Faculty of Graduate Studies

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Measurement of Radon Exhalation Rate and Radium Activity in different types of Foodstuff samples used in Palestine

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DEDICATION

I dedicate this project to God Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. To my loving parents (Isaa Dowek, Ibtehaj Mohtaseb), who have been my source of strength throughout this program. To my husband (Ghassan Karajeh) who has encouraged me all the way and on his wings only have I soared. To my children (Leen, Baraˈa, Anas, Kareem), who have been affected in every way possible by this quest. My sisters have never left my side and are very special. All my family and many friends who have supported me throughout the process. My love for you all can never be quantified.

Dedication to my dear university, Hebron University. To my wonderful homeland, beloved Palestine.

DECLARATION

I hereby declare that the project work entitled “Measurement of Radon Exhalation Rate and Radium Activity in different types of Foodstuff samples used in Palestine” submitted to the Hebron University, is a record of an original work done by me under the guidance of Prof. Dr. Khalil Thabayneh, Professor of Nuclear and Radiation Physics in Hebron university and this thesis work is submitted in the partial fulfillment of the requirements for the award of the degree of Master of Science in Chemistry.

The result embodied in this thesis has not been submitted to any other University or Institute for the award of any degree.

Name: Samar Issa Dowek

Signed

Date: 4 / 7 / 2022

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List of Abbreviations

UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
^{222}Rn	Radon-222
^{238}U	Uranium- 238
^{226}Ra	Radium- 226
Bq	Becquerel
Bq/m^3	Becquerel per cubic meter
Ci	Curie
DNA	Deoxyribonucleic acid
WHO	World Health Organization
CR-39	Columbia Resin No. 39 Plastic Nuclear Track Detector.
AED	Annual Effective Dose
NTDs	Nuclear Track Detectors
ppm	Part per million
IAEA	International Atomic Agency
OECD	Organization of Economic Cooperation and Development
UV	Ultraviolet
NORMs	Naturally Occurring Radioactive Materials
PET	Positron Emission Tomography
H_{in}	Annual effective dose for inhalation radon in food
SSNTD	Solid-State Nuclear Track Detector

Abstract

Radon is a radioactive element in the ^{238}U decay series which is naturally occurring and found in different concentrations in many geological formations. This radioactive gas rises from the ground, enters the homes and human lungs. This thesis shows the nature of radioactivity as an alpha particle produced from decaying of radium to radon so this thesis describes the radon in 51 sample of household food (Legumes, Seeds, Medicinal Plants, Spices, and some of different foods like coffee, powder milk, rice, sugar, and flour) by using Solid State Nuclear Detectors (SSNTDs), were analyzed by closed-can technique (CR-39).

Analysis the concentrations of the Radon-222 and Radium-226 for different types of household foods samples are very substantial for realizing the comparative contributes of specific substances to the whole radon content set within the human body and his environment.

After study it is found, the concentration of ^{222}Rn in Legumes (78.5- 1216.4) in Pill Lentil and Bean respectively, the average value is 428.6 Bq/m^{3}. The concentration of ^{226}Ra (3.8- 59.9) in Pill Lentil and Bean respectively, the average value is 28.8 Bq/Kg. In Spices, the concentration of ^{222}Rn (115.5- 812.4) in Cumin and Spice Tabikh respectively, and the average value 399.3 Bq/m^{3}, also the value of ^{226}Ra (7.3- 66.8) and the average value is 32.9 Bq/Kg$^{.}$ In Medicinal Plants, the concentration of ^{222}Rn (141.7- 438.2) in Thyme and Chamomile respectively, also the average value is 259.1 Bq/m^{3}. And the concentration of ^{226}Ra is (17.2- 44.2) in Anise and Sage respectively, also the average value is 30.5 Bq/Kg. In Seeds, the concentration of ^{222}Rn is (143.9- 837.4) in Sesame and Linum Seeds respectively. And the average value is 400.7 Bq/m^{3}, and the concentration of ^{226}Ra is (10.3- 46.9) in Sesame and Linum Seeds respectively, the average value is 29.9 Bq/Kg. Finally, the concentration of ^{222}Rn in some Foods is (67.6- 735.8) in Biscuit Olkar and Wheat Semolina respectively, the average value is 362.1 Bq/m^{3}. The concentration of ^{226}Ra is (3.7-147.8) in Rice Diamond and Mulukhiyah respectively, the average value is 34.5 Bq/Kg.

We note that some foods have ^{222}Rn concentrations greater than 800 Bq/m^{3}, which is the recommended limit for ICRP values (200-800) Bq/m^{3,} and also there are some foods with a concentration of ^{226}Ra higher than 30 Bq/Kg, which is the permissible limit of ^{222}Rn and ^{226}Ra for all foods.

الملخص

الرادون هو عنصر مشع في سلسلة اضمحلال U-238 والذي يحدث بشكل طبيعي ويوجد بتركيزات مختلفة في العديد من التكوينات الجيولوجية. هذا الغاز المشع يرتفع من الأرض ويدخل الى المنازل ورئة الانسان. توضح هذه الأطروحة طبيعة النشاط الإشعاعي كجسيم ألفا ينتج من تحلل الراديوم إلى الرادون ، لذا تصف هذه الرسالة الرادون في 51 عينة من الطعام المنزلي (البقوليات، البذور، النباتات الطبية، التوابل ، وبعض الأطعمة المختلفة مثل القهوة والحليب المجفف والأرز والسكر والدقيق) باستخدام كاشفات الحالة الصلبة النووية (SSNTDs) ، تم تحليلها باستخدام تقنية العلبة المغلقة (CR-39), حيث يعد تحليل تركيزات الرادون -222 والراديوم -226 لأنواع مختلفة من عينات الأطعمة المنزلية فهو أمر مهم للغاية لتحقيق المساهمات المقارنة لمواد معينة في محتوى الرادون بالكامل داخل جسم الإنسان وبيئته.

بعد الدراسة وتحليل النتائج وجد أن تركيز الرادون في البقوليات يتراوح (1216.4-78.5) في العدس الحب والفول على التوالي. ومعدل القيم هو 428.6 بيكريل/م^3. أما قيم الراديوم تتراوح بين (3.8-59.9) في العدس الحب والفول على التوالي، ومعدل القيم هو 28.8 بيكريل/كغم.

أما تركيز الرادون في البهارات يتراوح بين (115.5-812.4) في الكمون وبهار الطبيخ على التوالي. ومعدل القيم هو 399.3 بيكريل/م^3. أما قيمة تركيز الراديوم فهي تتراوح بين (7.3-66.8) في الكمون وبهار الطبيخ على التوالي، والمعدل هو 32.9 بيكريل/كغم.

في النباتات الطبية تتراوح قيمة تركيز الرادون بين (141.7-438.2) في الزعتر البلدي والبابونج على التوالي، أما معدل القيم هو 259.1 بيكريل/م^3. وقيمة تركيز الراديوم تتراوح بين (17.2-44.2) في اليانسون والميرمية على التوالي، ومعدل القيم هو 30.5 بيكريل/كغم.

في البذور كانت قيم تركيز الرادون تتراوح بين (143.9-837.4) في السمسم وبذور الكتان على التوالي، ومعدل القيم هو 400.7 بيكريل/م^3. أما تركيز الراديوم يتراوح بين (10.3-46.9) في السمسم وبذور الكتان على التوالي. ومعدل القيم هو 29.9 بيكريل/كغم.

وأخيراً في بعض المواد الغذائية كانت قيم تركيز الرادون تتراوح بين (67.6-735.8) في بسكويت أولكر وسميد القمح، ومعدل القيم هو 362.1 بيكريل/م^3. أما قيمة الراديوم تتراوح بين (3.7-147.8) في أرز ديموند والملوخية على التوالي، ومعدل القيم هو 34.5 بيكريل/كغم.

نلاحظ أن بعض الأطعمة تحتوي على تركيزات Rn أكبر (200-800) بيكريل/م^3، وهو الحد الموصى به لقيم ICRP ، وهناك أيضًا بعض الأطعمة التي يزيد تركيز Ra فيها عن 30 بيكريل/كغم ، وهو الحد المسموح به لـ 222- .Rn و Ra-226 لجميع الأطعمة.

CHAPTER ONE

INTRODUCTION TO RADON

Chapter One - Introduction to Radon

1.1 What is Radon?

The greatest concern for humans is radioactivity in the environment according to UNSCEAR (1988), natural radiation sources account for around 82 % of mankind's radiation dosage, with manmade radiation accounting for the remainder. Natural radioactivity is found in the rocks, soils, sediments, water, and oceans that make up our globe and our building materials. Cosmic rays, terrestrial radioactivity, and internal radioactivity all contribute to the natural background radiation level that humans are exposed to [1].

The radioactive noble gas radon (^{222}Rn) has an atomic number of 86 and an atomic weight of 222 [2]. It's made up of naturally occurring radionuclides like ^{238}U and ^{232}Th that decay over time. The isotope ^{222}Rn, which is generated when ^{238}U decays, is the primary source of internal radiation exposure to humans (about 55 percent) [3]. ^{222}Rn is produced by the natural decay of uranium, which may be found in almost all soils. It emerges mostly as a result of diffusion processes from the point of basis following α- decay of ^{226}Ra in underground soil and rocks. It rises naturally from the earth to the air above, entering homes through cracks and other breaches in the foundation [1].

Because it is odorless, tasteless, and invisible, ^{222}Rn is a radioactive noble gas that cannot be detected by the human senses. Furthermore, radon is monochromatic under normal conditions, with the exception of when it cools below its freezing point (-71 ˚C) [4], it is a relatively stable inert gas with a half-life of 3.82 days and no significant interactions with other elements. Other gases or liquids (e.g CO_2) act as transporters for a radon in soil and water [5], it is a type of ionizing radioactivity that occurs from the natural decay of radioactive elements found in soils and rocks. For most people, radon exposure at home is their primary source of ionizing radiation (characterized by their ability to excite and ionize atoms of matter with which interact. The energy needed to cause a valence electron to escape an atom in the order of (4-25) ev, radiation must carry of quantum energies in excess of this magnitude) exposure. Radon is the second leading cause of lung cancer in the United States, with more than 21,000 lung cancer death each year [6].

1.2 Chemical and Physical Properties of Radon

In the periodic table, radon is assigned to group 18 (noble gas, p-block and period 6; [Xe] $4f^{14}5d^{10}$ $6s^2$ $6p^2$). Noble gases are chemically inert, although their interactions with other species are weaker (in comparison to van der Waals type, with bonding energies on the order of 1-3 eV, comparable to ionic and covalent bonds (on the scale of 3-8 eV)), hence interactions should be less complicated [7, 8]. Uranium contains three isotopes (^{238}U, ^{235}U and ^{232}Th) which are found in commonly found in nature. However, when compared to the other noble gases, these isotopes have the lowest molar abundance, and there is a lot of technology available to measure such low abundance with counting equipment [9]. Because radon and other noble gases have a closed-shell electronic structure and high ionization enthalpies, their atoms are extremely stable. Electron-pair interactions with other noble gas atoms are not possible. The weak forces (London and van der Waals) are proportional to polarization and inversely proportional to ionization of atoms enthalpies [10]. Like radon, the ionization energy (the energy required to remove one electron from the outer filled shell) is 1,037 KJ /mol, and for the other noble gases, it increases as the atomic number decreases. Radon has a lower electronegativity (electronegativity =2.2 Pauling scale Table 1.1) than xenon (electronegativity =2.60 Pauling scale), and it is also more reactive than xenon. Electronegativity decreases with increasing atomic numbers in a column on the periodic table. Because the solubility in a column increases with increasing the atomic number, radon is more soluble than xenon; also, radon is more soluble in organic liquids than in water. The heat of vaporization (which quantifies the amount of work required to overcome atomic bonds) is a term used to describe the amount of work required to overcome atomic bonds. Although there is no proof of the presence of radon compounds or ions in aqueous solutions, solutions of cationic radon have been prepared. Radon exists on the diagonal of the periodic table between metals and non-metals, and it has been suggested that it can be classified as a metalloid because it has characteristics of both groups. Furthermore, radon can react spontaneously at 25°C or lower temperatures with fluorine, halogen fluorides (except IF5), and a number of oxidizing salts [9].

Table 1.1 Atomic number, physical and chemical properties of Radon

property	**Values**
Atomic number	86
Standard atomic weight	222
Outer shell electron configuration	$6S^2$ $6P^6$
Density	9.73 kg m^{-3} (at 0 °C, 1.013×10^5 Pa)
Melting point (°K)	202
Normal boiling point (°K)	208.2
Heat of fusion (KJ mol^{-1})	3.247
Heat of vaporization (KJ mol^{-1})	18.0
First ionization enthalpy (KJ mol^{-1})	1037
Oxidation states	0, 2, 6
Electronegativity	2.2 (Pauling scale)
Covalent radius (nm)	0.150
Van der Waals radius (nm)	0.220

Table 1.1 summarizes the physical features of radon. Radon's atomic, physical, and chemical properties, such as melting point, density, vaporization and fusion heats, electronegativity, oxidation states, and initial ionization potential (highest energy) [9].

1.3 Decay Products of Radon

Radon, a naturally radioactive gas, decays via a sequence of short-lived decay products before stabilizing at ^{206}Pb, a nuclide with a 20-year half-life. Lead-210 is an important nuclide in and of itself. Figure 1 depicts the radon decay scheme in further detail. [11]. When radon, or its decay products, is breathed in, the risk of lung cancer is known to exist. This risk was identified early on [12], When consuming water with very high radon levels, you run the risk of developing stomach cancer [13], Deposition of radon decay products may provide substantial doses to sensitive cells in the skin in some circumstances, and drinking water with extremely high levels of radon can increase the risk of stomach cancer.

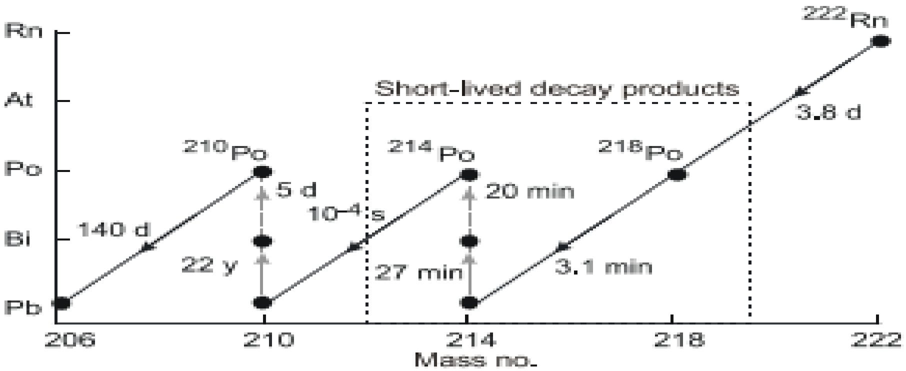

Figure 1.1 decay scheme for ^{222}Rn showing the short-lived decay products to ^{210}Pb and the subsequent transformations to ^{206}Pb

The previous graph (Figure 1.1) shows in order all the decay products. These radon products are named “radon progeny” and the preceding name is “radon daughters”

Organs and tissues, on the other hand, receive a dose of radon and its decaying products, which, while generally less important, do pique curiosity. It is now known that the most important component of the dose is not the gas itself, but rather the short-lived decay products. In addition, the decay products are isotopes of solid elements, which swiftly bind molecules of atmospheric gases and water. These, in turn, bind to the particles in natural aerosols. If inhaled, the decay products, whether connected to an aerosol particle or not, will mostly settle on the respiratory tract's surface and decay there due to their short half-lives (less than half an hour) [11].

1.4 Characteristics of Radon and its decay products

The radioactive decay chain of thorium or uranium produces radon, a noble gas. The majority of radon comes from the soil and some construction materials, therefore it can be found in many places around the world, particularly in areas with granite or slate soils. Because radon gas is invisible, odorless, tasteless, and colorless, it is nearly impossible to detect without the right tools. [4]. Radon, like other elements, contains a number of radioactive isotopes, but these isotopes are unstable, and the number of radioactive isotopes is approximately 40. Furthermore, each isotope has a different atomic weight, half-life, and mass.

The most famous isotopes of radon are:

1. Radon-222 (Radon-^{222}Rn) is produced through the decay of the ^{238}U chain, specifically ^{226}Ra. It is one of the most important isotopes because of its abundance and 3.825-day half-life, which is considered long when compared to other radioisotopes [14]. It is useful in the geohydrology studies [15].
2. The disintegration of the ^{232}Th chain, specifically the decay of ^{222}Ra, produces radon-220 (Thoron-^{220}Tn). Due to its short half-life of 55.6 seconds, its half-life is less essential.
3. Radon-219 (Actinium-^{219}Ac) is formed when the ^{235}U chain decays, specifically when ^{223}Ra decays. It also has a 3.96-second half-life.

Table 1.2: Radon isotopes, their chemical symbols, half-lives, and energy released

NO.	Radon isotope name	Chemical symbol	Decay series from	Half-life	Energy released MeV
1.	Radon	Rn (^{222}Rn)	^{238}U	3.82 d	5.59031
2.	Thoron	Tn (^{220}Rn)	^{232}Th	55.6 s	6.404
3.	Actinium	Ac (^{219}Rn)	^{235}U	3.96 s	6.946

The most important gas is ^{222}Rn, which is converted into the lead (^{206}Pb) by disintegration's short-lived progeny. Every radioactive element on the list releases alpha, beta, and gamma radiation in some form. The last element on the list is ^{206}Po, which has no half-life because it is neither radioactive nor decays. ^{218}Po and ^{214}Po are radon daughters that are formed by radon decay and are short-lived. They get deposited on the airways and eventually cause cancer. It produces high-energy alpha particles with energies of 6.00 MeV and 7.69 MeV. The total amount of energy deposited in the lungs by decay products is around 500 times greater than the amount deposited by ^{222}Rn itself. [14].

1.5 Radon Sources

1.5.1 Radon in Soil

Radon formed within the mineral grains of rocks and soils can escape by recoiling into the air or through fluid-filled fissures and into the adjoining pore space. The emanation coefficient, which is dependent on the availability of ^{226}Ra, porosity, moisture content, and temperature, can be used to quantify this. Diffusion and convection/advection transport the gas/fluid phase near the earth's surface. This transport is influenced not only by local geology, such as rock types, but also by other geophysical and geochemical parameters, such as links, breaks, hydrology, porosity, permeability, and the presence of other gas carriers. The character of the base, glacial deposits, or transported sediments from which the soil was formed, determines these properties [16, 17]. On hourly, diurnal, and monthly time scales, soil-gas radon concentrations can shift in response to climate and weather variations. The most relevant meteorological parameters appear to be barometric pressure, wind, relative humidity, rainfall, and temperature. [18]. The majority of the grain size distribution is usually seen in soil samples. The soil surface and structure, which are critical for radon transmission, are made up of this distribution. Soils are divided into several categories, such as silt, sand, and clay.

A radon atom will result from all of the radium atoms that have decomposed in the grains of rocks and soil. And if this atom is produced near the soil's surface, it has the potential to escape into the environment. Porosity, soil CO_2 concentration, soil permeability, moisture content, inhabitant lifestyle, weather, house construction characteristics, and atmospheric pressure are all elements that influence the amount of radon emitted from the soil [19, 20].

The normal particle sizes for the major divisions are: silt, which ranges from 2 – 60 µm, sand which typically ranges from 60 to 2000 µm, and clays which are less than 2 µm [21]. Different states produce different types of soil. Large particles are created as a result of physical processes of mechanical activities in the weather. Chemical reactions produce clay. Clay and other metals, in combination with carbonates, regularly formed complexes with radium and uranium, resulting in the radioactive distribution in soil. The presence of grain cement, along with changes in grain size spreading and control of the range thereof, causes the rearrangement of the previously described complexes that developed. The soil's permeability would be altered as a result of this. [2].

1.5.2 Radon in Air

Historically, radon exposure has been thought to be higher in cold-season countries where people primarily live in closed indoor air environments for lengthy periods of time to avoid unfavorable weather conditions. Climate change and the widespread use of air conditioning in all locations, however, may change this 20th-century norm [22]. The isotopes of radon are gases that reach the atmosphere by being carried over great distances by air currents [14].

Indoor radon levels are influenced by the home's construction, architecture, and ventilation. Radon-containing soil air can enter a home through cracks below the construction level in solid floors and walls; through timber floors, gaps in suspended concrete, and around service tubes; and through cavities in walls, crawl spaces, construction joints, and small pores or cracks in hollow-block walls [20].

1.5.3 Radon in water

Even if there is a small level of radon in the drinking water, it will be detected as a cause of cancer [22]. Indoor radon levels can vary depending on the type of soil, water, and construction materials used for drinking, as well as different household uses [23]. Information on the quantity of radon in each source of household water, particularly groundwater sources, is necessary to protect individuals from the dangers of excessive radiation exposure, which can lead to lung cancer [24].

Radon in the indoor air may be increased by radon produced from domestic water while showering and other household activities. Areas with significant quantities of uranium in the original rocks are more prone to have radon concerns from home water supplies [25]. A significant role in the whole population radioactivity has the content of radon in drinking water but used for other aims This primarily relates to water used in swimming pools, bathtubs, and tubs for inhalation in both recreational and medicinal settings. Water radon contributes to the overall inhalation risk linked with radon in indoor air [26]. The amount of radon that enters the body through drinking water is determined by the concentration activity in the water, the radon kinetic in the body, and metabolism. Radon is a radioactive gas that can be dissolved in water, blood, and bodily tissue. [14].

1.5.4 Radon in foodstuff

Except for indoor radon, the most common sources of exposure include food, construction materials, and drinking water [27].

Radiation contamination in soil and water can be transmitted to animals and people through the food chain [28, 29] When a humanoid eats animal meat, vegetation, or drinks liquids (coffee, water, tea, and juice), he can become contaminated with various radioactive isotopes (^{222}Rn, ^{226}Ra, ^{238}U etc). Plants take radioactive isotopes from the soil, which they absorb with the help of other natural components. Low levels can also be found in drinking fluids including water. Humanoids breathe air, which is the principal source of radioactive doses that enter the body [28, 30].

The main in a healthy safe are the measures of ^{226}Ra & ^{222}Rn concentrations in foodstuff. ^{226}Ra is widely distributed in the environment and can be found at some concentrations in water, soils, sediments, foods, and rocks. Radium, on the other hand, has a chemical structure similar to calcium, therefore it is absorbed into the blood from the lungs or the gastrointestinal tract (GI-tract) or precipitated in bone in the same way as calcium is [29].

1.6 Health Effects of Radon

Radon has received a lot of attention as a radiological health hazard. Concerns initially focused on underground miners' exposure to uranium and other ores. Eastern European miners were documented to have a significant occurrence of lethal respiratory sickness as early as the sixteenth century. Lung cancer was the name given to the disease in the nineteenth century. Gradually, over the first half of the twentieth century, a consensus evolved that radon decay products in the air were the source of this health hazard [31].

The radioactive elements that result from radon fragmentation, known as the progeny of radon or radon daughters, are directly linked to the health-specific effects caused by their presence. Different types of gaseous radon are solid and adhere to surfaces, just as dirt particles in the air. Inhalation is the most common method of exposure to radon and its offspring. Radiation from radon is only received indirectly. The main source of health risk is radioactive compounds generated during radon disintegration, rather than radon itself. The radioactivity of the human body has a wide range of impacts, including the risk of radiation-induced cancer [1].

The most prevalent substance in cells is water. Because of its abundance, the water molecule absorbs the vast majority of all incident radiation. Because these ions have low energy and recombine quickly, high energy absorption can cause the water molecules' molecular bonds to break, releasing H+ and OH- ions into the cell, which then forms water; however, at higher energies, "hydrogen peroxide" will form through a series of reactions that can be shown as [32].

$$3(H_2O) + \text{energy} \longrightarrow 3H^+ + 3OH^- \longrightarrow H_2O_2 + 2H_2O \quad (1.1)$$

The oxidizing compound hydrogen peroxide (H_2O_2) is a highly reactive oxidizing substance that can destroy other molecules such as DNA and other essential molecules that order and govern important cellular operations. Although the cell can repair most molecular damage, severe molecular damage can lead to mutation or cellular death [33].

Decomposition of ^{222}Rn emits alpha particles, which cause significant DNA damage that is nearly hard for human lung cells to repair without causing genetic mistakes [34].

Radon is a dangerous pollutant that has a global impact on the quality of indoor air. The inhalation of high levels of radon has been linked to the development of lung cancer following smoking, according to epidemiological research [35].

Lung cancer can also be caused by dust particles tainted by radon daughters [1]. Exposure to radon is the second most common cause of lung cancer after smoking, according to the World Health Organization (WHO), and it is the leading cause of lung cancer in persons who have never smoked [14], when smoking is combined with radon, it is a very dangerous combination for one's health. Smokers are more likely than nonsmokers to die from radon-caused lung cancer. Because of their breathing rate and lung shape, children have been discovered to be at a higher risk than adults for certain types of cancer induced by radiation [36, 37].

Curie: is the number of disintegrations per second in a mass of 1g of $^{226}_{88}Ra$.

Becquerel: is one disintegration per second.

Sievert unit: J/Kg but has the special name Sievert when applied to dose equivalent.

1.7 Literature Review - Previous Studies for Radon in Foodstuffs

Abdalsattar Kareem Hashim, et al., (2018), assess the concentration of alpha radiation activity in 22 distinct biscuit samples obtained from an Iraqi market. The alpha-sensitive CR-39 plastic track detectors were used to measure radium activity and radon exhalation rate. With a mean value of 58.9 Bq/Kg, the effective radium levels varied from 23.3 to 200.4 Bq/Kg. The mass unit's radon emission values ranged from 0.172 to 1.515 Bq/Kg h, with a mean of 0.445 Bq/Kg h, while the surface unit's radon emission values ranged from 3.988 to 34.3 Bq/m^2.h, with a mean of 10.081 Bq/m^{2}h. Furthermore, radium activity and radon exhalation rate had a direct link [38].

Gooniband Shooshtari et al., (2017), assessed ambient radioactivity in Ramsar (an Iranian city) using 70 market samples collected over four seasons based on the daily consumption habits of residents with the highest consumption and their availability over the season. After washing, drying, and preparation, the samples were tested for ^{226}Ra radionuclide detection using alpha spectrometry. The mean radioactivity concentration of ^{226}Ra in beef was 7± 1 mBq Kg^{-1} wet weight, while tea dry leaves had 318 ±118 mBq Kg^{-1}. The quantities of ^{226}Ra activity in the samples ranged from below the minimum detectable activity to 530 ±30 mBq Kg^{-1}. When compared to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reference values, the ^{226}Ra activity concentrations found in chicken, milk, and eggs appear to be higher. And there's less of it in grains, fruits, vegetables, and seafood. These findings indicate that there is no significant ^{226}Ra contamination in market consumables and offer reference values for Ramsar commodities [39].

Asmaa Deiaa Nusseifl et al., (2020), measurements the concentration of the radon gas in four milk samples (Anchor, NIDO, MAHMOOD, and RAINBOW) collected from the local markets in Baghdad city, by using CR-39 detector and other parameters. The results show that the highest average is found in the sample of RAINBOW milk (Oman) was equal to 44.1 Bq/m^3, while the lowest average value was found in the sample of Anchor milk which made in New Zealand, and was equal to 24.7 Bq/m^3. In addition, results indicate that the radon concentration of all the studied samples was below the recommended level by (ICRP). Effective annual dose values were from 0.779 mSv /y to 1.389 mSv /y, with an average of 1.373 mSv/y. while the Annual Effective Dose (*AED*), surface exhalation rate, and effective radon content for all samples were below the global limits, therefore these kinds of milk can be considered safe to use as it relates to the concentration of radon [40].

Asmaa Ahmad Aziz (2018), uses Nuclear Track Detectors (NTDs) model CV-85 to assess the radioactivity in samples of legumes and cereals in Iraq. The data show that the Yellow Corn sample had the highest percentage of radon and uranium. The radon concentration was 137.1 × 10^2 Bq/m^3, and the uranium concentration was 2.63 (ppm). While Oats had the lowest radon and uranium concentrations, with radon concentrations of 24.27×10^2 Bq/m^3, and uranium concentrations of 0.466 (ppm), the concentrations of other legumes fluctuated between these two figures. And these uranium and radon concentrations are within the global permissible limits, as determined by the International Atomic Agency (IAEA) [41].

Alkafaji, H. N. et al., (2019), used CR-39 detectors to quantify effective radium activity, radon exhalation rates, and uranium in medicinal plants collected from the market in Iraq. Radium concentrations range from (0.0297± 0.004) to (0.327± 0.126) Bq/kg, radon exhalation rates from (2.287± 0.384) Bq/m^2d to (25.193± 9.729) Bq/m^2d, with an average of (10.986± 1.989) Bq/m^2d, and uranium concentrations from (0.018± 0.002) ppm to (0.202± 0.057) ppm, with an average of (0.087 ± 0.002) ppm. All of the medicinal plant samples had lower radium concentrations, exhalation rates, and uranium levels than the Organization of Economic Cooperation and Development (OECD), United Nations and Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), findings demonstrated that the concentrations of uranium and radium, as well as exhalation rates in medicinal plants and the related exhalation of radon, did not constitute a health concern to humans. Respectively [42].

Mohammed Al-Sadil and Inaam Kadhim (2019), studying radon concentrations in controlled airspace Ca and inside samples Cs, as well as conducting quantitative and qualitative estimates of some radionuclides, and then recognizing the proper limits knowingly allowed by typically using CR-39 detector in 30 different medicinal plants, Alpha particles recorded at the detector range between (18-54) Tr.cm^{-2} and evaluated the concentration of radon in controlled airspace ranged between lowest value (9.5420) Bq/m^3 and the highest value of (28.626) Bq/m^3, for samples (Petroselinum, Aloe Vera) respectively, whereas the lowest radon concentration was (259.637) Bq/m^3 and the highest radon concentration was (778.912) Bq/m^3 for the same samples [43].

Tayseer AL-Naggar, and Doaa H. Shaban (2018), ^{222}Ra concentrations and effective radium content in household foods were investigated (powder milk, tea, rice, coffee, powder coconut, cornstarch, sugar, and flour). Large differences in radon concentrations and effective radium content were discovered in Egypt utilizing the CR-39 detector for all samples. The maximum value for the annual effective dose was 17.70 mSv/y which was found in sugar, and the minimum value of its, was 4.29 mSv/y which found in coconut powder. The average activity concentration of ^{222}Rn in Coffee (262.19 ± 18.31) Bq/m^3, powder Milk (333.05 ± 8.07) Bq/m^3, Tea (276.36 ± 15.35 Bq/m^3), powder Coconut (170.07 ± 37.52) Bq/m^3, Rice (304.71 ± 11.03) Bq/m^3, Cornstarch (517.29 ± 34.88) Bq/m^3, Flour (233.84 ± 24.22) Bq/m^3, and sugar (701.53 ± 73.30) Bq/m^3, the maximum values of ^{222}Rn concentration were found in sugar and Cornstarch respectively, and the lowest value was observed at powder Coconut [28].

Hayder Salah Naeem, et al., (2020), Using a Continuous Radon Monitor (CRM model no.1029), researchers assessed the ^{222}Rn concentration in nineteen different types of plants taken from several marketplaces in Al-Samawah city, Al-Muthana province- Iraq, the highest rates were recorded in Cinnamon (imported from India) was (21.5 Bq/m^3), while the lowest rates were in Nigella Sativa (from India too) was (6.65 Bq/m^3). The measured rates were higher than known acceptable levels was (7 Bq/m^3) [44].

Hussein A. Hussein, et al., (2020), measured the radon concentration in twenty types of benefits of grains food, which collected from various markets in Samawah city in Iraq, by using the Monitoring of radon (CRM-1029), the highest reading recorded in Chard (origin from Iraq) was (23.25 Bq/m^3), and the lowest recorded value were in Sesame (origin from Egypt) was (5.95 Bq/m^3), the measured values were higher than known as acceptable levels were (7 Bq/m^3) [45].

Ali Mahdi Abdul Hussein et al., (2019), Using an LR-115 detector, the quantity of radon in 20 samples of milk taken from Misan markets in Iraq was measured. The samples ranged from 32.0 to 180.4 Bq/m^3, in Celia 1 and Primer samples, respectively, with the mean value of 109.92 Bq/m^3. In addition, the obtained value of radon concentration in the tea samples was noticed to vary from 40.0 to 220.0 Bq/m^3. In aero plane and appeared samples, with a mean value of 158.64 Bq/m^3. The concentration of radon in milk samples was lower than that in tea samples. As a result, the radon concentration appears to vary depending on the type of sample and the source of the sample. Furthermore, the concentration was below the International Commission on Radiological Protection's recommended action levels of 200-600 Bq/m^3. The collected samples did not pose any serious hazards, according to the findings [46].

1.8 Aims of the Present Work

The proposed thesis is basically aimed at:

1. Measure the activity concentration of ^{222}Rn & exhalation rate in foodstuff samples collected from Palestine and other countries.
2. Measure the activity concentration of ^{226}Ra in food samples.
3. Estimate the annual effective dose resulting from exposure to these radionuclides.
4. Investigate the effect of radiation exposure on the general public through eating this food.
5. Provide the database of radioactive elements under investigation in order to arrive at an irradiation map for this foodstuff in Palestine and other countries.

   I hope this thesis might serve as the basis to draw a national and international map of radon and radium concentration levels in Palestinian and imported food, in order to monitor and any observed hazardous changes in the radon concentration from one type to another of foodstuff.

Furthermore, it is also hoped that the study will prove list to the food which is a danger to our health which have a lot of radiation

CHAPTER TWO

THE THEORY OF BACKGROUND RADIATION

Chapter Two -The Theory of Background Radiation

2.1 Types of Radiation:

There are two types of radiation

2.1.1 Ionizing Radiation: Electromagnetic waves and particle beams are both capable of ionizing atoms in a substance (separating them into negatively charged electrons and positively charged ions).

All types of radiation with enough energy to ionize a molecule are referred to as ionizing radiation. Radiation from radioactive sources, short-wavelength UV, X-rays, accelerator particles, outer-space particles, and neutrons are all included in this term. It is divided into two categories.: -

a- Direct (primary) ionizing radiation which includes charged particles such as α-particles, β-particles (electrons) and positrons.

b- Indirect (secondary) ionizing radiation which includes γ-rays, x-rays, neutrons [47, 48].

2.1.2 Non-ionizing Radiation**:** It refers to electromagnetic radiation and fields with photon energies less than 10 eV, and wavelengths greater than 100 nm that are parallel to frequencies less than 3 PHz (3×10^{15}Hz) [49]. Electric waves, radio waves, microwaves, visible rays, and infrared rays are examples of electromagnetic waves. Although certain ultraviolet rays do induce ionization, ultraviolet rays are commonly labeled as nonionizing radiation [47, 50].

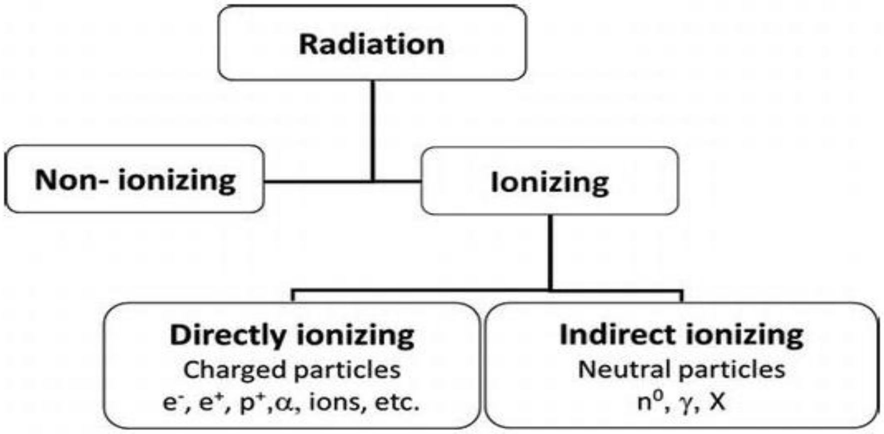

Figure 2.1: classification of radiation [51]

2.2 Radiation Sources

Radiation sources are all around us all the time. Some are natural background include cosmic radiation, cosmogenic radiation, internal radiation, and some are man-made.

2.2.1 Natural Radiation

Background radiation is present at all times on earth. The majority of background radiation comes from minerals, with a tiny amount from man-made components. Background radiation is produced by radioactivity metals occurring naturally in land, soil, and water. Some of these naturally occurring radioactive minerals can even be found in the human body. The background radiation surrounding us is augmented by cosmic radiation from space. Natural background radiation levels can vary greatly from one site to the next, as well as shift over time at the same location. [52].

2.2.1.1 Cosmic Radiation

Cosmic rays from space, terrestrial nuclides found in the earth's crust as construction materials, water, food, and the atmosphere [52]. And all living things on it are assaulted with radiation from space on a continuous basis, similar to constant drizzle of rain. The earth's atmosphere and magnetic field combine with charged particles from the stars and sun to produce a shower of radiation, usually gamma and beta radiation. Because of changes in altitude and the influence of the earth's magnetic field, the dose of cosmic radiation varies around the planet.

High-energy cosmic radiation produces an elemental shift in the atmosphere. The radiation interacts with different atomic nuclei in the atmosphere to produce cosmic producing radionuclides such as ^{3}H, ^{14}C and ^{7}Be [53].

2.2.1.2 Terrestrial Radiation

Terrestrial radiations are naturally occurring radionuclides that can be found in construction materials, rocks, and soils. For the general public's long-term health and environmental protection, natural radioactivity necessitates concentration monitoring. Radiant energy from naturally occurring radionuclides in the nearby area considerably contributes to the environment's background radiation level. Occurring Radioactive Materials (NORMs) are naturally occurring radioactive materials that generate ionizing radiation as a natural cause of the disintegration of radioactive materials [54].

The concentration of radionuclides, which affects the amount of background radiation in the area, is determined by the geological composition of the area in which the earth's crust is composed. According to research, NORMs account for more than 85% of total human radiation doses, with the remaining 15% coming from artificial sources [55].

The Thorium-232 and Uranium-238 series of gamma radiation is naturally emitted by environmental soils and rocks, whereas the Potassium-40 series is not. The radiated radiation reaches the general public either outside or inside a building. [56].

2.2.1.3 Internal Radiation

All persons contain radioactive carbon-14, lead-210, potassium-40, and other isotopes inside their bodies from birth, in addition to cosmic and cosmogenic sources. The difference in dose between people is not as great as the difference in dose of radioactive materials, which is around 40 mrem (the amount of energy that a radioactive source deposits in living tissue and one millirem equals 0.001 rem). Rb-87 and K-40 are the most common primordial radionuclides, and the elements of both types belong to the radioactive series headed by U-232 [52].

2.2.2 Man-Made Radiation (Artificial background radiation)

Humans are constantly exposed to ionizing radiation in their surroundings, which comes from both natural and man-made sources, with radon accounting for 80% and medical x-rays accounting for 20%. In recent years, the use of ionizing radiation in medical imaging for diagnostic and interventional purposes has expanded considerably, putting patients and health care personnel at risk of radiation exposure. Ionizing radiation has been linked to documented negative health impacts [57].

In the civilized world, the unique property of radioactivity, both artificial and natural, has been used fruitfully in almost all fields of science to suit human needs such as geology, medicine, agriculture, industry, nuclear technology, archaeology and many others.

However, the creation of artificial radioactive sources and their useful applications greatly enhance the current background radiation. Currently, advanced nuclear technology applied in medical imaging has become the main source of artificial background radiation. Occupational and industrial exposure which includes processing and management of radioactive waste from nuclear power plants, radioactive dust from nuclear experiments and accidents in the atmosphere, etc. also contributes to fractions of background ionizing radiation for the common man.

Man-made industrial consumer products such as Phosphate fertilizer, building materials and crushed rock, ceramics, radiation-emitting television sets, compact fluorescent lamps, smoke detectors and many more, it can also enhance the background radiation dose. Basic human activities involving advanced radiology research in various fields including radiometry it may sometimes lead to an increase in artificial radiation dosage in specific areas [53].

2.3 Radioactivity

2.3.1 Alpha Particle Decay

Alpha radiation is formed of alpha particles, or for short alpha (α) [58]. Alpha particles consist of two protons and two neutrons, with a structure a ${}^{4}_{2}He$ a nucleus without surrounding electrons (sometimes it is referred to as He^{2+}). Alpha particles are produced in alpha decay process [59].

The decaying atom that ejects an alpha particle decreases in atomic number by 2 and mass number by 4. For example, the decay from the most common isotope of uranium ${}^{238}_{92}U$, to the isotope of thorium is alpha decay: [58].

$$ {}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He \qquad (2.1)$$

The alpha particle is positively charged, has a high particle energy range of 5 -9 Mev, and has a very short range of 40-100 µm, equating to a particle range of 1-3 cells wide. Because of the small therapeutic range, alpha particle buildup inside the cell is desired for a better possibility of damaging the cell nucleus. Linear power transmission (LET) is a term used in ionizing radiation to measure ionizing density and thus molecular damage to a particle per unit length.

For alpha particles, LET is too high (80-100 keV/ µm) throughout its range, and three times higher at the path's end [59].

2.3.2 Beta decay

Beta radiation is made up of beta particles (β) (also known as betas). Beta particles are just positrons or electrons, indicated by the letters as β+ and β- respectively. Negatively charged electrons released from radioactive atoms during beta decay are known as beta-emitting radioactive atoms.

By emitting a positron and a neutrino, a proton can be transformed into a neutron. By emitting an electron and an antineutrino, a neutron can become a proton. Negatively charged beta particles with a travel length of 0.0 to 12 mm and particle energy of 50 to 2300 keV. Along the path, the LET for beta decay is minimal (0.2 keV/µm) (i.e., it is low ionization). In comparison to alpha particles, significantly more particles are required to get the same absorbed dose. The following are the interactions:

$$ {}^{1}_{1}p \rightarrow {}^{1}_{0}n + \beta^{+} + v_{e} \qquad (2.2) $$

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}n + \beta^{-} + v_{e}^{-} \qquad (2.3) $$

Through the beta decay, the atomic number of a nucleus changes without changing the mass number of the nucleus. The nucleus can then decay towards a more stable proton number.

Beta radiation is used in both medicine and industry. In medicine, beta emitters are used in treating certain types of cancer or as tracer material for diagnostic methods such as Positron Emission Tomography (PET).

Beta radiation is used in industry to test the thickness of some flat materials. By irradiating and measuring radiation coming out on the other side of the material, the manufacture can tell if the thickness of the material is the same everywhere in the material [58, 59].

2.3.3 Gamma Decay

Gamma decay is the phenomenon of a radioactive substance emitting a gamma-ray photon. A nucleus can experience gamma decay, which is a type of radioactive decay. The difference between this type of decay with alpha or beta decay is that no particles are emitted from the nucleus during this phase. Instead, a photon of gamma rays is emitted, which is a high-energy kind of electromagnetic radiation Gamma rays are photons with extremely high energy and ionizing properties. Furthermore, gamma radiation is unique in the sense that exposure to gamma decay does not change the structure or composition of an atom. Instead, because gamma rays have no charge and no mass, they merely modify the energy of the atom [60].

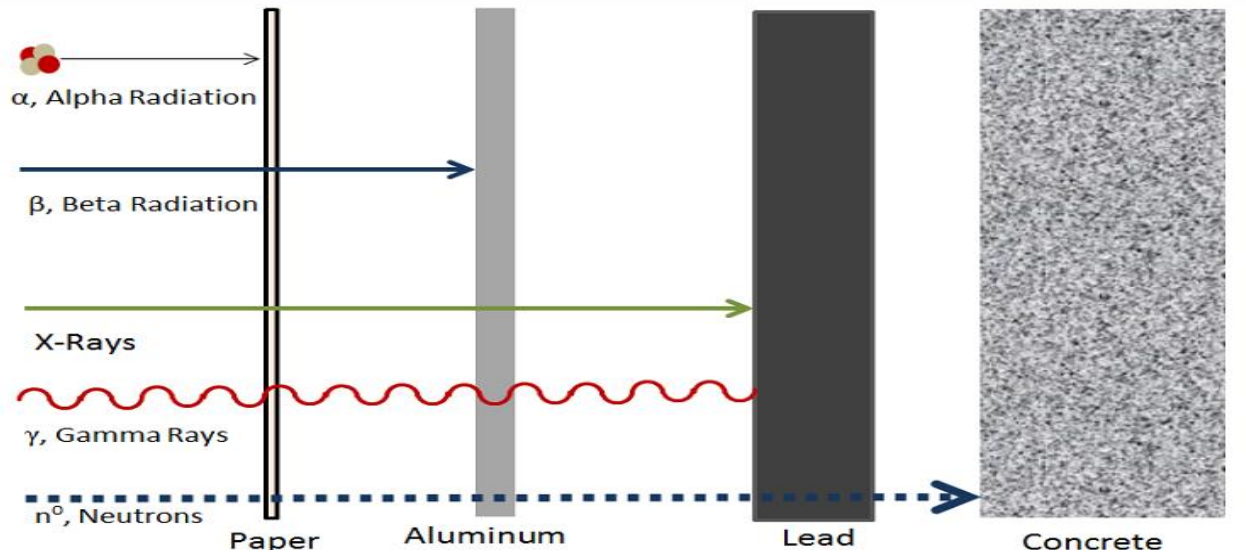

Figure 2.2: Different penetration levels of different products of decay, with gamma being one of the most highly penetrating [60]

2.3.4 Law of Radioactivity

The most essential law of radioactivity is the law of radioactive decay. When an alpha particle or beta electron emits from the nucleus, it transforms, allowing radium to be transformed to radon or tritium to be converted to helium, for example. however, the number of atoms in the radioactive substance is constantly reduced in such processes. However, the number of emissions per second decreases at the same time. The activity of a sample is defined as the rate at which nuclei decay, and it is proportional to the number of nuclei present.

The shape of the rule of decay is simple to understand if the nucleus regains stability after emitting the particle: similar to a currency that loses certain percentage points of its ever-decreasing worth every year. This sort of decay is known as "exponential decay," and its mathematics is well understood. The half-life is the amount of time it takes for a particular sample of a substance to be halved, and it is a good indicator of radioactive decay. Any substance's half-life is a property of its nucleus and does not change.

If the daughter nucleus (the product of the radiation process) is radioactive, the decay form is more difficult to comprehend and study. However, like any other such process, radioactive equilibrium is eventually reached.

Millions or billions of billions of atoms can be found in just a few grams of any substance. The number of radioactive nuclei in even the tiniest sample is unbelievably vast. As a result, radioactivity is always computed using extremely large quantities. Even for the least radioactive substance.

The emission of alpha, beta, or gamma photons during radioactive decay is a completely statistical process. The reason for this is that it is impossible to predict when a nucleus would dissolve. When only one unstable nucleus exists, it can disintegrate in a fraction of a second, an hour, a day, or many million years. When there are a large number of active isotope nuclei, however, it is possible to determine the number of nuclei that dissociate, as well as the relationship between this number and time. When there is a certain number of active nuclei, let it be N_o at a certain moment in time, it is possible to determine the number of nuclei remaining N without dissociation over a time of t, with decay rate parameter λ, according to the following relationship:

$$N = \quad N_{\circ} e^{-\lambda t} \qquad (2.4)$$

This law is known as the exponential law of radioactive decay [61].

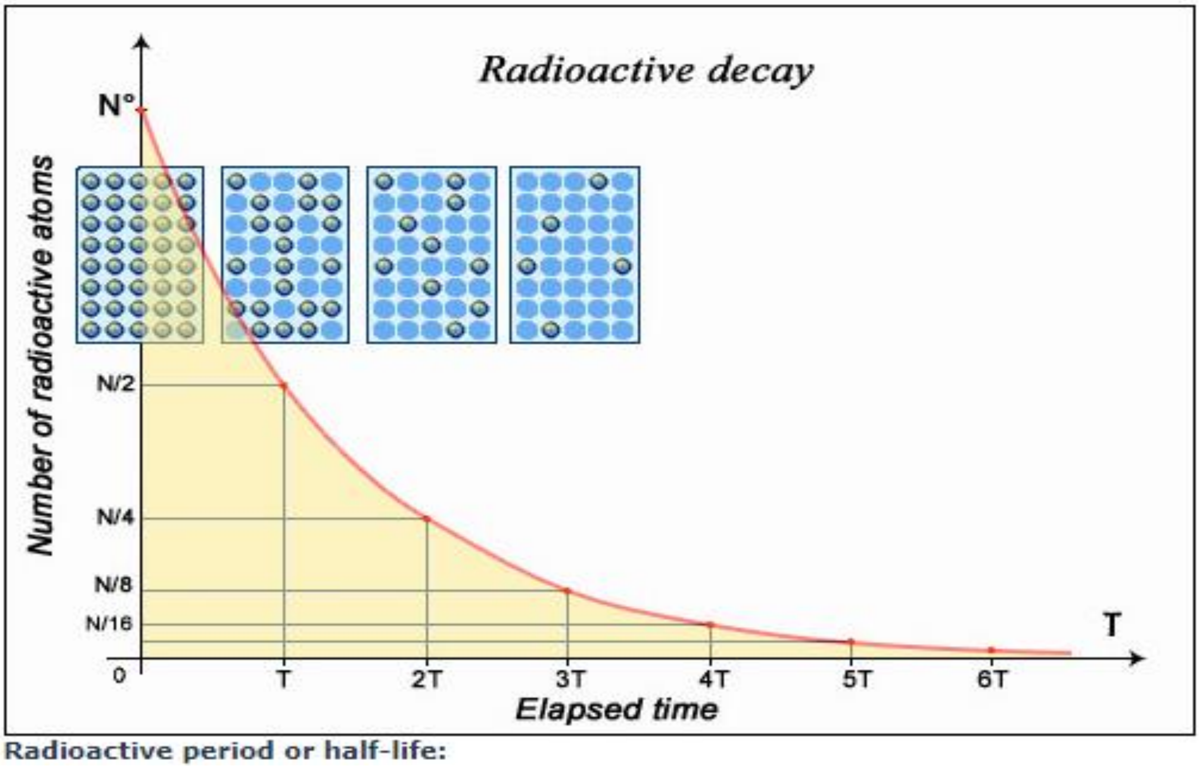

Figure 2.3: The exponential behavior of number of nuclei present in a sample (N) versus time (t) for a radioactive material

2.3.5 Specific Activity

In most cases, what is required is to know the number of nuclei that disintegrate per second, and not the number of nuclei remaining without disintegration, which is defined by the relationship. The number of nuclei that disintegrate per second of radioactive sample is called the radioactive intensity of the sample or the sample's radioactivity. The radiation intensity at the moment of preparing the sample is denoted by the symbol $A_\circ$ and over time the radiation intensity A of the sample decreases according to the relationship:

$$N = N_\circ \, e^{-\lambda t} \tag{2.5}$$

$$A = A_\circ e^{-\lambda t} \tag{2.6}$$

2.4 Decay series of natural radionuclide

2.4.1 ^{238}U decay series

Approximately 99.3% of natural uranium is contained in the radionuclide form of uranium-238, which contains a half-life is about 4.5 billion years. The decay series of uranium -238 ends in the formation of the stable ^{206}Pb nuclide. The daughter nuclides are radon-222 and radium-226, and the most common radionuclides are radon. Formed by alpha decay (alpha particle emission contains two neutrons and two protons) of radium-226. A primary health concern associated with the decay chains of uranium-238 and thorium-232 is the daughter products of radon-222 and radon-220, respectively, because it can cause lung cancer at the sufficient exposure [62, 63].

$$^{226}_{88}Ra \rightarrow \ ^{222}_{86}Rn + \, ^{4}_{2}\propto$$

The number of minerals containing uranium-238 and radium-226, as well as the radon emission percentage of mineral crystals found in sediments, rocks, and materials generated from sediment and rock, influence the amount of radon gas emitted into groundwater and the atmosphere (i.e., some building materials). The number of radon atoms released per number of radon atoms generated is known as the radon emission fraction. Radon emissions vary by mineral and are enhanced by increasing moisture content, specific surface area, and temperature [62, 64]. The fractions of radon emission from sediments (soil minerals) are substantially bigger than those from unweathered rock minerals, implying that radon emission fractions are dependent on weathering. Radon in the gaseous state is mobile and can collect in confined places; radon gas concentrations in homes are mostly influenced by home construction and features such as ventilation [64].

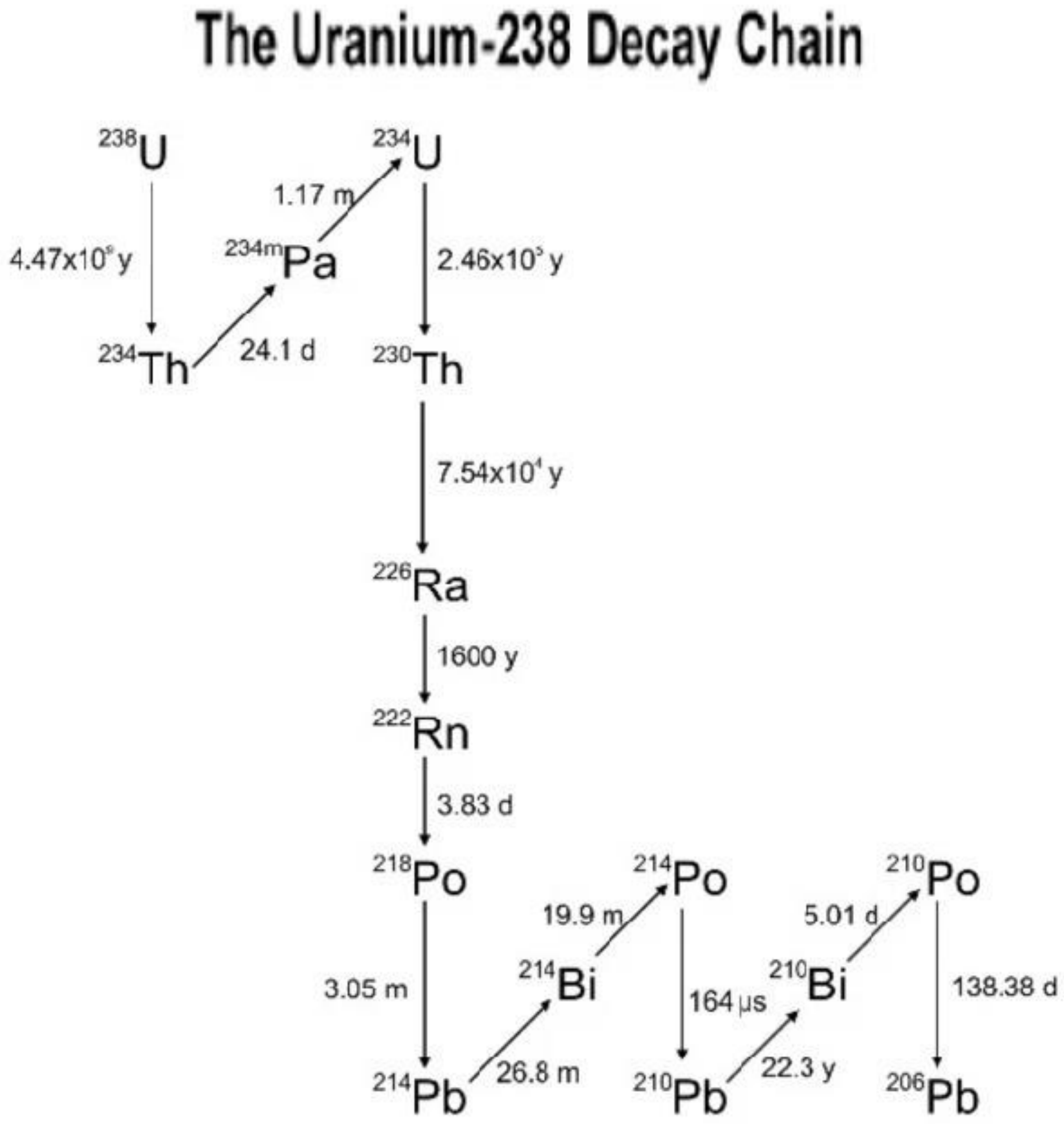

Figure 2.4 : The uranium-238 decay chain (source: U.S Geological Survey) [62]

2.4.2 ^{232}Th decay series

The decay sequence of thorium-232 is depicted in the diagram. The stable nuclide ^{208}Pb is formed towards the end of the thorium-232 decay sequence. Radium-224 and radon-220 are the most important daughter nuclides. Radon-220 (also known as thoron) is produced by the alpha decay of radium-224.figure(2.5) [64].

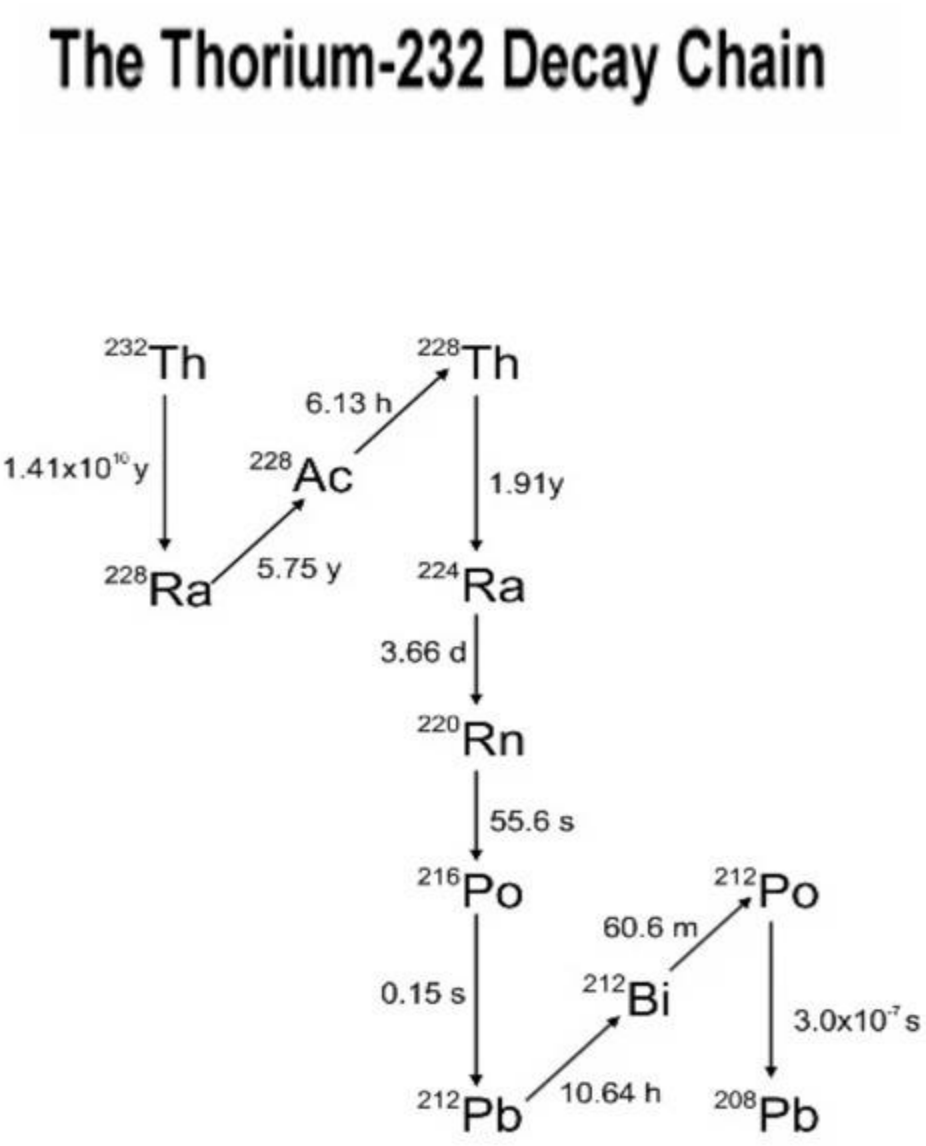

Figure 2.5 : The thorium-232 decay chain (source U.S Geological Survey) [64]

2.4.3 ^{235}U decay series (Actinium – Decay Series)

The Actinium chain is one of the natural radionuclide chains created by the radioactive isotope Uranium-238 decaying. This chain is one of the sorts of elements that can still be found in nature, albeit in fewer quantities than Thorium and Uranium. This chain's decay phase starts with Actinium-235 and concludes with Timbal-207, a stable form of Actinium [65].

The Uranium-235 chain is known as the (Actinium Series) or (Actinium Cascade). This decay sequence includes the elements Actinium, Astatine, Bismuth, Francium, lead, Polonium, Protactinium, Radium, Radon, Thallium, and Thorium, starting with the naturally occurring isotope U-235 (half-life=7.04 x 10^8 years). All are present in any Uranium-235 containing sample, whether metal, compound, ore, or mineral, at least transiently. The stable isotope Lead-207 concludes this sequence (stable). The total energy released from Uranium-235 to Lead-207, including the energy lost to neutrinos, is 46.4 MeV.

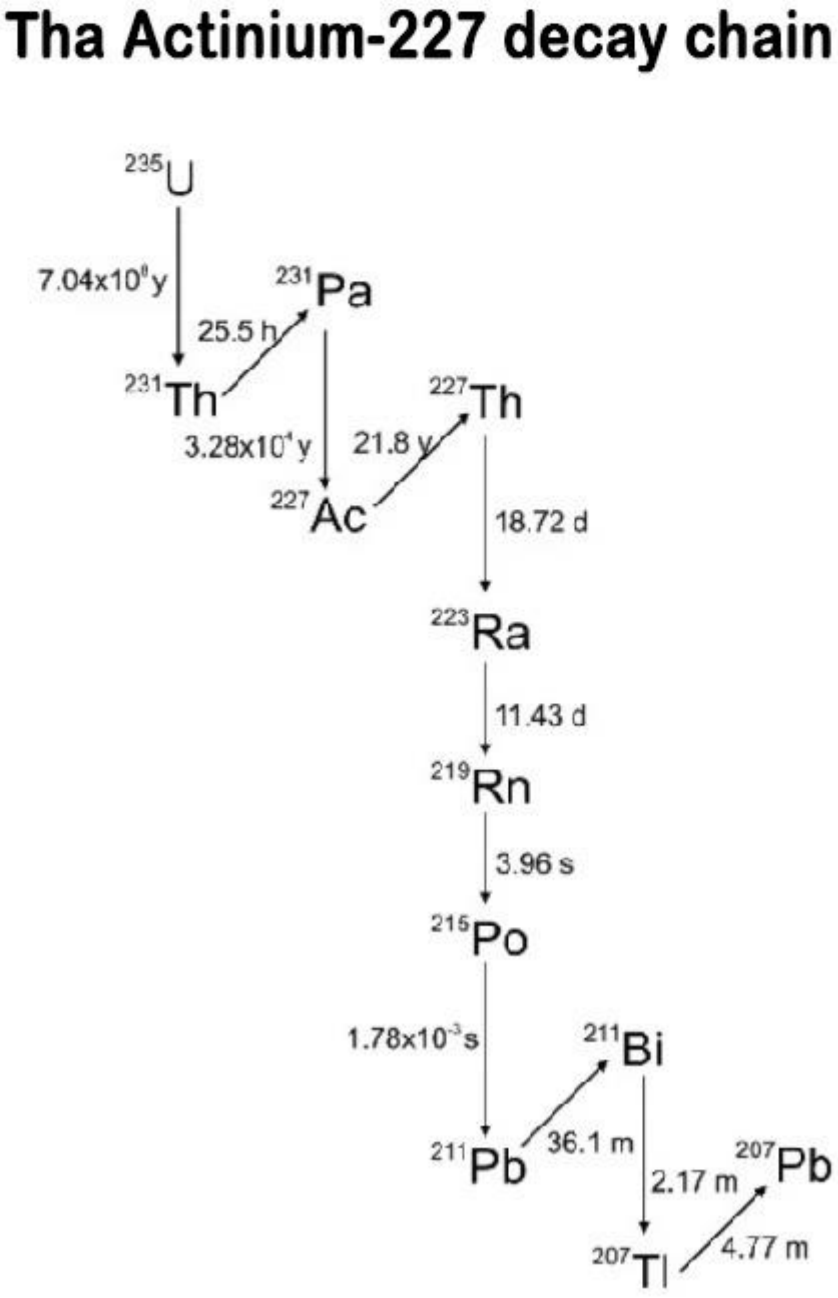

Figure 2.6: The Actinium-227 decay chain (source U.S Geological Survey [18]

2.5 Decay Equilibrium

2.5.1 Secular Equilibrium ($T_P \gg T_D$)

In the event the half-life of the daughter radionuclide is small (much shorter) compared to the parent radioisotope ($\lambda_D \gg \lambda_P$) the activity or abundance of the radioisotope remains constant as its production rate is equal to its decay rate, because the half-life of the parent is very long compared to the time scale considered, Namely:

$$A_{D=} A_P \tag{2.7}$$

The quantity of daughter radionuclides increases until the number of daughter atoms decaying per unit time equals the number created per unit time. The amount of radionuclides in the daughter approaches a steady-state equilibrium. If a daughter's initial radionuclide concentration is zero, full equilibrium normally takes several radioactive half-lives for the daughter to establish.

2.5.2 Transient Equilibrium ($T_P > T_D$)

Where the half-life of the radioactive isotope for the offspring (daughter) is less than the parent radioisotope ($\lambda_D > \lambda_P$) equilibrium is reached by a pair of radioactive isotopes from the parents and daughters. In this case the number of daughter’s atoms can be calculated using the following equation:

$$N_D = \frac{\lambda_P N_P}{\lambda_{D-}\lambda_P} \tag{2.8}$$

2.5.3 No Equilibrium

Should the half-life of the offspring’s (daughters) radioactive isotope be greater from the parent radioisotope ($\lambda_D < \lambda_P$) equilibrium will never be reached. In this case, calculating the number of offspring atoms is more complicated, as shown in equation [66]:

$$\frac{\lambda_P N_P}{\lambda_D N_D} = \frac{\lambda_P}{\lambda_D - \lambda_P} \left(e^{(\lambda_D - \lambda_{P)}\, t} - 1\right) \tag{2.9}$$

Table 2.1: Comparison between the type of Radioactive Equilibrium.

Secular	Half-life of parent much greater than (>100 times) that of decay product.
Transient	Half-life of parent only greater than that of decay product (>10 times).
No equilibrium	Half-life of parent less than that of decay product.

2.6 Health Effects of Radiation

2.6.1 The Human Radiation Exposure

Because of research on plants and animals, it must also be considered that ionizing radiation might cause genetic changes. Although there is no proof of radiation-induced mutation in people, it has an impact on future generations. Radiation can cause sickness and death within weeks of exposure at very high levels. The degree of radiation damage is determined by a number of parameters, including the dose, dose rate, kind of radiation, body part exposed, health, and age. [48].

Ionizing radiation is generally damaging to living beings and can be lethal, although it can be beneficial in the treatment of cancer and thyrotoxicosis. The majority of the negative health effects of radiation exposure can be divided into two categories:

- Inevitable side effects (tissue damage) owing to cell killing malfunction with high doses.

- Random effects, such as cancer and healthy effects, involve the development of cancer in people who are prone to somatic mutation cells or hereditary disease in their offspring as a result of germ cell mutation [29].

2.6.2 Radiation Damage in Human Tissue

Because our study is focused on radon radiation in foods and human exposure to radiation is a primary focus of this research, it was vital to understand how this radiation interacts with the human body and causes damage to living cells.

Ionizing radiation is produced by radioactive materials, which have enough energy to release electrons from atoms or break chemical bonds. Ionizing radiation can cause damage to living tissue in the human body, including leukemia (cancer of the blood) [48]. The body strives to restore the damaged tissue, but certain injuries are irreversible, severe, or widespread. Errors in the normal healing process can lead to the appearance of cancer cells. The most prevalent type of ionization radiation is alpha and beta particles, commonly known as gamma rays and x-rays [29, 48].

CHAPTER THREE

EXPERIMENTAL TECHNIQUES

Chapter Three -Experimental Techniques

3.1 Methodology

3.1.1 Samples Types and collections

In this study, 51 various samples of foodstuff were collected from grocery stores, supermarkets, and various factories and arranged as follows in table 3.1 below:

Table 3.1: Foodstuff samples collected for study purposes

Number	Legumes	Spices	Medicinal plants	Seeds	Foods
1.	Bean	Turmeric	Carob	Melon seeds	Choco
2.	Lupine	Cinnamon	Chamomile	Sunflower Seeds	Wheat semolina (Shilleh)
3.	Chickpeas	Ginger	Sage	Linum Seeds	White sugar
4.	Kidney Beans	Black Pepper	Anise	Squash	Vermicelli (Abu Aita)
5.	Lentil	Cumin	Thyme	Barley	Biscuit (Ulker)
6.	Yellow corn	Sumac		Oats	Rice (Maharani)
7.	Crushed Lentil	Spice Tabikh		Freekeh	Coffee
8.				Sow Water Melon	Milk (Materna)
9.				Sesame	Chips (Royal)
10.					Baby Food/Wheat
11.					Milk (Halibna)
12.					Wheat flour (Haifa)
13.					Wheat semolina (Haifa)
14.					Rice (Diamond)
15.					Gracious
16.					Starch
17.					Jelly
18.					Milk (puck)
19.					Spaghetti (Bravo)
20.					Chips (Doritos)
21.					Thyme
22.					Mulukhiyah
23.					Coconut

3.1.2 Samples location

Figure 3.1: The samples collections around the world

This study was conducted on 51 different types of foodstuff available in the market of Palestine, some of these products were locally grown and manufactured in Palestine such as (Hebron, Interior occupied land -1984 ((Haifa, Jaffa, Tel-Aviv, Al-Taiba, Sederot)) Nablus, Bethlehem, Jenin) and others were imported from several countries around the world such as (Turkey, Canada, India, Malaysia, Ceylon, Vietnam, Russia, Egypt, Mexico, Belgium, Argentina, Sudan, Denmark, America, Brazil, China). Figures, 3-1 and 3-2 show the places where samples are produced globally and locally

Figure 3.2: The samples collection from Palestine

Tables 3.2 to 3.6, shows the different types of foodstuff samples and their places of production locally and internationally.

Table 3.2: Country of Legumes

Name	**Arabic Name**	**Country**
Bean	فول	Sudan
Lupine	ترمس	Argentina
Chickpeas	حمص	Turkey
Kidney Beans	فاصوليا	Egypt
Lentil	عدس حب	Canada
Yellow Corn	ذرة صفراء	Jaffa
Crushed lentil	عدس مجروش	Turkey

Table 3.3: Country of Spices

Name	Arabic Name	Country
Turmeric	كركم	India
Cinnamon	قرفة	China
Ginger	زنجبيل	India
Black Pepper	فلفل اسود	Vietnam
Cumin	كمون	India
Sumac	سماق	Hebron
Spice Tabikh	بهار طبيخ	Mexico

Table 3.4: Country of Medicinal plants

Name	Arabic Name	Country
Carob	خروب	Hebron
Chamomile	بابونج	Egypt
Sage	ميرمية	Hebron
Anise	يانسون	India
Thyme	زعتر بلدي ورق	Hebron

Table 3.5: Country of Seeds

Name	Arabic Name	Country
Melon Seeds	بذر شمام	Russia
Sunflower Seeds	بذر دوار الشمس	America
Linum Seeds	بذر كتان	Haifa
Squash Seeds	بذر قرع	China
Barley	شعير بلدي	Hebron
Oats	شوفان	America
Wheat (Freekeh)	فريكه	Jenin
Sow Water Melon	بذر بطيخ	Occupational Land 1948
Sesame	سمسم	India

Table 3.6: Country of Different Foods

Name	Arabic Name	Country
Choco	شوكو	Nablus
Wheat Semolina (Shilleh)	سميد (الشلة)	Nablus
White Sugar	سكر أبيض	Al-Taiba (Al-Muthalth)
Vermicelli (Abu Aita)	شعيرية (أبو عيطة)	Bethlehem
Biscuit(Ulker)	بسكويت اولكر	Turkey
Rice (Maharani)	أرز بسمتي	India
Coffee	قهوة	Brazil
Milk (Materna)	حليب متيرنا	Tel-Aviv
Chips (Royal)	شيبس رويال	Hebron
Baby Food/Wheat (Materna)	طعام أطفال متيرنا	Tel-Aviv
Milk (Halibna)	حليب حليبنا	Belgium
Wheat Flour (Haifa)	طحين قمح	Haifa
Wheat Semolina (Haifa)	سميد قمح	Haifa
Rice (Diamond)	أرز ديموند	America
Gracious	كريمة حلويات	Nablus
Starch	نشا	Turkey
Jelly	جيلي الزهراء	Nablus
Milk (Puck)	حليب بوك	Denmark
Spaghetti (Bravo)	معكرونة برافو	Hebron
Chips (Doritos)	شيبس دوريتوس	Sederot
Thyme	زعتر دقة	Hebron
Mulukhiyah	ملوخية	Egypt
Coconut	جوز هند	Malaysia

3.1.3 Samples preparation

1- The dried samples were crushed into a very soft powder by using an electrical mill.

2- The samples were packed in cleaning plastic containers (bottles).

3- All bottles were marked with the name of sample; date and time were written upon them before closing the containers.

4- The CR-39 detector was stuck under the cover of the container.

5- The sample of food was placed at the bottom of the packaging with a distance of 1.5 cm away from the cover.

6- The electronic balance was used to calculate the various masses of the samples.

The container's height was 12 cm and its diameter was 6.5 cm, with the distance between the surface of the sample and the front face of the CR-39 being constant at 1.5 cm [67].

7- The samples were taken to Hebron University's Faculty of Science and Technology's radiation contamination laboratory in Hebron, Palestine (fig 3.3).

Figure 3.3: The samples of Foodstuff in Faculty of Science and Technology in Hebron University

3.1.4 Measurements Techniques

The technique chosen is determined by the planned study's goal. Radon concentration levels can be measured using a variety of methods and procedures. These technologies are divided into two types:

1- Passive technique (long-term measurements usually take 3 to 12 months) [68, 69].

2- Active technique (short-term measurements can be carried out from 2 to 7 days).

3.1.4.1 Passive Techniques

Passive approaches are better for monitoring radon exposure over long periods of time and for conducting large-scale surveys at a moderate cost. SSNTDs (Solid-State Nuclear Track Detectors) are less expensive and more suited to long-term assessments of radon and its offspring in the environment [70].

The cup technique was engaged in this work; the high of each cup container was 12 cm and the diameter was 6.5 cm also it contains (1×1) square cm of double sided CR-39 nuclear pathway detector adhesive tape at the top of the mug with the sensitive side down (fig 3.4) [71].

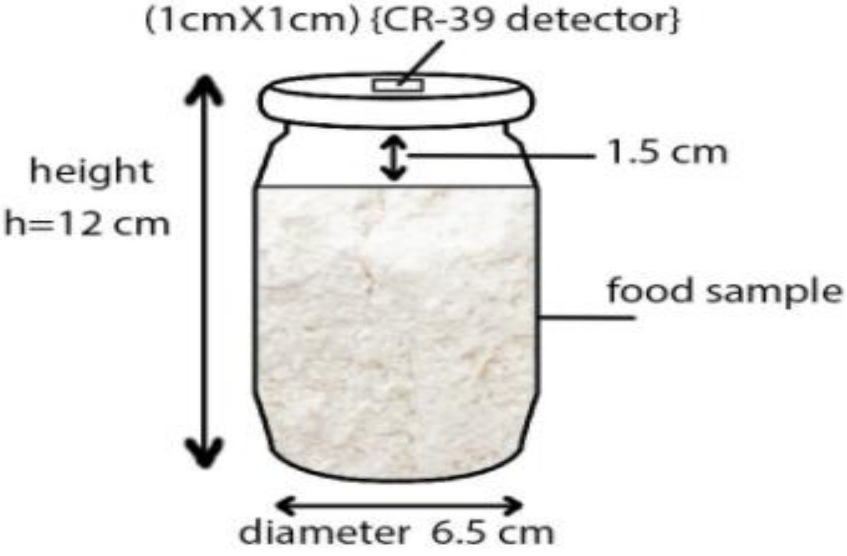

Figure 3.4 : Schematic Diagram of the Sealed-Cup Technique in bottled for foodstuff sample with Nuclear Track Detector (CR – 39) [71]

In this study, the type of Nuclear Track Detector (NTD) known commercially as CR-39 was mentioned. The CR-39 plastic is manufactured by polymerization of the Di (ethylene glycol) bis (Ally carbonate) CR-39 plastic sheets which are:

1- Ion sensitivity is high within particular energy ranges, but electrons and photons are insensitive at reasonable doses [72].
2- It is colorless and transparent to visible light.
3- It offers excellent abrasion resistance and optical characteristics.
4- Keep excellent optical qualities despite prolonged contact with substances such as solvents, strongly oxidizing acids, and strong bases.
5- Thermal distortion resistance up to 100°C, as well as resistance to small volatile hot particles such as welding sparks [73].

3.1.4.2 Active Techniques

In this method, the spectrometer RAD 7, with special accessories to measure the concentration of Radon [71]. Also a PC-based radon gas analyzer by emanation container was used [74].

With a soil probe in close proximity to a zinc sulphide-coated detecting chamber that acts as a scintillator to detect alpha activity and a glass bulb containing calcium chloride to absorb moisture. The air was then circulated in a closed-loop for 5-10 minutes to ensure that the radon was evenly distributed around the room. The radon concentration was determined by measuring the alpha activity that resulted. All sampling sites in the grab log were given a half-hour count time. Four measurements were collected at each sampling location, with a distance of 10-20 cm between them, and the average value of RAD7 was calculated (fig 3.5) [75].

Figure 3.5: RAD7 spectrometer (Active Technique) [75]

3.2 Materials and Apparatus

3.2.1 Solid State Nuclear Track Detectors [SSNTDS] (CR-39)

Solid State Nuclear Track Detectors (SSNTDs) are clear, colorless (1cm×1cm) small particle have long been used for radon measurements.

We utilized the CR-39 detector in this study since it is believed to be superior to other radon detectors. This is owing to the CR-39 detector's advantage in terms of radon concentration measurement. It is inexpensive, readily available, and produces acceptable results [76].

solid-state nuclear track detectors offer a wide range of applications in science and technology, including environmental experiments. Because of the narrow penetrating range of alpha particles, measuring alpha activity on sources in the environment, such as air, is difficult.

Furthermore, most gas ionization detectors suffer from a strong background caused by the associated gamma radiation while measuring alpha activity [77].

3.2.2 Types of Solid State Nuclear Track Detectors

We employed the passive integral approach in this work, which incorporates Solid-State Nuclear Track Detectors (SSNTDs) commonly known as (CR-39), (SSNTDs) specially produced plastic typically accessible in three forms: -

1. Polyallyl diglycol carbonate ($C_{12}H_{18}O_7$) commercially known as (CR-39).
2. Cellulose nitrate ($C_6H_8O_8N_2$) and known as (CR-85).
3. Plastic track detector known as (CR-115).

SSNTD is alpha sensitive to particles with the same energy spectrum as radon particles. This is the most popular and accurate method. Furthermore, SSNTDs are largely insensitive to beta and gamma radiation. Beta and gamma rays, on the other hand, do not produce single tracks. In typically, the sample exposure duration for SSNTD is one month to one year. Humidity, temperature light, and moderate heating have little effect on it [76].

3.2.3 Calibration of CR-39 Detector

CR-39 detectors are fixed to the underside of the cup and pointed toward the radium-226 source (as a source of alpha particles at activity 800 Bq/ m^3 with (2.12×10^4 Bq. d/m^3) concentration for exposure) putting inside the plastic container at the distance 1.5cm. In this study, a cupping technique was used; each cup container measures 12 cm height and 6.5 cm diameter. A CR-39 nuclear track detector (1×1) cm^2 is attached to the upper surface of the cup with double-sided adhesive side tape with the sensitive side facing downward. The detector should be left undisturbed over the sample for at least three weeks. In this experiment, two detectors were exposed to a known activity of ^{226}Ra (solid radon source) for a specific time period, then the detectors were chemically etched. The average number of tracks/cm^2 was calculated. As the detectors were inserted into the same volume (plastic cup) of the sample, they were considered a calibration standard. A similar method was also used for the detector technique to determine the calibration factor (constant)K, calculated by dividing the track density by the total radon exposure as shown below [1]:

$$C_{Rn}\left(\frac{Bq}{m^3}\right) = \frac{c_\circ t_\circ}{\rho_\circ}\left(\frac{\rho}{t}\right) = k\left(\frac{\rho}{t}\right) \tag{3.1}$$

The calibration process for detectors in this survey was carried out at a nuclear lab in Ain Shams University at the physics department. Since then, the average k was calculated:

$$K = 24.2\left(\frac{B_q.day.cm^2}{track.m^3}\right) \tag{3.2}$$

K: is known as the calibration factor, and the standard deviation error was 8%. The overall uncertainty calibration was calculated as ±8%. If we substitute the calibration constant in equation (3.1) then, it becomes:

$$C_{Rn}\left(\frac{Bq}{m^3}\right) = 24.2\left(\frac{\rho}{t}\right) \tag{3.3}$$

The gross level of alpha contamination was calculated using this equation.

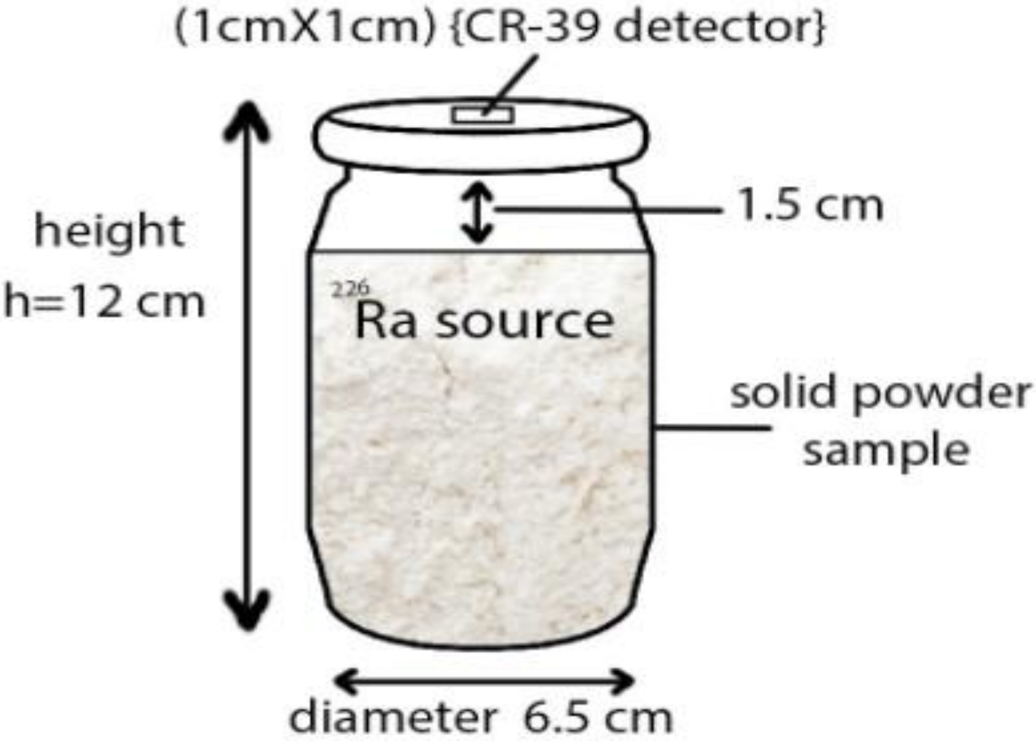

Figure 3.6: Measurement (Calibration) Technique for a solid source of radium [1].

3.2.4 Preparation of Etching Solution

In Solid State Nuclear Track Detectors, chemical etching is a necessary stage in the expansion of buried tracks (SSNTD). Various parameters that govern the sensitivity of the track detector determine the bulk and track etch rates in the etching technique. In order to introduce a new chemical etchant, the etching parameters must be determined [77].

The most frequent approach for expanding traces is chemical etching. The solution assaults the trace's damaged core and penetrates its length at a VT pace, while the surrounding undamaged material is attacked at a VB rate. For certain etching conditions, the etch rate VB is generally constant, and the efficacy of detector track registration is more dependent on the chemical etchant composition and concentration, temperature, and etching time. The bulk etch rate of SSNTDs has been determined using a variety of methods.

A new etchant was studied to find etchants that would produce desirable results. For this reason, three new etchants were discovered, including

1. NaOH dissolved in 1-propanpol.
2. NaOH dissolved in ethanol.
3. NaOH dissolved in methanol + water [76].

- Chemical etching at the same time at constant time 6 hours which carried out at temperature of 110 °C by using 6.25 N concentration of alkali NaOH.

To prepare 6.25 M NaOH solution, we dissolve 6.25 moles of NaOH in 1 liter of deionized H_2O. NaOH has a molar mass of 39.9997 g/mol, so for a 6.25M solution, we need 250g NaOH (39.997×6.25) in 1L of H_2O.

3.2.5 Collecting detectors and Chemical Etching

1- To acquire the clear tracks, the dosimeters were calibrated at the Radiation Laboratory.
2- For three months, the detectors were exposed to food samples to gather a-particle tracks at room temperature (about 30°C).
3- At a height of 1.5 cm from the surface of the sample inside the packaging, the detectors are connected to the plastic cover at the top of the plastic packing.

4- To prevent particles from entering the packing, the samples were saved in a vertical posture in a tightly closed packaging [78].

5- A calibration process is required to fix the calibration constant in units of tracks in order to consider these tracks.

6- High constant approaches have been developed for applications where simply the assessment of track density is required, which frequently expand the track pictures.

7- The most essential criteria for controlling the etching speed of the detectors in practice are temperature, etching time, and etching solution concentration [79].

Chemical Etching:

1- The exposed detectors were collected after 3 months (90 days) of exposure.

2- Chemical etching at the same time at constant time 6 hours which carried out at temperature of 110 °C by using 6.25 N concentration of alkali NaOH.

3- At the end of etching process, the detectors were washed carefully with distilled water and then left to dry (fig 3.7).

optical microscope with magnification of as (40 × 10) used to count the number of tracks in each detector [69, 80].

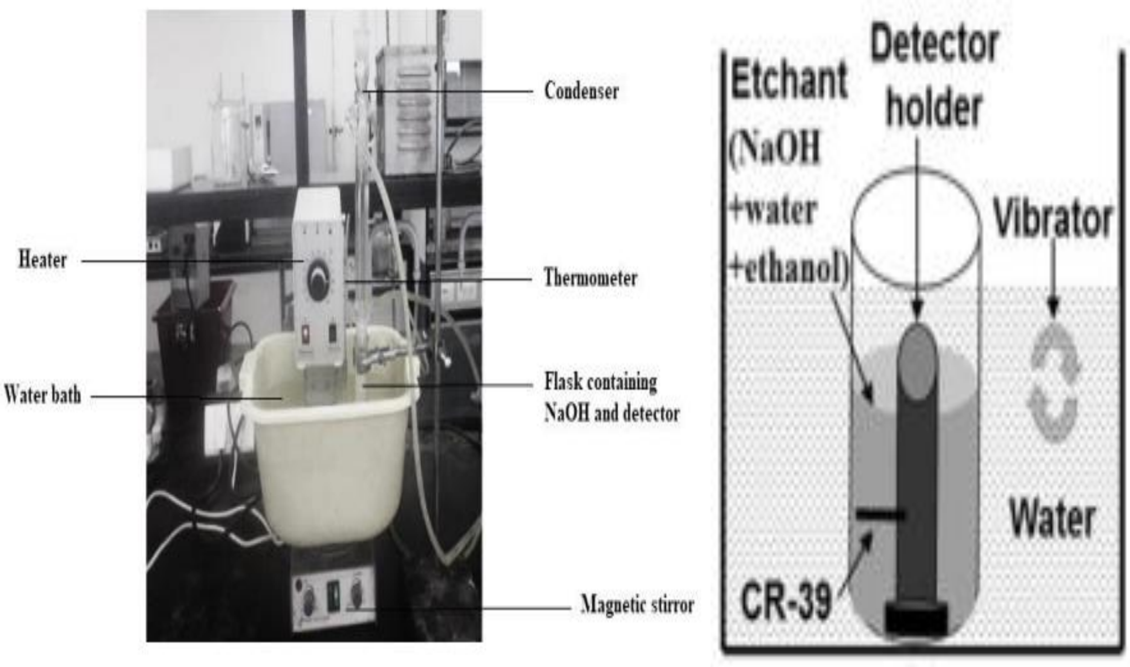

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Figure 3.7: Etching process experimental set up [81]

3.2.6 Microscopic Viewing

The average numbers of tracks in 1mm^2 were calculated by moving microscope stage to left and to right, then up and down about 10 times to assure that not any tracks were missed or counted twice.

The resulting track counts are used to determine track densities, which are then utilized to calculate radon concentrations in foods, as indicated in figure (3.8).

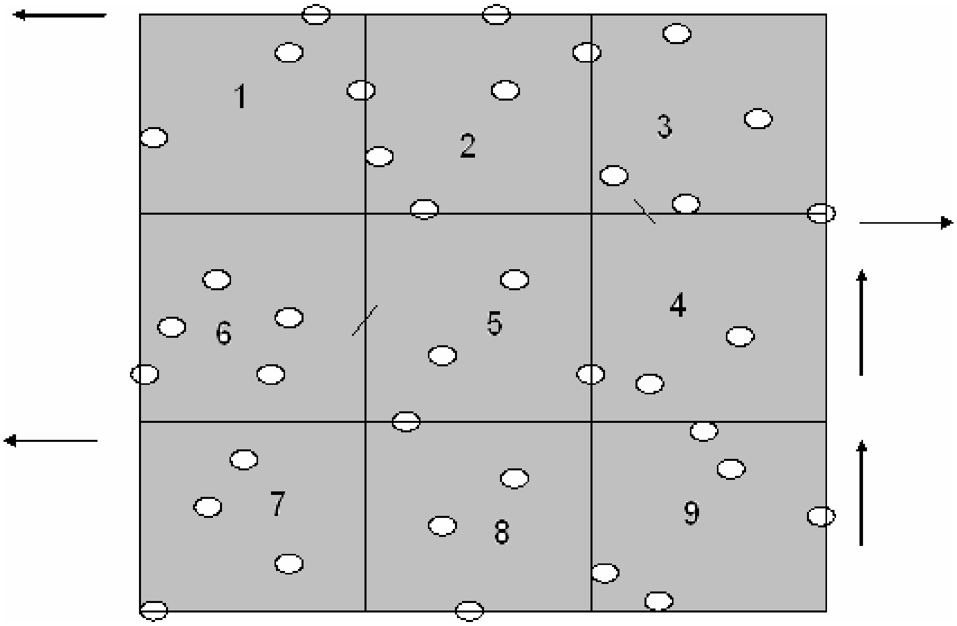


Figure 3.8 : Microscopic images of CR-39 detector irradiated with alpha particles [76]

3.3 Theoretical calculations.

3.3.1 Determination of Radon Concentration

To measure the tracks density in detector, we can use the following equation[40] :

$$\rho = \frac{N}{A} \qquad (3.4)$$

Where, ρ: Density of tracks (Track/cm^2), N: Total average tracks, and A: Field view area (cm^2).

The concentration of ^{222}Rn in foods samples will be calculated in (Bqm^{-3}) unit from the following relation [71, 83].

$$C_{Rn}\,(Bq/m^3) = \frac{C_o\,t_o}{\rho_o}\,(\frac{\rho}{t}) = k(\frac{\rho}{t}) \qquad (3.5)$$

Where:- C_{Rn} : the activity concentration of ^{222}Rn in food sample; C_o: activity concentration of ^{226} Ra (solid radon source) equal 800 Bqm^{-3} ; ρ_o: track density (number of tracks /cm^2) in detectors exposed to ^{226}Ra; t_o: exposure time (in days) of detectors exposed to ^{226}Ra, equal 70 days; ρ : track density (number of tracks /cm^2) in detectors exposed to food samples and t: exposure time (in days) of detectors exposed to soil samples which equal 90 day, K: is the calibration factor of CR-39 nuclear track detector which equal 24.2 [71].

The calibration factor (K) was calculated by using the equation:

$$k = \frac{C_o t_o}{\rho_o} = 24.2\ Bq/m^3 day/tracks/cm^2 \qquad (3.6)$$

Substituting calibration constant in equation (3.1), the activity concentration of alpha particles in food becomes:

$$C_{Rn}(Bq/m^3) = \frac{C_o t_o}{\rho_o}(\frac{\rho}{t}) = k(\frac{\rho}{t}) = 24.2\frac{\rho}{t} \qquad (3.7)$$

Note: 1pCi/L= 37 Bq/m^3 and 1 Bq/L=1000 Bq/m^3 are used as conversion unit [71].

3.3.2 Determination of Radium Contents

The concentration of Ra (C_{Ra}) in foods samples will be calculated in unit from the following equation [84].

$$C_{Ra} = \frac{\rho h A}{K T_e M} \tag{3.8}$$

Where ρ: is the track density (tracks per cm^2), h: is the distance between the top of the sample and the detector which equal 1.5 cm, A: is the surface area from which radon is exhaled (m^2), M: is the mass of the sample (Kg), and $T_{eff:}$ is the effective exposure time in (hour), which is related to the actual exposure time t, by the equation [76].

$$T_e = t - \frac{1}{\lambda\left(1-e^{-\lambda t}\right)} \tag{3.9}$$

Where λ*:* is the decay constant for radon which equal $(7.56 \times 10^{-3}\ h^{-1})$.

3.3.3 The Annual Effective Dose (AED)

To calculate the mean annual effective dose due to radon concentrations received by persons, the conversion coefficient from the absorbed dose and the indoor occupancy factor must be taken into account. The UNSCEAR recommendation was followed, and the relationship can be used to predict the annual effective dose for one-year radon exposure [85].

$$AED\ (mSvy^{-1}) = C_{Rn} \times F \times T \times Q \tag{3.10}$$

Where C_{Rn} is the concentration of radon, F is the conversion factor (F= 9 nSv $(Bq.hm^{-3})^{-1}$, T is time = 8760 hours of a year (Assuming an indoor occupancy factor is about 80% of 8760 hours, which equals 7008 hours and 20% for outdoors, which equals 1752 hours); Q is the equilibrium fraction (0.6) for outdoors and (0.4) for indoors [86].

3.3.4 The annual effective dose due to the inhalation of radon

The Annual Effective Dose due to radon inhalation, which corresponds to the values of indoor air radon concentrations, H_{inh} resulting from the radon concentration in foodstuff, was calculated according to the following expression [71, 87].

$$H_{inh=}\ C_{Rn} \times R\ \times T \times F \times\ 9nSv\ (Bqhm^{-3})^{-1} \tag{3.11}$$

Where C_{Rn} is the average indoor air radon concentration, in Bq/m^3, R is the air-water cocentration ratio (=10^{-4}), F is the equilbrium factor between indoor radon and its progeny (=0.4), T is the exposure time to this concentration (which assumed to be equal 7000 hour per year) and 9 nSv (Bqhm^{-3})$^{-1}$ is the dose conversion factor.

3.3.5 The surface exhalation rate

Understanding the relative contribution of the substance to the total radon concentration found in the residences depends on the results of the radon exhalation research. The formula for the radon surface exhalation rate is as follows [71]:

$$E_A = \frac{Cv\lambda}{AT_{eff}} \qquad (3.12)$$

Where; E_A (Bqm^{-2}h $^{-1}$): is the surface exhalation rate, C: is the integrated radon exposure in (Bqm^{-3} h), V: is the void volume of the container (m^3), λ: is the decay constant of radon ($\lambda = 7.56\times10^{-3}$ h^{-1}). A: is the area of the sample (m^2), T_{eff} is the effective exposure time in (hr).

3.3.6 The Specific Activity of radon

The activity per quantity of radionuclides atoms is known as a specific activity. It is normally expressed in units of (Bq/Kg), however, the curie (Ci) is another popular unit of activity that allows a specific activity to be described in Ci/g. The level of ionizing radiation exposure, and hence the exposure or absorbed dose, should not be confused with the particular amount of activity. In assessing the consequences of ionizing radiation on humans, the absorbed dose is critical [62,71].

The specific activity of radon in Bq/Kg was calculated by the equation:

$$C_p \left({}^{B_q}\!/_{K_g} \right) = \frac{A}{m} \qquad (3.13)$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Chapter Four-Results and Discussions

4.1 Introduction

This chapter shows the nature of radioactivity an alpha particle which produce from the decaying of radium to radon so to determine the radon contents in some types of household food (coffee, tea, powder milk, rice, flour, cornstarch, and powder coconut) and different types of legumes, spices, medicinal plants by using Solid State Nuclear Track Detectors (SSNTD), were analyzed by closed-can technique (CR-39).

Equations 3.1 through 3.13, respectively, were used for calculating the Annual effective dose due to the inhalation of radon, radon-222 concentration, the annual effective dose, the radium concentration from food samples, specific activity of ^{222}Rn, and the exhalation rate. The results are summarized in tables 4.1 to 4.10 representing a comparison of radon concentration levels in food samples at the present work with those in Palestine. The correlation between radium concentrations with radon concentration is represented in Figures 4.2, 4.4, 4.6, 4.8, and 4.10.

4.2 Results of Measurements of the ^{222}Rn concentrations, ^{226}Ra, the specific activity of ^{222}Rn and radon surface Exhalation rate in foodstuff samples

The Activity concentration of ^{222}Rn, the effective radium ^{226}Ra content, the specific activity of ^{222}Rn, and radon surface Exhalation rate are listed in Tables 4.1 to 4.5, for all types of foodstuff samples.

4.2.1: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface Exhalation rate for Legumes samples

Table 4.1, shows the value of the Activity concentration of ^{222}Rn, the effective radium ^{226}Ra content, the specific activity of ^{222}Rn, and radon surface Exhalation rate in legumes samples collected from Palestine and other countries. the values of radon concentration in the collected samples vary from 78.5 Bq/m^3 in Pill Lentil to 1216.4 Bq/m^3 in Bean with an average value of 419.2 Bq/m^3. The values of radium concentration are ranged between 3.8 – 74.8 Bq/Kg, with an average values are 35.0 Bq/Kg. The lowest specific activity ^{222}Rn value is 50.8 in Pill Lentil and the highest specific activity ^{222}Rn value is 988.8 Bq/Kg in Bean, with an average value is

463.4 Bq/Kg. The radon surface exhalation rate is ranged between 73.8-1143.4 mBqm^{-2}h $^{-1}$ with an average value is 394.0 mBqm^{-2}h $^{-1}$.

Table 4.1: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface exhalation rate for Legumes samples

Arabic name	**Sample Type**	**Sample code**	**Mass (gm)**	C_{Rn} *(Bq/m^3)*	C_{Ra} *(Bq/Kg)*	C_P *(Bq/Kg)*	E_A *(mBqm^{-2}h $^{-1}$)*
ترمس	Lupine	LLS1	323.5	246.3	18.7	247.5	231.5
حمص	Chickpeas	CLS2	383.5	118.3	71.7	947.7	111.2
فاصوليا	Kidney Bean	KBLS3	380.5	148.2	9.6	126.6	139.3
عدس حب	Pill Lentil	PLS4	502.1	78.5	3.8	50.8	73.8
ذرة صفراء	Yellow Corn	YCLS5	360.5	529.7	36.1	477.6	497.9
فول	Bean	BLS6	399.8	1216.4	74.8	988.8	1143.4
عدس مجروش	Crushed lentil	CLLS7	479.5	597.3	30.69	404.9	561.4
Average			**----**	**419.2**	**35.0**	**463.4**	**394.0**

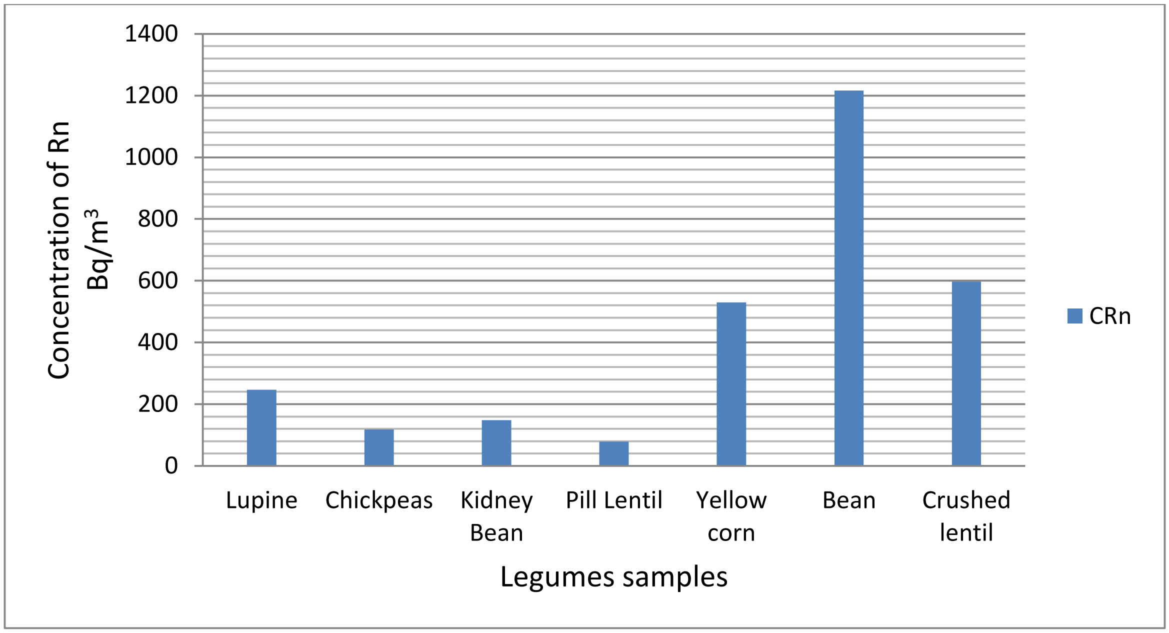


Figure 4.1: ^{222}Rn concentrations in Legumes samples from foodstuff, was collected from Palestine

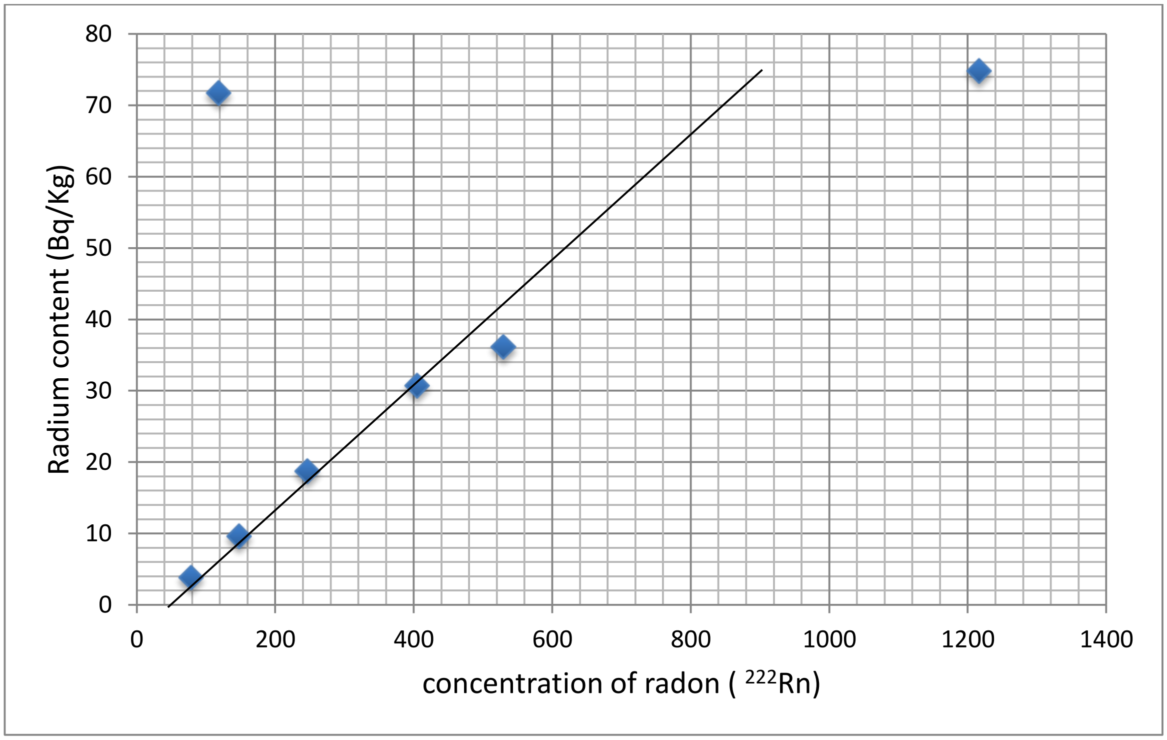


Figure 4.2: Correlation between ^{222}Rn concentration and ^{226}Ra content Legumes samples collected from Palestine

4.2.2: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface Exhalation rate for Spices samples.

Table 4.2, shows the values of the radon concentrations, the radium contents the specific activity of ^{222}Rn and radon surface exhalation rate in Species samples collected from Palestine and other countries. The values of the radon concentration in the collected samples vary from 115.5 Bq/m^{3} in Cumin to 812.4 Bq/m^{3} in Spice Tabikh with an average value of 399.3 Bq/m$^{3.}$ The values of radium concentration are ranged between (7.3 - 66.8) Bq/Kg, with an average value is 32.9 Bq/Kg. The lowest specific activity ^{222}Rn value is 95.9 in Cumin and the highest specific activity ^{222}Rn value is 882.6 in Spice Tabikh, with an average value of 434.6 Bq/Kg. and the radon surface exhalation rate are ranged between (108.57- 763.6) mBqm^{-2}h^{-1} with average value 375.3 mBqm^{-2}h^{-1}.

Table 4.2: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface Exhalation rate for Spices samples

Arabic name	**Sample Type**	**Sample code**	**Mass (gm)**	***C_{Rn} (Bq/m^{3})***	***C_{Ra} (Bq/Kg)***	***C_{P} (Bq/Kg)***	***E_{A} (mBqm^{-2}h $^{-1}$)***
كركم	Turmeric	TSS8	357.9	122.1	8.4	110.9	114.8
زنجبيل	Ginger	GSS9	272.5	200.6	18.1	239.2	188.6
فلفل اسود	Black Pepper	BPSS10	301.9	226.7	18.5	244.1	213.1
كمون	Cumin	CuSS11	391.5	115.5	7.3	95.9	108.57
سماق	Sumac	SSS12	298.5	730.3	60.2	795.1	686.4
قرفة	Cinnamon	CiSS13	283.0	587.2	51.0	674.4	551.9
بهار طبيخ	Spice Tabikh	STSS14	299.5	812.4	66.8	882.6	763.6
Average			**----**	**399.3**	**32.9**	**434.6**	**375.3**

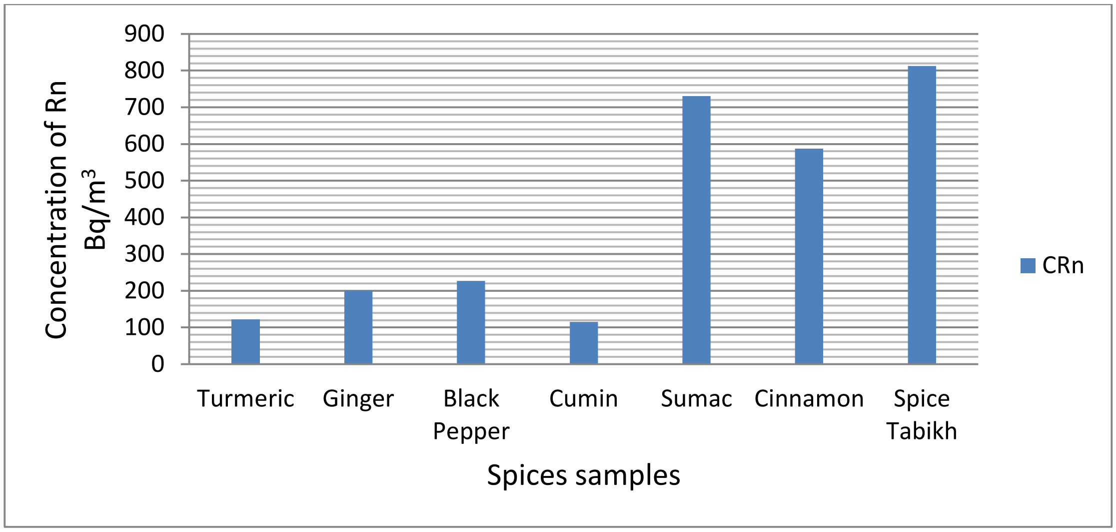
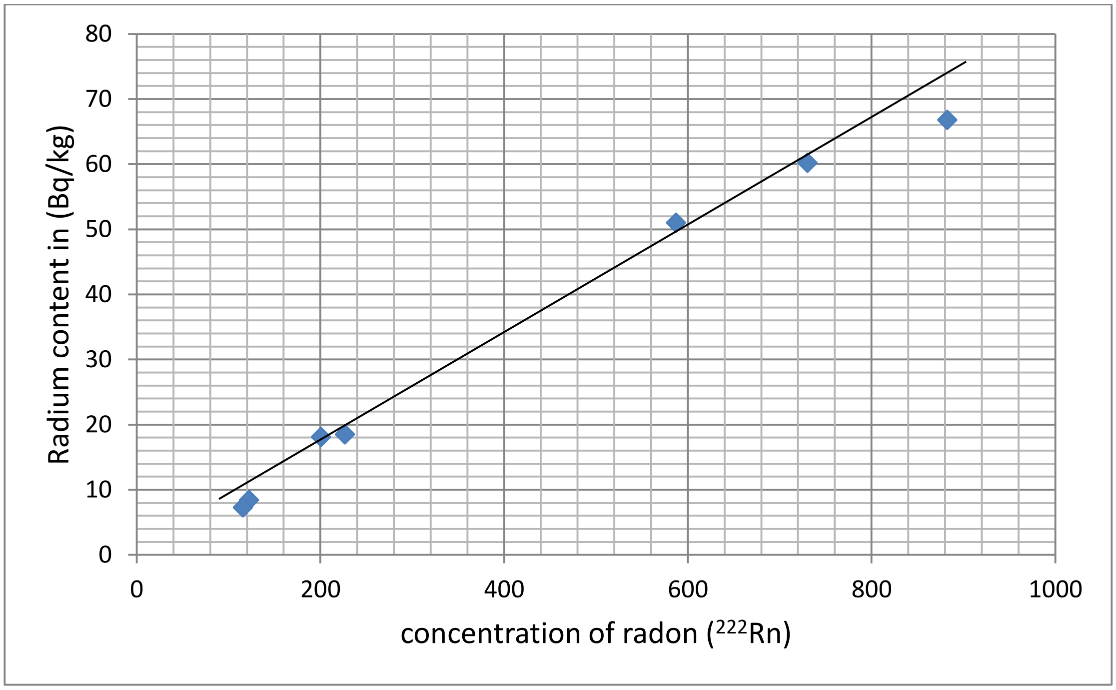


Figure 4.3: ^{222}Rn concentrations in spices sampled from foodstuff, was collected from Palestine



. **Figure 4.4:** Correlation between ^{222}Rn concentration and ^{226}Ra content spices samples collected from Palestine

4.2.3: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface Exhalation rate for Medicinal plants samples.

Table 4.3, shows the values of radon concentrations, the radium contents, the specific activity of ^{222}Rn and radon surface exhalation rate in Medicinal plants samples collected from Palestine and other countries., the values of radon concentration in collected samples vary from 141.7 Bq/m^3 in Thyme to 438.2 Bq/m^3 in Chamomile with an average value of 259.1 Bq/m^3. The values of radium concentration are ranged between (17.2 -44.2) Bq/Kg with an average value of 30.5 Bq/Kg. The lowest specific activity ^{222}Rn value is 222.6 in Carob and the highest specific activity ^{222}Rn value is 584.4 in Sage with an average value of 398.5, and the radon surface exhalation rate ranged between (133.1-411.9) mBqm^{-2}h $^{-1}$ with average value 243.5 mBqm^{-2}h $^{-1}$.

Table 4.3: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface Exhalation rate for Medicinal plants samples

Arabic name	**Sample Type**	**Sample code**	**Mass (gm)**	***C_{Rn}* *(Bq/m^3)***	***C_{Ra}* *(Bq/Kg)***	***C_P* *(Bq/Kg)***	***E_A* *(mBqm^{-2}h $^{-1}$)***
بابونج	Chamomile	ChMPS15	275.5	438.2	39.1	516.9	411.9
ميرمية	Sage	SMPS16	88.5	159.1	44.2	584.4	149.5
يانسون	Anise	AMPS17	362.5	252.9	17.2	226.7	237.7
زعتر بلدي ورق	Thyme	TMPS18	104.2	141.7	33.4	442.0	133.1
خروب	Carob	CaMPS19	442.9	303.5	18.8	222.6	285.3
Average			**---**	**259.1**	**30.5**	**398.5**	**243.5**

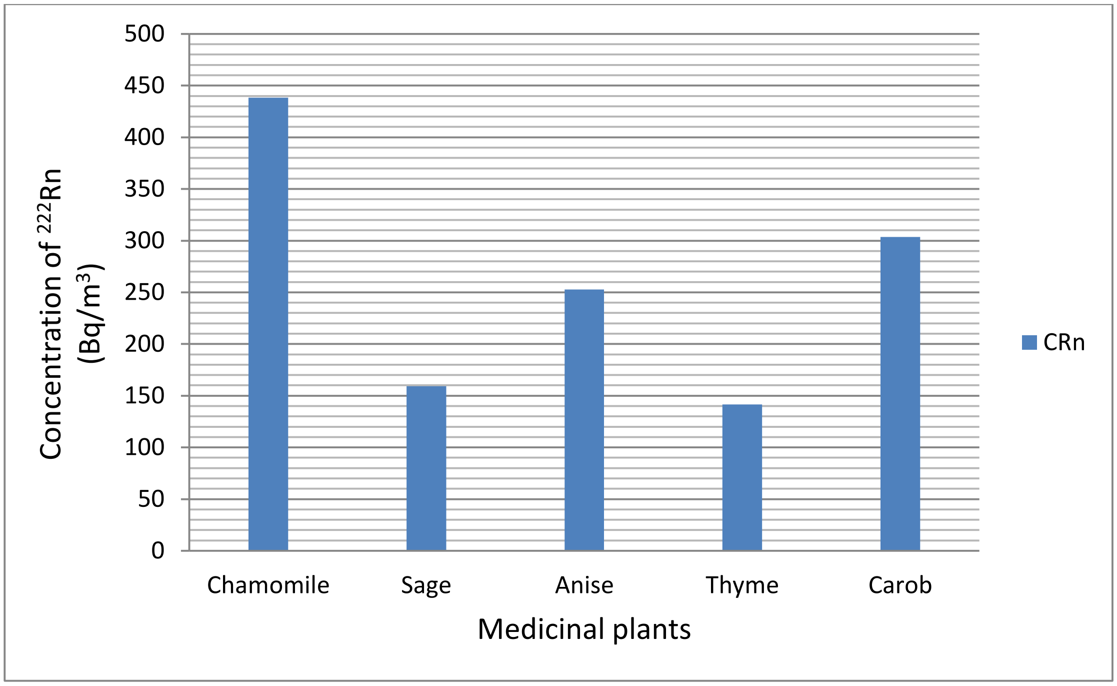


Figure 4.5: ^{222}Rn concentrations in Medicinal plants sampled from foodstuff, was collected from Palestine

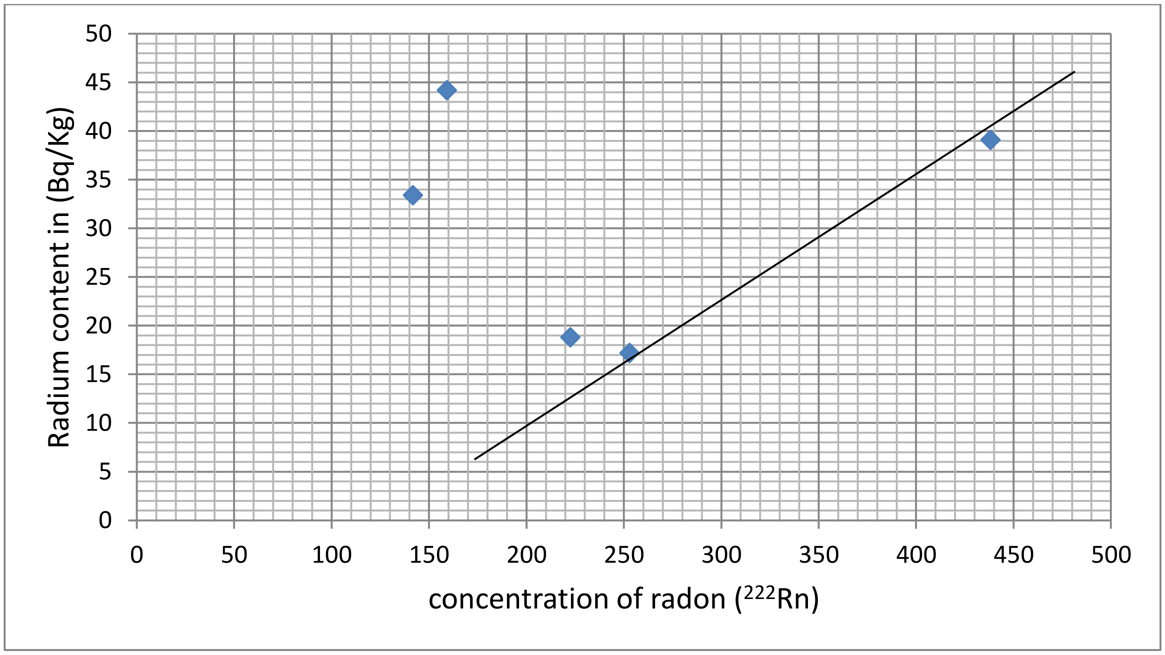


Figure 4.6: Correlation between ^{222}Rn concentration and ^{226}Ra content Medicinal plants samples collected from Palestine

4.2.4: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface Exhalation rate for Seeds samples.

Table 4.4, shows the values of the radon concentrations, radium contents, the specific activity of ^{222}Rn and the radon surface exhalation rate in Seeds samples collected from Palestine and other countries. The values of the radon concentration in collected samples vary from 143.9 Bq/m^3 in Sesame to 837.4 Bq/m3 in Linum Seeds with an average value of 400.7 Bq/m^3. The values of radium concentration are ranged between (10.3- 46.9) Bq/Kg with an average value of 29.9 Bq/Kg. The lowest specific activity ^{222}Rn value is 136.4 in Sesame and the highest specific activity ^{222}Rn value is 620.1 in Linum Seeds with an average value of 395.9 Bq/Kg, and the radon surface exhalation rate ranged between (135.2-787.1) mBqm^{-2}h^{-1} with average value 376.6 mBqm^{-2}h^{-1}.

Table 4.4: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface Exhalation rate for seeds samples

Arabic name	**Sample Type**	**Sample code**	**Mass (gm)**	C_{Rn} *(Bq/m^3)*	C_{Ra} *(Bq/Kg)*	C_P *(Bq/Kg)*	E_A *(mBqm^{-2}h^{-1})*
بذر شمام	Melon Seeds	MSS20	237.8	231.1	23.9	315.8	217.2
بذر دوار الشمس	Sunflower Seeds	SuSS21	226.5	209.3	22.7	300.3	196.7
بذر كتان	Linum Seeds	LSS22	329.1	837.4	46.9	620.1	787.1
بذر قرع	Sow Pumpkin	SPSS23	262.5	359.7	33.7	445.3	338.1
شعير بلدي	Barley	BSS24	283.5	521.0	45.2	597.3	489.7
شوفان	Oats	OSS25	341.2	492.7	35.5	469.3	463.1
فريكه	Wheat (Freekeh)	WFSS26	455.5	523.2	28.2	373.3	491.8
بذر بطيخ	Sow Water Melon	SWMSS27	306.5	287.8	23.1	305.1	270.5
سمسم	Sesame	SeSS28	342.8	143.9	10.3	136.4	135.2
Average			**---**	**400.7**	**29.9**	**395.9**	**376.6**

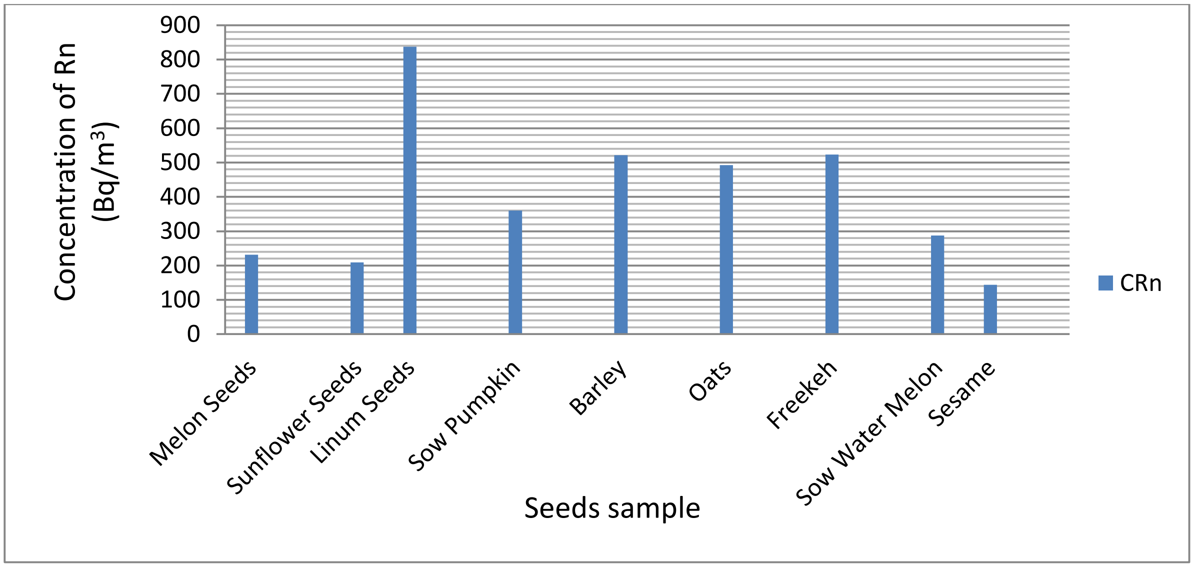


Figure 4.7: ^{222}Rn concentrations in Seeds sampled from foodstuff, was collected from Palestine

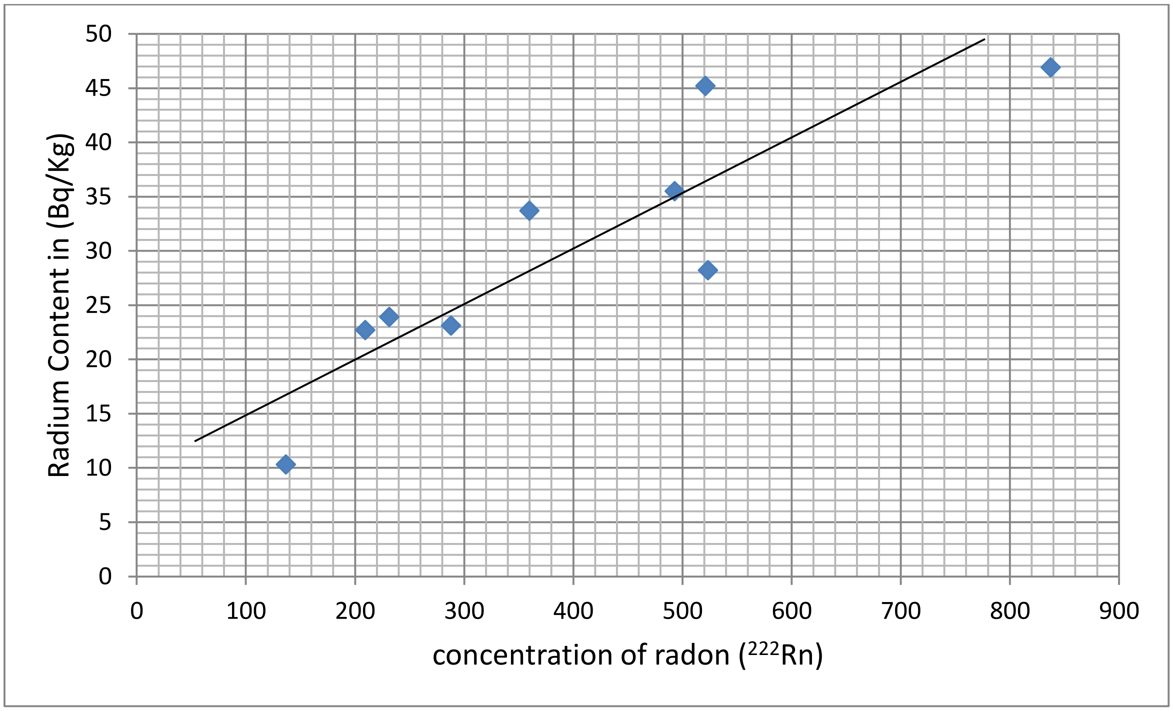


Figure 4.8: Correlation between ^{222}Rn concentration and ^{226}Ra content Seeds samples collected from Palestine

4.2.5: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface Exhalation rate for Food samples.

Table 4.5, shows the values of the radon concentrations, radium contents, the specific activity of ^{222}Rn and radon surface exhalation rate in Foods samples collected from Palestine and other countries. The values of the radon concentration in the collected samples vary from 67.6 Bq/m^3 in Biscuit Olkur to 735.8 Bq/m^3 in Wheat Semolina (Shilleh) with an average value of 362.1 Bq/m^3. The values of radium concentration are ranged between (3.7- 147.8) Bq/Kg with an average value of 34.5 Bq/Kg, the lowest specific activity ^{222}Rn value is 49.5 in Rice Diamond and the highest specific activity ^{222}Rn value is 1949.8 in Mulukhiyah with an average value of 455.8, and the radon surface exhalation rate ranged between (63.5- 691.6) mBqm^{-2}h^{-1} with average value 340.3 mBqm^{-2}h^{-1}.

Table 4.5: The Activity concentration of ^{222}Rn, the effective radium content, the specific activity of ^{222}Rn, and radon surface Exhalation rate for Food samples.

Arabic name	**Sample Type**	**Sample code**	**Mass (gm)**	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	C_P (Bq/Kg)	E_A $(mBqm^{-2}h^{-1})$
شوكو	Choco	ChFS29	419.5	296.5	17.4	229.7	278.7
سميد	Wheat Semolina (Shilleh)	WSeFS30	420.8	735.8	43.0	568.5	691.6
سكر أبيض	White Sugar	WSuFS31	509.1	248.5	12.0	158.7	233.6
شعيرية	Vemicelli	VFS32	515.0	209.3	10.0	132.1	196.7
بسكويت اولكر	Biscuit Olkur	BOFS33	327.5	67.6	5.1	67.1	63.5
أرز بسمتي	Rice Maharani	RBFS34	503.0	328.1	16.1	212.0	308.4
قهوة	Coffee	CoFS35	267.1	514.5	47.4	626.0	483.6
حليب متيرنا	Milk Mterna	MMFS36	284.0	278.0	24.1	318.1	261.3
شيبس رويال	Chips Royal	CRFS37	116.9	250.7	52.7	696.9	235.6
طعام أطفال متيرنا	Baby Food/Wheat	BFWFS38	151.0	315.0	51.3	678.0	296.1
حليب حليبنا	Milk Halibna	MHFS39	297.5	283.4	23.4	309.6	266.3
طحين قمح	Wheat flour	WFFS40	372.5	475.2	31.4	414.6	446.6
سميد قمح	Wheat Semolina	WSFS41	412.5	148.2	8.8	116.8	139.3
أرز ديموند	Rice Diamond	RDFS42	486.5	74.1	3.7	49.5	69.6
كريمة حلويات	Gracious	GFS43	367.5	453.4	30.3	401.0	426.1
نشا	Starch	SFS44	336.5	344.4	25.2	332.7	323.7
جيلي الزهراء	Jelly	JFS45	392.5	436.0	27.3	361.0	409.8
حليب بوك	Milk Puck	MPFS46	127.8	159.5	30.7	405.8	149.9
معكرونة برافو	Spaghetti Bravo	SBFS47	442.5	419.7	23.3	308.2	394.5
شيبس دوريتوس	Chips Doritos	CDFS48	367.5	536.3	35.9	474.3	504.1
زعتر دقة	Thyme	ThFS49	316.8	631.1	48.9	647.5	593.2
ملوخية	Mulukhiyah	MFS50	114.1	685.6	147.8	1949.8	644.4
جوز هند	Coconut	CFS51	139.0	438.2	77.5	1024.5	280.4
Average			**---**	**362.1**	**34.5**	**455.8**	**340.3**

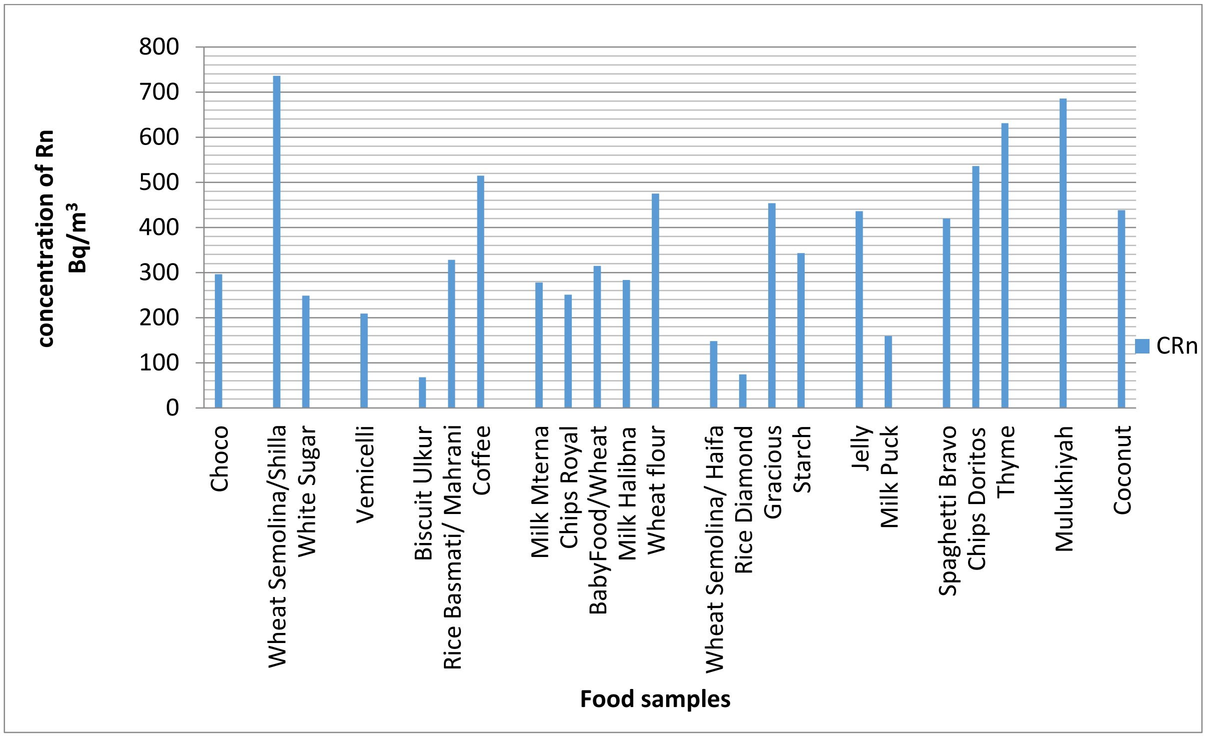


Figure 4.9: ^{222}Rn concentrations in Food samples from foodstuff, was collected from Palestine

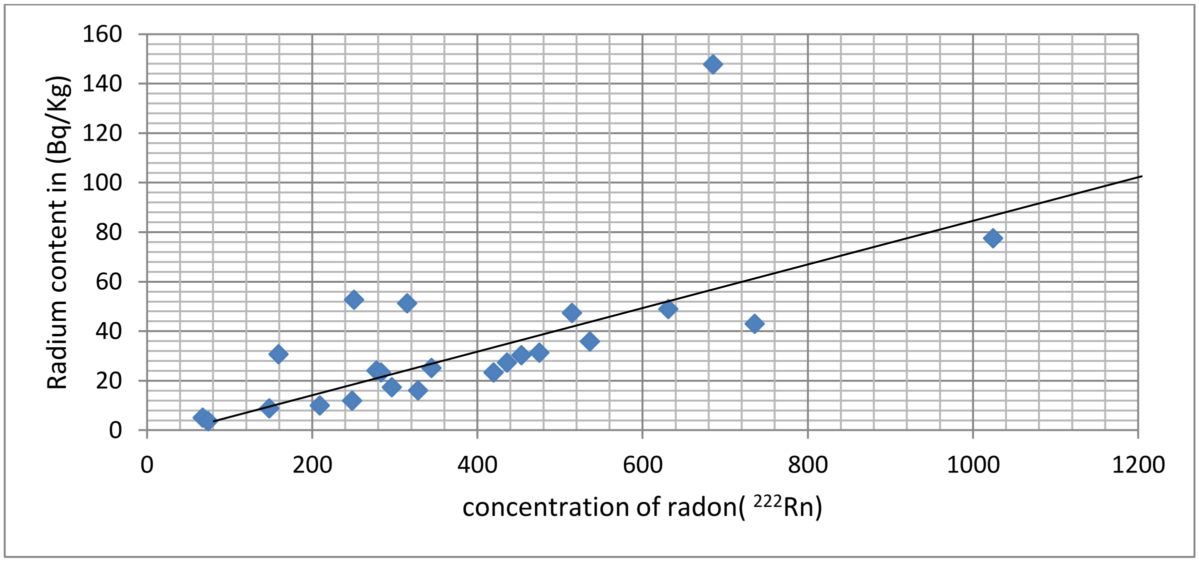


Figure 4.10: Correlation between ^{222}Rn concentration and ^{226}Ra content Food samples collected from Palestine

4.3. The Annual effective dose due to the inhalation of radon, the indoor effective dose, the outdoor effective dose, and total effective dose in foodstuff samples.

Inhalation is the main route of entry into the body for radon and its decay products. However, People may ingest trace amounts of radon with food. The main objective of this study was to measure the H_{inh}, indoor (AED_{in}) and outdoor (AED_{out}) radiation dose rates and to calculate annual effective dose (AED_{tot}) in food samples used in Palestine regions by using standard method. The Annual effective dose due to the inhalation of radon, Indoor effective dose, outdoor effective dose and total effective dose is listed in Tables 4.5 to 4.8, for all types of food samples.

4.3.1 The Annual effective dose due to the inhalation of radon, the indoor effective dose, the outdoor effective dose, and total effective dose for Legumes samples.

Table 4.6, shows the value of the Annual effective dose due to the inhalation of radon also the values of effective dose in Legumes samples collected from Palestine and other countries. The value of the Annual effective dose due to the inhalation of radon vary from 1.96 µSv/yr in Pill Lentil to 30.4 µSv/yr in Bean with average value of 10.46 µSv/yr, the values of indoor effective dose vary from 1.98 µSv/yr in Pill Lentil to 18.42 µSv/yr in Bean with an average value of 10.80 µSv/yr. The lowest outdoor value is 0.74 µSv/yr in Pill Lentil and the highest value is 6.9 µSv/yr in Bean with an average value 4.05 µSv/yr. The values of total effective dose ranged between 2.72- 25.32 µSv/yr with an average value of 14.86 µSv/yr.

Table 4.6: The value of the Annual effective dose due to the inhalation of radon, The indoor effective dose, the outdoor effective dose, and total effective dose for Legumes samples

Arabic name	**Sample Type**	**Sample code**	H_{inh} **(µSv/ yr)**	AED_{in} **(µSv/yr)**	AED_{out} **(µSv/yr)**	AED_{tot} **(µSv/yr)**
ترمس	Thermos	TLS1	6.15	6.22	2.33	8.55
حمص	Chickpeas	CLS2	2.9	16.93	6.35	23.28
فاصوليا	Kidney Bean	KLS3	3.70	3.70	1.40	5.10
عدس حب	Pill Lentil	PLS4	1.96	1.98	0.74	2.72
ذرة صفراء	Yellow corn	YCLS5	13.24	13.37	5.01	18.38
فول	Bean	BLS6	30.4	18.42	6.9	25.32
عدس مجروش	Crushed lentil	CLLS7	14.93	15.07	5.65	20.72
Average			**10.46**	**10.80**	**4.05**	**14.86**

4.3.2: The Annual effective dose due to the inhalation of radon, the indoor effective dose, the outdoor effective dose, and total effective dose for Spices samples

Table 4.7, shows the value of the Annual effective dose due to the inhalation of radon also the values of effective dose in Species samples collected from Palestine and other countries. The value of the Annual effective dose due to the inhalation of radon vary from 2.88 µSv/yr in Cumin to 20.31µSv/yr in Spice Tabikh with average value of 9.97 µSv/yr. The value of indoor effective dose varies from 2.92 µSv/yr in Cumin to 20.53 µSv/yr in Spice Tabikh with an average value 10.08 µSv/yr. The lowest outdoor effective dose value is 1.09 µSv/yr in Cumin and the highest value is 7.70 µSv/yr in Spice Tabikh with an average value of 3.78 µSv/yr. The total effective dose is ranged between 4.01-28.23 µSv/yr with an average value of 13.86 µSv/yr.

Table 4.7: The value of the Annual effective dose due to the inhalation of radon, The indoor effective dose, the outdoor effective dose, and total effective dose for Spices samples

Arabic name	**Sample Type**	**Sample code**	H_{inh} (µSv/ yr)	AED_{in} (µSv/yr)	AED_{out} (µSv/yr)	AED_{tot} (µSv/yr)
كركم	Turmeric	TSS8	3.05	3.08	1.16	4.24
زنجبيل	Ginger	GSS9	5.01	5.06	1.90	6.96
فلفل اسود	Black Pepper	BPSS10	5.66	5.72	2.15	7.87
كمون	Cumin	CuSS11	2.88	2.92	1.09	4.01
سماق	Sumac	SSS12	18.25	18.43	6.91	25.34
قرفة	Cinnamon	CiSS13	14.68	14.82	5.56	20.38
بهار طبيخ	Spice Tabikh	STSS14	20.31	20.53	7.70	28.23
Average			**9.97**	**10.08**	**3.78**	**13.86**

4.3.3: ***The Annual effective dose due to the inhalation of radon, the indoor effective dose, the outdoor effective dose, and total effective dose for Medicinal plants samples.***

Table 4.8, shows the value of the Annual effective dose due to the inhalation of radon also the values of effective dose in Medicinal plants samples collected from Palestine and other countries. The value of the Annual effective dose due to the inhalation of radon vary from 3.54 µSv/yr in Thyme to 10.95µSv/yr in Chamomile with average value of 6.47µSv/yr. The value of indoor effective dose varies from 3.58 µSv/yr in Thyme to 11.05 µSv/yr in chamomile with an average value of 6.54 µSv/yr. The lowest outdoor effective dose value is 1.34 (µSv/yr) in Thyme and the highest value is 4.15 µSv/yr in Chamomile with an average value of 2.45. The total effective dose is ranged between 4.92-15.20 µSv/yr with an average value of 8.99 µSv/yr.

Table 4.8: The value of the Annual effective dose due to the inhalation of radon, The indoor effective dose, the outdoor effective dose, and total effective dose for Medicinal plants samples

Arabic name	Sample Type	Sample code	H_{inh} (µSv/ yr)	AED_{in} (µSv/yr)	AED_{out} (µSv/yr)	AED_{tot} (µSv/yr)
بابونج	Chamomile	ChMPS15	10.95	11.05	4.15	15.20
ميرمية	Sage	SMPS16	3.97	4.02	1.51	5.53
يانسون	Anise	AMPS17	6.32	6.38	2.39	8.77
زعتر بلدي ورق	Thyme	TMPS18	3.54	3.58	1.34	4.92
خروب	Carob	CaMPS19	7.58	7.66	2.87	10.53
Average			**6.47**	**6.54**	**2.45**	**8.99**

4.3.4: The Annual effective dose due to the inhalation of radon, the indoor effective dose, the outdoor effective dose, and total effective dose for seeds samples.

Table 4.9 shows the value of the Annual effective dose due to the inhalation of radon also the values of effective dose in Seeds samples collected from Palestine and other countries. The value of the Annual effective dose due to the inhalation of radon vary from 3.59µSv/yr in Sesame to 20.93µSv/yr in Linum Seeds with average value of 10.01µSv/yr. The value of indoor effective dose varies from 3.63 µSv/yr in Sesame Seeds to 15.84µSv/yr in Linum Seeds with an average value of 10.65µSv/yr. The lowest outdoor effective dose value is 1.36 (µSv/yr) in Sesame Seeds and the highest value is 5.94µSv/yr in Linum Seeds with an average value of 3.57

µSv/yr. The total effective dose is ranged between 4.99 - 21.78 µSv/yr with an average value of 13.09 µSv/yr.

Table 4.9: The value of the Annual effective dose due to the inhalation of radon, The indoor effective dose, the outdoor effective dose, and total effective dose for Seeds samples.

Arabic name	**Sample Type**	**Sample code**	***H_{inh}* *(µSv/ yr)***	***AED_{in}* *(µSv/yr)***	***AED_{out}* *(µSv/yr)***	***AED_{tot}* *(µSv/yr)***
بذر شمام	Melon Seeds	MSS20	5.77	5.83	2.19	8.02
بذر دوار الشمس	Sunflower Seeds	SuSS21	5.23	5.28	1.98	7.26
بذر كتان	Linum Seeds	LSS22	20.93	15.84	5.94	21.78
بذر قرع	Sow Pumpkin	SPSS23	8.99	9.08	3.40	12.48
شعير بلدي	Barley	BSS24	13.02	13.15	4.93	18.08
شوفان	Oats	OSS25	12.31	12.43	4.66	17.09
فريكه	Wheat Freekeh	WFSS26	13.08	13.20	4.95	18.15
بذر بطيخ	Sow Water Melon	SWMSS27	7.19	7.26	2.72	9.98
سمسم	Sesame	SESS28	3.59	3.63	1.36	4.99
Average			**10.01**	**10.65**	**3.57**	**13.09**

4.3.5: The Annual effective dose due to the inhalation of radon, the indoor effective dose, the outdoor effective dose, and total effective dose for Foods samples.

Table 4.10, shows the value of the Annual effective dose due to the inhalation of radon also the values of effective dose in Foods samples collected from Palestine and other countries. The value of the Annual effective dose due to the inhalation of radon vary from 1.69µSv/yr in Biscuit Olkur to 18.39µSv/yr in Wheat Semolina (shilla) with average value of 9.05 µSv/yr. The value of indoor effective dose varies from 1.71 µSv/yr in Biscuit Olkur to 40.26 µSv/yr in Milk Puck with an average value of 12.61 µSv/yr. The lowest outdoor effective dose value is 0.64 µSv/yr in Biscuit Olkar and the highest value is 15.09 µSv/yr in Milk Puck with an average value of 4.72 µSv/yr. The total effective dose is ranged between 2.35 – 55.35 µSv/yr with an average value of 17.34 µSv/yr.

Table 4.10: The value of the Annual effective dose due to the inhalation of radon, The indoor effective dose, the outdoor effective dose, and total effective dose for Foods samples

Arabic name	**Sample Type**	**Sample code**	***H_{inh}* *(μSv/ yr)***	***AED_{in}* *(μSv/yr)***	***AED_{out}* *(μSv/yr)***	***AED_{tot}* *(μSv/yr)***
شوكو	Choco	ChFS29	7.41	7.48	2.80	10.28
سميد	Wheat Semolina (shilla)	WSeFS30	18.39	18.56	6.96	25.52
سكر أبيض	White Sugar	WSuFS31	6.21	6.27	2.35	8.62
شعيرية	Vemicelli	VFS32	5.23	5.28	1.98	7.26
بسكويت اولكر	Biscuit Olkur	BOFS33	1.69	1.71	0.64	2.35
أرز بسمتي	Rice Basmati	RBFS34	8.20	8.28	3.11	11.39
قهوة	Coffee	CoFS35	12.86	12.98	4.87	17.85
حليب متيرنا	Milk Materna	MMFS36	6.95	7.01	2.63	9.64
شيبس رويال	Chips Royal	CRFS37	6.26	6.33	2.37	8.70
طعام أطفال متيرنا	Baby Food/Wheat	BFWFS38	7.87	7.95	2.98	10.93
حليب حليبنا	Milk Halibna	MHFS39	7.08	7.15	2.68	9.83
طحين قمح	Wheat flour	WFFS40	11.88	12.00	4.50	16.50
سميد قمح	Wheat Semolina(Haifa)	WSFS41	3.70	3.74	1.40	5.14
أرز ديموند	Rice (Diamond)	RFS42	1.85	1.87	0.70	2.57
كريمة حلويات	Gracious	GFS43	11.33	11.44	4.28	15.72
نشا	Starch	STFS44	8.61	8.69	3.25	11.94
جيلي الزهراء	Jelly	JFS45	10.9	11.0	4.12	15.12
حليب بوك	Milk (Puck)	MIFS46	3.98	40.26	15.09	55.35
معكرونة برافو	Spaghetti	SPFS47	10.49	21.17	7.93	29.11
شيبس دوريتوس	Chips (Doritos)	CHFS48	13.40	13.53	5.07	18.60
زعتر دقة	Thyme	TFS49	15.77	31.84	11.94	43.78
ملوخية	Mulukhiyah	MUDFS50	17.14	34.59	12.97	47.56
جوز هند	Coconut	COFS51	10.95	11.05	4.14	15.20
Average			**9.05**	**12.61**	**4.72**	**17.34**

4.4 Discussions

The alpha particles and breakdown products of radon have health impacts. These particles have enough energy to infiltrate the tissues and reach the inner section of the cells, causing the tissues to be destroyed. Radon and its breakdown products can enter the human body through two routes: inhalation and digestion. Digestion is thought to be safe because the presence of food in the stomach, even if only 1.5 mm thick, can intercept most of the alpha particles released by the decomposition of radon and its offspring. Because radon is a noble gas with a long half-life in comparison to the respiratory cycle, it either enters the circulatory system or returns to the lungs and departs by exhalation. Because radon disintegration products adhere to air suspensions, they have a greater chance of entering the lungs, disintegrating, and causing lung damage.

The results presented and discussed in this study include 51 foodstuff samples collected from local markets in Palestine, and these samples were divided into five groups, which are Legumes, Spices, Medicinal Plants, Seeds and different foods, conducted measurements using the SSNTD method. Compare the results internationally show that the radiation levels for higher samples from the globally allowed. In the samples that were clear some samples to contained a high concentration of radon-222 and radium-226 also, absorbed that was the increase in the annual effective does in these samples of food, therefore must decrease from eating these foods, because its danger in a long time, note that the permissible concentration of radon globally according to the ICRP is (100-300) Bq/m^{3}in 2014.

Radium-226 is widely distributed in the environment because it is present in different concentrations in water, air and soil sediments and rocks. The radiological importance of radium is that it behaves chemically like calcium, which is it is deposited on bone surfaces and areas of mineral metabolism. When radium is swallowed, most of the substances it are rapidly excreted, however, because the chemical behavior of radium is similar to that of calcium, it is absorbed into the blood through the digestive system (intestinal-Gastro) (or lungs) and follows the behavior of calcium, it is deposited primarily in the bones [88] .

Because radium is a highly radioactive chemical element and the most important source of radioactive activity in a variety of foodstuffs, there has been an increasing interest in studying its radioactivity in various plants and food over the last decade. Under normal temperature and pressure circumstances, radium is a solid radioactive element. As a result, even minute levels of radium in the environment can cause radium to accumulate in bone tissue. If consumed or exposed to the body, it can cause major health problems such as sores, anemia, bone cancer, the darkness of the eye lenses, and other problems. [89, 90].

The activity concentration of ^{222}Rn in Bq/m^3 of foodstuff samples in the present study as well as in other studies for many different countries were compared in table 4.11. some value obtained in the present study were noticeably low, and others were higher than international values. This is due to the fact that the fabricated foodstuff used in the study samples were generally around the international levels

Table 4.11: Comparison levels of radionuclide in foodstuff samples in (Bq/m^3)

Type of foodstuff	Country	C_{Rn} (Bq/m^3)	Ref. No
Biscuit	Iran	35.185	[38]
	Palestine	67.6	Present work
Wheat	Tikrit -Iraq	117.74	[41]
	Samawah city-Iraq	7.45	[45]
	Palestine	735.8	Present work
Rice	Tikrit -Iraq	69.84	[41]
	Palestine	69.84	Present work
Lentil	Tikrit -Iraq	86.94	[41]
	Samawah city-Iraq	8.35	[45]
	Palestine	78.5	Present work
Oats	Tikrit -Iraq	28.43	[41]
	Palestine	492.7	Present work
Yellow Corn	Tikrit -Iraq	156.24	[41]
	Samawah city-Iraq	7.0	[45]
	Palestine	529.7	Present work
Chickpeas	Tikrit -Iraq	136.14	[41]
	Samawah city-Iraq	10.1	[45]
	Palestine	670.8	Present work

Continue Table 4.11: Comparison levels of radionuclide in foodstuff samples in (Bq/m^3

Type of foodstuff	**Country**	**C_{Rn} (Bq/m^3)**	**Ref. No**
White Bean (Kidney Bean)	Tikrit -Iraq	131.4	[41]
	Samawah city-Iraq	17.15	[45]
	Palestine	148.2	Present work
Curcuma (Turmeric)	Iraq	634.66	[43]
	Al-Muthana-Iraq	7.95	[44]
	Palestine	122.1	Present work
Cinnamon	Iraq	461.57	[43]
	Al-Muthana-Iraq	21.5	[44]
	Palestine	587.2	Present work
Thymes	Iraq	401.37	[43]
	Al-Muthana-Iraq	8.8	[44]
	Palestine	141.7	Present work
Chamomile	Iraq	526.8	[43]
	Al-Muthana-Iraq	8.0	[44]
	Palestine	438.2	Present work
Sage	Iraq	494.54	[43]
	Al-Muthana-Iraq	8.5	[44]
	Palestine	159.1	Present work
Cumin	Iraq	336.56	[43]
	Al-Muthana-Iraq	9.9	[44]
	Palestine	115.5	Present work
Anise	Al-Muthana-Iraq	10.1	[44]
	Palestine	252.9	Present work
Ginger	Al-Muthana-Iraq	6.7	[44]
	Palestine	200.6	Present work
Barley	Samawah city-Iraq	7.4	[45]
	Palestine	521.0	Present work
Sesame	Samawah city-Iraq	5.95	[45]
	Palestine	143.9	Present work

4.5 Conclusions

Since the formation of the Earth, natural radioactive isotopes have been present in rocks, air, soil, and water, and because some of these isotopes have extremely long decay half-lives (hundreds of millions of years or more), huge amounts of these nuclides are still present on the planet today (UNSCEAR, 2000). Plants absorb radionuclides in the soil, making them available for further distribution throughout the food chain, including direct incorporation into the human diet or indirect incorporation as animal feed [91, 92].

Radionuclide levels in foods fluctuate and are influenced by a number of factors. The type of food and the geographical area where these materials were generated are two of these determinants, with potassium (^{40}K) radium (^{226}Ra) and thorium (^{232}Th) being the most prevalent radionuclides in foodstuffs.

Other naturally occurring radioactive isotopes, such as K-40, are found in lower concentrations and result from the decay of uranium and thorium. K-40 is an important radionuclide in terms of health physics because it is the largest contributor to the dose received by humans due to its widespread distribution in the environment and living organisms [93].

- The results of radon concentration levels in Legumes samples were from 78.5 Bq/m^3 to 729.6 Bq/m^3 with a total average value of 428.6 Bq/m^3. The total value of the effective dose in Legumes is 14.86 μSv/yr.
- The radon concentration levels in the spices samples in different sites of the regions were from (115.5 - 812.4) Bq/m^3 with a total average value of 399.3 Bq/m^3. The total value of the effective dose in spices is 13.86 μSv/yr.
- The recorded values of radon concentration in Medicinal plants samples are ranged from (141.7 - 438.2) Bq/m^3 with a total average value of 259.1 Bq/m^3. The total value of effective dose in medicinal plants is 8.99 μSv/yr.
- The ^{222}Rn concentrations obtained in Seeds samples ranges from 143.9 to 837.4 Bq/m^3 with a total average value of 400.7Bq/m^3. The total value of the effective dose in seeds is 13.09 μSv/yr.
- The radon concentration levels in the Food samples from different sources in the regions was from 67.6 to 735.6 Bq/m^3 with a total average value of 362.1 Bq/m^3. The total value of the effective dose in food is 17.34 μSv/yr.

- The study showed the highest concentrations of radon in samples of legumes and seeds, and the reason for this is due to the composition of the material, where legumes and seeds retain radon for a longer period, and also the process of storing food for long periods has a role in the high concentrations of radon, so carrying out some mechanical operations on foods such as storing for a short period and grinding legumes and seeds before using them And the process of continuous ventilation of foods, especially stored ones, which reduces the concentration of radon. Sometimes the high concentration of radon in food depends on the type of soil in which the food is grown and on the concentration of radon in this soil. It also depends on the country of origin from which the food is exported, fertilizer which add to plants, finally, it depends on the area where the plants were grown and the amount of radon in the air that is breathed and the amount of water taken.
- As the long-term average radon concentration increased by 100 Bq/m^3, the risk of lung cancer increased by 16%. It is assumed that the dose-response relationship is linear, that is, the risk of developing lung cancer increases directly with increasing exposure to radon.
- Smokers have a much higher risk of radon causing lung cancer. In fact, it is estimated that smokers are 25 times more likely to be at risk of radon than non-smokers. No risks for other cancers or other health effects have yet been identified, although inhaled radon can deliver radiation to other organs, but to a much lower level than the lungs.

4.6 Recommendations

On the basis of this research, certain recommendations have been made. First, while certain guidance level equation variables (reference level, ingestion dose coefficient, and ratio of contaminated food) can be harmonized, the food intake factor is impossible to harmonize because it is based on national data consumption, which is plainly different between nations. In particular, all countries or any connected stakeholder should apply the most recent 2007 ICRP Recommendation in order to harmonize the Regulation/Standards and the National radiological protection system in order to minimize trade barriers and to ensure high-level public health protection. In emergency exposure circumstances, the method has simple qualities that could improve the effectiveness of contaminated food monitoring and sampling.

Then, for current exposure conditions, such as those in the EU, a particular regulation should be devised to assure high-level public health protection in all exposure situations and to meet the 2011 IAEA International BSS standard.

- Avoid canned food and eat fresh food.
- Try to aerate foods after buying or picking them up.
- Storage in areas check-up by the Ministry of Health.
- Storing food for a short period and using a chemical such as Granular Activated Carbon (GAC) System GAC systems reduce radon from food.
- Monitoring the food packaging and storage process.
- Checking the percentage of radon in food before packing.
- Develop programs and electronic systems to store foodstuffs in a healthy, radon-free manner.

Finally, as with the EU, the USA, and Indonesia, General Standard for Contaminants and Toxins in Food and Feed (CXS 193-1995) should be used to establish food-related radiological protection regulations, as well as the Codex Working Principles for Risk Analysis Application for Food Safety for Governments to establish food-related radiological protection systems based on the risk analysis principle.

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