Faculty of Graduate Studies

Chemistry Department

Determination of the Radiation Dose from Radon Ingestion and Inhalation in Different Types of Drinking Water Samples Collected from Bethlehem Province – Palestine

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Determination of the radiation dose from radon ingestion and inhalation in different types of drinking water samples collected from Bethlehem province - Palestine

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DEDICATION

I dedicate this work to my beloved parents (Emad Ighraib, Basma Ighraib), who have been my source of strength and financial support. To my husband Kamel Aeid Ighraib and all my family. To my children Aeid, Roya, and Aya Dedication to my dear university, Hebron University .To my wonderful homeland, beloved Palestine

DECLARATION

1 declare that the work in this thesis was carried out in accordance with the regulations of Hebron University. It is original and is the result of my own work, unless otherwise indicated or acknowledged as referenced work. This thesis has not been submitted to any other academic institution or non-academic institution for any other degree or qualification. I, hereby, acknowledge that I have been supplied with the academic
rules and regulations for Post Graduate, Hebron University, regulation the conduct of my study and research.

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In the name of God, the Most Gracious, the Most Merciful. Praise be to God, Lord of the Worlds, who has honored me with this success and reaching this degree of knowledge.

I would like to thank Prof. Dr. Khalil Thabayneh for his guidance through this project and for the support throughout the year. I consider myself fortunate to work under their supervisor. The only thing I can tell them is thank you for everything.

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List of Abbreviations

EPA	Environmental Protection Agency
WHO	World Health Organization
Bq	Becquerel
Bq/m^3	Becquerel per cubic meter
Ci	Curie
pCi/ℓ	Picocurie per liter
NCRP	International Commission on Radiological Protection
^{222}Rn	Radon-222
^{238}U	Uranium- 238
^{226}R	Radium- 226
A (t)	activity, the number of nuclei decaying per second
N	Number of radioactive nuclei,.
Λ	decay constant
N_0	number of atoms at time equal to zero
N(t)	number of atoms at any different time
$T_{1/2}$	Half-life
t_{av}	Average lifetime
SI unit	International System of Units
SSNTD	solid-state nuclear track detector
CR-39	Columbia Resin No. 39 Plastic Nuclear Track Detector.
H_{in}	annual effective dose for inhalation radon in water
H_{ing}	annual effective dose for ingestion radon in water
CPPP	lung cancer cases per year per million person
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
EU	Council of Europe Union

Abstract

Radon is the main source of natural background radiation It contributes about more than 60% of the annual radiation dose to which humans are exposed on earth. As an inert gas, it has the ability to spread through solid materials and mix with atmospheric air, and its accumulation in closed places or places where ventilation is low may lead to high concentrations. Radon gas enters the respiratory system during the breathing process. The danger of radon to human health lies in the presence of its births as plankton in the air atmospheric which are considered heavy elements (Po- 214),which makes the probability of their adhering to the lung wall at ^{218} Po and their entry into the respiratory system is certain.

This study aims to study radon gas as the most important natural radioactive sources in the environment, raise awareness of its dangers to public health. This study dealt with the study of radon in several scattered villages in the city of Bethlehem during the winter and fall of 2019 using solid-state reagents for nuclear pathways, known commercially as (CR-39). 79 samples were collected and processed in the laboratories of Hebron University and after the expiration of the exposure period of 75 days, the reagents were placed inside a solution of sodium hydroxide at a concentration of 6 molars and at a temperature of 70°C, where the pathways resulting from hitting the alpha particles emitted from radon gas on the detector were then calculated. Tracks using a light microscope at a magnification of 160 X to obtain the concentration of radon gas.

Radon gas concentrations in the province ranged between (0.71- 2.17) Bq/ℓ with average value 0.93 Bq/ℓ. The study showed that radon levels in most of the places that were studied are within the international assigned standard levels. Since the results are more than 1 Bq/ℓ about 38.2% , and 47.05 % the results are between (0.5- 1) Bq/ℓ ,but 14.66 % result are lower than 0.1 Bq/ℓ.

Radon is considered slightly soluble in water. The rate of dissolution increases as the temperature of the water is decrease. Groundwater absorbs quantities of radon when it passes over the rocky layers and the soil below when the water flows or is exposed to a rise in its temperature, this helps to release radon from it.

الملخص

تحديد الجرعة الإشعاعية الناتجة عن ابتلاع واستنشاق غاز الرادون في أنواع مختلفة لعينات من مياه الشرب تم تجميعها من محافظة بيت لحم – فلسطين

اعداد: ألاء عماد غرايبيه

اشراف: أ. د. خليل ذباينه

تهدف هذه الدراسة إلى دراسة غاز الرادون كأهم المصادر الطبيعية المشعة في البيئة والتوعية بمخاطره على الصحة العامة. تناولت هذه الدراسة دراسة غاز الرادون في عدة قرى متناثرة في مدينة بيت لحم خلال شتاء وخريف 2019 باستخدام كواشف الحالة الصلبة للمسارات النووية ، والمعروفة تجاريا باسم (CR-39).

تم جمع 79 عينة ومعالجتها في مختبرات جامعة الخليل وبعد انقضاء فترة التعرض 75 يومًا ، تم وضع الكواشف داخل محلول هيدروكسيد الصوديوم بتركيز 6 أضراس وعند درجة حرارة 70 درجة مئوية ، حيث تم حساب المسارات الناتجة عن اصطدام جسيمات ألفا المنبعثة من غاز الرادون على الكاشف. يتتبع باستخدام مجهر ضوئي بتكبير 160 X للحصول على تركيز غاز الرادون.

بينت الدراسة ان تركيز غاز الرادون في المحافظة بين (0.71 - 2.17) بيكريل / لتر بمتوسط قيمة 0.93 بيكريل /لتر . أظهرت دراسة أن مستويات الرادون في معظم الأماكن التي تم دراستها تقع ضمن المستويات القياسية الدولية المحددة. أظهرت الدراسة أن تركيز الرادون لأأكثر من 1 بيكريل /لتر حوالي 38.2٪ ، و 47.05٪ كانت النتائج بين (0.5 - 1) بيكريل /لتر ، لكن 14.66٪ كانت النتيجة أقل من 0.1 بيكريل /لتر .

يعتبر الرادون قليل الذوبان في الماء ويزداد معدل الذوبان مع انخفاض درجة حرارة الماء. تمتص المياه الجوفية كميات الرادون عندما تمر فوق الطبقات الصخرية والتربة تحتها عندما تتدفق المياه أو تتعرض لارتفاع في درجة حرارتها ، وهذا يساعد على إطلاق غاز الرادون منه.

CHAPTER ONE

INTRODUCTION

Chapter 1- Introduction

1.1 General Background

All mater around us was created by nuclear reactions and the concomitant radioactivity. The natural relative abundance of stable element is a result of variation in the stability of nuclides of the more than 5000 atoms (nuclides) known, about 95 % are radioactive. Partially all materials and environment compartments on the Earth are either radioactive or naturally exposed to ionizing radiation [1].

Radioactivity was discovered in 1896 by Henri Becquerel by experimenting with uranium. He discovered that the uranium continuously emitted radiation. Marie and Pierre curie in 1897 found that the elements Thorium, Radium, and Polonium shared the same effect that Henri Becquerel investigating.

In 1900, Fried rich Ernst Dorn discovered that radium emanates a gas that was first called Niton (the latin word for nitens which means shining), In 1923 this gas was named Radon [2].

Radioactivity is the emission of radiation originating from a nuclear reaction or spontaneous decay of unstable atomic nuclei. The term of radioactive decay refers to the process when by unstable atomic nuclei decay with the loss of energy by the emission of elementary particles, e.g. (alpha, beta, neutrons or gamma ray photons) directly from electrons shells of atoms with in which the nucleus resides [3].

1.2 Types of Radiation

The term "radiation" is referred to the energy originated from a source and transmitted as particles that can travel through material or space. Atoms and nuclides emit radiation as they attempt to decay into a more stable from either by naturally or artificially processes [4, 5].

Radiations in general were classified into two categories depend on its ability to form ions during interactions with matter, these are:

1- Non- ionizing radiation do not have enough energy to emit electrons from electrically neutral atoms .e.g. (visible light, radio wave , micro wave, Infrared light and some ultraviolet light).

2- Ionizing radiation which has enough energy to emit electrons from atoms includes alpha and beta particles, gamma ray, neutron [6].

1.2.1 Alpha particles

This consists of heavy, positively charged particles emitted by large atoms of electrons such as uranium and radium. It can be stopped completely by a sheet of paper or by thin surface layer of our skin. However , if alpha emitting materials are taken into the body by breathing , eating , or drinking they can be expose internal tissues directly and may, therefore, cause biological damage [7].

1.2.2 Beta particles

This is an electrons or positrons .They are more penetrating than alpha particles and can pass through up to around 1 centimeter of water . In general a sheet of aluminum a few millimeters thick will stop it [7].

1.2.3 Gamma radiation

Gamma ray is an electromagnetic radiation similar to x- ray; it depending on their energy can pass right through the human body, but can be stopped by thick walls of concrete or lead [7].

1.2.4 Neutrons

Neutrons are uncharged particles and do not produce ionization directly. But, their interaction with the atoms of matter and can give rise to then produce ionization [7].

1.3. Radiation sources

Every day, humans come in contact with radiation in both their living and work environments and exposed to natural radiation arising from the earth as well as from outside the earth. Radio nuclides found in the planet`s environment can be divided into two categories: Naturally Occurring Radioactive Material (NORM) and Man- Made radioactive materials (Artificial). NORM can be divided into form:

● Cosmic radiation: it is created by energetically charged particles from outer space continuously hit the earth's atmosphere and the secondary particles and photons they create and arrives at the earth's surface.

● Terrestrial radiation: it emitted from radioactive materials such as isotopes of uranium-238 in the earth's rocks, soils, waters and minerals [8].

● Internal radiation: It is generated in the human body by the food he eats, the air he breathes, and the liquid he drinks, then the human body becomes radiant from internal.

1.4 Radioactive Decay

Radioactivity is a part of an our earth- it has exited all along. The term " radioactivity" is generally referred to the spontaneous transformation of an unstable atomic nucleus to a new nucleus by the emission of a certain ionizing radiation such as alpha, beta, and gamma radiation. This process is referred to transformation, decay or disintegrations of an atom. Elements that emit ionizing radiation are called radioactive; in some cases, one or more isotopes of an element are radioactive, and are called radioisotopes, or radionuclides [9].

The naturally occurring radioactive materials include radioactive elements found in the environment. The long- lived radioactive elements of interest include uranium, thorium and any of their radioactive decay products, such as radium and radon.

The time that it takes for half the radionuclides to disintegrate or decay is called half – life. This differ for each radioelement, ranging from fractions of a second to billions of years. For example, the half-life of Iodine- 131 is eight days, but for Uranium -238, which is present in varying amounts all over the world, it is 4.5 billion year. Potassium -40, the main source of radioactivity in our bodies has a half –life 1.42 billion year, where the half-life of Radon- 222, Radon- 220 and Radon -219 are 3.82 days, 55 second and 4 second respectively. The radioactive decay is expressed in units called Becquerel's, where 1 Becquerel equal one disintegration per second [9].

As radionuclides decays, it becomes an isotope of another element. If this new isotope is also radioactive it decays further. Thus, there can develop a "decay series ". The two most common naturally occurring radioactive materials decay series are the Uranium- 238 and the Thorium -232 series [10.].

1.4.1 The half-life and the average lifetime

The Half-life ($T_{1/2}$) is the time taken for half the unstable particles in a pure sample to decay also the time taken for activity of a sample to halve .

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.639}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.1$$

♦ The product λN is the activity and written as:

$$A = \lambda N = \lambda N_0 e^{-\lambda t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2$$

♦ The expectation value of the time needed for an initial population of N_0 radioactive nuclei to decay to *1/e* of their original number is called the mean life (average life).

$$\text{Average life time } t_{av} = \frac{1}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.3$$

Where, λ is called the decay constant.

♦ The relation between average lifetime and half-life is:

$$t_{av} = 1/\lambda = T_{½}/0.693 = 1.44\ T \quad \ldots\ldots\ldots\ldots\ldots\ldots 1.4$$

♦ From the definition of the half-life, it follows that the fraction of a radionuclide remaining after *n* half-lives is given by the relationship:

$$\frac{A}{A_\circ} = \frac{1}{2^n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.5$$

Where A_0 is the original quantity of activity *and A* is the activity left after n half-lives.

The fact that the graph of activity versus time shown in figure 1.1 below is a straight line tells us that the quantity of activity left after any time interval is given by the following equation:

$$\ln A(t) = \ln A_0 - \lambda t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.6$$

Where A_0 is the initial quantity of activity, *A* is the amount left after time *t,* λ is the transformation rate constant (decay constant).

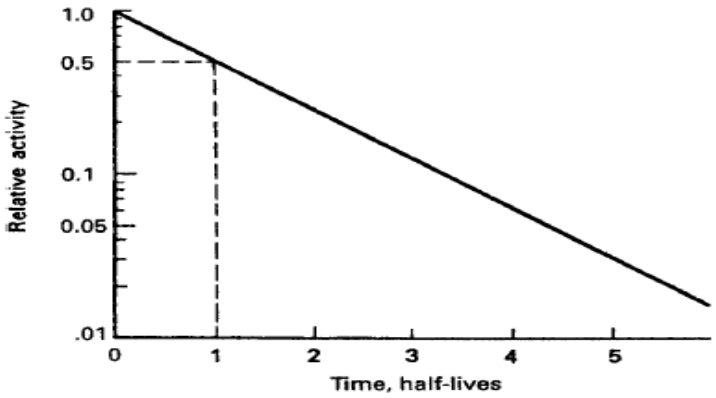


Figure 1.1: The activity versus time

The transformation rate constant is the fractional decrease in activity per unit time and is defined as:

$$\lambda = \frac{\Delta N/N}{\Delta t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.7$$

where N is a number of radioactive atoms and ΔN is the number of these atoms that are transformed during a time interval Δt. The fraction ΔN/N is the fractional decrease in the number of radioactive atoms during the time interval Δt.

Another parameter that is useful for characterizing radioactive decay is the half-life $T_{1/2}$. The half-life of a radioactive substance is the time it takes for half of a given number of radioactive nuclei to decay.

The number of radioactive nuclei written as:

$$N = N_0 \left(\frac{1}{2}\right)^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.8$$

where *n* is the number of half-lives. From the definition, it follows that *n* is related to time t and the half-life $T_{1/2}$ by:

$$n = 1/T_{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.9$$

1.4.2 Activity

Activity is the measure of the rate of a radioactive sample. The SI unit of activity is the Becquerel (Bq) [11].

The theory of radioactive decay depends on one fact: -

1) The number of atoms which decay in a given time is proportional to the number of atoms present at the beginning of that time.

2) Nuclear decay is an essentially random process: we cannot accurately predict) when a given unstable nucleus will decay. However, we can determine the probability that a nucleus will decay within a given time period.

3) The **Becquerel** (**Bq)** is that quantity of radioactive material in which one atom is transformed per second (tps) .

4) Very often, we use the term disintegration instead of transformation and the becquerel is defined in term of disintegrations per second, dps.

$$1 \text{ Bq} = 1 \text{ tps} = 1 \text{ dps}$$

5) The **curie (Ci),** is the unit for quantity of radioactivity that was used before the adoption of the SI units and the becquerel. The curie, which originally was defined as the activity of 1 g of ^{226}Ra, is now more explicitly defined as

6) The ***curie*** is the activity of that quantity of radioactive material in which 3.7×10^{10} atoms are transformed in one second.

7) The curie is related to the Becquerel by $1 \text{ Ci} = 3.7 \times 10^{10}$ Bq.

8) The number of particles that decay in a given time is proportional to the total number of particles in a radioactive sample:

$$dN = -\lambda N \, dt \qquad \ldots\ldots 1.10$$

Separating variables and integrating from t = 0 (when $N = N_0$) to time t, we have :

$$\int_N^N \frac{dN}{N} = -\int_0^t \lambda dt \qquad \ldots\ldots 1.11$$

Or $N = N^{\circ}\, e^{-\lambda t}$

This is called the radioactive decay law, where N_o is the number of parent nuclei at t=0 N is the number of nuclei at any time t (see figure 1.1).

So we can write for the ratio of activities at time t to that at $t_0 = 0$

$$\frac{\lambda N}{\lambda N^{\circ}} = e^{-\lambda t}$$

$A = \lambda N = A_o\, e^{-\lambda t}$ …….1.12

The decay constant (λ) is proportionality between the size of a population of radioactive atoms and the rate at which the population decreases because of radioactive decay.

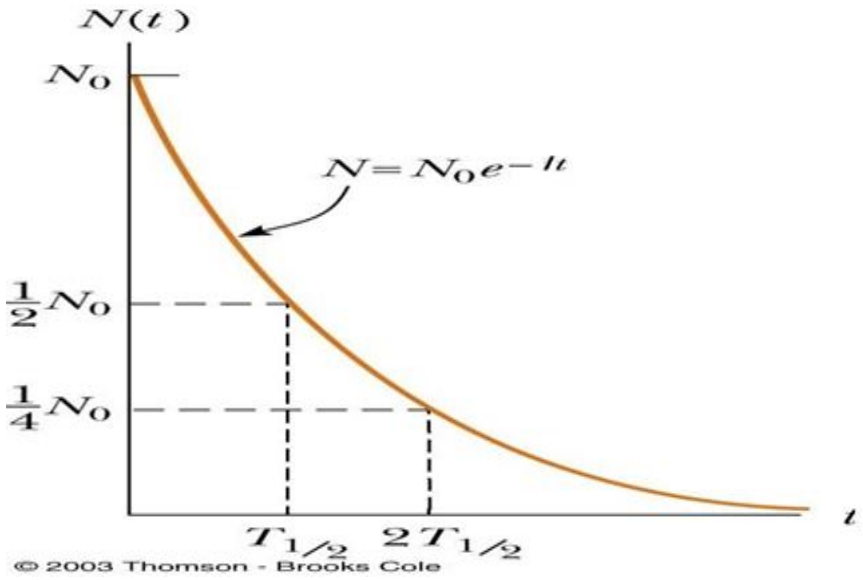


Figure 1.2: The ratio of activities at time *t*

1.4.3 The radioactive decay

There are three main types of radioactive decay:

(i) Alpha decay*:* Alpha decay occurs when the atom ejects a particle from the nucleus, which consists of two neutrons and two protons. When this happens, the atomic number decreases by 2 and the mass decreases by 4. Examples of alpha emitters include radium, radon, uranium and thorium.

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

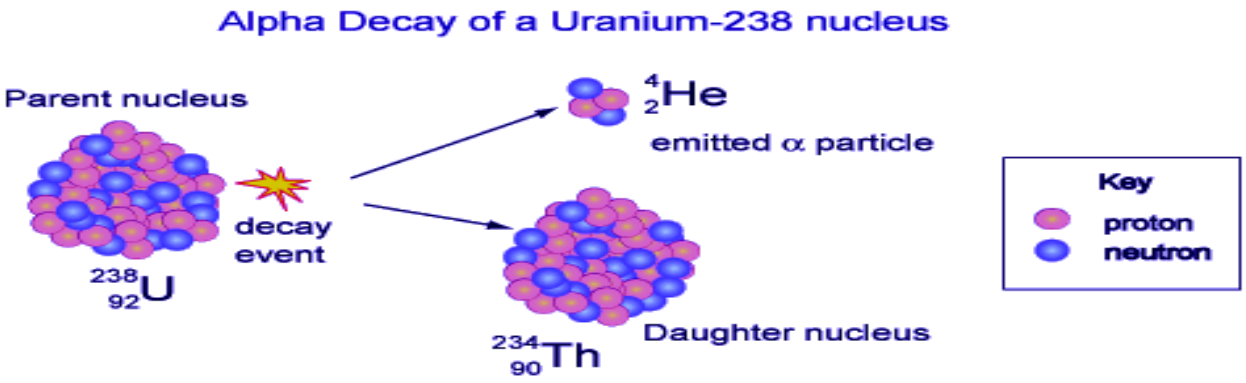


Figure 1.3: Alpha decay of Uranium -238 nucleus.

(ii) Beta decay*:* In basic beta decay, a neutron is turned into a proton and an electron is emitted from the nucleus. The atomic number increases by one, but the mass only decreases slightly. Examples of pure beta emitters include strontium-90, carbon-14, tritium and sulphur-35.

$$^{234}_{90}Th \rightarrow {}^{0}_{-1}e + {}^{234}_{91}Pa$$

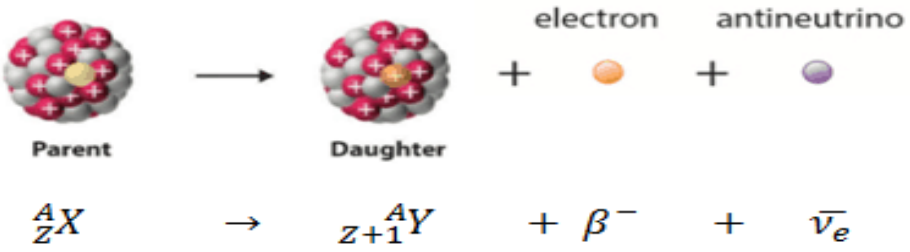
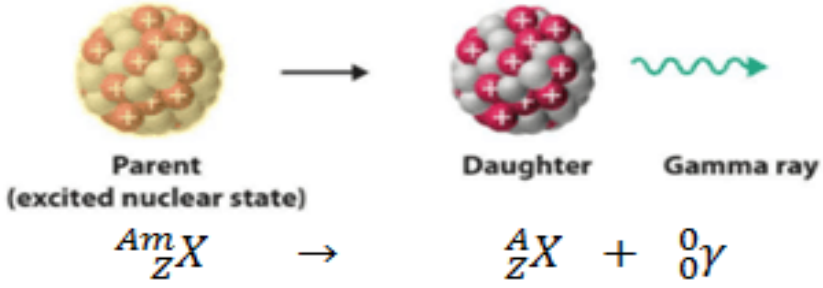


Figure 1.4: Beta decay of Thorium -234 nucleus.

(iii) Gamma decay: Gamma decay takes place when there is residual energy in the nucleus following alpha or beta decay, or after neutron capture (a type of nuclear reaction) in a nuclear reactor. The residual energy is released as a photon of gamma radiation.

Gamma decay generally does not affect the mass or atomic number of a radioisotope. Examples of gamma emitters include iodine-131, cesium-137, cobalt-60, radium-226 and technetium-99m.

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



$$^{Am}_{Z}X \rightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$$

Figure 1.5: Gamma decay of thorium-234 nucleus

If the original source of the radioactivity is known, it can be predicted how long it will take to decay to a given activity. The decay is exponential and the isotope must go through many half-lives to become nonradioactive[11].

1.5 Natural Decay Chains

Uranium, radium, and thorium occur in three natural decay series, headed by uranium-238, thorium-232, and uranium-235, respectively. In nature, the radionuclides in these three series are approximately in a state of secular equilibrium, in which the activities of all radionuclides within each series are nearly equal [12].

Two conditions are necessary for secular equilibrium.

- First, the parent radionuclide must have a half-life much longer than that of any other radionuclide in the series.
- Second, a sufficiently long period of time must have elapsed, for example ten half-lives of the decay product having the longest half-life, to allow for ingrowth of the decay products (see the companion fact sheet on Ionizing Radiation). Under secular equilibrium,

the activity of the parent radionuclide undergoes no appreciable changes during many half-lives of its decay products. The radionuclides of the uranium-238 thorium-232, and uranium-235 decay series are shown in Figures along with the major mode of radioactive decay for each. Radioactive decay occurs when an unstable (radioactive) isotope transforms to a more stable isotope, generally by emitting a subatomic particle such as an alpha or beta particle. Radionuclides that give rise to alpha and beta particles are shown in these figures, as are those that emit significant gamma radiation.

Gamma radiation is not a mode of radioactive decay (such as alpha and beta decay). Rather, it is a mechanism by which excess energy is emitted from certain radionuclides, i.e., as highly energetic electromagnetic radiation emitted from the nucleus of the atom. For simplicity, only significant gamma emissions associated with the major decay modes are shown in Figures 1.6 through 1.8; that is radionuclides listed are those for which the radiation dose associated with gamma rays may pose a health concern. The gamma component is not shown for those radionuclides whose gamma emissions do not generally represent a concern.

1.5.1 ^{238}U decay series

Uranium nucleus consist of 92 proton and 146nutron, giving a total atomic number of 238. The number of protons in atoms is determined what element it is. Whilst the number of proton and electrons remains constant for a particular element, but number of neutrons can vary that give vary in mass number of the same element as different forms. These are named as isotopes. This sequence contains the following ingredients: astatine, bismuth, plum, polonium, protactinium, radium, radon, thallium, thorium, beginning with naturally occurring uranium-238 finishes with Lead-206 (Stable) where ($T_{½}$ = 4.5×10^{9} years) [24].

1.5.2 ^{232}Th decay series

Thorium Series are included: actinium, bismuth, plum, polonium, radium, and 9 thallium, beginning at naturally occurring Thorium-232 ($T_{½}$ = 1.4×10^{10} year). All are present in every natural thorium, whether metal, compound, or mineral sample, at least temporarily. Lead-208 (Stable) is the finishing touch [25].

1.5.3 ^{235}U decay series

is generally called "Series of Actinium" or "Cascades of Actinium." The following components of this decay sequence start with natural isotope U-235 (T½ = 7×10^{8} years). Actinium, astatine, bismuth, francium, lead, polonium, rhythm, thallium, radium. The stable isotope Lead-207 (Stable) ends this cycle.

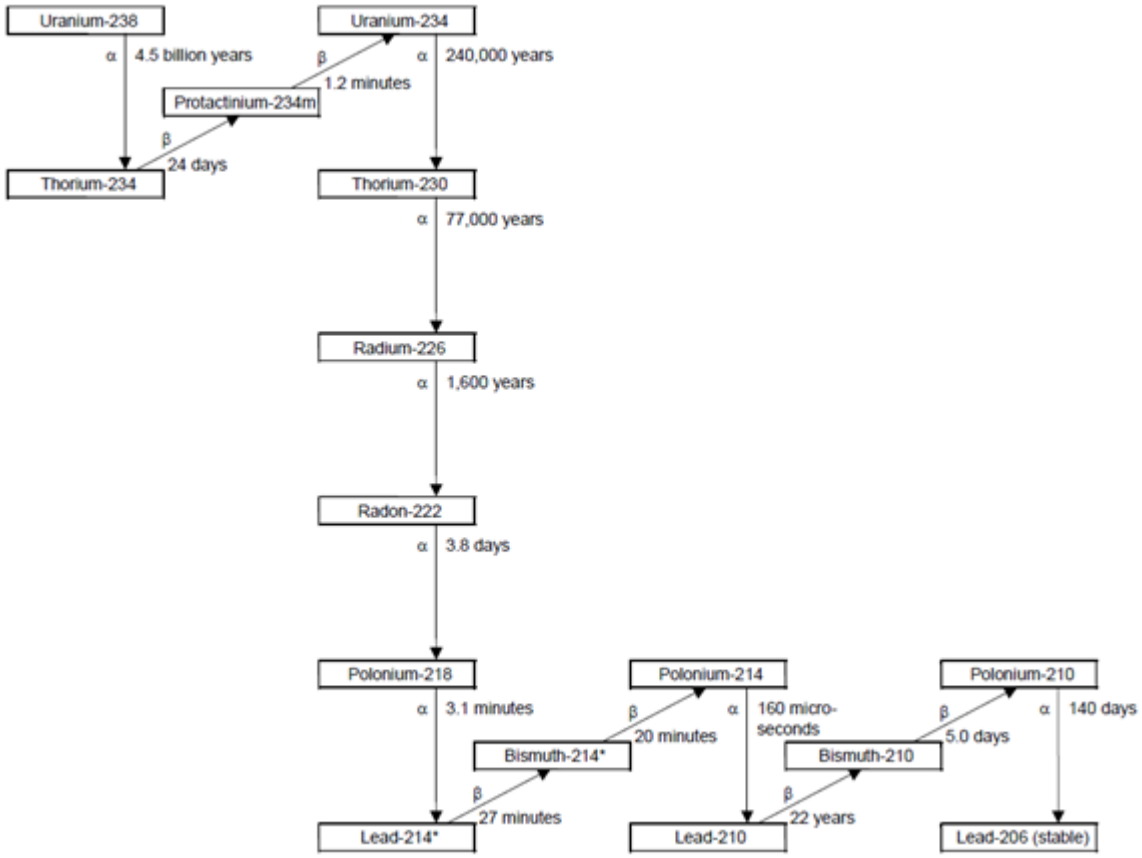


Figure 1. 6 : Natural Decay series uranium – 238 [12].

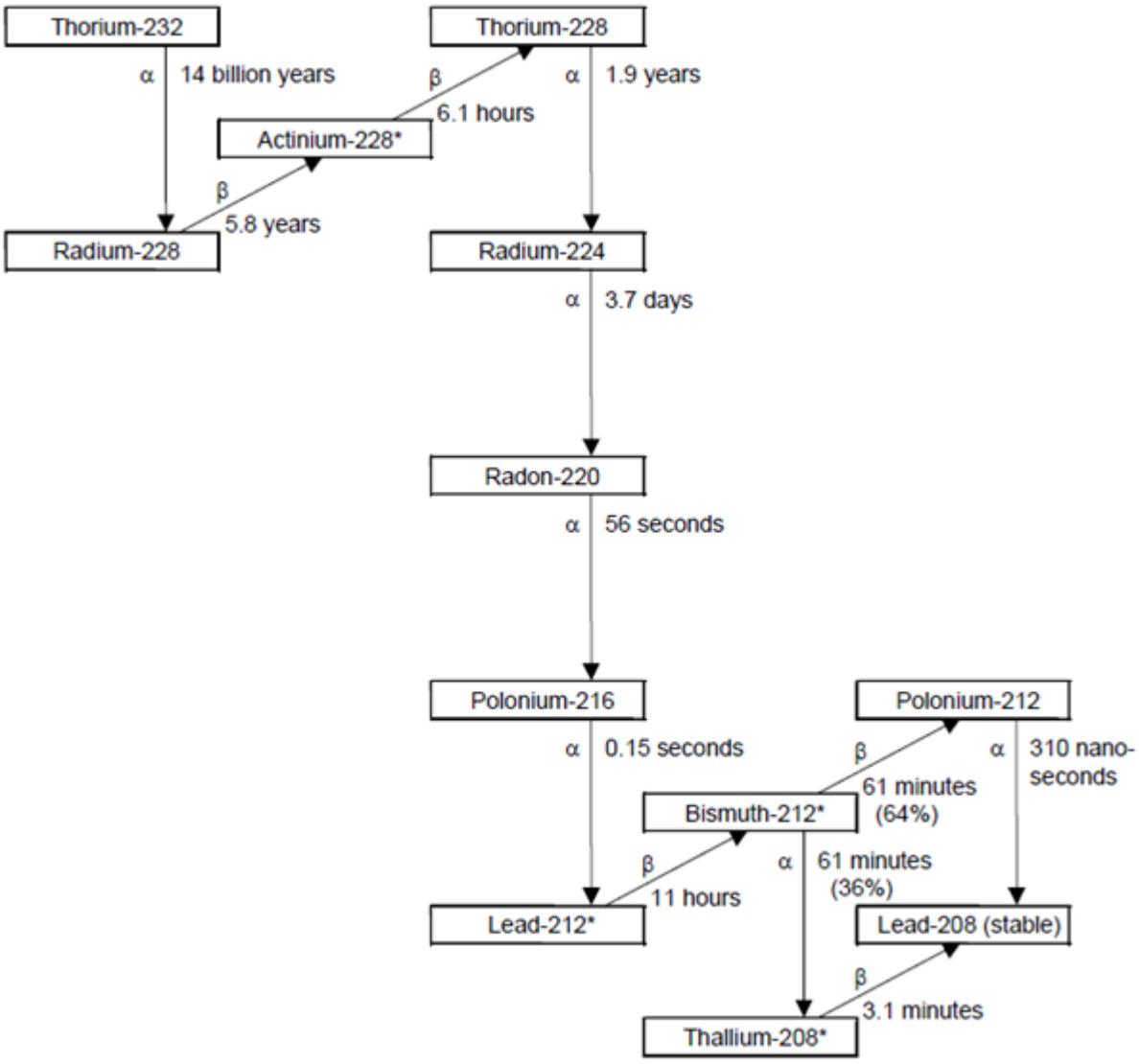


Figure 1.7: Natural Decay series thorium – 232 [12].

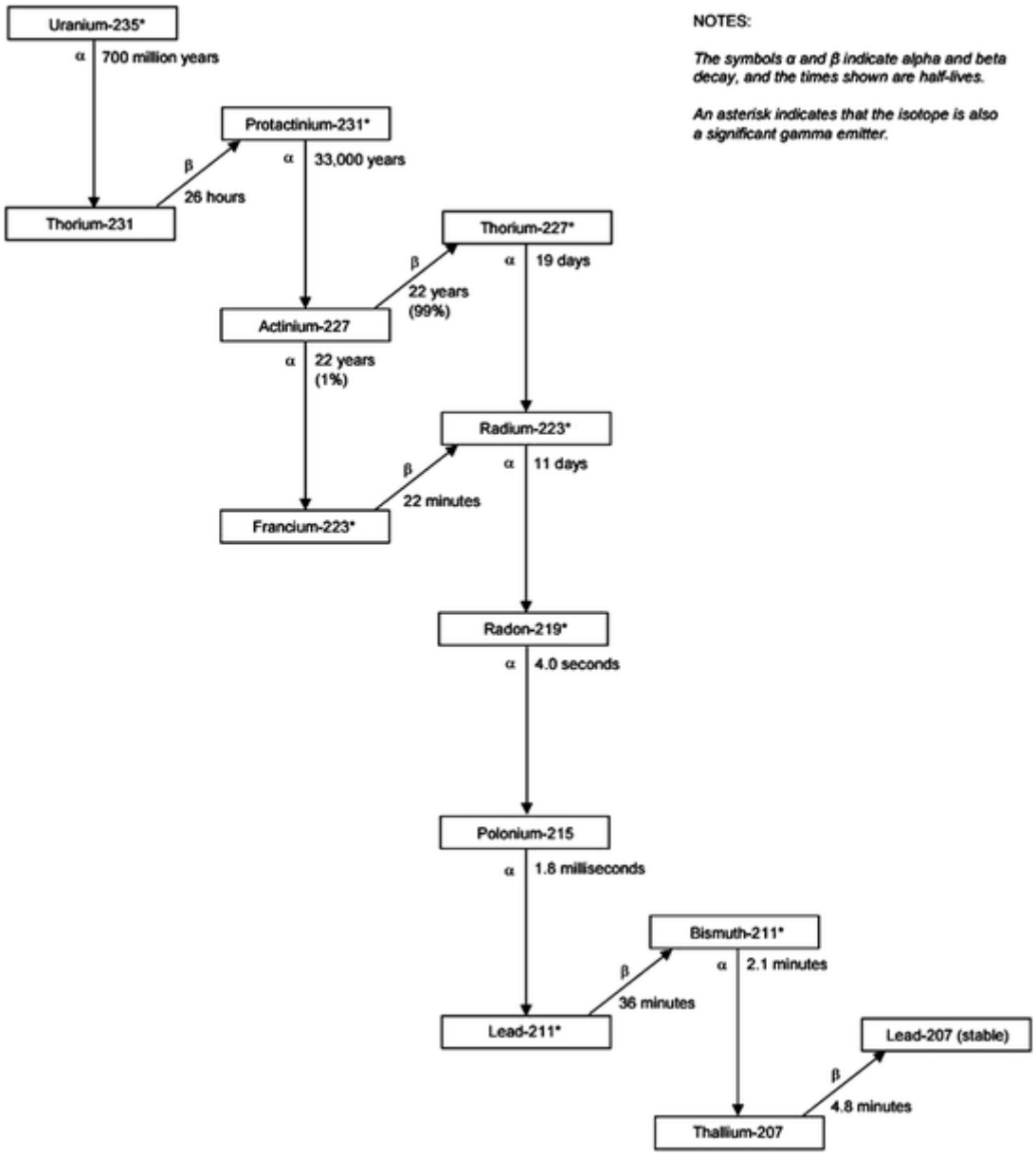


Figure 1.8: Natural Decay series uranium – 235 [12].

1.6 Literature Review

1.6.1 International studies

● Al-Bataina et al., (1998), measured the radon concentrations in water samples in Jordan [13]. The concentration of Rn-222 ranged from 3.3 to 10.7 Bq/ℓ in cold spring water, from 3.2 to 5.5 Bq/ℓ in hot spring water, from 3.1 to 5.7 Bq/ℓ in well water, from 2.5 to 4.7 Bq/ℓ in drinking water and from 4.3 to 6.3 Bq/ℓ in the sea water. The study concluded that these measurement levels were within the usual standard limits of radon.

● Abdallaha et al., (2007), measured the radon concentrations in well and spring water in Lebanon. The study on water sources was performed and found that the water dissolved radon concentrations ranged from a low of 0.91 Bq/ℓ in a coastal well source to a high of 49.6 Bq/ℓ in a spring source in a mountainous region. Of the 20 sites sampled, only five had radon levels above 11 Bq/ℓ (the U.S EPA maximum contaminant level) [14]] and these mostly occurred in areas adjacent to well-known geological fault zones. In general, the concentrations found in the previous mentioned studies were all below the 100 and 146 Bq/ℓ level proposed by the European Union [15] and the United States alternative maximum contaminant level (AMAL), respectively [14].

● Raymond L. Njinga et al., (2018), studied the health exposure to radon in drinking water sources from Dutse and Chikun environs in Nigeria. 76.47 % of the radon concentration falls within the range of 11.49 – 31.29 Bq/ ℓ while only 23.53 % falls below the range prescribed by the UNSCEAR, 2008 and the limit recommended by the European Commission of 2001 on the protection of the public against exposure to radon in drinking water [16].

● Binesh and Arabshahi, (2011), measured the radon and radium concentrations in 120 samples of drinking springs and rivers water sources of northwest regions of Mashhad, Iran. The results showed that only 14.67% sample concentrations were higher than the normal 11 Bq/ℓ, set by United States Environmental Protection Agency (USEPA). 148 Bq/ℓ is limit amount of action or reaction that radon should be reduced. Radium concentration of all samples, except sample number 21, drinking water of Shandiz were small and less than 1 Bq/ℓ. Therefore, radon and radium concentration in the water of the regions were not high and these were appropriate [17].

● Hammood and Al-Khalifa, (2011), determined the radon concentration in water samples of Dhi - Qar governorate (in Iraq) Using Emanometer. The obtained radon concentrations ranged from 116 Bq/m^3 to 601 Bq/m^3 in river water and from 355 Bq/m^3 to 681 Bq/m^3 in the wells water. The results are presented and compared with other studies. The results could be utilized to make distinctive supplementary contributions when contamination event occurs and to implement water quality standards by concerned authorities to maintain radioactive contamination-free drinking water supplies for the people [18].

1.6.2 Local studies

There are limited numbers of radon research that had been performed in Palestine

● Hararah (2007), Investigate the radon pollution in ground water in the Gaza Strip – Palestine. The results indicate that the difference between the minimum 58 Bq/m^3 and maximum value 154 Bq/m^3 of the radon concentrations for each well in the governorate is very high. This large variation in Radon concentrations may be mainly due to the difference in the soil type, rock type and the depth of these well [19].

● Thabayneh (2015), measured the radon concentrations in drinking water in 184 samples in the Southern Part of West Bank – Palestine. In a tap water the, average radon concentrations ranged from 0.20 to 1.23 Bq/ℓ with a total average value of 0.6 Bq/ℓ. In the rain waters, the average concentration ranges between 0.18 to 1.51 Bq/ℓ with a total average value of 0.76 Bq/ℓ . The recorded values of radon concentration in groundwater samples are found ranged from 0.42 to 0.89 Bq/ℓ with a total average value of 0.64 Bq/ℓ. The ^{222}Rn concentrations obtained for the mineral (potable) water samples at the used as drinking water in the area under investigation are ranges from 0.44 to 1.14 Bq/ℓ with a total average value of 0.66 Bq/ℓ [20].

● El-Ghossain and Abu Shammala (2012), measured the radioactivity in tap water in Gaza Strip (Al-Naser Area). The average gross alpha concentration from C4-39 is 35.50 Bq/m^3, the maximum concentration is 64.67 Bq/m^3, and minimum concentration is 24.20 Bq/m^3. Results obtained from all detectors, and their methods will be shown, and compared with the word average of 15 pci/L, all results indicate low level of activity [21].

● Al Zabadi et al., (2012), determined the radon level in the drinking water sources in Nablus city in order to set up a sound policy on water management in Palestine. The

mean (range) concentration of radon in the main sources were 6.9 (1.5-23.4) Bq/ ℓ. Separately, springs and wells' means were 4.6 Bq/ ℓ and 9.5 Bq/ ℓ; respectively. For the residential tap water in the 7 regions, the results of the mean (range) concentration values were found to be 1.0 (0.9-1.3) Bq/ ℓ. For the old city, the mean (range) concentration values were 2.3 (0.9-3.9) Bq/ ℓ [22].

1.7 Aim of Study

The main goals of this study are:

1. To measurement the activity concentrations of Ra -226 in water samples that will be collected from many sites in Bethlehem province.
2. To measurement the radon concentration levels in these samples collected from the area under investigation.
3. To calculate the average annual effective dose due to the ingestion (H_{ing}) and inhalation (H_{inh}) of radon in water samples.
4. Provide the database of radioactive elements in the area under investigation to arrive at an irradiation map for these elements and other radionuclides in Palestine. It is hoped that this study might serve as the basis to draw a national map of radon concentration levels in Palestinian regions, to monitor and resolve any observed hazardous changes in the radon concentration levels from place to place and from season to season. Furthermore, it is also hoped that the study will pave the way for future there surveys to establish a Palestinian map of all types of radiation concentration on radon.

1.8 Study problem

Therefore it was necessary to estimate natural radioactivity levels particularly radon in water. In According to Mohammed (2011) and IAEA (2006) findings, radon in surface water is not a major problem as most of it diffuse into the atmosphere, but its concentration may be influenced by various factors such as the geology of the area, bottom sediments and mining or mineral processing activities going on in the area. With the mining and mineral processing activities conducted at Newmont-Akyem, it is likely that the levels of radon are elevated. It was therefore necessary to determine concentrations of radon in water samples and compare the results with national and international standards as well as work done elsewhere .

CHAPTER TWO

INFORMATION ABOUT RADON

Chapter 2- Information about Radon

2.1 Introduction

Radon (^{222}Rn) is the radioactive gas generated by the decay of Radium (^{226}Ra) originating in the earth's crust, i.e. in soil, rocks and water. In soil and rocks, a fraction of radon emanates, enters pore volume and dilutes in pore's fluid. Similar processes govern the movement of ^{220}Rn (Thoron). In water all radon atoms produced are dissolved in the liquid. In both cases, radon migrates by diffusion and convection and may move through building structure, into indoor air. The use of water and movement of outdoor air are other agents by which radon generated in soil or water may enter indoor air [25].

2.2 Characteristics of Radon

2.2.1 How radon emits to alpha particles ?

Radon formed by the disintegration of radium, which is a decay product of uranium. Radon emits alpha particles and produces several solids radioactive products called radon daughters. Some amounts of radon gas and radon daughter are present everywhere in the soil, rock, and water throughout the U.S. It has numerous different isotopes, but Rn-220, and Rn-222 are the most common. Radon causes lung cancer, and is a threat to health because it tends to collect in homes, sometimes to very high concentrations. As result, radon is the largest source of exposure to naturally occurring radiation [26, 27].

2.2.2 Radon gas properties and sources

● Radon is a noble, invisible, odorless, colorless, taste, heavy gas. Radon-222 is produced by the decay of radium, has a half- life of 3.82 days, and emits an alpha particle as it decays to polonium-218, and eventually to stable lead.

● Radon- 220 is the decay product of thorium – it is sometimes called Thoron, has a half-life of 55.6 seconds and emits an alpha particle in its decay to polonium-216 [28].

● Radon is formed through the breakdown of uranium in soil and rocks. Uranium is present as a trace element in granite rock.

2.2.3 Radon isotopes and daughters

Radon occurs in several isotopic forms, it has 33 isotopes whose half-lives are known with mass numbers from 195 to 229, and none are stable.

The most known isotopes are:

(1) ^{222}Rn called Radon (belongs to ^{238}U decay series).

(2) ^{220}Rn (called Thoron, belongs to ^{232}Th decay series).

(3) ^{219}Rn (called Actinon, belongs to, ^{235}U decay series).

As shown in table 2.1, ^{222}Rn has 3.82 days half-life, whereas ^{220}Rn (55.6 s) and ^{219}Rn (3.96 s) have much shorter half-lives. Because of such short half-lives, their emanation from building materials, as well as, its infiltration from the ground and further migration is restricted to a few centimeters only. This is why 220Rn and 219Rn are given less importance in environmental studies [29].

Table 2.1: Radon isotopes, their chemical symbols and half-lives

No.	**Radon isotope name**	**Chemical symbol**	**Decay series it belongs to**	**Half – life**
1	Radon	^{222}Rn	^{238}U	3.82 d
2	Thoron	^{220}Rn	^{232}Th	55.6 s
3	Actinon	^{219}Rn	^{235}U	3.96 s

2.3 Radon in Environmental Samples

Humans are exposed to ionizing radiation (IR) from natural sources which are on a large scale in the earth's environment and remains in several geological formations in soils, rocks, plants, water and air. The public subjection to IR includes natural radiation sources such as cosmic and terrestrial radiation which also involve inhalation or ingestion of natural radioactive materials [30, 31].

Natural radioactive concentration depends mainly on geological and geographical positions, conditions and is found at various surfaces, locations in soils, water from several geological areas respectively [4, 32].

2.3.1 Radon in water

Uranium is present in small amounts in most rocks and soil. It slowly decays to other products such as radium (^{226}Ra), which decays to ^{222}Rn. Some of ^{222}Rn moves to the soil surface and enters the air, while part of it remains below the soil surface enters the groundwater. The isotopes in the ^{238}U decay series that may pose a health risk because of their presence in water are ^{226}Ra and ^{222}Rn [4, 33].

In areas of the country that have high radium content in soils and rocks, local ground water may contain high concentration of radon. While radon dissolve into water, it can easily escape from water when exposed to the atmosphere, especially if it stirred or agitated [34, 35].

Radon is particularly well suited to study groundwater and surface water and their respective interaction, because the activity in groundwater 1–100 Bq/ℓ; depending on the lithology of the area, which is much higher than the surface water 1–0.1 Bq/ℓ [36, 37].

2.3.2 Radon in Soil

Radon release mechanisms from rock, soil, and other materials are not very well known and possibly not similar. Radon emanations were stated to be affected by the soil's condition and its porosity, humidity, temperature, and atmospheric pressures.

The radon emanation from the soil was found to depend not only upon the concentration of ^{238}U and ^{226}Ra, but also on the composition, and permeability, of the rock and soil [38]. At long-term average radon concentrations, the risk of lung cancer increases by 16% per 100 Bq/m^3 increases [39].

The dose-response relationship is linear; such as, with increasing 27 radon exposures, the risk of lung cancer increases proportionally establishing a national annual average concentration reference level of 100 Bq/m^3, but if this level cannot be reached under the prevailing country-specific conditions, the reference level should not exceed 300 Bq/m^3 [40].

2.3.3 Radon in Air

The radon concentration in outdoor air is higher over large continents than over sea. During temperature inversions (a reversal of the normal atmospheric temperature gradient), levels may reach hundreds of Bq/m3 over regions with enhanced concentrations of uranium and radium in the ground [41.

Indoor radon concentrations about 50 Bq/m^3, but much higher values are possible in some areas. In the open air, it ranges from 1 to 100 Bq/m^3, even less (0.1 Bq/m^3) above the ocean. In caves or aerated mines, or ill- aerated houses, its concentration climbs to 20-2000 Bq/m^3. Radon concentration can be much higher in mining context. Outdoor radon level varies between 5 and 15 Bq/m^3[42].

2.4 Different Sources of Radon

2.4.1 Sources of radon in Groundwater

It might be supposed that Radon in groundwater could be derived from two different sources [44]:

● Radioactive decay of dissolved radium (the immediate precursor to radon in the decay chain).

● Direct release of Radon from the mineral matrix from minerals containing members of the uranium/thorium decay series. For these reasons, only the measurement methodology for Radon-222 will be discussed below. Once Radon is formed in radium-bearing material, some of it leaves the grains to the pore space.

Radon can therefore reach the air or water to which humans have access, provided that transport is sufficiently rapid to be completed before the Radon decays [45].

2.4.2 Soil as a radon source

The major source of Radon in the atmosphere at least 80% is from emanations from soil that derived from rocks. These rocks contain some uranium, where the decay of ^{238}U through ^{226}Ra gives Radon. Certain types of rock, including granites, dark shale, light-colored volcanic rocks, sedimentary rocks containing phosphate and metamorphic rocks derived from these rocks have higher average uranium contents [46]. Because Radon is a gas, it has much greater mobility than uranium and radium, which are fixed in the solid matter in rocks and soils. Radon can more easily leave the rocks and soils by escaping

into fractures and openings in rocks and into the pore spaces between grains of soil as shown in figure 2.1.

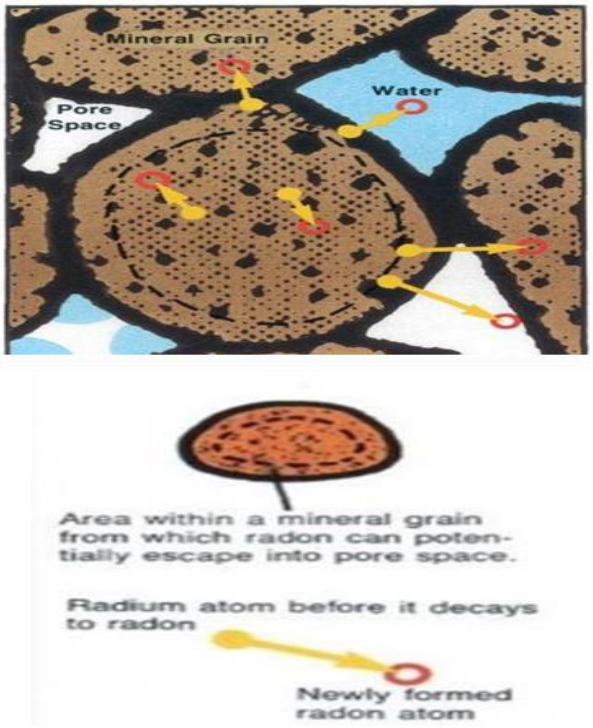


Figure 2.1. Migration of radon through pore space and water [47]

2.4.3 Water supplies as Radon source

Water supply can be a route of entry of Radon that exists in the ground water, In addition to soil and building material. Because the systems of water supply are often closed so that cause short water transit times that do not allow Radon to be completely removed or decayed, then Radon escapes from the water into the indoor environment as people use the water for washing and swimming as shown in figure (2.2) [47].

Radon in drinking water is found only in groundwater supplies (the insoluble Radon gas quickly degasses in surface water supplies). In many countries, some homes obtain drinking water from groundwater sources (springs, wells and boreholes). Underground water often moves through rock containing natural uranium and radium that produce Radon. This is why water from deep drilled wells normally has much higher concentrations of Radon than surface water from rivers, lakes, and streams [48].

Most of the Radon in indoor air comes from soil underneath the home. As uranium breaks down, Radon gas forms and seeps into the house. Radon from soil can get into any type of building; homes, offices, and schools; and build up to high levels in the air inside the

building. Radon gas can also dissolve and accumulate in water from underground sources, such as wells.

Many factors that affect the formation and movement of Radon in the ground; the uranium content, grain size, and permeability of the host rock and the nature and extent of fracturing in the host rock and these important factors affecting the amount of Radon in groundwater[47]. Radon concentrations in ground water vary from time to time (before and after winter) because of dilution by recharge or changes in contributing areas of the aquifer because of pumping [44].

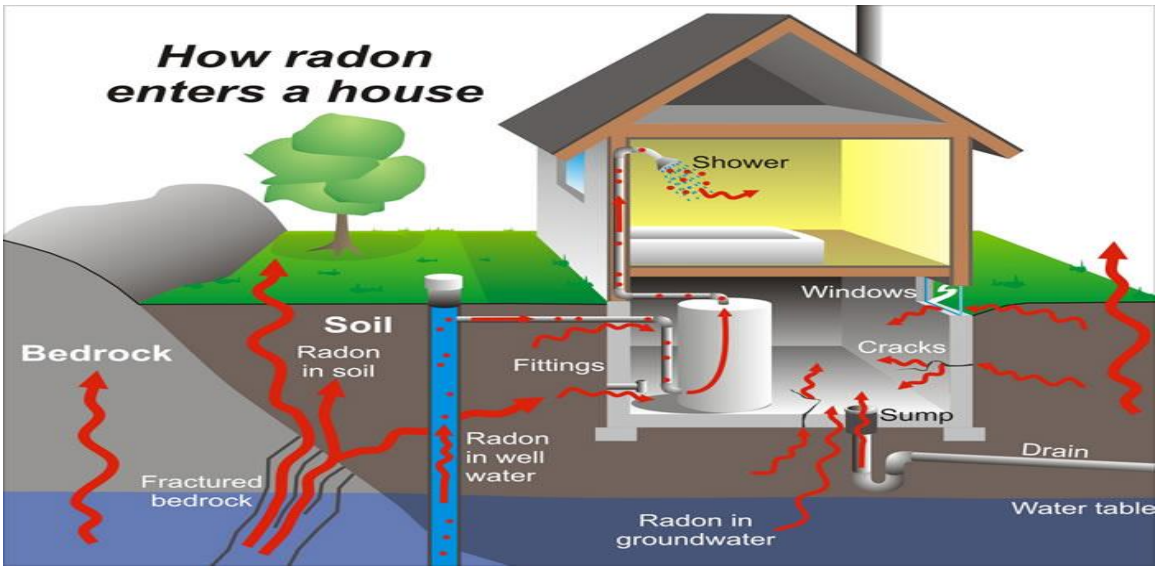


Figure 2.2: How radon enters a house [49].

2.5 Guidelines for Concentrations of Radon in Water

Many countries have defined an Action Level of Radon Concentration to guide their program to control domestic exposure to Radon. The Action Level is not a boundary between safe and unsafe, but rather a level at which action on reduction of Radon level will usually be justified. Some people may choose to take action when the Action Level is approached. For example, many countries consider radon concentration in the air of 0.2 Bq/ℓ as an Action Level at which mitigation measures should be taken to reduce radon level in homes [50].

The World Health Organization (WHO) Guidelines for Drinking Water Quality and the European Commission recommend that controls (for example repeat measurements) should be implemented if radon in public drinking water supplies exceeds 0.1 Bq/ℓ, treatment of the water source should be undertaken to reduce the radon levels to well

below 0.1 Bq/ℓ. The United States has proposed a Maximum Contaminant Level for Radon of 0.15 Bq/ℓ for private water supplies [50].

In USA People who have private wells should test their well water to ensure that radon levels meet EPA's newly proposed standard (EPA's Action Level of 0.15 Bq/ℓ). In addition, exposure to uranium in drinking water may cause toxic effects to the kidney. To protect public health, EPA (Environmental Protection Agency) has established drinking water standards for several types of radioactive contaminants combined Radium 226/228 (0.2 Bq/ℓ), gross alpha standard (0.5 Bq/ℓ) [51,52]. The Norwegian Radiation Protection Authority has recommended an action level of 0.5 Bq/ℓ for Radon in domestic water, and 0.2 Bq/ℓ in household air [53]. Radon in water is responsible for the whole body internal radiation dose that may be more harmful than Radon in air. Thus, determination of Radon in groundwater has also been of major interest.

2.6 Health Effects of Radon

- Radon in air is ubiquitous; The most public exposure to natural radiation comes from radon which can accumulate in homes, School, and office buildings. EPA estimates that the national average indoor radon level in homes is about 1.3 pCi/ℓ of air, or above the level of 4 pCi/ℓ , the level at which EPA recommends taking action to reduce concentration .

- People may ingest trace amounts of radon with food and water, However inhalation is the main route of entry into the body for radon and its decay products. Radon decay products may attach to particulates and aerosols in the air we breathe (for examples, cooking oil vapors). When they inhaled or ingested, some of these particles are retained in the lungs, where they emit ionizing radiation which can penetrate the cells of mucous membranes, bronchi, and other pulmonary tissues [54].

EPA estimates that about 20,000 lung cancer deaths each year in the U.S are radon – related. Exposure to radon is the second leading cause of lung cancer after smoking. Lung cancer is the only known effect on human health from exposure to radon in air. Thus far, there is no evidence that children are at greater risk of lung cancer than adults.

The ionizing radiation energy affecting the bronchial epithelial cells is believed to initiate the process of carcinogenesis. An individual's risk of getting lung cancer from radon depends mostly on three factors:

- The level of radon
- The duration of exposure
- Their smoking habits

Either smoking or radon exposure can independently increase the risk of lung cancer; however, exposure to both greatly enhances that risk. Non-smokers exposed to radon at the new guideline level of 200 Bq/m^3 have a 2% lifetime chance of developing lung cancer; however, exposure to both greatly enhances that risk.[55, 56].

2.7 Methods to Reduce Radon Concentration in Waters

Radon can dissolve and build up in water from underground sources. If your water comes from a well, it may contain radon. Radon in the water dissolves and escapes into the air during household water use, especially when it is heated. Radon levels in the air will increase for a short period of time when you use your dishwasher, washing machine, shower and bath.

The Connecticut Department of Public Health (CT DPH) recommends testing for radon in your water if your home is served by well water. It is possible to have elevated radon levels in your water even if the radon level in your indoor air is low. The only way to know for sure is to test for radon in both air and water.

Radon laboratory results are reported in picocuries per liter (pCi/L), a unit of measure for radioactivity. The CT DPH has established a recommended action level of 5,000 pCi/L for radon in water. Take action to reduce radon in your water if the average radon level of two water samples (drawn simultaneously from the same location) is equal to or above 5,000 pCi/L. Radon concentrations in water vary from one test to another due to many reasons including water usage and seasonal fluctuations in the water table. Therefore, you may choose to test your water more than once [57, 58].

There are two types of systems to reduce radon levels in your water:

• Granular Activated Carbon (GAC) System GAC systems reduce radon effectively when levels are below 10,000 pCi/L. These systems contain a fiberglass tank filled with

granular activated carbon, a fine material that traps radon as the water passes through it. The carbon also captures other contaminants, which is beneficial, but it shortens the life of the carbon. The carbon eventually becomes saturated and can no longer trap radon. Replacement of the carbon is essential for the GAC system to effectively reduce radon. Service periods vary based on the amount of carbon, household water usage, and radon level. Hire a nationally certified radon mitigation professional to replace the GAC system's carbon on a regular basis [57, 58].

. • Aeration System Aeration systems are the only effective method for reducing radon levels that are at or above 10,000 pCi/L. These systems aerate or agitate water to allow radon to escape so it can be captured and vented to the outside away from your home. Other water quality issues, such as iron and manganese, need to be taken into account when considering installation of an aeration system. There are different models of aeration systems with varying specifications. A radon mitigation professional can help you decide which system is best for your home [57, 58].

CHAPTER THREE

THE STUDY AREA AND EXPERIMENTAL WORK

Chapter 3- The Study Area and Experimental Work

3.1. Introducing the area of study

3.1.1 Geography and geology

The study area is Bethlehem Governorate (fig.3.1), which is located in the in the south central of West Bank, Palestine, and located at an elevation of about 775 meters above sea level, 30 meters higher than nearby Jerusalem [59]. Bethlehem is situated on the southern portion in the Judean Mountains. The city is located 10 km in the south of Jerusalem [60].

In the study, we will concentrate on the measurements of radon concentration levels in water in different places in Bethlehem province, Palestine. The study area include these villages and towns. Bethlehem city, Beit Sahour , Beit Jala , Al-Obadyia , Zat'atra, AlKhuder , Al-Shawawrh , Dar Salah , Wadi Neus , Wadi Fukine , Beit Fajar, Battir , Nahalin , Tuku' , Hussan , Janata , Jurat Alsham'a. Fig. (3.1) displays the provinces; while Fig (3.2) show the inspected sectors.

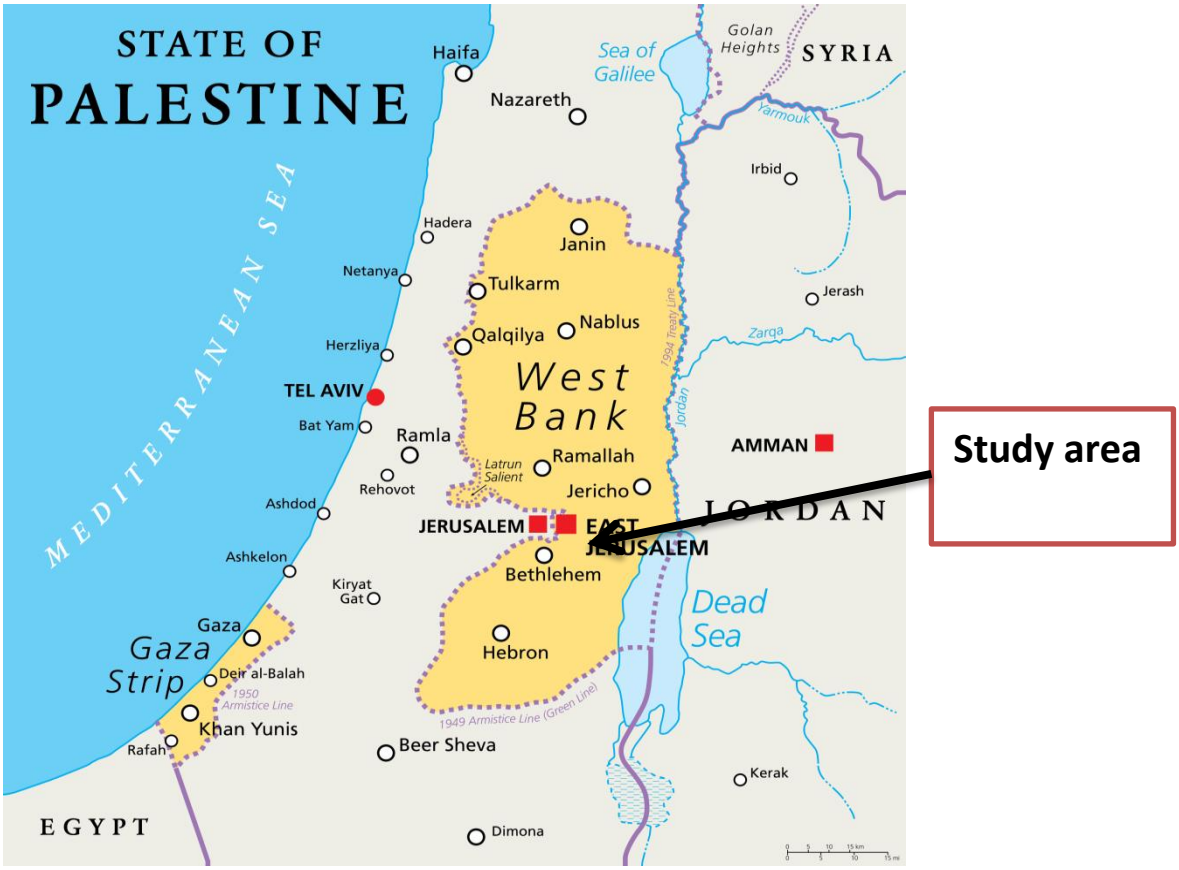


Fig 3.1: Map of Palestine contain the study area [60]

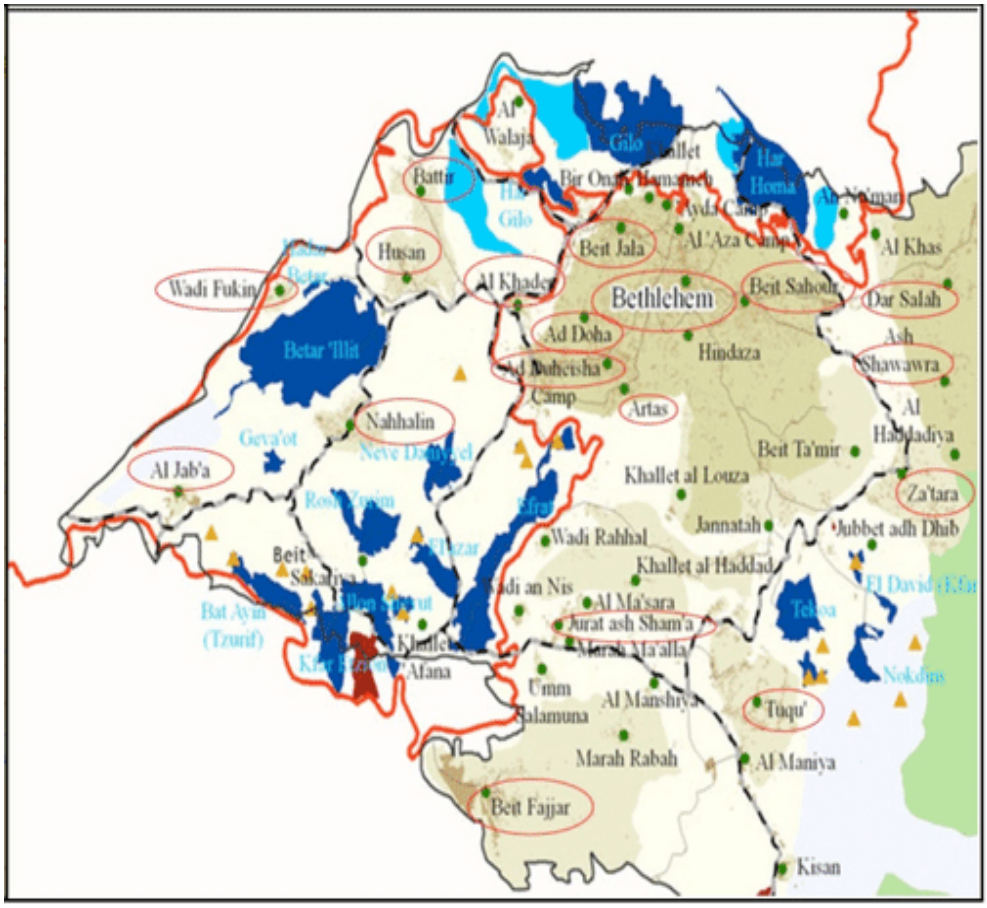


Fig 3.2: Map of Bethlehem Province where the investigated sites are marked by ovals [61]

3.1.2 Climate

Bethlehem has a Mediterranean climate, with hot and dry summers and mild, weather winters. Winter temperatures (mid-December to mid-March) can be cool and rainy. January is the coldest month, with temperatures ranging from 1 to 13 ˚C (33–55 °F). July is the hottest month, with a high of 30 ˚C (86 °F). Bethlehem receives an average of 700 millimeters of rainfall annually, 70% between November and January [62].

Bethlehem's average annual relative humidity is 60% and reaches its highest rates between January and February. Humidity levels are at their lowest in May. Night dew may occur in up to 180 days per year. The city is influenced by the Mediterranean Sea breeze that occurs around mid-day. However, Bethlehem is affected also by annual waves of hot, dry, sandy and dust Khamaseen winds from the Arabian desert, during April, May and mid-June.

3.2 Methodology

3.2.1 Water types

Renewable water sources consist in the Bethlehem Governorate in a way Essential from groundwater. The province is one of the richest region of groundwater in the West Bank, where the parts of each of The eastern and western basin of underground water tanks within governorate boundaries. In addition to groundwater, it is rain water. It is one of the important water sources in the ground water that can be collected from rooftops is about 8.1 m^3/year.

The Governorate's drinking water sources are divided into many main sources:

- Self-sources of underground wells and springs
- Sources purchased by the Israeli water company, "Mekorot company"
- Self-water sources are in the governorate of Bethlehem
- Wells of the Palestinian Water Authority in the south which supplies the governorates of Bethlehem and Hebron and Bir Bet Fajar which is owned by the Water and Sewer Authority.
- The water purchased from Mekorot comes from three primary sources are wells known as wells West Bank water department, .Mekorot Wells, Inside West Bank and Mekorot wells inside the line the green.

In this study, 79 drinking water samples were collected from 17 regions of the area under investigation (Fig. 3.2). The main water sources are tap water (46 samples), groundwater (11 samples), rain waters (17 samples) and mineral potable waters (5 samples).

3.2.2 Samples locations

This was a descriptive study performed on two phases. In the first phase we covered all the wells and springs in Bethlehem city. In the second phase we selected a randomized sample that represents the residential tap water of the city different sources in the region.

3.2.3 Samples collection and preparation

In this procedure, a bottle was connected via a short plastic hose to the water tap. After the water flowed for several minutes, the flow rate was slowed down and the water was allowed to be collected in the funnel.

The other samples were collected in well washed bottles which were sealed immediately so that radon may not get out of it. All bottles were marked and date and time of sample collection were written upon them.

The groundwater samples were taken after five minutes from operating the wells, and we put the samples in plastic containers. Information data for each well such as well name, well number, site, data of collection sample and exposure period is registered in a form fixed on container. The samples were brought to radiation pollution laboratory of the Faculty of Science and Technology, Hebron University Hebron, Palestine to be done without any aeration which might lead to escaping gases from water [20, 64]

3.3 Measurement Techniques

The choice of the technique depends on the objective of the proposed study. There are several ways and technique used for measuring radon concentration levels. These techniques can be classified into two main categories [65] :

1- Active technique (short- term measurement of 2 to 7 days can be performed)

2- Passive technique (long term measurements are typically 3 to 12 months in duration)

3.3.1 Passive Techniques

In this method, radon the calibrated dosimeter techniques were used and long period radon measurements, the measurements were made with the solid state nuclear track detector (SSNTD) technique [66]. The SSNTDs is a passive technique which has several advantages;

1. Low cost, cheap and can be easily obtained, long term method, most widely used for measuring Radon and can be used for site assessment both indoors and outdoors.

2. SSNTDs are sensitive to alpha particles in the energy range of the particles emitted by radon.

3. SSNTDs are largely- insensitive to beta and gamma rays.

4. SSNTDs also have the advantage to be mostly unaffected by humidity, low temperatures, moderate heating and light and do not require an energy source to be operated [67].

In this research we are concerned with the Nuclear-Track Detector (NTD) type commercially known as (CR-39). The CR-39 plastic is made by polymerization of the Di(ethylene glycol) bis(allyl carbonate)

The CR39 plastic sheets:

- Are colorless and completely transparent to the visible light
- Have high abrasion resistance and high-quality optically properties
- Keep their excellent optical properties despite long-term exposure to chemicals like solvents, highly oxidizing acids, and strong basis
- Resist to heat distortion up to 100º C and are resistant to small hot flying particles such as
- welding sparks [68].

3.3.1.1 Preparation of dosimeters

The close vessel technique was used in this study (dosimeters) are plastic cylindrical vessels fig 3.3 or the cup technique was employed in this work; each cup container was 12 cm height and 6.5 cm in diameter and contains (1 x 1) cm square of CR-39 nuclear track detector fixed with double sided adhesive tape to the upper of the cup with its sensitive side downward [20] .

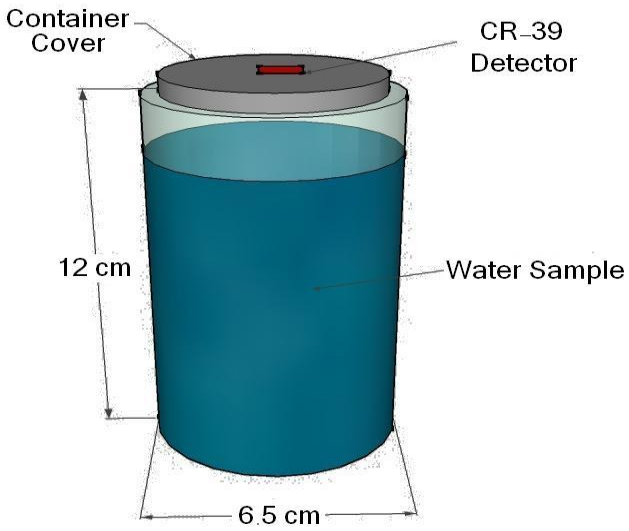


Fig. 3.3: Schematic Diagram of the Sealed-Cup Technique in bottled natural mineral drinking water sample with Nuclear Track Detector (CR – 39) [20].

3.3.1.2 Collecting detectors and chemical etching

The dosimeters were calibrated at the physics laboratory to obtain the obvious tracks. The detectors were exposed to water samples to collect a-particle tracks at room temperature (nearly about 30 ˚C) for three months. The detectors attached to the plastic cover at the top of plastic cups at an altitude or height of 1.5 cm from the surface of the water inside the cups. The samples were saved in vertical position in tightly closed cups to prevent any particles from entering into the cups [69].

To consider these tracks, a calibration process is required to determine the calibration constant in units of tracks. For applications where only the measurement of track density is required, high contrast techniques have been developed which usually enlarge the track images.

In practice, the most important parameters for control of the etching speed of the detectors are temperature, concentration of the etching solution and time etching [70].

Chemical Etching

The exposed detectors were collected after 90 days of exposure and then chemical etching simultaneously at a constant time 6 h and NaOH for 6.25 N at temperature 70 °C. At the end of the etching process the detectors were washed thoroughly with distilled water and then left to dry. An optical microscope with magnification of as (40 x 10) used to count the number of tracks in each detector [65, 71]

3.3.1.3 Detectors scanning counting tracks

we counted the average number of tracks in 1 mm^2 by moving microscope stage from left to right about 10 times to insure that no tacks are missed but counted twice, as shown in figure 3.4. The obtained numbers of tracks are used to calculate the track densities, which is used to calculate the water radon concentration.

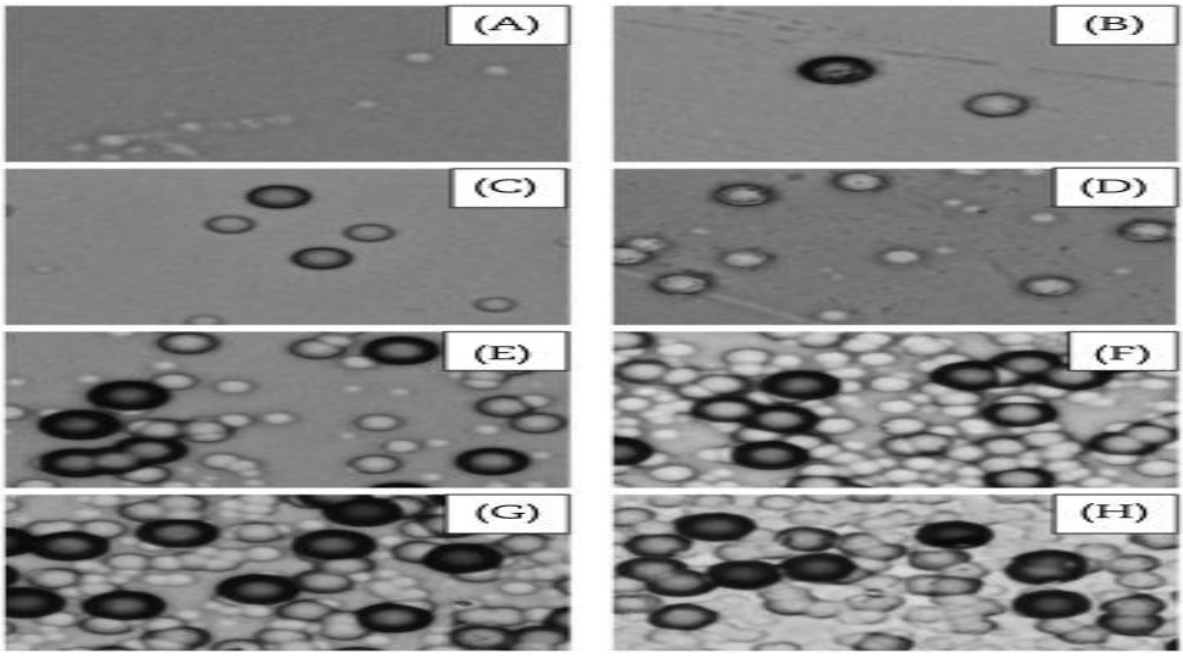


Fig 3.4: A typical microscopic slide representing a certain field view obtained for one of the scanned detector using a magnified microscope [72].

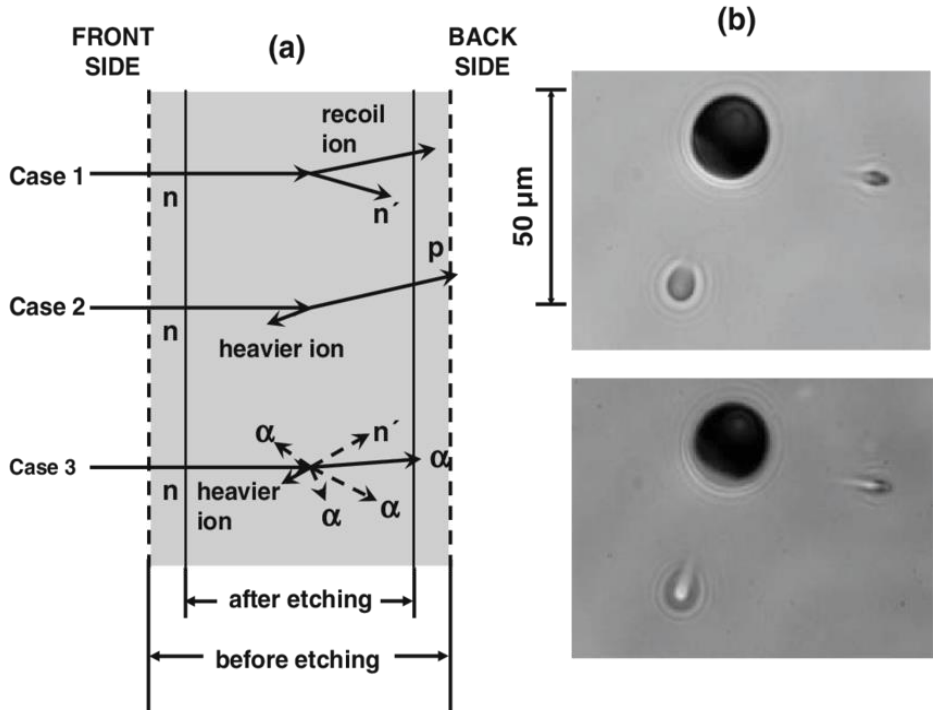


Figure3.5: Schematic-drawing-of-the-CR-39-track-detector-and-the-neutron-interaction-processes [73].

3.3.2 Active Techniques

In some cases, a more rapid indication of the radon may be required. Testing durations can be performed of 2 to 7 days , and the result of radon concentration by this technique is strongly recommended that be confirmed with a " follow-up" long –term measurement (measurement should be made at the same location as the initial measurement [66].

In this method, the spectrometer RAD 7, with special accessories for radon measurement in water ($RADH_2O$) was used for measurements of radon concentration in some drinking water samples [74].

3.4 Calculations of radon concentrations

The concentration of ^{222}Rn in the water samples wascalculated in (Bqm^{-3}) unit from the following relation [75]:

$$C_{Rn}(Bq/m^3) = \frac{c_0 t_0}{\rho_0}(\frac{\rho}{t}) = k(\frac{\rho}{t}) \quad \text{.....3.1}$$

where C_{Rn}: The activity concentration of ^{222}Rn in a water sample; C_0,: The activity concentration of ^{226}Ra (solid radon source) equal 800 Bqm^{-3}; ρ_0: The track density (number of tracks/cm^2) in detectors exposed to ^{226}Ra; t_0: The exposure time (in days) of detectors exposed to ^{226}Ra, equal 70 days; ρ:The track density (number of tracks/cm^2) in detectors exposed to water samples and t: The exposure time of detectors exposed to water samples, equal 75 days.

The calibration factor (K) was calculated by using the equation [76]

$$K = \frac{c_0 t_0}{\rho_0} = 30.3\ Bq/m^3 day/tracks/cm^2 \quad \text{.....3.2}$$

Substituting calibration constant in equation (1), the activity concentration of alpha particles in water becomes:

$$C_{Rn}(Bq/m^3) = \frac{c_0 t_0}{\rho_0}(\frac{\rho}{t}) = k(\frac{\rho}{t}) = 30.3\frac{\rho}{t} \quad \text{.....3.3}$$

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

3.5 Determination of Radium Contents in Water

The effective radium content Ra_{eff} (Bq/kg) in the sample could be calculated from the relation [77]:

$$Ra_{eff} = \frac{\rho VK}{M[T - \lambda^{-1}(1 - e^{-\lambda T})]} \quad \text{.....3.4}$$

Where ρ is track density in Tr/cm^2, V is the volume of the air space in the can in m^3, M is the mass of the sample in kg, K the calibration factor in $(Bq/m^3).\ day/tracks/cm^2$, T is total exposure length (days), λ= radon decay constant (0.19 day^{-1}).

The effective radium content Ra_{eff} (Bq/L) has been calculated from the following formula [77]:

$$Ra_{eff} = \frac{C_{Rn}V}{V_W[T - \lambda^{-1}(1 - e^{-\lambda T})]} \quad \text{.....3.5}$$

Where V is the effective volume of the cup in m^3, V_W is the volume of sample (L).

3. 6 The Annual Effective Dose

3.6.1 The annual effective dose due to the inhalation of radon

The annual effective dose due to the inhalation of radon, H_{inh}, resulting from the radon concentration in drinking water, was calculated according to the following expression [78]:

$$H_{inh}(nSv/yr) = C_{Rn} \times R \times F \times T \times D_{inh} \quad \text{.....3.6}$$

where C_{Rn} is the average indoor air radon concentration, in Bqm^{-3}, R ratio radon released to air when water is used to radon in water (=10^{-4}), F is the equilibrium factor between indoor radon and its products (=0.4), T is the exposure time to this concentration, in hours (assumed to be equal to 7000 h y^{-1}) and D_{inh} is the conversion dose factor (9 $nSv\ (Bqhm^{-3})^{-1}$).

3.6.2 The annual effective dose due to the ingestion of radon

The annual effective dose due to the ingestion of radon from water, H_{ing}, was calculated according to equation

$$H_{ing}(mSv/yr) = C_{Rn} \times D_{ing} \times L \quad \text{.....3.7}$$

Where C_{Rn}: radon concentration in water, $Bq\ell^{-1}$; D_{ing}: conversion factor, equal to $1\times10^{-8}SvBq^{-1}$; and L is annual water consumption by an adult in liters. We have used daily water consumption by an adult as 2 liters (730 liters per year) [80]. The United Nations Scientific Committee on the Effects of Atomic Radiation estimated that the committed effective dose from the ingestion of radon in water is $10^{-8}SvBq^{-1}$for an adult, 2 x $10^{-8}SvBq^{-1}$for a child and 7 x $10^{-8}SvBq^{-1}$for an infant [80]. According to UNSCEAR, doses to children and infants for similar consumption rates could be a factor of 2 and 7 higher, respectively [4].

World Health Organization (WHO) and the Council of Europe Union (EU) have determined the permitted level of annual effective dose in drinking water as 0.1 mSv/y (100 μSv/y) for annual effective dose level in drinking water.

3.6.3 The lung cancer cases per year per million person (*CPPP*

Radon is the number one cause of lung cancer among nonsmokers, according to EPA estimates [81]. Overall, radon is the second leading cause of lung cancer. Lung cancer is the most commonly occurring cancer in men and the third most commonly occurring cancer in women. There were 2 million new cases in 2018. About 3,000 of these deaths occur among people who never smoked. Exposed to 0.481 nBq/L (the average indoor radon level) never-smokers have a 2 in 1,000 chance of dying from lung cancer, while smokers exposed to same level have a 20 in 1,000 chance. The World Health Organization (WHO) says radon causes up to 15% of lung cancers worldwide [82].

The lung cancer cases per year per million person (CPPP) in samples water allowable limited 230- 170 per million person which recommended by ICRP, 1993 [83].The lung cancer cases per year per million person (CPPP) was obtained using the relation [84, 85, 86]:

$$CPPP = H_{inh} \times (18\times10^{-6}\, mSv^{-1}.y) \quad \text{.....3.8}$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Chapter 4- Results and Discussions

4.1 Introduction

This chapter will serve as a document to present and explore the result of radon concentration levels in Bethlehem governorates is measured in Bq/m^3 .

Equations 3.1 through 3.12, respectively, were used for calculating radon concentration, the annual effective dose, the radium concentration from water samples used in this study which include tap, rain , ground and mineral water samples. The results are summarized in tables 4.1 to 4.9 and table 4.9 represented a comparison of radon concentration levels in water samples at the present work with those in Palestine. The correlation between radium concentrations with radon concentration is represented in Figures 4.1, 4.2, 4.3 and 4.4 for tap, rain, ground and mineral water, respectively.

4.2 Results of Measurements of ^{222}Rn concentrations and ^{226}Ra contents in water samples

4.2.1 Results ^{222}Rn concentrations and radium contents in tap water samples

The ^{222}Rn concentrations and radium content are listed in Tables 4.1 to 4.4, for all types of drinking water. Table 4.1, shows the values of radon concentrations and radium contents in tap water samples collected from different sites in the Bethlehem Governorate -Palestine. The values of radon concentration in the collected samples vary from 17.4 Bq/m^3 to 3285.6 Bq/m^3 with an average value: 934.1 Bq/m^3. From figure 4.1, that the radon concentration of tap water samples is the highest in the Tuku' site (2170.1Bq/m^3), but the least value in the Alshawawra site (361.1 Bq/m^3). The values of radium concentration are the highest in Tuku' (105.7 Bq/Kg) and the least in the Alshawawra site (17.6 Bq/Kg).

Table 4. 1: Results of ^{222}Rn concentrations and radium contents in tap water samples for Bethlehem

Province

Zone	No. of Samples	C_{Rn} (Bq/m^3)			C_{Rn} (Bq/ℓ)	C_{Ra} (Bq/kg)
		Min.	Max.	Av.		
Bet Jala	3	144.3	757.0	435.1	0.43	21.2
Dar Salah	3	693.3	1355.4	947.3	0.95	46.1
Battir	3	724.3	2102.0	1202.1	1.2	58.5
Wadi Fukine	3	1448.7	3266.3	2081.2	2.1	101.3
Alobeidiya	4	484.0	1021.2	711.5	0.71	34.6
Alshawawra	3	348.5	386.3	361.1	0.36	17.6
Tuku'	2	1054.5	3285.6	2170.1	2.17	105.7
Hussan	2	983.5	528.4	756.0	0.76	36.8
Beit Sahour	3	361.9	799.2	589.8	0.59	28.7
Nahalin	2	466.2	919.1	692.7	0.69	33.7
Beit Fajar	4	239.8	1516.3	733.2	0.73	35.7
Jananta	1	-	-	1824.8	1.82	88.9
Wadi Neus	2	350.8	983.5	667.2	0.67	32.5
Al Khader	3	799.2	1671.7	1117.4	1.11	54.4
Zat'atra	3	501.7	1594.0	982.0	0.98	47.8
Jurat Alsham'a'	3	333.0	723.7	580.1	0.58	28.2
Bethlehem city	2	17.4	37.4	27.4	0.03	1.3
Total	**46**	**Min value: 17.4 Bq/m^3 Max value: 3285.6 Bq/m^3 Av. value: 934.1 Bq/m^3**			**Total Av. 0.93**	**Total Av. 45.5**

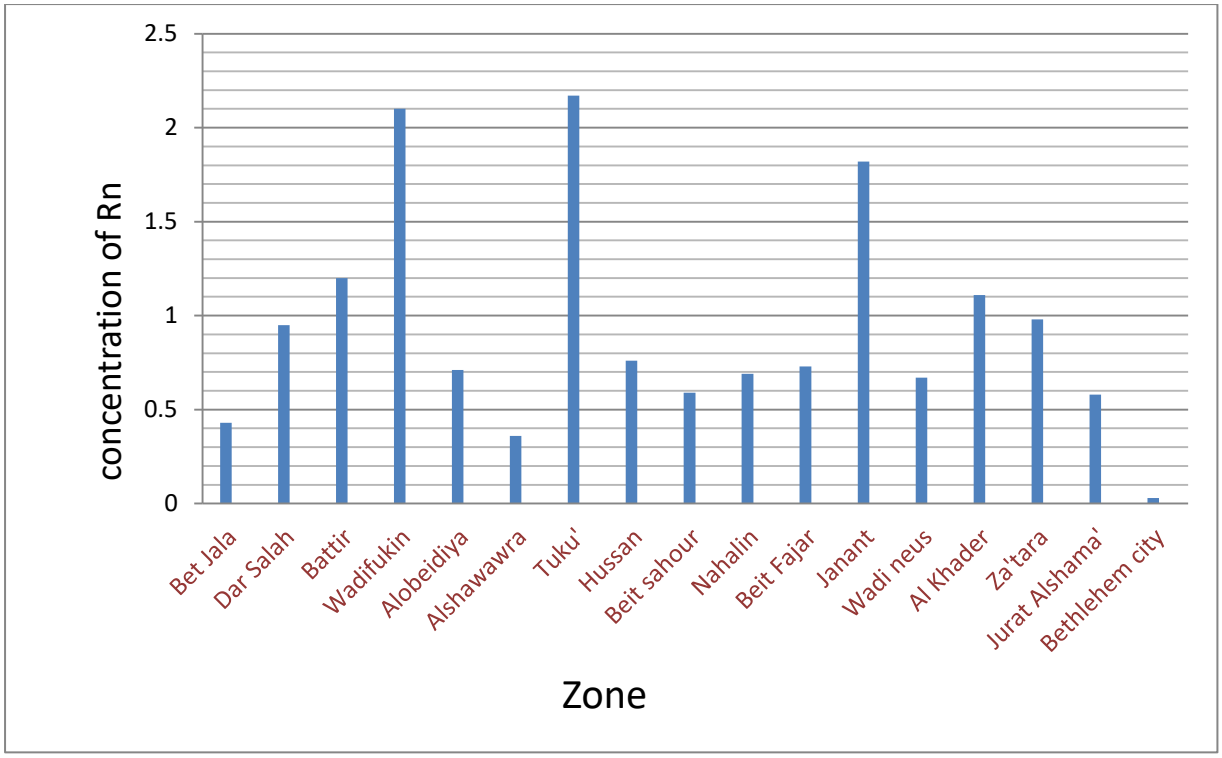


Fig 4.1: ^{222}Rn concentrations in tap water samples collected from Bethlehem region-Palestine

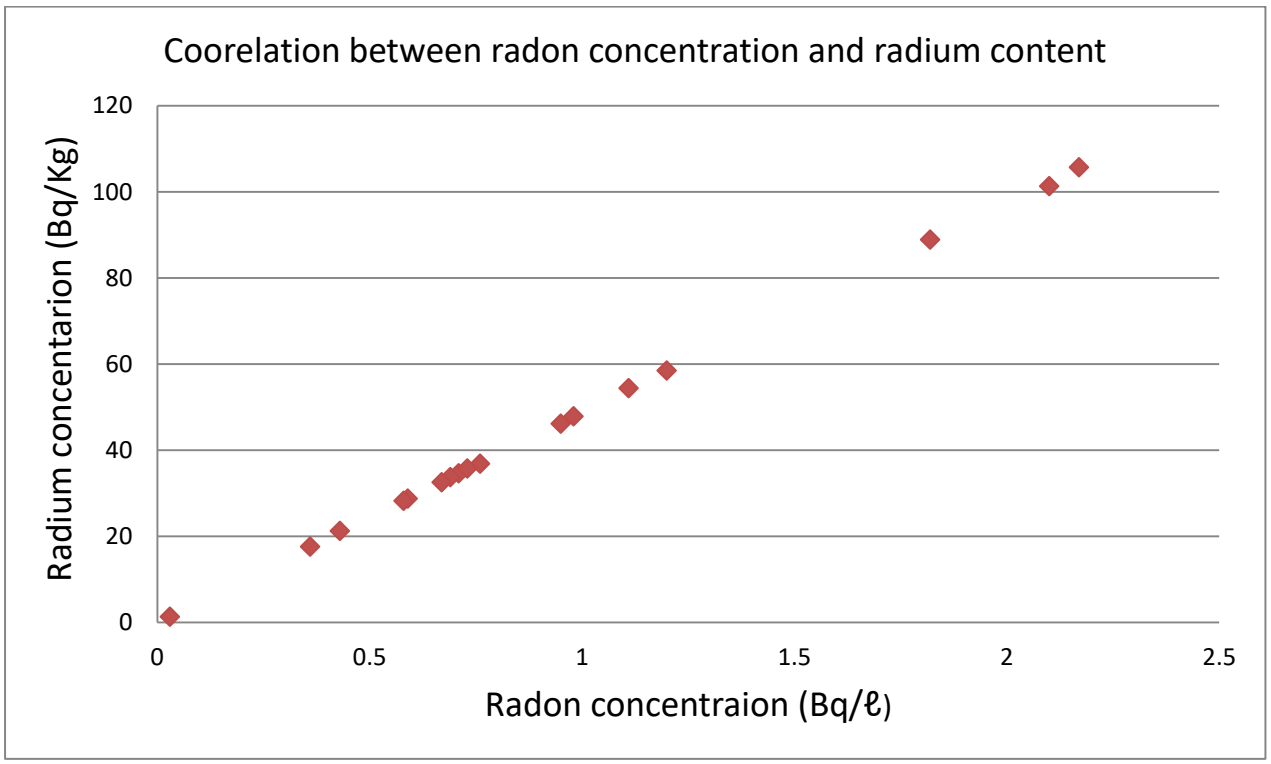


Fig 4.2: Correlation between ^{222}Rn concentration and ^{226}Ra content in tap water in Bethlehem province.

4.2.2 Results of ^{222}Rn concentrations and radium contents in rain water samples

Table 4.2, shows the values of radon concentrations and radium contents in rain water samples collected from different sites in the Bethlehem Governorate -Palestine. The values of radon concentration in the collected samples vary from 631.0 Bq/m^3 to 1363.1 Bq/m^3 with an average value of 1010.0 Bq/m^3. As shown in figure 4.3, the radon concentration of tap water samples is the highest in the Alshawawra site (1768.6 Bq/m^3) but the lowest in the Wadi Neus site (155.4 Bq/m^3). The values of radium concentration are the highest in Alshawawra site (86.1Bq/Kg) but the lowest in the Wadi Neus site (7.5 Bq/Kg).

Table 4. 2: Results of ^{222}Rn concentrations in rain water sampled from water containers, was collected from Bethlehem region- Palestine

Zone	**No. of Samples**	**C_{Rn} (Bq/m^3)**			**C_{Rn} (Bq/ℓ)**	**C_{Ra} (Bq/k$_g$)**
		Min.	**Max.**	**Av.**		
Wadi Fukine	3	631.0	1804.0	1066.0	1.06	51.9
Al Obadyia	2	1083.3	1212.1	1147.7	1.15	55.9
Alshawawra	3	1363.1	2442.0	1768.6	1.77	86.1
Tuku'	2	590.5	777.0	683.8	0.68	33.3
Hussan	2	879.1	1776.0	1327.6	1.33	64.6
Janata	1	-	-	825.8	0.83	40.2
Wadi Neus	1	-	-	155.4	0.15	7.5
Dar Salah	3	144.4	2188.9	1128.1	1.13	54.9
Total	**17**	**Min value: 631.0 Bq/m^3** **Max value: 2442.0 Bq/m^3** **Av. Value: 1012.9 Bq/m^3**			**Total Av. 1.01**	**Total Av. 49.3**

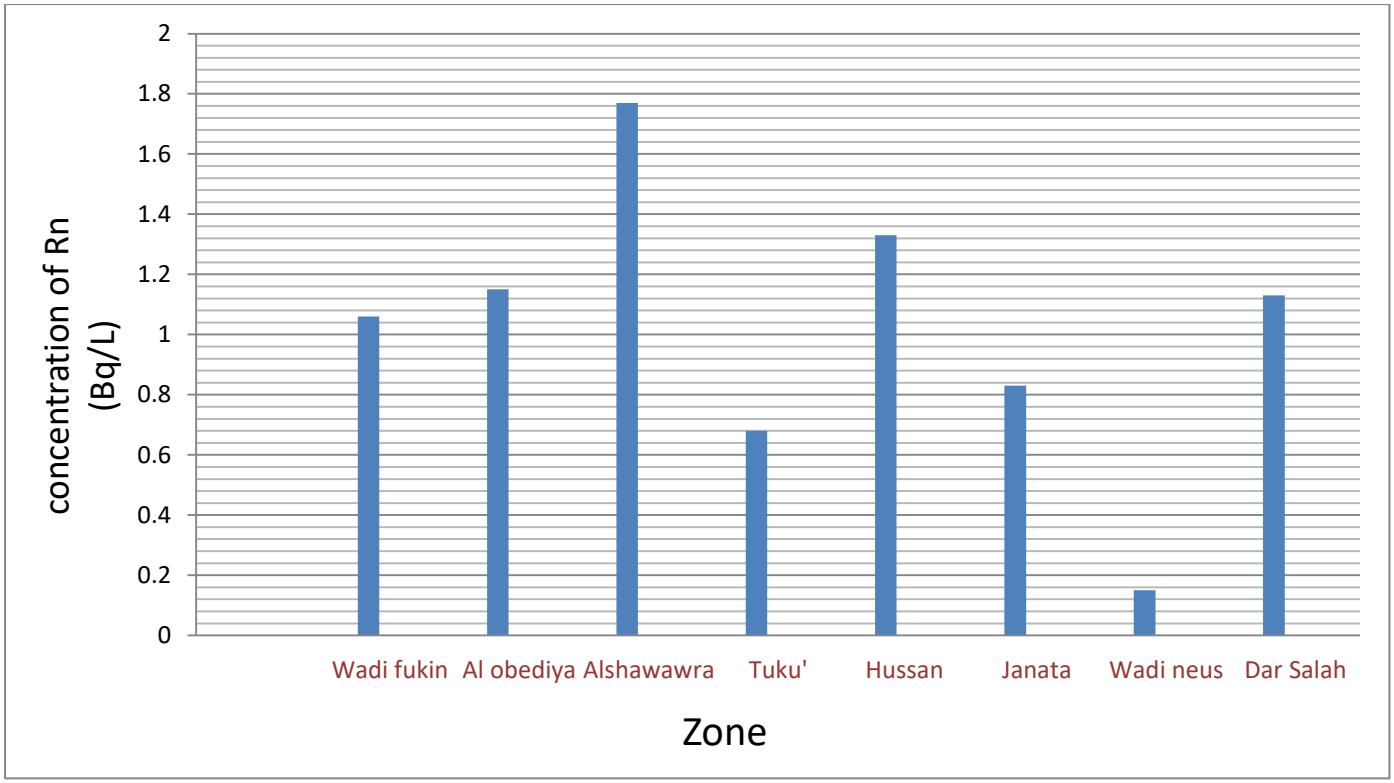


Figure 4.3 : ^{222}Rn concentrations in rain water sampled from water containers, was collected from Bethlehem region- Palestine.

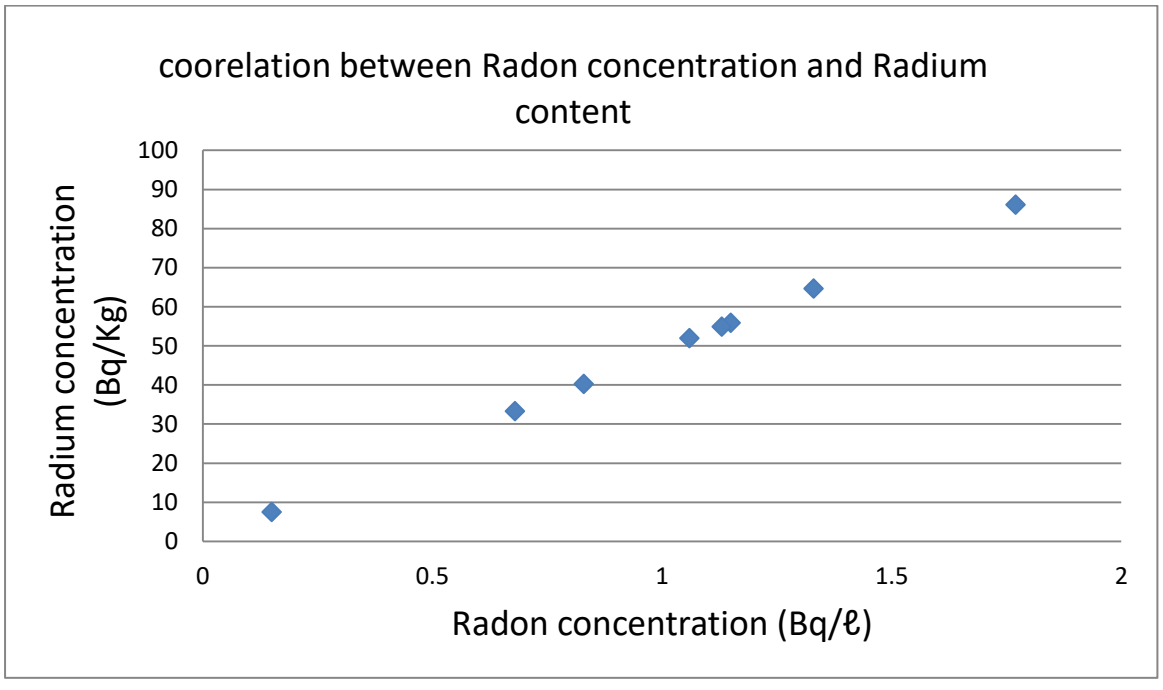


Figure 4.4: Correlation between ^{222}Rn concentration and ^{226}Ra content in rain water samples collected from water containers for Bethlehem region- Palestine.

4.2.3 Results of ^{222}Rn concentrations and radium contents in ground water samples

Table 4.3, shows the values of radon concentrations and radium contents in ground water samples collected from different sites in the Bethlehem governorate -Palestine. The values of radon concentration in the collected samples vary from 111.0 Bq/m^3 to 2168.9 Bq/m^3 with an average value of 1217.7 Bq/m^3. As shown in figure 4.5, the radon concentration of ground water samples is the highest in Wadi Fukine site (1550.2 Bq/m^3) but the lowest in the Nahalin site (672.7Bq/m^3). The values of radium concentration are the highest in Wadi Fukine site (75.5 Bq/Kg) and the lowest in Nahalin site (32.7 Bq/Kg).

Table 4. 3: Results of ^{222}Rn concentrations and ^{226}Ra contents in ground water samples collected from Bethlehem region- Palestine

Zone	**No. of Samples**	**C_{Rn} (Bq/m^3)**			**C_{Rn} (Bq/ℓ)**	**C_{Ra} (Bq/k$_g$)**
		Min.	**Max.**	**Av.**		
Wadi Fukine	3	295.5	2177.6	1550.2	1.55	75.5
Battir	4	699.9	1908.7	1148.2	1.15	55.9
Hussan	2	830.1	2168.9	1499.6	1.50	73.0
Nahalin	2	111.0	1234.3	672.7	0.67	32.7
Total	**11**	**Min value: 111.0 Bq/m^3** **Max value: 2168.9 Bq/m^3** **Av. Value: 1217.7 Bq/m^3**			**Total Av.** **1.21**	**Total Av.** **59.3**

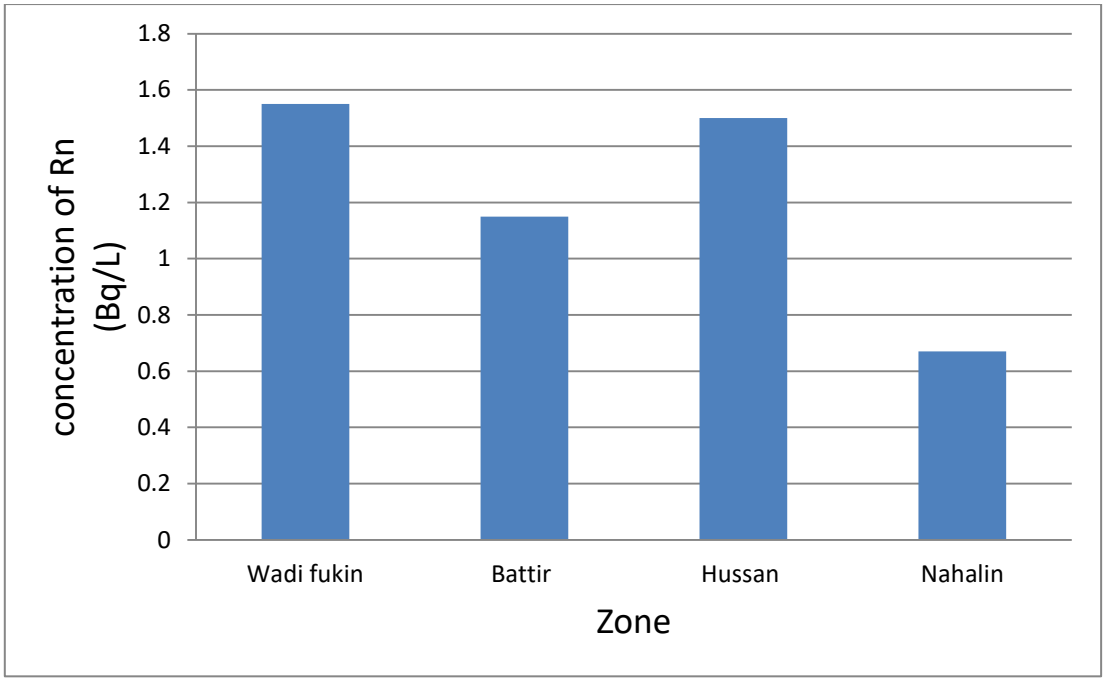


Figure 4.5: ^{222}Rn concentrations in ground water sampled from water containers, was collected from Bethlehem region- Palestine

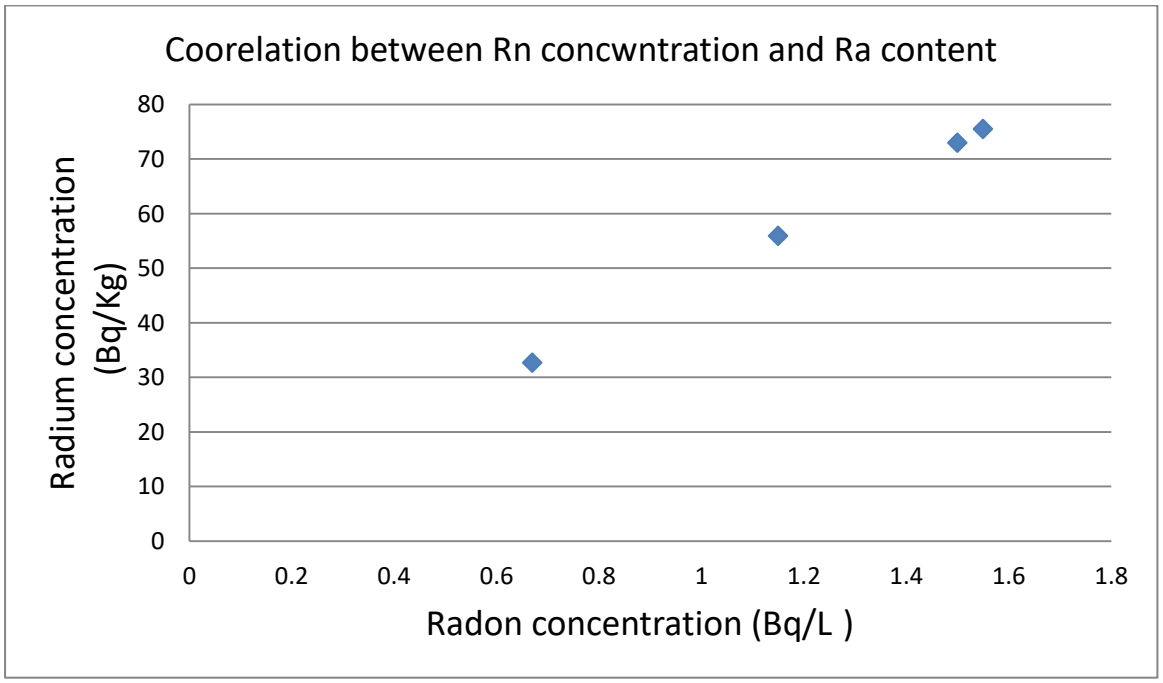


Figure 4.6: Correlation between ^{222}Rn concentration and ^{226}Ra content in ground water samples collected from Bethlehem region- Palestine.

4.2.4 Results of ^{222}Rn concentrations and ^{226}Ra contents in mineral water samples

Table 4.4, shows the values of radon concentrations and radium contents in mineral water samples collected from different sites in the Bethlehem governorate -Palestine. The values of radon concentration in the collected samples vary from 450.0 Bq/m^3 to 800.0 Bq/m^3 with an average value of 598.0 Bq/m^3. Figure 4.7, shows that the radon concentration of mineral water samples is the highest in Ain Gidi sample (800.0 Bqm^3) but the lowest in Vera sample (450.0 Bqm^3). The values of radium contents are the highest in Ain Gidi sample (39.0 Bq/Kg) but the lowest in the veria sample (21.9Bq/Kg).

Table 4.4: Results of ^{222}Rn concentrations and ^{226}Ra contents in mineral spring (potable) water.

Zone	**No. of Samples**	**Av. C_{Rn} (Bq/ℓ)**	**C_{Ra} ($Bq/k_{g)}$**
Ain Gidi	1	0.80	39.0
Arwa	1	0.50	24.3
veria	1	0.45	21.9
Jericho	1	0.59	28.9
Aqunova	1	0.65	31.7
Total	**5**	**Total Av. 0.60**	**Total Av. 53.8**

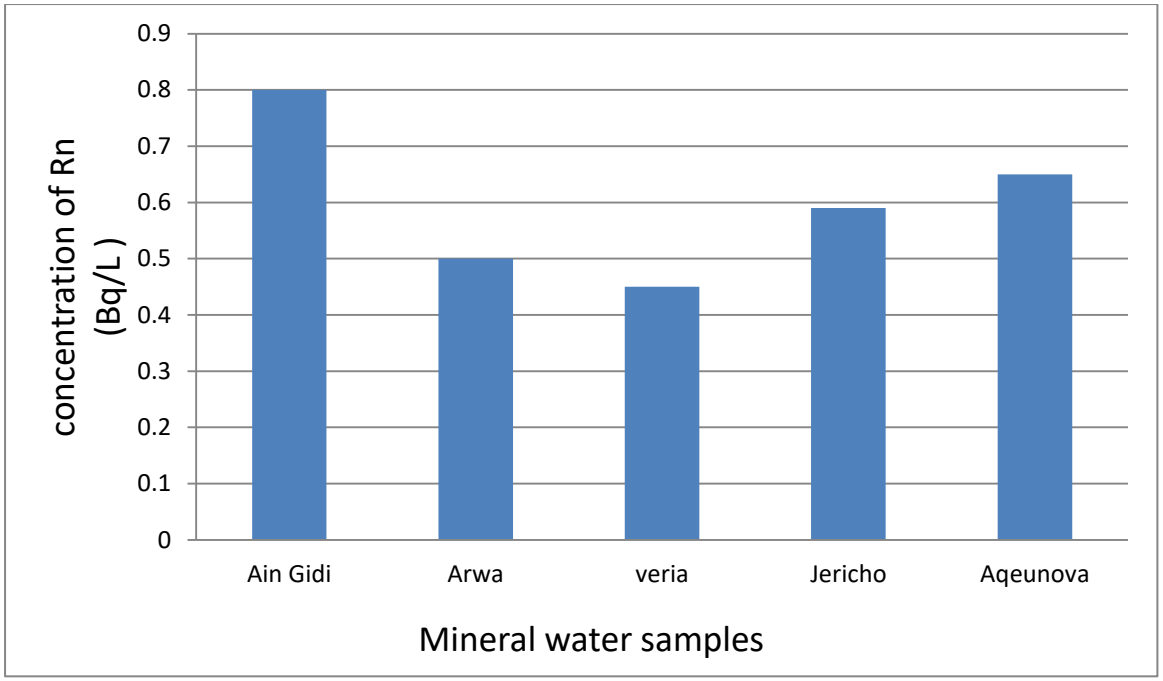


Figure 4.7: ^{222}Rn concentrations in mineral water samples collected from Bethlehem region- Palestine

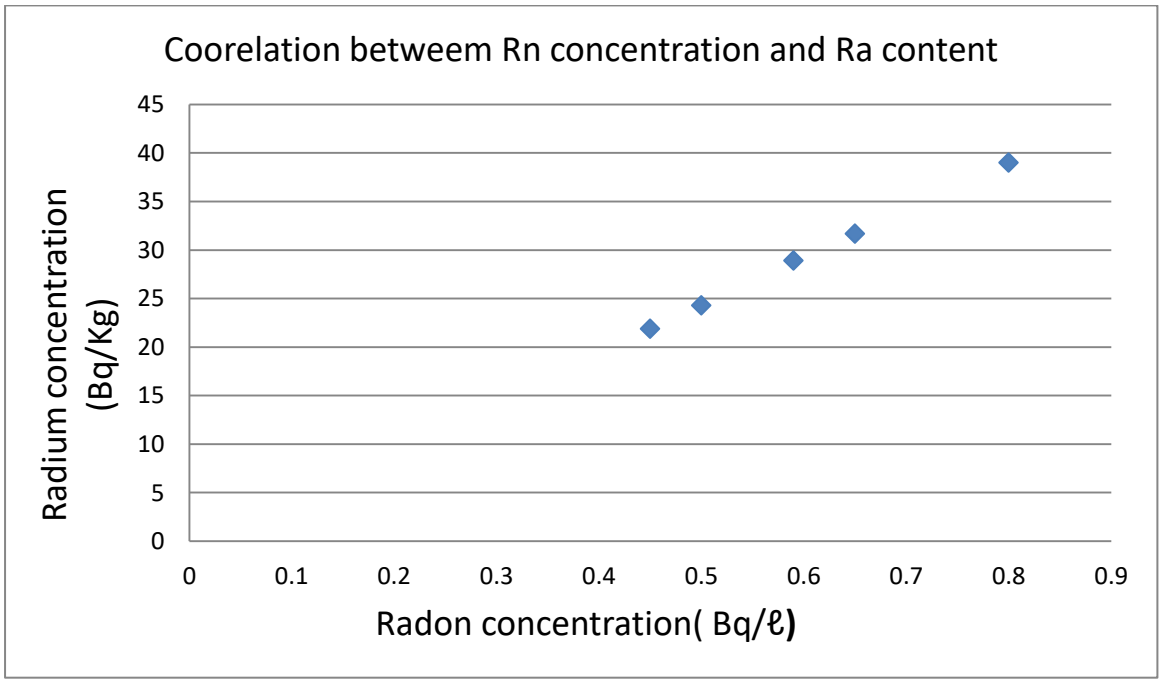


Figure 4.8: Correlation between ^{222}Rn concentration and ^{226}Ra content in mineral water samples collected from Bethlehem region- Palestine**.**

4.3. The annual effective doses for ingested and inhaled ^{222}Rn from water

People may ingest trace amounts of radon with food and water; however inhalation is the main route of entry into the body for radon and its decay products. Therefore, radon in water is a source of radiation dose to the stomach and lungs. The annual effective doses for ingestion and inhalation due to radon from water, for adult's, child's and infants were calculated according to parameters introduced by UNSCEAR; report (UNSCEAR, 2000). The annual effective dose due to inhalation and due to ingestion is listed in Tables 4.5 to 4.8, for all types of drinking water.

4.4. The lung cancer cases per year per million person (CPPP)

Another purpose of this study, to estimate the number of people who may be exposed to lung cancer from inhaling radon emitted from water sample available in the area that is listed in tables from 4.5 to 4.8 for all types of drinking water.

Table 4.5: Results of the average annual effective dose due to the ingestion (H_{ing}) and inhalation (H_{inh}) of radon in tap water samples and CPPP per million person.

Zone	No. of Samples	Av. H_{ing} (μSv/yr)			Av. H_{inh} (μSv/ yr)	CPPP per million person
		Adult	Child	Infant		
Bet Jala	3	3.1	6.3	21.9	1.1	19.8
Dar Salah	3	6.9	13.9	48.5	2.4	43.2
Battir	3	8.8	17.5	61.3	3.0	54.0
Wadi Fukine	3	15.3	30.6	107.3	5.2	93.6
Alobeidiya	4	5.2	10.4	36.3	1.8	32.4
Alshawawra	3	2.6	5.3	18.4	0.91	16.4
Tuku'	2	15.8	31.7	110.9	5.5	99.0
Hussan	2	5.5	11.1	38.8	1.9	34.2
Beit Sahour	3	4.3	8.6	30.1	1.5	27
Nahalin	2	5.0	10.1	35.3	1.7	30.6
Beit Fajar	4	5.3	10.7	37.3	1.8	32.4
Jananta	1	13.3	26.6	93.0	4.6	82.8
Wadi Neus	2	4.9	9.8	34.2	1.7	30.6
Al Khader	3	8.1	16.2	56.7	2.8	50.4
Zat'atra	3	7.1	14.3	50.1	2.5	45
Jurat Alsham'a'	3	4.2	8.5	29.6	1.5	27
Bethlehem city	2	0.22	0.42	1.5	0.07	1.3
Total Av.	**17**	**6.8**	**13.6**	**47.7**	**2.3**	**41.4**

The annual effective dose inhalation H_{inh} and ingestion H_{ing} in tap water was reported in Table 1. The annual effective dose ingestion H_{ing} were yielded for adult from 0.22 to 15.3 μSv/y with mean value 6.8 μSv/y; H_{ing} values for child from 0.42 to 31.7 μSv/y with mean value 13.6; H_{ing} values for infant from 110.9 to 1.5 μSv/y with mean value 47.7 μSv/y; The annul effective dose inhalation H_{inh} were yielded from 0.07 to 5.5 μSv/y with mean value 2.3 μSv/y .

The EU Council recommended the level of annual effective dose for radon in drinking water is o.1 mSv/y. The International Commission on Radiological Protection [10] has reported the limits of dose from radon is (3 -10 mSv/y). The results show that the total annual effective dose from all sample were lower than limits recommendation from agency ICRP. Results reveal that in about 83.33% for ground water samples higher than the EU recommended safe limit and WHO while the drinking water samples lie within the WHO and EU recommended safe limit.

Table 4.5 summarizes the results of lung cancer cases per year per million person (CPPP) in different tap water samples. It can be seen from the results that the lung cancer cases per year per million person (CPPP) in different drinking samples water various from 1.3 to 99.0 with average value 41.4 per million person. These results were lower than the allowable limited 230- 170 per million person which recommended by ICRP 2007 [10].

Table 4. 6: Results of the average annual effective dose due to the ingestion (H_{ing}) and inhalation (H_{inh}) of radon in rain water samples and CPPP per million person.

Zone	**No. of Samples**	**Av. H_{ing} (µSv/yr)**			**Av. H_{inh} (µSv/ yr)**	**CPPP per million person**
		Adult	**Child**	**Infant**		
Wadi Fukine	3	7.7	15.5	54.2	2.7	48.6
Al Obadyia	2	8.4	16.8	58.8	2.9	52.2
Alshawawra	3	12.9	25.8	90.4	4.4	79.2
Tuku'	2	4.9	9.9	34.7	1.7	30.6
Hussan	2	9.7	19.4	67.9	3.3	59.4
Janata	1	6.1	12.1	42.4	2.1	37.8
Wadi neus	1	1.1	2.2	7.7	0.39	7.0
Dar Salah	3	8.2	16.5	57.7	2.8	50.4
Total Av.	**17**	**7.4**	**14.8**	**51.7**	**2.5**	**45.0**

Table 4.6 was reported The annual effective dose inhalation H_{inh} and ingestion H_{ing} and CPPP in rain water. The annual effective dose ingestion H_{ing} were yielded for adult from 1.1 to 12.9 μSv/y with mean value 7.4 μSv/y; H_{ing} values for child from 2.2 to 25.8 μSv/y with mean value 14.8 μSv/y H_{ing} values for infant from 7.7 to 90.4 μSv/y with mean value 51.7 μSv/y; The annul effective dose inhalation H_{inh} were yielded from 0.39 to 4.4 μSv/y with mean value 2.5 μSv/y .

The results of lung cancer cases per year per million person (CPPP) in different rain water samples. It can be seen from the results that the lung cancer cases per year per million person (CPPP) in different rain samples water various from 7.0 to 79.2 with average value 45.0 per million person. These results were higher than the allowable limited 230- 170 per million person which recommended by ICRP 2007.

Table 4. 7: Results of the average annual effective dose due to the ingestion (H_{ing}) and inhalation (H_{inh}) of radon in ground water samples.

Zone	**No. of Samples**	**Av. H_{ing} (μSv/yr)**			**Av. H_{inh} (μSv/ yr**	**CPPP per million person**
		Adult	**Child**	**Infant**		
Wadifukin	3	11.3	22.6	79.2	3.9	70.2
Battir	4	8.4	16.8	58.8	2.9	52.2
Hussan	2	11.0	21.9	76.7	3.8	68.4
Nahalin	2	4.9	9.8	34.2	1.7	30.6
Total Av.	**11**	**8.9**	**17.8**	**62.2**	**3.1**	**55.8**

Table 4.7 was reported the annual effective dose inhalation H_{inh} and ingestion H_{ing} and CPPP in ground water. The annual effective dose ingestion H_{ing} were yielded for adult from 4.9 to 11.3 μSv/y with mean value 8.9 μSv/y; H_{ing} values for child from 9.8 to 22.6 μSv/y with mean value 17.8 μSv/y; H_{ing} values for infant from 34.2 to 79.2 μSv/y with

mean value 62.2 μSv/y; The annul effective dose inhalation H_{inh} were yielded from 1.7 to 3.9 μSv/y with mean value 3.1 μSv/y .

The results of lung cancer cases per year per million person (CPPP) in different rain water samples. It can be seen from the results that the lung cancer cases per year per million person (CPPP) in different rain samples water various from (30.6 to 70.0 /10^6) person with average value 55.8 per million person. These results were higher than the allowable limited 230- 170 per million person which recommended by ICRP 2007.

Table 4.8: Results of the average annual effective dose due to the ingestion (H_{ing}) and inhalation (H_{inh}) of radon in mineral water samples.

Zone	**No. of Samples**	**Av. H_{ing} (μSv/yr)**			**Av. H_{inh} (μSv/ yr**	**CPPP per million person**
		Adult	**Child**	**Infant**		
Ain Gidi	1	5.8	11.7	40.6	2.0	36.0
Arwa	1	3.6	7.2	25.2	1.3	23.4
Veria	1	3.3	6.6	23.1	1.1	19.8
Jericho	1	4.3	8.6	30.1	1.5	27.0
Aqeunova	1	4.7	9.4	32.9	1.6	28.8
Total Av.	**5**	**4.3**	**8.7**	**30.4**	**1.5**	**27.0**

Table 4.8 was reported the annual effective dose inhalation H_{inh} and ingestion H_{ing} and CPPP in mineral water. The annual effective dose ingestion H_{ing} were yielded for adult from 3.3 to 5.8 μSv/y with mean value 4.3 μSv/y; H_{ing} values for child from 6.6 to 11.7 μSv/y with mean value 8.7 μSv/y H_{ing} values for infant from 23.1 to 40.6 μSv/y with mean value 30.4 μSv/y; The annul effective dose inhalation H_{inh} were yielded from 1.1 to 2.0 μSv/y with mean value 1.5 μSv/y.

The results of lung cancer cases per year per million person (CPPP) in different mineral water samples. It can be seen from the results that the lung cancer cases per year per million person (CPPP) in different rain samples water various from 19.8 to 36.0 with average value 27.0 per million person. These results were higher than the allowable limited 230- 170 per million person which recommended by ICRP 2007**.**

4.5 Discussions

The results presented and discussed in this study includes 46 tap water samples, 17 rain water samples, 11 groundwater samples and 5 minerals (potable) water samples were collected from taps, containers, wells and shops in Bethlehem region- Palestine . The results of radon concentration levels in residential tap water are listed in Table 1. Tap water which is supplied to the public is also obtained from tube well depends the use of water directly from underground wells or after storing it for the purpose of purification and treatment before using it as it is the case in the public water networks. Storage of water before using it reduces the concentration of radon in it for the dissolution of radon and it's off spring with water during the storage period. As for the use of water directly from wells, it is harmful to raise the level of radon concentration in places of use, especially if the concentration of radon in water is high.

Tables 2, 3 and 4, represent the radon concentration levels in the rain waters, groundwater and mineral (potable) water samples in many sites of the regions. It is observed that the radon total average concentration is the highest in ground water samples and it is the lowest in tap water. Because radon is moderately soluble in water, the rate of dissolution increases as the temperature of the water increases low. Groundwater absorbs quantities of radon when it passes over the rocky layers and the soil below when the water flows or is exposed to a rise in its temperature, this helps to release radon from it. When the rate of radon dissolution in water at normal atmospheric pressure changes with the change in temperature, so the melting of radon increases in water with decreasing temperature.

The radon concentration measured in the mineral (potable) water samples used as drinking water in the area under investigation is lower than the maximum allowable concentration in portable water of 18 Bq/ℓ , as recommended by the EPA (2011). The reported of UNSCEAR was tentatively estimated that between 1% and 10% of the world's population consumes water containing concentrations in order of 100 Bq/ℓ or higher, drawn from relatively deep wells [87[88]. When water is consumed from aquifers or

surface sources, the weighted world average concentration is probably less than 1 Bq/ℓ [87]. In this study radon concentration of water is allowable as recommended by the EPA and UNSCEAR for the weighted world average concentration of water drawn from relatively deep wells, but higher than the weighted world average concentration of water from aquifers or surface sources [87][89].

It is apparent that radon in water is a significant source of radon in dwellings only when the radon concentration in water is the order of 11 Bq/ℓ or more or above 400 Bq/ℓ as recommended by UNSCEAR [89].

The results of lung cancer cases per year per million person (CPPP) in different water samples detect that the lung cancer cases per year per million person (CPPP) are lower than the allowable limited 230- 170 per million person which recommended by ICRP 2007.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Chapter 5

Conclusions and Recommendations

● In this study, the use of passive technique containing SSNTDS type (CR-39) to estimate the radon concentration, the annual effective dose, the radium concentration in water samples collected in the different locations in the southern part of the west bank-Palestine. A total of 79 water samples were collected from the area under investigation to determined and assess the radiological hazards.

● The results of radon concentration levels in residential tap water was from 0.63 to 1.3 Bq/ℓ with a total average value of 1.01 Bq/ℓ.

People store this water in small tanks for daily use and after passing through pipes it is used in drinking, cooking and bathrooms. Low level of radon in piped treated water is due to the fact that most of the dissolved ^{222}Rn in water is vented/ released during treatment and transportation.

● The radon concentration levels in the rain waters in different site of the regions was from 0.63 to 2.4 Bq/ℓ with a total average value of 1.01 Bq/ℓ

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● The recorded values of radon concentration in groundwater samples are given in Table 4.3 found that the average radon concentrations in these samples ranged from 0.11 to 2.2 Bq/ℓ with a total average value of 1.2 Bq/ℓ .

● The ^{222}Rn concentrations obtained for the mineral (potable) water samples at the used as drinking water in the area under investigation are presented in Table 4.4. The average radon concentrations obtained ranges from 0.45 to 0.80 Bq/ℓ with a total average value of 0.60Bq/ℓ.

● It is observed that the radon total average concentration in rain and ground water samples is the highest and that in tap water, it is the lowest. The rain water in the area under investigation dissolves some uranium oxide in the clay and thus enhances the uranium content in water.

● The annual effective dose inhalation H_{inh} and ingestion H_{ing} in tap water was reported in Table 4.5 The annual effective dose ingestion H_{ing} were yielded for adult from 0.22 to 15.3 μSv/y with mean value 6.8 μSv/y; H_{ing} values for child from 0.42 to 31.7 μSv/y with mean value 13.6 ; H_{ing} values for infant from 110.9 to 1.5 μSv/y with mean value 47.7 μSv/y; The annul effective dose inhalation H_{inh} were yielded from 0.07 to 5.5 μSv/y with mean value 2.3 μSv/y .

The results of lung cancer cases per year per million person (CPPP) in different tap water samples. It can be seen from the results that the lung cancer cases per year per million person (CPPP) in different drinking samples water various from 1.3 to 99.0 with average value 41.4 per million person.

● The annual effective dose inhalation H_{inh} and ingestion H_{ing} and CPPP in rain water. The annual effective dose ingestion H_{ing} were yielded for adult from 1.1 to 12.9 μSv/y with mean value 7.4 μSv/y; H_{ing} values for child from 2.2 to 25.8 μSv/y with mean value 14.8 μSv/y H_{ing} values for infant from 7.7 to 90.4 μSv/y with mean value 51.7 μSv/y; The annul effective dose inhalation H_{inh} were yielded from 0.39 to 4.4 μSv/y with mean value 2.5 μSv/y .

The results of lung cancer cases per year per million person (CPPP) in different rain water samples. It can be seen from the results that the lung cancer cases per year per million person (CPPP) in different rain samples water various from 7.0 to 79.2 with average value 45.0 per million person.

● The annual effective dose inhalation H_{inh} and ingestion H_{ing} and CPPP in ground water. The annual effective dose ingestion H_{ing} were yielded for adult from 4.9 to 11.3 μSv/y with mean value 8.9 μSv/y; H_{ing} values for child from 9.8 to 22.6 μSv/y with mean value 17.8 μSv/y; H_{ing} values for infant from 34.2 to 79.2 μSv/y with mean value 62.2 μSv/y; The annul effective dose inhalation H_{inh} were yielded from 1.7 to 3.9 μSv/y with mean value 3.1 μSv/y .

The results of lung cancer cases per year per million person (CPPP) in different rain water samples. It can be seen from the results that the lung cancer cases per year per million person (CPPP) in different rain samples water various from 30.6 to 70 with average value 55.8 per million person

● The annual effective dose inhalation H_{inh} and ingestion H_{ing} and CPPP in mineral water. The annual effective dose ingestion Hing were yielded for adult from 3.3 to 5.8 μSv/y with mean value 4.3 μSv/y; H_{ing} values for child from 6.6 to 11.7 μSv/y with mean value 8.7 μSv/y H_{ing} values for infant from 23.1 to 40.6 μSv/y with mean value 30.4 μSv/y; The annul effective dose inhalation H_{inh} were yielded from 1.1 to 2.0 μSv/y with mean value 1.5 μSv/y .

The results of lung cancer cases per year per million person (CPPP) in different mineral water samples. It can be seen from the results that the lung cancer cases per year per million person (CPPP) in different rain samples water various from 19.8 to 36.0 with average value 27.0 per million person.

- All the values were found to be within risk limits as recommended by ICRP and WHO Consequently, the health hazards related to radiation are expected to be not negligible.

- This work is the first work to be conducted in the water of the area under investigation; further work is to be conducted to cover other places in different seasons. The measurements taken in this study represent a baseline database of activity levels that can serve as a reference point for future studies to indicate impacts from future events.
- The results normally provide preliminary reconnaissance coverage of radon concentration in water. However a radiometric survey under certain conditions can be used for drawing maps for the radiation pollution in water and the other type of water in Bethlehem province.
- The area surveyed was selected on basis of geological, topographical consideration and other preliminarily studies. This fact is related to the soil (sand and clay) being the primary source of Radon, where we suspect that an industrial nuclear waste are buried in that area.

5.2 Recommendations

- It is recommended not to build homes in areas with a high level of radon gas to prevent exposure to radiation that leads to cancer. Radon has been recognized as one of the health risks to humanity because long-term exposure to radon increases the risk of lung cancer.
- The present work recommends further investigations to verify radon concentrations in other areas of the West Bank and to map radon gas in water in the West Bank. This would give a good stimulus to treat areas of radioactive contamination and protect people from radiation hazards.
- Water is affected by weather factors and natural and industrial changes such as exposure to radiation. The main cause of radiation exposure is radioactive waste that flows from industrial areas towards soil and water.
- Health laws that obligate factories to dispose of solid waste in a safe and hygienic manner so as not to pose numbness to human health must be established. Therefore, factories must be established away from residential areas. Also, he suggested the development and improvement of groundwater and tap water extensions in terms of using techniques that help to extract and discharge radon gas from water with scientific and engineering research.
- It is important to starting with making epidemiological studies of the general population to determine lung cancer incidence due to high level of radiation, although there is hope for future. This would give a good motivation to remedial the area of radiation pollution and to protect people of radiation.
- We suggest that more studying to Radon before and after winter because Radon concentrations in ground water vary with time because of dilution by recharge of rainfall.
- It is necessary to involve radiation guidelines within Palestinian standards for water quality.

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