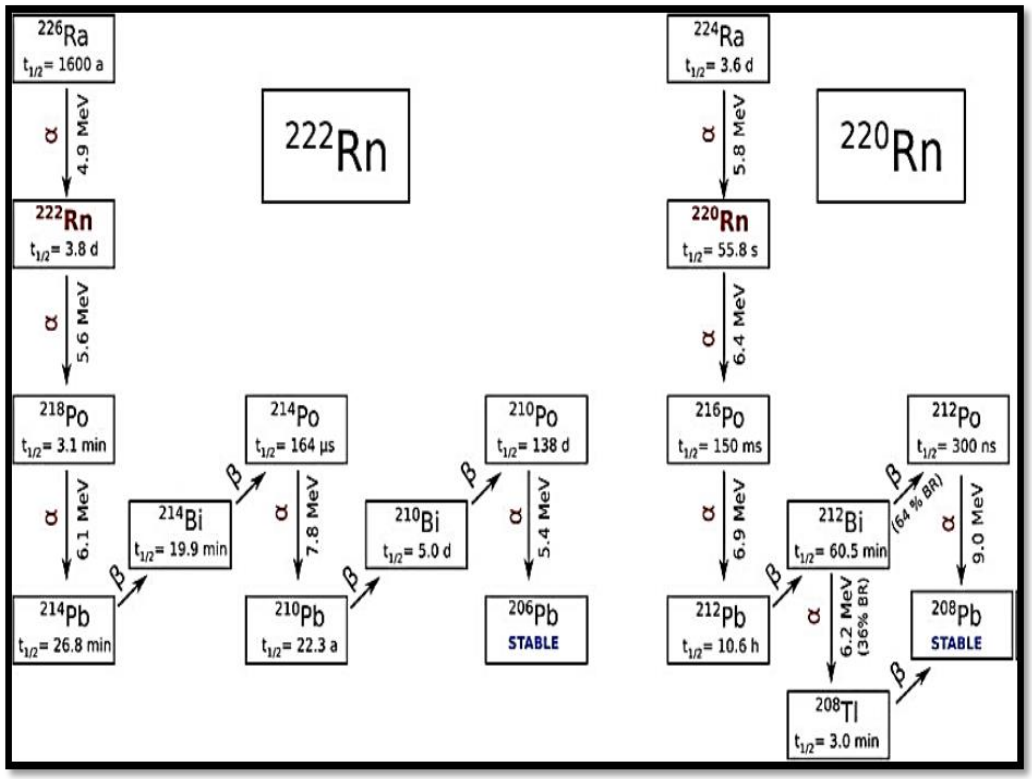

Figure 1.5 Decay Series of radon- 222 and thoron-220 [21].

1.5 Radionuclides in Soil

The primary sources of natural radioactivity in soil are radionuclides of the elements uranium, thorium, and potassium (referred to as radioelements), specifically the uranium-238, thorium-232 decay chains, and potassium-40. The emitted radiation is due to both the decay of the parent radionuclides and their daughter radionuclides. The natural radiation of soil and depends upon mineralogical composition. Soil composed of minerals with relatively high concentrations of uranium, thorium, and potassium have relatively high natural radioactivity. Soils typically reflect the radioelement concentrations of their parent rock [22].

Soil plays a vital role in both agricultural and construction processes. One remarkable property of soil is its ability to serve as a migratory medium, allowing for the continuous transmission of radionuclides into biological systems [23]. The radioactivity present in soil is predominantly influenced by the geology of the rocks that make up the soil [23]. However, factors beyond geology also contribute to the distribution of radionuclides in soil, including regional geological events, latitude and altitude of the site, industrial waste, pesticide and fertilizer usage, mineral processing, water treatment, burning of fossil fuels, and unforeseen events such as earthquakes and forest fires. As a result, the natural radioactivity levels can vary significantly among different soil types [24].

1.6 Radionuclides in Plant

The main sources of radioactive contamination in human nutrition and drinking water are naturally occurring radioactive materials. These naturally occurring radioactive materials consist of radionuclides from the natural decay series ^{238}U, ^{232}Th, and ^{40}K. In particular, alpha-emitting radionuclides from the uranium and thorium families, such as ^{238}U, ^{232}Th, ^{226}Ra pose significant risks of internal radiation exposure and potential health effects [25]. These radionuclides are found in soil, which is of concern since plants can absorb them along with essential nutrients. As a result, varying amounts of these radionuclides can accumulate in different parts of plants, including their fruits. This absorption occurs through two main pathways: the transfer of radionuclides from the air to the plant and their transfer from the soil to the plant. Ultimately, through

the food chain, these radionuclides can find their way into the human body [26].

1.7 Transferred Radionuclides from Soil to Plant

The uptake of radioisotopes from the soil by plants is a key step in the introduction of radioisotopes into the human food chain; this phenomenon is described by the soil-to-plant transfer factor, which is defined as the ratio of plant-specific activity to soil-specific activity. Plants are the main receptors for radioactive contamination into the food chain after the release of radioisotopes into the atmosphere. The transfer factor is a value used in assessment studies on the impact of routine or accidental releases of radioisotopes into the environment for major agricultural products.

The soil-to-plant transfer factor is one of the most important parameters in assessing the environmental safety. These parameters are essential for environmental transfer models that are useful in predicting radioisotope concentrations in agricultural crops to estimate human dose [27]**.** The concentration of natural radionuclides in soil depends on the type of rock from which the soil was formed. The concentration of radionuclides in soil is influenced by several factors that control their uptake by plants. These factors are Physicochemical form of radionuclides, plant species and internal transport mechanisms within plants, soil properties, fertilizers and agricultural chemicals, and distribution of radionuclides in soil. The physicochemical form of radionuclides strongly influences their retention by soil particles and their availability for uptake by plants. Soil type strongly influences the behavior of radionuclides in soil [28].

1.8 Biological Effects of Radiation

The biological effect of radiation depends on several factors, including the type of radiation, the method of exposure, and the sensitivity of the organ exposed to radiation. When exposed directly to radiation, the atoms of the material that make up the living cell become ionized or excited, which can occur somewhere in the body exposed to radiation. The part affected by radiation is the cell nucleus or the genetic material in it as a result of breaking the bonds between the molecules of the material, leading to cell death or a change in the genetic code, which results in the formation of a mutation that may be cancer-

ous in the cell, or the occurrence of deformities in the cell or the loss of the genetic material's ability to transfer genetic information to new cells[29].

When these mutations occur, they may be in the genetic cells, causing this mutation to be transmitted to the next generation, or in the somatic cells, causing this mutation to be transmitted to the resulting cell. Hence, the direct biological effect of radiation is mostly represented in the formation of these mutations and their transmission or development into other mutations. These effects include the small doses to which a person is exposed continuously, as this effect can occur and thus there is a cumulative effect of radiation and potentially in radiation doses up to 250 mGy.

After this dose, this effect begins to increase in proportion to the amount of the dose, and therefore there are no experimental values that can be relied upon in the dose range of 0-250 mGy, but there are many studies that have confirmed the occurrence of these changes at high doses of radiation as a result of the possibility of the dual effect of radiation that occurs when the amount and energy of radiation are sufficient to cause a dual break in the partial bond that connects the DNA material carrying the genetic code (i.e. in two different locations in the genetic chain), which is known as (Theory of Dual Radiation Action) between the atoms that make up the genetic material (DNA), which causes the cell to lose its ability to repair itself, and the repair process is easier when the break in the bond is from one location, and therefore the number of damaged cells in this case is proportional to the square of the dose. When the amount of radiation and its linear effect are large according to the radiation quality factor, the probability of this double effect occurring in two close locations in the genetic chain is greater, thereby causing the destruction of the cell nucleus as a result of the cell losing its ability to repair itself. In contrast, the probability of the cell repairing itself will be greater when the break in the bond is single [29,30].

Hence, two main types of radiation exposure can be considered. The first is exposure to a high dose of radiation in a short period of time in an accidental manner, and this type is called acute exposure. This type of exposure shows biological effects directly or within a short period of time after exposure and after exposure to a certain amount of radiation. The other type of exposure is exposure to a small dose of radiation over a long period of time, and this is

called continuous exposure or chronic exposure. In this case, the biological effects may not appear directly and may take several years after exposure or appear in subsequent generations. It may appear probabilistically and the probability of appearance increases with the dose. One of the most important delayed effects resulting from exposure to radiation is the possibility of developping cancer in the blood, skin, bones, lungs, and thyroid gland [30].

1.9. Literature Review

Literature survey is classified in two types according to the techniques that used to measure natural radioactivity as follows:

1.9.1 Using NaI(Tl) Technique

Author, Year and Reference	Country	Results
Mandić, et al. (2010) [31]	Serbia	The results show measured the radioactivity for soil samples that of Concentration The Average value of in ^{238}U, ^{232}Th ,and ^{40}K, were (2.52 ± 0.73 , 9.40 ± 2.86 and 160 ± 0.40%) Bq kg^{-1}, respectively.
Senthilkumar B. et al. (2010) [32]	India	Measured levels of gamma rays of radiation in soil samples. Concentration of activity for ^{238}U, ^{232}Th and ^{40}K were (43.0±9.04, 14.70 ±1.70 and 149.50±3.10) Bq/kg respectively. Outdoors were determined was between (31.9–59) $nGy.h^{-1}$ and average 43.30±9 nGy/h. The world avera-ged population measured value of 60 $nGy.h^{-1}$ was max. from these figures. An effective dose ranged from 39.2 to 72.6 Sv/y, and with rate of 53.111 Sv/y
Alharbi, et al. (2013) [33]	Saudi Arabia	The mean and range of the concentrations of ^{226}Ra and ^{232}Th were 12.96 ± 3.4 (9.6–19.1) and 16.6 ± 7.1(9.2– 28.3) Bq kg^{-1}.The range of the concentrations of ^{40}K in soil samples was(542–773) Bq kg^{-1} with a mean value of 618 ± 82 Bq kg^{-1}.The transfer factor for ^{226}Ra and ^{40}K to Alfalfa and wheat and Palm dates were measu-red. ^{226}Ra TF values from soil to Alfalfa were found to be higher than wheat grains and Palm dates. ^{40}K TF were lower than

		those values reported in other studies.
Rasheed, et al. (2013) [34]	Iraq (Kurdistan)	The results show measured the radioactivity for soil samples that, the average values of concentrations in ^{238}U, ^{232}Th and ^{40}K were (83.337, 19.147 and 284.86)Bq/kg respectively.
Chakraborty, et al.(2013) [35]	Bangladesh	The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil were found to be 22.13±2.30, 38.47 ±2.72, 451.90±24.89 Bq kg^{-1} respectively while in grass, their values were 1.26 ±0.11, 3.66± 0.31, 134.95±3.68 respectively. For soil to grass, the transfer factor values were found to be 0.056, 0.089, 0.275 respectively for ^{226}Ra, ^{232}Th, ^{40}K.
Jazzar, et al. (2014) [36]	Palestine	For soil to plant, the average transfer factor (TF) values were found to be 0.60, 0.50, 0.31, and 1.70 for ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K respectively. For soil to grass the TF values were found to be 1.26, 1.12, 1.15 and 1.20 for ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K respectively.
K.S. Al Mugren. (2015) [37]	Saudi Arabia	The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were found in surface soil samples ranged from 17. 4±1.2 Bq/kg to 28.3±2.3 Bq/kg with an average value of 23±1.6 Bq/kg, ranging from 1.1±1.8 Bq/kg to 81.0±1.7 Bq/kg with the average value 20±1.4 Bq/kg and from 218±11 Bq /kg to 255±18 Bq/kg, with the mean value of 233±12 Bq/kg respectively.
Hatif, et al. (2015)[38]	Iraq (Hilla)	The results show measured the radioactivity for soil samples that, The average concentration activity of uranium, thorium, and potassium found 14.079 ± 0.46, 12.326± 0.43 and 416.655 ±2.86 Bq/kg respectively.
Abojassim. (2016)[39]	Iraq (Babylon)	This study has been carried out to measure the specific activates and radiation hazard indices in soil samples. The results show that, the average value centration ^{238}U , ^{232}Th and ^{40}K

		(16.07 ±2.89 ,9.60± 0.954 and 271.42 ± 11.60) Bq/Kg respectively.
Kadhim, et al (2016)[40]	Iraq (Karbala)	Activity concentrations ranges of the concerned radionuclides for the soils were as follows: ^{40}K was (271.2-170) with the average (245.1), ^{238}U, (30.96-5.86) Bq/Kg with the average (19.45) Bq/Kg, and ^{232}Th, (67.09-2.9) with average (24.47) Bq/Kg respectively The results have been compared with those of different countries of the world and Iraq.
Yildirim. (2017) [41]	Turkey	The activity concentrations of radionuclides in 24 soil samples from the study area were measured by means of gamma spectrometry with a Nal(Tl) detector. The activity concentrations in soil samples varied in the range of 7.4–79.8 Bq kg^{-1} for ^{238}U, 9.5–170.8 Bq kg^{-1} for ^{232}Th, 35.7–913.8 Bq kg^{-1} for ^{40}K, and 0.6–154.3Bqkg^{-1} for ^{137}Cs.
Alausa, et al . (2017) [42]	Nigeria	The activity concentrations of ^{40}K, ^{238}U and ^{232}Th in the soil samples ranged from 412.43 Bqkg^{-1} to 672.16 Bqkg^{-1}; 10.25 Bqkg^{-1}to17.43 Bqkg^{-1} and 8.12 Bqkg^{-1} to 12.48 Bqkg^{-1} respectively. The mean transfer factors were 0.17±0.02 ,0.27±0.06 and 0.28±0.02 for ^{40}K, ^{238}U and ^{232}Th respectively. The ^{40}K, ^{238}U and ^{232}Th radioactivity levels in the soil are comparable to the world average values of 420 Bqkg^{-1} ,32 Bq kg^{-1} and 40Bqkg^{-1} respectively. The transfer factors indicated that about 17%, 27% and 28% of ^{40}K, ^{238}U and ^{232}Th respectively are transferred from soil to the palm.
Haque, et al. (2017) [43]	Bangladesh (Dhaka)	The transfer factors for ^{226}Ra, ^{228}Ra and ^{40}K were found to range from 0.04 to 0.10, 0.12 to 0.32, and 0.24 to 0.72, respectively. The soil to plant transfer factors for ^{40}K was found to be much higher in plants, which might be due to

		this element being vital in plants.
Rajesh S. et al. (2018)[44]	India	Studied the ionizing radiation emitted from the nuclei of ^{40}K, ^{232}Th and ^{238}U for soil samples from Devadurga and Lingasugur of Raichur area of Karnataka, India. Which were found in environmental materials and which it contributed significantly to the radiation dose received by humans. They found in range (10 – 119) Bq/kg, (8 – 285) Bq/kg, and (46 – 1646) Bq/kg respectively .
Azeez, et al. (2019)[45]	Iraq (Erbil)	The soil-to-plant crops transfer factors were determined for radioactive nuclides. The results showed that the activity concentration ranges for ^{226}Ra, ^{232}Th, and ^{40}K in agricultural soils were (11.94–18.24) Bq/kg, (8.80–12.36) Bq/kg and (247.65–338.26) Bq/kg, respectively. The activity concentrations ranges for ^{226}Ra, ^{232}Th, and ^{40}K in plant crops were (0.20–1.45) Bq/kg, (0.11–0.48) Bq/kg, and (68.07–1355.36) Bq/kg, respectively. The transfer factors from soil to plant crops for ^{226}Ra, ^{232}Th and ^{40}K were in the ranges of (0.011–0.087), (0.011–0.046), and (0.201–5.130),respectively .
Al-Alawy, et al. (2020)[46]	Iraq(Al-Taji city)	The mean specific activity for U-238, Th-232 and K-40 in the basil plant were 4.455 ± 2.944 ,18.774 ±14.998 and 123.767 ±23.047 Bq/kg respectively. For celery it was 3.904 ±3.326 Bq/kg ,32.899 ±6.739 Bq/kg ,85.032 ±35.650 Bq/kg. As for mint, it was 2.233±4.337 Bq/kg, 25.354±8.696 Bq/kg and 92.115± 33.070 Bq/kg.
Mostafa, et al. (2021) [47]	Iraq	The transfer factors of the natural radionuclides ^{238}U, ^{232}Th, and ^{40}K were estimated for several crops cultivated in farms in the suburbs of Baghdad and one farm in Al-Najaf. The results showed that the highest transfer factors for ^{238}U, ^{232}Th, and ^{40}K are 0.32, 0.70, and 3.44, respe-ctively, in wheat. The average transfer factors for ^{238}U and ^{232}Th were founded 0.23 and 0.2 which are lower than the default unity

		value but the 1.85 were reported for ^{40}K higher than unity.
Ibrahim, et al. 2022 [48]	Iraq (Karbala)	The specific activity of ^{238}U, ^{232}Th, and ^{40}K for soil samples were measured using gamma ray spectroscopy system with NaI(Tl) "3×3" detector. The results showed that, the specific activity of ^{238}U, ^{232}Th and ^{40}K were ranged from (35.3±1.7 to 3±0.35) Bq/kg, (2.8±0.21 to 8.22±2.9) Bq/kg, (447.4±6.2 to109.2±2.3) Bq/kg respectively.
Hamzah, et al. 2022 [49]	Iraq (Karbala)	Natural gamma emitters (^{238}U, ^{232}Th and ^{40}K) were determined in some grains samples collected from Kerbala governorate markets, Iraq using gamma-ray spectroscopy. The results show that the average value of specific activity with (S.D) for ^{238}U was 7.02±0.80 Bq/kg,for ^{232}Th was 3.29±0.26 Bq/kg, and for ^{40}K was 254.88±31.06 Bq/kg. Also, the average value with (S.E) for internal hazard index (H_{in}), total annual effective dose (AED_{total}), threshold consumption rate (DIthresh), and excess lifetime cancer risk ($ELCR\times10^{-3}$) that calculated in different types of food were 0.103±0.008, 0.137±0.014 mSv/y, 86.3±8.1 Kq/y, and 0.394 ± 0.042, respectively.
Sharrad, et al. 2023 [50]	Iraq (Khidir City)	In this study choosing crops consisting of okra , onions, cucumber, tomatoes, eggplant, sweet potato, zucchini, and organic pepper showed obvious variability as follows: the activity levels of ^{226}Ra varied from 0.16±0.1 Bq/kg (in eggplant) to 3.984±0.19 Bq/kg (in tomato), with an average of 1.57±0.14 Bq/kg. ^{232}Th were found to be within the range of (0.023±0.01-2.93±0.19 Bq/kg) (in onions-in cucumber), and an average value of 0.80±0.12 32 Bq/kg. For ^{40}K ranged between 87.801±2.24 Bq/kg (in cucumber) and 409.45±2.94 Bq/kg (in tomato), with an average of (273.53±2.43 Bq/kg). On the other hand, the radionuclides activity concentrations in the corresponding soils ranged between 4.644±0.24 Bq/kg, with

		an average of 16.124±0.50 Bq/kg for 226 Ra, and from 1.315±0.11 Bq/kg to 22.783±0.61 Bq/kg, with a mean value of 8.32±0.32 Bq/kg for ^{232}Th, and from 284.482±2.48 Bq/kg to 451.468±3.93 Bq/kg, with a mean value of 406.53±2.77 for ^{40}K. TF of ^{226}Ra was found to be within the range of (0.056-0.143), with an average of 0.095, for ^{232}Th ranged between 0.056 and 0.192, with an average of 0.101, while for ^{40}K, it is found to be varied from 0.933 to 0.216, with an average of 0.669.
Hady, et al. 2023 [51]	Iraq (Karbala)	In this study choosing three samples of agricultural crops (Eggplant, Okra, Common pea). It was found that the highest rate of the ^{238}U specific activity was in the Okra plant sample, where it reached 17.896±2.020 Bq.kg^{-1}, and the sample of the soil was 24.520±1.563 Bq.kg^{-1}. The specific activity of ^{232}Th in the common pea plant sample was 10.959 ± 1.519 Bq.kg^{-1} while the soil sample was 12.86± 0.944 Bq.kg^{-1}. The specific activity of ^{40}K in the eggplant plant sample reached to 274.583 ± 7.583 Bq.kg^{-1} and in soil sample was 324.40 ±15.811 Bq.kg^{-1}. Radiation Transfer Factor TF of ^{238}U was the highest rate in the eggplant samples, in which it reached 0.885, ^{232}Th.
EYIBIO et al. (2024) [52]	Nigeria	The activity concentration of ^{238}U, ^{232}Th, ^{40}K of soil and maize. Also studied are the transfer factor (TF) from soil to maize and the radiological health risk associated with consumption of maize. The mean activity concentration (Bqkg^{-1})of ^{238}U, ^{232}Th, ^{40}K in soil are 12.77±0.25, 41.36±0.70 and 458.61 ±8.04 while that of maize are 14.36±0.27, 19.23± 0.46and 425.25±7.87 respectively. Transfer factor (TF) from soil to maize of ^{238}U, ^{232}Th and ^{40}K are 1.14, 0.50 and 0.94 correspondingly.

1.9.2 Using solid state nuclear track detectors technique.

Author, Year and Reference	Country	Results
Mujahid, et al. (2010)[53]	Punjab (Pakistan)	The radon concentrations and the radon exhalation rate were found in the ranges of 34 ±7 to 260 ±42 Bq m^{-3} and 38 ± 8 to 288 ± 46 mBq m^{-2} h^{-1}, respectively. The onsite measurements of radon in the soil gas were also carried out in these areas using a scintillation alpha counter. The concentration of radon in the soil gas was found in the range of 423± 82-3565±438 Bq m^{-3}.
Drweesh, et al. (2012)[54]	Iraq(Baghdad)	The result show that the concentrations of uranium in soils samples (3.67 and3.99 ppm)with average of 3.82 ppm. the concentrations of uranium in plant samples was ranging between (0.8-2.37 ppm) with average of (1.59 ppm).
Kakati, et al. (2013)[55]	(India)	The radioactive elements such as uranium, radium and radon are present in soil, air and water. The inhalation and ingestion of these radionuclides, above the permissible level, becomes a health hazard. In the present investigation, uranium concentration has been determined by EDXRF technique and radium and radon exhalation rate of soil samples have been determined by Can technique method. Uranium concentration in soil samples has been found to vary from 1.47 ppm to 10.66 ppm whereas radium concentration varies from 10.54 Bq/kg to 49.67 Bq/kg. The radon exhalation rate in these samples has been found to vary from 502.34 $mBqm^{-2}h^{-1}$ to 2062.53 $mBqm^{-2}h^{-1}$. A good positive correlation coefficient (R= 0.98) has been observed between uranium concentration and radon exhalation rate of soil samples.
Abd Elmoniem Ahmed	Sudan	The results of radon concentrations from soil samples in the selected areas were found to be 5.50 ± 0.75 kBq. m^{-3}, 11.05 ± 4.95 kBq. m^{-}

Elzain. (2015)[56]		^{3}, 15.10 ± 1.47 kBq. m^{-3}, while the effective dose was calculated to be from 24.51 ± 3.32 mSv.y-1, 48.22 ± 10.25 mSv.y-1 and 67.28 ± 6.56 mSv.y^{-1}, for El-Hosh, Um-Turibat and Medani towns, respectively.
Hashim, et al. (2015)[57]	Iraq	The values of effective radium content are found to range from 0.074 Bq/ kg to 0.566 Bq/ kg with the mean value of 0.317 Bq/kg. The values of uranium concentrations are found to range from 0.081 ppm to 0.615 ppm with the mean value of 0.345 ppm. Positive correlation has been observed between radium concentration and uranium concentrations in vegetable samples.
Battawy, et al. (2016)[58]	Iraq (Tikrit)	The radon concentration in a ten different imported samples of tea collected from Iraqi local markets. The results showed that , the highest Concentrations of radon was (45.97 kBq / m^{3}) found in Jihann tea ,while the lowest value is recorded in Mahmoud tea which was about(25.44 kBq/m^{3}). The radioactivity of radon content in the samples which is equivalent to obtained values is found between (811.46-1446.29) pCi/kq.
Ali Nadhim Sabbar (2016) [59]	Iraq (Samawah)	Sixteen different samples of feed grains have been collected. The results indicate that the highest rate of radon found in the Nigella sativa (34.7 Bq/m^{3}) and the lowest rate of radon concentration was in the Vigna radiata and Medicago sativa (1Bq/m^{3}).So, all feed grains that we tasted contain concentrations of radon, however it is within the allowable limits as recommended by the International Commission of Radiological Protection ICRP and The World Health Organization.
Hashim, et al. (2016) [60]	Iraq (Karbala)	In this study work a set of indoor radon levels were measured carried out in different dwellings in Karbala city. The results show that, the radon concentrations varied from (32.21-139.01)Bq/m^{3} with an average value (62.07)

		Bq/m^3, and (36.70-243.97) Bq/m^3 with an average value (93.36) Bq/m^3 for closed and open dosimeters respectively, which are less than the lower limit of recommended range (200-300 Bq/m^3) (ICRP, 2009).The values of the indoor annual effective dose vary from (0.02-2.76) mSv/y with an average value (0.68) mSv/y and (0.02-7.49) mSv/y with an average value (1.43) mSv/y for closed and open dosimeters respectively.
Hesham Yousef. (2017) [61]	Egypt	Radon concentrations were measured in some crops samples from the local market by Suez government, Egypt, using alpha track detector from the type of CR-39. The values of the annual effective dose varied from 1.94 - 1.21$mSvy^{-1}$. The obtained results indicate that the values of annual effective dose lower than the recommended limit of ICRP.
Ayoub, et al. (2018)[62]	Iraq	Average values of ^{222}Rn level, ^{226}Ra content and ^{238}U concentration in pharmaceutical herbs were 27.7 Bq. m^{-3}, 0.39 $Bq.kg^{-1}$ and 0.48 ppm, respectively. While, the mean values of radon level, radium content and uranium concentration in vegetables were 33.89 $Bq.m^{-3}$, 0.40 $Bq.kg^{-1}$ and 0.49 ppm, respectively. ^{226}Ra and ^{238}U concentrations are positively correlated in the studied herbs and vegetables samples.
Rejah B. K. et al.(2019) [63]	Iraq	The concentrations of uranium for four species of plants; Spinacia, Brassica Oleracea, BEA-SSICA Oleracea Var Capitata and Beta Vulgaris were measured in addition to the measurement of uranium concentrations in the selected soil by calculating the number of significant traces of alpha in CR-39. The 2.455 Bq/kg in Spinacia plant were the highest concentration while the lowest concentration of uranium were 1.91 Bq/kg in BEA-SSICA Ol-eracea Var Capitata plant. As for

		the transfer factor, the highest value 0.416 were found in Spinacia plant and the lowest value 0.323 were found in BEASSICA Oleracea Var Capitata plant. The uranium in the models studied in it did not exceed the international limit, according to the International Atomic Energy Agency.
Kheder, et al. (2019)[64]	Iraq(Al-Hamdaniya)	The concentration of uranium in soil varies widely, Depending on the geological location, its concentration in the surface soil vary from 0.1 $mg.Kg^{-1}$ (ppm) to 20 $mg.Kg^{-1}$ (ppm) with a world average of 2.8 ppm and the allowed limit that equals 11.7 ppm. The estimated values for the uranium activity which equal to radon activity at secular equilibrium were found to be (581.11-1453.5) mBq with mean value 905.89 mBq, the uranium concentration are between (0.313-0.784) ppm with mean value of 0.488 ppm.
Kheder, et, al. (2020) [65]	Iraq	This work aimed to determine radon, radium, and uranium in barley and wheat crops planted in the Nineveh plains region. Radon, radium, and uranium mean concentrations found are 92.58 $Bq.m^{-3}$, 0.4212 Bq kg^{-1} and 0.368 ppm, respectively. The uranium activity concentration and the total annual effective dose equivalent mean values are 4.546 $Bq.kg^{-1}$ and 67.73 μSv/y. The results showed that the activity in locations depends on the Radioactivity concentrations in barley and wheat crops 51 agriculture soil of the area, and the amount of fertilizer applied in soil. All results are below the world permissible limits so the wheat and barley in the studied area are safe for consumption.
Ibrahim, et al. (2021) [66]	Iraq (karbala)	In this study, alpha particles in the 60 soil samples of the University of Kerbala (Freiha-Sites). The results show that the average value of radon concentrations in air space, radon concentrations ^{222}Rn in samples, Annual effective dose, Radium content, mass ex-

		halation rates, surface exhalation rates and uranium concentrations were 120.82±1.19 Bq /m^3, 3769.71±6.67 Bq/m^3 , 3.02± 0.18 mSv /y, 0.093±.033 Bq/kg, 0.70±0.09 mBq /kg.h, 30.93±0.62 mBq/m^2 .h and 2.75 ±0.18 Bq /kg, respectively.
EL-Araby,et al. (2021) [67]	Egypt	This research cares to study the concentration of radon for fourteen samples of soil from deferent fourteen locator in Wadi Hodein region in Egypt. The mean value concentration of radon was 265.96± 25.45 Bq/m^3. The results of samples show that 28.27% of the radon gas concentrations. Radium, shows good relationship with radon exhalation rate in soil. Good correlation observed between lung cancer per year per million people and radon concentrations for all soil samples.
Kadhim, et al. (2021) [68]	Iraq (Al-Diwaniyah)	In this study, we measured the concentrations of naturally occurring radioactive nuclides in cereals and the corresponding soil collected from agricultural fields in AlShamiyah, Al-Diwaniyah governorate in Iraq using nuclear detector of tracks (CR-39). The mean activity concentration of uranium (ppm) in soil, wheat and rice samples were found to be 1.18 ± 0.19, 0.02 ± 0.001 and $0.88 \times 10^{-2} \pm 0.00085$, respectively. Factors of transfer from soil-to-cereals were limited to be 0.012 and 0.017 for wheat and rice. The results of TFs of ^{238}U were found to be in agreement with previous studies values, these results refer to radionuclides movement were very low in these soils. Results have been shown the uranium concentration to be less than permissible limit (11.7 ppm) proposed by UNSCEAR.
Hamzah, et al. (2021) [69]	Iraq (karbala)	Alpha emitters (concentrations of ^{222} Rn, ^{226} Ra, and ^{238}U) using CR-39 detectors in selected samples of grain that are collected from Kerbala governorate. the average value of alpha emitters concentrations for ^{222}Rn, ^{226}Ra,

		and ^{238}U were 3.99±1.13 Bq/m³ , 4.69±1.28 mBq/kg and 0.072±0.019 Bq/kg respectively.
Al-Hamzawi, et al. (2022) [70]	Iraq (Babil)	This study focuses on the uranium concentration (UC), radium content (RC) and radon exhalation rates (RER) in selected food crops. In the current study, the highest UC was found to be 0.0346 ppm in the turnip crop, whereas the lowest value of UC (0.0142 ppm) was found in grape crop. The highest RC was found to be 0.651 Bq/kg in turnip, while the lowest RC (0.169 Bq/kg) was found in the fig crop. The values of RER ranged from 0.016 Bq/m2.h found in the fig to 0.065 Bq/m2.h found in the turnip. The levels of UC in food crops were lower than 1.7 ppm, the recommended limits of UNSCEAR. A strong direct correlation was found between the UC and RC in selected food crops.
Malik H. Kheder (2023) [71]	Iraq (Ninawa)	Concentrations of uranium and radium were measured. in some fruit and vegetable samples collected from locally cultivated plants in the Nineveh governorate and chosen from among the people's most popular foods. Radium concentrations ranged from 0.085 to 0.366 $Bq.Kg^{-1}$ and the range of uranium concentrations was 0.0935 to 0.4010 ppm with a mean value of 0.2327 ppm. The annual total effective equivalent dose from natural radionuclide ingestion ranged from 6.1988 to 41.883 $Sv.y^{-1}$, with a mean value of 18.602 $Sv.y^{-1}$. These values are much lower than the background dose from natural radionuclide ingestion in food, which is approximately 0.25-0.4 mSv per year. The samples' total radon concentrations were all found to be far below the ICRP's (International Committee on Radiological Protection) permitted level of 400 $Bq.m^{-3}$ in fruits.
Al-Naggar, et al. (2024) [72]	Saudi Arabia	In this investigation, the nuclear track detector CR-39 was employed to measure Radon concentrations in 14 soil samples collected

		from diverse locations in the Najran region. The outcomes reveal that around 71.4% of the soil samples in this study have radon level below the 300 Bqm^{-3} permitted threshold, and approximately 28.60% have radon content beyond the values set by the International Commission on Radiological Protection. The average effective Radium concentration in the soil samples is 10.10 ± 1.39 $Bqkg^{-1}$, with a range spanning from 2.71 ± 1.20 to 24.10 ± 4.52 $Bqkg^{-1}$.

1.10 Justification of this Study

The motives for choosing the study "Transferred Radionuclides from Soil to Plants in Karbala Governorate" can be clarified with the following:

1- The soil contains many radioactive isotopes such as (uranium-238, thorium-232, potassium-40). Plants absorb these radioactive elements from the agricultural soil, which in turn, transfer to humans and animals through the food they consume.
2- Iraq has recently been exposed to numerous military operations and wars, including in Karbala Province, as well as the use of chemical fertilizers, which led to an increase in the concentration of radionuclides in the soil.
3- The rate of cancer cases has risen in recent times, with significantly higher numbers recorded compared to the previous periods.

1.11 Aim of the Study

Determination of the increased lifetime risk of cancer and the risk of hereditary cancer due to the transfer of radioactive nuclei from the soil to the plants grown therein, using sodium iodide detector NaI(Tl) and solid-state nuclear track detectors type CR-39, as well as calculating the external and internal hazard index, gamma index, alpha index, radium equivalent activity, exposure rate, absorbed dose rate, annual gonadal equivalent dose, radon, radium, and uranium concentration, mass and surface exhalation rate, effective annual dose, and annual average internal dose, as well as comparing the obtained results with global and local results.

Chapter Two

Theoretical Part

2.1 Introduction

The particles or waves released by an atom during radioactive decay are known as radiation. They are created through nuclear fission and radioactive decay, in which nuclei can go through a variety of processes that result in radiation being emitted [73]. Extra-terrestrial sources and radioactive materials in the earth's crusted are both sources of natural radioactive [74]. In nature, there are three radioactive series (^{238}U, ^{235}U, and ^{232}Th) whereby heavy atoms eventually underwent changes in their atomic number and mass before becoming stable lead isotopes. Three forms of radiation were identified in all of these spontaneous changes, namely: alpha (helium nuclei), Beta, and gamma (photons) [75].

2.2. Types of Radiation

2.2.1 Alpha Particles

It is the nucleus of the helium atom and consists of two protons and two neutrons. The spectrum of the emitted alpha particles is a discontinuous spectrum, meaning that they are emitted singly and are launched from the nucleus of the element with an energy that distinguishes it from others, which ranges between (4-9) MeV [76]. The range of these particles in the air is a few centimeters, and thus they have a low ability to penetrate materials [77].

2.2.2 Beta Particles

Beta particles emit from the nucleus of the atom and are negative electrons or positive positrons with an energy lower than the energy of alpha particles, which ranges between (0.02-4) MeV, where their emitted spectrum is continuous. Because of their low mass, they travel longer distances than alpha particles, and although these particles cause ionization of materials less than alpha, they remain a very dangerous source inside the body [78].

2.2.3 Gamma Rays

They are electromagnetic waves with a very short wavelength ranging between (3×10^{-8}-10^{-11}) cm or less and are emitted during nuclear processes such as nuclear reactions, and their speed is equal to the speed of light [78]. They have no electrical charge, and gamma rays are emitted in the form of photons that have wave properties. Gamma rays are the most penetrating type of radia-

tion and can penetrate the human body if they have high energy. They can travel hundreds of meters in the air and several centimeters in tissues. The penetrating power of gamma rays is much greater than alpha or beta particles. These rays can only be stopped by using several centimeters of lead or more than a meter of concrete, and the emission of gamma rays is often accompanied by alpha or beta particles and is emitted from some natural sources and all industrial radioactive sources [79].

2.3. Gamma-Rays Interaction with Matter

Gamma rays can interact with matter in three main ways, depending on their energy and the atomic number of the interacting matter. The collision can be either complete absorption of the photon or scattering of the photon [80]. These processes are:

1- Photoelectric Effect
2- Compton Scattering
3- Pair Production

2.3.1 Photoelectric Effect

In the photoelectric process, gamma photons interact with an orbital electrons of an atom. The electron receives kinetic energy from the gamma photon and is knocked out of its orbit. The kinetic energy with which the released electron is [81,82]:

$$T_e = E_\gamma - B.E \quad (2.1)$$

T_e : The kinetic energies of the released electron.

E_γ : The energy of incident photons.

B.E : The binding energies of the shell electron.

The vacancy created is promptly filled by one of the outer electrons whose transition is accompanied by the emission of characteristic electromagnetic radiation in the x-rays, as shown in the figure (2.1)

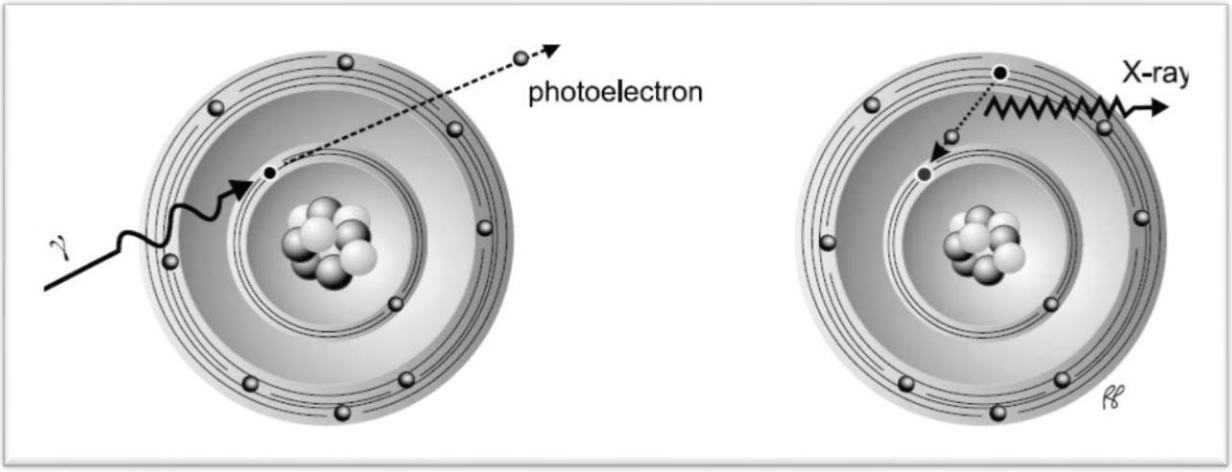

Figure 2.1 Photoelectric Effect [82].

The probability of interaction with this phenomenon is inversely proportional to the energy of the incident photon and directly proportional to the atomic number of the absorbing material, as this phenomenon prevails at low photon energies and for materials with large atomic number [82].

2.3.2 Compton Scattering

Compton scattering is the process whereby a gamma ray interacts with a free or weakly bound electron ($E_\gamma >> E_b$) and transfers part of its energy to the electron (see figure 2.2). Conservation of energy and momentum allows only a partial energy transfer when the electron is not bound tightly enough for the atom to absorb recoil energy. This interaction involves the outer, least tightly bound electrons in the scattering atom. The electron becomes a free electron with kinetic energy equal to the difference of the energy lost by the gamma 'ray and the electron binding energy. Because the electron binding energy is very small compared to the gamma-ray energy, the kinetic energy of the electron is very nearly equal to the energy lost by the gamma ray [83,84]:

$$E_e = E_\gamma - E' \qquad (2.2)$$

Where

E_e = energy of scattered electron.

E_γ = energy of incident gamma

E' = energy of scattered gamma ray.

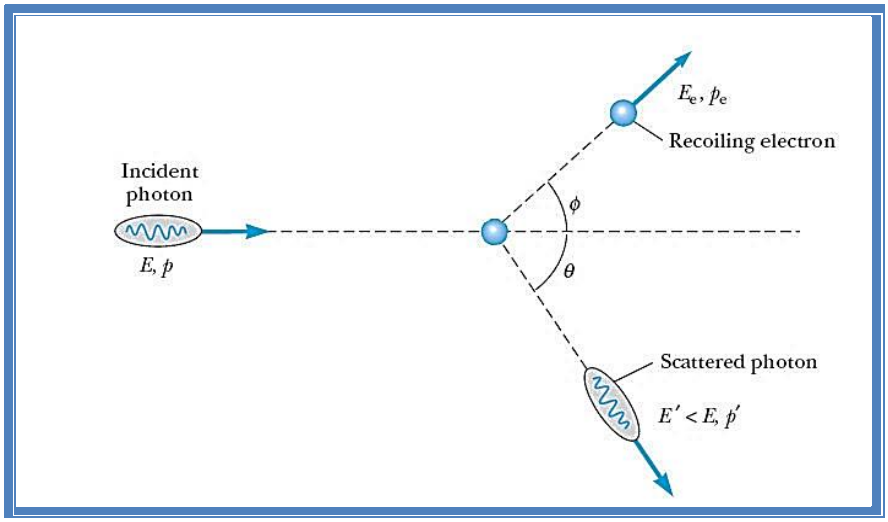

Figure 2.2 The compton scattering [80].

2.3.3 Pair Production

A gamma ray with an energy of at least 1.022 MeV can create an electron-positron pair when it is under the influence of the strong electromagnetic field in the vicinity of a nucleus (see figure 2.3). In this interaction the nucleus receives a very small amount of recoil energy to conserve momentum, but the nucleus is otherwise unchanged and the gamma ray disappears. This interaction has a threshold of 1.022 MeV because that is the minimum energy required to create the electron and positron. If the gamma ray energy exceeds 1.022 MeV, the excess energy is shared between the electron and positron as kinetic energy. From equation (2.3), can be determined the energy of the photon [85]:

$$T_{e^-} + T_{e^+} = h\upsilon - 2m_o c^2 \qquad (2.3)$$

Where:

$T_{e^-} + T_{e^+}$: The kinetic energy of the positron and the electron respectively.

$h\upsilon$: Energy of the photon.

$2m_o c^2$: The sumation of the resters energy of the electeron and positeron.

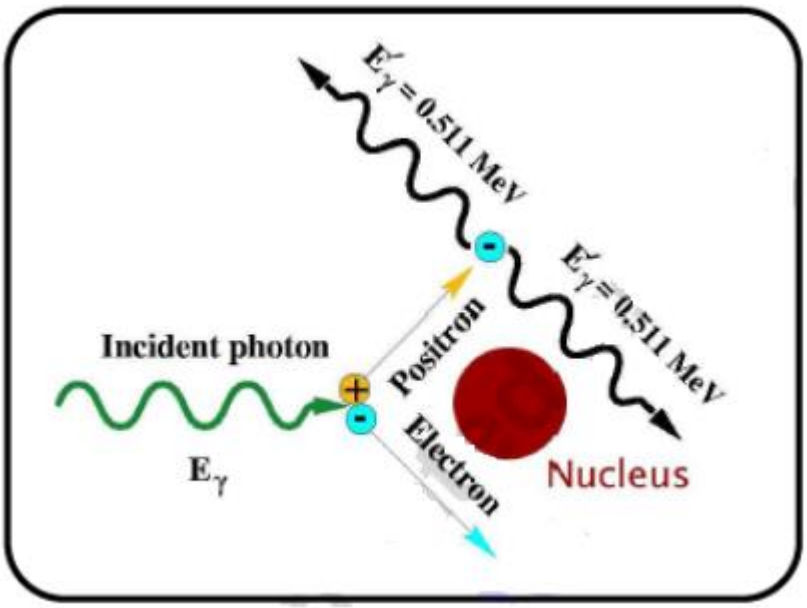

Figure 2.3 Pair Production [85].

The electron and positron from pair production are rapidly slowed down in the absorber. After losing its kinetic energy, the positron combines with an electron in an annihilation process, which releases two gamma rays with energy of 0.511 MeV [86].

2.4 Alpha Particle Interaction with Matter

Alpha particles are easily absorbed by materials. Alpha particles emitted from radioactive sources can be absorbed by a sheet of paper, an aluminium plate thickness (4 mm), or a few centimetres of air [87].

The main way by which charged particles lose their charge is their interaction with the electrons of the substance through Coulomb forces, causing irritation and ionization of the atoms of the substance. Therefore, the alpha particle can produce ion pairs in this process, and the intensity of the ionization caused by the alpha particles is expressed in specific ionization. Specific ionization is defined as the number of ion pairs per unit path [88].

The amount of energy lost by the particle per unit path at the beginning of its entry into the material is small, and the specific ionization it causes is approximately constant in amount, while at the end of the path, where the speed of the particle becomes small, the probability of collision will increase. The

specific ionization increases from its fixed value, but it quickly decreases quickly to zero. After the alpha particle loses all its energy [88].

2.5. Radioactive Equilibrium

The term radioactivity equilibrium is usually used to explain the situation when the rate of radioactive decay in parent nuclei equals the rate produced by daughter nuclei. There are three different cases of this equilibrium, which are classified based on the half-life of the parent nuclei, whether it is greater or smaller than the half-life of the daughter nuclei [89], and they can be summarized as follows:

2.5.1. Secular Equilibrium

This equilibrium occurs once in the life of the nucleus and continues until the end. It occurs in one case, which is when the half-life of the parent nucleus is much greater than the half-life of the daughter nucleus, as the radioactivity of the parent nucleus is equal to the radioactivity of the daughter nucleus. This equilibrium state can be observed in figure (2.4) [89,90].

When the half-life of the daughter atom is very small, the value of λ_2 will be very large. Since the half-life of the mother atom is very large, λ_1 will be very small. In this case, the equation can be written as follows [90]:

$$N_2 = \frac{\lambda_1}{\lambda_2} N_1\left(1 - e^{-\lambda_2 t}\right) \qquad (2.4)$$

Since the decay coefficient of the daughter atom λ_2 is very large, the exponential term in the equation will tend to zero, so the equation becomes as follows:

$$N_2 \lambda_2 = N_1 \lambda_1 \qquad (2.5)$$

From this equation we can find the value of the decay constant for nucleus with very long half-life when the half-life of the daughter nucleus is small compared to the first.

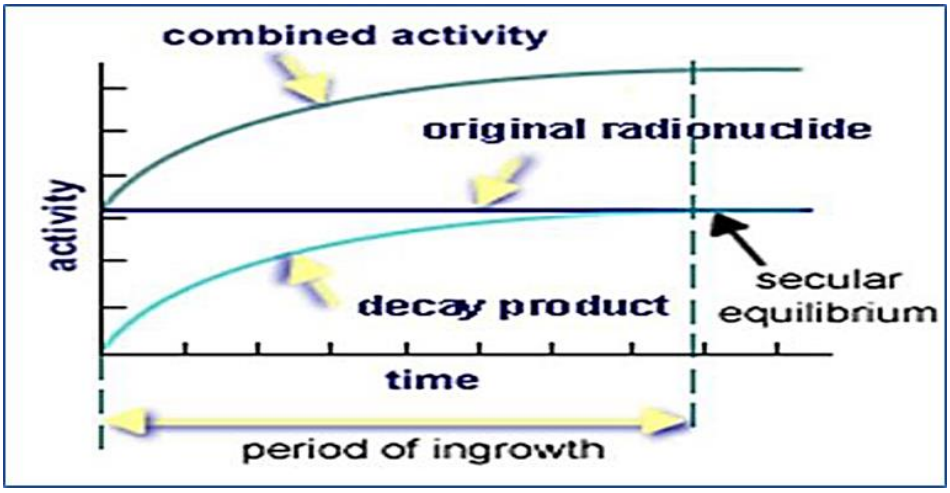

Figure 2.4 Secular Equilibrium [90].

2.5.2 Transient Equilibrium

This equilibrium occurs when the half-life of the parent nucleus is slightly greater than the half-life of the daughter nucleus. In this case, the decay constant is greater than zero, so the exponential term of daughter atom $e^{-\lambda_2 t}$ approaches zero faster than the exponential term of the parent atom $e^{-\lambda_1 t}$. After sufficient time has passed, the transitional equilibrium occurs, as shown in the figure (2.5) [89,90].

The mathematical relationship for this equilibrium is as follows:

$$N_2 = \left(\frac{\lambda_1}{\lambda_2 - \lambda_1}\right) N_1 \tag{2.6}$$

This means that the parent atom decay at a rate equal to the rate of decay of the daughter atoms, so the ratio between the radioactivity of each of the parent and daughter atoms will be:

$$\frac{A_1}{A_2} = \frac{\lambda_1 N_1}{\lambda_2 N_2} = \frac{\lambda_2 - \lambda_1}{\lambda_1} \tag{2.7}$$

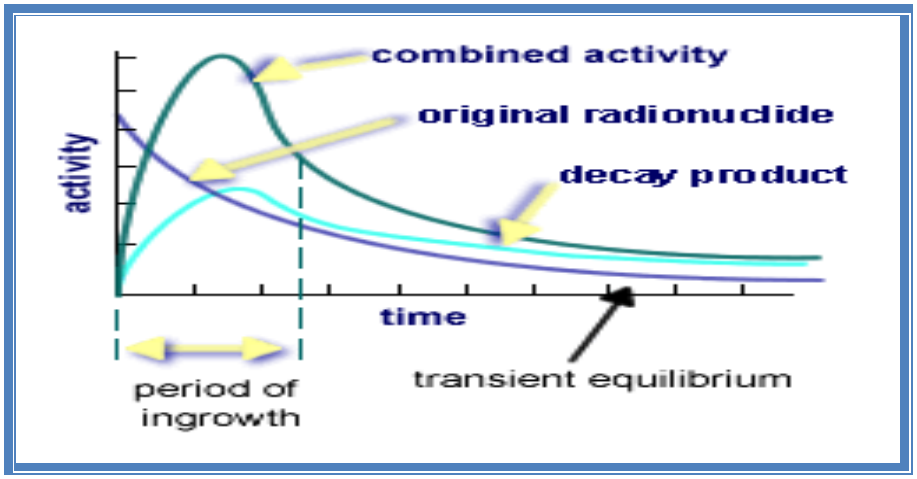

Figure 2.5 Transitional equilibrium [90].

2.5.3 No Equilibrium

The situation in which the half-life of the parent nucleus is short compared to the half-life of the daughter nucleus is called a state of no equilibrium. This can be observed in figure (2.6). The parent nuclei, due to their short half-life, will decay quickly, while the number of daughter nuclei increases until they reach their maximum value, and in the end they will decay, due to their half-life, after a certain period [89,90].

$$(t_{1/2})_1 < (t_{1/2})_2 \text{ , or } \lambda_1 > \lambda_2 \qquad (2.8)$$

$$\lambda_p > \lambda_d \qquad (2.9)$$

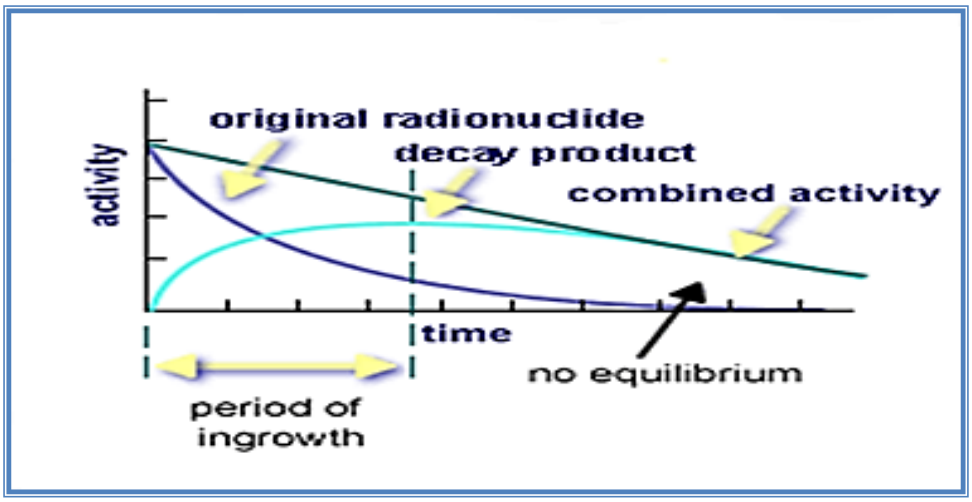

Figure 2.6 No Equilibrium [90].

2.6 Scintillation Detectors

The process of measuring and detecting radiation using scintillation detectors is one of the effective methods of detecting radiation. Scintillation detectors are materials that emit a pulse of light when radiation falls on them. By measuring the intensity and amount of this pulse of light, we can know the intensity of the radiation. Scintillation detectors are considered one of the most important types of detectors used in detecting ionizing radiation. Their work depends on the fact that some materials, when ionizing radiation passes through them, emit pulses of light that in turn fall on the photocathode, which emits an electron. The amount of electrons generated is usually small, so their number must be increased or amplified before they are recorded as a pulse. The amplification or multiplication of these electrons is done using a device called a photomultiplier tube. When this detector is connected to an amplifying device such as an optical amplifier, these pulses can be converted into an electronic pulse to provide information about the incident radiation [91].

The most common crystal in scintillation detectors is the sodium iodide crystal doped with thallium NaI(Tl) for the purpose of detecting gamma rays because of its high efficiency in detecting these rays due to the large atomic number of thallium and iodine, which is considered higher than the efficiency of other detectors for detecting gamma rays [91].

2.7 NaI(Tl) Detector

The detector consists of two main parts: the scintillation material, which produces photons when exposed to gamma rays, and the photomultiplier tube, which faces the crystal. When radiation passes through the crystal, some electrons are displaced, leaving gaps. These electrons tend to return to these gaps, emitting photons with short wavelengths that cannot be seen. To obtain visible light, the crystal is fed with another material such as thallium (Tl), which in turn represents the mediator, as the electrons give part of their energy to the thallium atoms, causing them to be excited. To get rid of the excess energy, the thallium atoms emit photons within the visible region. In order to obtain a good output for all absorbed gamma rays, iodine equips the system with a high atomic number to increase the possibility of the photoelectric effect. The light produced by the crystal must be measured and converted into an electrical signal. This is done by a photomultiplier tube (PMT), which consists of a

photocathode that emits electrons when the photons fall on the crystal, as a high voltage is applied to concentrate the electrons on the dynode. The first of the dynode series is considered an electron multiplication series, and due to the collision, a number of secondary electrons are released for each primary electron and the secondary electrons are accelerated through the vacuum to the second dynode, where the number of electrons is doubled again. Thus, the electron multiplication continues until it reaches the anode and then passes to the measurement circuit as shown in the figure (2.7) [91].

The multi-channel analyzer (MCA) used in the current study analyzes the pulses coming out of the main amplifier, records them, and displays them in the form of a visual image of the spectrum. It records and processes the pulses according to their amplitude. Each storage unit is called a channel, and the amplitude of the pulse is proportional to the energy of the photon falling on the detector. Each of these pulses is stored in a specific channel according to its energy. A multi-channel analyzer of the type ORTEC –Digi Base was used in this study [91].

In order to reduce the radiation background reaching the detector to the minimum possible, a cylindrical chamber made of lead was used to shield the system. The shield used consists of two parts: the upper part is 5 cm thick and 20 cm long, surrounding the crystal and a cover (22 cm in diameter and 5 cm thick). The lower part represents the base of the detector, so that the detector and the detector holder were covered by the shield. The shielding image is shown in figure (2.8) [91].

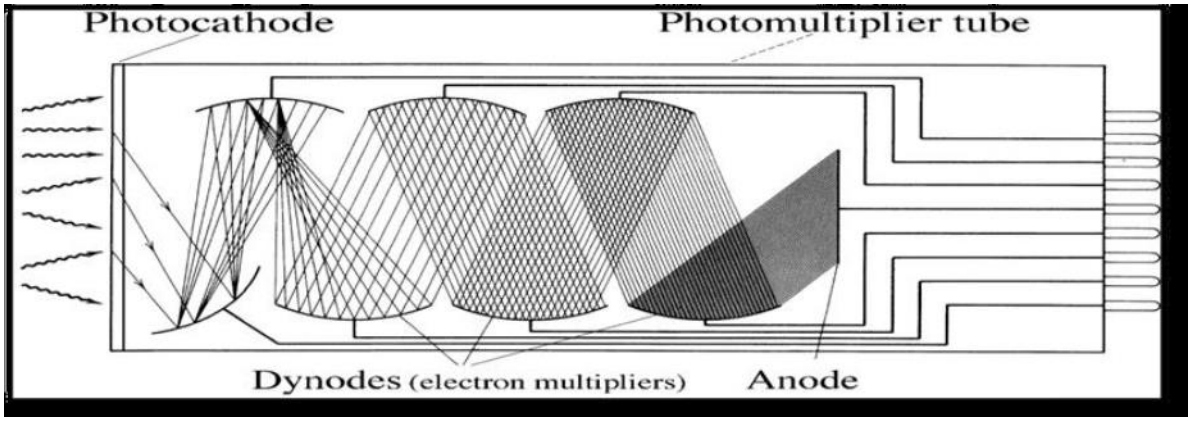

Figure 2.7 The Structure of the NaI(Tl) Detector [91].

Figure 2.8 Shield chamber and detector location inside the shield.

2.8. Solid State Nuclear Track Detectors

Young discovered solid-state detectors in 1958 when he noticed small pits appearing on plates of lithium fluoride crystals after chemical treatment that had been exposed to a beam of thermal neutrons fired from a uranium plate. In the year (1959), studies in this field were conducted by the researchers (Barnes and Silk), who were also working at the Atomic Energy Research Establishment in England, where they used the transmission electron microscope to observe linear damage in thin sheets of mica that had been bombarded by spontaneous fission fragments resulting from uranium -238. In the early 1960s, a team of scientists (Leischer, Price and Walker) working at the General Electrical Research Laboratories in New York followed them, and they developed on a large scale what Barnes and Silk had reached by presenting a new type of solid-state nuclear track detectors (SSNTDS) using glass, plastic and crystals of various metals instead of mica [92,93].

Many studies have shown that nuclear track detectors in general have a number of characteristics such as ease of use, availability, low cost, no need for an electrical power source. The process of scraping that displaying track is a relatively easy process, and they have the ability to preserve traces when stored for a long period of time at normal temperatures. These characteristics have made

them widely used in many laboratories and by a large number of researchers and in various applied journals [92,93]. Solid nuclear track detectors are classified into:

2.8.1 Inorganic Detectors

These are the detectors whose chemical composition does not include the elements carbon and hydrogen, and the atoms of their molecules are linked by ionic bonds. There are many inorganic detectors used in the field of nuclear physics, the most prominent of which are the mica detector and the glass detector. They are considered good inorganic detectors in detecting neutrons and fission fragments, especially in nuclear reactors, due to their ability to withstand temperatures of up to 400℃ [94].

2.8.2 Organic Detectors

These are the detectors that include carbon, hydrogen and oxygen elements in their chemical composition, such as polymeric materials. Polymers are large molecules made up of small units linked together called monomer. Organic polymers, in addition to carbon, hydrogen, oxygen and nitrogen atoms, contain sulfur and halogens. The atoms are linked to each other by covalent bonds. Organic detectors have greater sensitivity than inorganic detectors and also have a higher analytical ability to detect than inorganic detectors. Most of the bonds that connect these atoms break easily after exposure to radiation. The most prominent types of organic detectors are cellulose detectors such as (CN-85) and (LR-115) in its various types. Among the organic detectors are the (CR-39) detector, the PM-355 detector, as well as the Macrofol detector and the Lexan detector [94].

2.9 CR-39 Detector

It is one of the most important organic nuclear trace detectors. It was discovered in (1978) by researchers (Cartwright and Shirk). It has a randomly arranged hydrocarbon structure. Its molecular formula is ($C_{12}H_{18}O_7$). The monomer of this detector is composed of two allyl groups, as shown in figure (2.9). Its scientific name is (PADC) (Polyallyl altelea diglyol carbonate), and the commercial name is (CR-39). It is a polymeric material and is symbolized by (CR) which is an abbreviation of (Columbia Resin). Its density is 1.32 gm /cm^3. The detector (CR-39) is widely used in the detection of charged particles, alpha particles and nuclear fission fragments because of its high radiation

sensitivity and resolving power. It is not affected by beta particles or gamma rays [95,96].

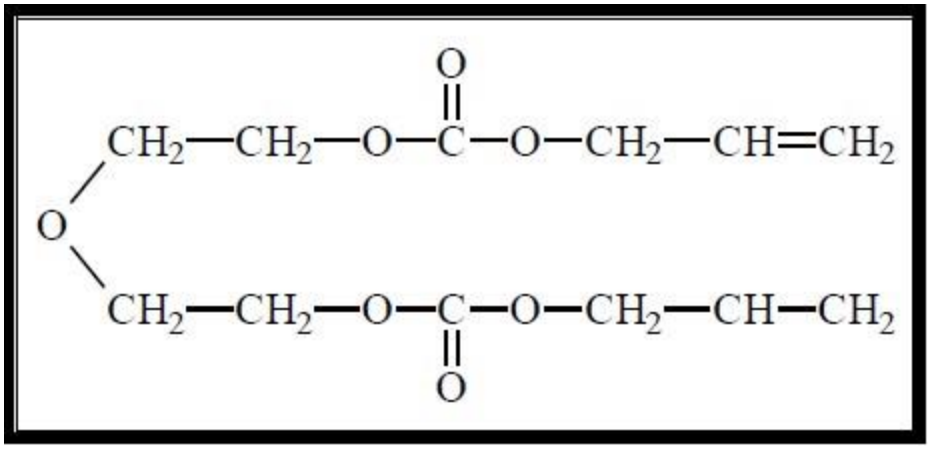

Figure 2.9 The chemical form of CR-39 detector [95].

2.10. Mechanism of Track Formation

When particles fall on solid-state detectors with a structure consisting of long molecular chains, these particles lose part of their energy due to ionization and excitation caused by these particles in the components of the detector, where an electrostatic interaction occurs between the falling particles with the electrons and nuclei of the components of the detector, and thus what is called nuclear trace tracks are formed. The shape and size of the track depend on both the nature and energy of the falling particle and the type of solid detector. In plastic (organic) detectors, tracks are formed when part of the electrons are ionized, excited and released so that the excitation energy is transferred from one molecule to another. As for the freed electrons, they may combine with some molecules to form negative ions, or with some positive ions to form excited molecules. Atomic displacements also result from elastic collisions in crystals, as well as lattice voids and destruction of molecular chains, and then tracks are formed. If the charged particle falls on the solid state inorganic detectors, it leads to the ionization of some atoms and thus the production of free electrons. When the energy of the falling particle is low, it produces a number of atomic displacements due to elastic collisions as well as the ability of the liberated electrons to create such atomic signals. The fall of heavy ions on the inorganic detector leads to the formation of a track, and this track is chemically active, which makes its erosion during the chemical etching process more

and faster than the undamaged areas of the detector [97]. Two models have been proposed to explain the mechanism of track formation in solid detectors:

2.10.1 Thermal Spike Model

Some incident charged ionized particles on the detector leave their tracks in the form of established tracks before they come to rest. They also cause heating in the impacted area, leading to a rise in temperature. Due to thermal conductivity in this model, the heating causes damage to the crystal lattice. The temperature of a spike at a point located a distance of (r) from the center of the spike and at a time of (t) is given by the following equation [98]:

$$T(r,t) = \frac{Q}{4c\rho\pi Dt}\exp\left(-\frac{r^2}{4Dt}\right) + T_{\circ} \qquad (2.10)$$

Where, T_o is the thermal distribution of the lattice at t=0, D is the thermal diffusivity, ρ is the density, and c is the capacity of the medium.

Metals are unable to show particle tracks due to the significant energy loss by electrons that are liberated as a result of particle impact. This large energy loss is due to collisions between the liberated electrons and the electrons of the conductive material, and the electron relaxation time is shorter than the electron photon interaction time. This leads to the excitation spreading over a large volume of electrons before transferring to the lattice, resulting in a broad, unfocused thermal spike that disperses from the metal. In the case of insulators, energy loss occurs due to the interaction of liberated electrons with phonons, causing the excitation to transfer to the crystal lattice, creating a concentrated thermal spike that leads to localized destruction in the detector [98].

2.10.2 Ion-Explosion Spike Model

This model is based on the formation of positive ions due to the release of some electrons as ionizing particles pass through the detector. The repulsion between these positive ions pushes them into interstitial position within the lattice. If the electron recombination time is longer than the lattice vibration time, approximately 10^{-13} sec, these ions become neutralized in their new position [99]. To ensure that the detector can maintain the particles track, the following conditions must be met:

1- The electrostatic stress (coulomb repulsive forces within the ionized region) must exceed the mechanical strength or cross-linking forces.

This implies that materials with low mechanical strength or low dielectric constant are more likely to store drillable tracks.

2- The maximum allowable density of free electrons must be low. This condition restricts track formation in good insulators and excludes metals.
3- Tracks will not form in materials with high hole mobility. The reason is that the rapid outward diffusion of holes will neutralize the core atoms, thereby preventing track formation. Consequently, semiconductors such as silicon and germanium, which exhibit high overall mobility, will not register tracks.

This model is currently the most widely accepted in the field of tracks, although it is entirely possible that certain combinations of models that may provide a more accurate representation of the actual mechanism of nuclear track formation in solids [99].

Chapter Three

Experimental Part

3.1 Introduction

In this chapter, we will discuss, starting with the process of selecting the areas from which samples were collected, passing through the process of preparing those samples for the examination process and the stages of drying and storing them, and ending with the process of conducting tests on those samples using two different technologies, which are both the scintillation detector system NaI(Tl) and the nuclear track detectors CR-39.

3.2 The Study Area

The governorate of Karbala is geographically located between the two latitudes 32°10'30" - 32°50'33" N and longitudes 40°10'43" - 44°12'30" E. It is bordered to the north by Babylon and Anbar provinces, to the east by Babylon province and to the south and west by Najaf and Anbar provinces, as shown in figure (3.1) [100].

The area of the province of Karbala is estimated at 5034 km^2, with a ratio that reaches 1.2% of the total area of Iraq (434,934 km^2). An estimate places the governorate's population at approximately 1,350,577 people. The agricultural lands in the eastern and northeastern parts of the irrigated governorate extend along the Euphrates River and are characterized by fertile clay soil, while the desert plains cover the far western parts of the province and are characterized by sandy soil. A salt lake lies to the west of the province called Al-Razzazah [100]. The crops grown in the province include wheat, barley, vegetables, palm trees, and fodder such as alfalfa and corn.

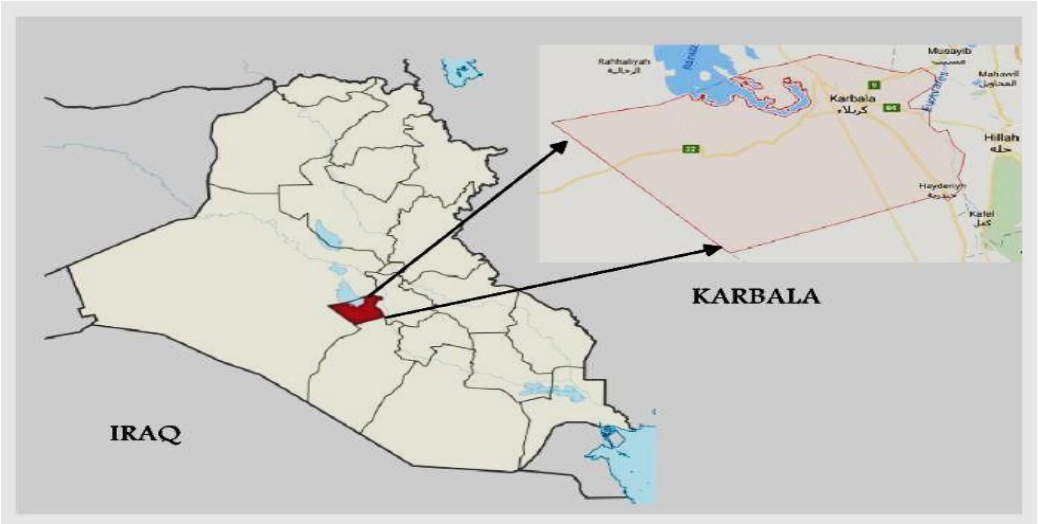

Figure 3.1 Map of Iraq showing Karbala Governorate [100].

3.3 Samples Collection

During the months of November and December 2023, 100 samples were collected, including 50 soil samples and 50 plant samples. They included agricultural areas in Karbala Governorate (Husseiniyah, Hindiyah, Al-Hur, and Ain Al-Tamar districts). The soil was taken at a depth of 15 cm from the same place where the plant was collected. The plants included (alfalfa, chard, spinach, radish, and barley). The location of the samples was determined using the global positioning system (GPS), as shown in figure 3.2. Table (3.1) shows the code and location for samples of soil and plants.

Table 3.1: Code of the sample location with their latitude and longitude.

NO	Sample code				Latitude (°N)	Longitude (°E)
	Plant	Type of Plant	Soil			
1	P1	Alfalfa	S1	Al-Hur	32°43'46.5"N	44°02'04.2"E
2	P2	Alfalfa	S2		32°43'11.2"N	44°01'47.7"E
3	P3	Alfalfa	S3		32°39'52.1"N	43°57'60.0"E
4	P4	Spinach	S4		32°43'27.9"N	43°59'60.0"E
5	P5	Spinach	S5		32°43'55.9"N	43°57'22.9"E
6	P6	Radish	S6		32°40'14.8"N	43°58'47.5"E
7	P7	Alfalfa	S7		32°40'45.0"N	43°58'53.4"E
8	P8	Radish	S8		32°43'30.3"N	43°57'13.1"E
9	P9	Alfalfa	S9		32°41'54.3"N	43°56'02.7"E
10	P10	Alfalfa	S10		32°42'28.7"N	43°55'56.2"E
11	P11	Alfalfa	S11	Husseiniyah	32°38'10.9"N	44°11'15.8"E
12	P12	Chard	S12		32°39'54.3"N	44°13'09.5"E
13	P13	Alfalfa	S13		32°42'15.7"N	44°12'53.7"E
14	P14	Alfalfa	S14		32°38'48.4"N	44°07'12.0"E
15	P15	Radish	S15		32°39'49.2"N	44°05'01.1"E
16	P16	Alfalfa	S16		32°38'34.2"N	44°04'26.2"E
17	P17	Alfalfa	S17		32°37'38.8"N	44°04'34.9"E
18	P18	Alfalfa	S18		32°41'02.0"N	44°08'14.3"E
19	P19	Alfalfa	S19		32°40'50.5"N	44°11'00.5"E
20	P20	Radish	S20		32°40'17.2"N	44°05'28.9"E
21	P21	Alfalfa	S21		32°38'15.8"N	44°09'29.7"E
22	P22	Spinach	S22		32°37'29.2"N	44°07'52.2"E
23	P23	Alfalfa	S23		32°36'11.0"N	44°07'54.9"E
24	P24	Alfalfa	S24		32°41'17.6"N	44°02'05.5"E
25	P25	Spinach	S25		32°42'40.3"N	44°07'16.7"E

26	P26	Alfalfa	S26		32°41'51.4"N	44°07'26.2"E
27	P27	Alfalfa	S27		32°41'25.8"N	44°03'57.7"E
28	P28	Alfalfa	S28	Hindiyah	32°35'40.3"N	44°09'19.7"E
29	P29	Spinach	S29		32°35'25.6"N	44°07'04.3"E
30	P30	Spinach	S30		32°29'15.8"N	44°15'14.3"E
31	P31	Alfalfa	S31		32°37'21.4"N	44°09'40.9"E
32	P32	Alfalfa	S32		32°31'34.0"N	44°13'58.2"E
33	P33	Chard	S33		32°34'31.8"N	44°09'05.7"E
34	P34	Chard	S34		32°32'43.0"N	44°07'37.8"E
35	P35	Alfalfa	S35		32°33'30.1"N	44°11'50.4"E
36	P36	Chard	S36		32°27'45.0"N	44°13'49.2"E
37	P37	Alfalfa	S37		32°25'50.8"N	44°13'53.0"E
38	P38	Alfalfa	S38		32°27'36.6"N	44°12'54.2"E
39	P39	Alfalfa	S39		32°29'16.3"N	44°10'09.3"E
40	P40	Alfalfa	S40		32°28'06.9"N	44°10'48.0"E
41	P41	Chard	S41		32°29'05.9"N	44°11'56.6"E
42	P42	Alfalfa	S42		32°33'14.5"N	44°09'50.1"E
43	P43	Alfalfa	S43		32°30'49.9"N	44°12'54.9"E
44	P44	Radish	S44		32°32'06.8"N	44°10'49.8"E
45	P45	Alfalfa	S45		32°34'04.0"N	44°06'59.6"E
46	P46	Barley	S46	Ayn Al-Tamr	32°34'52.4"N	43°29'01.9"E
47	P47	Radish	S47		32°34'49.0"N	43°31'09.5"E
48	P48	Barley	S48		32°34'52.1"N	43°29'02.4"E
49	P49	Chard	S49		32°33'04.7"N	43°32'00.2"E
50	P50	Radish	S50		32°31'31.4"N	43°32'27.0"E

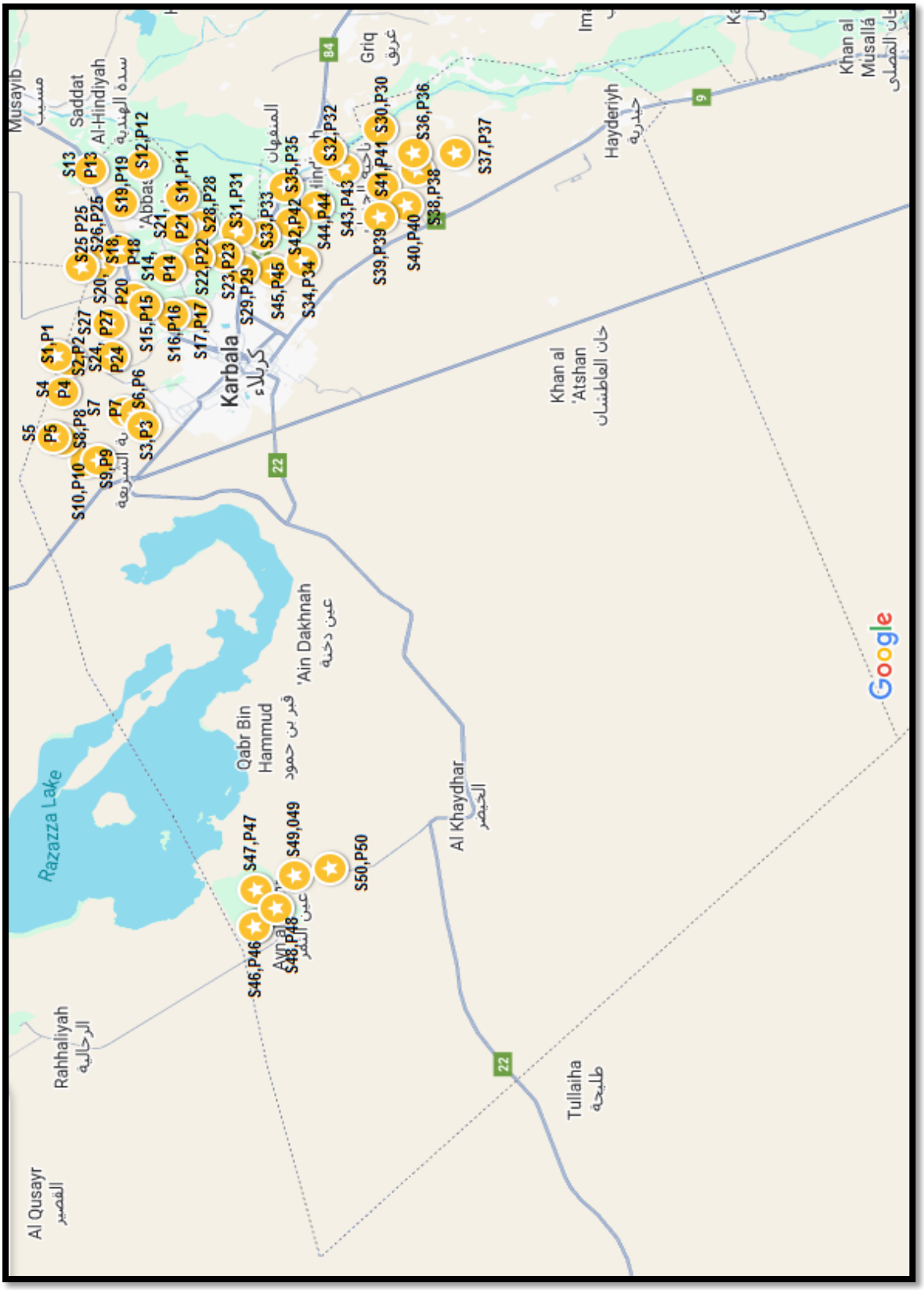

Figure 3.2 Map of location sample.

After placing the samples in plastic bags and labeling them, they were transported to the laboratory for processing before being prepared for activity concentration analysis. The soil samples were dried in an oven as shown in figure (3.3) at 100˚C for one hour, and the plant samples at 100˚C for 2 hours to remove all moisture content from them, and crushed then with a mill as shown in figure (3.4) to obtain a fine powder. After grinding, the powder was filtered through a sieve of 1 mm as shown in figure (3.5) and then weighed by 750 gm each using a digital balance with an accuracy of ±0.01% gm as shown in figure (3.6). Following that, the samples were filled into Marinelli Becker as shown in figure (3.7). Each sample's code name was installed on Marinelli. After that, the Marinelli Becker's were closed for four weeks to achieve a secular equilibrium of radium-226 and radon-222.

Figure 3.3 Oven

Figure 3.4 Electronic mill

Figure 3.5 Sieve

Figure 3.6 Sensitive balance

Figure 3.7 Marinelli Becker.

3.4. Detection Using NaI(Tl) Detector

3.4.1 Energy Calibration

Calibration means finding the linear relationship between the channel number and the energy of the gamma rays falling on its crystal. This is the first step we take for any spectral measurement. Standard sources with known energy and activity are used to calibrate the gamma ray spectrum. The purpose of multiple sources is to obtain an energy spectrum used in the field of research [101]. In this research, we used standard sources, which are (^{137}Cs and ^{60}Co), as shown in the table (3.2), and figure (3.8) represents the relationship between energy of the standard sources and the channel number.

Table 3.2: Properties of radioactive sources consulted for this study.

Isotope	**Serial number**	**Production date**	**Activity μCi**	**Energy keV**	**I_γ (%)**
^{137}Cs	Pc-95	1/1/2009	1	661.66	85.10
^{60}Co	IRS-28	1/1/2009	1	1173.24	99.97
				1332.50	99.99

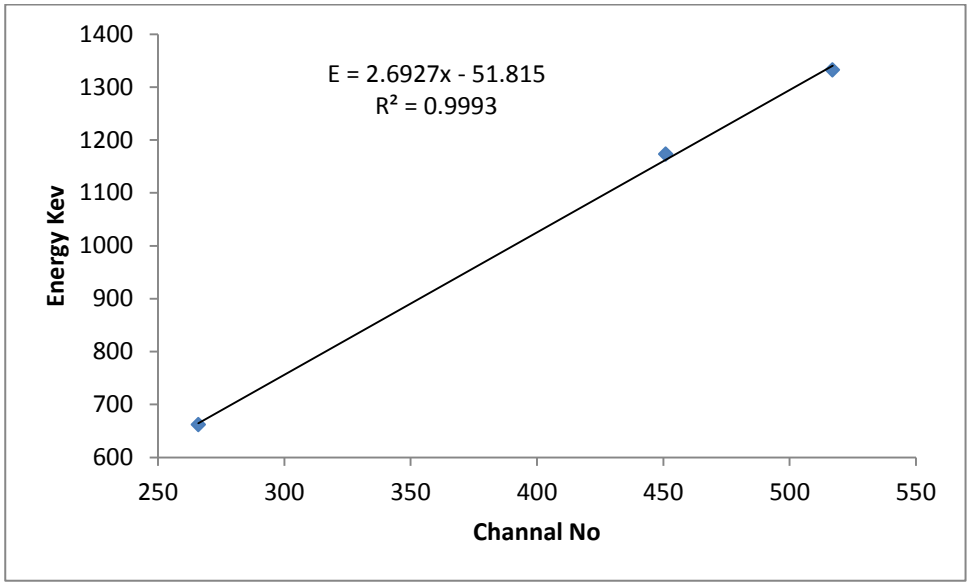

Figure 3.8 The NaI(Tl) 3"× 3" energy calibration curve.

3.4.2 Detection Efficiency

The efficiency of a detector is defined as the ratio of the number of pulses emitted from it to the number of photons incident on it and is given by the relation [102]:

$$\varepsilon = \frac{N}{A.I_{\gamma}.T} \times 100\% \quad (3.1)$$

Where: N: (Under the photo peak) is the net area, T: is the measurement time in second, I_{γ}: Is the percentage of gamma ray intensity emitted for each energy of the radioactive source, A: Is the activity of a radioactive source at time t, expressed in units of Bequral, at the moment of measurement, which is commonly determined using equation (3.2) [103].

$$A = A_{\circ} e^{-\lambda.\Delta t} \quad (3.2)$$

Where: A_o: The activity of source at time t_o, λ: The decay constant using equation (3.3). Δt (Δt= t-t_o): Is time of decay between the product of the standard source (t_o) and time measurement (t).

$$\lambda = \frac{0.693}{t_{1/2}} \quad (3.3)$$

$t_{1/2}$: is the half-life of radioactive source.

To calibrate the efficiency of the thallium-doped sodium iodide detector NaI (Tl) system, it is necessary to use standard sources with known energies placed in a (1) (liter) Marinelli-Baker vessel. The decay equation (3.2) was used to calculate the activity of the radioactive sources. The radioactivity recorded by the detector was also measured for each energy of the radioactive sources and for a period of (3600 s). This is followed by calculating the efficiency(%) through the equation (3.1). Figure (3.9) shows the relationship between efficiency and energy for standard sources used.

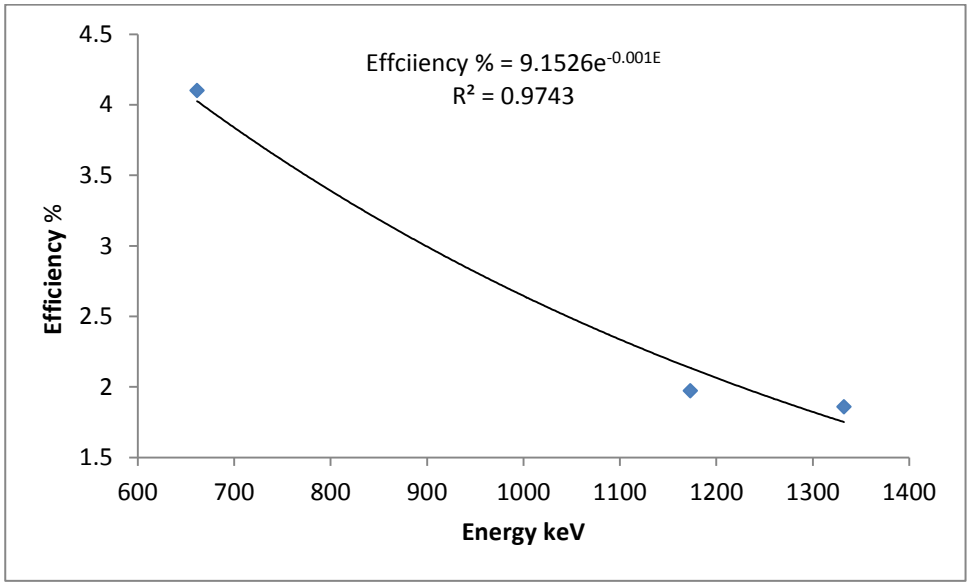

Figure 3.9 The curve of efficiency for NaI(Tl) detected in present study.

From the figure (3.9) it is found that the relationship between efficiency and energy is:

$$\varepsilon = 9.1526e^{-0.001E} \quad (3.4)$$

Where ε is the relative efficiency, E: is the energy of radioactive sources in keV.

3.4.3 Energy Resolution of Detector

It is the ability of the detector ability to differentiate between two peaks. Equation (3.5) was used to measure the detector separation ability [104]:

$$R = \frac{FWHM}{Ch} \times 100\% \quad (3.5)$$

Where: R: Energy Resolution, FWHM (Full Width at Half Maximum): represents the measurement of the width of the photo peak in the spectrum of a gamma-ray source, Ch: represents the channel number corresponding to the centroid of the gamma peak.

The energy separation capability of the detector NaI(Tl) used in the measurement is (7.9%) with respect to the energy of the element cesium ^{137}Cs that energy 661.66 keV.

3.4.4 Background Radiation Measurement

It is necessary to measure the background radioactivity before starting to measure the radioactivity of the studied samples due to the presence of natural radioactivity in the earth's materials, cosmic rays, synthetic materials in the system, and the walls of the laboratory itself, and this background varies from one place to another. To measure the net radioactivity of the samples studied in the research, the background radioactivity spectrum must be recorded and subtracted from the spectrum of the studied samples. The background radioactivity was measured inside the laboratory by placing an empty one-liter Marinelli container inside the detector, which is the same container used to measure the radioactivity of the samples for a period of time of 14400 sec to collect the spectrum on the calculator screen, which is the same time period used in counting the samples.

3.4.5 Detection Limit

The detection limit (DL) can be defined as the minimum concentration that laboratory devices can measure in the sample to be measured. The minimum detection limit can be calculated based on the background radiation spectrum of the detector. The detection limit can be calculated using the following equation (3.6)[105]. The minimum detection limit for ^{238}U, ^{232}Th, and ^{40}K, as shown in table (3.3).

$$DL = \frac{4.66\sqrt{N}}{\varepsilon\, I_\gamma\, m\, t} \qquad (3.6)$$

Where $\sqrt{N}$: is the background radiation spectrum under the square root of ^{238}U, ^{232}Th, and ^{40}K. m: is the mass of Marinelli Baker 175gm

Table 3.3: Minimum detection limit for ^{238}U, ^{232}Th, and ^{40}K.

Isotopes	DL (Bq/kg)
^{40}K	3.8
^{232}Th	0.7
^{238}U	0.6

3.4.6 Measurement Radioactivity of Samples

After the end of the storage period of the samples, calibration of the detector and recording the background radiation spectrum, the specific activity of the uranium ^{238}U was measured by measuring the specific activity of bismuth ^{214}Bi with an energy of 1764 keV, and also in the thorium series ^{232}Th. The specific activity of the radioactive thallium ^{208}Tl with an energy 2614 keV was measured, which represents the specific activity of ^{232}Th, and then the specific activity of the radioactive potassium ^{40}K with an energy 1460 keV was measured, as the radioactive of any element in the radioactive series that are described as being in a state of delayed equilibrium can be calculated in terms of the radioactive of another element[106], as shown in figure (3.10). Using the NaI(Tl) detector, the natural radioactive of the nuclei emitting gamma rays was measured and the measurement time was (14400) s.

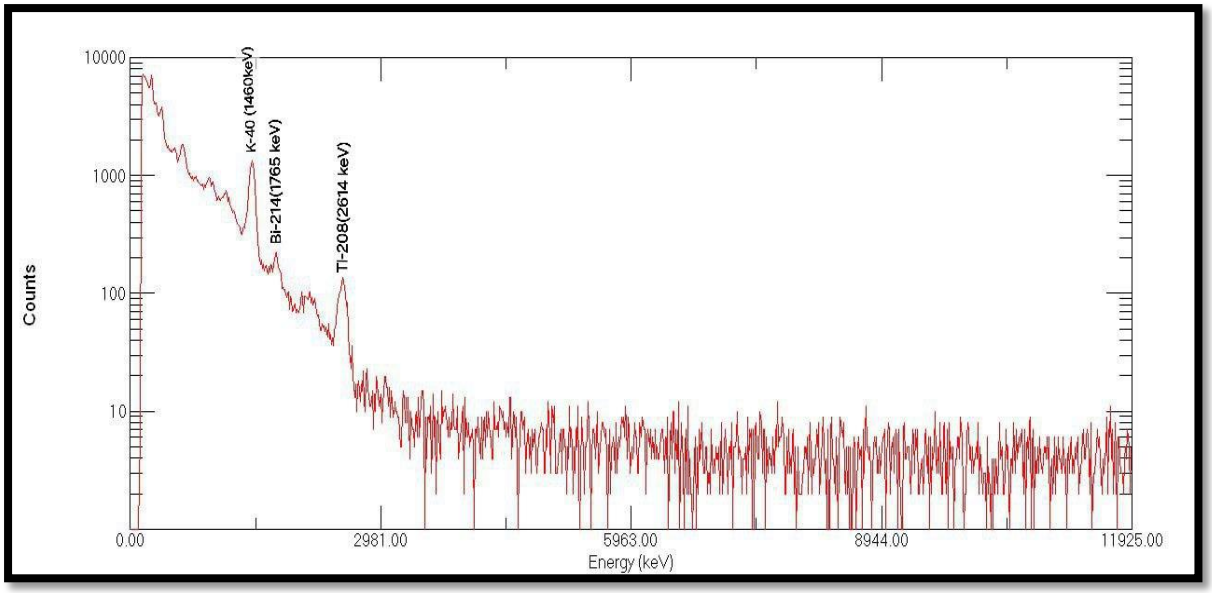

Figure 3.10 Gamma ray spectrum of sample S1.

3.5. Detection Using CR-39 Detector

3.5.1 Samples Preparation

The samples were prepared for testing using a nuclear track detector (CR-39) to determine the concentration of radon. This was done by grinding, sieving, and weighing each soil and plant sample to 35 gm. The samples were then placed in tightly sealed plastic containers with a height of 7 cm. Each sample was labeled with its name and number and stored for 30 days before placing the detector to achieve a secular equilibrium of radium-226 and radon-222. Figure (3.11) shows the process of preparing and storing samples in plastic containers.

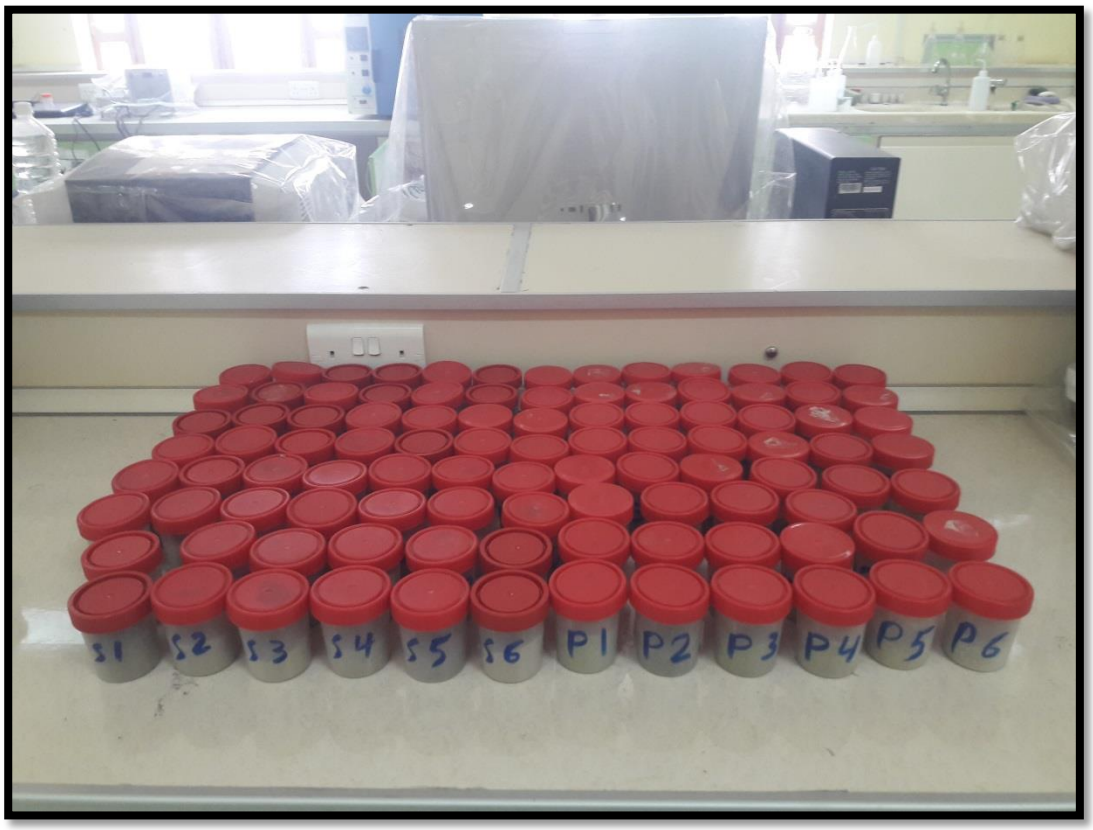

Figure 3.11 Store samples in plastic containers.

3.5.2 Irradiation Process

After 30 days, the plastic container cover was quickly removed to avoid disturbing the radiation balance inside the containers. The CR-39 detector was attached with dimensions of (1.5×1.5) cm^2 by means of adhesive tape in the middle of the bottom of the cover, while the cover was tightly closed and

covered with adhesive tape to prevent radon gas from leaking out. The distance between the detector and the surface of the sample was 3.5 cm, and the height of the sample was 3.5 cm, as shown in figure (3.12). The samples were stored with the detector for 90 days. After the exposure period ended, the detectors were removed to perform the chemical etching process.

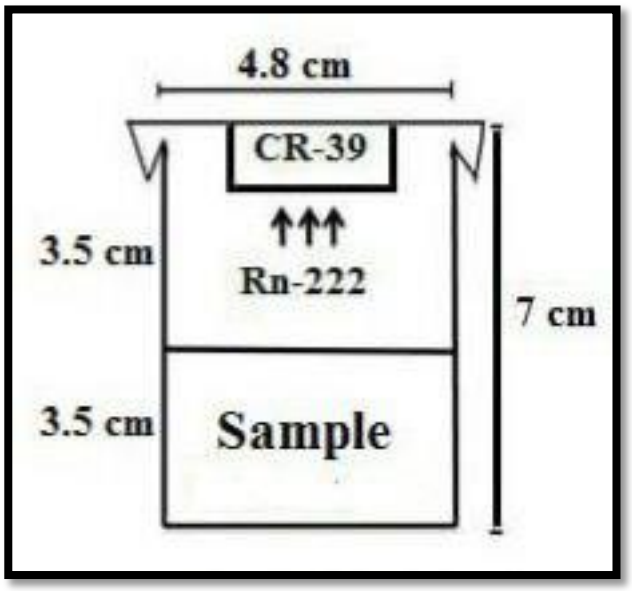

Figure 3.12 Irradiation Process.

3.5.3 The Chemical Etching

The chemical etching of the detectors was carried out using a sodium hydroxide (NaOH) solution with a molarity of 6.25 N, which we obtained by dissolving 100 gm of sodium hydroxide granules in 400 ml of distilled water as in the following equation [107]:

$$W = N \times V \times W(eq) \quad (3.7)$$

Where: W: is the weight of NaOH, $W(\text{eq})$: the molecular weight of NaOH is equal to 40, N: is the molarity = 6.25 N, V: is the volume of distilled water.

The detectors were placed inside the solution in the thermal Pyrex by connecting them with a wire. When the temperature of the water bath reached 70℃, the Pyrex was placed inside the water bath for 6 hours. After that, the detectors were removed from the solution, washed with distilled water, and then dried. Figure 3.13 shows a picture of the water bath.

Figure 3.13 Water Bath.

3.5.4 Counting of Alpha Particles Track

Track of alpha particles generated on the surface of the nuclear detector (CR-39) were counted using an optical microscope (kruss-mbl 2000), as shown in figure (3.14), with a magnification (400X). The detector was divided into 30 viewing areas, and then the traces were counted for different locations for each detector, where 30 attempts were taken for each detector. Figures 3.15 and 3.16 show the effects of alpha particles formed on CR-39 nuclear track detectors in samples S48 and P15.

Figure 3.14 Optical microscope

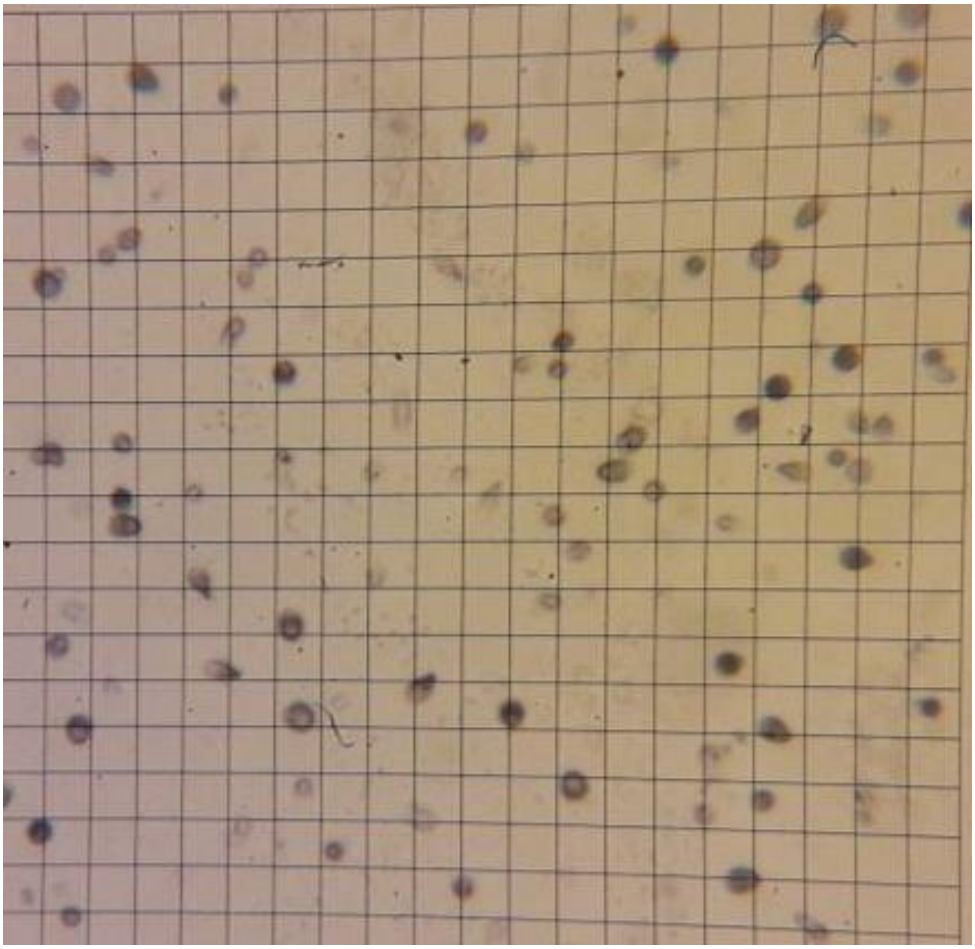

Figure 3.15 The tracks of alpha particles on the surface of the detector in S48 sample.

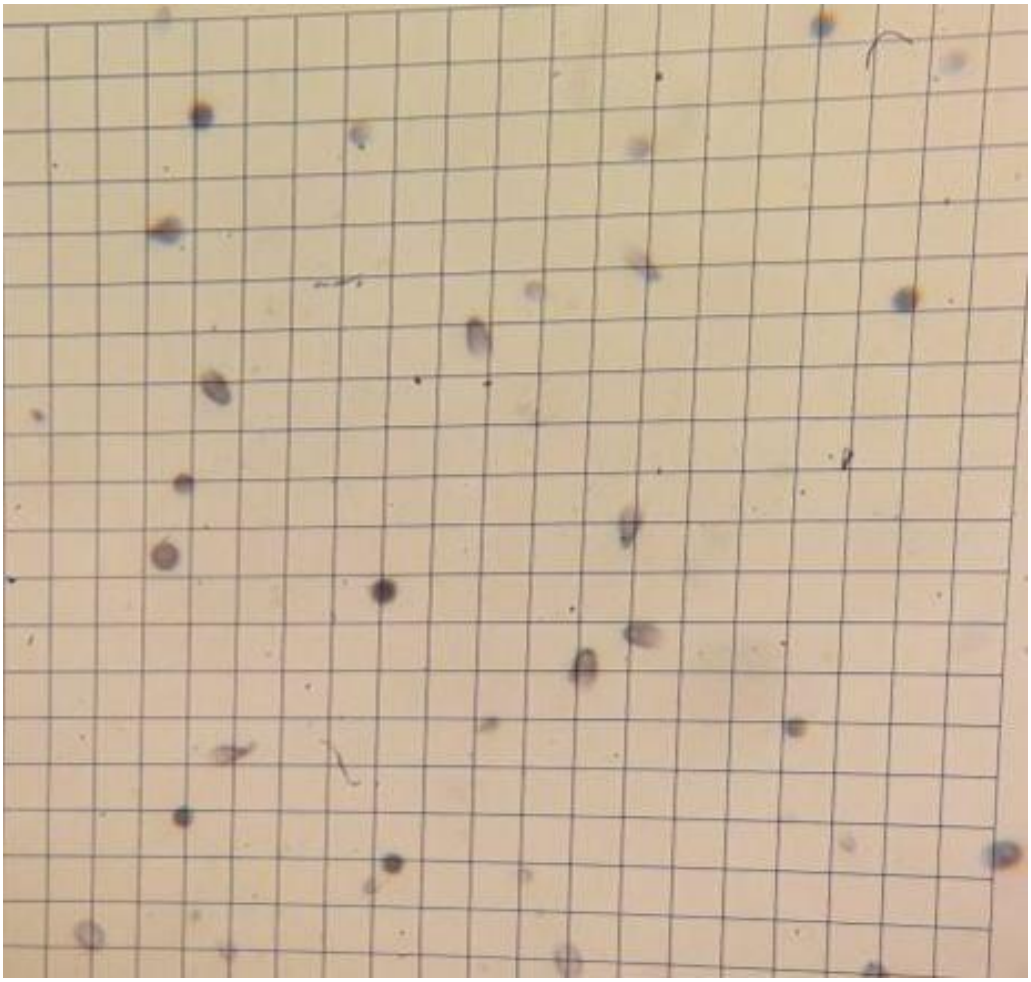

Figure 3.16 The tracks of alpha particles on the surface of the detector in P15 sample.

3.6. Theoretical Calculations for Gamma Emitters

3.6.1 Specific Activity

The activity concentration of the gamma emitting radionuclides in the sample can be calculated from the following equation (3.8) [108,109]:

$$A = \frac{N}{I_\gamma \, \varepsilon \, m \, T} \qquad (3.8)$$

Where: A is the specific activity of the radionuclide in the sample in Bq/kg , N is net area under photo peak, I_γ is the percentage of gamma ray intensity, ε is the efficiency of the gamma-ray detector, m is the mass of sample in Kg, and T is the time for collecting the spectrum in seconds.

3.6.2 External and Internal Hazard Index

The external hazard index (H_{ex}) is used to estimate the biological effected of the natural gamma radiation, and alpha particles emitted by ^{222}Rn when inhaled, along with gamma rays. There is a risk that can be expressed by the internal hazard (H_{in}). The equation of H_{ex} and H_{in} given by the following (3.9), and (3.10) [110,111]:

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3.9)$$

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3.10)$$

A_U, A_{Th} and A_K are the specific activity of ^{238}U, ^{232}Th and ^{40}K, respectively.

3.6.3 Gamma Index (I_γ)

To assess the risk posed by gamma radiation from naturally occurring radionuclides found in the subject under study, the activity concentration index is used. The following formula (3.11) can be used to calculate this index [112]:

$$I_\gamma = \left(\frac{1}{150}\right) A_U + \left(\frac{1}{100}\right) A_{Th} + \left(\frac{1}{1500}\right) A_K \quad (3.11)$$

3.6.4 Alpha Index (I_α)

Alpha index has been created to evaluate the excess alpha radiation because of the radon inhaled breath beginning from building materials. The alpha index was can be calculate by using equation (3.12) [113,114]:

$$I_\alpha = \frac{A_U}{200\ (\frac{Bq}{kg})} \quad (3.12)$$

3.6.5 Radium Equivalent (Ra_{eq})

The radiological hazard associated with samples contained radionuclides, namely ^{238}U,^{232}Th, and ^{40}K, can be assessed using a common radiological index, called radium equivalent activity. It can be expressed mathematically as [115]:

$$Ra_{eq}\left(\frac{Bq}{kg}\right) = A_U + 1.43\ A_{Th} + 0.077 A_K \quad (3.13)$$

3.6.6 Exposure Rate ($\dot{X}$)

To calculate the exposure rate of gamma radiation in air, the equation (3.14) was utilized [116]:

$$\dot{\mathrm{X}} = 1.90\ \mathrm{A_U} + 2.82\ \mathrm{A_{Th}} + 0.197\mathrm{A_K} \quad (3.14)$$

$\dot{X}$ is the exposure rate (μR/h).

3.6.7 Absorbed Dose Rate in Air (D_r)

The absorbed dose rate in the air comes from terrestrial gamma-ray radionuclides. Dose rate measurements are of based on measurements of the specific activity concentrations of radionuclides, particularly ^{238}U, ^{232}Th and ^{40}K, can be calculated from equation (3.15) [117,118]:

$$\mathrm{D_r}\ \left(\frac{\mathrm{nGy}}{\mathrm{h}}\right) = 0.462\ \mathrm{A_U} + 0.604\ \mathrm{A_{Th}} + 0.0417\mathrm{A_K} \quad (3.15)$$

3.6.8 Annual Gonadal Equivalent Dose (AGED)

The annual gonadal equivalent dose can be calculated from equation (3.16) [119,120]:

$$\mathrm{AGED}\ \left(\frac{\mathrm{mSv}}{\mathrm{y}}\right) = 3.09\ \mathrm{A_U} + 4.18\ \mathrm{A_{Th}} + 0.314\mathrm{A_K} \quad (3.16)$$

3.6.9 Annual Effective Dose Equivalent (AEDE)

The United Nations Scientific Committee on the Effects of Ionizing Radiation (UNSCEAR) provides conversions of 0.7 Sv/Gy, which are used to convert the absorbed dose from gamma radiation agents in air into the annual effective dose received by adults. Furthermore, the proportion of time spent outdoors (0.2), and the proportion of time spent indoor (0.8) is taken into account in the calculations. Based on this information, the annual effective outdoor and indoor dose can be determined using the following equation (3.17), (3.18), and (3.19) [121,122]:

$$AEDE_{outdoor}\left(\frac{mSv}{y}\right) = \left[D_r(mGy/h) \times 8760\frac{h}{y} \times 0.2 \times 0.7\ Sv/Gy\right] \times 10^{-6} \quad (3.17)$$

$$AEDE_{indoor}\left(\frac{mSv}{y}\right) = \left[\mathrm{D_r(mGy/h)} \times 8760\ \mathrm{h/y} \times 0.8 \times 0.7\ \mathrm{Sv/Gy}\right] \times 10^{-6} \quad (3.18)$$

(8760), is the number of hours of the year.

$$AEDE = AEDE_{outdoor} + AEDE_{indoor} \quad (3.19)$$

Where: AEDE is the total annual equivalent effective dose

3.6.10 Excess Lifetime Cancer Risk (ELCR)

It is a factor that measures the increased risk of developing lung cancer over a person's lifetime. According to the ICRP (International Commission on Radiological Protection) guidelines. According to the ICRP, the fatal cancer risk ratio for low doses is (0.05 Sv^{-1}), which means that there is a 5% increase in the risk of dying from cancer for a total dose of $(1Sv)$ that a person receives over his lifetime. Therefore, to estimate the cancer risk for an adult, we can use the equation below [123,124]:

$$ELCR = AEDE \times DL \times RF \quad (3.20)$$

Where :AEDE is the total annual effectives dose in mSv/y, DL is the life expectancy, RF = The fatal cancer risk.

3.6.11 Annual Effective Dose (AED)

The annual effective dose in foods can be calculated by using equation (3.21) [125]:

$$AED = A \times I \times CF \quad (3.21)$$

Where A specific activity. CF dose conversion factor equal to 4.5×10^{-7}Sv Bq^{-1} for ^{238}U, 2.30×10^{-7} Sv Bq^{-1} for ^{232}Th and 6.20×10^{-9} Sv Bq^{-1} for ^{40}K [122]. annual consumption rate (I), the values of annual consumption rate of vegetables for human and alfalfa, and barley as food for animals(cow and sheep) in present study were taken from previous studies see table (3.4).

Table 3.4: The values of annual consumption rate.

Sample name		Annual consumption rate (I) kg/y	Ref.
Vegetables for (human)		60	[122]
Alfalfa and Barley	cow	5475	[123]
	sheep	1080	[123]

3.6.12 Hereditary Cancer Risk

To estimate the hereditary cancer risk from the consumption of plants, can be calculated by using equation below [127]:

$$HCR = AED \times DL \times RF \quad (3.22)$$

where :HCR is hereditary cancer risk, AED is the effective dose (Sv/y), DL is life expectancy (70 years for human) (20 years for cow) (5 year for sheep), and RF is risk factor (Sv). For stochastic effects ICRP uses a value of 0.04 for the public as risk factor.

3.7. Theoretical Calculations for Alpha Emitters

The average number of track taken for each sample was calculated and then the density of track was calculated using the equation (3.23) [128]:

$$\rho = \frac{N_{average}}{a} \quad (3.23)$$

Where: ρ is the track density, $N_{average}$ is the track average, a is the area of field view.

3.7.1 Radon Concentration

The ^{222}Rn concentration C_a in the air of the space above the sample were determined by measuring the tracks density on the detector according to the following relation (3.24) [129,130]:

$$C_a\ (Bq/m^3) = \rho\ /kT \quad (3.24)$$

Where ρ is the surface density of tracks on the exposed detectors (Track/cm^2), T is the exposure time, and (k) is the calibration factor, equal (0.223 Tracks.cm^{-2}.day^{-1}/Bq.m^{-3}) [131].

The radon concentration C_s in sample was calculated using the following equation (3.25) [132]:

$$C_s = \frac{C_a \lambda HT}{L} \quad (3.25)$$

Where C_s =radon concentration in sample (Bq/m^3), λ= decay constant for radon (0.1814d^{-1}), H=the distance from the surface of sample to detector, T=time of exposing and L=: thickness of samples in cup.

The activity concentration of ^{222}Rn in sample (C_{Rn}) in unit (Bq/kg) is determined using the following equation (3.26) [133]:

$$C_{Rn} = \frac{C_s \, \mathrm{L} \, \mathrm{A}}{\mathrm{M}} \quad (3.26)$$

Where : A : is the area of the cup, M : The sample's mass.

3.7.2 Radium Concentration

The concentration of radium (^{226}Ra), of samples **(C_{Ra}),** is determine by using the relation (3.27) [134]:

$$C_{Ra}\left(\frac{\mathrm{Bq}}{\mathrm{kg}}\right) = \frac{C_a \mathrm{H} \, \mathrm{A}}{\mathrm{M}} \quad (3.27)$$

3.7.3 Uranium Concentration

To find uranium concentrations (C_U)in units of part per million using the following equation (3.28) [135]:

$$C_U = \frac{W_U}{W_s} \quad (3.28)$$

Where W_s *is* the weight of sample, W_U is uranium weight in sample can calculate from the following equation (3.29) [136]:

$$W_U = \frac{N_U \; W_{mol.}}{N_{Av.}} \quad (3.29)$$

Where

$W_{mol.}$: weight molecular uranium.

N_{av} : number of Avogadro 6.023×10^{23}atom/mol.

N_U: the samples uranium atom number can calculate from equation (3.30):

$$N_U = \frac{A_{Rn}}{\lambda_U} \quad (3.30)$$

Where λ_U is the uranium decay constant equal (4.883×10^{-18} sec^{-1}), A_{Rn} is the activity of radon.

The concentration of uranium to activity unit in $Bq.kg^{-1}$

1 ppm of Uranium = 12.35 $Bq.kg^{-1}$ of ^{238}U

3.7.4 Surface Exhalation Rate (E_s)

The surface exhalation rate of the sample for release of radon can be calculated by using the expression [137]:

$$E_S\left(\frac{Bq}{m^2 d}\right) = \frac{CV\lambda}{A[T-\lambda^{-1}(e^{-\lambda T}-1)]} \quad (3.31)$$

Where C is radon exposure expressed, V is the effective volume of the cup, T is the exposure time, λ is the decay constant for ^{222}Rn radon, and A is the area of the cup.

3.7.5 Mass Exhalation Rate (E_M)

The mass exhalation rate of the sample for the release of the radon can be calculated by using the expression [137]:

$$E_M\left(\frac{Bq}{kg\ d}\right) = \frac{CV\lambda}{M[T-\lambda^{-1}(e^{-\lambda T}-1)]} \quad (3.32)$$

3.7.6 Alpha Index (I_α)

The alpha index has been used as an indicator of the extra alpha radiation exposure resulting from the inhalation can be calculated from the following relation (3.33) [138]:

$$I_\alpha = \frac{C_{Ra}}{200\ Bq\ kg^{-1}} \quad (3.33)$$

3.7.7 Effective Annual Dose (D_{eff})

The effective annual dose of radon can be calculated from [139]:

$$D_{eff}(\frac{mSv}{y}) = C_a \times F \times O \times T \times D \quad (3.34)$$

Where C_a the radon concentration in air space of cup (Bq/m^3), F is a factor of an equilibrium 0.4, O is the factor for occupancy its value 0.8, T (8760 $h.y^{-1}$) in hour is a time of one year, and D is the factor of conversion (9×10^{-6} $mSv.h^{-1}(Bq.m^{-3})^{-1}$)

3.7.8 Excess Lifetime Cancer Risk (ELCR)

The excess lifetime cancer risk is one of the radiologic parameters, which can be determined using the following equation (3.35) [123,124]:

$$ELCR(\frac{mSv}{y}) = D_{eff} \times DL \times RF \quad (3.35)$$

Where DL: the normal duration of life, RF: risk factor (0.05 Sv^{-1})

3.7.9 Annual Average Internal Dose (AD)

As a result of the intake of radionuclides, the annual average internal dose was calculated according to the equation (3.36) [140]:

$$AD(\frac{nSv}{y}) = C \times I \times CF \quad (3.36)$$

where, C is the activity concentration of (radon, radium and Uranium) inside of the ingested sample (Bq/kg) , I represents the rate of consumption within a year (kg/y) which was equal as above table (3.4), and CF represents the effective dose conversion factor of the radioactive element. The effective dose

conversion factor for radon, radium and uranium ingestion are 3.5 nSv/Bq, 280 nSv/Bq, and 45 nSv/Bq, respectively.

3.8 Transfer Factor (TF)

The transfer factor , is a mathematical equation used to represent the uptake of radionuclides by plants from the soil. The transfer factor can be calculated by dividing the activity of dry plant by the activity radionuclides in soil [141].

$$TF = \frac{A_P}{A_S} \tag{3.37}$$

Where A_p The specific activity of plant dry in Bq/kg, and A_s The specific activity of soil dry in Bq/kg.

Chapter Four

Results and Discussion

4.1 Introduction

This chapter includes discussion of the results reached and the most important conclusions by measuring the effectiveness of the gamma ray spectrum using the sodium iodide system activated with thallium NaI(Tl), collecting the spectrum for each soil and plant sample. As well as determining alpha emitters (^{222}Rn, ^{226}Ra, and ^{238}U) for the same samples after irradiation for 90 days using a nuclear trace detector (CR-39).

4.2. Results of Gamma Emitters in Agricultural Soil Samples

The results of activity concentrations for (^{238}U, ^{232}Th, and ^{40}K) in 50 soil samples using the sodium iodide detector NaI(Tl), as well as radiological effects, are listed as follows:

4.2.1 Specific Activity

The results specific activity of the natural radionuclides (^{238}U, ^{232}Th, and ^{40}K) in soil samples are seen in table (4.1), reveals the specific activity of ^{238}U ranged from 2.361±0.655 Bq/kg in sample S12 to 21.284±1.505 Bq/kg in sample S22, with an average value of 10.136±1.040 Bq/kg. The range of specific activity for ^{232}Th was from 3.968±0.392 Bq/kg in sample S25 to 22.340±1.224 Bq/kg in sample S12, with an average value of 10.392 ± 0.654 Bq/kg, while the specific activity for ^{40}K was ranged from 206.509±4.876 Bq/kg in sample S21 to 409.448±6.867 Bq/kg in sample S12, with an average value of 347.777 ±6.151 Bq/kg. All these results of activity concentration in natural radioactivity for the collected agricultural soil samples according to the study were lower than the permissible limits (33, 45, and 420 Bq/kg for ^{238}U, ^{232}Th, and ^{40}K, respectively) as reported by (UNSCEAR, 2008) [142]. Figures 4.1, 4.2, and 4.3 show distribution of specific activity for ^{238}U, ^{232}Th, and ^{40}K in soil samples, respectively.

Table 4.1: The specific activity of (^{238}U, ^{232}Th and ^{40}K) in agricultural soil.

No	Sample code	The specific activity Bq/kg		
		^{238}U	^{232}Th	^{40}K
1	S1	5.889±0.646	9.778±0.503	303.602± 4.828
2	S2	7.308±0.720	9.726±0.502	337.618±5.091
3	S3	15.183±1.038	10.426±0.520	354.049±5.213
4	S4	15.467±1.048	8.766±0.476	370.097±5.330
5	S5	11.494±0.903	7.496±0.440	328.480±5.022
6	S6	16.673±1.088	10.764±0.528	370.174±5.331
7	S7	9.719±0.830	9.440±0.494	356.659±5.233
8	S8	14.544±1.016	9.389±0.493	341.610±5.121
9	S9	9.046±0.981	15.484±0.776	339.883±6.256
10	S10	8.898±1.271	14.625±0.991	320.187±6.072
11	S11	3.995±0.852	12.009±0.898	357.043±6.412
12	S12	2.361±0.655	22.340±1.224	409.448±6.867
13	S13	6.901±1.119	15.028±1.004	381.230±6.626
14	S14	5.266±0.978	14.759±0.995	392.633±6.724
15	S15	6.901±1.119	12.009±0.898	399.658±6.784
16	S16	5.993±1.043	9.258±0.788	359.001±6.430
17	S17	7.990±1.205	8.051±0.735	298.304±5.861
18	S18	8.898±1.271	10.734±0.849	266.631±5.541
19	S19	5.630±1.011	6.910±0.681	334.469±6.206
20	S20	12.345±1.146	9.415±0.605	362.572±6.462
21	S21	5.853±0.789	7.898±0.554	206.509±4.876
22	S22	21.284±1.505	8.442±0.573	372.017±6.545
23	S23	4.363±0.681	12.644±0.701	310.398±5.979
24	S24	12.770±1.165	5.368±0.457	334.699±6.208
25	S25	12.132±1.136	3.968±0.392	326.522±6.132
26	S26	8.407±0.945	7.703±0.547	347.599±6.327
27	S27	10.642±1.064	10.037±0.624	315.004±6.023
28	S28	7.556±0.897	8.209±0.565	360.959±6.447
29	S29	7.237±0.878	9.609±0.611	364.185±6.476
30	S30	12.913±1.354	10.893±0.752	398.046±7.818
31	S31	5.959±0.796	12.293±0.692	277.803±5.656
32	S32	10.429±1.054	7.819±0.552	312.241±5.996
33	S33	13.622±1.204	15.212±0.769	325.255±6.120
34	S34	9.791±1.021	17.507±0.825	395.051±6.745
35	S34	11.174±1.090	8.831±0.586	268.473±5.560
36	S36	13.303±1.189	13.422±0.723	370.519±6.532
37	S37	9.578±1.009	10.777±0.647	313.162±6.005
38	S38	10.536±1.059	15.134±0.767	359.923±6.438
39	S39	7.449±0.890	8.520±0.576	289.436±5.773
40	S40	9.365±0.998	12.955±0.709	380.309±6.618
41	S41	9.897±1.026	9.648±0.613	277.918±5.657
42	S42	10.961±1.080	14.433±0.749	393.208±6.729
43	S43	12.345±1.146	7.859±0.552	386.413±6.671

44	S44	14.686±1.250	6.302±0.495	373.283±6.556
45	S45	12.132±1.136	4.668±0.426	372.938±6.553
46	S46	8.939±0.975	5.563±0.465	394.130±6.737
47	S47	12.770±1.165	12.216±0.689	404.496±6.825
48	S48	14.899±1.259	10.037±0.624	401.962±6.804
49	S49	13.302±1.189	8.131±0.562	380.194±6.617
50	S50	12.025±1.131	7.119±0.526	392.863±6.726
Minimum		**2.361±0.655**	**3.968±0.392**	**206.509±4.876**
Maximum		**21.284±1.505**	**22.340±1.224**	**409.448±6.867**
Average ± S.D		**10.136±1.040**	**10.392±0.654**	**347.777±6.151**
UNSCEAR [142]		**33**	**45**	**420**

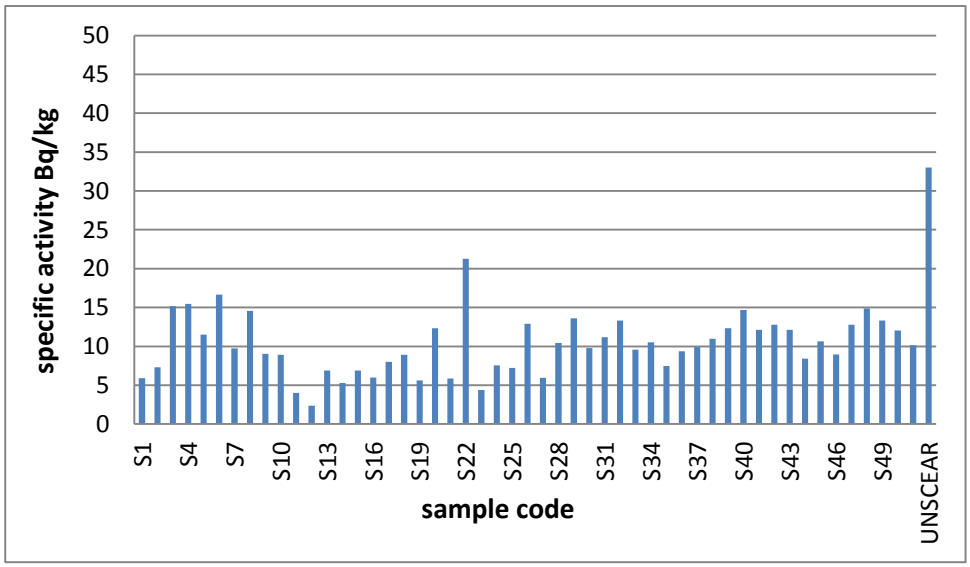

Figure 4.1 Specific activity of ^{238}U in agricultural soil.

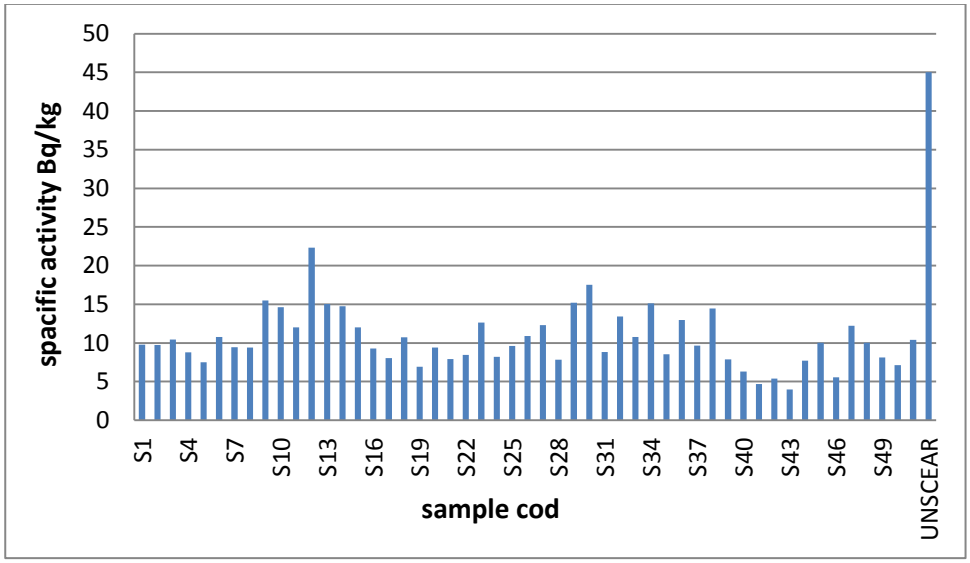

Figure 4.2 Specific activity of ^{232}Th in agricultural soil.

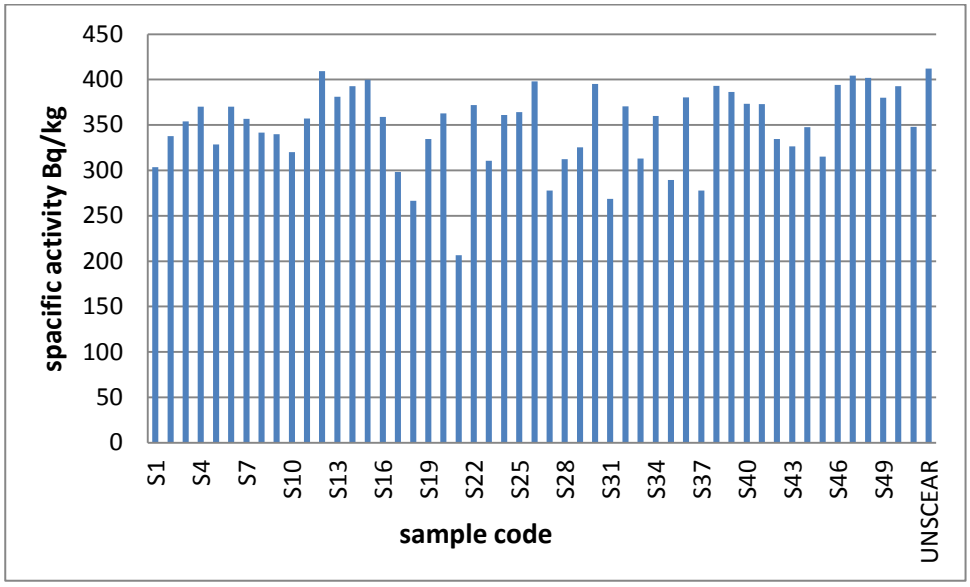

Figure 4.3 Specific activity of ^{40}K in agricultural soil.

4.2.2 Radiological Effects

Table (4.2) show the radium equivalent (R_{eq}), absorbed dose rate in air (D_r), external hazard index (H_{ex}), internal hazard index (H_{in}), gamma index (I_γ), and alpha index (I_α). From table (4.2), we found the value of R_{eq} varied from 33.048 Bq/kg in sample S21 to 65.834 Bq/kg in sample S12, with an average ±S.D of 51.776±7.269 Bq/kg. The radium equivalent index value is well and less the permissible limits of 370 Bq/Kg [143]. Results of D_r varied from 16.085 nGy/h in sample S21 to 31.658 nGy/h in sample S12, with an average ± S.D of 25.461±3.442 nGy/h. Values of D_r in all soil samples were smaller than the value of the world average, which is equal to 55 nGy/h according to UNSCEAR, 2000 [125]. Results of (H_{ex}, H_{in}, I_γ and I_α) varied from 0.089 at sample S21 to 0.177at sample S12 with an average± S.D of 0.139±0.019, varied from 0.105 at S21 to 0.224 at S22 with an average±S.D of 0.166± 0.025, varied from 0.255 at sample S21 to 0.512 at sample S12, with an average±S.D of 0.402±0.054, and varied from 0.011 in sample S12 to 0.106 in sample S22 with an average± S.D of 0.050±0.018, respectively. These values are less than the recommended permissible safety limit values (≤1) [144].

From table (4.3), we found the value of exposure rate ($\dot{X}$) varied from 74.074 μR/h in sample S21 to 148.146 μR/h in sample S12, with an average± S.D of 117.078±15.757 μR/h. Values of annual gonadal equivalent dose (AGED) varied from 115.942 mSv/y in sample S21 to 229.243 mSv/y in sample S12, with an average±S.D of 183.964±24.541 mSv/y. These calculated values of AGED in all soil samples are less than the worldwide average values ≤300 mSv/y [145]. The average value of annual effective dose equivalent ($AEDE_{outdoor}$, $AEDE_{indoor}$, and $AEDE_{total}$) is 0.030±0.004 mSv/y, 0.124±0.016 mSv/y, 0.155±0.021 mSv/y, respectively. These values are lower than the corresponding worldwide values of (0.08, 0.42, and 0.50) mSv/y, respectively [146]. Results of excess lifetime cancer risk (ELCR) varied from 0.345 $\times 10^{-3}$ in sample S21 to 0.679×10^{-3} in sample S12, with an average ± S.D of $(0.545 \pm 0.073)\times10^{-3}$. These values of ELCR are less than the comparable worldwide values (1.45×10^{-3}) [145].

Table 4.2: Radium equivalent (Ra_{eq}), absorbed dose rate (D_r), internal hazard index (H_{in}), external hazard index(H_{ex}), gamma index (I_γ), and alpha index (I_α) in agricultural soil.

No	Sample code	Ra_{eq} Bq/kg	D_r nGy/h	H_{ex}	H_{in}	I_γ	I_α
1	S1	43.248	21.286	0.116	0.132	0.339	0.029
2	S2	47.212	23.329	0.127	0.147	0.371	0.036
3	S3	57.354	28.075	0.154	0.195	0.441	0.075
4	S4	56.500	27.873	0.152	0.194	0.437	0.077
5	S5	47.505	23.534	0.128	0.159	0.370	0.057
6	S6	60.568	29.640	0.163	0.208	0.465	0.083
7	S7	50.683	25.065	0.136	0.163	0.396	0.048
8	S8	54.274	26.635	0.146	0.185	0.418	0.072
9	S9	57.358	27.704	0.154	0.179	0.441	0.045
10	S10	54.466	26.296	0.147	0.171	0.419	0.044
11	S11	48.660	23.987	0.131	0.142	0.384	0.019
12	S12	65.834	31.658	0.177	0.184	0.512	0.011
13	S13	57.745	28.162	0.155	0.174	0.450	0.034
14	S14	56.604	27.720	0.152	0.167	0.444	0.026
15	S15	54.847	27.107	0.148	0.166	0.432	0.034
16	S16	46.875	23.330	0.126	0.142	0.371	0.029
17	S17	42.472	20.993	0.114	0.136	0.332	0.039
18	S18	44.778	21.712	0.120	0.144	0.344	0.044
19	S19	41.265	20.722	0.111	0.126	0.329	0.028

20	S20	53.726	26.509	0.145	0.178	0.418	0.061
21	S21	33.048	16.085	0.089	0.105	0.255	0.029
22	S22	62.002	30.445	0.167	0.224	0.474	0.106
23	S23	46.344	22.596	0.125	0.136	0.362	0.021
24	S24	46.219	23.099	0.124	0.159	0.361	0.063
25	S25	42.948	21.617	0.115	0.148	0.338	0.060
26	S26	46.187	23.031	0.124	0.147	0.364	0.042
27	S27	49.250	24.114	0.133	0.161	0.381	0.053
28	S28	47.088	23.501	0.127	0.147	0.373	0.037
29	S29	49.020	24.333	0.132	0.151	0.387	0.036
30	S30	59.139	29.143	0.159	0.194	0.460	0.064
31	S31	44.930	21.763	0.121	0.137	0.347	0.029
32	S32	45.654	22.561	0.123	0.151	0.355	0.052
33	S33	60.419	29.044	0.163	0.199	0.459	0.068
34	S34	65.244	31.571	0.176	0.202	0.503	0.048
35	S34	44.475	21.691	0.120	0.150	0.341	0.055
36	S36	61.026	29.703	0.164	0.200	0.469	0.066
37	S37	49.101	23.992	0.132	0.158	0.380	0.047
38	S38	59.891	29.017	0.161	0.190	0.461	0.052
39	S39	41.919	20.657	0.113	0.133	0.327	0.037
40	S40	57.174	28.010	0.154	0.179	0.445	0.046
41	S41	45.094	21.989	0.121	0.148	0.347	0.049
42	S42	61.878	30.178	0.167	0.196	0.479	0.054
43	S43	53.336	26.563	0.144	0.177	0.418	0.061
44	S44	52.441	26.157	0.141	0.181	0.409	0.073
45	S45	47.524	23.976	0.128	0.161	0.376	0.060
46	S46	47.243	23.925	0.127	0.151	0.377	0.044
47	S47	61.385	30.145	0.165	0.200	0.476	0.063
48	S48	60.203	29.707	0.162	0.202	0.467	0.074
49	S49	54.205	26.911	0.146	0.182	0.423	0.066
50	S50	52.457	26.238	0.141	0.174	0.413	0.060
Minimum		**33.048**	**16.085**	**0.089**	**0.105**	**0.255**	**0.011**
Maximum		**65.834**	**31.658**	**0.177**	**0.224**	**0.512**	**0.106**
Average ±S.D		**51.776 ±7.269**	**25.461 ±3.442**	**0.139 ±0.019**	**0.166 ±0.025**	**0.402 ±0.054**	**0.050 ±0.018**
Worldwide average		**<370 [143]**	**<55 [125]**	**≤1 [144]**	**≤1 [144]**	**≤1 [144]**	**≤1 [144]**

Table 4.3: Exposure rate ($\dot{X}$), annual gonadal equivalent dose (AGED), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR) in agricultural soil**.**

No	Sample Code	$\dot{X}$ μR/h	AGED mSv/y	$AEDE_{outdoor}$ mSv/y	$AEDE_{indoor}$ mSv/y	AEDE mSv/y	ELCR $\times 10^{-3}$
1	S1	98.572	154.399	0.026	0.104	0.130	0.456
2	S2	107.822	169.247	0.028	0.114	0.143	0.500
3	S3	127.997	201.668	0.034	0.137	0.172	0.602
4	S4	127.017	200.646	0.034	0.136	0.170	0.598
5	S5	107.685	169.989	0.028	0.115	0.144	0.505
6	S6	134.955	212.745	0.036	0.145	0.181	0.636
7	S7	115.352	181.488	0.030	0.122	0.153	0.537
8	S8	121.408	191.453	0.032	0.130	0.163	0.571
9	S9	127.808	199.397	0.033	0.135	0.169	0.594
10	S10	121.225	189.166	0.032	0.128	0.161	0.564
11	S11	111.793	174.653	0.029	0.117	0.147	0.514
12	S12	148.146	229.243	0.038	0.155	0.194	0.679
13	S13	130.593	203.847	0.034	0.138	0.172	0.604
14	S14	128.974	201.251	0.033	0.135	0.169	0.594
15	S15	125.710	197.014	0.033	0.132	0.166	0.581
16	S16	108.217	169.943	0.028	0.114	0.143	0.500
17	S17	96.650	152.009	0.025	0.102	0.128	0.450
18	S18	99.702	156.085	0.026	0.106	0.133	0.465
19	S19	96.073	151.303	0.025	0.101	0.127	0.444
20	S20	121.432	191.347	0.032	0.130	0.162	0.568
21	S21	74.074	115.942	0.019	0.078	0.098	0.345
22	S22	137.534	217.870	0.037	0.149	0.186	0.653
23	S23	105.094	163.799	0.027	0.110	0.138	0.484
24	S24	105.340	166.998	0.028	0.113	0.141	0.495
25	S25	98.566	156.603	0.026	0.106	0.132	0.463
26	S26	106.173	167.323	0.028	0.112	0.141	0.494
27	S27	110.581	173.751	0.029	0.118	0.147	0.517
28	S28	108.614	171.002	0.028	0.115	0.144	0.504
29	S29	112.592	176.882	0.029	0.119	0.149	0.522
30	S30	133.667	210.419	0.035	0.142	0.178	0.625
31	S31	100.719	157.033	0.026	0.106	0.133	0.467
32	S32	103.378	162.956	0.027	0.110	0.138	0.484
33	S33	132.853	207.806	0.035	0.142	0.178	0.623
34	S34	145.797	227.479	0.038	0.154	0.193	0.677
35	S34	99.024	155.744	0.026	0.106	0.133	0.465
36	S36	136.117	213.552	0.036	0.145	0.182	0.637

37	S37	110.280	172.974	0.029	0.117	0.147	0.514
38	S38	133.600	208.830	0.035	0.142	0.177	0.622
39	S39	95.199	149.515	0.025	0.101	0.126	0.443
40	S40	129.248	202.507	0.034	0.137	0.171	0.601
41	S41	100.762	158.178	0.026	0.107	0.134	0.471
42	S42	138.991	217.670	0.037	0.148	0.185	0.647
43	S43	121.740	192.329	0.032	0.130	0.162	0.570
44	S44	119.213	188.935	0.032	0.128	0.160	0.561
45	S45	109.685	174.105	0.029	0.117	0.147	0.514
46	S46	110.317	174.634	0.029	0.117	0.146	0.513
47	S47	138.398	217.535	0.036	0.147	0.184	0.646
48	S48	135.800	214.210	0.036	0.145	0.182	0.637
49	S49	123.102	194.474	0.033	0.132	0.165	0.577
50	S50	120.319	190.277	0.032	0.128	0.160	0.563
Minimum		**74.074**	**115.942**	**0.019**	**0.078**	**0.098**	**0.345**
Maximum		**148.146**	**229.243**	**0.038**	**0.155**	**0.194**	**0.679**
Average ±S.D		**117.078 ±15.757**	**183.964 ±24.541**	**0.030 ±0.004**	**0.124 ±0.016**	**0.155 ±0.021**	**0.545 ±0.073**
Worldwide average		**---------**	**≤ 300 [145]**	**0.08 [146]**	**0.42 [146]**	**0.50 [146]**	**1.45 [145]**

4.3. Results of Gamma Emitters in Plant Samples

The results of activity concentrations for natural radioactivity (^{238}U, ^{232}Th, and ^{40}K) in 50 plant samples using the sodium iodide detector NaI(Tl), as well as radiological effects, are listed as follows:

4.3.1 Specific Activity

The results specific activity of the natural radionuclides (^{238}U, ^{232}Th, and ^{40}K) in plant samples are seen in table (4.4), the specific activity for ^{238}U varied from BDL in sample P1, P3, P7, P8, P9, P12, P20, P22, P23, p25, P26, p28, P29, P30, P34, P37, P38, and P44 to 4.363 ±0.681 Bq/kg in sample P24, with an average value of 2.235±0.489 Bq/kg. The specific activity for ^{232}Th ranged from BDL in sample P4, P9, P12, P16, P23, P25, p29, p30, P36, and P 45 to 9.661±0.805 Bq/kg in sample P15, with an average value of 3.158±0.336 Bq/kg, while the specific activity in ^{40}K ranged from 131.837± 3.182 Bq/kg in sample P7 to 370.289±6.530 Bq/kg in sample P48, with an average value of 247.593±5.147 Bq/kg. All these results of activity concentration in natural

radioactivity for the collected plant samples according to the study were lower than the permissible limits (33, 45, and 420 Bq/kg for ^{238}U, ^{232}Th, and ^{40}K, respectively) as reported by (UNSCEAR, 2008) [142].

The amounts of natural radioactivity of plant samples in the present study varied according to the nature of the soil in which these plants grow, such as the type of soil, the geological nature of the soil, and the amount of chemical fertilizers used for the plants. Figures 4.4, 4.5, and 4.6 show distribution of specific activity for ^{238}U, ^{232}Th, and ^{40}K in plant samples, respectively.

Table 4.4: The Specific Activity of (^{238}U, ^{232}Th and ^{40}K) in plant.

No	Sample code	The specific activity Bq/kg		
		^{238}U	^{232}Th	^{40}K
1	P1	BDL	3.443±0.259	235.303±3.681
2	P2	4.310±0.479	3.054±0.244	303.545±4.181
3	P3	BDL	1.284±0.158	339.709±4.423
4	P4	4.204±0.473	BDL	308.613±4.216
5	P5	1.489±0.282	0.992±0.139	143.797±2.878
6	P6	1.224±0.255	2.996±0.241	234.669±3.676
7	P7	BDL	4.435±0.339	131.837±3.182
8	P8	BDL	0.026±0.026	278.187±4.622
9	P9	BDL	BDL	219.294±5.026
10	P10	2.724±0.703	5.166±0.589	215.378±4.980
11	P11	0.908±0.406	1.073±0.268	290.832±7.583
12	P12	BDL	BDL	299.456±5.872
13	P13	2.361±0.655	6.508±0.661	300.915±7.713
14	P14	0.363±0.257	2.952±0.445	266.515±5.540
15	P15	0.908±0.406	9.661±0.805	278.724±5.665
16	P16	1.634±0.545	BDL	220.560±5.040
17	P17	3.087±0.749	5.635±0.615	174.260±4.480
18	P18	3.269±0.770	1.208±0.285	199.599±4.794
19	P19	2.724±0.703	4.495±0.549	254.537±5.414
20	P20	BDL	1.712±0.258	242.674±5.286
21	P21	1.453±0.514	0.470±0.177	160.093 ±4.294
22	P22	BDL	4.707±0.428	238.758±5.243
23	P23	BDL	BDL	300.492±5.882
24	P24	4.363±0.681	0.077±0.055	308.670±5.962
25	P25	BDL	BDL	277.803±5.656
26	P26	BDL	1.672±0.255	267.207±5.547
27	P27	1.277±0.368	3.267±0.356	243.020±5.290

28	P28	BDL	3.774±0.383	301.529±5.893
29	P29	BDL	BDL	249.009±5.355
30	P30	BDL	BDL	229.775±5.144
31	P31	2.128±0.476	5.058±0.444	174.721±4.485
32	P32	3.193±0.583	2.723±0.325	201.902±4.822
33	P33	2.554±0.521	6.614±0.507	163.549±4.340
34	P34	BDL	5.836±0.476	246.475±5.328
35	P35	1.596±0.412	1.167±0.213	140.398± 4.021
36	P36	1.916±0.452	BDL	224.016±5.079
37	P37	BDL	3.813±0.385	188.081±4.654
38	P38	BDL	5.369±0.457	225.052±5.091
39	P39	1.383±0.384	4.085±0.399	150.419±4.162
40	P40	1.489±0.398	3.696±0.379	209.273±4.909
41	P41	1.064±0.337	0.195±0.089	176.218±4.505
42	P42	1.916±0.452	3.424±0.365	259.144± 5.463
43	P43	2.979±0.563	0.467±0.135	332.857±6.191
44	P44	BDL	0.350±0.116	295.194±5.830
45	P45	0.212±0.150	BDL	272.389±5.601
46	P46	0.532±0.237	0.894±0.186	291.393±5.793
47	P47	3.511±0.611	1.206±0.216	360.729±6.445
48	P48	4.256±0.673	3.229±0.354	370.289±6.530
49	P49	3.405±0.602	5.018±0.441	282.179±5.700
50	P50	3.086±0.573	4.590±0.422	300.607±5.884
Minimum		**BDL**	**BDL**	**131.837±3.182**
Maximum		**4.363±0.681**	**9.661±0.805**	**370.289±6.530**
Average ± S.D		**2.235±0.489**	**3.158±0.336**	**247.593±5.147**
UNSCEAR [142]		**33**	**45**	**420**

BDL: Below Detection Limit.

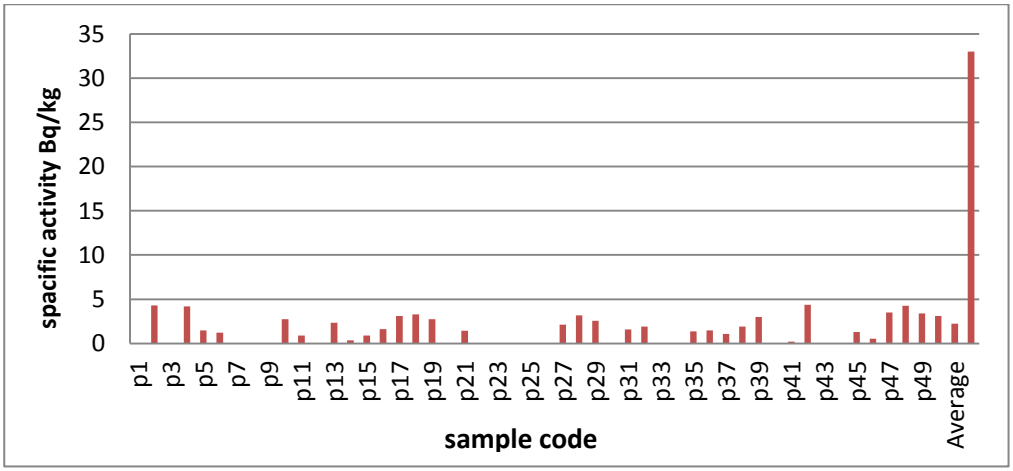

Figure 4.4 Specific activity of ^{238}U in plant samples.

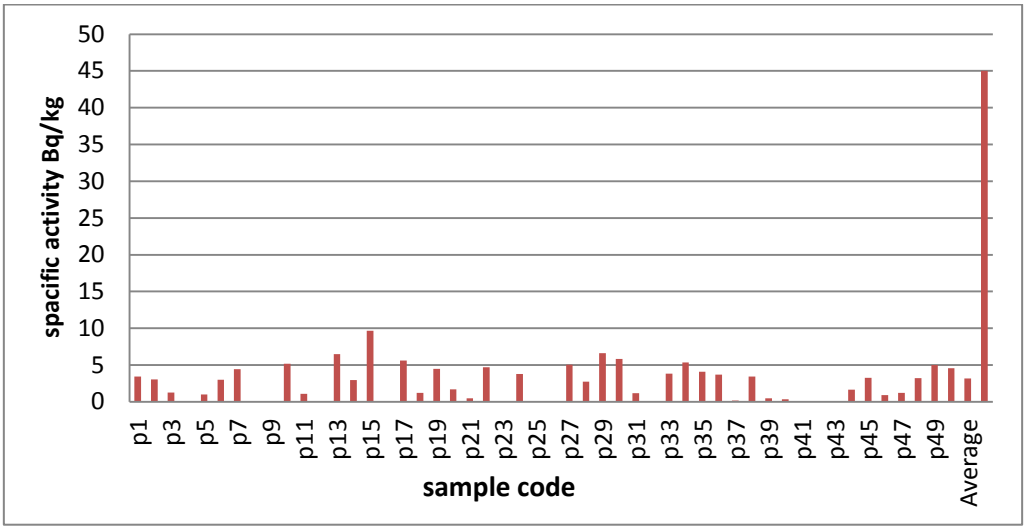

Figure 4.5 Specific activity of ^{232}Th in plant samples.

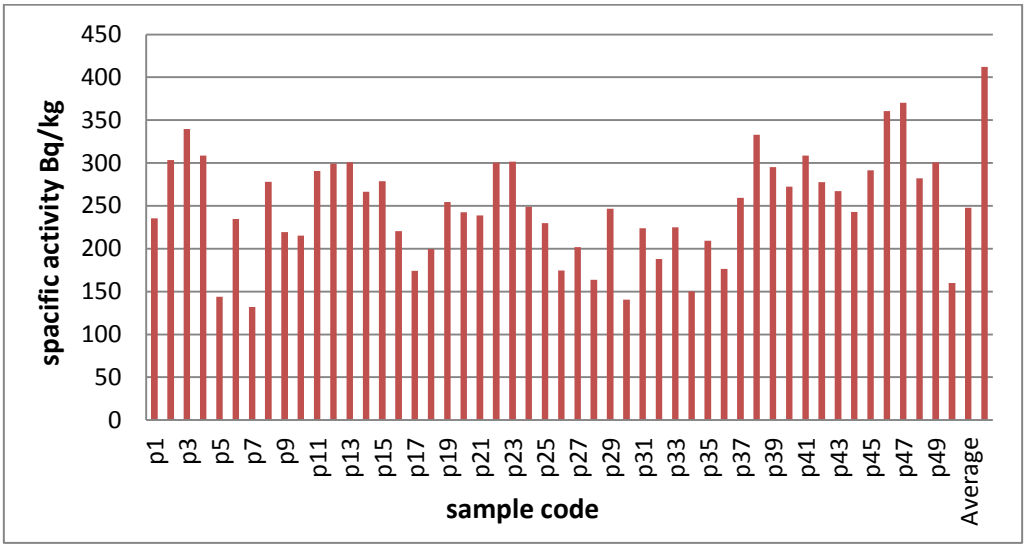

Figure 4.6 Specific activity of ^{40}K in plant samples.

Figures 4.7, 4.8, and 4.9 show the correlation between specific activity in plant and soil for ^{238}U (R^2 =0.1288), and for ^{232}Th (R^2 =0.2391), and for ^{40}K (R^2 = 0.3981). It is observed that the correlation between specific activity in soil and plant samples is weak.

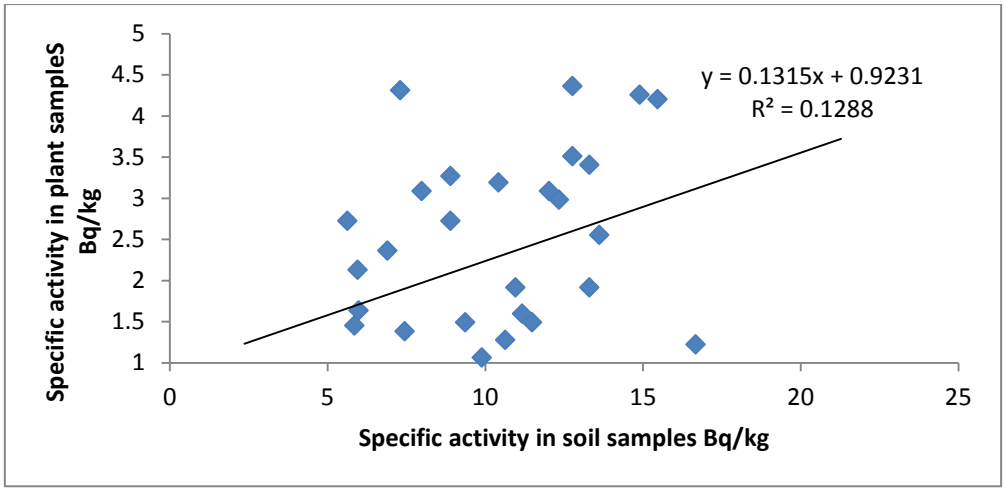

Figure 4.7 Correlation between specific activity in plant and soil samples for ^{238}U

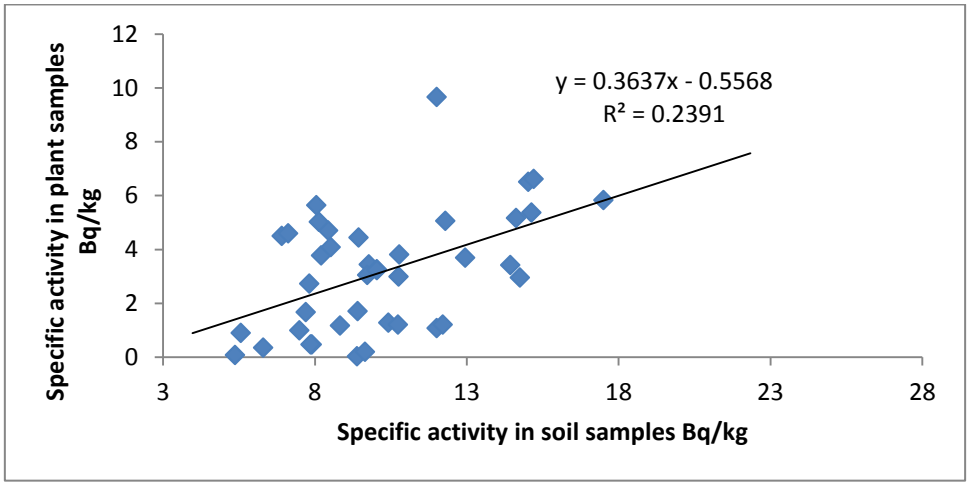

Figure 4.8 Correlation between specific activity in plant and soil samples for ^{232}Th

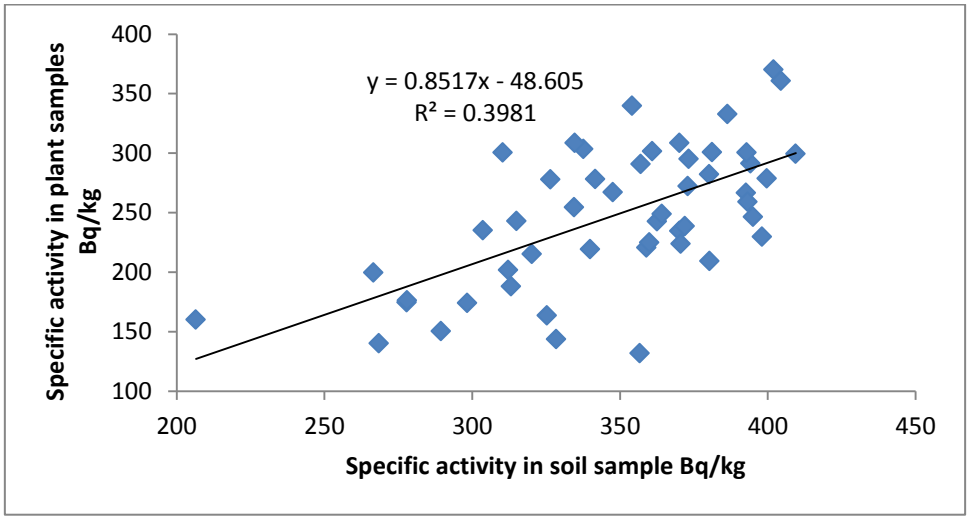

Figure 4.9 Correlation between specific activity in plant and soil samples for ^{40}K

4.3.2 Radiological Effects

The results of radium equivalent (R_{eq}), absorbed dose rate in air (D_r), exposure rate ($\dot{X}$), and annual gonadal equivalent dose (AGED) in plant samples are seen in table (4.5). From table (4.5), we found the minimum value of R_{eq} was 13.980 Bq/kg in sample P5, while the maximum value was 37.386 Bq/kg in sample P48, with an average±S.D value of 24.108±5.678 Bq/kg. The radium equivalent index value is well and less the permissible limits of 370 Bq/Kg [143]. Results of D_r found ranged from 7.283 nGy/h in sample P5 to 19.358 nGy/h in sample P48, with an average±S.D value of 12.511±2.845 nGy/h. These values of D_r in all plant samples were smaller than the value of the world average, which is equal to 55 nGy/h according to UNSCEAR, 2000 [125]. Results of exposure rate ranged from a minimum value 33.956 µR/h in sample P5 to a maximum value of 90.140 µR/h in sample P48, with an average ±S.D value of 58.619±13.236 µR/h. For AGED, values ranged from 53.902 mSv/y in sample P5 to 142.921 mSv/y in sample P48, with an average±S.D value of 92.726±20.864 mSv/y. These calculated values of AGED in all soil samples are less than the worldwide average values of ≤300 mSv/y [145].

From table (4.6), values of external hazard index (H_{ex}), internal hazard index (H_{in}), gamma index (I_γ), and alpha index (I_α) ranged from 0.037 in sample P5 to 0.100 in sample P48, with an average±S.D value of 0.064±0.015, from 0.041 in sample P5 to 0.112 in sample P48, with an average±S.D value of 0.068±0.017, from 0.115 in sample P5and P35 to 0.307 in sample P48, with an

average±S.D value of 0.199±0.045, and from BDL in sample P1, P3, P7, P8, P9, P12, P20, P22, P23, P25, P26, P28, P29, P30, P32, P30, P34, P37, p38, and P44 to 0.021 in sample P2, P4, P24, and P48, with an average ±S.D value of 0.010±0.006, respectively. These resulted values are less than the recommended permissible safety limit values (≤1) [144].

Table 4.5: Radium equivalent (Ra_{eq}) , absorbed dose rate (D_r) , exposure rate ($\dot{X}$), and annual gonadal equivalent dose (AGED) in plant samples.

No	Sample code	Ra_{eq} Bq/kg	D_r nGy/h	$\dot{X}$ µR/h	AGED mSv/y
1	P1	23.041	11.891	56.064	88.277
2	P2	32.050	16.493	76.599	121.396
3	P3	27.993	14.941	70.543	112.035
4	P4	27.966	14.811	68.783	109.893
5	P5	13.980	7.283	33.956	53.902
6	P6	23.577	12.160	57.003	89.989
7	P7	16.493	8.176	38.478	59.935
8	P8	21.457	11.616	54.875	87.459
9	P9	16.885	9.144	43.200	68.858
10	P10	26.695	13.360	62.173	97.639
11	P11	24.836	13.195	62.044	98.612
12	P12	23.058	12.487	58.992	94.029
13	P13	34.837	17.569	82.118	128.986
14	P14	25.106	13.064	61.517	97.147
15	P15	36.185	17.877	83.877	130.708
16	P16	18.617	9.952	46.555	74.305
17	P17	24.563	12.096	56.085	87.810
18	P18	20.365	10.563	48.938	77.824
19	P19	28.751	14.587	67.995	107.131
20	P20	21.133	11.153	52.634	83.355
21	P21	14.452	7.631	35.624	56.723
22	P22	25.116	12.799	60.310	94.647
23	P23	23.137	12.530	59.197	94.354
24	P24	28.242	14.934	69.317	110.730
25	P25	21.390	11.584	54.727	87.230
26	P26	22.967	12.152	57.357	90.895
27	P27	24.662	12.697	59.517	93.914
28	P28	28.614	14.853	70.043	110.454
29	P29	19.173	10.383	49.054	78.188

30	P30	17.692	9.581	45.265	72.149
31	P31	22.814	11.323	52.726	82.579
32	P32	22.633	11.539	53.520	84.646
33	P33	24.605	11.994	55.722	86.892
34	P34	27.323	13.802	65.012	101.786
35	P35	14.076	7.297	33.982	53.896
36	P36	19.164	10.226	47.770	76.260
37	P37	19.934	10.145	47.803	74.994
38	P38	25.006	12.627	59.475	93.108
39	P39	18.807	9.378	43.780	68.581
40	P40	22.889	11.647	54.480	85.764
41	P41	14.911	7.957	37.285	59.434
42	P42	26.765	13.759	64.345	101.601
43	P43	29.277	15.538	72.550	115.676
44	P44	23.230	12.521	59.140	94.154
45	P45	21.186	11.456	54.065	86.188
46	P46	24.248	12.937	60.938	96.882
47	P47	33.012	17.393	81.137	129.162
48	P48	37.386	19.358	90.140	142.921
49	P49	32.310	16.371	76.212	120.105
50	P50	32.797	16.733	78.029	123.116
Minimum		**13.980**	**7.283**	**33.956**	**53.902**
Maximum		**37.386**	**19.358**	**90.140**	**142.921**
Average ±S.D		**24.108±5.678**	**12.511±2.845**	**58.619±13.236**	**92.726±20.864**
Worldwide average		**<370 [143]**	**<55 [125]**	**---------**	**≤300 [145]**

Table 4.6: External hazard index (H_{ex}), internal hazard index (H_{in}), gamma index (I_{γ}), and alpha index (I_{α}) in plant samples.

No	Sample Code	H_{ex}	H_{in}	I_{γ}	I_{α}
1	P1	0.062	0.062	0.191	BDL
2	P2	0.086	0.098	0.261	0.021
3	P3	0.075	0.075	0.239	BDL
4	P4	0.075	0.086	0.233	0.021
5	P5	0.037	0.041	0.115	0.007
6	P6	0.063	0.066	0.194	0.006
7	P7	0.044	0.044	0.132	BDL
8	P8	0.057	0.057	0.185	BDL
9	P9	0.045	0.045	0.146	BDL
10	P10	0.072	0.079	0.213	0.013
11	P11	0.067	0.069	0.210	0.004
12	P12	0.062	0.062	0.199	BDL
13	P13	0.094	0.100	0.281	0.011
14	P14	0.067	0.068	0.209	0.001
15	P15	0.097	0.100	0.288	0.004
16	P16	0.050	0.054	0.157	0.008
17	P17	0.066	0.074	0.193	0.015
18	P18	0.054	0.063	0.166	0.016
19	P19	0.077	0.084	0.232	0.013
20	P20	0.057	0.057	0.178	BDL
21	P21	0.039	0.042	0.121	0.007
22	P22	0.067	0.067	0.206	BDL
23	P23	0.062	0.062	0.200	BDL
24	P24	0.076	0.088	0.235	0.021
25	P25	0.057	0.057	0.185	BDL
26	P26	0.062	0.062	0.194	BDL
27	P27	0.066	0.070	0.203	0.006
28	P28	0.077	0.077	0.238	BDL
29	P29	0.051	0.051	0.166	BDL
30	P30	0.047	0.047	0.153	BDL
31	P31	0.061	0.067	0.181	0.010
32	P32	0.061	0.069	0.183	0.015
33	P33	0.066	0.073	0.192	0.012
34	P34	0.073	0.073	0.222	BDL
35	P35	0.038	0.042	0.115	0.007
36	P36	0.051	0.056	0.162	0.009

37	P37	0.053	0.053	0.163	BDL
38	P38	0.067	0.067	0.203	BDL
39	P39	0.050	0.054	0.150	0.006
40	P40	0.061	0.065	0.186	0.007
41	P41	0.040	0.043	0.126	0.005
42	P42	0.072	0.077	0.219	0.009
43	P43	0.079	0.087	0.246	0.014
44	P44	0.062	0.062	0.200	BDL
45	P45	0.057	0.057	0.183	0.001
46	P46	0.065	0.066	0.206	0.002
47	P47	0.089	0.098	0.275	0.017
48	P48	0.100	0.112	0.307	0.021
49	P49	0.087	0.096	0.261	0.017
50	P50	0.088	0.096	0.266	0.015
Minimum		**0.037**	**0.041**	**0.115**	**BDL**
Maximum		**0.100**	**0.112**	**0.307**	**0.021**
Average ± S.D		**0.064±0.015**	**0.068±0.017**	**0.199±0.045**	**0.010±0.006**
Worldwide average		**≤1[144]**	**≤1[144]**	**≤1[144]**	**≤1[144]**

Table (4.7) shows results of health impacts annual effective dose (AED), hereditary cancer risk (HCR), and excess lifetime cancer risk (ELCR) in vegetable samples for human. The (AED) for ^{238}U ranged from BDL in sample P8, P12, P20, P22, P25, P29, P30, P34, and P44 to 0.114 mSv/y in sample p48, with an average value of 0.071±0.030 mSv/y. (AED) for ^{232}Th was ranged from BDL in sample P4, P12, P25, P29, P30, and P36 to 0.133 mSv/y in sample P15, with an average value of 0.046±0.039 mSv/y, while (AED) for ^{40}K ranged from 0.053 in sample P5 mSv/y to 0.137 mSv/y in sample P48, with an average value of 0.096±0.021mSv/y. Results of (AED_{Total}) ranged from 0.085mSv/y in sample P30 to 0.297 mSv/y in sample P48, with an average value of 0.166±0.070 mSv/y. It is noted that values are less than 0.32 mSv/y recommended by (UNSCEAR, 2008) [142]. The minimum value of (HCR) was 0.239×10^{-3} in sample P30, while the maximum value was 0.832×10^{-3} in sample P48, with an average value of $(0.466\pm 0.198)\times10^{-3}$. The values of (ELCR) ranged from 0.299×10^{-3} in sample P30 to 1.040×10^{-3} in sample P48, with an average value of $(0.582\pm0.248)\times10^{-3}$. These results of

(ELCR) for all vegetable samples in the present study are less than the worldwide value of 1.45×10^{-3} [145].

Table (4.8) shows the results of annual effective dose (AED), hereditary cancer risk (HCR), and excess lifetime cancer risk (ELCR) in alfalfa, and barley samples as food for cow. From this table, (AED) for ^{238}U ranged from BDL in samples P1, P3, P7, P9, P23, P26, P28, P37, and P38 to 10.750 mSv/y in sample P24, with an average value of 5.150±2.920 mSv/y. (AED) for ^{232}Th ranged from BDL in samples P9, P16, P23, and P45 to 8.195 mSv/y in sample P13, with an average value of 3.836±2.284 mSv/y, while (AED) for ^{40}K ranged from 4.475 mSv/y in sample P7 to 11.531 mSv/y in sample P3, with an average value of 8.122±1.990 mSv/y. Values of (AED_{Total}) ranged from 7.443 mSv/y in sample P9 to 24.768 mSv/y in sample P2, with an average value of 15.053±4.597 mSv/y. These results of (AED_{Total}) are higher than 0.32 mSv/y recommended by (UNSCEAR,2008) [142]. For (HCR), values ranged from 5.955×10^{-3} in sample P9 to 19.814×10^{-3} in sample P2, with an average value of $(12.042\pm3.677)\times10^{-3}$. Results of (ELCR) ranged from 7.443×10^{-3} in sample P9 to 24.768×10^{-3} in sample P2, with an average value of $(15.053\pm4.597)\times10^{-3}$. These results of (ELCR) for all alfalfa and barley samples in the present study are higher than the worldwide value of 1.45×10^{-3} [145]. The reason for exceeding the permissible dosage is due to the increase in annual consumption, as cow consumption accounts for more than 91.25 of human consumption. The annual consumption of alfalfa and barley by cow is approximately 5475 kg/y, while the annual consumption of vegetables by humans is 60 kg/y.

Table (4.9) shows the values of annual effective dose (AED), hereditary cancer risk (HCR), and excess lifetime cancer risk (ELCR) in alfalfa, and barley samples as food for sheep. From this table, Results of (AED) for ^{238}U ranged from BDL in samples P1, P3, P7, P9, P23, P26, P28, P37, and P38 to 2.120 mSv/y in sample P24, with an average value of 1.016±0.576 mSv/y. Results of (AED) for ^{232}Th ranged from BDL in samples P9, P16, P23, and P45 to 1.616 mSv/y in sample P13, with an average value of 0.756±0.450 mSv/y. For ^{40}K, values of (AED) ranged from 0.882 mSv/y in sample P7 to 2.274 mSv/y in sample P3, with an average value of 1.601±0.392 mSv/y. The minimum value of (AED_{Total})was 1.468 mSv/y in sample P9, while the maximum value was 4.885mSv/y in sample P2, with an average value of 2.969± 0.906 mSv/y. These results of (AED_{Total}) are higher than 0.32 mSv/y recomm-

endded by (UNSCEAR, 2008) [142]. Results of (HCR) ranged from 0.293 $\times 10^{-3}$ in sample P9 to 0.977×10^{-3} in sample P2, with an average value of $(0.593\pm0.185)\times10^{-3}$, while values of (ELCR) ranged from 0.367×10^{-3} in sample P9 to 1.221×10^{-3} in sample P2, with an average value of $(0.742\pm0.231)\times10^{-3}$. These results of (ELCR) for all alfalfa and barley samples in the present study are lower than the worldwide value of 1.45×10^{-3} [145]. The reason for exceeding the permissible dosage for (HCR) is due to the increase in annual consumption, as sheep consumption accounts for more than 18 of human consumption. The annual consumption of alfalfa and barley by sheep is approximately 1080 kg/y, while the annual consumption of vegetables by humans is 60 kg/y.

Table 4.7 Annual effective dose (AED), hereditary cancer risk (HCR), and excess lifetime cancer risk (ELCR) in vegetable samples.

No	Sample code	AED mSv/y			AED_{Total} mSv/y	HCR $\times10^{-3}$	ELCR $\times10^{-3}$
		^{238}U	^{232}Th	^{40}K			
1	P4	0.113	BDL	0.114	0.228	0.639	0.799
2	P5	0.040	0.013	0.053	0.107	0.300	0.375
3	P6	0.033	0.041	0.087	0.161	0.452	0.565
4	P8	BDL	0.0003	0.103	0.103	0.290	0.363
5	P12	BDL	BDL	0.111	0.111	0.311	0.389
6	P15	0.024	0.133	0.103	0.261	0.732	0.915
7	P20	BDL	0.023	0.090	0.113	0.318	0.398
8	P22	BDL	0.064	0.088	0.153	0.430	0.538
9	P25	BDL	BDL	0.103	0.103	0.289	0.361
10	P29	BDL	BDL	0.092	0.092	0.259	0.324
11	P30	BDL	BDL	0.085	0.085	0.239	0.299
12	P33	0.068	0.091	0.060	0.221	0.619	0.773
13	P34	BDL	0.080	0.091	0.172	0.482	0.602
14	P36	0.051	BDL	0.083	0.135	0.378	0.472
15	P41	0.028	0.002	0.065	0.096	0.271	0.339
16	P44	BDL	0.004	0.109	0.114	0.321	0.401
17	P47	0.094	0.016	0.134	0.245	0.687	0.859
18	P48	0.114	0.044	0.137	0.297	0.832	1.040
19	P49	0.091	0.069	0.104	0.266	0.745	0.931
20	P50	0.083	0.063	0.111	0.258	0.723	0.904
Minimum		**BDL**	**BDL**	**0.053**	**0.085**	**0.239**	**0.299**
Maximum		**0.114**	**0.133**	**0.137**	**0.297**	**0.832**	**1.040**
Average		**0.071**	**0.046**	**0.096**	**0.166**	**0.466**	**0.582**

±S.D	±0.030	±0.039	±0.021	±0.070	±0.198	±0.248
Worldwide average	---------	---------	---------	**0.32 [142]**	----------	**1.45 [145]**

BDL: Below Detection Limit.

Figures 4.10 and 4.11 show a good correlation between total annual effective dose, hereditary cancer risk and excess lifetime cancer risk in vegetable samples (R^2=1).

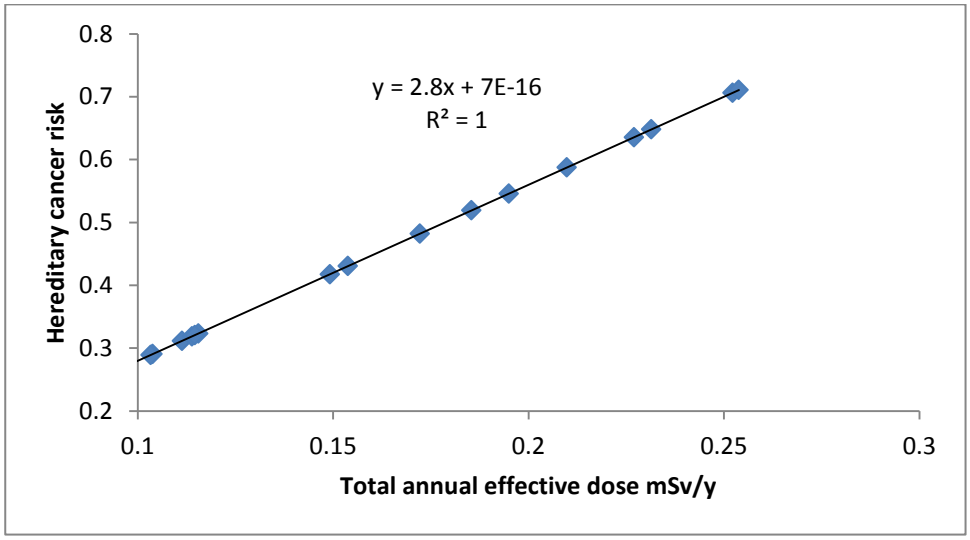

Figure 4.10 Correlation between total annual effective dose and hereditary cancer risk in vegetable samples.

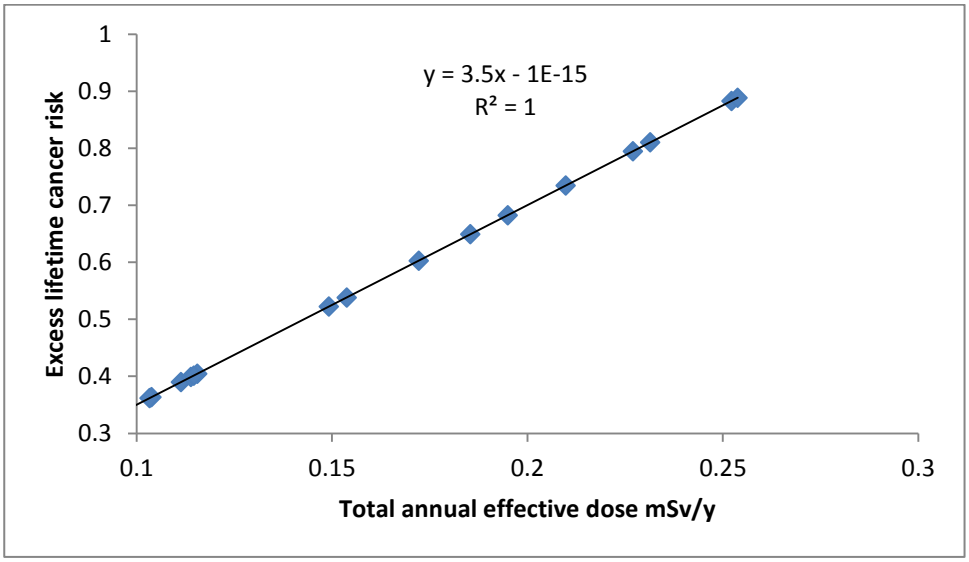

Figure 4.11 Correlation between total annual effective dose and excess lifetime cancer risk in vegetable samples.

Table 4.8: Annual effective dose (AED), hereditary cancer risk (HCR), and excess lifetime cancer risk (ELCR) in alfalfa, and barley for cow.

No	Sample code	AED mSv/y			AED_{Total} mSv/y	HCR $\times 10^{-3}$	ELCR $\times 10^{-3}$
		^{238}U	^{232}Th	^{40}K			
1	P1	BDL	4.335	7.987	12.323	9.858	12.323
2	P2	10.618	3.845	10.303	24.768	19.814	24.768
3	P3	BDL	1.616	11.531	13.148	10.518	13.148
4	P7	BDL	5.584	4.475	10.060	8.048	10.060
5	P9	BDL	BDL	7.443	7.443	5.955	7.443
6	P10	6.711	6.505	7.311	20.527	16.422	20.527
7	P11	2.237	1.351	9.872	13.460	10.768	13.460
8	P13	5.816	8.195	10.214	24.226	19.381	24.226
9	P14	0.894	3.717	9.046	13.658	10.926	13.658
10	P16	4.025	BDL	7.486	11.512	9.210	11.512
11	P17	7.605	7.095	5.915	20.616	16.493	20.616
12	P18	8.053	1.521	6.775	16.350	13.080	16.350
13	P19	6.711	5.660	8.640	21.011	16.809	21.011
14	p21	3.579	0.591	5.434	9.606	7.684	9.606
15	P23	BDL	BDL	10.200	10.200	8.160	10.200
16	P24	10.750	0.097	10.477	21.325	17.060	21.325
17	P26	BDL	2.106	9.070	11.176	8.941	11.176
18	P27	3.146	4.115	8.249	15.510	12.408	15.510
19	P28	BDL	4.752	10.235	14.987	11.989	14.987
20	P31	5.243	6.368	5.930	17.543	14.034	17.543
21	P32	7.865	3.429	6.853	18.148	14.519	18.148
22	P35	3.932	1.469	4.765	10.168	8.134	10.168
23	P37	BDL	4.801	6.384	11.185	8.948	11.185
24	P38	BDL	6.760	7.639	14.400	11.520	14.400
25	P39	3.408	5.143	5.105	13.658	10.926	13.658
26	P40	3.670	4.654	7.103	15.428	12.342	15.428
27	P42	4.719	4.311	8.796	17.827	14.261	17.827
28	P43	7.341	0.587	11.298	19.228	15.382	19.228
29	P45	0.524	BDL	9.246	9.770	7.816	9.770
30	P46	1.310	1.126	9.891	12.329	9.863	12.329
Minimum		**BDL**	**BDL**	**4.475**	**7.443**	**5.955**	**7.443**
Maximum		**10.750**	**8.195**	**11.531**	**24.768**	**19.814**	**22.029**
Average ±S.D		**5.150 ±2.920**	**3.836 ±2.284**	**8.122 ±1.990**	**15.053 ±4.597**	**12.042 ±3.677**	**15.053 ±4.597**
Worldwide average		---	---	---	**0.32[142]**	---	**1.45 [145]**

BDL: Below Detection Limit.

Figures 4.12 and 4.13 show a good correlation between total annual effective dose, hereditary cancer risk and excess lifetime cancer risk in alfalfa, and barley for cow (R^2=1).

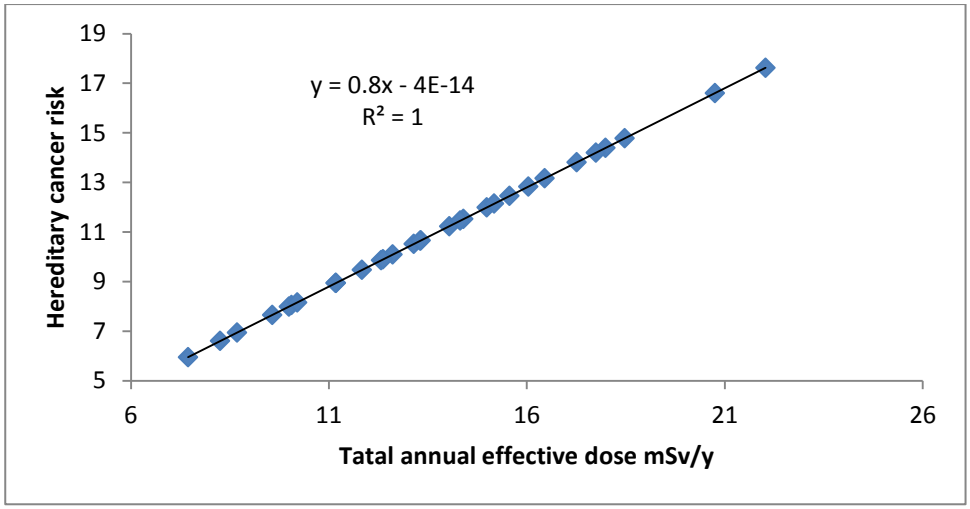

Figure 4.12 Correlation between total annual effective dose and hereditary cancer risk in alfalfa, and barley for cow.

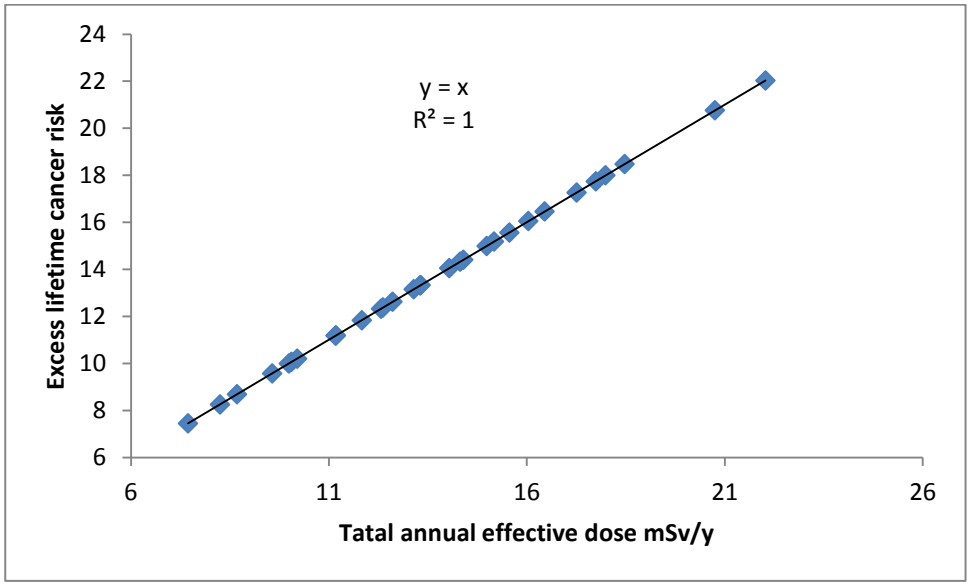

Figure 4.13 Correlation between total annual effective dose and excess lifetime cancer risk in alfalfa, and barley for cow.

Table 4.9: Annual effective dose (AED), hereditary cancer risk (HCR), and excess lifetime cancer risk (ELCR) in alfalfa, and barley for sheep.

No	Sample code	AED mSv/y			AED_{Total} mSv/y	HCR $\times 10^{-3}$	ELCR $\times 10^{-3}$
		^{238}U	^{232}Th	^{40}K			
1	P1	BDL	0.855	1.575	2.430	0.486	0.607
2	P2	2.094	0.758	2.032	4.885	0.977	1.221
3	P3	BDL	0.318	2.274	2.593	0.518	0.648
4	P7	BDL	1.101	0.882	1.984	0.396	0.496
5	P9	BDL	BDL	1.468	1.468	0.293	0.367
6	P10	1.323	1.283	1.442	4.049	0.809	1.012
7	P11	0.441	0.266	1.947	2.655	0.531	0.663
8	P13	1.147	1.616	2.014	4.778	0.955	1.194
9	P14	0.176	0.733	1.784	2.694	0.538	0.673
10	P16	0.794	BDL	1.476	2.271	0.454	0.567
11	P17	1.500	1.399	1.166	4.066	0.813	1.016
12	P18	1.588	0.300	1.336	3.225	0.645	0.806
13	P19	1.323	1.116	1.704	4.144	0.828	1.036
14	p21	0.706	0.116	1.071	1.894	0.378	0.473
15	P23	BDL	BDL	2.012	2.012	0.402	0.503
16	P24	2.120	0.019	2.066	4.206	0.841	1.051
17	P26	BDL	0.415	1.789	2.204	0.440	0.551
18	P27	0.620	0.811	1.627	3.059	0.611	0.764
19	P28	BDL	0.937	2.019	2.956	0.591	0.739
20	P31	1.034	1.256	1.169	3.460	0.692	0.865
21	P32	1.551	0.676	1.351	3.580	0.716	0.895
22	P35	0.775	0.289	0.940	2.005	0.401	0.501
23	P37	BDL	0.947	1.259	2.206	0.441	0.551
24	P38	BDL	1.333	1.506	2.840	0.568	0.710
25	P39	0.672	1.014	1.007	2.694	0.538	0.673
26	P40	0.724	0.918	1.401	3.043	0.608	0.760
27	P42	0.930	0.850	1.735	3.516	0.703	0.879
28	P43	1.448	0.115	2.228	3.792	0.758	0.948
29	P45	0.103	BDL	1.823	1.927	0.385	0.481
30	P46	0.258	0.222	1.951	2.432	0.486	0.608
Minimum		**BDL**	**BDL**	**0.882**	**1.468**	**0.293**	**0.367**
Maximum		**2.120**	**1.616**	**2.274**	**4.885**	**0.977**	**1.221**
Average ±S.D		**1.016 ±0.576**	**0.756 ±0.450**	**1.601 ±0.392**	**2.969 ±0.906**	**0.593 ±0.185**	**0.742 ±0.231**
Worldwide average		**---------**	**----------**	**----------**	**0.32 [142]**	**----------**	**1.45 [145]**

BDL: Below Detection Limit.

Figures 4.14 and 4.15 show a good correlation between total annual effective dose, hereditary cancer risk and excess lifetime cancer risk in alfalfa, and barley for sheep (R^2=1).

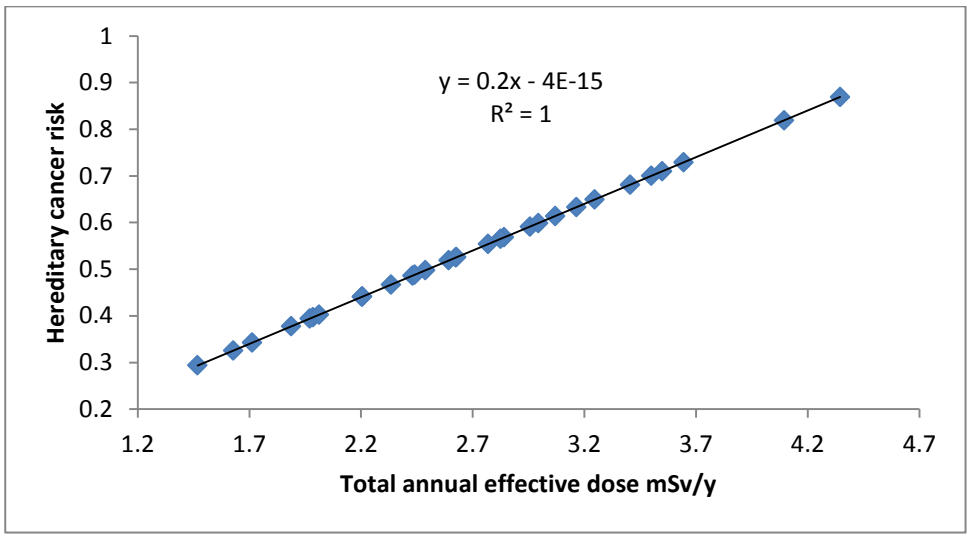

Figure 4.14 Correlation between total annual effective dose and hereditary cancer risk in alfalfa, and barley for sheep.

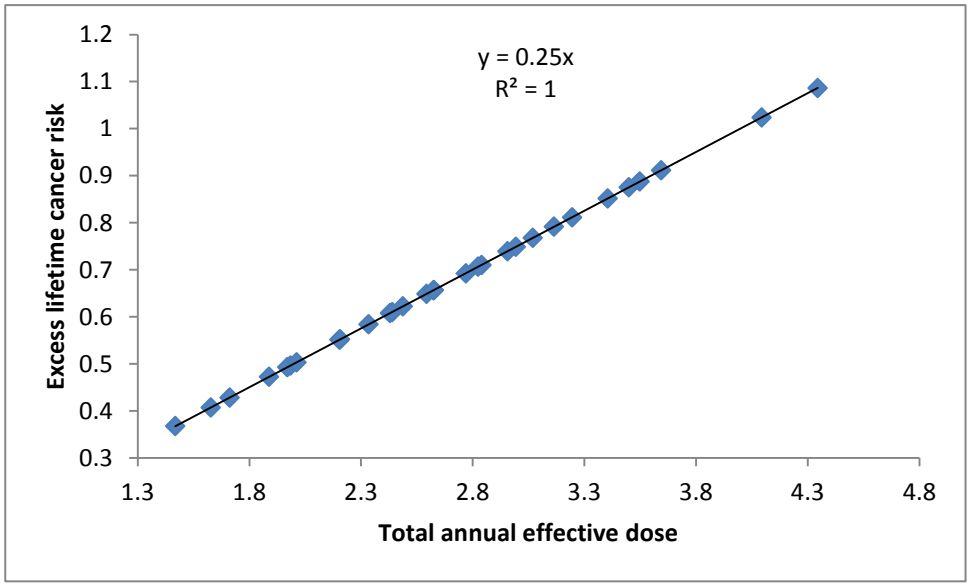

Figure 4.15 Correlation between total annual effective dose and excess lifetime cancer risk in alfalfa, and barley for sheep.

4.4. Results of Alpha Emitters

This section of the study is measure natural alpha emitters ^{222}Rn, ^{226}Ra, and ^{238}U in selected samples from agricultural soil and plants from the same place by using CR-39 (solid nuclear trace detectors). The results of the radon, radium, and uranium concentrations, as well as radiological hazards in agricultural soil for 50 samples and 50 plant samples, were compared with worldwide average.

4.4.1 Results of Alpha Emitters in Agricultural Soil

Table (4.10) shows the results of radon, radium, and uranium concentrations. The results concentration of radon (^{222}Rn) in the air space of the cup (C_a) ranged from 61.993 Bq/m^3 at sample S4 to 313.115 Bq/m^3 at sample S48, with an average value of 115.452±42.592 Bq/m^3. These values are less than the corresponding worldwide values of (200-600) Bq/m^3 [147]. The concentration of radon in sample (C_S) values ranged from 1012.104Bq/m^3 at sample S4 to 5111.915 Bq/m3 at sample S48, with an average value of 1884.882 ±695.361 Bq/m^3. These values are less than the corresponding worldwide values of 7400 Bq/m^3 [148], while the values of (C_{Rn}) ranged from 1.531 mBq/kg at sample S4 to 7.731 Bq/kg at sample S48 with an average value of 2.849±1.052 Bq/kg. Values of the activity concentrations of radium (C_{Ra}) were between 0.094 Bq/kg at sample S4 to 0.474 Bq/kg at sample S48, with an average value of 0.174±0.064 Bq/kg.These value lower than the average global value of 35 Bq/kg [125].

The values of uranium concentration in unit ppm varied from 0.121 ppm in sample S4 to 0.613 ppm in sample S48, with an average value of 0.226±0.083 ppm. These values are lower than 11 ppm that was published by (UNSCEAR, 1994) [122]. The values of (C_U) in unit Bq/kg ranged from 1.499 Bq/kg in sample S4 to 7.572 Bq/kg in sample S48 with an average value of 2.791±1.030 Bq/kg. The results of (C_U) are less than the allowed limit of 40 Bq/kg from (UNSCEAR,1994) [122]. Figures 4.16, 4.17, 4.18, and 4.19 shows distribution concentration of radon, radium, and uranium for all different soil samples.

Table 4.10: Concentrations of radon, radium and uranium in agricultural soil.

No	Sample code	^{222}Rn			C_{Ra} Bq/kg	C_U (ppm)	C_U Bq/kg
		C_a Bq/m^3	C_s Bq/m^3	C_{Rn} Bq/kg			
1	S1	82.548	1347.676	2.038	0.125	0.162	1.996
2	S2	85.229	1391.445	2.104	0.129	0.167	2.061
3	S3	101.315	1654.066	2.502	0.153	0.198	2.450
4	S4	61.993	1012.104	1.531	0.094	0.121	1.499
5	S5	98.634	1610.296	2.435	0.149	0.193	2.385
6	S6	93.272	1522.756	2.303	0.141	0.183	2.256
7	S7	133.487	2179.312	3.296	0.202	0.261	3.228
8	S8	172.809	2821.279	4.267	0.261	0.338	4.179
9	S9	107.571	1756.197	2.656	0.163	0.211	2.601
10	S10	94.166	1537.346	2.325	0.142	0.184	2.277
11	S11	70.036	1143.415	1.729	0.106	0.137	1.694
12	S12	132.594	2164.722	3.274	0.201	0.260	3.206
13	S13	131.700	2150.131	3.252	0.199	0.258	3.185
14	S14	210.343	3434.066	5.194	0.318	0.412	5.087
15	S15	114.720	1872.918	2.833	0.174	0.225	2.774
16	S16	83.441	1362.266	2.060	0.126	0.163	2.018
17	S17	113.826	1858.328	2.811	0.172	0.223	2.753
18	S18	115.614	1887.508	2.855	0.175	0.226	2.796
19	S19	96.847	1581.116	2.319	0.146	0.190	2.342
20	S20	95.059	1551.936	2.347	0.144	0.186	2.299
21	S21	102.209	1668.625	2.524	0.155	0.200	2.472
22	S22	112.039	1829.147	2.766	0.169	0.219	2.709
23	S23	106.677	1741.607	2.634	0.161	0.209	2.580
24	S24	175.490	2865.050	4.333	0.265	0.344	4.244
25	S25	97.740	1595.706	2.413	0.148	0.191	2.364
26	S26	92.378	1508.166	2.281	0.140	0.181	2.234
27	S27	62.887	1026.694	1.553	0.095	0.123	1.521
28	S28	134.381	2193.902	3.318	0.203	0.263	3.250
29	S29	128.125	2091.771	3.164	0.194	0.251	3.098
30	S30	145.105	2368.984	3.583	0.219	0.284	3.509
31	S31	122.763	2004.230	3.031	0.186	0.240	2.969
32	S32	123.657	2018.820	3.053	0.187	0.242	2.990
33	S33	121.869	1989.639	3.009	0.184	0.239	2.947
34	S34	90.591	1478.986	2.237	0.137	0.177	2.191
35	S35	88.803	1449.806	2.193	0.134	0.174	2.147
36	S36	116.507	1902.098	2.877	0.176	0.228	2.817
37	S37	86.122	1406.036	2.127	0.130	0.169	2.083
38	S38	89.697	1464.396	2.215	0.136	0.176	2.169
39	S39	87.910	1435.216	2.171	0.133	0.172	2.126
40	S40	103.102	1683.247	2.546	0.156	0.202	2.493
41	S41	75.398	1230.955	1.862	0.114	0.148	1.823

42	S42	187.108	3054.721	4.620	0.283	0.366	4.525
43	S43	100.421	1639.476	2.480	0.152	0.197	2.428
44	S44	91.484	1493.576	2.259	0.138	0.179	2.212
45	S45	104.890	1712.427	2.590	0.159	0.205	2.536
46	S46	71.824	1172.595	1.773	0.109	0.141	1.737
47	S47	154.935	2529.476	3.826	0.234	0.303	3.747
48	S48	313.115	5111.915	7.731	0.474	0.613	7.572
49	S49	125.444	2048.00	3.097	0.190	0.246	3.034
50	S50	164.766	2689.968	4.068	0.249	0.323	3.984
Minimum		**61.993**	**1012.104**	**1.531**	**0.094**	**0.121**	**1.499**
Maximum		**313.115**	**5111.915**	**7.731**	**0.474**	**0.613**	**7.572**
Average ±S.D		**115.452 ±42.592**	**1884.882 ±695.361**	**2.849 ±1.052**	**0.174 ±0.064**	**0.226 ±0.083**	**2.791 ±1.030**
World Wide average		**200-600 [147]**	**7400 [148]**	**----------**	**35 [125]**	**11 [122]**	**40 [122]**

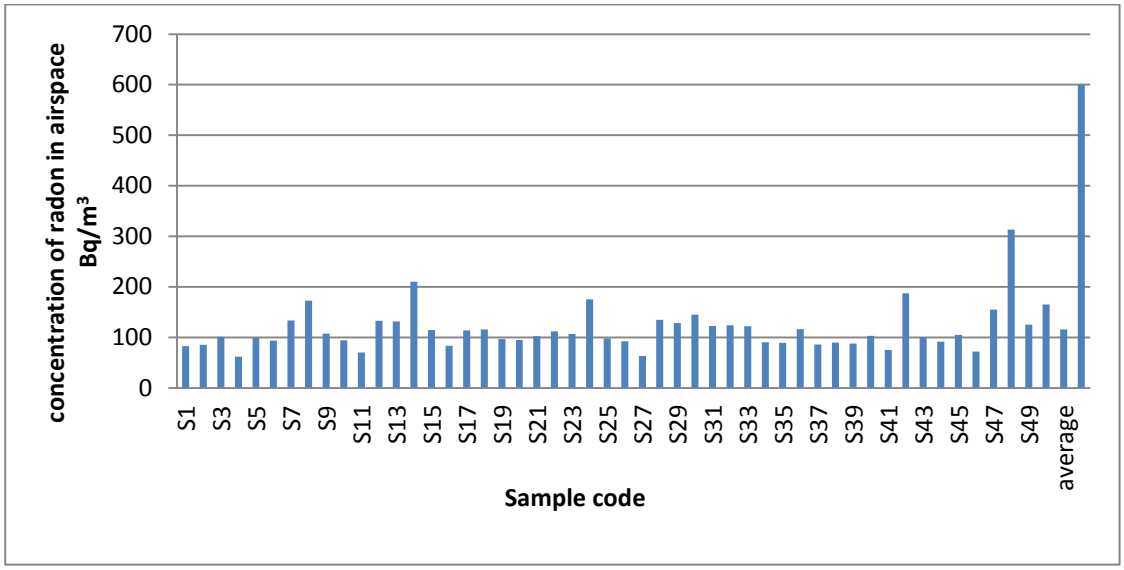

Figure 4.16 Concentration of radon in airspace of cup for soil samples.

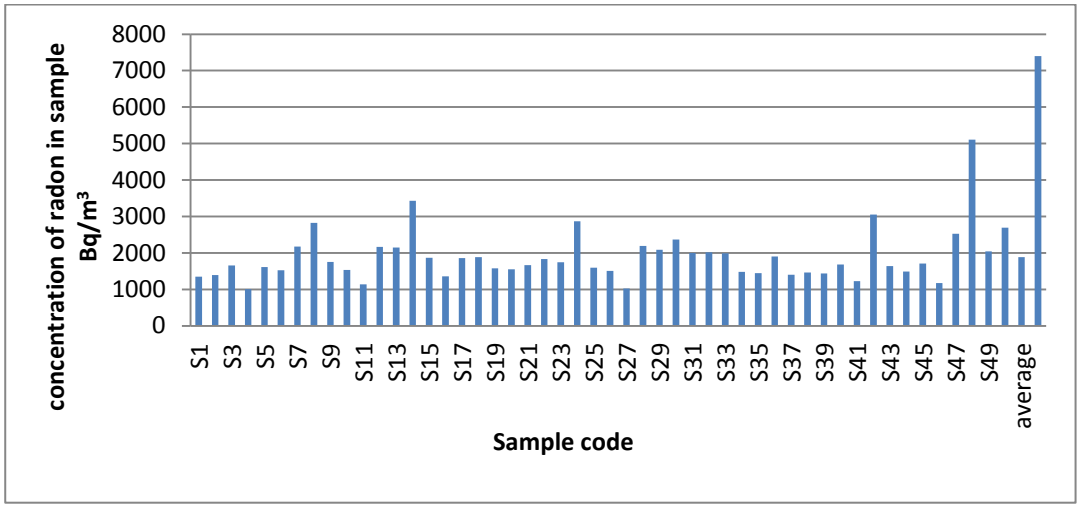

Figure 4.17 Concentration of radon in sample for soil samples.

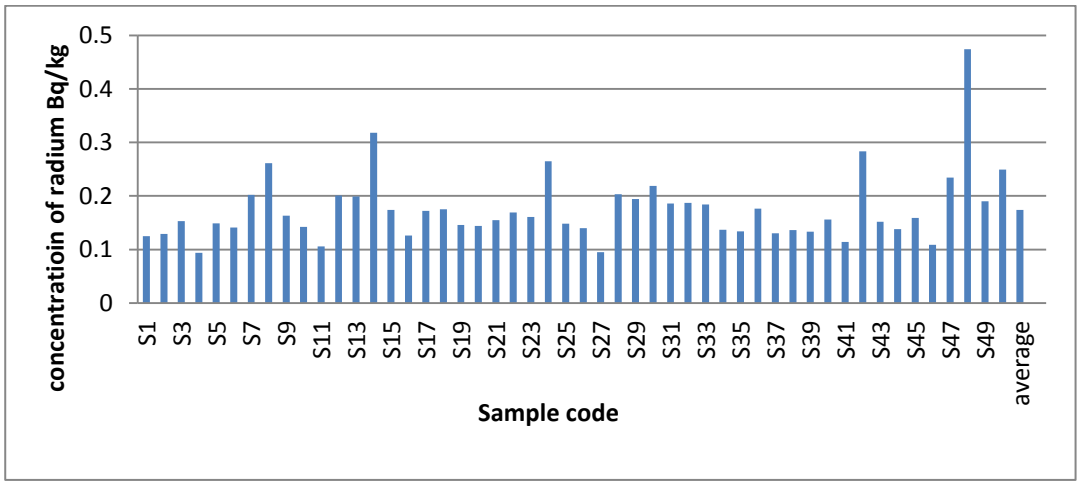

Figure 4.18 Concentration of radium for soil samples.

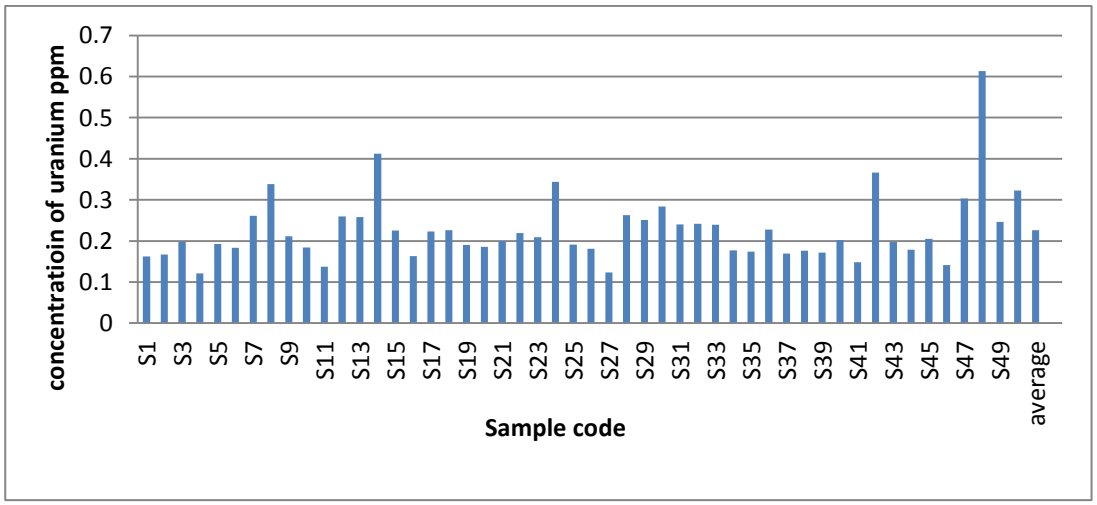

Figure 4.19 Concentration of uranium for soil samples.

Shown in table (4.11), result of mass exhalation rate (E_M) and surface exhalation rate (E_S) ranged from 0.755 Bq/kg.d in sample S4 to 3.813 Bq/kg.d in sample S48, with an average value of 1.405±0.518 Bq/kg.d and from 17.470 Bq/m^2.d in sample S4 to 88.237 Bq/m^2.d in sample S48, with an average value of 32.534±12.002 Bq/m^2.d, respectively. The values of the radon exhalation rate in the present study were below the world average of 57.6 [125].

Also from table (4.11), result of annual effective dose (D_{eff}) varied from 1.638 mSv/y in sample S4 to 8.273 mSv/y in sample S48, with an average value of 3.050±1.125 mSv/y. These values of (D_{eff}) for all soil samples were less than the range of acceptable levels (3-10) mSv/y that were recommended by ICRP (1993) [146]. The values of alpha index (I_α) varied from 0.00046 in sample S4 to 0.00236 in sample S48, with an average value of 0.0008731± 0.00032211. These resulted values are less than the recommended permissible safety limit values (≤1) [145]. Values of excess lifetime cancer risk (ELCR) ranged from 0.0063×10^{-3} in sample S4 to 0.0318×10^{-3} in sample S48 with an average value of (0.011±0.004)×10^{-3}. These values of (ELCR) are less than the comparable worldwide average value of (1.45×10^{-3}) [145].

Table 4.11: Mass exhalation rate (E_M), surface exhalation rate (E_S), annual effective dose of radon(D_{eff}), alpha index (I_α), and excess lifetime cancer risk (ELCR) in agricultural soil.

No	Sample code	E_M Bq/kg.d	E_S Bq/m^2.d	D_{eff} mSv/y	Iα	ELCR ×10^{-3}
1	S1	1.005	23.262	2.181	0.00062	0.0083
2	S2	1.038	24.018	2.252	0.00064	0.0086
3	S3	1.234	28.551	2.677	0.00076	0.0103
4	S4	0.755	17.470	1.638	0.00046	0.0063
5	S5	1.201	27.795	2.606	0.00074	0.0100
6	S6	1.136	26.284	2.464	0.00070	0.0094
7	S7	1.625	37.617	3.527	0.00100	0.0135
8	S8	2.104	48.698	4.566	0.00130	0.0175
9	S9	1.310	30.314	2.842	0.00081	0.0109
10	S10	1.147	26.536	2.488	0.00071	0.0095
11	S11	0.853	19.736	1.850	0.00053	0.0071
12	S12	1.615	37.365	3.503	0.00100	0.0134
13	S13	1.604	37.113	3.480	0.00099	0.0133
14	S14	2.561	59.275	5.557	0.00159	0.0213
15	S15	1.397	32.328	3.031	0.00086	0.0116
16	S16	1.016	23.514	2.205	0.00063	0.0084
17	S17	1.386	32.077	3.007	0.00086	0.0115
18	S18	1.408	32.580	3.055	0.00087	0.0117

19	S19	1.179	27.292	2.559	0.00073	0.0098
20	S20	1.158	26.788	2.511	0.00071	0.0096
21	S21	1.245	28.803	2.700	0.00077	0.0103
22	S22	1.364	31.573	2.960	0.00084	0.0113
23	S23	1.299	30.062	2.818	0.00080	0.0108
24	S24	2.137	49.454	4.636	0.00132	0.0178
25	S25	1.190	27.543	2.582	0.00073	0.0099
26	S26	1.125	26.032	2.441	0.00069	0.0093
27	S27	0.766	17.722	1.661	0.00047	0.0063
28	S28	1.636	37.869	3.550	0.00101	0.0136
29	S29	1.560	36.106	3.385	0.00096	0.0130
30	S30	1.767	40.891	3.834	0.00109	0.0147
31	S31	1.495	34.595	3.243	0.00092	0.0124
32	S32	1.506	34.847	3.267	0.00093	0.0125
33	S33	1.484	34.343	3.220	0.00092	0.0123
34	S34	1.103	25.529	2.393	0.00068	0.0092
35	S35	1.081	25.025	2.346	0.00067	0.0090
36	S36	1.419	32.832	3.078	0.00088	0.0118
37	S37	1.049	24.270	2.275	0.00065	0.0087
38	S38	1.092	25.277	2.370	0.00067	0.0091
39	S39	1.070	24.773	2.323	0.00066	0.0089
40	S40	1.255	29.054	2.724	0.00078	0.0104
41	S41	0.918	21.247	1.992	0.00057	0.0076
42	S42	2.278	52.727	4.943	0.00141	0.0190
43	S43	1.223	28.299	2.653	0.00075	0.0102
44	S44	1.114	25.781	2.417	0.00069	0.0093
45	S45	1.277	29.558	2.771	0.00079	0.0106
46	S46	0.875	20.240	1.898	0.00054	0.0073
47	S47	1.887	43.661	4.093	0.00117	0..0157
48	S48	3.813	88.237	8.273	0.00236	0.0318
49	S49	1.528	35.350	3.314	0.00094	0.0127
50	S50	2.006	46.431	4.353	0.00124	0.0167
Minimum		**0.755**	**17.470**	**1.638**	**0.00046**	**0.0063**
Maximum		**3.813**	**88.237**	**8.273**	**0.00236**	**0.0318**
Average ±S.D		**1.405 ±0.518**	**32.534 ±12.002**	**3.050 ±1.125**	**0.0008 ±0.0003**	**0.011 ±0.004**
World Wide average		**57.6 [125]**	**57.6 [125]**	**3-10 [146]**	**≤1 [144]**	**1.45 [145]**

4.4.2 Results of Alpha Emitters in Plant

The results concentration of radon in air space of cup (C_a), concentration of radon in samples (C_s), effective radium (C_{Ra}), uranium concentration (C_U), and uranium concentration unit to activity unit in Bq/kg of uranium (U) as shown in Table (4.12). For C_a, values ranged from 24.275 Bq/m^3 in sample P41 to 64.534 Bq/m^3 in sample P48, with an average value of 44.823±11.714 Bq/m^3. These values are less than the corresponding worldwide values of (200-600) Bq/m^3[147]. Results concentration of radon in sample (C_s) varied from 396.314 Bq/m^3 in sample P41 to 1053.583 Bq/m^3 in sample P48, with an average value of 731.784±191.256 Bq/m^3. These values are less than the corresponding worldwide values of 7400 Bq/m^3 [148], while the minimum value of (C_{Rn}) was(0.599 Bq/kg) in sample P41, and the maximum value was found in sample P48 (1.593 Bq/kg), with an average value of 1.106±0.289 Bq/kg.

Values of the activity concentrations of radium (C_{Ra}) ranged from 0.037 Bq/kg in sample P41 to 0.098 Bq/kg in sample P48, with an average value of 0.067±0.017 Bq/kg. These values lower than the average global value of 35 Bq/kg [125]. Results of uranium concentration in unit ppm varied from 0.048 ppm in sample P41 to 0.126 ppm in sample P48, with an average value of 0.087±0.022 ppm. These values are lower than 11 ppm that was published by UNSCEAR,1994 [122]. Values of (C_U) in unit Bq/kg ranged from 0.587 Bq/kg in sample P41 to 1.561Bq/kg in sample P48 with an average value of 1.083±0.283 Bq/kg. Results of (C_U) are less than the allowed limit of 40 Bq/kg from (UNSCEAR,1994) [122].

From table (4.13), values of mass exhalation rate (E_M) varied from 0.296 Bq/kg.d in P41 to 0.786 Bq/kg.d in P48, with a mean value of 0.545± 0.142 Bq/kg.d, while the surface exhalation rate (E_S) ranged from 6.841 Bq/m^2.d in P41 to 18.186 Bq/m^2.d in P48, with a mean value of 12.631± 3.301Bq/m^2.d. Values of mass and surface exhalation rate in the present study were below the world average of 57.6 [125]. Results alpha index (I_α) ranged from 0.184×10^{-6} in sample P41 to 0.488×10^{-6} in sample P48, with an average value of $(0.338\pm 0.088)\times10^{-6}$. These resulted values are less than the recommended permissible safety limit values (≤1) [144]. Figures 4.20, 4.21, 4.22, and 4.23 show distribution concentration of radon, radium, and uranium for all different soil samples.

Table 4.12: Concentrations of radon, radium and uranium in plant samples.

No	Sample code	^{222}Rn			C_{Ra} Bq/kg	C_U ppm	C_U Bq/kg
		C_a Bq/m^3	C_s Bq/m^3	C_{Rn} Bq/kg			
1	P1	46.015	751.239	1.136	0.070	0.090	1.113
2	P2	54.872	895.838	1.355	0.083	0.107	1.327
3	P3	37.963	619.786	0.937	0.057	0.074	0.918
4	P4	31.522	514.622	0.778	0.048	0.062	0.762
5	P5	46.820	764.385	1.156	0.071	0.092	1.132
6	P6	43.599	711.803	1.077	0.066	0.085	1.054
7	P7	40.379	659.222	0.997	0.061	0.079	0.976
8	P8	54.067	882.693	1.335	0.082	0.106	1.307
9	P9	41.184	672.367	1.017	0.062	0.081	0.996
10	P10	33.132	540.913	0.818	0.050	0.065	0.801
11	P11	39.573	646.076	0.977	0.060	0.077	0.957
12	P12	50.041	816.966	1.236	0.076	0.098	1.210
13	P13	52.456	856.402	1.295	0.079	0.103	1.269
14	P14	63.729	1040.438	1.574	0.096	0.125	1.541
15	P15	42.794	698.658	1.057	0.065	0.084	1.035
16	P16	47.625	777.530	1.176	0.072	0.093	1.152
17	P17	57.287	935.275	1.415	0.087	0.112	1.385
18	P18	33.937	554.059	0.838	0.051	0.066	0.821
19	P19	38.768	632.931	0.957	0.059	0.076	0.938
20	P20	53.262	869.548	1.315	0.081	0.104	1.288
21	P21	37.158	606.640	0.917	0.056	0.073	0.899
22	P22	56.482	922.129	1.395	0.085	0.111	1.366
23	P23	26.691	435.750	0.659	0.040	0.052	0.645
24	P24	48.430	790.675	1.196	0.073	0.095	1.171
25	P25	29.106	475.186	0.719	0.044	0.057	0.704
26	P26	55.677	908.984	1.375	0.084	0.109	1.346
27	P27	29.911	488.332	0.739	0.045	0.059	0.723
28	P28	60.508	987.856	1.494	0.092	0.118	1.463
29	P29	59.703	974.711	1.474	0.090	0.117	1.444
30	P30	62.924	1027.292	1.554	0.095	0.123	1.522
31	P31	41.989	685.512	1.037	0.064	0.082	1.015
32	P32	36.353	593.495	0.898	0.055	0.071	0.879
33	P33	44.405	724.949	1.096	0.067	0.087	1.074
34	P34	30.716	501.477	0.758	0.046	0.060	0.743
35	P35	27.496	448.896	0.679	0.042	0.054	0.665
36	P36	58.093	948.420	1.434	0.088	0.114	1.405
37	P37	35.548	580.349	0.878	0.054	0.070	0.860
38	P38	32.327	527.768	0.798	0.049	0.063	0.782
39	P39	34.742	567.204	0.858	0.053	0.068	0.840
40	P40	51.651	843.257	1.275	0.078	0.101	1.249
41	P41	24.275	396.314	0.599	0.037	0.048	0.587

42	P42	45.210	738.094	1.116	0.068	0.089	1.093
43	P43	28.301	462.041	0.699	0.043	0.055	0.684
44	P44	27.496	448.896	0.679	0.042	0.054	0.665
45	P45	49.236	803.821	1.216	0.074	0.096	1.191
46	P46	58.898	961.565	1.454	0.089	0.115	1.424
47	P47	61.313	1001.001	1.514	0.093	0.120	1.483
48	P48	64.534	1053.583	1.593	0.098	0.126	1.561
49	P49	50.846	830.112	1.255	0.077	0.100	1.230
50	P50	62.119	1014.147	1.534	0.094	0.122	1.502
Minimum		**24.275**	**396.314**	**0.599**	**0.037**	**0.048**	**0.587**
Maximum		**64.534**	**1053.583**	**1.593**	**0.098**	**0.126**	**1.561**
Average ±S.D		**44.823 ±11.714**	**731.784 ±191.256**	**1.106 ±0.289**	**0.067 ±0.017**	**0.087 ±0.022**	**1.083 ±0.283**
World Wide average		**200-600 [147]**	**7400 [148]**	**---------**	**35 [125]**	**11 [122]**	**40 [122]**

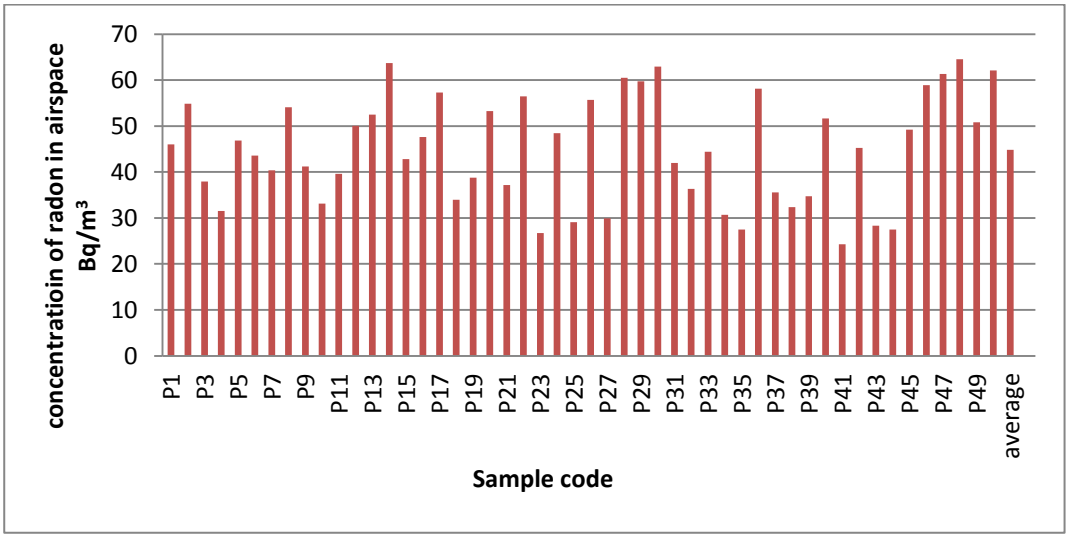

Figure 4.20 Concentration of radon in airspace of cup for plant samples.

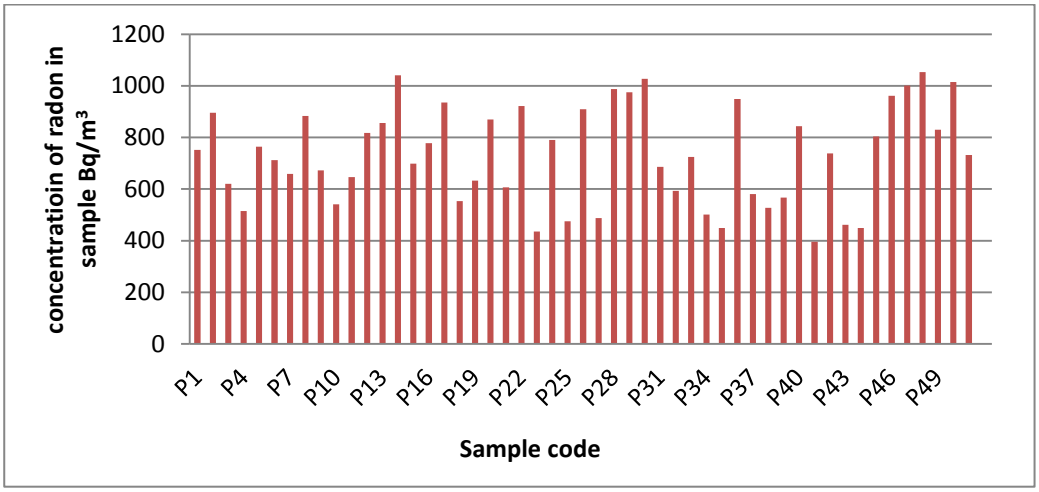

Figure 4.21 Concentration of radon in sample for plant samples.

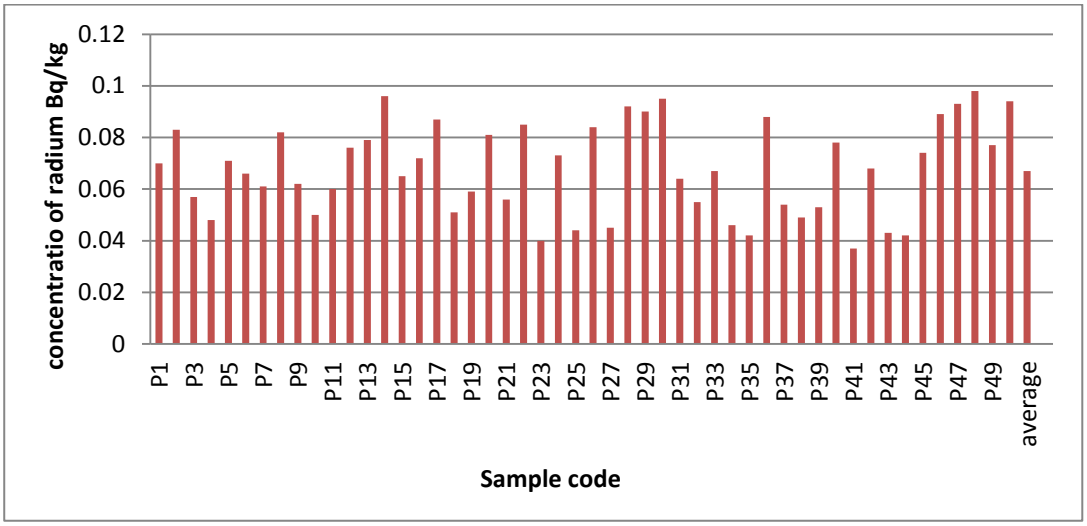

Figure 4.22 Concentration of radium for plant samples.

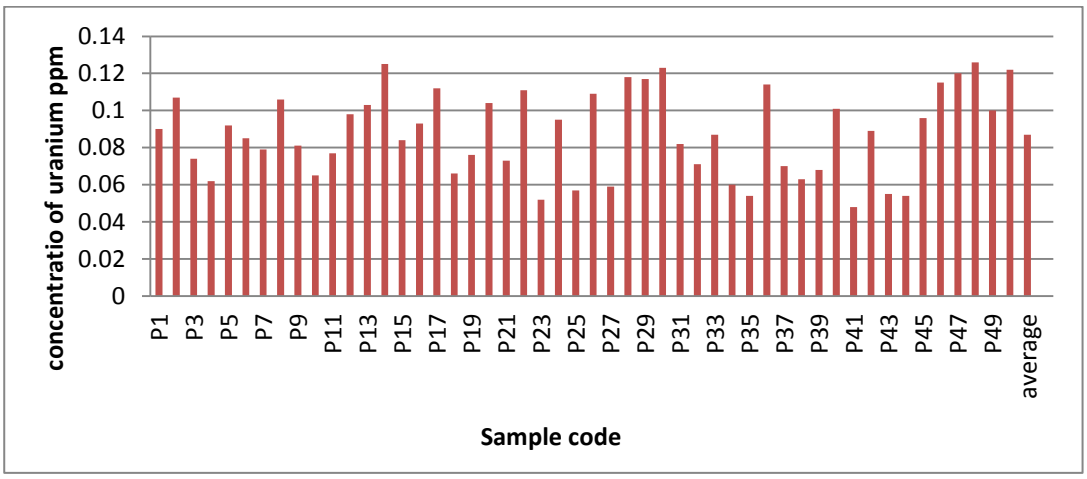

Figure 4.23 Concentration of uranium for plant samples.

Figures 4.24, 4.25, and 4.26 show correlation between concentration of radon, radium, and uranium in plant and soil, for radon in samples (R^2 =0.299), and for radium (R^2 =0.2985), and uranium (R^2 = 0.3004). It is observed that the correlation between concentration radon, radium, and uranium in soil and plant samples is weak.

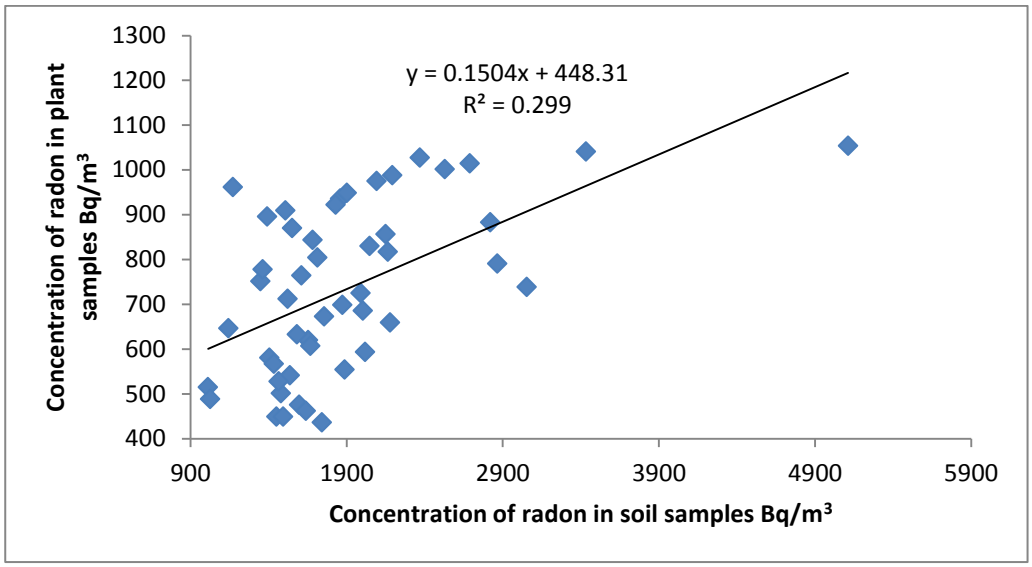

Figure 4.24 Correlation between concentration radon in plant and soil samples.

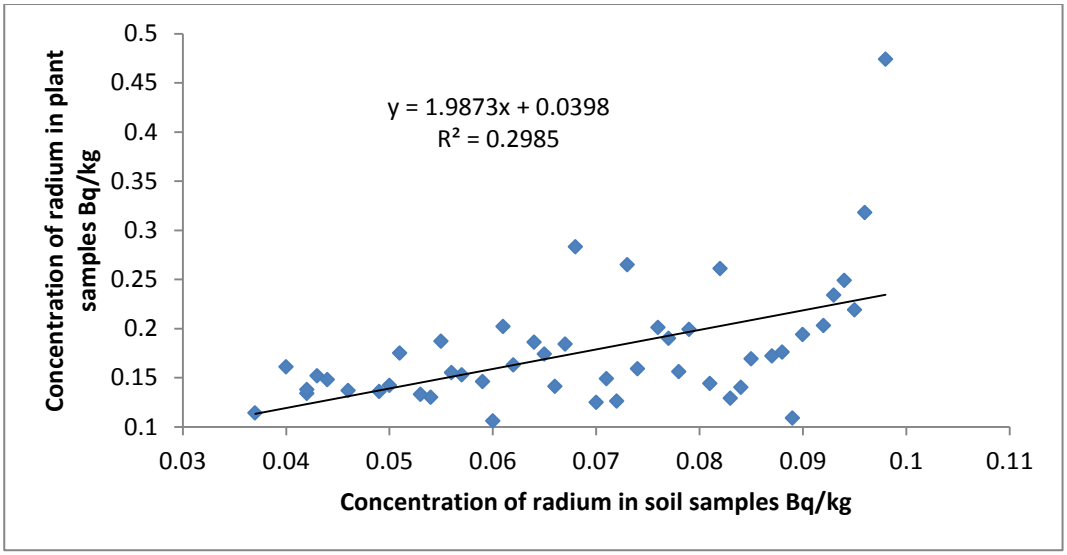

Figure 4.25 Correlation between concentration radium in plant and soil samples.

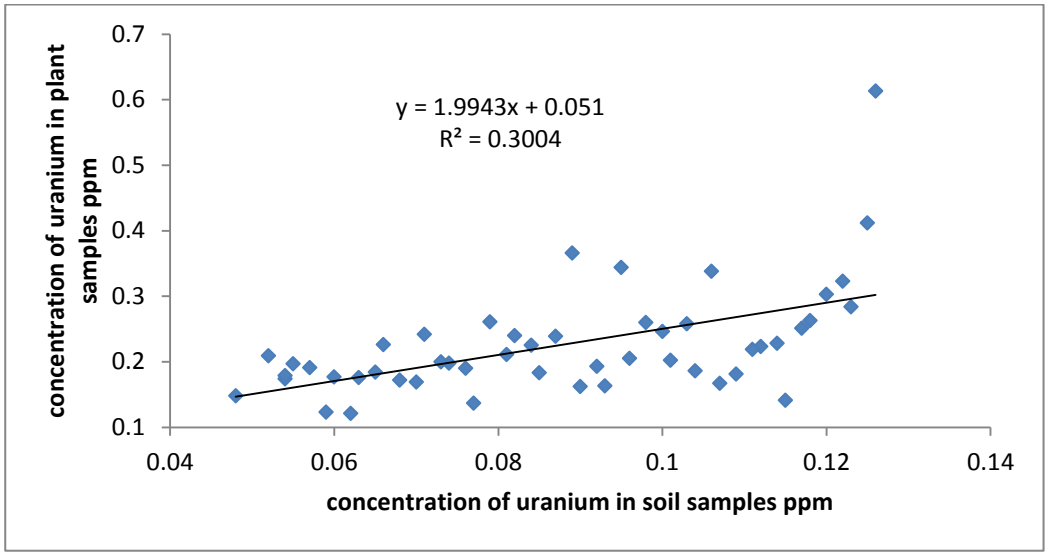

Figure 4.26 Correlation between concentration uranium in plant and soil samples.

Table 4.13: Mass exhalation rate (E_M), surface exhalation rate (E_S), and alpha index (I_α) in plant samples.

No	Sample code	E_M Bq/kg.d	E_S Bq/m^2.d	I_α $\times 10^{-6}$
1	P1	0.560	12.967	0.348
2	P2	0.668	15.463	0.415
3	P3	0.462	10.698	0.287
4	P4	0.384	8.883	0.238
5	P5	0.570	13.194	0.354
6	P6	0.531	12.286	0.330
7	P7	0.492	11.379	0.305
8	P8	0.658	15.236	0.409
9	P9	0.502	11.606	0.311
10	P10	0.403	9.337	0.251
11	P11	0.482	11.152	0.299
12	P12	0.609	14.102	0.378
13	P13	0.639	14.782	0.397
14	P14	0.776	17.959	0.482
15	P15	0.521	12.060	0.324
16	P16	0.580	13.421	0.360
17	P17	0.698	16.144	0.433
18	P18	0.413	9.564	0.257
19	P19	0.472	10.925	0.293
20	P20	0.649	15.009	0.403
21	P21	0.452	10.471	0.281
22	P22	0.688	15.917	0.427
23	P23	0.325	7.521	0.202
24	P24	0.590	13.648	0.366
25	P25	0.354	8.202	0.220

26	P26	0.678	15.69	0.421
27	P27	0.364	8.429	0.226
28	P28	0.737	17.051	0.458
29	P29	0.727	16.824	0.451
30	P30	0.766	17.732	0.476
31	P31	0.511	11.833	0.318
32	P32	0.443	10.244	0.275
33	P33	0.541	12.513	0.336
34	P34	0.374	8.656	0.232
35	P35	0.335	7.748	0.208
36	P36	0.707	16.371	0.439
37	P37	0.433	10.017	0.269
38	P38	0.394	9.11	0.244
39	P39	0.423	9.79	0.263
40	P40	0.629	14.555	0.391
41	P41	0.296	6.841	0.184
42	P42	0.551	12.74	0.342
43	P43	0.345	7.975	0.214
44	P44	0.335	7.748	0.208
45	P45	0.600	13.875	0.372
46	P46	0.717	16.598	0.445
47	P47	0.747	17.278	0.464
48	P48	0.786	18.186	0.488
49	P49	0.619	14.329	0.384
50	P50	0.756	17.505	0.470
Minimum		**0.296**	**6.841**	**0.184**
Maximum		**0.786**	**18.186**	**0.488**
Average ± S.D		**0.545±0.142**	**12.631±3.301**	**0.338±0.088**
World Wide average		**57.6 [125]**	**57.6 [125]**	**≤1 [144]**

Table (4.14) demonstrates results of annual average internal dose for radon (AD_{Rn}), annual average internal dose for radium (AD_{Ra}), annual average internal dose for uranium (AD_{U}), and total annual average internal dose (AD_{Total}) in a vegetable samples for human. From this table, values of (AD_{Rn}) varied from 0.126 nSv/y in sample P41 to 0.335 nSv/y in sample P48, with an average 0.247±0.067 nSv/y. Results of (AD_{Ra}) ranged from 0.617 nSv/y in P41 to 1.640 nSv/y in P48, with an average of 1.212±0.331 nSv/y, while the values of (AD_{U}) ranged from 1.585 nSv/y in the P41 sample to 4.214 nSv/y in the P48 sample, with an average value of 3.114±0.851 nSv/y. The minimum value of (AD_{Total}) was 2.328 nSv/y in P41, while the maximum value was 6.188 nSv/y in sample P48, with a mean value of 4.574±1.250 nSv/y. The

results of total annual average internal dose are less than the worldwide average of 1.2 mSv/y [149].

Results of risk of an excess cancer fatality for radon (REC_{Rn}), risk of an excess cancer fatality for radium (REC_{Ra}), risk of an excess cancer fatality for uranium (REC_{U}), and total risk of an excess cancer fatality (REC_{Total}) in vegetable samples for human, as shown in table (4.15). The results of (REC_{Rn}) varies from 0.485×10^{-6} in sample P41 to 1.288×10^{-6} in sample P48, with a mean value of $(0.953\pm0.259)\times10^{-6}$. Values of ($REC_{Ra}$) ranged from 2.375×10^{-6} in P41 to 6.313×10^{-6} in P48, and the average value of $(4.670\pm1.270)\times10^{-6}$, while the results of ($REC_{U}$) varied between 6.102×10^{-6} at P41to 16.222×10^{-6} at P48, with an average value of $(12.001\pm3.263)\times10^{-6}$. Results of ($REC_{Total}$) ranged from 8.961×10^{-6} in P41 to 23.823×10^{-6} in P48, with a mean value of $(17.625\pm4.793)\times10^{-6}$.

Table 4.14: Annual average internal dose for radon (AD_{Rn}), annual average internal dose for radium (AD_{Ra}), annual average internal dose for uranium (AD_{U}), and total annual average internal dose (AD_{total}) in vegetable samples.

No	Sample code	AD_{Rn} nSv/y	AD_{Ra} nSv/y	AD_{U} nSv/y	AD_{Total} nSv/y
1	P4	0.163	0.801	2.058	3.022
2	P5	0.243	1.190	3.057	4.489
3	P6	0.226	1.108	2.847	4.181
4	P8	0.280	1.374	3.530	5.184
5	P12	0.259	1.271	3.267	4.798
6	P15	0.222	1.087	2.794	4.103
7	P20	0.276	1.353	3.478	5.107
8	P22	0.293	1.435	3.688	5.416
9	P25	0.151	0.740	1.900	2.791
10	P29	0.310	1.517	3.898	5.725
11	P30	0.326	1.599	4.108	6.033
12	P33	0.230	1.128	2.899	4.258
13	P34	0.159	0.780	2.006	2.945
14	P36	0.301	1.476	3.792	5.570
15	P41	0.126	0.617	1.585	2.328
16	P44	0.143	0.699	1.795	2.636
17	P47	0.318	1.558	4.003	5.879
18	P48	0.335	1.640	4.214	6.188
19	P49	0.264	1.292	3.319	4.875
20	P50	0.322	1.578	4.056	5.956
Minimum		**0.126**	**0.617**	**1.585**	**2.328**
Maximum		**0.335**	**1.640**	**4.214**	**6.188**
Average ± S.D		**0.247±0.067**	**1.212±0.331**	**3.114±0.851**	**4.574±1.250**

World Wide average	---	---	---	**1.2 mSv/y [149]**

Table 4.15: Risk of an excess cancer fatality for radon (REC_{Rn}), risk of an excess cancer fatality for radium (REC_{Ra}), risk of an excess cancer fatality for uranium (REC_{U}), and total risk of an excess cancer fatality (REC_{total}) in vegetable samples.

No	Sample code	REC_{Rn} 10^{-6}	REC_{Ra} 10^{-6}	REC_{U} 10^{-6}	REC_{Total} 10^{-6}
1	P4	0.629	3.084	7.924	11.637
2	P5	0.935	4.580	11.769	17.284
3	P6	0.870	4.265	10.959	16.095
4	P8	1.079	5.289	13.591	19.959
5	P12	0.999	4.895	12.578	18.473
6	P15	0.854	4.186	10.757	15.798
7	P20	1.063	5.210	13.388	19.662
8	P22	1.128	5.525	14.198	20.851
9	P25	0.581	2.847	7.317	10.745
10	P29	1.192	5.840	15.007	22.040
11	P30	1.256	6.155	15.817	23.229
12	P33	0.886	4.344	11.162	16.392
13	P34	0.629	3.084	7.924	11.637
14	P36	1.160	5.683	14.603	21.445
15	P41	0.485	2.375	6.102	8.961
16	P44	0.549	2.690	6.912	10.150
17	P47	1.224	5.998	15.412	22.634
18	P48	1.288	6.313	16.222	23.823
19	P49	1.015	4.974	12.781	18.770
20	P50	1.240	6.077	15.615	22.932
Minimum		**0.485**	**2.375**	**6.102**	**8.961**
Maximum		**1.288**	**6.313**	**16.222**	**23.823**
Average ± S.D		**0.953±0.259**	**4.670±1.270**	**12.001±3.263**	**17.625±4.793**

Figure (2.27) shows the positive correlation between total annual average internal dose and total risk of an excess cancer fatality in vegetable sample (R^2=0.9998).

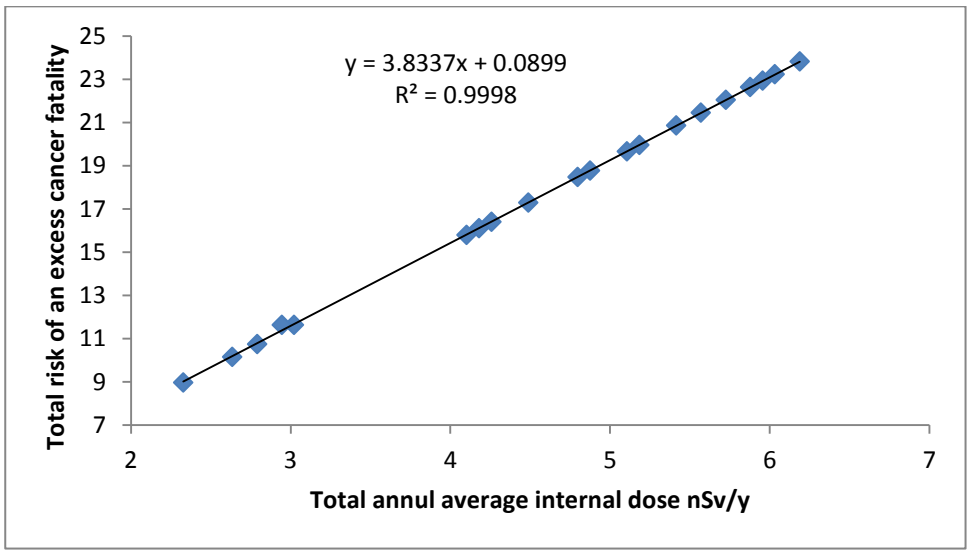

Figure 4.27 Correlation between total annual average internal dose and total risk of an excess cancer fatality in vegetable samples.

Results of annual average internal dose for radon (AD_{Rn}), annual average internal dose for radium (AD_{Ra}), annual average internal dose for uranium (AD_U), and total annual average internal dose for (AD_{Total}) in alfalfa, and barley samples as food for cow are listed in table (4.16). The calculated (AD_{Rn}) values ranged from 12.317 nSv/y in P23 to 29.410 nSv/y in P14, with an average value of 19.795±4.860 nSv/y. Values of (AD_{Ra}) varied from 60.357 nSv/y in P23 to 144.114 nSv/y in P14, with an average value of 97.015 ±23.820 nSv/y, while results of (AD_U) ranged from 155.098 nSv/y in P23 to 370.328 nSv/y in P14, with an average value of 248.100±59.465 nSv/y. The results of (AD_{Total}) varies from 227.773 nSv/y in P23 to 543.852 nSv/y in P14, and average value of 366.114±89.894 nSv/y. Results of total annual average internal dose are less than the worldwide average 1.2 mSv/y [149].

Table (4.17) shows results of risk of an excess cancer fatality for radon (REC_{Rn}), risk of an excess cancer fatality for radium (REC_{Ra}), risk of an excess cancer fatality for uranium (REC_U), and total risk of an excess cancer (REC_{Total}) in alfalfa, and barley samples as food for cow. Results of (REC_{Rn}) varies from 13.549×10^{-6} in P23 to 32.351×10^{-6} in P14, with an average value of $(21.778\pm 5.347)\times10^{-6}$. Results of ($REC_{Ra}$) varied from 66.393×10^{-6} in P23

to 158.525×10^{-6} in P14, with an average value of $(106.717\pm 26.202)\times10^{-6}$, while values of ($REC_U$) ranged from 170.608×10^{-6} in P23 to 407.361×10^{-6} in P14, with an average value of $(273.230\pm65.971)\times10^{-6}$. Results of ($REC_{Total}$) ranged from 250.550×10^{-6} in sample P23 to 598.237×10^{-6} in sample P14, with an average value of $(402.726\pm98.883)\times10^{-6}$.

Table 4.16: Annual average internal dose for radon (AD_{Rn}), annual average internal dose for radium (AD_{Ra}), annual average internal dose for uranium (AD_U), and total annual average internal dose (AD_{total}) in alfalfa, and barley samples for cow.

No	Sample code	AD_{Rn} nSv/y	AD_{Ra} nSv/y	AD_U nSv/y	AD_{Total} nSv/y
1	P1	21.135	104.056	267.393	392.684
2	P2	25.323	124.085	318.860	468.268
3	P3	17.519	85.848	220.603	323.971
4	P7	18.634	91.310	234.640	344.585
5	P9	19.006	93.131	239.319	351.456
6	P10	15.290	74.923	192.530	282.743
7	P11	18.263	89.490	229.961	337.714
8	P13	24.208	118.622	304.823	447.654
9	P14	29.410	144.114	370.328	543.852
10	P16	21.978	107.698	276.750	406.426
11	P17	26.437	129.547	332.897	488.882
12	P18	15.662	76.744	197.209	289.615
13	P19	17.891	87.669	225.282	330.842
14	P21	17.148	84.027	215.924	317.100
15	P23	12.317	60.357	155.098	227.773
16	P24	22.350	109.518	281.429	413.298
17	P26	25.694	125.906	323.539	475.139
18	P27	13.804	67.640	173.814	255.258
19	P28	27.924	136.830	315.612	516.367
20	P31	19.377	94.952	243.998	358.327
21	P32	16.776	82.206	211.245	310.228
22	P35	12.689	62.178	159.777	234.644
23	P37	16.405	80.386	206.566	303.357
24	P38	14.918	73.102	187.851	275.872
25	P39	16.033	78.565	201.888	296.486
26	P40	23.836	116.802	300.145	440.783
27	P42	20.864	102.235	262.713	385.813
28	P43	13.060	63.998	164.456	241.516
29	P45	22.722	111.339	286.108	420.169
30	P46	27.180	133.189	342.255	502.624
Minimum		**12.317**	**60.357**	**155.098**	**227.773**
Maximum		**29.410**	**144.114**	**370.328**	**543.852**
Average±S.D		**19.795±4.860**	**97.015±23.820**	**248.100±59.465**	**366.114±89.894**
World Wide average		**----------**	**----------**	**----------**	**1.2 mSv/y[149]**

Table 4.17: Risk of an excess cancer fatality for radon (REC_{Rn}), risk of an excess cancer fatality for radium (REC_{Ra}), risk of an excess cancer fatality for uranium (REC_{U}) , and total risk of an excess cancer fatality (REC_{Total}) in alfalfa, and barley samples for cow.

No	Sample code	REC_{Rn} $\times 10^{-6}$	REC_{Ra} $\times 10^{-6}$	REC_{U} $\times 10^{-6}$	REC_{Total} $\times 10^{-6}$
1	P1	23.359	114.462	294.131	431.952
2	P2	27.855	136.493	350.746	515.095
3	P3	19.271	94.433	242.664	356.368
4	P7	20.498	100.441	258.104	379.043
5	P9	20.906	102.444	263.251	386.602
6	P10	16.819	82.416	211.783	311.018
7	P11	20.089	98.439	252.957	371.485
8	P13	26.629	130.485	335.306	492.420
9	P14	32.351	158.525	407.361	598.237
10	P16	24.176	118.467	304.425	447.069
11	P17	29.081	142.502	366.187	537.770
12	P18	17.228	84.418	216.930	318.576
13	P19	19.680	96.436	247.810	363.927
14	P21	18.863	92.430	237.517	348.810
15	P23	13.549	66.393	170.608	250.550
16	P24	24.585	120.470	309.572	454.627
17	P26	28.264	138.496	355.893	522.653
18	P27	15.184	74.404	191.196	280.784
19	P28	30.716	150.513	386.774	568.004
20	P31	21.315	104.447	268.397	394.160
21	P32	18.454	90.427	232.370	341.251
22	P35	13.958	68.395	175.755	258.109
23	P37	18.045	88.424	227.223	333.693
24	P38	16.410	80.413	206.636	303.459
25	P39	17.636	86.421	222.076	326.134
26	P40	26.220	128.482	330.159	484.861
27	P42	22.950	112.459	288.985	424.394
28	P43	14.367	70.398	180.902	265.667
29	P45	24.994	122.473	314.719	462.186
30	P46	29.899	146.508	346.480	552.887
Minimum		**13.549**	**66.393**	**170.608**	**250.550**
Maximum		**32.351**	**158.525**	**407.361**	**598.237**
Average ± S.D		**21.778±5.347**	**106.717±26.202**	**273.230±65.971**	**402.726±98.883**

Figure (2.28) shows a good correlation between total annual average internal dose and total risk of an excess cancer fatality in alfalfa and barley sample for cow. (R^2=1).

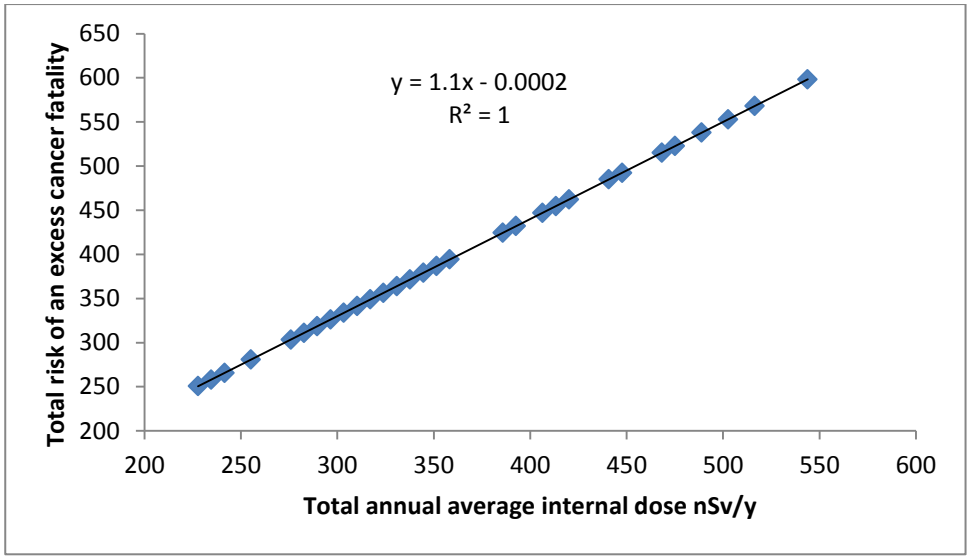

Figure 4.28 Correlation between total annual average internal dose and total risk of an excess cancer fatality in alfalfa and barley samples for cow.

Results of measurements for annual average internal dose for radon (AD_{Rn}), annual average internal dose for radium (AD_{Ra}), annual average internal dose for uranium (AD_U), and total annual average internal dose (AD_{Total}) in an alfalfa, and barley sample as food for sheep are listed in table (4.18). The calculated (AD_{Rn}) values ranged frome 5.051 nSv/y in P23 to 12.061 nSv/y in P14, with an average value of 8.134±1.987 nSv/y. Values of (AD_{Ra}) varied from 24.753 nSv/y in P23 to 59.103 nSv/y in P14, with an average value of 40.120±9.882 nSv/y, while results of (AD_U) ranged from 63.607 nSv/y in P23 to 151.876 nSv/y in P14, with an average value of 102.240±25.103 nSv/y. Results of (AD_{Total}) varies from 93.413 nSv/y in P23 to 223.040 nSv/y in P14, and average value of 150.148±36.866 nSv/y. Results of total annual average internal dose are less than the worldwide average of 1.2 mSv/y [149].

Table (4.19) shows the results of risk of an excess cancer fatality for radon (REC_{Rn}), risk of an excess cancer fatality for radium (REC_{Ra}), risk of an excess cancer fatality for uranium (REC_U), and total risk of an excess cancer fatality (REC_{Total}) in alfalfa, and barley samples as food for sheep. Values of (REC_{Rn}) ranged from 1.389×10^{-6} in P23 to 3.317×10^{-6} in P14, with an average value of $(2.232 \pm 0.549) \times 10^{-6}$. The results of ($REC_{Ra}$) varied from 6.807×10^{-6} in P23 to 16.253×10^{-6} in P14, with an average value of $(10.941 \pm 2.686) \times 10^{-6}$, while values of (REC_U) ranged from 17.4922×10^{-6} in P23 to 41.7659×10^{-6} in P14, with an average value of $(28.116 \pm 6.903) \times 10^{-6}$. Results of ($REC_{Total}$) ranged from 25.688×10^{-6} in sample P23 to 61.336×10^{-6} in sample P14, with an average value of $(41.290 \pm 10.138) \times 10^{-6}$.

Table 4.18: Annual average internal dose for radon (AD_{Rn}), radium (AD_{Ra}), and uranium(AD_U), total annual average internal dose (AD_{total}) in alfalfa, and barley samples for sheep.

No	Sample code	AD_{Rn} nSv/y	AD_{Ra} nSv/y	AD_U nSv/y	AD_{Total} nSv/y
1	P1	8.709	42.675	109.661	161.044
2	P2	10.385	50.889	130.768	192.042
3	P3	7.185	35.207	90.472	132.865
4	P7	7.642	37.448	96.228	141.319
5	P9	7.794	48.194	98.147	144.137
6	P10	6.271	30.727	78.959	115.957
7	P11	7.490	36.701	94.310	138.501
8	P13	9.928	48.648	125.012	183.588
9	P14	12.061	59.103	151.876	223.040
10	P16	9.014	44.168	113.498	166.680
11	P17	10.842	53.129	136.525	200.496
12	P18	6.423	31.474	80.877	118.775
13	P19	7.337	35.954	92.391	135.683
14	P21	7.471	34.461	88.553	130.047
15	P23	5.051	24.753	63.607	93.413
16	P24	9.166	44.915	115.417	169.498
17	P26	10.538	51.635	132.687	194.860
18	P27	5.661	27.740	71.283	104.685
19	P28	11.452	56.116	144.200	211.768
20	P31	7.947	38.941	100.066	146.955
21	P32	6.880	33.714	86.634	127.229
22	P35	5.204	25.500	65.526	96.231
23	P37	6.728	32.967	84.715	124.411
24	P38	6.118	29.980	77.040	113.139
25	P39	6.575	32.220	82.796	121.593
26	P40	9.776	47.902	123.093	180.770

27	P42	8.556	41.928	107.742	158.226
28	P43	5.356	26.247	67.445	99.049
29	P45	9.318	45.662	117.336	172.316
30	P46	11.147	54.622	140.363	206.132
Minimum		**5.051**	**24.753**	**63.607**	**93.413**
Maximum		**12.061**	**59.103**	**151.876**	**223.040**
Average ± S.D		**8.134±1.987**	**40.120±9.882**	**102.240±25.103**	**150.148±36.866**
World Wide average		**----------**	**----------**	**----------**	**1.2 mSv/y [149]**

Table 4.19: Risk of an excess cancer fatality for radon (REC_{Rn}), radium (REC_{Ra}), and uranium (REC_U), total risk of an excess cancer fatality (REC_{total}) in alfalfa, and barley samples for sheep.

No	**Sample code**	**REC_{Rn} $\times 10^{-6}$**	**REC_{Ra} $\times 10^{-6}$**	**REC_U $\times 10^{-6}$**	**REC_{Total} $\times 10^{-6}$**
1	P1	2.395	11.736	30.1567	44.287
2	P2	2.856	13.994	35.9613	52.812
3	P3	1.976	9.682	24.8798	36.538
4	P7	2.102	10.298	26.4629	38.863
5	P9	2.143	10.503	26.9906	39.638
6	P10	1.724	8.450	21.7113	31.888
7	P11	2.060	10.093	25.9352	38.088
8	P13	2.730	13.378	34.3783	50.487
9	P14	3.317	16.253	41.7659	61.336
10	P16	2.479	12.146	31.2121	45.837
11	P17	2.982	14.610	37.5444	55.137
12	P18	1.766	8.655	22.2414	32.663
13	P19	2.018	9.887	25.4075	37.313
14	P21	1.934	9.477	24.3521	35.763
15	P23	1.389	6.807	17.4922	25.688
16	P24	2.521	12.352	31.7398	46.612
17	P26	2.898	14.200	36.4890	53.587
18	P27	1.557	7.629	19.6029	28.788
19	P28	3.149	15.432	39.6552	58.236
20	P31	2.185	10.709	27.5183	40.412
21	P32	1.892	9.271	23.8244	34.988
22	P35	1.413	7.012	18.0198	26.463
23	P37	1.850	9.066	23.2968	34.213
24	P38	1.683	8.245	21.1860	31.113
25	P39	1.808	8.861	22.7691	33.438
26	P40	2.688	13.173	33.8506	49.712
27	P42	2.353	11.530	29.6290	43.512
28	P43	1.473	7.218	18.5475	27.238
29	P45	2.563	12.557	32.2675	47.387
30	P46	3.065	15.021	38.5998	56.686
Minimum		**1.389**	**6.807**	**17.4922**	**25.688**

Maximum	3.317	16.253	41.7659	61.336
Average ± S.D	2.232±0.549	10.941±2.686	28.116±6.903	41.290±10.138

Figure (2.29) shows a good correlation between total annual average internal dose and total risk of an excess cancer fatality in alfalfa, and barley samples for sheep. (R^2=1).

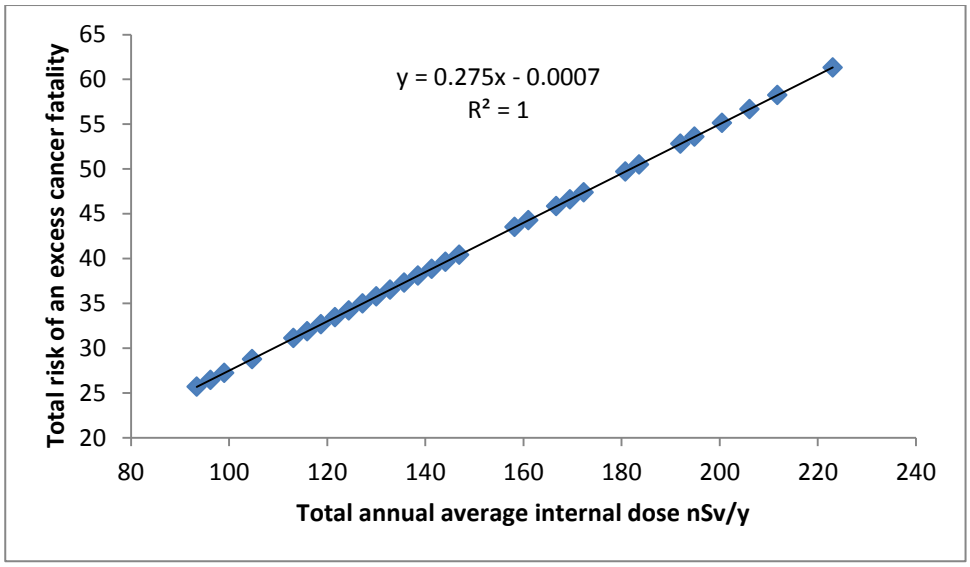

Figure 4.29 Correlation between total annual average internal dose and total risk of an excess cancer fatality in alfalfa, and barley samples for sheep.

4.5. Transfer Factor (TF)

The transfer factor soil-to-plant, which are the ratios of specific activities in plant parts and soil, can be used as an index for the accumulation of trace elements by plants or the transfer of elements from soil to plant through the roots. The specific activity for radioisotopes (^{238}U, ^{232}Th, and ^{40}K) and radioisotopes (^{222}Rn, ^{226}Ra, and ^{238}U), were calculated in the plant and in the corresponding soil.

4.5.1 Transfer Factor for ^{238}U, ^{232}Th, and ^{40}K

Table (4.20) summarizes the transfer factor for ^{238}U, ^{232}Th, and ^{40}K from 50 soil samples to their corresponding dry plants at the same site. It was found that the minimum value of ^{238}U was BDL in samples P1, P3, P7, P8, P9, P12, P20, P22, P23, P25, P26, p28, P29, P30, P34, P37, P38, and P44, while the maximum value was 0.589 in sample P2, with an average value of 0.234 ±0.126. Values of ^{232}Th ranged from BDL in samples P4, P9, P12, P16, P23, P25, P29, P30, P36, and P45 to 0.804 in sample P15, with an average value of 0.304±0.206. Values of ^{40}K varied from 0.369 in sample P7 to 0.968 in sample P23, with an average value of 0.720±0.133. Results of this study showed that the contribution of soil for radioactive nuclei (^{238}U, ^{232}Th, ^{40}K) in the plants grown in it is 0.234, 0.304, and 0.720, respectively. This means that the soil contributes 234 Bq/kg per 1000 Bq/kg for ^{238}U, 304 Bq/kg per 1000 Bq/kg for ^{232}Th, and 720 Bq/kg per 1000 Bq/kg for ^{40}K. From the contribution pattern, it is evident that potassium contributes more than thorium and uranium. Figures 4.30, 4.31, and 4.32 show distribution of transfer factor for all different samples.

Table 4.20: Transfer factor for ^{238}U, ^{232}Th, and ^{40}K from soil to plant samples.

No	Sample code		TF		
			^{238}U	^{232}Th	^{40}K
1	S1	P1	BDL	0.352	0.775
2	S2	P2	0.589	0.314	0.899
3	S3	P3	BDL	0.123	0.959
4	S4	P4	0.271	BDL	0.833
5	S5	P5	0.129	0.132	0.437
6	S6	P6	0.073	0.278	0.633
7	S7	P7	BDL	0.469	0.369
8	S8	P8	BDL	0.002	0.814
9	S9	P9	BDL	BDL	0.645
10	S10	P10	0.306	0.353	0.672
11	S11	P11	0.227	0.089	0.814
12	S12	P12	BDL	BDL	0.731
13	S13	P13	0.342	0.433	0.789
14	S14	P14	0.068	0.200	0.678
15	S15	P15	0.131	0.804	0.697
16	S16	P16	0.272	BDL	0.614
17	S17	P17	0.386	0.699	0.584
18	S18	P18	0.367	0.112	0.748
19	S19	P19	0.483	0.650	0.761
20	S20	P20	BDL	0.181	0.669
21	S21	P21	0.248	0.059	0.775
22	S22	P22	BDL	0.557	0.641
23	S23	P23	BDL	BDL	0.968
24	S24	P24	0.341	0.014	0.922
25	S25	P25	BDL	BDL	0.850
26	S26	P26	BDL	0.217	0.768
27	S27	P27	0.12	0.325	0.771
28	S28	P28	BDL	0.459	0.835
29	S29	P29	BDL	BDL	0.683
30	S30	P30	BDL	BDL	0.577
31	S31	P31	0.357	0.411	0.628
32	S32	P32	0.306	0.348	0.646
33	S33	P33	0.187	0.434	0.502
34	S34	P34	BDL	0.333	0.623
35	S35	P35	0.142	0.132	0.886
36	S36	P36	0.144	BDL	0.604
37	S37	P37	BDL	0.353	0.600
38	S38	P38	BDL	0.354	0.625
39	S39	P39	0.185	0.479	0.519
40	S40	P40	0.159	0.285	0.550
41	S41	P41	0.107	0.020	0.634
42	S42	P42	0.174	0.237	0.659

43	S43	P43	0.241	0.059	0.861
44	S44	P44	BDL	0.055	0.790
45	S45	P45	0.017	BDL	0.730
46	S46	P46	0.059	0.160	0.739
47	S47	P47	0.275	0.098	0.891
48	S48	P48	0.285	0.321	0.921
49	S49	P49	0.256	0.617	0.742
50	S50	P50	0.256	0.644	0.765
Minimum			**BDL**	**BDL**	**0.369**
Maximum			**0.589**	**0.804**	**0.968**
Average ± S.D			**0.234±0.126**	**0.304±0.206**	**0.720±0.133**

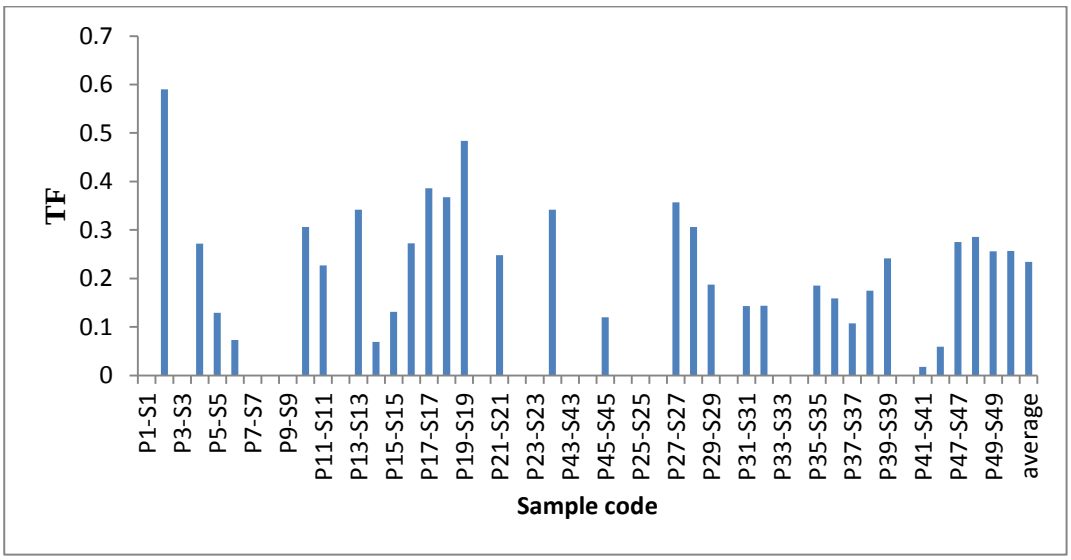

Figure 4.30 Transfer factor from soil to plant samples for ^{238}U.

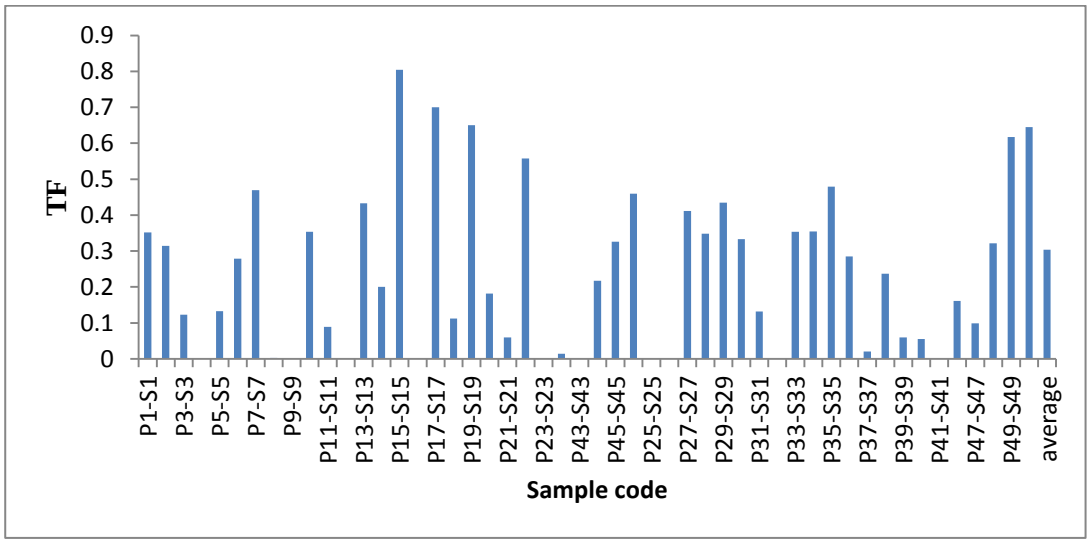

Figure 4.31 Transfer factor from soil to plant samples for ^{232}Th.

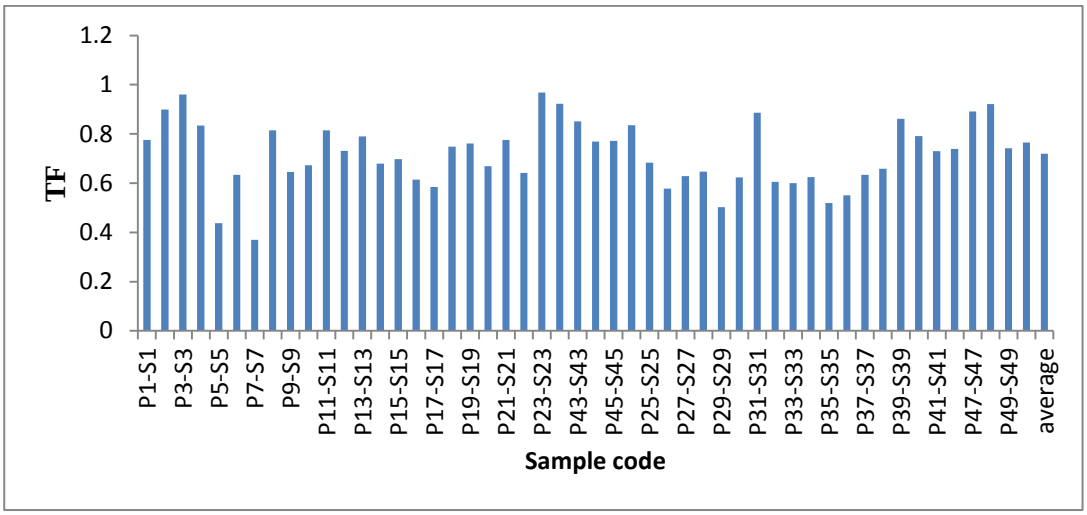

Figure 4.32 Transfer factor from soil to plant samples for ^{40}K.

4.5.2 Transfer Factor for ^{222}Rn, ^{226}Ra, and ^{238}U

Table (4.21) shows the results of the transfer factor for ^{222}Rn, ^{226}Ra, and ^{238}U from 50 soil samples to their corresponding dry plants at the same site. It was found that the minimum value of ^{222}Rn was 0.206 in samples P48, while the maximum value was 0.820 in sample P46, with an average value of 0.4098 ±0.1174. Values of ^{226}Ra ranged from 0.206 in samples P48 to 0.816 in sample P46, with an average value of 0.4097±0.1172. Values of ^{238}U varied from 0.206 in sample P48 to 0.819 in sample P46, with an average value of 0.4095 ±0.1174. Results of this study showed that the soil's contribution of alpha particle radionuclides (^{222}Rn, ^{226}Ra, ^{238}U) to plants is 0.409, meaning it contributes 409 Bq/kg per 1000 Bq/kg of radon, radium, and uranium. This indicates that all contributions of these radionuclides are equal, as they are in a state of radiological equilibrium within the uranium series. Figures 4.33, 4.34, and 4.35 show distribution of transfer factor for all different samples.

Table 4.21: Transfer factor for ^{222}Rn, ^{226}Ra, and ^{238}U from soil to plant.

No	Sample code		TF		
			^{222}Rn	^{226}Ra	^{238}U
1	S1	P1	0.557	0.56	0.557
2	S2	P2	0.644	0.643	0.643
3	S3	P3	0.374	0.372	0.374
4	S4	P4	0.508	0.510	0.508
5	S5	P5	0.474	0.476	0.474
6	S6	P6	0.467	0.468	0.467
7	S7	P7	0.302	0.301	0.302
8	S8	P8	0.312	0.314	0.312
9	S9	P9	0.382	0.380	0.382
10	S10	P10	0.351	0.352	0.351
11	S11	P11	0.565	0.566	0.564
12	S12	P12	0.377	0.378	0.377
13	S13	P13	0.398	0.396	0.398
14	S14	P14	0.303	0.301	0.302
15	S15	P15	0.373	0.373	0.373
16	S16	P16	0.570	0.571	0.570
17	S17	P17	0.503	0.505	0.503
18	S18	P18	0.293	0.291	0.293
19	S19	P19	0.412	0.404	0.400
20	S20	P20	0.560	0.562	0.560
21	S21	P21	0.363	0.361	0.363
22	S22	P22	0.504	0.502	0.504
23	S23	P23	0.250	0.248	0.25
24	S24	P24	0.276	0.275	0.275
25	S25	P25	0.297	0.297	0.297
26	S26	P26	0.602	0.6	0.602
27	S27	P27	0.475	0.473	0.475
28	S28	P28	0.450	0.453	0.450
29	S29	P29	0.465	0.463	0.466
30	S30	P30	0.433	0.433	0.433
31	S31	P31	0.342	0.344	0.341
32	S32	P32	0.294	0.294	0.293
33	S33	P33	0.364	0.364	0.364
34	S34	P34	0.338	0.335	0.339
35	S35	P35	0.309	0.313	0.309
36	S36	P36	0.498	0.5	0.498
37	S37	P37	0.412	0.415	0.412
38	S38	P38	0.360	0.360	0.360
39	S39	P39	0.395	0.398	0.395
40	S40	P40	0.500	0.5	0.501
41	S41	P41	0.321	0.324	0.321
42	S42	P42	0.241	0.240	0.241
43	S43	P43	0.281	0.282	0.281

44	S44	P44	0.300	0.304	0.300
45	S45	P45	0.469	0.465	0.469
46	S46	P46	0.820	0.816	0.819
47	S47	P47	0.395	0.397	0.395
48	S48	P48	0.206	0.206	0.206
49	S49	P49	0.405	0.405	0.405
50	S50	P50	0.377	0.377	0.377
Minimum			**0.206**	**0.206**	**0.206**
Maximum			**0.820**	**0.816**	**0.819**
Average ± S.D			**0.4098±0.1174**	**0.4097±0.1172**	**0.4095±0.1174**

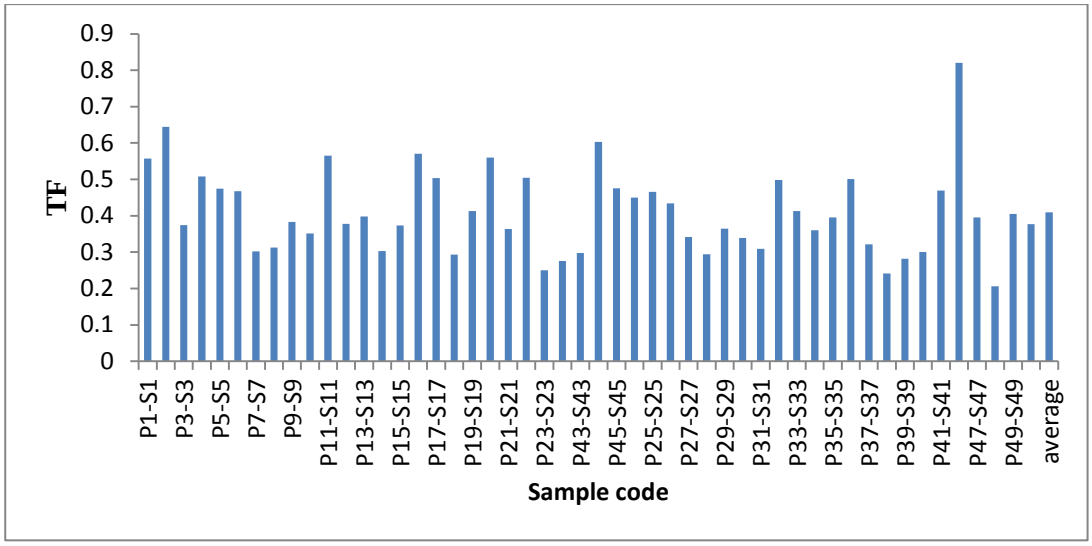

Figure 4.33 Transfer factor from soil to plant samples for ^{222}Rn.

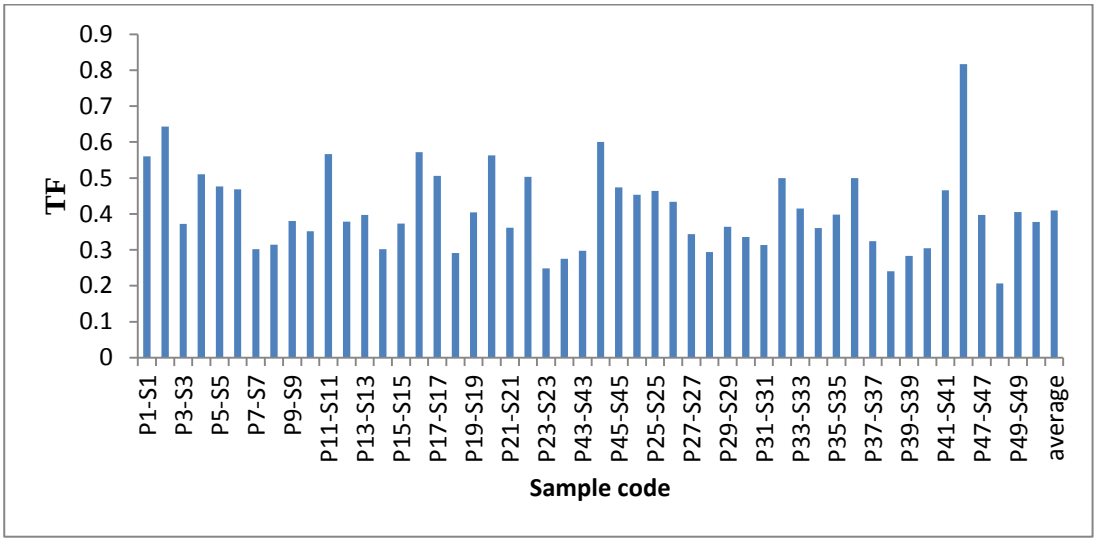

Figure 4.34 Transfer factor from soil to plant samples for ^{226}Ra.

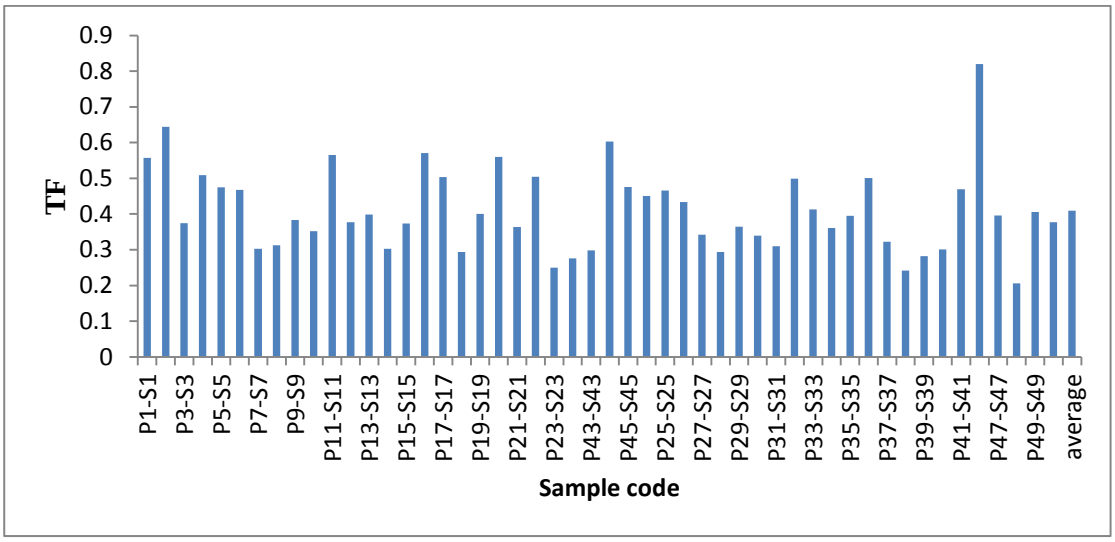

Figure 4.35 Transfer factor from soil to plant samples for ^{238}U.

4.6 Compare the results of gamma emitters in the present study with previous studies

Table (4.22) shows a comparison of the average specific activity of ^{238}U, ^{232}Th, and ^{40}K in soil and plants observed in the current study with those conducted by other researchers in different locations around the world. In the present study, the mean value of ^{238}U in soil and plant samples is lower than values in Bangladesh(Dhaka) , Nigeria , Jordan, Egypt, Qatar, Iraq(Mosul), Iraq, and Vietnam, while it is almost identical to those in Saudi Arabia, Malaysia, Kuwait, and Iraq(Al-Taji city). The average value of ^{232}Th in soil and plant samples is less than values in Saudi Arabia, Bangladesh (Dhaka), Jordan, Egypt, Malaysia, Iraq, and Vietnam, while it is almost identical to those in Kuwait, Qatar, Iraq(Mosul), Malaysia, and Turkey. The average value of ^{40}K in soil and plant samples is lower than values in Saudi Arabia and Bangladesh(Dhaka) and higher than values in Malaysia, Qatar, Iraq, Iraq(Al-Taji city), Turkey, and Jordan, while it is almost identical to those in Nigeria, Jordan, Egypt, Kuwait, Iraq(Mosul), and Vietnam.

Table 4.22: Comparison of gamma emitters in the present study with others studied in many different countries.

No	Country	sample	Average of specific activity in Bq/kg			Ref.
			^{238}U	^{232}Th	^{40}K	
1	Saudi Arabia	soil	12.96	16.6	618	[33]
2	Bangladesh(Dhaka)	soil	52.07	77.35	892.65	[150]
3	Nigeria	soil	52.91	76.79	393.73	[151]
4	Jordan	soil	49	70	291	[152]
5	Egypt	soil	37	18	320	[153]
6	Malaysia	soil	11.08	22.60	119.23	[154]
7	Kuwait	soil	13.2	11.1	303	[155]
8	Qatar	soil	17.2	6.38	16	[156]
9	Iraq(Mosul)	soil	33	9	354	[157]
10	Iraq	soil	40.0	21.4	29.0	[158]
11	Saudi Arabia	plant	1.51	1.33	98.92	[35]
12	Iraq(Al-Taji city)	plant	2.233	0.042	92	[46]
13	Bangladesh(Dhaka)	plant	3.34	13.36	329.26	[150]
14	Nigeria	plant	25.881	19.898	327.165	[151]
15	Malaysia	plant	1.58	1.41	122.70	[154]
16	Iraq(Mosul)	plant	10	3	214	[157]
17	Turkey	plant	0.67	1.04	171	[159]
18	Vietnam	plant	24.1	30.8	258	[160]
19	Jordan	plant	57.7	18.1	138.1	[161]
20	Iraq (Karbala)	soil	10.136	10.392	347.777	Present study
		plant	2.235	3.158	247.593	

4.7 Compare the results of alpha emitters in the present study with previous studies

Table (4.23) shows a comparison of the average specific activity of radon, radium, and uranium in soil and plant observed in the current study with those conducted by other researchers in different locations around the world. In the present study, the concentration of ^{222}Rn in soil and plant samples are higher than values in Egypt, Saudi Arabia, Palestine, Lebanon, Iraq(Babylon), Iraq (Baghdad), Iraq(Al-Tuwaitha), Iraq(Maysan), Jordan, Iraq, Iraq(Karbala), and Iraq(Ninawa), while less than values in Iraq(Al Hamdaniya). The concentration of ^{226}Ra in soil and plant sample less than values in India, Saudi Arabia, Palestine, Iraq(Al-Tuwaitha), Iraq(Maysan), Iraq, Iraq(Karbala), Iraq(Babil), Iraq(Ninawa), and Jordan, while it is almost identical to those in Lebanon. The concentration of ^{238}U in soil and plant samples in current study higher than values in Iraq(Al Hamdaniya), Iraq(Babylon), Iraq (Baghdad), Iraq, Iraq(Babil), and Iraq(Ninawa) and less than values in India, Iraq(Baghdad), and Jordan , while it is almost identical to those in Lebanon.

Table 4.23: Comparison of alpha emitters in the present study with others studied in many different countries.

No	Country	sample	Average concentration			Ref.
			^{222}Rn Bq/m^3	^{226}Ra Bq/kg	^{238}U ppm	
1	India	soil	---------	23.297	4.346	[55]
2	Egypt	soil	265.96	----------	----------	[67]
3	Saudi Arabia	soil	276.33	10.10	----------	[72]
4	Palestine	soil	145.0	11.1	----------	[162]
5	Lebanon	soil	451.01	1.079	1.467	[163]
6	Iraq(Al Hamdaniya)	soil	9104.52	----------	0.488	[164]
7	Iraq(Babylon)	soil	57.656	----------	0.023	[165]
8	Iraq (Baghdad)	soil	281.59	----------	0.01	[166]
9	Iraq(Al-Tuwaitha)	soil	20.939	7.393	----------	[167]
10	Iraq(Maysan)	soil	776.98	37.79	----------	[168]
11	Egypt	plant	57.320	---------	----------	[61]
12	Iraq	plant	27.7	0.39	0.48	[62]

13	Iraq(Karbala)	plant	3.99	4.69	----------	[69]
14	Iraq(Babil)	plant	----------	0.301	0.0190	[70]
15	Iraq(Ninawa)	plant	51.506	0.212	0.232	[71]
16	Jordan	plant	93.3	8.20	93	[169]
17	Iraq	plant	---------	0.317	0.345	[170]
18	Iraq(Baghdad)	plant	---------	0.037	3.038	[171]
19	Iraq	plant	210.12	0.434	---------	[172]
20	Iraq (Karbala)	soil	1884.882	0.174	2.791	Present study
		plant	731.784	0.067	1.083	

4.8 Compare the results of transfer factor in the present study with previous studies

Table (4.24) shows a comparison of the transfer factor observed in the current study with those conducted by other researchers in different locations around the world. In the present study, the average value of ^{238}U is lower than values in Iraq (Karbala) and Palestine and higher than values in Iraq (Tuwaitha), while it is almost identical to those in Iraq(Al-Taji city) and Romania. The average value of ^{232}Th is higher than values in Iraq(Khidir City), Malaysia, and Bangladesh(Chittagong) and lower than values in Iraq (Karbala), Nigeria(Nasarawa), Palestine, and Iraq (Tuwaitha), while it is almost identical to those in Iraq(Al-Taji city), Nigeria, Iraq (Mosul), and Egypt. The average value of ^{40}K is higher than values in Saudi Arabia, Bangladesh(Dhaka), Nigeria(Oyo), and Bangladesh (Chittagong) and less than values in Iraq(Al-Taji city), Malaysia, Nigeria, Nigeria(Nasarawa), Egypt, Palestine, Iraq(Tuwaitha), and Iraq(Baghdad), while it is almost identical to those in Iraq(Khidir City), Iraq (Karbala), and Iraq(Mosul).

Table 4.24: Comparison of transfer factor in the present study with others studied in many different countries.

No	Country	TF			Ref
		^{238}U	^{232}Th	^{40}K	
1	Saudi Arabia	--------	---------	0.16	[33]
2	Iraq(Al-Taji city)	0.346	0.260	1.029	[46]
3	Iraq(Khidir City)	--------	0.101	0.669	[50]
4	Iraq (Karbala)	0.885	0.647	0.855	[51]
5	Bangladesh(Dhaka)	--------	--------	0.38	[150]
6	Malaysia	---------	0.07	1.30	[154]
7	Nigeria	--------	0.39	26.58	[151]
8	Iraq(Mosul)	-------	0.42	0.65	[157]
9	Nigeria(Nasarawa)	--------	1.18	02.02	[173]
10	Nigeria(Oyo)	---------	----------	0.370	[174]
11	Egypt	-------	0.31	1.06	[175]
12	Bangladesh(Chittagong)	--------	0.088	0.266	[176]
13	Palestine	1.12	1.15	1.20	[177]
14	Romania	0.36	---------	---------	[178]
15	Iraq(Tuwaitha)	0.020	1.608	1.007	[179]
16	Iraq(Baghdad)	--------	0.9	1.02	[180]
17	Iraq (Karbala)	0.234	0.304	0.720	Present study

4.9 Conclusions

Based on the results obtained from the analysis of agriculture soil samples and plant samples, the following can be concluded:

1- It was found value of specific activity in soil and plant samples for ^{238}U, ^{232}Th, and ^{40}K in the current study were less than the global average value reported by UNSCEAR, 2008. The concentration of ^{222}Rn, ^{226}Ra, and ^{232}U in soil and plant samples found all samples lower than the worldwide average value.

2- The results reveal that the radiological hazard of gamma and alpha emitters (Radium equivalent, absorbed dose rate, internal and external hazard index, gamma and alpha index, exposure rate, annual gonadal equivalent dose, annual effective dose equivalent, and excess lifetime cancer risk, radon exhalation rate mass and surfers, annual effective dose of radon, total annual dose, and total risk of an excess cancer) for all soil and plant samples is lower than the global average value reported by UNSEAR and ICPR. We conclude that the agricultural soil in the research area does not present any radiation health hazard due to the release of radionuclides.

3- The results of annual effective dose and hereditary cancer risk in vegetable samples were less than the permissible limit. Therefore, eating these vegetables does not pose a risk to humans, while found that the results of annual effective dose and hereditary cancer risk for alfalfa, and barley samples were higher than the permissible international limit. The reason for exceeding the permissible dosage is due to the increase in annual consumption. The annual consumption of alfalfa and barley for cow is approximately 5475 kg/y. The annual consumption of alfalfa and barley for sheep is approximately 1080 kg/y, while the annual consumption of vegetables by humans is 60 kg/y.

4- The results of the transfer factor for ^{238}U, ^{232}Th, and ^{40}K, from agricultural soil to plant in this study showed that the contribution of soil for radioactive nuclei is 0.234, 0.304, and 0.720, respectively. This means that the soil contributes 234 Bq/kg per 1000 Bq/kg for ^{238}U, 304 Bq/kg per 1000 Bq/kg for ^{232}Th, and 720 Bq/kg per 1000 Bq/kg for ^{40}K . The TF values for ^{40}K were higher than those for ^{238}U and ^{232}Th. This is due to the presence of phosphate fertilizers, which have an increased potassium concentration.

The transfer factor of alpha particle radionuclides (^{222}Rn, ^{226}Ra, ^{238}U) to plants is 0.409, meaning it contributes 409 Bq/kg per 1000 Bq/kg of radon, radium, and uranium. This indicates that all contributions of these radionuclides are equal, as they are in a state of radiological equilibrium within the uranium series.

4.10 Recommendations

1- The competent authorities should issue instructions to all farmers to promote the use of organic fertilizers in agriculture and reduce reliance on chemical fertilizers. This can help reduce the concentration of radionuclides in the soil.
2- Educating people about the health risks of naturally occurring radioactive elements in soil and plants.
3- Scientific and research institutions must be provided with modern and sufficient equipment to conduct environmental studies on radioactivity.
4- He also suggests repeating these studies for all governorates of Iraq and create a map of radioactivity.

4.11 Future Studies

1. Expanding this study to include more plants by conducting more research and studies on the radioactive contamination of other types of plants that Iraqi eat to ensure that they are free of radioactivity.
2. Using different techniques to measure radioactive nuclei (^{238}U, ^{232}Th, and ^{40}k), such as high-tech detectors (HPGe) for the same samples studied and compared to the current study.
3. Use another type of nuclear trace detector to measure the concentration of ^{222}Rn, such as a detector (LR-115), (CN-85), or (PM-355) for the same models studied and compared to the current study.

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جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة كربلاء/ كلية العلوم
قسم الفيزياء

مخاطر السرطان للنويدات المشعة المنتقلة من التربة الى النباتات في محافظة كربلاء العراق

رسالة مقدمة الى
مجلس كلية العلوم / جامعة كربلاء
كجزء من متطلبات نيل درجة الماجستير في علوم الفيزياء

من قبل

علاء مالك وعد

بكالوريوس علوم الفيزياء 2013

بإشراف

أ. د. عبد الستار كريم هاشم

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الخلاصة

تحتوي التربة على العديد من النظائر المشعة الطبيعية مثل (اليورانيوم-238 ، الثوريوم- 232 ، البوتاسيوم-40). تنتقل هذه العناصر المشعة الى النباتات من التربة المزروعة فيها، والتي بدورها تنتقل الى الانسان من الطعام الذي يتناوله. وتعتمد الجرعات الاشعاعية على تركيز النظائر المشعة الطبيعية وسلالاتها في المواد الغذائية، وبالتالي فأن تقييم النشاط الاشعاعي في النباتات له اهمية كبيرة من وجهة نظر السلامة الاشعاعية. حيث تم جمع 100 عينة بواقع 50 عينة نبات كل من (البرسيم ،الشعير، السبانغ ، الفجل، السلق) و50 عينة تربة من نفس موقع النبات وشملت المناطق الزراعية في محافظة كربلاء وهي كل من قضاء الهندية وقضاء الحسينية وقضاء الحر وقضاء عين التمر، حيث ترفد هذه المناطق الاسواق المحلية بالمحاصيل الزراعية. تم قياس تراكيز النظائر المشعة (^{40}K, ^{238}U ^{232}Th) باستخدام كاشف يوديد الصوديوم المطعم بالثاليوم NaI(Tl) والنظائر المشعة (^{238}U, ^{226}Rn, ^{222}Ra) باستخدام كاشف CR-39.

أظهرت النتائج ان متوسط قيم النشاط الاشعاعي النوعي ل ^{238}U ,^{232}Th, ^{40}K في عينات التربة (10.136±1.040، 10.392±0.654، 347.777±6.151) Bq/kg على التوالي، اما في عينات النبات فكانت النتائج (2.235±0.489، 3.158±0.336، 247.593±5.147) Bq/kg على التوالي. تم مقارنة هذه القيم مع متوسط القيم العالمية لمنظمة (UNSCEAR 2008) حيت وجدت اقل من القيم المسموح بها عالميا. اما نتائج معامل الخطر الداخلي (H_{in})، معامل الخطر الخارجي(H_{ex})، معدل الجرعة الممتصة في الهواء(D_r)، مكافئ الراديوم(Ra_{eq})، خطر الاصابة بالسرطان مدى الحياة (ELCR)، مكافئ الجرعة الفعالة السنوية (AEDE)، الجرعة المكافئة السنوية للغدد التناسلية(AGED)، معدل التعرض، مؤشر الفا(I_α)، مؤشر كاما(I_γ)، لبواعث اشعة كاما في عينات التربة والنبات كانت ضمن الحدود المسموح بها عالميا. كذلك نتائج الجرعة الفعالة السنوية (AED) ومخاطر السرطان الوراثي (HCR) في عينات الخضروات كانت ضمن الحدود المسموح بها عالميا، بينما نتائج (AED) و (HCR) في عينات البرسيم والشعير التي تتناولها الأبقار والاغنام كانت اعلى من القيم المسموح بها بسبب زيادة الاستهلاك السنوي لها.

كما وجد معدل قيم تراكيز (^{238}U, ^{226}Ra, ^{222}Rn) في عينات التربة (1.030±2.791، 0.064±0.174، 1.052±2.849) Bq/kg على التوالي، بينما متوسط القيم في عينات النبات كانت (0.283±1.083، 0.017±0.067، 0.289±1.106) Bq/kg على التوالي. حيث وجدت ضمن الحد العالمي المسموح به وفقا لـ UNSCEAR. وجدت نتائج معدل الانبعاث الكتلي (E_M)، ومعدل الانبعاث السطحي (E_S)، والجرعة السنوية الفعالة (D_{eff})، ومؤشر الفا (I_α)، ومؤشر الاصابة بالسرطان مدى الحياة (ELCR)، والجرعة الداخلية المتوسطة السنوية (AD)، وزيادة مخاطر الاصابة بالسرطان (REC) لعينات التربة والنبات كانت اقل من الحدود المسموح بها وفقا لـ (ICRP, UNSCEAR). اما نتائج عامل الانتقال لـ (^{238}U, ^{232}Th, ^{40}K) و (^{238}U, ^{226}Ra, ^{222}Rn) من التربة الى النبات فكانت (0.234, 0.304, 0.720)، (4098, 4097, 0.4095) على التوالي.